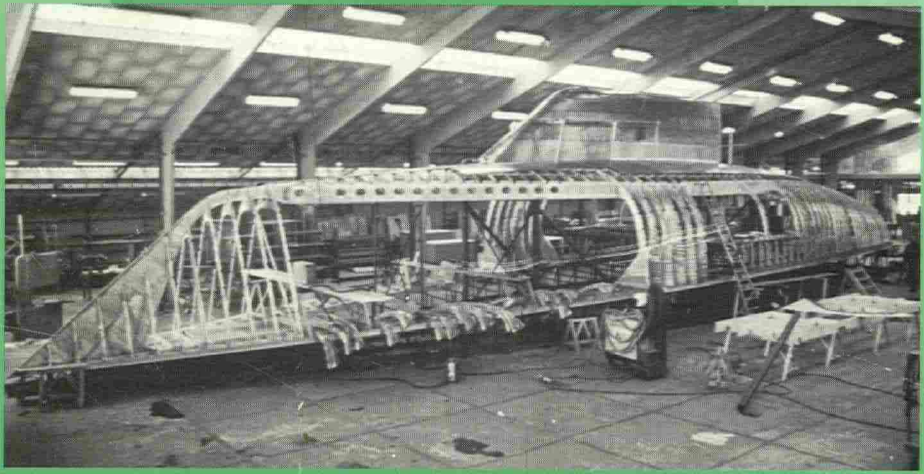
ALUMINIUM

AS A CONSTRUCTION MATERIAL IN NAVAL ARCHITECTURE



KIVI
Koninklijk Instituut van Ingenieurs

ALUMINIUM SYMPOSIUM 1991

ALUMINIUM AS A CONSTRUCTION MATERIAL IN NAVAL ARCHITECTURE

AN ASSEMBLY OF PAPERS AND LECTURES
COLLECTED FOR THE SHIPBUILDING INDUSTRY

COLLECTED BY

Koninklijk Instituut van Ingenieurs
Maritieme Techniek

Editor: Ir W.A.Th. Bik

ALUMINIUM SYMPOSIUM
1991

ALUMINIUM
AS A CONSTRUCTION MATERIAL
IN NAVAL ARCHITECTURE

Koninklijk Instituut van Ingenieurs - Maritieme Techniek
Ned. Ver. van Technici op Scheepvaartgebied
Aluminium Centrum
Scheepsbouwkundig Gezelschap "William Froude"

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THE CHAIRMAN'S ADDRESS

Ir. A.P.A. Jaeger
(Chairman, Maritime Technology Division
Royal Institute of Engineers in the Netherlands):

Ladies and Gentlemen,

On behalf of the Maritime Technology division of the Royal Institute of Engineers in the Netherlands and her associated sister institute, the Netherlands Society of Marine Technologists, as well as Student Association "William Froude", the Mechanical division of the Royal Institute of Engineers and the Aluminium Centre Netherlands, I should like to extend to you a very warm welcome to this symposium, especially to those of you who have come the long way from abroad.

The purpose of this symposium is to keep up with the latest trends in the application of aluminium as construction material in the shipbuilding industry. The element aluminium as such is known for ages, the metal aluminium however just a 100 years. Also the application of aluminium as construction material for hulls of yachts and small boats, for fittings and superstructures has been going on for some time. As a matter of fact the first aluminium boat hull is presumably built about 75 years ago.
Aluminium's favourable weight/strength ratio, a-magnetic properties and corrosion resistance sometimes compensate for its financial disadvantage in comparison with steel.

Recently the scope of aluminium application in shipbuilding has increased dramatically as result of opening up of new markets and research.

The oncoming competition with the Channel Tunnel has added a new dimension in the size and speed of fast ferries. But don't forget: aluminium cannot replace steel, because the comfort of a 300 ton wave piercer can never match the comfort on board of a 20.000 ton passenger ferry.

The developments of special profiles and sections, new welding and other connecting methods offer wider opportunities for aluminium application in shipbuilding, but require a non-traditional design and production process.

The traditional shipbuilding centres (including the Netherlands) have in fact a tradition in steelbuilding to overcome and in this respect it is not surprising that Australian shipbuilders, who moved straight from timber into aluminium, have set the tone in the fast ferry market.

Today various aspects of aluminium as construction material will be highlighted in state-of-the-art lectures by distinguished specialists.
One day is not enough to cover all aspects. Topics like safety, fire resistance, maintenance and repair, cathodic protection, galvanic action can only partly be covered.
Conversion from steel into aluminium shipbuilding is a process full of pitfalls. Therefore the sequence of the lectures will be concluded with some critical notes.

I hope this day will add a little to your and my knowledge and will benefit our industry. I am most grateful that so many people attended this symposium and it gives me greatest pleasure to introduce this extended collection of papers and other contributions.

This edition could be issued with contributions of
Hoogovens Aluminium GmbH, Koblenz and
Alusuisse Nederland BV, Rotterdam

THE USE OF ALUMINIUM IN SHIPBUILDING, ESPECIALLY IN YACHTBUILDING

ACCORDING TO THE RULES OF AMERICAN BUREAU OF SHIPPING

Ludo F. DERT

CONSULTANT

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1. Introduction

In shipbuilding probably the designers of beautiful large passenger ships took the lead in the application of aluminium on a large scale for superstructures and deckhouses.
Aluminium has the advantage of being light with stability improvement and reduction of displacement as result. Consequently aluminium is conducive to fuel efficiency and/or speed of the vessel.
Furthermore aluminium (of good quality) has the advantage of being corrosion resistant and a-magnetic, a favourable property in connection with the location of the compass.
A remarkable but commonly unknown property of aluminium is an elasticity modulus which is 1/3 compared to steel. At equal load aluminium bends three times as much as steel. Subsequently at an equal bend the stress of aluminium is three times less than steel.
Above mentioned passenger ship designers made use of the latter property at an early date.

Before World War II there were two tendencies regarding passenger ship design in the Netherlands. One disregarded the superstructure in relation to the strength of the vessel and used expansion joints. The other tendency took partly account of the superstructure strengthwise, but placed the strength-deck one deck-level higher as a result of which the stresses in the higher decks were less so that no expansion joints were needed.

Excessive increase of stress can be prevented by using aluminium, which reduces the stress to 1/3 at the same change of form.

The use of aluminium for superstructure at supply vessels, tugs, trawlers, coasters et cetera is, of course, not from a strength point of view, but for reasons of light weight, corrosion resistance and a-magnetic properties.

2. Aluminium Vessels

The use of aluminium on a large scale for construction of entirely welded vessels is of a recent date.

In the Caribbean fast crew boats were used to take people, mail and light cargo, like provisions, to the drilling rigs. Part of the semi-displacement vessels as built in the Netherlands for years ago originated from these designs. In spite of their limited length these vessels can reach a speed up to 50 knots.

For reasons of among others weight saving, aluminium can also be recommended for lower speeds.
One would expect that the weight of an aluminium vessel will be about 1/3 of a steel ship. However, as aluminium is not as strong as steel (tensile strength 28 kg/mm^2 versus 42 kg/mm2 for steel) heavier scantlings shall be put in. Furthermore aluminium plates have to be approximately 30% - 40% thicker than steel plates. Therefore the weight of an aluminium vessel is about 50% of a steel vessel.

There has been a tendency to improve the mechanical properties of aluminium. In the last 5 years the strength of the H116 temper has increased 5 to 10%. The H321 usually has a tensile strength of 350 N/mm^2 and more, but is in this respect still far away from steel 42. One is getting close to the strength of steel 37, the material of which pre-WW II vessels were built. Experts do not expect that a higher tensile strength for aluminium will be reached in the short run.

3. Kinds of Aluminium and their Welding Properties

Unlike steel, of which basically only two different qualities concerning the tensile strength are used (steel 42 and steel 52), there are dozens of aluminium alloys with product names like peraluman, extrudal, anti-corrodal, unidur, perunal, peraluma 460/462 etc. The names vary from manufacturer to manufacturer.

Various authorities have tried to order this chaos by introducing of certain standards. (Table 1)

Out of this diversity one kind of aluminium alloy has emerged that meets nearly all requirements, like decent mechanical properties, corrosion resistance, weldability and, last but not least, short delivery times. (Table 2)
The most prevailing and suitable kind of aluminium alloy is called 5083 in the USA and in Germany it is called AlMg 4,5 Mn.

Prominent NorthEuropean manufacturers of this sort of aluminium are Alusuisse, Alcan, Hoogovens, Kaiser and Pechiney.

In the USA this quality is called heat treatable, in my opinion a very confusing name.
In general heat treatable aluminium has been used for extruded profiles.

The 5083 material has rarely been used for profiles, because it requires a higher pressure (up to 7 times) and significantly longer pressing time than heat treatable material.

Since the cheap (labour) countries went into the production of extruded material, many profiles are available against somewhat lower prices.

The production of extruded profiles is a magnificent sight. A bar is heated to approximately 480 degrees. From the energy input during pressing the temperature rises to approx. 530 ^{0}C. The profile spurts out of the press at a high speed as result of a diameter constriction. If the profile diameter is 1/50 of the plunger diameter, the profile comes out 50 times faster than the plunger goes in.

The profile has to cool down to 120 degrees within 2,5 minutes. At that moment the yield stress amounts about
60 N/mm^2.

Afterwards it is stretched and straightened at a drawing bench.

The F28 quality has to glow for 3 hours at 120 degrees. The F22 has to glow 8 hours at 160 degrees and to cool down according to certain directions.

The glowing to improve the mechanical properties explains why this material loses 30 or 40% of its strength during the welding.

The 5083 material loses about 10% of its strength at welding.

3. **Welding Wire and Welders**

Welding wire is almost as important as the plating material and profiles. Welding wire should have the same properties as the mother material. (Table 4 and 5)

Under good welding conditions the welding rod material 5183 can reach a tensile strength between 275 and 300 N/mm^2 and should therefore be recommended for welding of 5083 material. (Table 3)

Aluminium melts at a temperature between 500 and 630 ^{0}C and aluminium oxide at approximately 2000 ^{0}C degrees. This explains the difficulties arising when the oxide skin lager is not brushed away properly before welding.

The critical welds in shipbuilding are the butts. If welders prove to be able to weld a vertical butt, they can execute other welds as well, with the possible exception of overhead welds.

It is advisable to judge the quality of the demonstration welds on basis of X-rays. The interpretation of the X-rays of aluminium welding is a delicate matter that requires much know-how and experience. Compared to the results of X-rays of steel plate welds sometimes unknown factors can play a role.
Worth mentioning in this respect is a case from my own experience.
At a shipyard were the quality of aluminium welding was excellent on the average, suddenly all X-rays photo's showed a "cheese with holes", indicative of a high porosity.

The ultimate cause turned out to be the use of new grinding discs with a different composition. During grinding plastic-like material at the disc started to melt leaving small and hardly visible drips in the welds.
The shining aluminium reflected the X-rays more than the dull drips of plastic what explained the described result of the X-rays.
On the other hand beautiful X-rays photos can cover welds that do not meet all requirements. A too low heat input may result in beautiful pictures, whereas the fusion is not proper. Examples are given in figure 1.

If the sample has been welded satisfactory, strips will be cut and from that two drawing bars, two face bents and two root bents are made. (Figure 2, according to ABS)

If the welding wire is geared to the mother material the weld will break in the middle. During the welding process the mother material loses 10% of its yield stress, but even than the mother material is approximately 10% stronger than the weld.

Single sided ground welds have an approximately 10% higher tensile strength so that the weld will break in the transition zone.

As welds on board of a ship will never be ground double sided, it is a comforting thought that these welds will be 10% stronger than indicated by the test weld, leaving aside the fact that the heat release on board is much better than at the test sample, which also increases the actual strength of the welds.
A round weld - whatever the reason may be (usually a too high heat input) - will cause problems with the bent tests.

Contrary to the tensile strength, the limit of stretching strain cannot easily be determined. In this regard Atma made a proposal on basis of the 0,2% offset method. Provided one has a certain skill, the application of this method is sufficiently reliable to check the performance.

4. Finally some remarks on the use of ceramic strips

In my opinion the disadvantages of the use of ceramic strips outweigh the advantages for the following reasons:

a. ceramic strips are expensive and for single use

b. the wide front opening (4 - 5 mm) cannot always be maintained, as a result of which the plate sides need to be ground in order to correct the opening width.

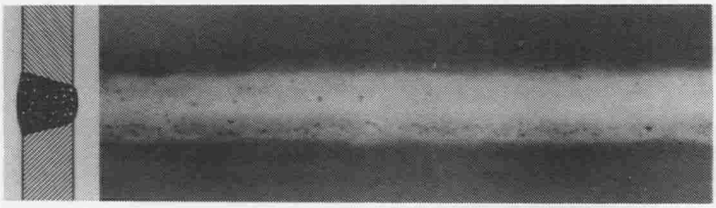
c. the wide front opening causes shrinkage in the hull what may result in heavily creased centre keelson, side keelson and floors upon the welding of the shell plates.

Furthermore the number of seams that can be welded continuously is very limited. Usually the welding has to be interrupted every 500 to 1000 mm. Consequently, after removal of the ceramic strips the welds have still to be ground in some places and welded afterwards.

Moreover one has to be specially alert on setting errors at the outside. Therefore a dye penetration test of all welds after grinding of the outside is required.

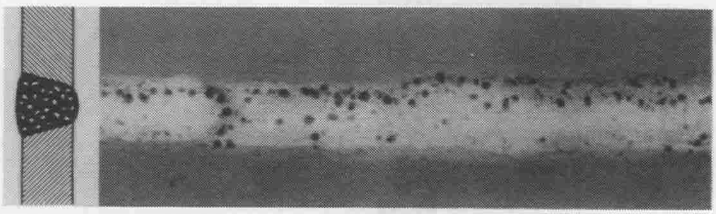
Obviously welding with the use of ceramic strips is a different way of welding which is qualitative a step back and probably not more economical.

1.



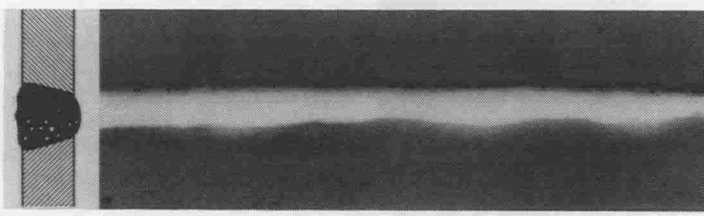
Small, sparse pores do not affect the mechanical properties of welds.

2.



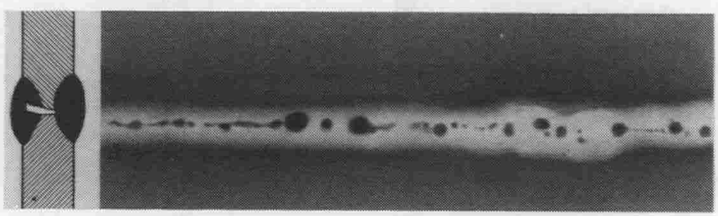
Large pores - usually caused by improperly cleaned material surface or welding wire, moisture, etc. - can harm the mechanical properties of a weld and is therefore not permissible.

3.



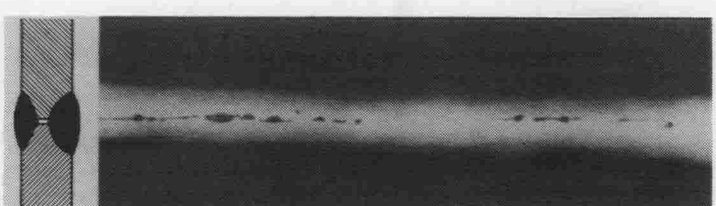
Porosity in the sides of the weld is an indication of an inferior quality of welding wire or improperly cleaned material surfaces. This kind of porosity shows a preference for the upper side of "vertical - horizontal welds" or in the transition zone of upright plates of the keel weld.

4.



Porosity in the middle is usually a sign of insufficient penetrated welding.

5.

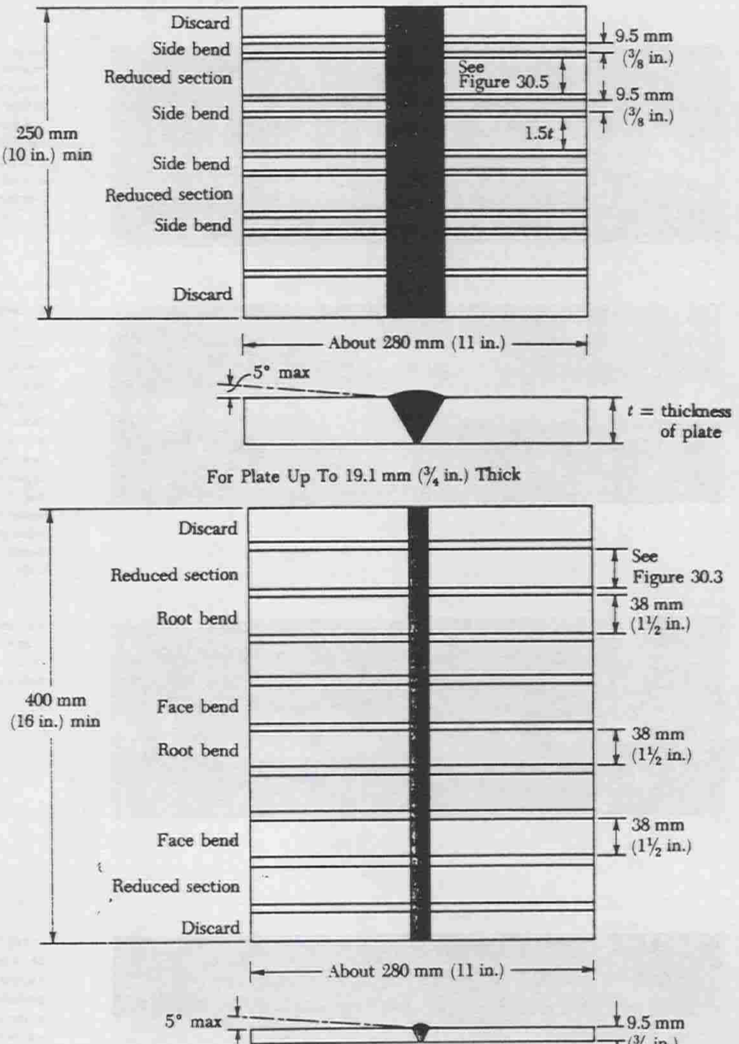


Insufficient penetration of welding can be caused by a too low power adjustment, insufficiently trained welders as well as ineffective side preparation.

Figure 1 X-ray series (Publication Alusuisse)

Preparation of Test Plates and Pipes for Weld Tests Nos. 1 and 2

For Plate Over 19.1 mm (3/4 in.) Thick



Note Edge preparation, welding procedure and postweld heat treatment, if any, are to be the same as those for the work represented.

Figure 2.

Glossary

Aluminium extrusie-legeringen
Aluminium Knetlegierungen
Aluminium wrought alloys
Alliages aluminium d'extrusion

NL-oud	NL & France	U.K.	Germany	
	AA	BS	DIN	Werkstoffnr.
50SW	6063 - F13	HE 9 TB	AlMgSi 0,5 F13	(3.3206.51)
50ST	6063 - F22	HE 9 TF	AlMgSi 0,5 F22	(3.3206.71)
C 50ST-F25	6063 - F25	HE 9 TF	AlMgSi 0,5 F25	(3.3206.72)
C 51ST-F27	6005 - F27	HE19 TF	AlMgSi 0,7 F27	(3.3210.71)
B 51ST-F28	6082 - F28	HE30 TF	AlMgSi 1,0 F28	(3.3215.71)
B 51ST-F31	6082 - F31	HE30 TF	AlMgSi 1.0 F31	(3.3215.72)

Table 1

Mechanische eigenschappen
Festigkeits Eigenschaften
Mechanical properties
Propriétés mécaniques

Legering Legierung Alloy Alliage	Treksterkte Zufestigkeit Tensile Strength Charge de rupture	0,2 Rekgrens 0,2 Grenze 0,2% Proof Stress Limite 0,2% elastique	Rek Bruchdehnung Elongation Allongement	Hardheid Harte Hardness Dureté	
	σB N/mm2	σ0,2 N/mm2	% δ5	Brinell	Webster
AlMgSi 0,5 F13	130	65	15	45	6
AlMgSi 0,5 F22	215	160	12	70	11
AlMgSi 0,5 F25	245	195	10	75	13
AlMgSi 0,7 F27	270	225	8	80	14
AlMgSi 1.0 F28	275	200	12	80	14
AlMgSi 1.0 F31	310	260	10	95	15

Table 2

American Bureau of Shipping
Rules for Building and Classing Aluminium Vessels Edition 1975

Extract of tables, concerning one specimen Aluminium Alloy 5083

Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminium Alloy (Table 35-3)				
Alloy and Temper	Thickness	Ultimate Tensile Str.	Minimum Yield 0,2% offset	Minimum Elongation in 50 mm
	mm	kg/mm2	kg/mm2	percent
		min.- max.	min.- max.	
5083-0	1,5-38,0 38,1-76,5	28,1-35,9 27,4-35,2	12,7-20,4 12,0-20,4	16
5083-H112	6,5-38,0 38,1-76,5	28,1 27,4	12,7 12,0	12 12
5083-H116	4,5-38,0	30,9-39,4	21,8-30,2	12
5083-H117	38,1-76,5	28,8-39,4	20,4-30,2	12
Minimum Mechanical Properties for Butt-Welded Aluminium Alloys (Table 30.1)				
5083 All tempers		28,1	14,8	

Table 3

Filler Metals for Welding Aluminium Alloy - Sheet, Plate and Extrusions (Table 30.3 - ABS)

Recommendations in this table apply to gas shielded-arc welding processes.

Base Metal Alloys 5083 to be welded with Filler Metal Alloy 5183

Table 4

Chemical Composition Limits of Wrought Aluminium Alloy 5083 resp. (Table 35.1) Aluminium Alloy Filler Metal Composition 5183 (Table 30.2)								
Alloy	Si	Fe	Si+Fe	Cu	Mn	Mg	Cr	Zn
5083	0,40	0,40		0,10	0,40-1,0	4,0-4,9	0,05-0,25	0,25
5183	0,40	0,40	0,40	0,10	0,50-1,0	4,3-5,2	0,05-0,25	0,25

Table 5

LARGE EXTRUSIONS - DEFINITIONS, FABRICATION

FRANK WEHNER

ALUSUISSE

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1. Definition

The size of a "Large Extrusion" is not clearly defined in standards of literature. At ALUSINGEN it has the following characteristics:

weight	8 kg/m
length	18 - 30 m

These demands result together with 30% ends scrap in a billet size: 190 - 1200 kg (1200 kg the biggest billet used at ALUSINGEN.

The shape is limited by the size of the container.
Figure 1 shows examples of hollow and solid sections fitting into the biggest available circular or rectangular container.

Generally spoken only extrusion presses with a load larger than 4500 t can produce large extrusions.

2. Extrusion press

Figure 2 is a scheme of an extrusion press. It is run either with hydraulic oil or water as a hydraulic medium. The container size is limited by the available maximum load in order to press the heated metal through the die.

3. Manufacturing

The entire process is explained in figure 3. The steps are:

- Heating the billets
- Extruding through the die
- Quenching the section by air or water in order to provide sufficient solution reatment for the heat treatable alloys used normally in the process
- Sawing the irregular end scrap at beginning and end of section
- Stretching
- Cutting to length
- Levelling

- Artificial aging about 160 ^{0}C several hours

- Controlling shape, surface, mechanical properties, extrusion seams at hollow shapes, etc.

- Packing and shipping

4. Basic Methods of Aluminium Extrusion

Figure 4 again explains the mode of operation of an extrusion press. A heated billet at about 500^{0}C is
pressed through a die which gives the metal the desired shape. The transition of the container to the die is usually rectangular.
With this arrangement the metal is worked through, the as cast structure of the billets is turned to the kneaded extrusion structure with fibre like grains (figure 5).
The corner between container and tool is filled with metal from the first billet, the flow is retarded.
It is called "dead metal zone".
Special attention has to be paid to the metal flow in this area to meet quality requirements.

This arrangement enables extruding of almost all kind of solid sections. For hollow sections a mandrel has to be used to shape the inner walls. For sections with one chamber a fixed or floating mandrel initially put through a pierced billet is used as shown in figure 6.
The mandrel is positioned in the inner space of the die.

Another method of producing hollow sections is employed by using of a porthole die (figure 7).
The mandrel is fixed to the outer part of the die.
In this part the metal is divided into several streams flowing through the portholes and then brought together again in the welding chamber of the die.

After welded together the reunited metal flows through the gap between mandrel and die insert and forms the tube wall.
Complicatedly shaped chambers or multicell hollow sections are produced by similar tools.

A further development of the multihole die is the spider die showing in figure 8. This tool is chosen, if bigger masses of metal are to be extruded close to the container walls or even outside of the container walls.

Again special attention has to be paid to the correct welding of the metal flows. Any pollution of air or grease has to be avoided in order to prevent forming of inner surfaces.High pressure and good blending has to be provided in the welding chambers. Special know-how is required.

5. Availability

In Europe are quite a number of extrusion presses with the required load and container size suitable for large extrusions. The table gives a general view.

BIG EXTRUSION PRESSES FOR AL - ALLOYS IN EUROPE			
Company	max.load (t)	Container mm	Capacity (t)
Alusingen A-L BRD	10.000 4.500	750x260/650/560/450 500x180/355	5.600 5.500
Walliser Werke A-L CH	7.200 5.000	660x240/500/405 300/350	7.000 6.000
V A W BRD	7.200 5.000	675x230/560/500/412 410x360	5.000 4.000
Aluminia P. Maghera Boze It.	5.100 5.000	310/400/460 500x250/360/420	3.000 3.000
British Alcan HDA; Workington Latchford UK Bank Quay	 5.000 5.000 5.000	 508 ?? ?? ??	 3.000 2.800 2.800
Munchenstein CH	5.000	??	3.000
SIDAL Be.	5.000	??	6.000
FIAT (own prod.)	5.000	??	(2.500)

Data: ALUSINGEN 1990

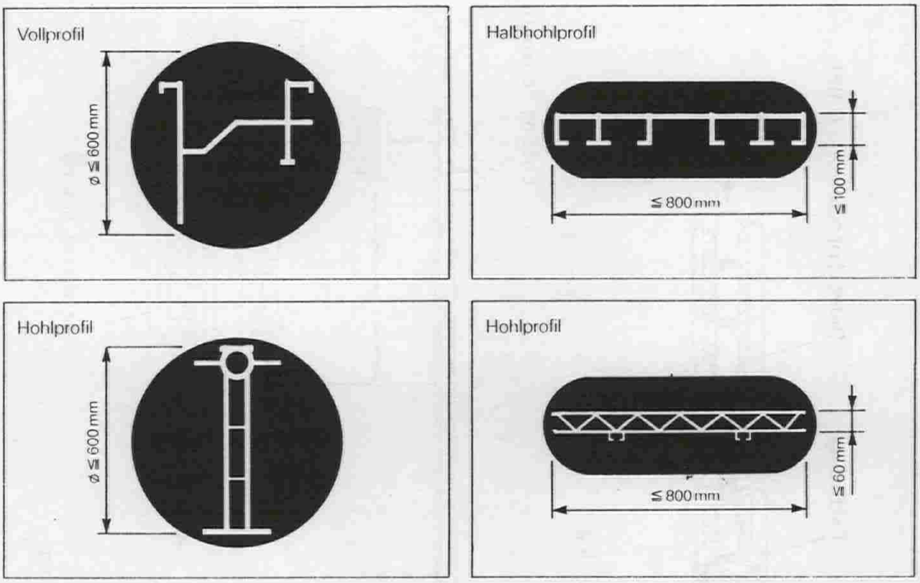


Figure 1 Definition of extrusions, fitting into the various containers at 10 000 tons press in Alusingen

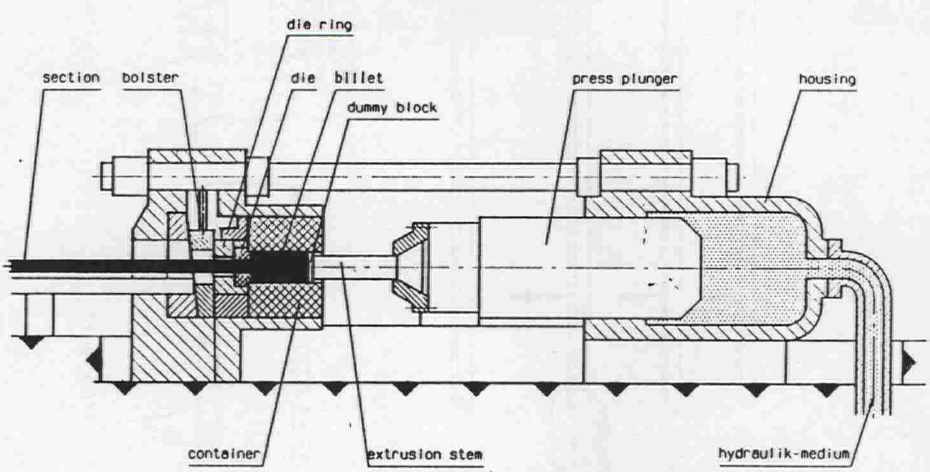


Figure 2 Scheme of an extrusion press

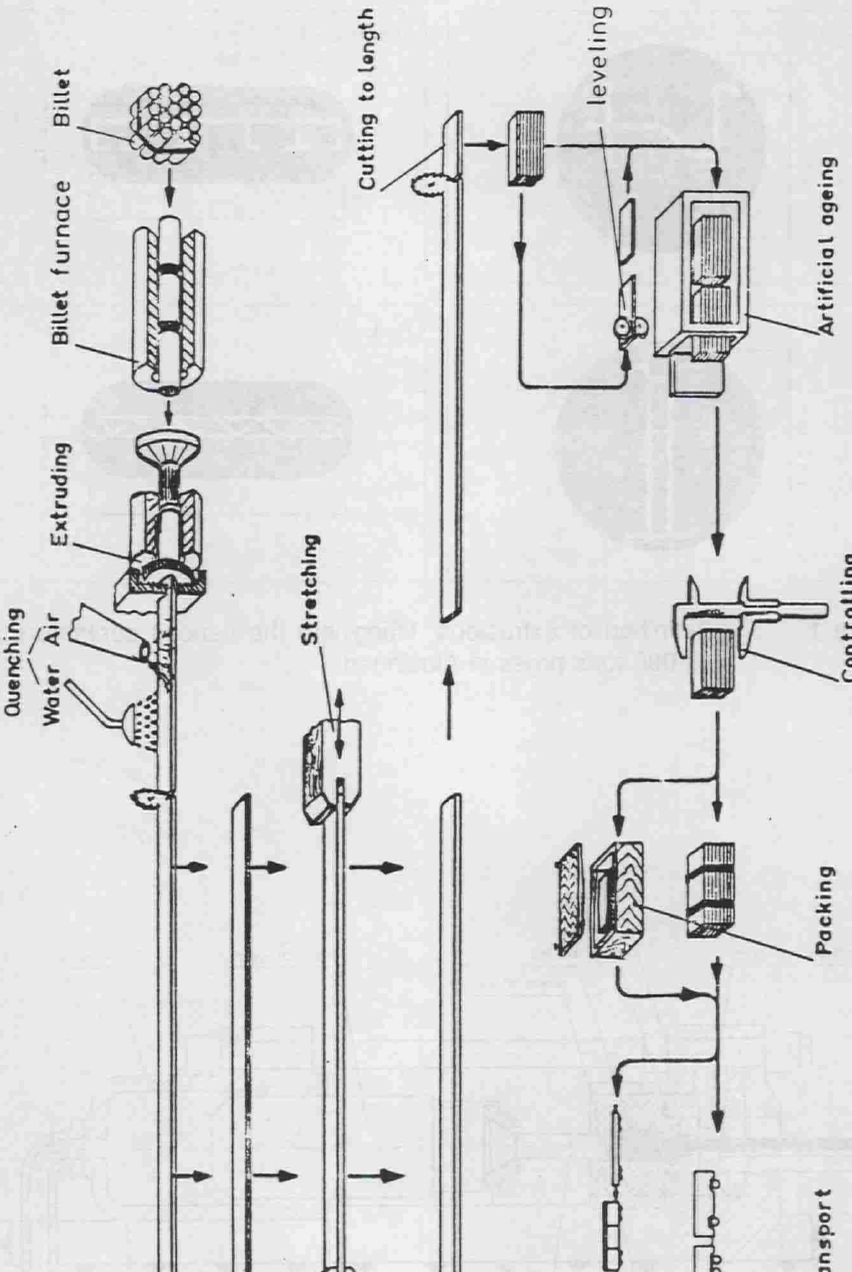


Figure 3 Manufacture of extrusions

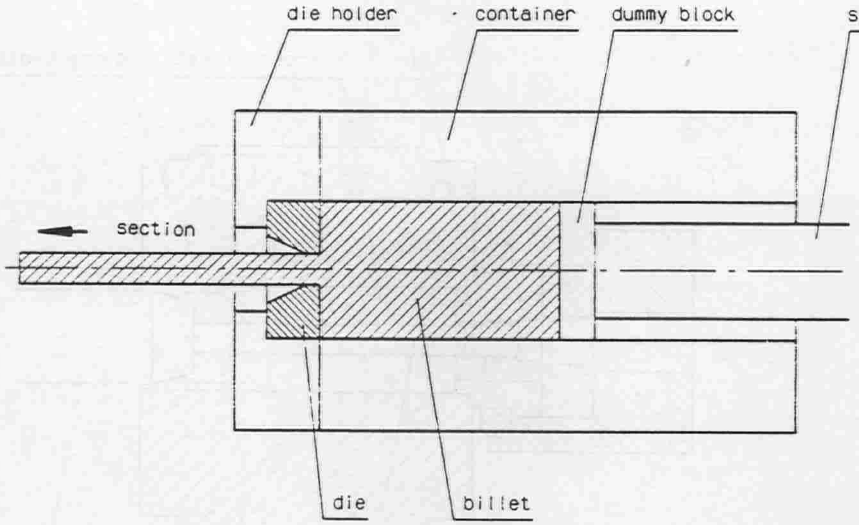


Figure 4 Basic method of extrusion

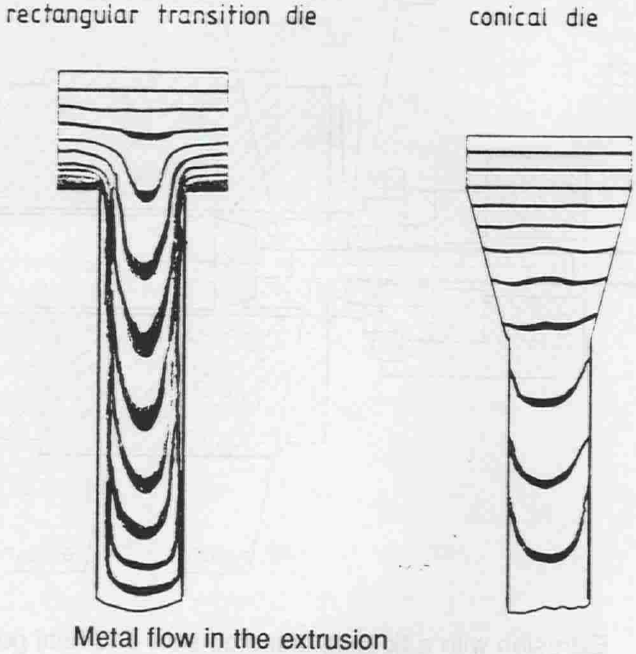


Figure 5 Metal flow in the extrusion

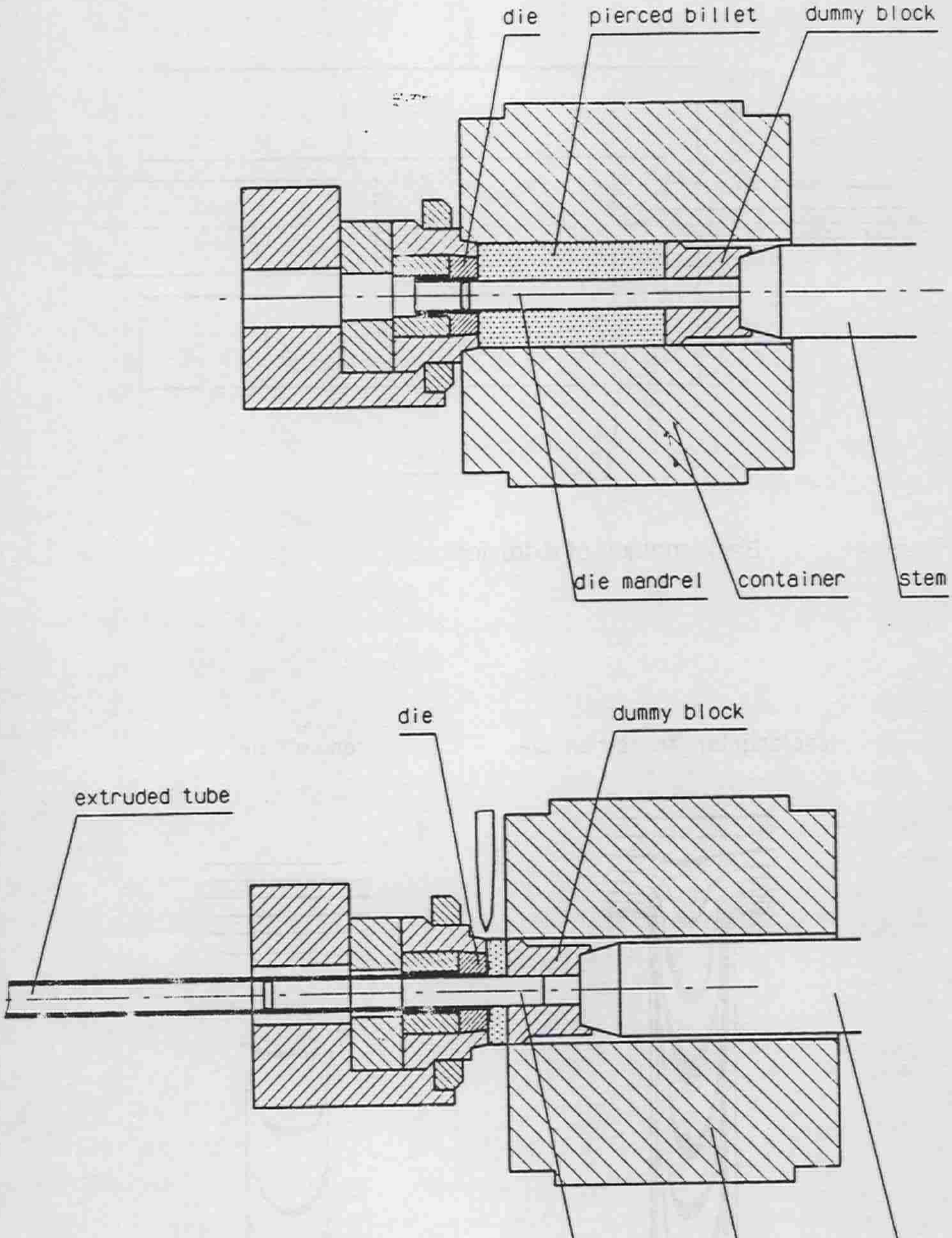


Figure 6 Extrusion with a floating mandrel: start and final position

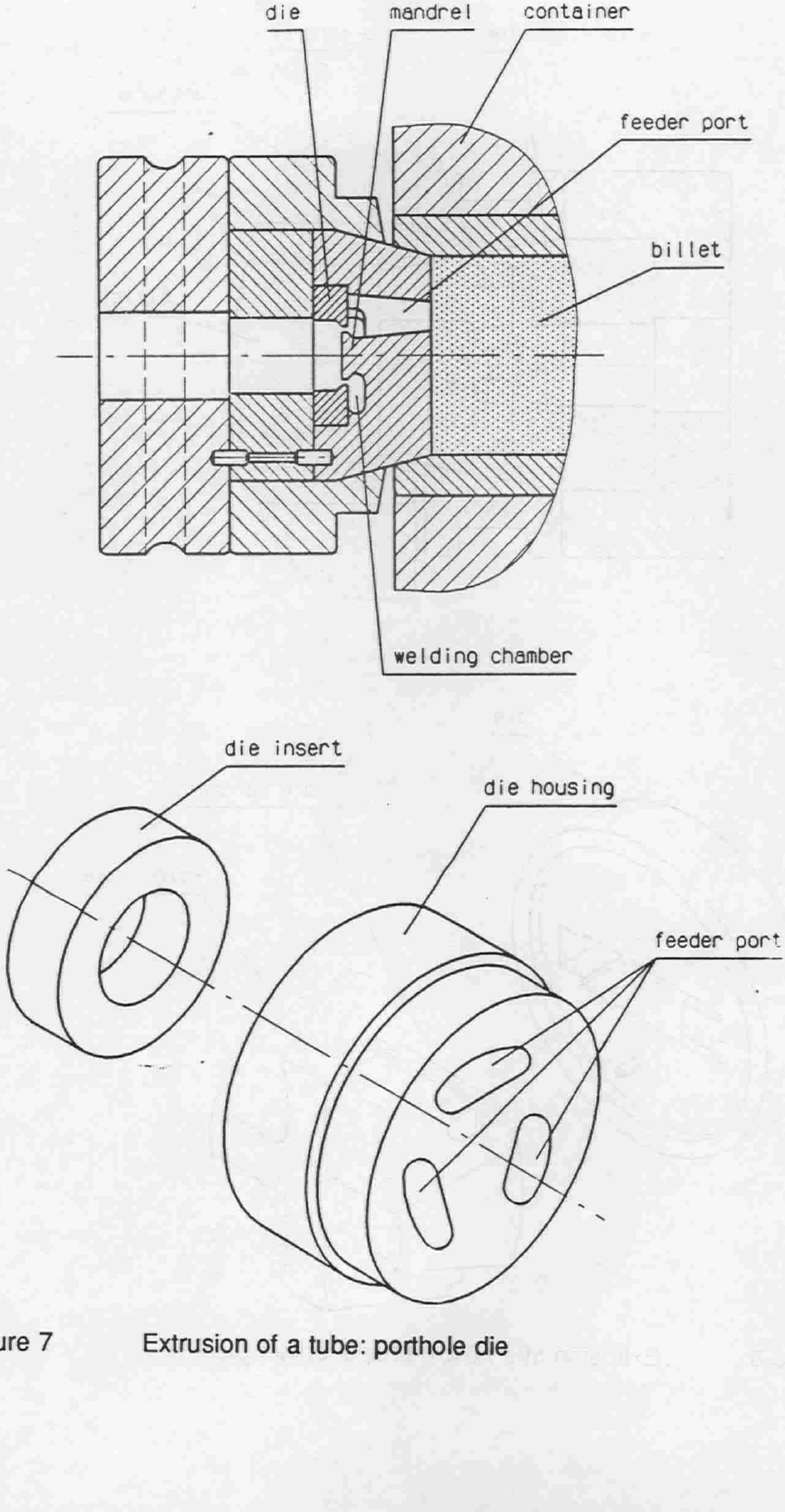
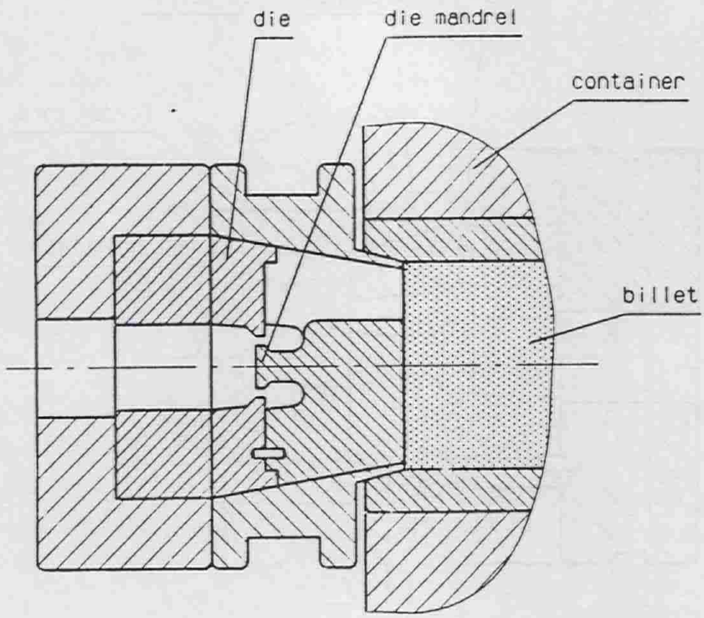


Figure 7 Extrusion of a tube: porthole die



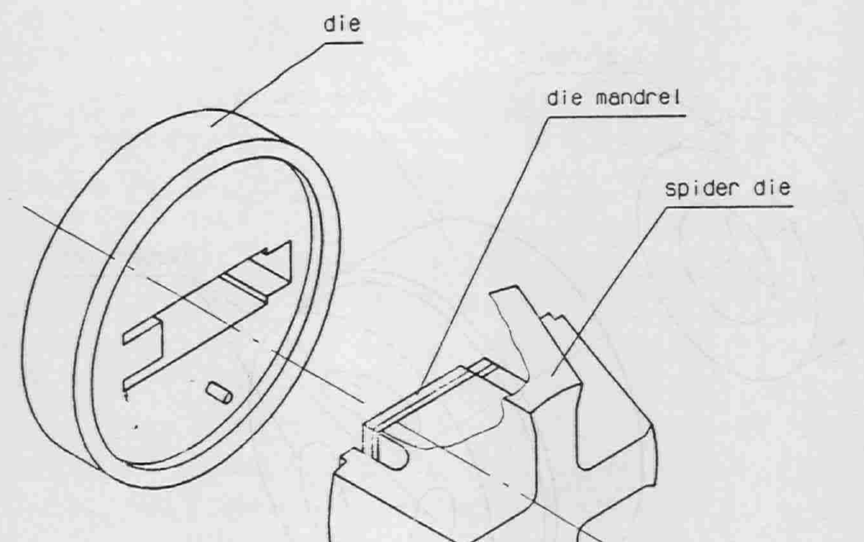


Figure 8 Extrusion of a hollow shape: spider die

LARGE EXTRUSION DESIGN IN SHIPBUILDING

Giorgio De-Stefani

Alusuisse-Lonza Services Ltd., Zürich

The Alusuisse-Lonza large extrusion design was developed some 20 years ago for railway applications.
The results achieved have been excellent since this technology makes use of all the advantages offered by special aluminium alloys, like excellent extrudability, corrosion resistance and good weldability.
During the last years, the same design criteria have been adopted for several important projects in the shipbuilding sector. The results are very promising :

- Weight saving about up to 30% compared to traditional solutions
- Reduction of manufacturing time
- Less scrap
- Optimalization of welding, especially with automatic welds
- Better quality of design and shape
- Substantial reduction of local deformation
- Good corrosion resistance

GENERAL ASPECTS

Aluminium and steel are two different metals which have similar properties but are still quite different.
In a first approach, the design engineer is therefore tempted to use aluminium in a similar way as steel, which normally leads to satisfactory results from the technical point of view but is not at all interesting cost-wise.

The most important difference between aluminium and steel is extrudability. With aluminium it is possible to manufacture sections of up to 800 mm width and 32 m length. Also, the design engineer has nearly unlimited possibilities with regards to extrusion shape.

As one of the leading aluminium producers world-wide Alusuisse-Lonza has been active in the railway field for many years. The experience and success obtained in this sector with a new design based on the use of large welded aluminium sections can in principle be transferred to other transportation segments, like for example shipbuilding.

LARGE EXTRUSION DESIGN - ALUSUISSE EXPERIENCE

On the European continent, more than 10.000 passenger cars are in service with welded, fully integral body shells. About 6000 of the body shells were built to the Alusuisse large extrusion design first developed in 1971. Until then, most of the aluminium structures for passenger rolling stock had been designed and built like steel vehicles.
Although some labour saving could be achieved, the price was considerably higher than for a steel body due to higher material costs. A typical example is shown in figure 1 and 2.

Most of these traditionally designed aluminium body shells were built using the ALZnMg alloy (AA 7020).
This alloy offers some advantages like easy welding, high strength and the partial recovery of strength after softening due to welding. However, it is subject to stress corrosion and therefore needs high quality protection measures causing substantial extra costs.

These disadvantages led to the development of the large extrusion design which offered drastically reduced labor costs combined with structurally sound body shells by using the medium strength but trouble-free Magnesium- Silicon alloy (AA 6005 A).
The first successful application of this new concept were side-wall and roof components for the body shells of the Advanced Passenger Train.

A real breakthrough in favor of the large extrusion design was achieved when the former Franco-Belgian Company in France contracted Alusuisse for the design of the bodyshell for 1000 type MF 77 cars for the Paris Metro. This is illustrated in figure 2.

The target was to reduce workshop hours to such an extent that not only the higher price of the aluminium could be compensated but also the total costs of a welded body shell made out of steel could be undercut. After manufacturing 500 body shells the labour content was reduced to only 300 man-hours.

It is interesting to compare these figures with those for steel bodies: 1100 hours were needed for the previous build and for a new build 800 man-hours had been calculated.

This drastic cut in labor hours was possible not only by using large alumini-

um extrusions for building structural parts but also by integrating as many functions as possible into the large aluminium extrusions. A typical example are equipment mounting slots.
Thanks to this technology, aluminium body shells could be manufactured in about one third of the time required for building a comparable steel body.

As a result if this impressive cost cutting, other projects were realized using the Alusuisse large extrusion design:
750 suburban cars of type Interconnection for Paris (figure 3)
120 Metro cars for Atlanta (figure 4).
600 passenger cars for the Spanish Talgo trains and others.

In view of the increasing number of different car types made in large aluminium extrusion design, a large choice of extrusion dyes is available which can be used for small orders. Even for 30 type 7 Intercity cars of the Norwegian railways, large extrusion design was the most cost-effective solution because a lot of existing sec-tions from other project could be used.
The LUL "Stock" bodies, for example, had floor sections from the BART-Metro of San Francisco, for which 150 cars were produced in 1988.

ALUSUISSE LARGE-EXTRUSION DESIGN IN SHIPBUILDING

Some examples:

- Sovereign of the Seas (GEC Alsthom)
- Crown Princess (Fincantieri)

Alloys used for the large extrusions are specified in the tables as well in the recommendations established by Bureau Veritas No. 370 DNC ROO F, June 1990.

Material	AA 5085			AA 6082		
Condition	Base metal	Butt weld	Fillet weld	Base metal	Butt weld	Fillet weld
Rm (N/mm^2)	275	275	275	310	185	185
$R_{0.2}$	125	275	125	260	115	115
A_5 %	17	125	-	10	-	-
		-				
Fatigue R=0						
10^5	120	70	47	120	70	47
10^6	110	50	37	110	50	37
10^7	105	40	29	105	40	29
Fatigue R=-1						
10^5	80	59	40	80	59	40
10^6	75	40	30	75	40	30
10^7	70	30	20	70	30	20

AA Alusuisse	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
6060 Ed-043 AlMgSio.5	0.3-0,5	0.1-0.3	0.10	0,10	0,35-0,55	0.05	0.15	0.10
6005A AC-062 AlMgSi0.7	0.5-0.9	0.35	0.30	0.50 + Cr 0.12-0.5	0.4-0.7	0.30 + Mn 0.13-0.5	0.20	0.10
6061A AC-080 AlMgSiCu	0.4-0.8	0.7	0.15-0.4	0.15	0.8-1.2	0.04-	0.25	0.10
6082 AC-110 AlMgSi1	0.7-1.3	0.50	0.10	0.4-1.0	0.6-1.2	0.25	0.20	0.10
6106 AC-053 AlMgSI0.6	0.45-0.6	0.1-0,3	0.10	0.10	0.45-0.6	0.05	0.15	0.10

Table 1 Chemical analysis of AA 6060, 6061, 6082 and 6106

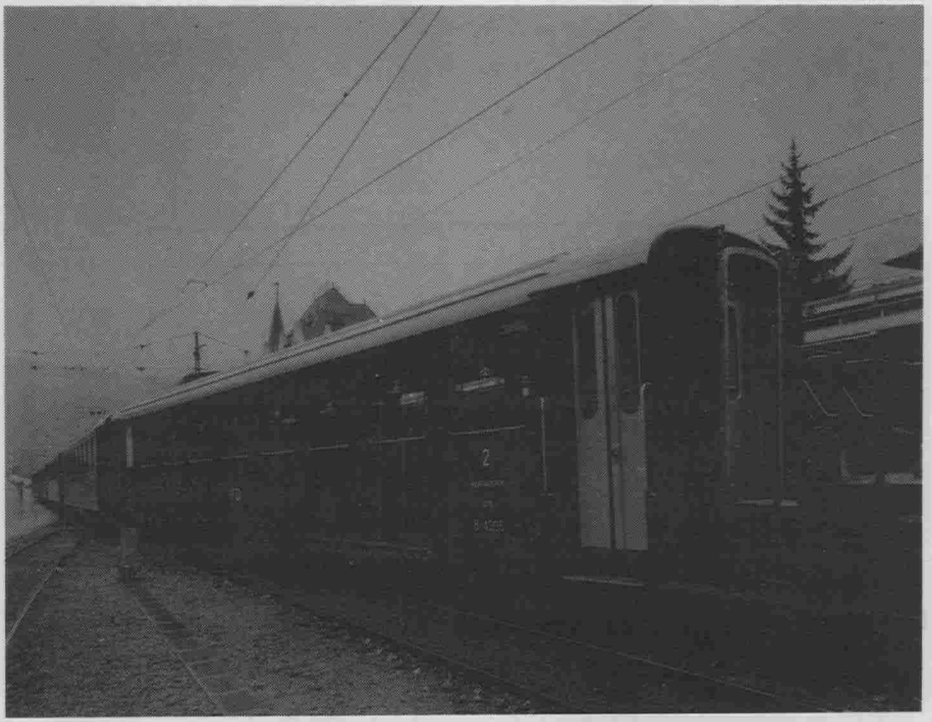


Figure 1a TEE-Zug Deutsche Bundesbahn

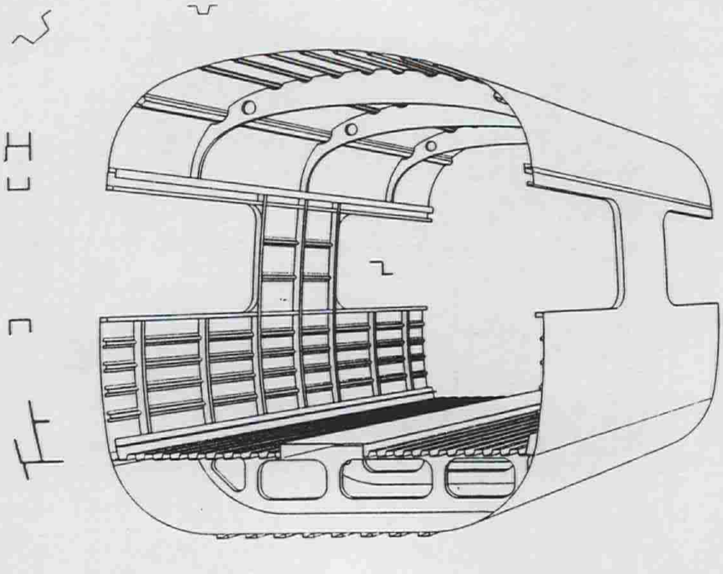


Figure 1b Section of railway car

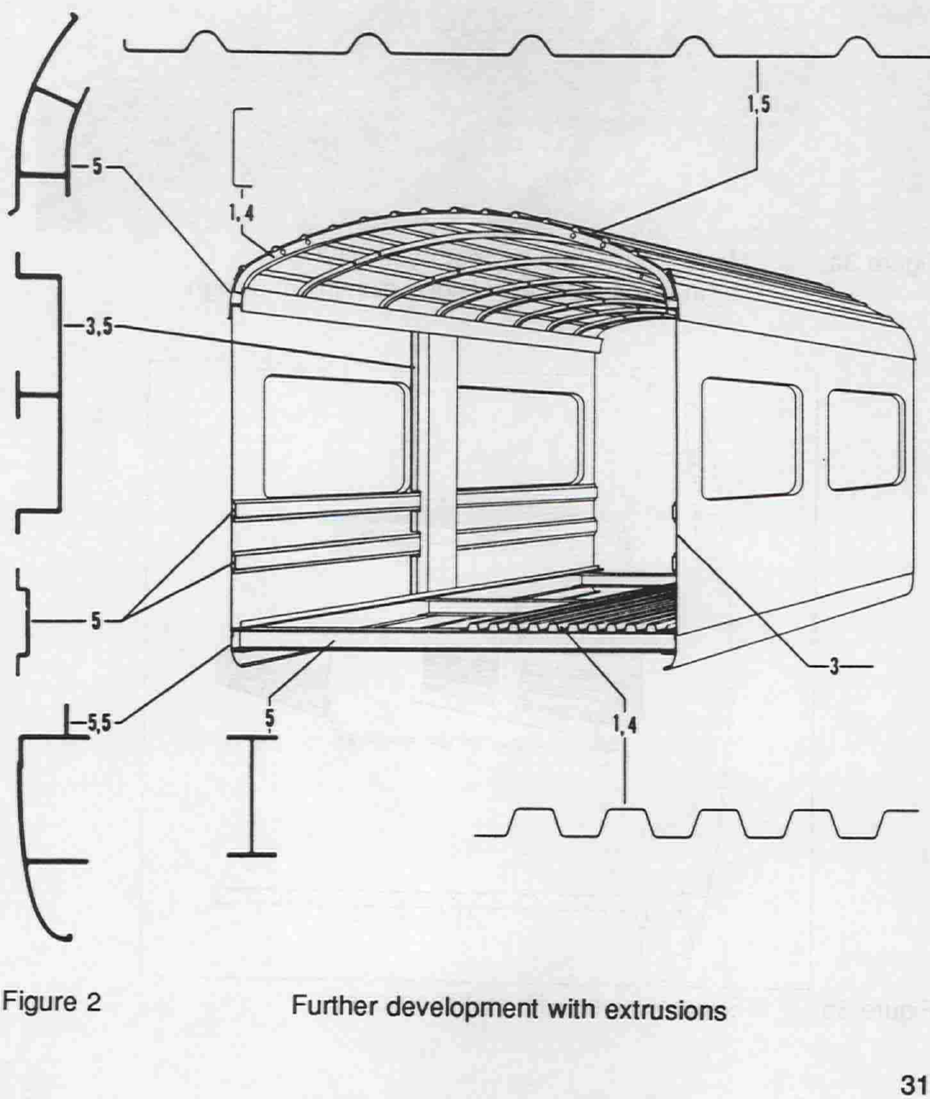


Figure 2 Further development with extrusions

Figure 3a. Metro Paris - Subway car, type MF77 in self-supporting welded aluminium design

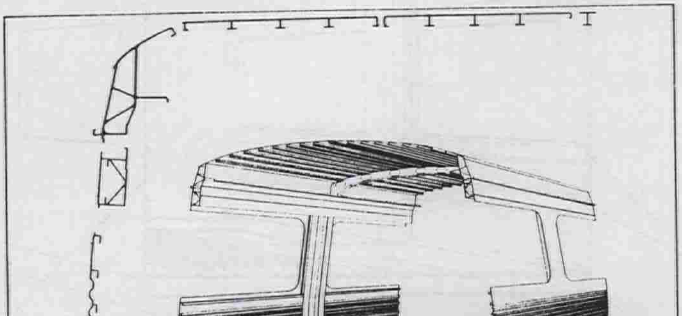


Figure 3b. Supersections with multifunctions

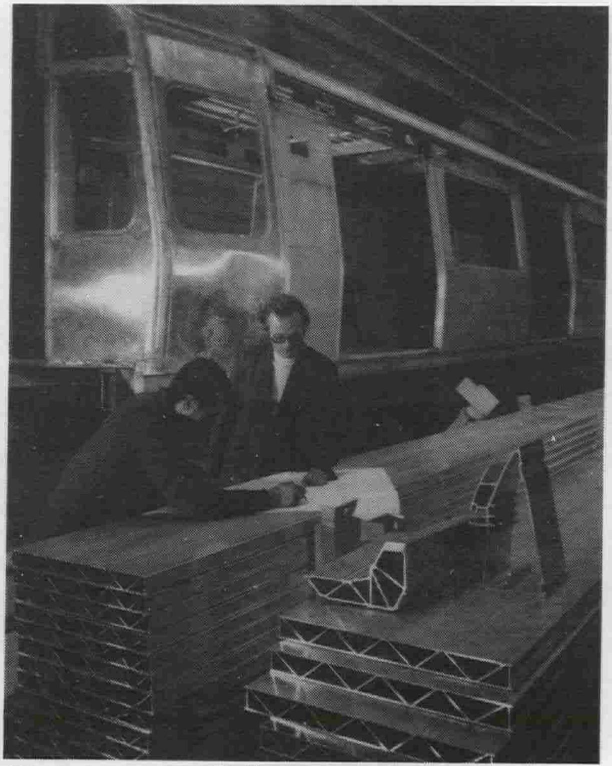


Figure 3c. Railwaycar under construction

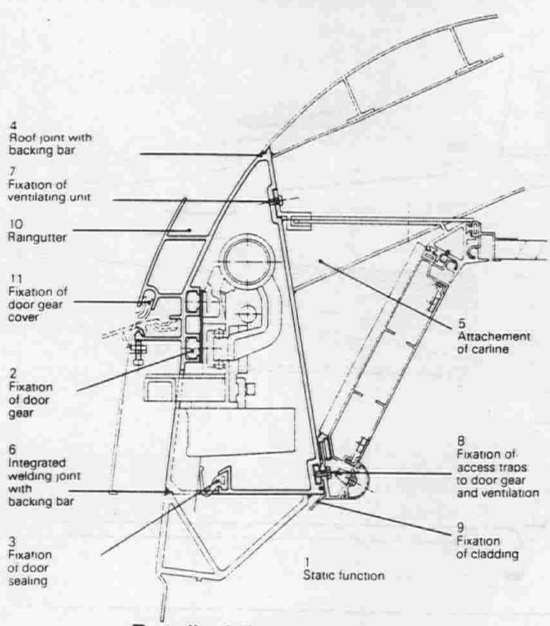


Figure 3d. Detail of figure 3b

Figure 4a. Metro Atlanta

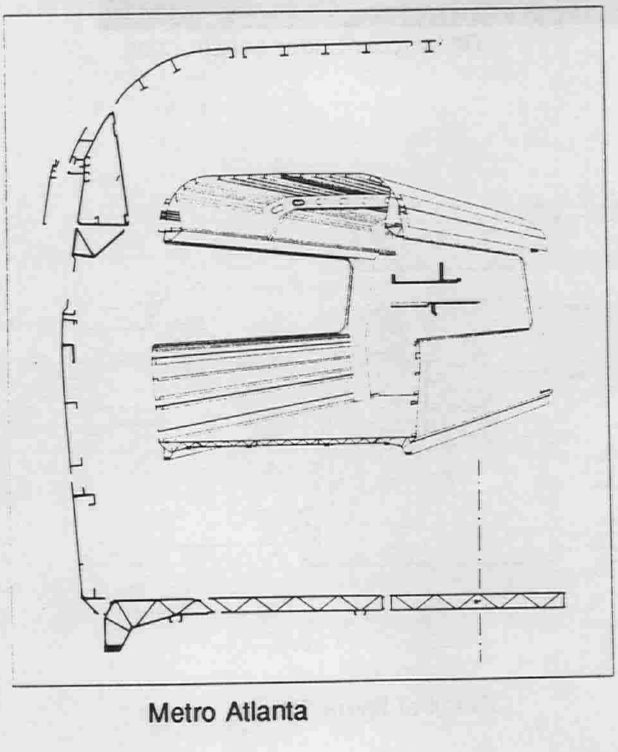


Figure 4b. Metro Atlanta

WELDING TECHNOLOGY
IN ALUMINIUM YACHT BUILDING

P.L.W.M. Bruinsma

AGA-GAS bv

Table of Contents

1. INTRODUCTION

Aluminium is a relatively light metal. with excellent resistance to weathering and corrosion. Its tensile strength is small. Many aluminium alloys have been developed especially to improve the strength characteristics. These are being variously used in a number of states, including yacht building.
The most important joining technique here is welding. The welding processes in general use are MIG- and TIG-welding. These welding processes and the influences of a number of physical properties of aluminium on welding will be described. The principles on which an increase in the tensile strength of aluminium and aluminium alloys depends on how these properties are effected by welding, will be dealt with briefly.
First some uses of aluminium in yacht building will be mentioned.

1.1 ALUMINIUM IN YACHT BUILDING

Modern yacht building without aluminium cannot be imagined anymore. At this time, just about every mast is made of high quality aluminium alloys. Next to racing-yachts, as for instance the "FLYER" (photo 1), also motorcruisers and pleasure yachts are partly or completely built of aluminium.
Photo 2 shows the construction of a motorcruiser of steel with aluminium upperstructure. Aluminium is also applicable when high demands are made regarding strength and rigidity.
For example a motorcruiser, length 40 m., engine power
3 x 3500 HP and a top speed of 50 knots.
Photo 3 shows the transom of this cruiser during construction. Next to the racing and recreation yacht, building aluminium is also all round used in tradeships. Another example is shown in photo 4, the lifeboat is completely constructed in aluminium.

1.2 ALUMINIUM AND ALUMINIUM ALLOYS

Some physical properties of pure aluminium are given in table 1.
The values for pure iron are given as a comparison.

Property		Al	Iron
Density	kg/m^3	2700	7850
Mod. of Elasticity	Kn/mm^2	66	210
0.2% Yield Strength	N/mm^2	10	100
Tensile Strength	N/mm^2	50	200
Melting Point	^0C	658	1500

Table 1. Physical properties

A number of methods are available for improving the tensile strength:

a. Strengthening by cold-working:

"work hardened" aluminium produced by cold-working
The 0.2 yield strength and the tensile strength increase and the elasticity decreases. The material becomes harder.

b. Alloying:

By alloying with manganese, magnesium or manganese and magnesium.
These are the so called non-heat-treatable aluminium alloys.

c. Precipitation hardening:

Precipitation hardening consists of the hardening by alloying with the use of magnesium and at least one of the following three elements: zinc, copper and silicon. These are called the heat-treatable aluminium alloys.

d. A combination:

Many combinations of point a, with b and c are used.

The result of the possibilities mentioned above is an extensive range of alalloys and states.
The coding for aluminium alloys much used in the Netherlands and internationally is that of the American Aluminium Association.
Their Alloy and Tempered Designation System consists of four figures which identify the alloy. These four figures may be followed by a letter plus a further one or two figures if necessary, which indicate post treatment such as strengthening or precipitation hardening.

.1 ALUMINIUM ALLOYS IN YACHT BUILDING

The alloys generally used in yacht building are designated by the Al Association under 5038, 5086 and 6061;
Each alloy with its appropriate temper.

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other elements each	tot.	Al
5083	0.40	0.50	0.10	0.30-1.0	4.0-4.9	0.05-0.25	0.25	0.15	0.05	0.15	rem.
5086	0.40	0.50	0.10	0.20-0.7	3.5-4.5	0.05-0.25	0.25	0.15	0.05	0.15	rem.
6061	0.40-	0.70	0.15-0.40	0.15	0.8-1.2	0.04-0.35	0.25	0.15	0.05	0.15	rem.

Table 2: Chemical composition limits of alloys used in yacht building

Sheets (under 1/4" thickness) or plate (over 1/4" used for decks, hulls, keels and rudders) is usually made of alloy 5083 with the H321 temper or 5086 with the H117 temper. Small parts like webframes, bulkheads, floors, chainplates etc. are made of similar materials.

Stringers, stiffeners and frames, however made of 6061 extruded material. The temper is the T6 type.

Mast sections are always extruded type 6061, although the welded on mast tangs and main boom connections are 5083 plate material.

The three fore-mentioned alloys have excellent corrosion resistance, especially in a salt water environment.

Furthermore, their mouldability is good.

A certain amount of bending and stretching is possible without reducing the quality of the material.

The mechanical property limits are mentioned in table 3.

Alloy and Temper	Tensile strength (kg/mm2)						Elongation	
	Ultimate (S4)			Yield (S0.2)			L = 2" (%)	
	min.	typ.	max.	min.	typ.	max.	min.	typ.
50863- H 321	30.9	32.3	39.4	21.8	23.2	30.2	12	16
5086 - H 116	28.1	29.5	-	19.7	21.1	-	8	12
6061 - T 6	26.7	31.6	-	24.6	28.1	-	10	12

Table 3. Mechanical property limits for the alloys

Aluminium in combination with magnesium and silicon gives a eutectic with a low solidification temperature and is therefore liable to heat cracking. Alloys containing magnesium are therefore welded for preference with a filler not containing silicon.

Table 4 gives the specification of a number of fillers as incorporated in the German standard DIN 1732 and the American Standard AWS A5.10-69.

2.2 THE INFLUENCE OF WELDING ON MECHANICAL STRENGTH

During welding the material near the weld is heated. Dependent on the sort and supply condition of the material this may result in decreased tensile strength as a result of the annealing effect.
The width of this zone is strongly dependent on the speed of welding and becomes less as the speed of welding increases.
Although the 0.2% yield strength does not completely return after welding to a level corresponding to the soft annealed state, account should be taken in the design with a decrease roughly amounting to a value lying about 20 to 30 % above that of the annealed state. In many manufacturing code it is fact prescribed that the 0.2% yield strength in the soft annealed state should be maintained.

The strength of the heat-treatable alloys will be adversely affected during welding since the hardening is locally negated.
For some alloys, such as AlZnMg1, for instance, the return immediately after welding, the self-hardening effect at room temperature can be reduced in the course of time.
In view of the extreme range of the heat-treatable alloys supplied it is advisable to consult the supplier.

DIN 1732	AWS ER	AL	Mg	Mn	Zn	Si	Cu	Fe	
	1100	>99.00		0.05	0.10	1.0 Si + Fe	0.05-0.20		
	1260	>99.60		0.01		0.40Si + Fe	.04		
S.Al 99.5		>99.5			0.07	0.30	.05	0.40	0.05 Ti
S.Al 99.5		>99.8			0.06	0.15	.02	0.15	0.05 Ti
S.Al 99.5 Ti		>99.5 incl Ti			0.07	0.30	.05	0.40	0.1-0.2 Ti
	2319	Al remainder	0.02	0.20-0.40	0.10	0.20	5.8-6.8	0.30	0.20 Ti
	4043	Al	0.05	0.05	0.10	4.5-6.0	0.30	0.8	0.20 Ti
S-Al Si 5		Al	0.1	0.1	0.2	4.5-5.5	0.05	0.4	0.25 Ti
	4047	Al	0.10	0.15	0.20	11.0-13.0	0.30	0.8	
S-Al Si 12		Al	0.05	0-0,5	0.10	11.0-13.5	0.05	0.6	0.25 Ti
	4145	Al	0.15	0.15	0.20	9.3-10.7	3.3-4.7	0.8	0.15 Cr
	5030	Al	3.3-4.3	0.30-0.50	2.4-3.2	0.10	.03	0.40	0.10-20 Cr 0.10 Ti
	5183	Al	4.3-5.2	0.5-1.0	0.25	0.40	.10	0.40	.05-.25 Cr 0.15 Ti
S-AlMg4.5Mn		Al	4.3-5.2	0.6-1.0	0.25	0.25	.05	0.40	.05-.25 Cr .10-.25 Ti
	5356	Al	4.5-5.5	0.05-0.20	0.10	0.50 + Fe	.10		.05-.20 Cr .06-.20 Ti
S-AlMg4.5Mn		Al	4.5-5.5	0-0.5	0.2	0.25	.05	0.40	0-0.3 Cr .10-.25 Ti
	5554	Al	2.4-3.0	0.50-1.0	0.2	0.40 + Fe	.10		.05-.20 Cr .05-.20 Ti
	5556	Al	4.7-5.5	0.50-1.0	0.2	0.40 + Fe	.10		.05-.20 Cr .05-.20 Ti
	5654	Al	3.1-3.9	0.01	0.20	0.45 + Fe	.05		.15-.35 Cr .05-.20 Ti
S-Al Mg3		Al	2.4-3.4	0-0.60	0.2	0.25	.05	0.40	.0 -.5 Cr .10-.25 Ti

Table 4 German standard DIN 1732 - Filler Material

2.3 THE WELDABILITY OF ALUMINIUM AND ALUMINIUM ALLOYS

Aluminium and the non heat-treatable alloys have an excellent weldability. The heat-treatable alloys have a good weldability but are liable to heat-cracking. This sensitivity is caused by the larger solidification zone.
A bigger solidification zone means that the weld metal is liable to cracking as a result of contraction for a longer time and over a greater distance. To reduce liability to heat-cracking these materials are welded with a filler of a non heat-treatable composition.

2.4 THE INFLUENCE OF SOME PHYSICAL PROPERTIES ON WELDING

Aluminium has a number of properties differing from those of steel which exercise considerable influence on behaviour during welding. They are:

A. Aluminium oxide.
As soon as aluminium comes into contact with oxygen, for example from the surrounding atmosphere, a close-knit tough oxide layer (Al_2O_3) forms on the surface. The melting point of this oxide layer is 2050 ^{0}C, considerably higher than the melting point of aluminium, which is 658 ^{0}C. Further, the density of the oxide is higher.
In order to obtain a qualitatively good weld this oxide skin must be removed or at least broken.
This occurs during gasshielded-arc welding as a result of the 'cleansing' effect of the arc.
This will be explained during the description of the TIG welding process.

B. Thermal conductibility
Despite its low melting point, aluminium demands the input of heat equal to or greater than that of steel because of its high thermal conductibility and high specific melting heat.
Pre-heating is advisable for sheets more than 15 mm thick.

C. Coefficient of linear expansion
The expansion under heating, double that of steel, and the shrinkage of 7% for aluminium and 4 - 6 % for alloys may cause considerable shrinkage tensions and distortions.

D. Poor solubility of hydrogen
In the fluid state the solubility of hydrogen is about 2N/cm^3 per 100 gram of weld material and in the solid state almost nil (0.5%).
During solidification all hydrogen must be removed from the weldpool in a

very short time, in view of the rapid cooling rate and the small solidification track. If this is not done or not done quickly, porosity results. This is one of the most frequent welding problems.
Porosity can be avoided by preventing the introduction of moisture in any form.
Aluminium oxide is strongly hygroscopic and contains moisture.
Thick layers of oxide and hydrogen-producing impurities such as oil, grease and paint must be removed from the welding sites and from the filler material.

2.5 FILLER MATERIAL

MIG-welding is always made with a filler material,
whilst TIG welding can be made both with and without one.
The best properties of the welded joint with respect to strength, corrosion and lack of cracks are obtained when a suitable filler metal is used in accordance with the following:
Heat-treatable alloys
Filler metal with increased content of SI or MG, AlSi5, AlMg5.
For material containing Cu AlSi5 ought to be chosen.

To reduce the liability to heat cracks, heat-treatable alloys are welded with a filler of non-heat-treatable composition. Alloys in the 5xxx group[(Al-Mg) should be given preference if the highest possible strength is desired.

3. GAS SHIELDED-ARC WELDING PROCESSES

In shielded-arc welding processes the material is heated and melted by using an electric arc.
The fluid material, which is very sensitive for the incorporation of oxygen, nitrogen and hydrogen, is protected by a shielding gas. When welding aluminium and aluminium alloys only the inert gasses are used. Inert gasses that do not form chemical reactions with other elements, even at higher temperatures.
In yacht building MIG welding is most often used and TIG-welding less frequently.

3.1 TIG-WELDING

(TIG + Tungsten Inert Gas). In TIG welding, the electric arc burns between an electrode made of tungsten (or tungsten alloy) and the workpiece. The weldpool and the electrode are protected by an inert gas which is fed to the weld area through a gas cup surrounding the electrode. The electric arc is struck by means of a spark generated by a pulsed high-frequency voltage between the electrode and the workpiece.

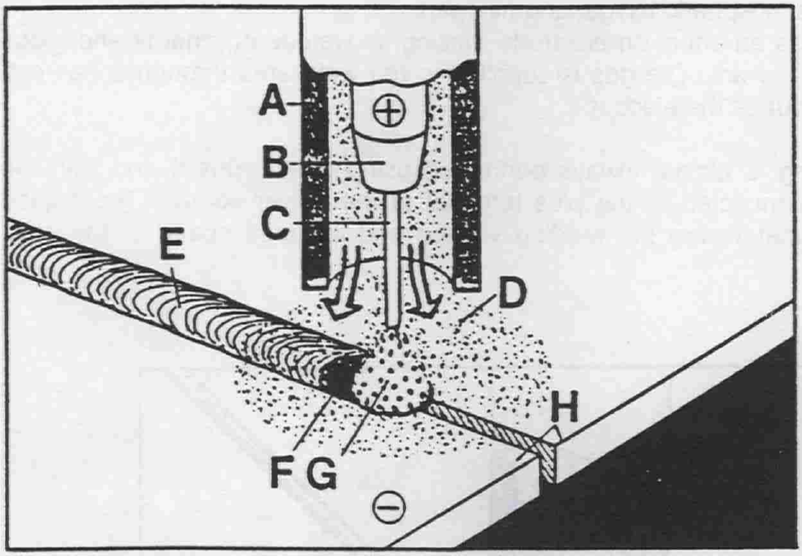


Fig 1 Schematic presentation of TIG-welding

A. Gas cup
B. Collet
C. Non-consumable tungsten electrode
D. Shielding gas
E. Completed weld
F. Weldpool
G. Arc
H. Parent metal
I. Filler rod

The electrode merely comprises one pole for the arc and does not supply molten metal. That is why electrode material with a high melting point is used (the melting point of tungsten is 3370 °C).
When necessary, filler material in the form of a rod can be supplied. In this case, it is fed, from the side into the arc, where it melts and drops into the weldpool.

3.2 MIG-WELDING

(MIG = Metal Inert Gas). MIG-welding is the general name for a group of processes using a consumable wire electrode.
In MIG-welding, the electric arc burns between a continuous fed wire

electrode and the workpiece.
The electrode is fed forward at a constant rate by means of an automatic drive device (wire feed unit), melts in the arc and is transferred to the weldpool; in droplet form.

A shielding gas protects the arc and the weldpool from the deleterious effects of atmospheric oxygenand nitrogen.
The gas has an effect on electrode melting as well as on energy and metal transfer in the arc. The gas is supplied to the weld area through a gas cup which surrounds the electrode.

MIG-welding is almost always performed using direct current and with the electrode connected to the plus terminal of the power source. The adjustment parameters are the welding voltage and the feed speed of the electrode wire.

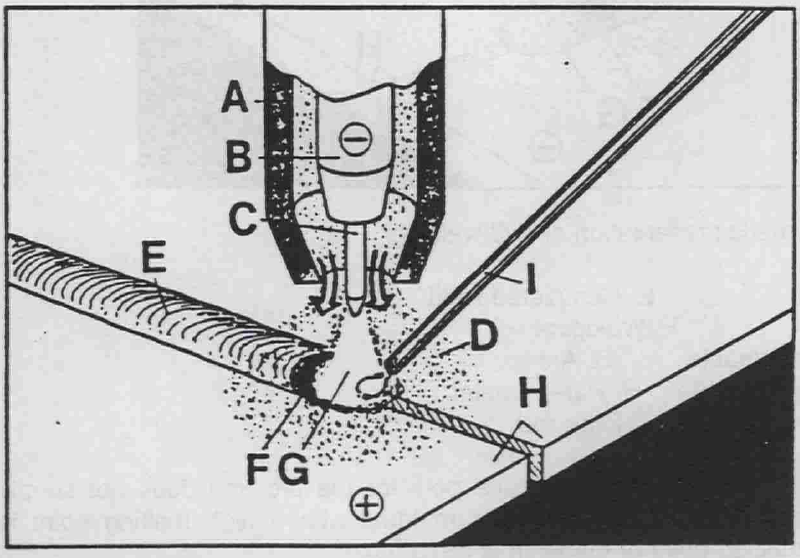


Figure 2 Schematic presentation of MIG welding

A. Gas cup
B. Electrode guide and contact tip
C. Electrode wire
D. Shielding gas
E. Completed weld
F. Weldpool
G. Arc
H. Parent metal

Depending on the welding current and the arc voltage, the metal is transferred to the workpiece in the form of large drops (which temporarily short-

circuit the arc gap) or in the form of fine, non-short-circuiting mode of globular transfer, whereas the latter type is known as spray-arc transfer.
When necessary, filler metal in the form of a rod can be supplied. In this case, it is fed, from the side into the arc, where it melts and drops down into the weld pool.

TIG-welding is carried out on most metals using direct current and with the electrode connected to the negative terminal of the power source. This results in less heat generation on the electrode than connection to the positive terminal.
When a metal with a heavy oxide layer such as aluminium is welded, the oxide layer must be broken up. The best way to do this is to use alternating current. The electrode will then be positive during half the time arc, which is enough to break up the oxide layer.
At present power supplies of square wave alternating current are available in which the duration of positive and negative phases can be altered. The advantage of this source of power is that the welding parameters can be optimally adjusted to the piece of work by altering the relationship between the cleansing operation (electrode positive) and heat input (electrode negative).

THE SHIELDING GAS

Argon is usually used during TIG-welding of aluminium and aluminium alloys and in specific applications Helium and mixtures of Helium and Argon, for instance when welding thicker sheets. In general Argon is to be preferred for the following reasons:

- with Argon, the weldpool metal can be controlled more easily and welding in position becomes possible.

- the Argon-welding arc strikes easier and can therefore be used with alternating current.

- Argon is 1.4 times heavier than air and Helium 7 times lighter.

The protection of the weldpool is disturbed earlier with Helium and is therefore more critical.

USES OF TIG WELDING

During TIG welding the heat from the arc and the filler are applied to the weldpool. The electric arc remains stable at a relatively low current. The process is free from spattering and can be used in all positions. Practically no smoke is formed and the welder has a good view on the weldpool.

The welding torch is light and can be supplied in many sizes and finishes. These factors enable good management of the welding process. TIG-welding is also used mainly for welding thin sheets (0.5 - 4 mm). These may be butt-welded, that is without a bevel, to a very high quality. When filler material is introduced by hand, the procedure is slow. For sheet thicknesses in excess of 3 mm, because of welding in several layers and the low welding speed the heat input is considerable and welding time-consuming and costly. For thicker sheets TIG welding by hand will remain limited to making through welds if high quality requirements are laid down.
Short-circuit welding is not suited for the welding of aluminium and aluminium alloys. No arc is produced during the short-circuiting and the cleansing operation, by which aluminium oxide enclosures may arise, is missing.
Further the heat input is limited, which may be the cause of incomplete fusion.

When the welding current is increased above a critical value a continuous ignited arc is produced. No further short-circuits take place. The end of the wire melts and through forces partly caused by Argon as the shielding gas, drops of fluid material are split off, which enter the weldpool as fine droplets. The arc makes a buzzing sound. The critical current intensity depends on the diameter of the wire and the gas used. See table 5.

real diameter in mm	critical current intensity in amperes
0.8	approx. 90
1.0	110
1.2	125
1.6	160
2.4	190

Table 5 The critical current intensity for the MIG welding of aluminium under argon for wire diameters between 0.8 and 2.4 mm

Spray-arc welding is excellently suited for welding aluminium. The cleansing effect of the arc is interrupted and the relatively high current intensity ensure high heat input.
In recent years, equipment has been developed for welding using a pulsed direct current. A spray-arc is then obtained at lower currents then required when ordinary direct current is used. During pulsed welding a peak current at a pre-determined frequency is superimposed on the basic current. The basic current maintains the arc and is under the critical welding current. The peak current exceeds the critical welding current. At each pulse, a drop is split off by the forces operating at the end of the electrode and propelled into the weld pool. During pulsed-welding occurs in the spray-arc area at an average current under the critical welding current. See the schematic presentation in figure 3:

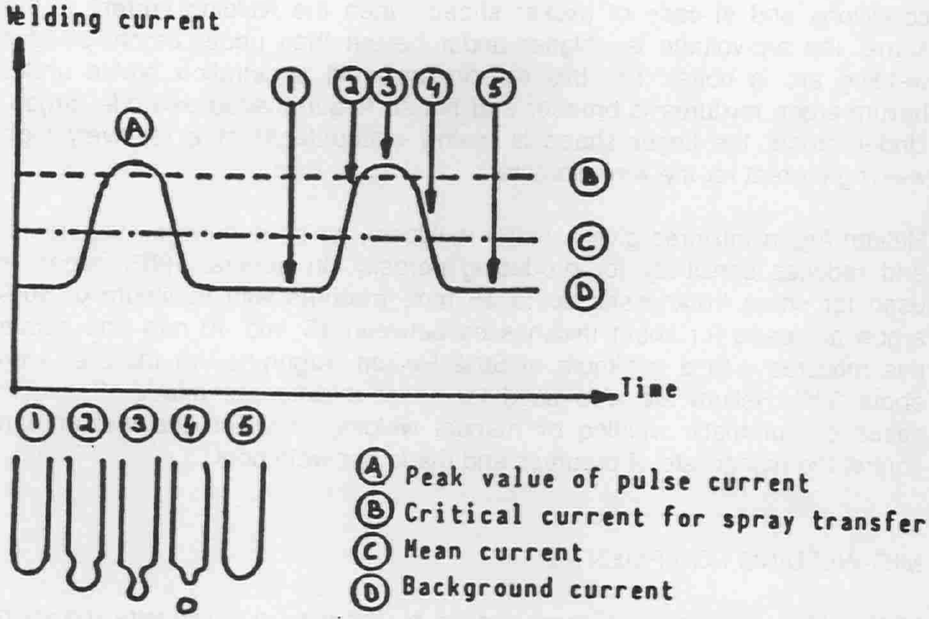


Figure 3 MIG-pulse, welding current and drop formation

When welding aluminium a fixed pulse frequency of 50 or 100 Hz is often used. Pulsed welding equipment in which the pulse frequency can be altered are also supplied and more sophisticated. The most important advantages of the pulsed welding of aluminium are:

- For the uses in which a small weldpool is required, such as the welding of thin sheet (2 mm.), making root passes in joints without backing in thicker sheets or on-site welding, the average welding current may be reduced without having to quit the spray-arc area. The chance of oxygen intrusion and incomplete fusion is small for this reason.
- Wire of larger diameter can be used. This reduced sensitivity for breakdowns in the wire transport. Thicker wires are cheaper and the surface-volume ratio is smaller, so that impurities originating in the surface are relatively smaller.
- Due to the high peak current the cleansing effect of the arc is enhanced.
- The burning-off of alloy elements such as zinc and magnesium is reduced.

THE SHIELDING GAS

For the MIG-welding of aluminium and aluminium alloys argon is in paramount use as shield gas and helium-argon mixtures, and used in special conditions and in case of thicker sheets when the welding current is the same, the arc-voltage is higher under helium than under argon, so that welding arc is hotter. For this reason the weld penetration profile under helium-argon mixtures is broader and not so finger-shaped as under argon. Under argon, the finger shape is mainly encountered at a relatively high welding current for the wire diameter.

Helium-Argon mixtures give a hotter weldpool, which enhances evaporation and reduces sensitivity for producing porosity. In general 100% argon is used for sheet thicknesses up to 15 mm, mixtures with minimum of 50% argon are used for sheet thicknesses between 15 and 40 mm and above this mixtures with a minimum of 50% Helium. Argon-helium mixtures with about 30% Helium are also used for sheet thicknesses under 15 mm in cases of automatic welding or manual welding in which the welder can control the higher rate of progress and the larger weld pool.

MIG-WELDING EQUIPMENT

MIG-welding equipment is characterised by the way in which wire transport takes place, etc. The systems on the market are shown diagrammatically in figure 4 (Nos. 1 through 5). The aluminium wires are relatively soft. This produces limitations, particularly with 'thin' wires between 0,8 mm and 1,0 mm.
At these diameters a push system with a hose connection between the wire spool and the laser pistol (no.1) is too much liable to breakdown and therefore not usable.
A push-pull system (Nos. 4 and 5) is recommended for wires of these diameters, in which the wire is not just pushed but is also drawn into the pistol by means of a drive system. The possibility of hose length of about 8 meters is an advantage.
It might be termed a disadvantage that the welding pistol becomes heavier, bigger and more expensive than a normal MIG-welding pistol.
Photo 7 shows a push-pull system (Nos. 5) in reality.
For wire thicknesses of 1,6 mm and to a lesser extent 1,2 mm a push system may be used provided the hose length is confined to 3 to 4 meters. (A plastic wire guide must be used in all cases.) For extremely thin welding wires and short welding lengths there are systems in which a small spool of wire is incorporated in the welding pistol (No. 3). The disadvantages of this system are the small amount of wire on the spool, the heavy pistol and the

limited number of types of wire in supply. When selecting MIG-welding equipment, the relatively high welding current needed for weld aluminium should be taken into account. With a light source of power, welding cannot take place in the spray-arc area. This is at the expense of the quality of the weld. How 'heavy' the power source should be depends on the type of welding to be undertaken. A current of 250-350 amps will usually be needed. The welding pistol is heavily taxed thermically when using 100% Argon as shield gas and as a result of the reflective property of aluminium. Preference should be given to a water-cooled pistol.

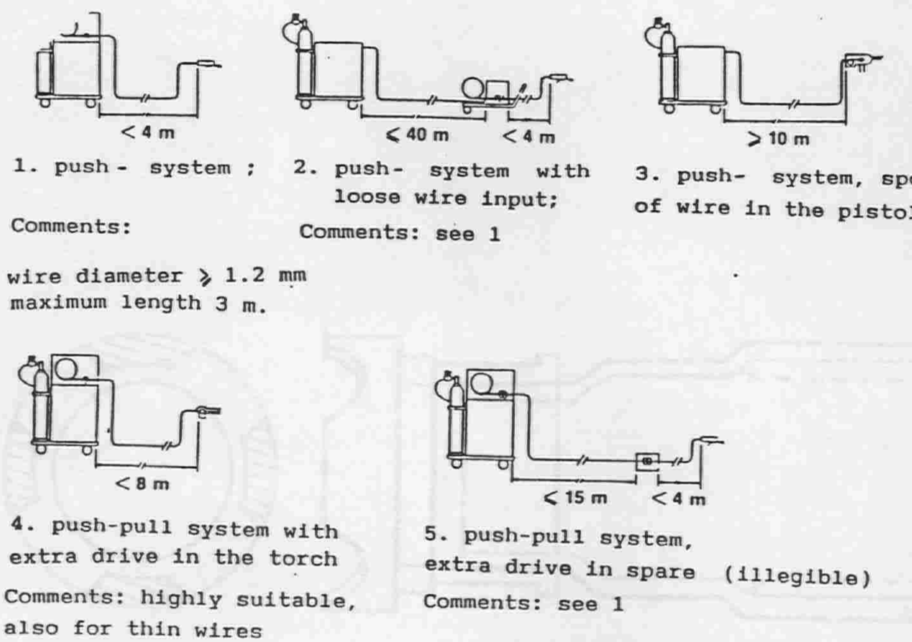


Figure 4 Wire transport systems for MIG welding the comments apply to the welding of aluminium.

Figure 4 Wire transport systems for MIG welding the comments apply to the welding of aluminium.

3.3 MIG-SPOT WELDING

The usual way of welding two plates together in a lap joint is electrical resistance spot welding. However, the method requires expensive investments in machinery and is limited to thicknesses up to 4 mm. As an alternative method MIG-spot welding can be used which
can be carried out with a time relay and a special gas nozzle, figure 5.
The welding is made by pressing the welding gun against the upper plate. The welding time is adjusted through the time relay, so that a good accuracy of reproduction is obtained. The penetration is controlled so that the smelt either penetrates both plates or stops on the lower one. Which method is to be preferred depends normally upon the thickness of the lower plate.
Constructive advantages with the method is that great differences in thickness between upper- and lower plate can be accepted. With a thick upper plate the welding can be made easier by first making a hole in that plate.

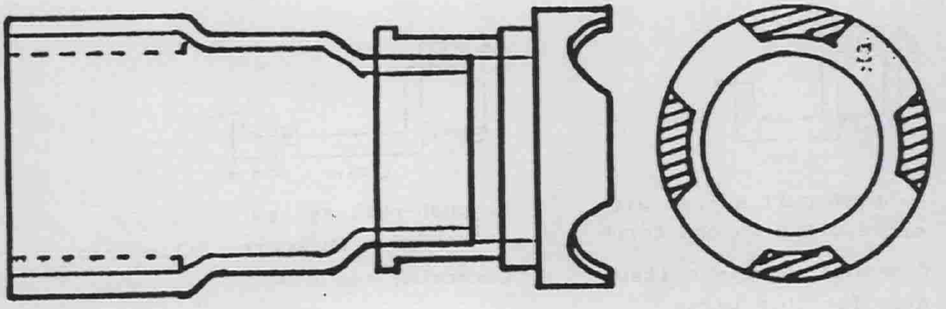


Figure 5

MIG-spot welding - Gas nozzle.

4 GUIDELINES FOR WELD PREPARATION

JOINT PREPARATION

In general, welding joints for aluminium and aluminium alloys do not differ much from those fore welding steel. Because the fluidity of aluminium is greater than that of steel a smaller gap can usually be used. The bevelling can be obtained by means of milling, sawing, cutting, plasma cutting and grinding.
Also, using a special grinding wheel suitable for aluminium and the careful removal of grindings has the disadvantage that dirt and so forth get on the surface, so that this preparation method is not to be preferred. The surfaces for welding have to be carefully debarred and degreased.

CLEANING BEFORE WELDING

With the aim of obtaining a faultless weld the surfaces should be made clean and free from grease before welding. The oxide film should be removed by using a rust-resistant steel brush, rust-resistant steel wool or clean emery paper. A steel brush is not allowed because particles of steel and rust may cause galvanic corrosion in aluminium.
As already stated, the oxide film is strongly hygroscopic. The moisture-saturated oxide film has to be removed. The oxide film that is formed immediately after cleansing will still be dry. This removes a very common cause of porosity. The same applies to the welding.
To reduce water intake in the oxide film, spools of wire should be stored in a dried area. For welding in which high quality requirements are laid down it is important that the surfaces to be welded should not further
touched with the bare hand. The moisture and grease given off may cause porosity in the weld.

PRE-STRESSING, CLAMPING AND TACK WELDING

When heat is applied, the high coefficient of expansion for aluminium will cause internal stresses and distortions in the pieces being worked that are substantially greater than those when welding steel. The following hints will help to reduce distortions:

- Reduce the number of welds, the length of the weld and the cross-section of the weld as much as possible. In fact, this is true for all welded constructions irrespective of the material.

- Weld as quickly as possible.

- Select a welding sequence in which the construction may shrink as far as possible free of stress. Carry out the work as symmetrically as possible.

- Clamp the parts to be welded in a welding jig of adequate sturdiness.

Pre-stress the parts in a direction opposite to that anticipated welding stresses. This requires experience and knowledge of the product.
When welding lack of fusion at the tackweld must be avoided. The tackweld back, the head and the crater in particular, must be partly be removed. It is often more advantageous, even when welding small series, to use a welding jig in which the parts are fixed without tacking.

PRE-HEATING

Pre-heating may be necessary to prevent condensation when the temperature of the items to be welded is less than 10 °C or when the heat introduced in welding is not enough in relation to the thickness of the part to be welded, which may occur at a sheet thickness above 15 mm. The preheating temperature depends on the material and the nature of the welding job and is usually between 80 °C and 200 °C.

5 BUILDING METHODS OF ALUMINIUM YACHTS

There are numerous ways of building and welding an aluminium yacht. It depends on the experience and know-how of the yard and of course the type and characteristics of the yacht being built. The following description illustrates the building method often used at the Royal Huisman Shipyards.
The most characteristic detail is the separate steel deck mould used in construction of the entire deck and there upon assembly of the entire hull (excluding the superstructure which is built separately and fitted afterwards).
This method has the advantage, of providing a very stable platform combined with the advantage of doing the welding downhand, which is very comfortable. The completion of the deck, the complete keel section with floors and stringers is positioned over the deck. Then frames, webbing, stem bars and transom are welded to deck and keelsection.
See the photos 9 and 10.

Next the hull plates are shaped and positioned, seams planed. Deformations caused by welding of seams and butts are then formed by hammer stretching and fitting of intercostals. After turning the partly finished hull to the upright position, the upperstructures and other parts which have been made

separately, are fitted and preformed stringers placed intercostally (between frames).
The next step is ballasting of the yacht.

6 WELDING THE HULL PLATES

When welding the hull plates the following aspects are of importance.

- deformation due to shrinkage, must be minimized.

- welding quality, at difficult accessible spots such as the frames must also meet the requirements.

- minimizing of cost in joint preparation, welding, inspection and finishing.

Welding methods of the hull plates in the Dutch yachtbuilding can be roughly divided into two methods.

- welding from both sides.

- welding from one side on ceramic backing strips.

In both methods is professional skill a foremost requirement to reach good welding quality. Skilled and trained welders, proper welding equipment and a clean working shop.

Both methods will, with the aid of some photographs, be illustrated.

6.1 WELDING FROM BOTH SIDES

The plates are bevelled on the side of the first pass (mostly inside the hull). Bevelling can be done with aid of a 'woodplane' (photo 10). The oxide layer on both sides of the joint is taken away by grinding to prevent moisture penetration from the oxide layer. The plates are tack-welded on the non-bevelled side without gap. (photo 11). After MIG-welding the first pass the opposite side is cut out, and bevelled till depth where the smooth weldmetal of the first pass becomes visible. (photo 13, 14 and 15) After that the joint is cleaned by brushing (photo 17). Now the hull-plates are welded in one or two passes depending on the thickness of the plates.

6.2 WELDING FROM ONE SIDE ON CERAMIC BACKING STRIPS

When welding from one side on backing strips the plates are bevelled over the whole thickness. The hull plates are positioned and fixed in place by means of tack-
bridges.
A gap of approximately 4 mm is kept for the welding joint. Before this the oxide layer is removed by grinding. Photo 16 shows the joint preparation and the ceramic backing strip. The backing strip is fitted with an adhesive strip which sticks to the hull plates holding the strip in it's place.
Photos 17 and 18 shows the welding joint on the welding side and the backside after fitting the backingstrip. The welder can begin with the root-pass. The backside is, by means at the backingstrip protected from the outside air. After the rootpass follows the second pass the ceramic backings-trip can be taken away from by grinding. The advantage of this welding method is the fact that the time consuming preparation of the joint as discussed with the welding method from both sides become redundant.

6.3 WELDING OF ALUMINIUM ON STEEL

Joining aluminium to steel for instance an aluminium upperstructure to a steel hull happens quite often. The traditional bolted- or riveted joint becomes more and more superseded by welding joints with special strips, the so called TRI-Clad strips.

These TRI-Clad strips were developed for connecting aluminium and its alloys to steel by welding. The TRI-clad strip consist of three layers: steel, pure aluminium and the aluminium alloy.
AIMG4,5, respectively 19 mm, 9,5 mm and 6,5 mm thick.
These three layers are explosively bonded by means of dynamite and make a very solid bond, even stronger than the pure aluminium itself. The standard height of the strip is 34 mm, length is 3350 mm where as the width can be varied. Figure 6 is an impression of this strip.
Photo 20 shows that this strip can be bended into the required shape.

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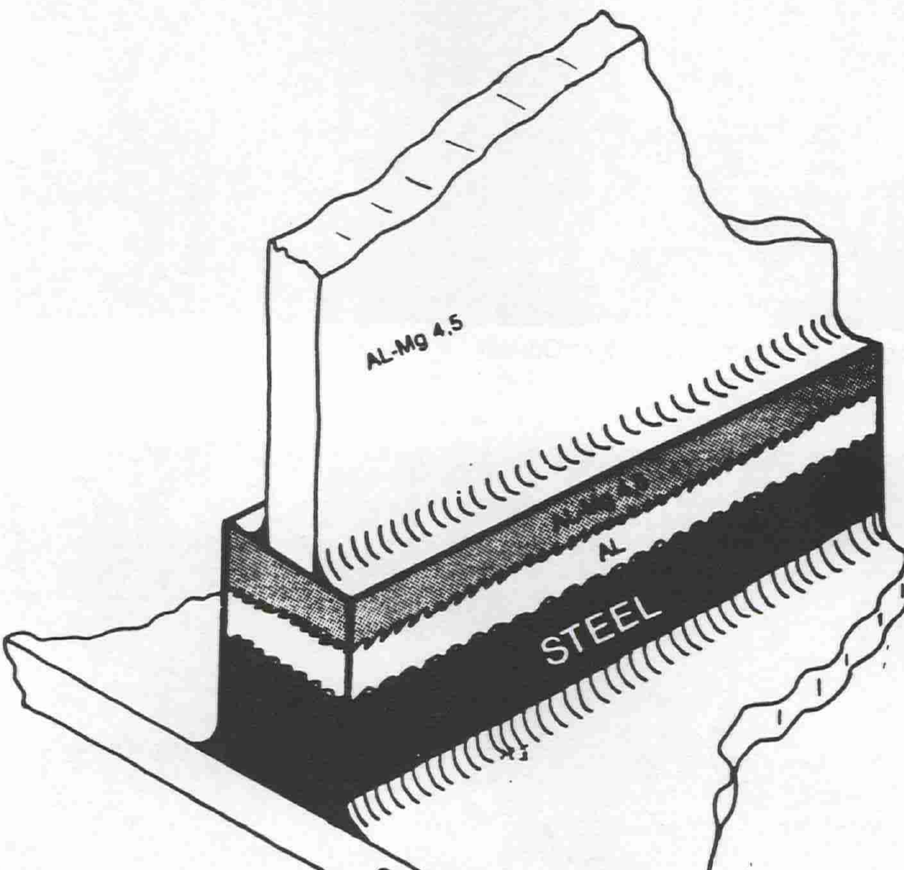

Figure 6. TRI-CLAD STRIP FOR WELDING ALUMINIUM TO STEEL

WELDING TECHNOLOGY

IN ALUMINIUM YACHT BUILDING

BY P. BRUINSMA AGA-GAS

Photo 1. Complete Aluminium Cruiser

Photo 2. Construction with steel hull and aluminium superstructure

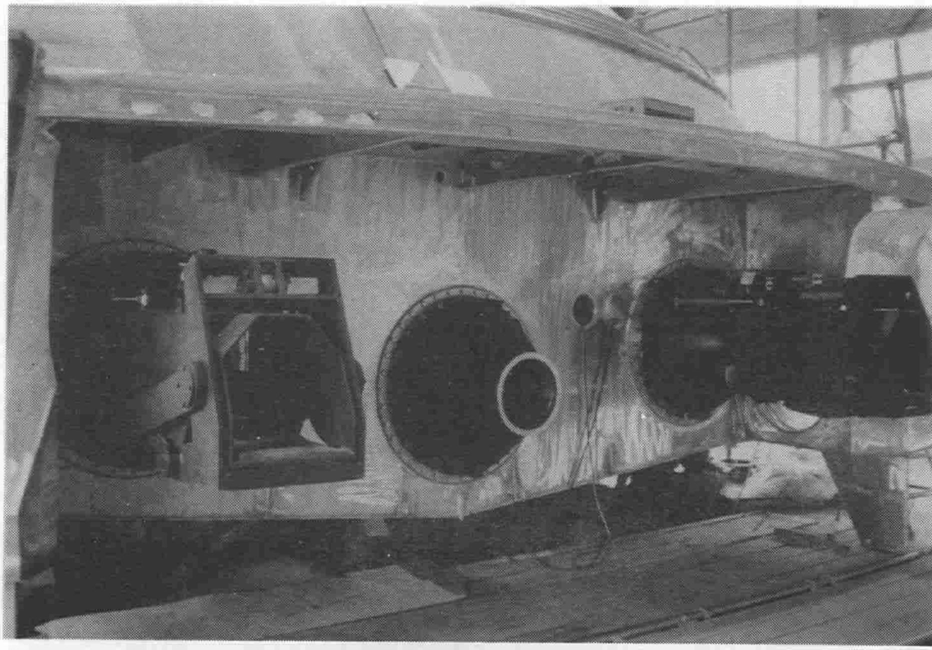

Photo 3. Transom of the cruiser from photo 2

Photo 4. Lifeboat, completely constructed of aluminium

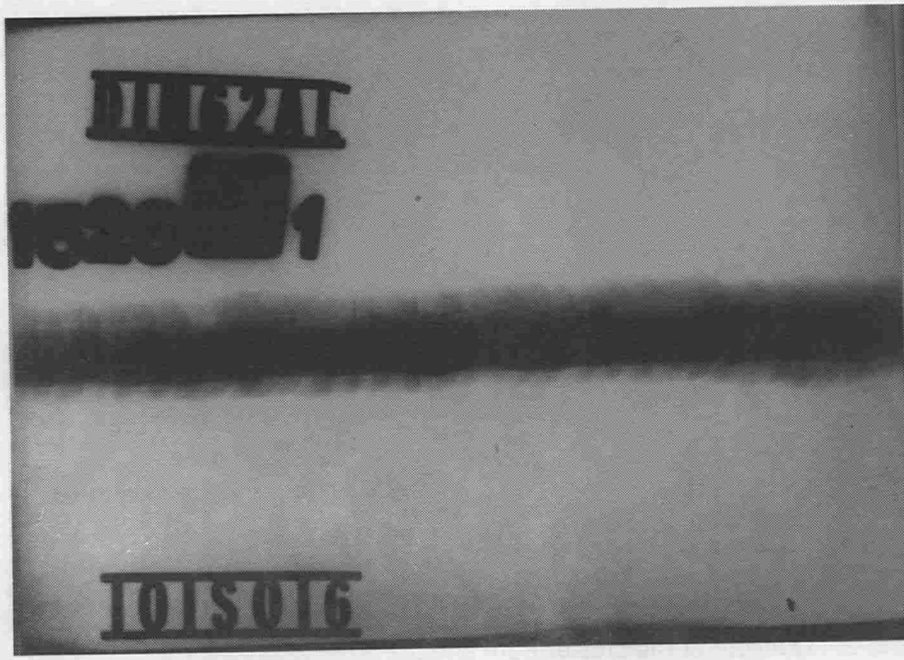

Photo 5. X-Ray without porosity

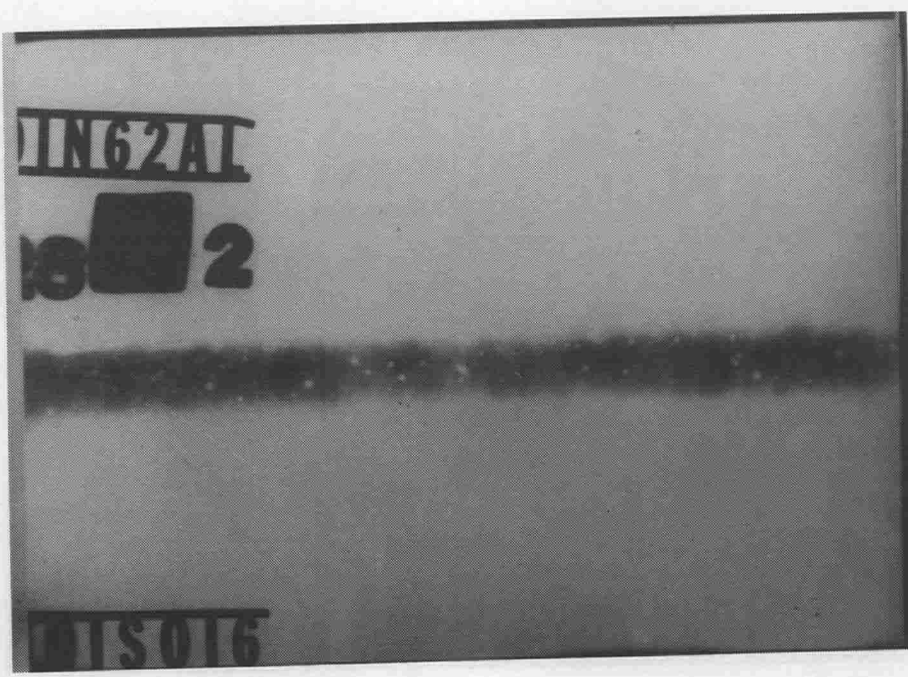

Photo 6. X-Ray, with internal porosity

Photo 7. MIG welding with push-pull wire transport system

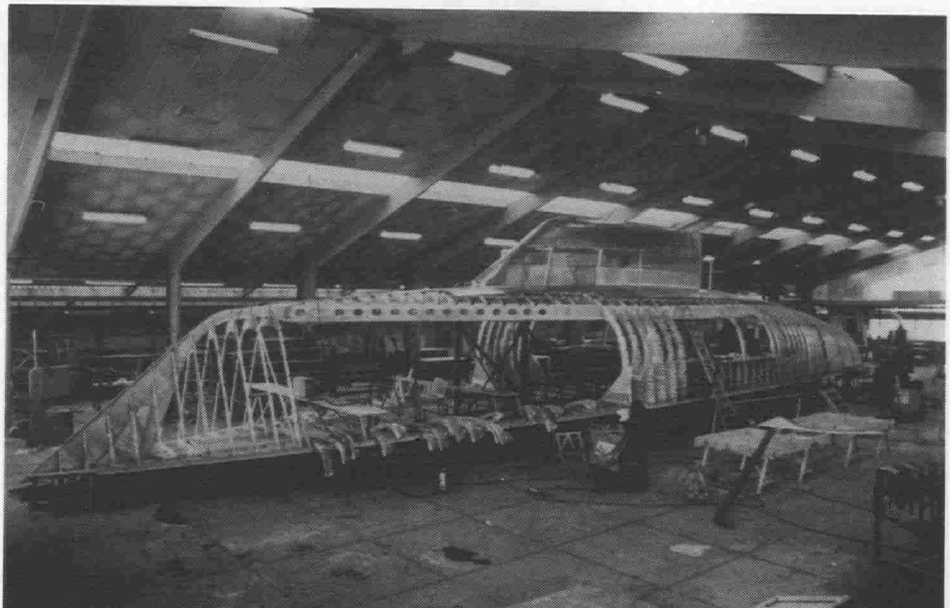

Photo 8. Frames, webframes, stembars and transom are welded to deck and keel section

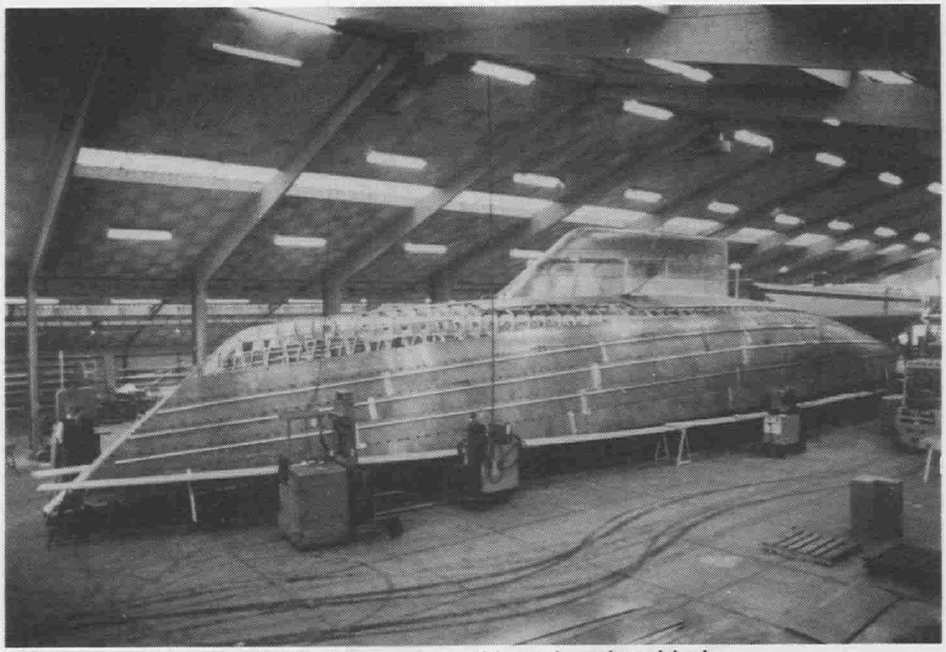

Photo 9. The hull plates are positioned and welded

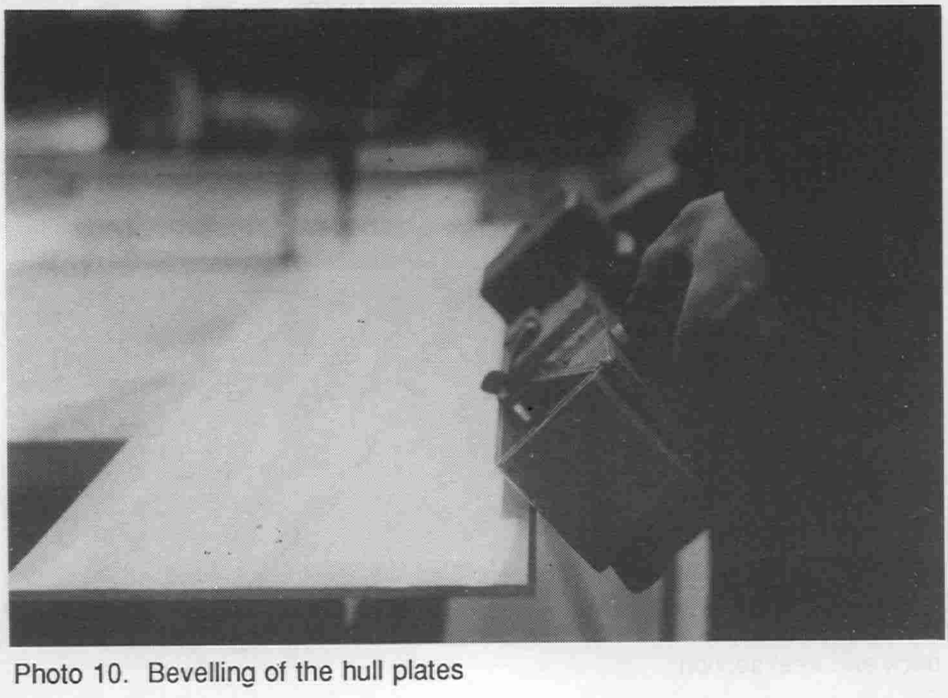

Photo 10. Bevelling of the hull plates

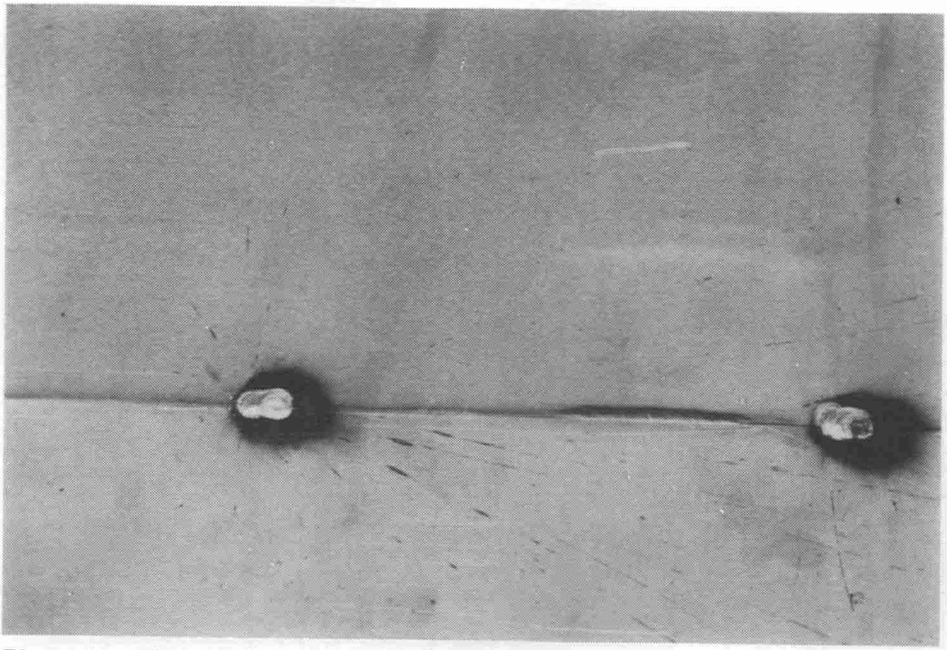

Photo 11. View on the tack-welded non-bevelled side

Photo 12.
Cut-out the oppo site side with saw-equipment

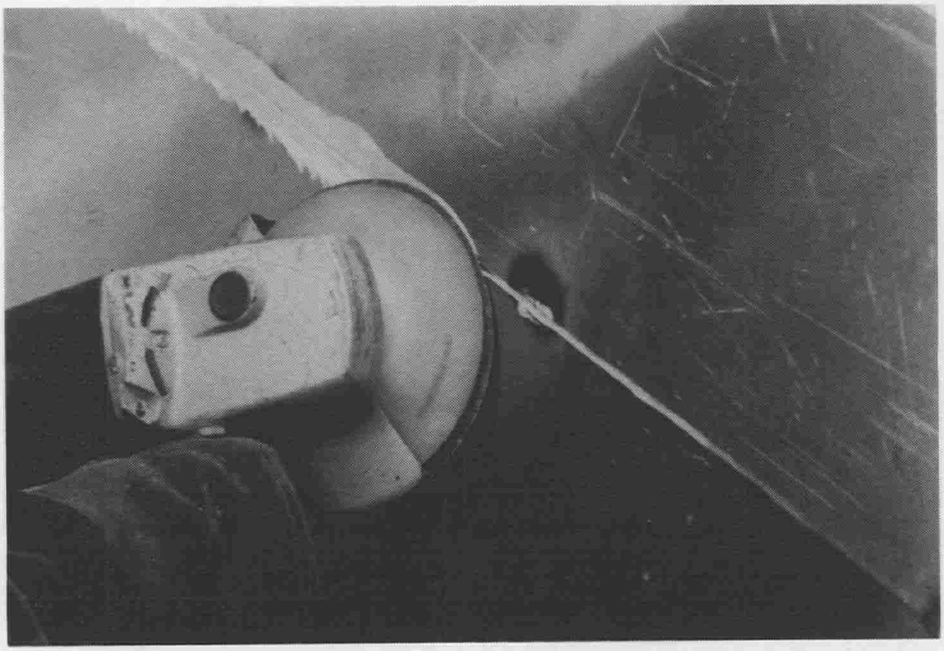

Photo 13. Removing the oxide layer by grinding

Photo 14. Bevelling the joint

Photo 15. Cleaning the joint by brushing

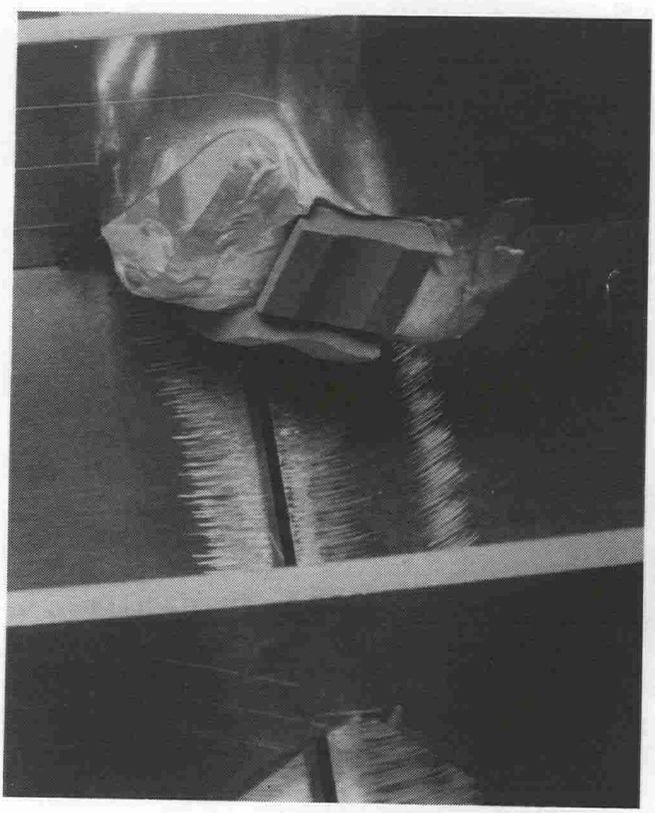

Photo 16.
View on the joint preparation and the ceramic backing strip

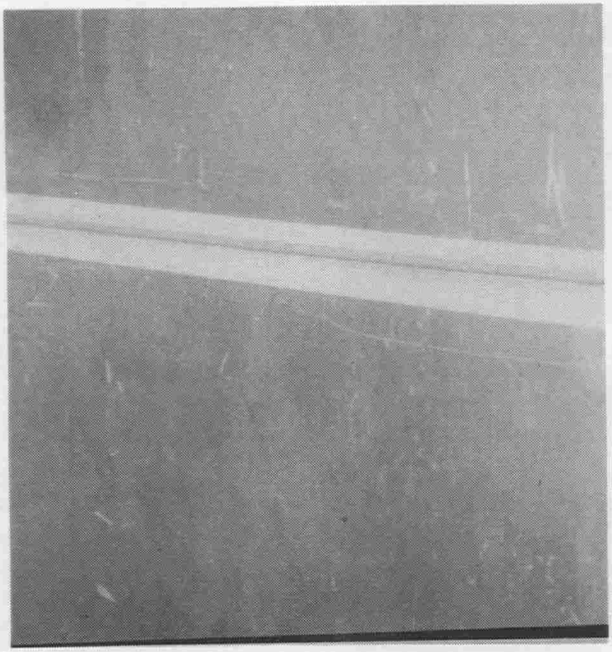

Photo 17. View on the welding joint on the welding side, ready for welding

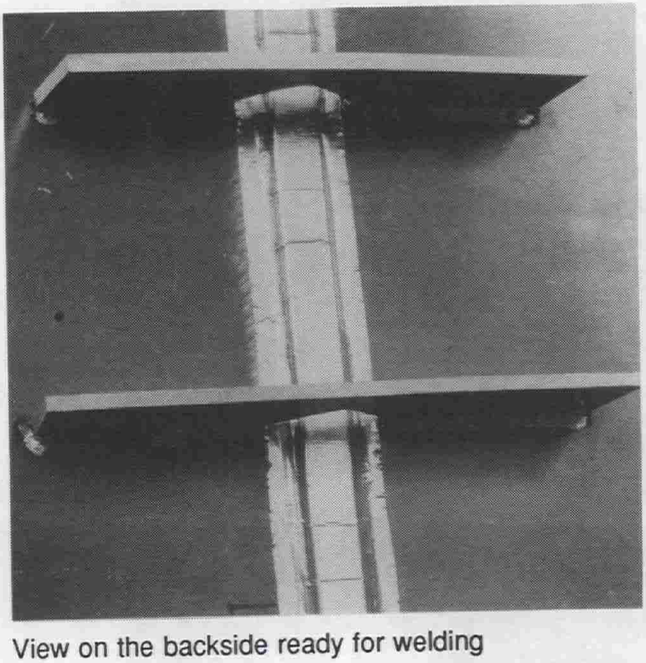

Photo 18. View on the backside ready for welding

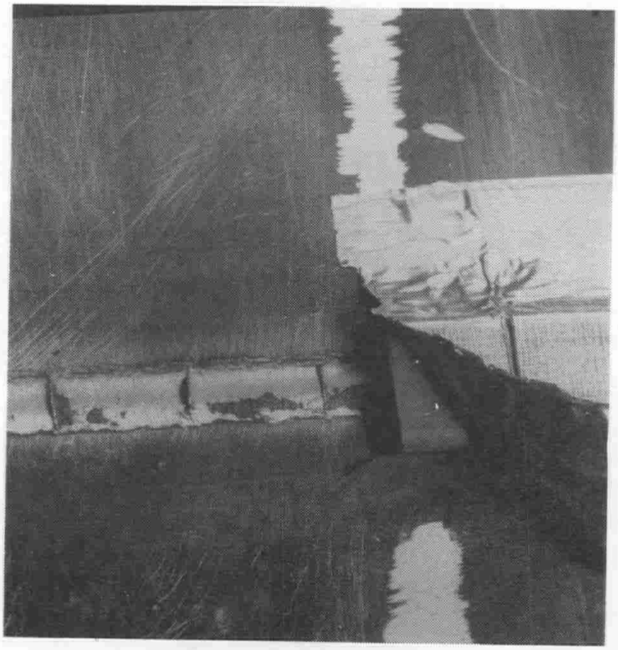

Photo 19. The ceramic backing strip is partly taken away after welding

Photo 20. TRI-CLAD after bending and welding to aluminium and steel

WELDING ALUMINIUM TO STEEL

KP.C.J.M. WITLOX

MERREM & LA PORTE

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1. INTRODUCTION

Dissimilar metals that cannot be joined by standard welding techniques are - sembly lay in fitting the insulating tape and nylon gaskets used to fight galvanic corrosion, as well as the laborious nature of the connection as such. (figure 1)
In spite of these precautionary measures however crevice corrosion will, in the long run, still do its devastating work because of the capillary effects in the presence of electrolyte.

Explosion cladding will solve all of these problems with one mighty "blow". A well-known example is TRI-CLAD, which is widely used in naval architecture. Thanks to TRI-CLAD, an aluminium superstructure can now be joined to the vessel's steel hull using standard welding practices.

2. HISTORY

Explosion cladding was "invented" in 1958. During explosion forming operations it was found that the metal that needed forming had stuck to the mould.
Closer investigation showed this to be a perfect metallic bond. The principle of explosion cladding was born. Further R&D work was carried out by the metallurgical department of the Massachusetts Institute of Technology. For obvious reasons explosive-manufacturers became interested and refined the idea even more.

3. PRINCIPLE

Figure 2 shows the setup of a so-called TRI-CLAD motherplate prior to the actual explosion. Figure 3 is an impression of what happens during the explosion (for clarity's sake the top-layer of aluminium-alloy is left off). The metal plates that are to be cladded are positioned at a carefully calculated distance of one another using polystyrene spacers. During the explosion the upper plate is projected onto the so-called backer plate with an enormous acceleration, releasing a pressure of millions newtons sq.cm. As a result here of both sides of the collision point will be stripped of a metal layer of some 5 microns thick.
This is the so-called jet which consists of metal particles, metal oxides and air. The contact between both (or more) virgin surfaces is brought about which, under extreme pressure, results in an inter-atomic interchange of electrons.

Often even without magnification one can clearly see the shock wave pattern at the interface. This phenomenon, which is typical of the explosion cladding process, is due to the limited super-plasticity during the travelling of the detonation front.

How unbelievable this may sound to the layman's ear, the entire process described so far takes place at or just above room temperature. The original mechanical values of the starting materials used will therefor only slightly be affected due to minor hardening. Welding operations during fabrication at a later stage will usually restore the mechanical values to their original levels.

TRI-CLAD consists of 3 layers viz. 19 mm of steel A516 gr55, a commercially pure aluminium interlayer of 9,5 mm thick and a 6,5 mm thick toplayer of the seawater resistant AlMg alloy 5086.
For the chemical composition of the materials used, please revert to table 1.

Steel A 516 gr. 55	Al-alloy 5086	Aluminium 110
C max. 0,20 Mn 0,60-1,20 P max. 0,035 S max. 0,04 Si 0,15-0,40	Mg 3,50-4,50 Cr 0,05-0,25 Mn 0,20-0,70 Ti 0,15 max. Cu 0,10 max. Zn 0,25 max.	Fe+Si 0,10 max. Cu 0,05-0,20 Mn 0,05 max. Zn 0,10 max.

Table 1

Thanks to its superior ductility the pure aluminium interlayers will ensure a perfect bond between the both other layers.

After cladding the plates are flattened, 100% ultra sonically tested and random samples are subjected to various destructive tests. On the basis of such rigorous quality control standards the material has been approved for naval applications by various classification societies.

4. FABRICATION

The motherplates are now ready to be cut in the form in which they are typically supplied: strips. This is usually done by using band saw equipment. Larger pieces such as circles can be readily plasma cut. A heat affected zone of a few mm however should be reckoned with.

It is recommended that the strip width should be equal to 4 times the thickness of the aluminium sheets used. (e.g. 6 mm aluminium sheet will call for 24 mm wide TRI-CLAD strips.)
The reasoning behind this is two-fold:
As shown in table 2 the strength of the pure aluminium interlayer is only a quarter of the aluminium alloy. Applying this 4 times ratio will assure an assembly
in which the weakest point is either the weld zone between the strip and the aluminium sheet or the sheet itself.
Secondly this "golden" rule will ensure sufficient heat discharge during subsequent welding operations. this is especially important since welding temperatures at the interface should never exceed a critical 300 ^{0}C above which diffusion products may form embrittlement that may potentially result in fractures.
It is for the same reason that we would advocate to position the aluminium sheet in the middle of the transition strip thus automatically avoiding welding close to the interface.
When bending the strip a minimum radius of ten times the strip's width should be observed.

Mechanical Values	Steel	AlMg 4.5	Aluminium
Ultimate tensile strength kg/m	38-52	29	7,7-10,5
Yield point	20,7	13	2,5
Elongation	27	12	28

Table 2

Ex works condition	11,2 kg/mm2
Bend condition (R = 10 W)	11,3 kg/mm2
15 min. at 350 0C	9,2 kg/mm2

Ultimate Tensile Strength of Bonded Area

5. WELDING

If at all possible the aluminium welds should be made first. This helps to achieve satisfactory welding temperatures in which the aluminium member acts as a heat sink and radiator for the higher steel temperature that follow.
If preheating the system is felt advisable,
DO NOT pre-heat the TRI-CLAD strips!

(WELDING-)TEMPERATURE SHOULD AT ALL TIMES TO BE KEPT BELOW 300 ^{0}C !!

Temperature indicating sticks applied to the wavy interface of the TRI-CLAD strip to monitor typical temperatures have more often proven their usefulness.
It will be obvious that the maximum rate of metal disposition is largely dependent upon such factors as the heat-balance achieved with conditions and equipment, the dimensions of the TRI-CLAD joint, the position of the strip, etc.

For the aluminium welds MIG-equipment and techniques are preferred using Argon shielding. Current 300 Amps., 27-29 Volts potential.
The best results are achieved with 1,6 mm wire type 4043 or AS5 aluminium.
For the steel side of the assembly standard welding techniques matching the type of steel to be weld to, will just do fine.
Normally 2,4 mm low hydrogen mild steel coated electrodes will suffice.
A faster technique utilizes MIG with a 0,9 mm carbon steel wire, low metalloid, carbon and manganese.
Recommend mitre connection and butt joint design are shown in figure 4 and 5.
After both aluminium as well as the steel welds have been made, the 3 mm unwelded gap should be hammer peened to ensure water tightness.

6. RENOVATION

It will hardly need arguing that the product here described attracted quite some interest in the world-wide shipbuilding world, especially in the case of newbuilding projects. Less widely known however is its application as a renovation product. The old-fashioned joining method as described at the very beginning of this article is prone to crevice corrosion. On the long run, vessels suffering from heavy corrosion may run the risk of being held up in port. In such cases the TRI-CLAD transition joint may well be the perfect solution. Figure 6 and 7 show the setup before and after renovation.

7. COMPOSITION OF TRI-CLAD

A question often raised in connection with the transition joint:
"Having two metals with a considerable difference in potential, how does it behave in a marine environment relative to galvanic corrosion?"
It will be obvious that a suitable paint or coating will prevent contact between the electrolyte and the ship, thus avoiding corrosion.
Yet, it is worthwhile to investigate more closely the effects in the absense of such protection.

Considering the lower galvanic potential of the steel, extreme corrosion of the aluminium may be anticipated, particularly near the interface, where the metal has been heavily worked and the anode is extremely close.
However, initial corrosion tests on unpainted samples of approximately equal aluminium-to-steel areas revealed a natural insulating effect. As expected, a slight penetration began at the interface as the aluminium started to corrode. But, instead of acting as a latent area of high ion concentration and thereby accelerating corro-sion, the penetration area gradually filled with an extremely hard and inert corrosion product aluminium oxide hydrate. This oxide acted as a seal and rendered the system passive after a penetration of 30-60 mils, depending on the severity of the initial corrosive environment. Accelerated salt-spray tests, simulating years of exposure, further demonstrated that corrosion of the cladding became negligible after the initial barrier had been built up. Painted examples, whose interface had been so scratched so as to expose only a small area, were subjected to the same testing environments. With these, the only interface corrosion was a slight pinpoint area beneath the scratch. The solid metallurgical bond restricted the electrolyte from penetrating the interface while the build-up of corrosion product prevented extensive pitting. This served to prove the transition joint system's advantage over mechanical connections. In the latter, a crevice exists between the facing surfaces and once the protective coating is broken, the electrolyte rapidly penetrates the interface.

8. EXPANSION

With an eye to the varying expansion coefficients of steel on the one and aluminium on the other hand, another question frequently raised is how TRI-CLAD overcomes this allegedly obvious problem.

Let us take 1 metre material.
What will the effect of a 40 ^{0}C temperature difference be?
Tthe expansion of steel will be:

$\delta l = l * \alpha * \delta T$
in which δT = temperature difference
α = linear expansion coefficient

$\delta l = 1000 * 12 * 10^{-6} * 40 = 0,48$ mm

For aluminium:

$\delta l = 1000 * 24 * 10^{-6} * 40 = 0,96$ mm

So the compression of the aluminium is 0,48 mm.

Compression tension will be:

$$\delta l = \frac{\sigma * l}{E} \text{ or}$$

$$\sigma = \frac{0{,}48 * 0{,}7 * 10^5}{1000} = 33{,}6 \text{ N/mm}^2$$

Clearly, this will present no problem whatsoever.

9. CONCLUSION

Transition joints do realize the shipbuilder's long cherished dream to have a more cost-effective method for joining aluminium and steel section. Owners are naturally pleased with the maintenance-free and esthetically sound solution to corrosion problems. Needless to say that the combination of such features is rapidly gaining global interest.

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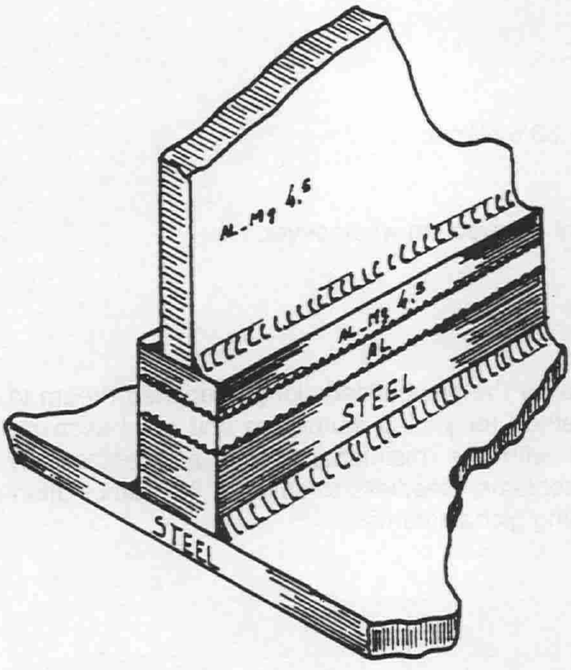


Figure 1. Composition of TRI-CLAD

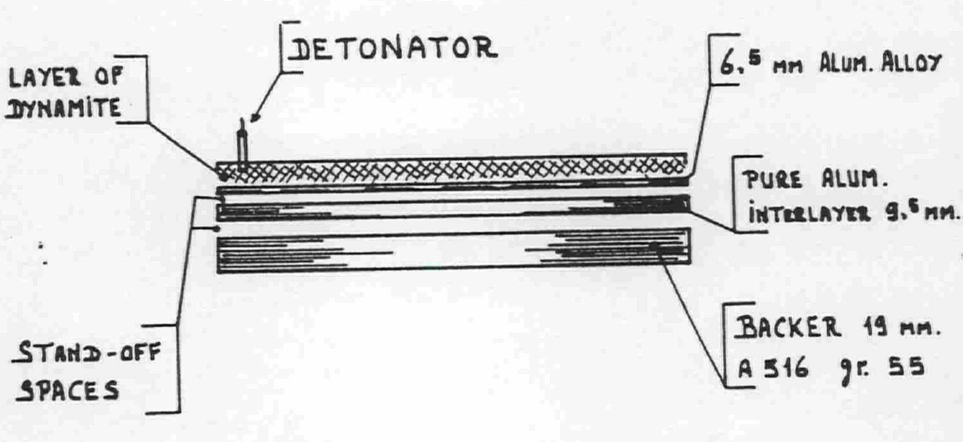


Figure 2. Explosion Cladding Setup

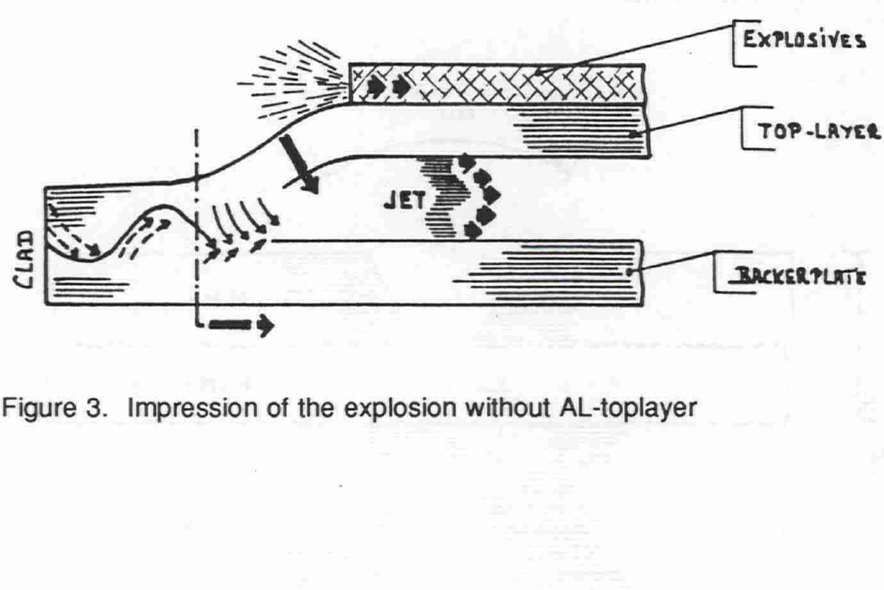


Figure 3. Impression of the explosion without AL-toplayer

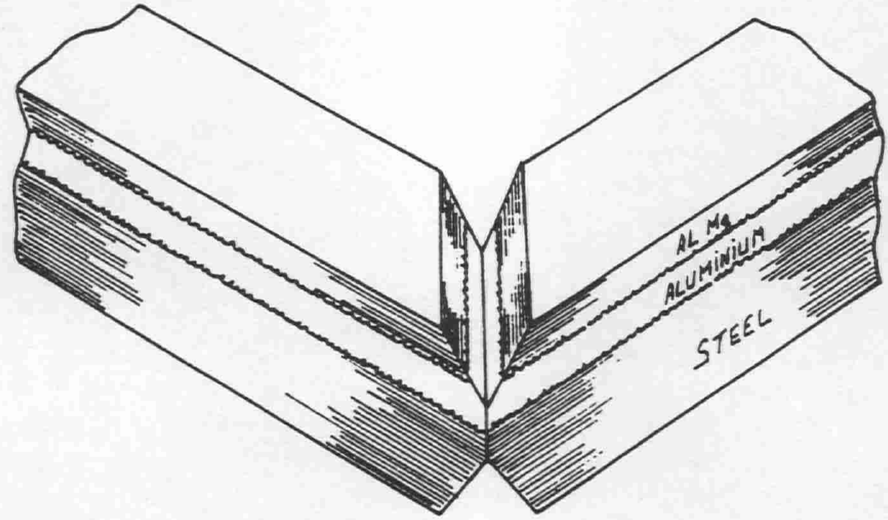


Figure 4. Mitre connection

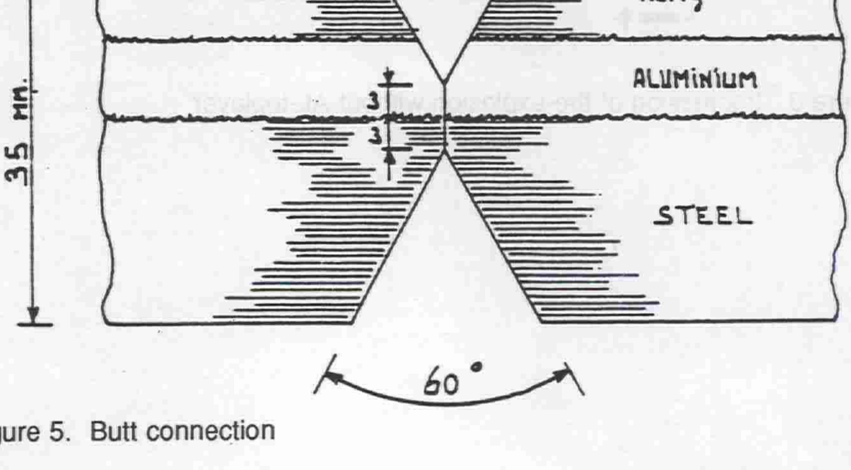


Figure 5. Butt connection

Figure 6.
Aluminium wall,
connected to steel
deck before
renovation

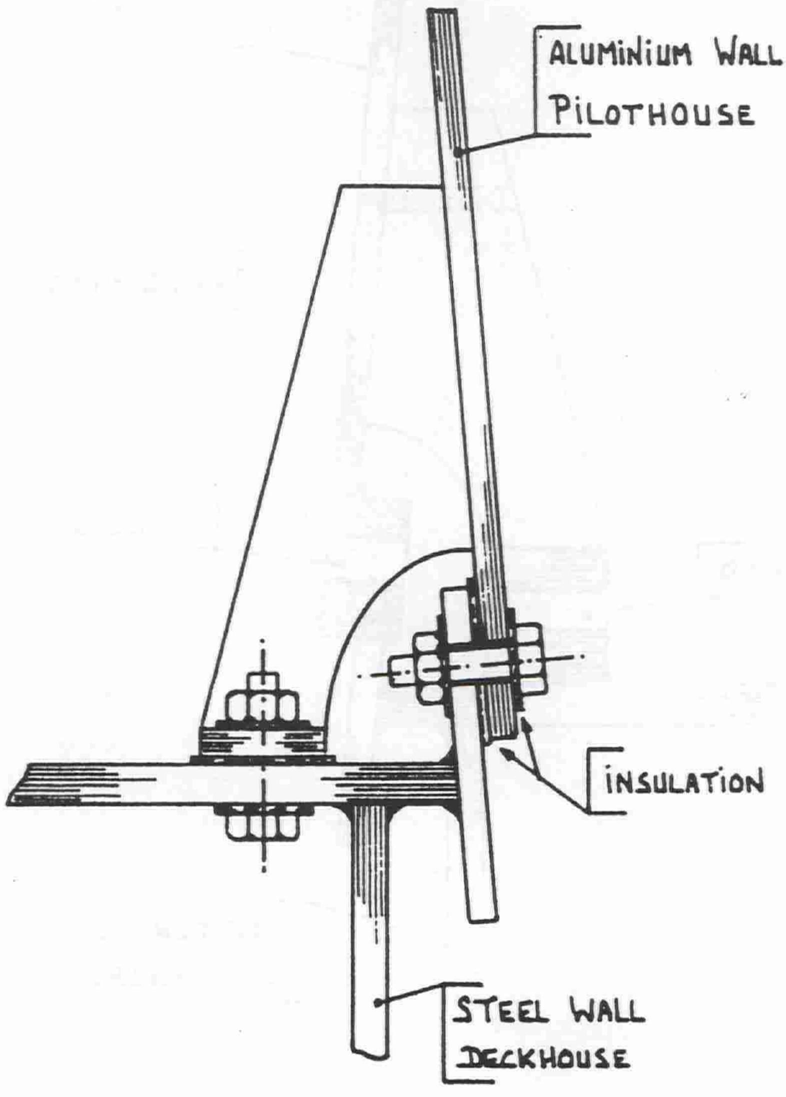
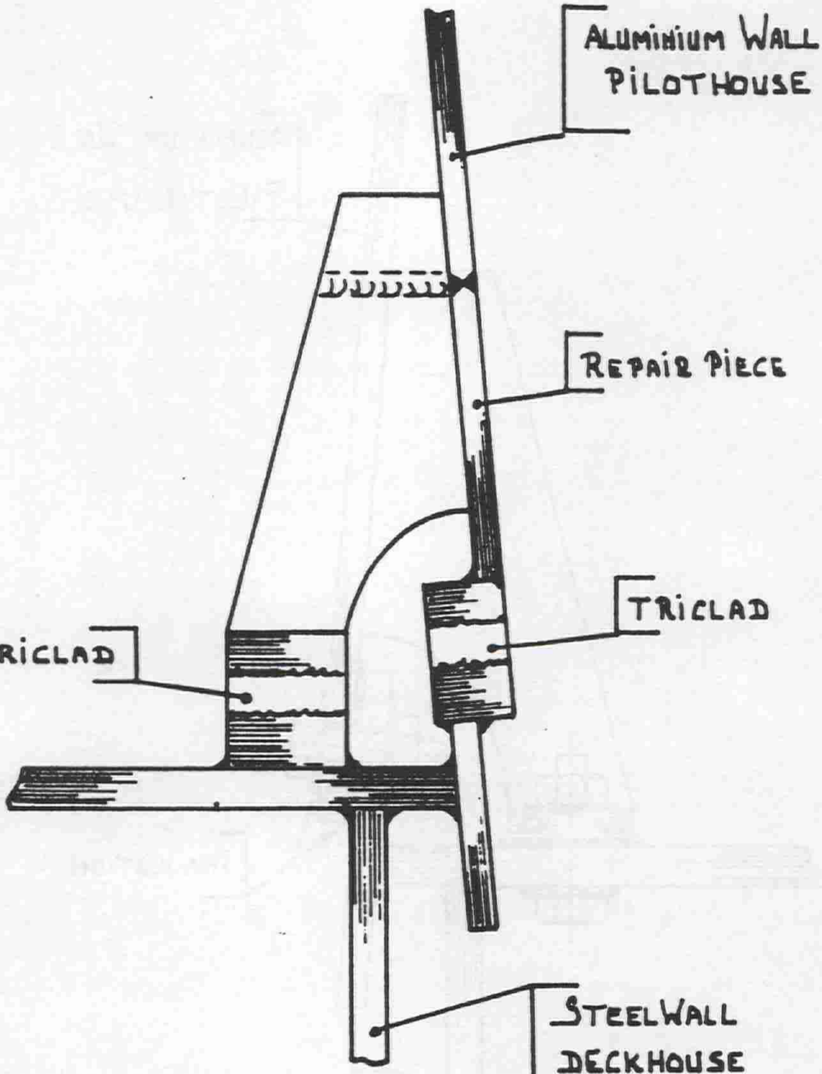


Figure 7.
After renovation.



APPLICATION OF LIGHT ALLOY ON PASSENGER VESSELS

GIORGIO BACICCHI

FINCANTIERI CNI MERCHANT SHIPBUILDING DIVISION

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APPLICATION OF LIGHT ALLOY ON PASSENGER VESSEL

1. General

In comparing present cruise vessels with passenger vessels built 25 years ago large differences can be noticed.

With similar lengths present ships are designed for lower speed, shallower draught, higher block coefficient and greater extension of upper decks towards the ends of the ship.

With similar or even lower displacements, present ships have a very much higher tonnage with large internal space more extended in the upper part than the old vessels.

In table 1 and figure 1 two recent ships built by Fincantieri are compared with the liners "RAFFAELLO" and "EUGENIO COSTA".

Ship Characteristics	"RAFFAELO"	"CROWN PRINCESS"	"EUGENIO COSTA"	"COSTA CLASSICA"
Lbp (m)	252	204,4	188,7	182
B (m)	31	32,25	29,3	30,8
T (m)	8,98	8,1	8,6	7,6
Cb (m)	0,57	0,665	0,58	0,68
GRT (tonnes)	42.500	70.000	30.560	50.000
Light Alloy Weight (tonnes)	~ 500	~ 310	~ 360	~ 150

Table 1

To guarantee the necessary stability, present ships require a higher metacentric height and very careful evaluation and control of weights especially those located high above the baseline. Since structural weight is roughly one half of the light ship weight, structural optimalization is very important and light weight structures are required. The whole structure should be de-signed in a rational way, fully assessing the enplane and out-of-plane forces applied and analyzing the structural arrangements and scantlings using FEM models.

Light weight structures, having thicknesses less than 8 mm, entail increased fabrication problems mainly due to increased post-welding distortions consequent to fillet and butt welds or buckling due to post welding stresses. Even introducing measures for the prevention or limitation of distortions, these cannot be completely eliminated and require technically difficult and expensive straightening work.

For productivity reasons, it is not convenient to use steel thicknesses less than a practical minimum value which depends upon the shipyard skill and available facilities.

After the steel scantlings have been reduced to the minimum acceptable for technical and practical reasons and after other possibilities for decreasing weights and heights have been investigated, the use of light alloy on higher decks represents a further, if less economic, solution to weight and stability problems in passenger vessel design.

2. Light alloy characteristics

Aluminium finds use in passenger vessels design due to their special characteristics:

1. Low specific gravity (approximately 1/3 of that for steel)

2. High strength to weight ratio

3. Good corrosion resistance under normal operating conditions

4. Good plasticity and formability (extruded profiles with very complicated sections can be obtained)

5. Good toughness and mechanical characteristics even at low temperatu res

6. Low modulus of elasticity (approx. 1/3 of that for steel)

7. Excellent weldability under gas-shielding

Compared with steel, aluminium has a relatively low melting points and tends to lose strength rapidly upon exposure to elevated temperatures. In consideration the use of aluminium, due consideration should be given to the requirement for the retention of structural integrity upon exposure to fire.

Although the weight of an aluminium structure is approx. 40 - 45 % that of a corresponding steel structure, this proportion can rise 55 - 60 % when appropriate fire insulation is included.

For marine structures both non-heat-treatable (series 5000) and heat-treatable (series 6000) aluminium find applications.
Among the non-heat treatable aluminium which require increased strength from cold working, the aluminium magnesium alloys AA5086 (AlMg4) and

AA5083 (AlMg4.5Mn) are the most widely used.
These alloys, which have good weldability and corrosion resistance in marine environment, are normally used in the mildly cold worked temper, extruded (H 112) or hardened by stretching (H 111).

Heat-treatable aluminium such as AA6061 (AlMg1SiCu) and AA 6082 (Al-SiMgMn) develops strength through heating to an annealing temperature, water quenching and then natural ageing (treatment T4) or artificial ageing by reheating to a lower temperature (treatment T6). These alloys have markedly better extrudibility and strength, but lower corrosion resistance and elongation, than the 5000 series. Moreover, the strength, ductility and corrosion resistance of the heat affected zones (HAZ) are severely degraded by the heat of the welding.

An indication of the degradation of mechanical properties due to welding is given for extruded panels in the following table 2.

Extruded Panels	(*)Alloy 5083			Alloy 6061			Alloy 6082		
	1	2	3	1	2	3	1	2	3
Ultimate Tensile strength (MPa)	270	270	270	260	170	170	290	185	185
0.2 % Proof stress (Mpa)	110	110	110	240	110	110	250	115	115
Max. Elongation A5 (Percent)	17	-	-	10	-	-	10	-	-
Fatigue Strength (R=0) (Mpa)									
10^5 cycles	120	70	47	120	70	47	120	70	47
10^6 cycles	110	50	37	110	50	37	110	50	37
10^7 cycles	105	40	29	105	40	29	105	40	29
Fatigue Strength (R=-1) (Mpa)									
10^5 cycles	80	59	40	80	59	40	80	59	40
10^6 cycles	75	40	30	75	40	30	75	40	30
10^7 cycles	70	30	20	70	30	20	70	30	20

Table 2 1 = Base material
2 = Butt welded (*) = slightly modified
3 = Fillet welded for better extrudibility

Due to the higher strength of the base material, the post-welded mechanical, properties of the 6000 series are no worse than those of the 5000 series. However, due to their reduced corrosion resistance in a marine environment, the heat-treatable alloys are normally limited to internal structures that are not in direct contact with seawater unless a suitable surface coating is provided and maintained.

3. Recent application in passenger vessels and design problems

In two cruise passenger vessels recently built for P&O by Fincantieri ("CROWN PRINCESS" and "REGAL PRINCESS") approximately 310 tonnes of light alloy material has been used in each ship. In two other vessels for Costa Crociere, the first of which was recently launched ("COST CLASSICA" and "COSTA ROMANTICA"), about 150 tonnes of the same material is being used (figure 2).
In the P&O ship, light alloy has been used for:

1. extended area of the uppermost full-width continuous deck No. 12 and deck above, both in protected and exposed areas
2. upper forward dome, having the profile of a dolphin head (figure 3)
3. deckhouse below funnels, main funnels and masts.

In the Costa ship, light alloy material is applied:

1. on the uppermost deck running at side amidships and full width at the ends
2. in the after weather area with a stepped configuration converging towards a swimming pool
3. for the deckhouse below funnels
4. for the forward observation lounge having a circular configuration.

For productivity reasons, deck areas have been fabricated with an extensive use light alloy panels.

In passenger vessels, especially if provided with intermediate large recesses like "CROWN PRINCESS", the evaluation of higher decks efficiency in the bending of hull girder is a difficult task due to :

1. vertical flexibility of transversal sections
2. shear deformations of upper decks, shell plating and longitudinal bulkheads which have low thickness and many openings
3. hull girders do not bend according to a plane-section assumption.

Due to these difficulties, proper calculations have been performed through global FEM models of the ships
(figure 4) to assess the actual in-plane stresses in higher decks, fabricated in the light material.
In the design of these ships, proper attention has been given to the longitudinal elements connecting the lower and upper parts, and to the rigidity of transversal sections and vertical alignment of pillars.

In comparing FEM models output stresses with theoretical values (figure 5 and 6) it is evident, for the analyzed ships, that the higher decks, both steel and light alloy, are almost completely efficient in hull girder bending and that there are significant differences between outboard and inboard stresses due to a shear effect.

The upper dome of the P&O vessel has been fabricated using conventional construction of shaped plated in 5083 alloy, extruded profiles and T-sections.

This structure, approximately 64 m long, 28,3 m wide and 9.5 m high, was assembled onshore, masts included and placed in one lift of 260 tonnes (figure 7). When transporting and installation the dome, serious technical problems had to be solved in order to avoid distortions in transit and ensure connection to the steel hull within required tolerances.

In the design of this upper dome, proper structural analyses had been carried out, taking into account the thermal expansion coefficient of light alloy material and a plating temperature ranging from + 50°C (measured value) to -20°C. In these conditions the foremost pillars and connecting details had to be designed for a load ranging from +31 to -35 tonnes.

4. Extruded light alloy panels

Best results from an aluminium alloy structure are obtained not simply by maintaining the structural concepts typical for a steel structure but by taking the full advantage of the alloy's properties. Good extrudibility of aluminium offer the possibility of obtaining large extruded profiles of any required shape or complete stiffened panels of certain dimensions with limitations dependent on the fabricating company. Typically, extrusion presses up to 10.000 tonnes have the following limitations:

1. an external diameter of the extruded section of up to 600 mm or a maximum 800 mm width by 100 mm height
2. some geometrical limitations in the extruded section profile and thickness, depending on the alloy used and relating to the billet to extrusion profile ratio
3. a weight of up to 35 kg per linear metre
4. profile length up to 32 m.

Both open and closed sections can be produced with the extrusions having complementary male and female edge preparations forming a backing support for subsequent welding (figure 8).
The advantages of producing large extruded panels are:

- decreased number of structural components
- possibility of easier optimalization of the weight
- less welding and welding inspection
- less distortion resulting from assembly
- reduced assembly time and fabrication cost.

From an economic point of view, the cost of extruded panels is minimized if the quantities produced, without exceeding pre-set tolerances, consume the service life of the extrusion die. Alloys of the 6000 series offer better extrudibility as they are more plastic at the 500 ^{0}C extrusion temperature.

As an indication, the material cost of extruded panels is about 35% higher than conventional fabricated stiffened plates. From a fabrication point of view, in the case of 5800 m^2 of extruded panels used for P&O passenger vessels, Fincantieri noted approximately 50% reduction in fabrication man-hours associated with prefabrication and automatic welding of panels in a fab-shop through advantages in assembly and particularly reduction in straightening work.

Of course, if extruded panels are utilized, adequate structural details must be adopted.
For example, (figure 9) shows a longitudinal girder produced by welding a T-section to the face bar of a panel stiffener, (figure 10) shows the intersection between panel stiffeners and transverse webs and (figure 11) the butt welding of panel stiffeners.

5. Fabrication problems

Aluminium alloys must be handled much more carefully than steel as the repair of damaged material is very difficult. Cold forming is possible with conventional equipment but using greater care than with steel. Plasma cutting is preferred for edge preparation and punching cut-outs is normally used.
Solvents or mechanical means have to be used to remove oil, grease, oxide films and other contaminants from joints prior to welding.

TIG- or MIG-welding processes are both used:

- TIG permits a limited speed (5-15 cm/min) with good control of the welding and high versatility but gives the highest heat input and therefore produces a more extensive HAZ with attendant greater distortion;
- MIG permits a speed range of 30-70 cm/min when performed manually and speeds greater than 100 cm/min by automated process when welding limited thicknesses. It gives a lower heat input and less distortion than TIG, together with higher productivity.

With aluminium alloys, post welding distortions can be a more severe problem than for steel due to the higher coefficient of expansion and lower elastic modulus. Removing distortion by heating must be very carefully controlled in order to preserve the material properties. Even the 5000 series alloys should be heated and cooled through the sensitised range of 65 °C to 200 °C as quickly as possible.

Fabrication of flat services becomes easier using extruded panels. Provided that geometric tolerances are strictly adhered to by the manufacturer, assembly is simple and welded connections can be effected by an automated process. Requiring less welding, having lower post-weld stresses and being normally less slender than conventional panels, extruded panels have lower susceptibility to buckling distortion and therefore require much less straightening work.

When the structure is curved and conventional construction has to be adopted, distortion may be minimized by:

1 providing suitable details, such as butts and seams in way of supporting primary or secondary structures (figure 12)
2. providing external restraint to the structures during welding
3. tack-welding together several plates with their stiffeners attached before welding the assembly (figure 13)
4. using proper welding sequences.

6. Bimetal transition joints: fabrication and properties

In recent passenger vessels built by Fincantieri, the connection of aluminium alloys to steel structures has been effected through bimetal transition joints.
These transition joints are fabricated by explosion. In this process the two metal plates are positioned above each other at a predefined distance (the acceleration or "stand-off" distance) using specialised spacers. The lower plate rests on a prepared sand bed. The explosive charge is placed on to the upper plate and is detonated from one edge.
The detonation travels across the upper plate as a wave and the joint is progressively formed in a extremely short time (i.e. micro-seconds) at a very high pressure causing interatomic bonding which is stronger than the weaker of the two metals joined.

The process is completed in two steps.
In the first, to avoid the formation of brittle compounds an interlayer of 3 mm of pure aluminium is clad on the steel thereby providing a strong bond without cavities.

In the second step, alloyed aluminium is clad onto the interlayer producing the final combined section
(Steel + Al 99.5% + Al Alloy).
The process is normally done on plates of 3 x 1.5 m, from which strips, pads or other shapes are cut.
The standard range is : steel 10 - 25 mm, pure aluminium 3 mm, aluminium alloy 8 - 20 mm.

The transition joint width should be at least four times as wide as the aluminium plate welded to it to compensate for the lower strength of the pure aluminium interlayer and provide an adequate load being capability for the joint which should exceed that of the attached aluminium plate (figure 14).
The tensile through-thickness strength has an average value of 101 Mpa after three heating cycles at 100 °C for 1 hour to simulate the welding process. A typical shear strength of the bonding area is 70 Mpa. For samples heat treated 15 minutes at 315 °C, minimum requirements are 58 Mpa for shear strength and 80 Mpa for tensile strength.

Corrosion resistance tests both on unpainted and painted samples have given very good results. Crevice corrosion problems, typical of fastened connections and associated with high maintenance costs, are virtually eliminated.

The only precaution necessary is to avoid the overheating of the explosion bonded zone above 315 °C during welding. This would case the formation of intermetallic brittle compounds with an attendant detrimental effect on the joint properties. Where more than one pass is required, short interpass cooling periods may be required to avoid excessive heating. Welding tests showed if the interpass temperature is below 204 °C peak temperature at the bond joint will be below limiting temperature of 315 °C regardless of process.

In order to reduce welding problems a trimetallic transition joint could be used. This joint is obtained through the insertion of a thin titanium interlayer between aluminium and steel and provides significantly increased bond strength and a permissible weld temperature up to 538 °C.

7 Bimetal Transition joints: Structural details at the connections

Double V butt-joints are recommended for connection of adjacent transition joints (figure 15) The weld preparation should have a 6 mm root-face, straddling the aluminium/steel bond.

To provide watertightness the unweldable bond zone may be hammered tight. This lack of penetration at the weld root may be interpreted as a through-thickness crack which cause particular concern from the point of view of fatigue. Application of these transition joints to the full-width uppermost continuous deck of P&O cruise vessels has been studied in detail by Lloyd's Register of Shipping and Fincantieri.

This has been evaluated on the basis of crack propagation calculations using a conservative 6 mm lack of penetration at the weld root face. This was found to propagate to a maximum of 14 mm due to the cyclical wave loading expected during a 20 year service life (applying a $5x10^7$ cycles stress spectrum). Although, with this crack length, the likelihood of brittle fracture down to -20 ^{0}C is minimal in both grade A-steel and 5083 aluminium alloy, the detail has been further improved. The drilling of a 6 mm diameter hole across the root face physically removes the lack of penetration and decreased the weld stress concentration factor at the root by at least 40% (figure 16). This solution has been applied to the above mentioned vessel, the holes being sealed by a mastic filler.

From the same passenger vessel, the following details have been collated:

1 bimetal strip used on a deck without protruding above deck plating (figure 17)
2 intersection of two bimetal strips coming from different planes (figure 18) in a bulkhead.
3 butt joint in way of a transverse (figure 19)
4 connection of deck transverses (figure 20)
5 upper connection in way of a steel pillar (figure 21)

Particular attention has to be paid to the welding of an element in way of the edge of a transition pad. In this case the tensile strength can equal to half of the normal value. Where tensile stresses are foreseen a symmetrical positioning of the bimetal strip is therefore strictly recommended (figure 22).

8. Conclusions

The use of light alloy in passenger vessels certainly entails higher material costs and higher insulation costs.

The use of non-conventional materials means that a shipyard has to face bigger fabrication problems which could greatly increase building costs.

Nevertheless, the efficiency of light alloy in weight reduction on higher decks, especially on exposed areas not requiring additional insulation, can represent the safety margin to cover other weight increases and the last solution to stability requirements.

The increase in building costs can be kept within acceptable levels through new solutions like the use of extruded light alloy panels for flat surfaces and the flexibility given by bimetal transition joints to connect light alloy to steel.

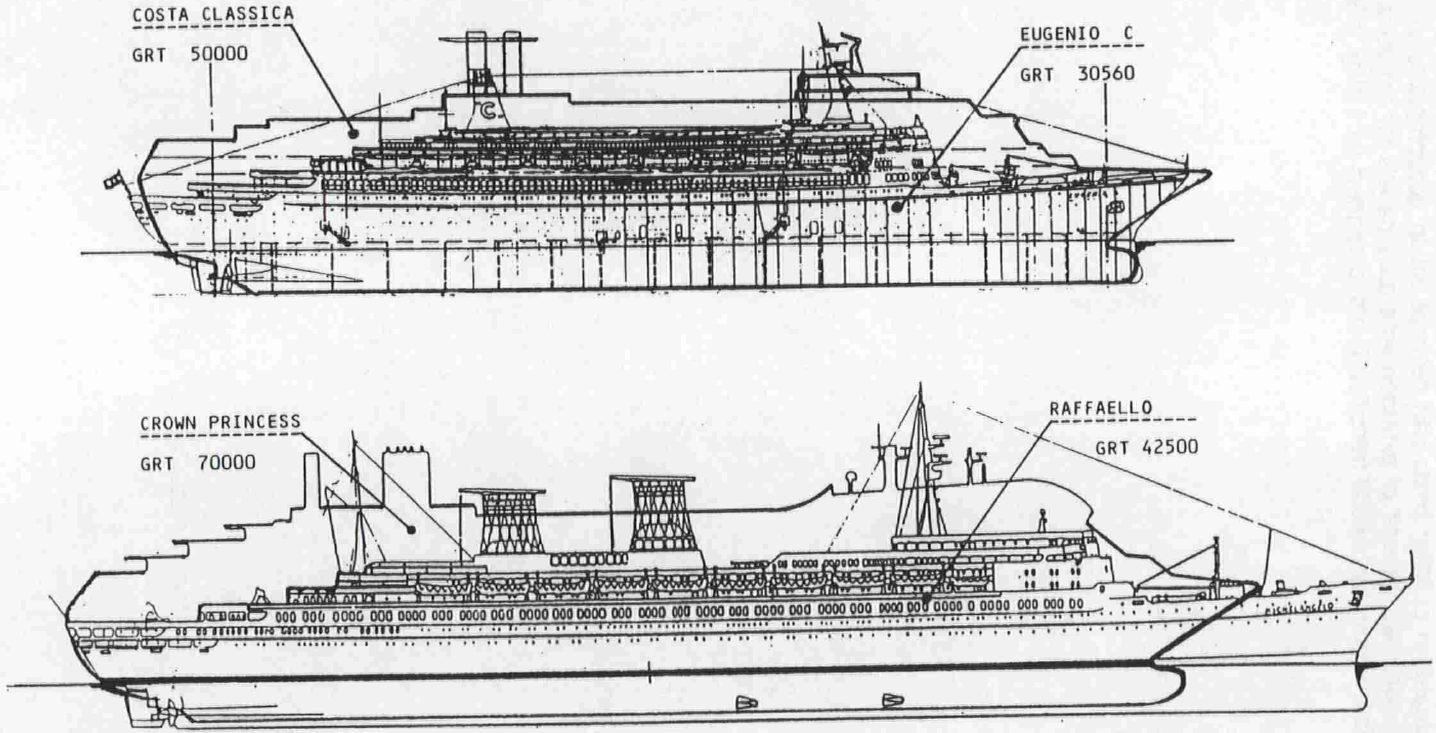


FIG. 1 COMPARISON BETWEEN NEW AND OLD PASSENGER VESSELS

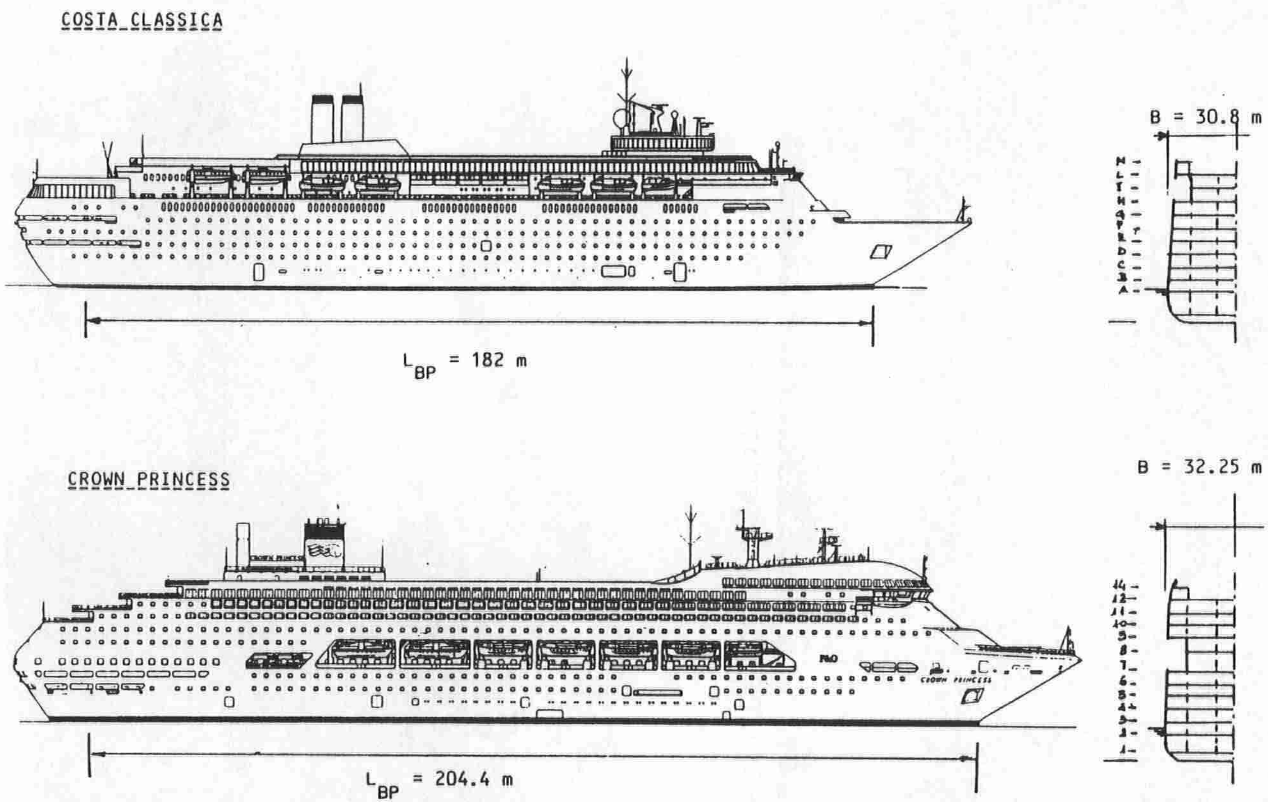


FIG. 2 RECENT PASSENGER VESSELS - FINCANTIERI DESIGN

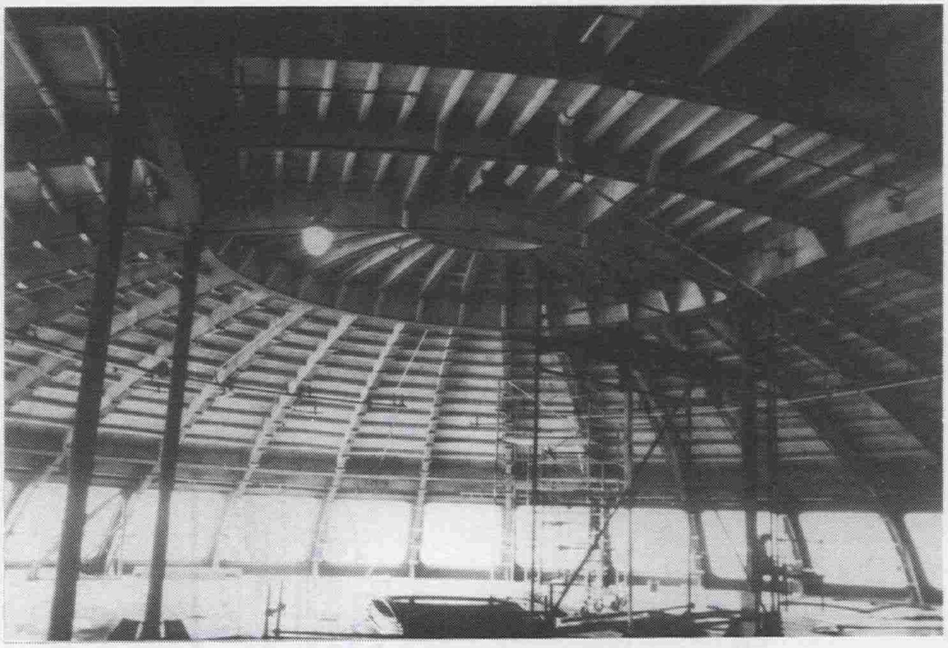


Fig 3 "CROWN PRINCESS" Upperdome Internal view

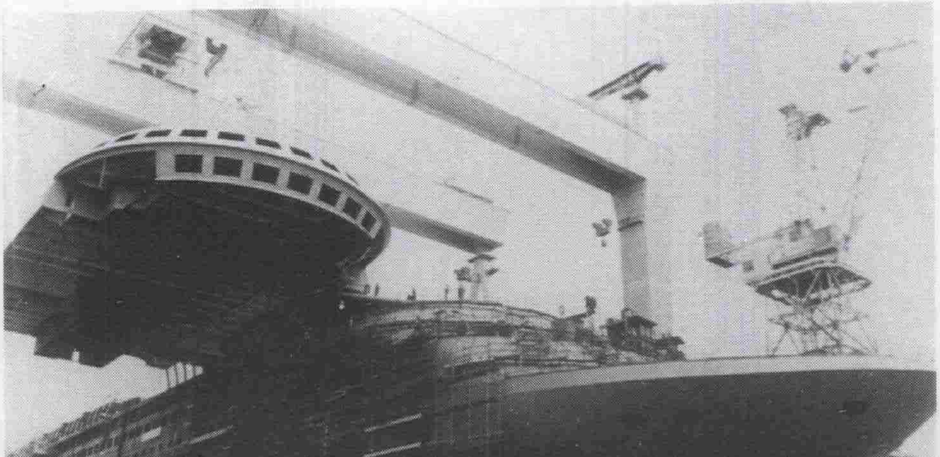


Figure 7 "CROWN PRINCESS" Upper dome during lifting

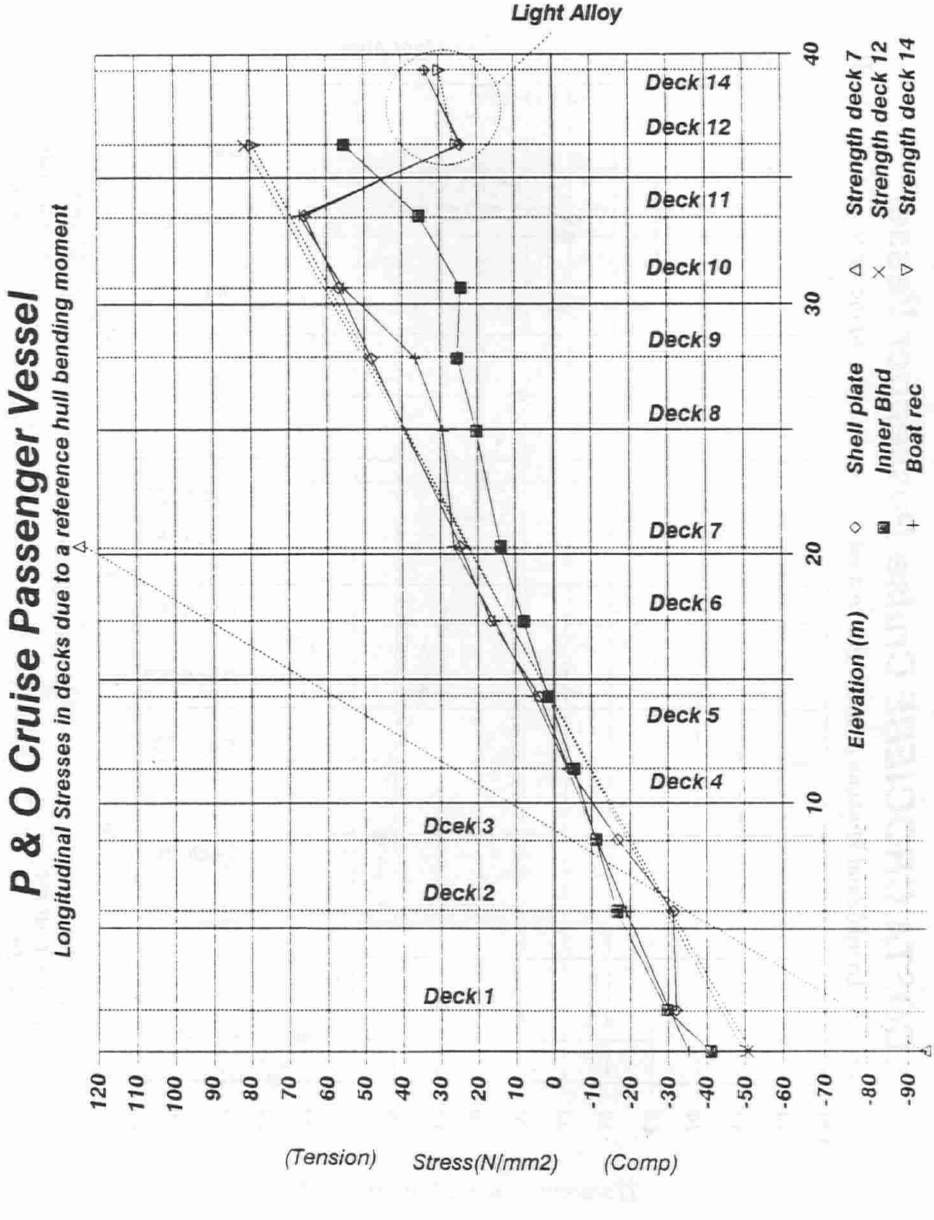


Figure 5 Comparison between FEM MODEL output and theoretical stresses "CROWN PRINCESS"

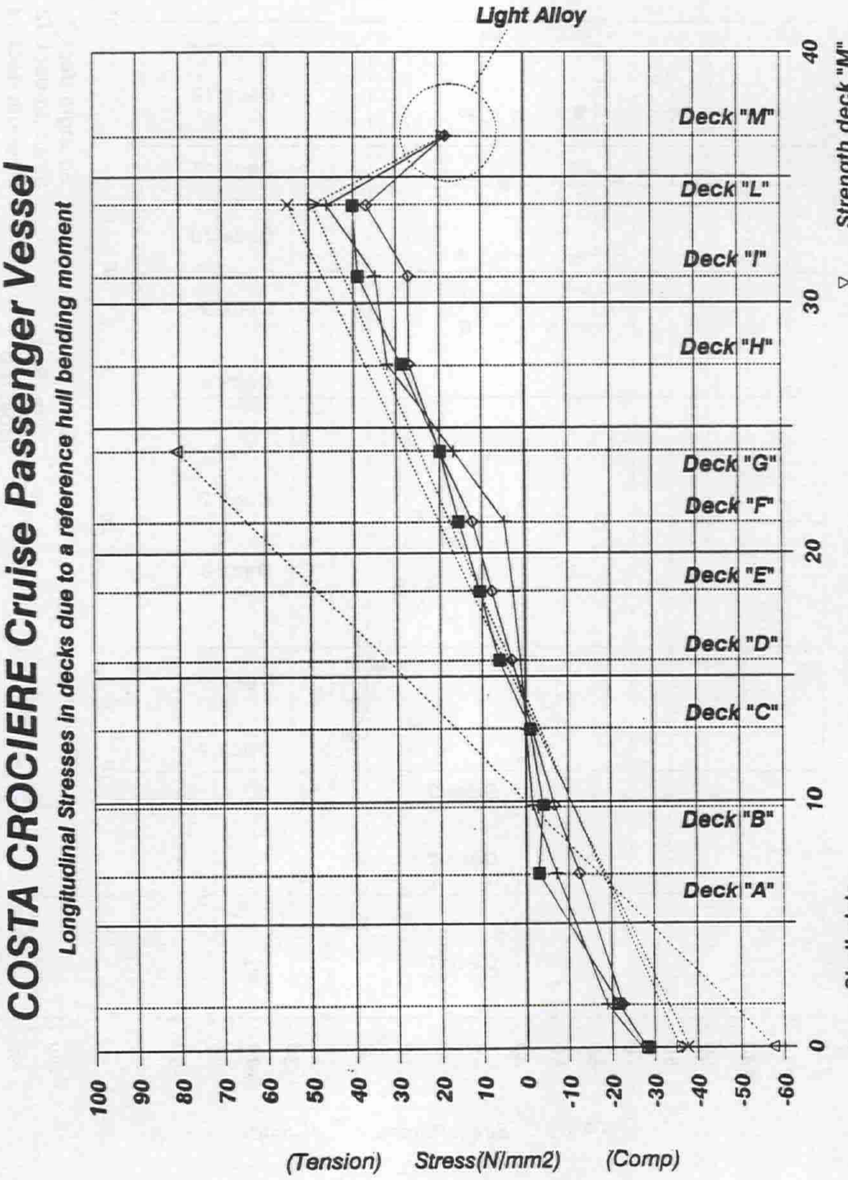


Figure 6 Comparison between FEM MODEL output and theoretical stresses "COSTA CLASSICA"

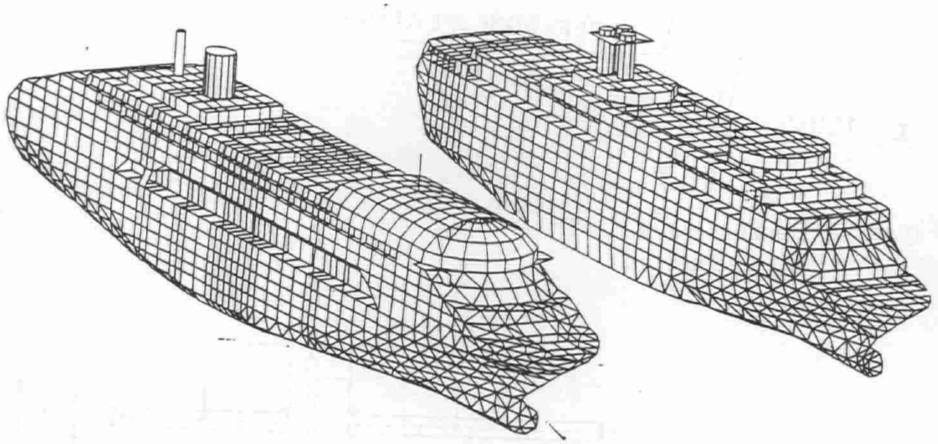


figure 4 FEM models of Fincantieri passenger vessels

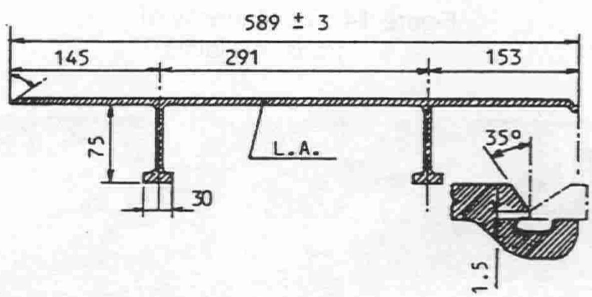


Figure 8 Typical extruded panel

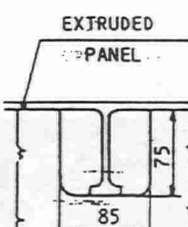


Figure 10 Typical web slot

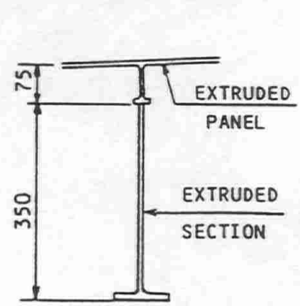


Figure 9 Long. Girder

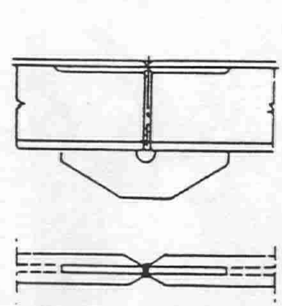


Figure 11 Butt welding of panel stiffeners

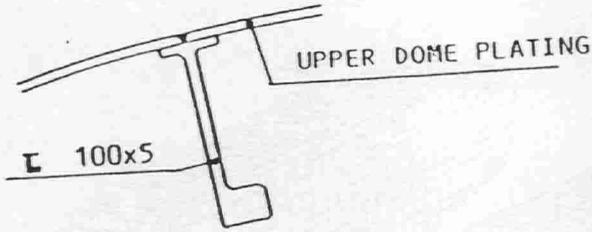


Figure 12 Detail in way of butts and seams

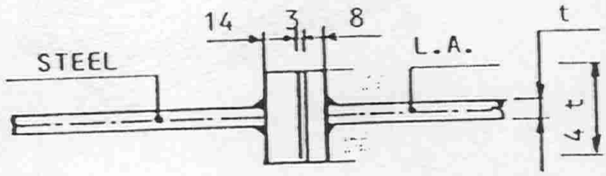


Figure 14 Detail in way of transition joints

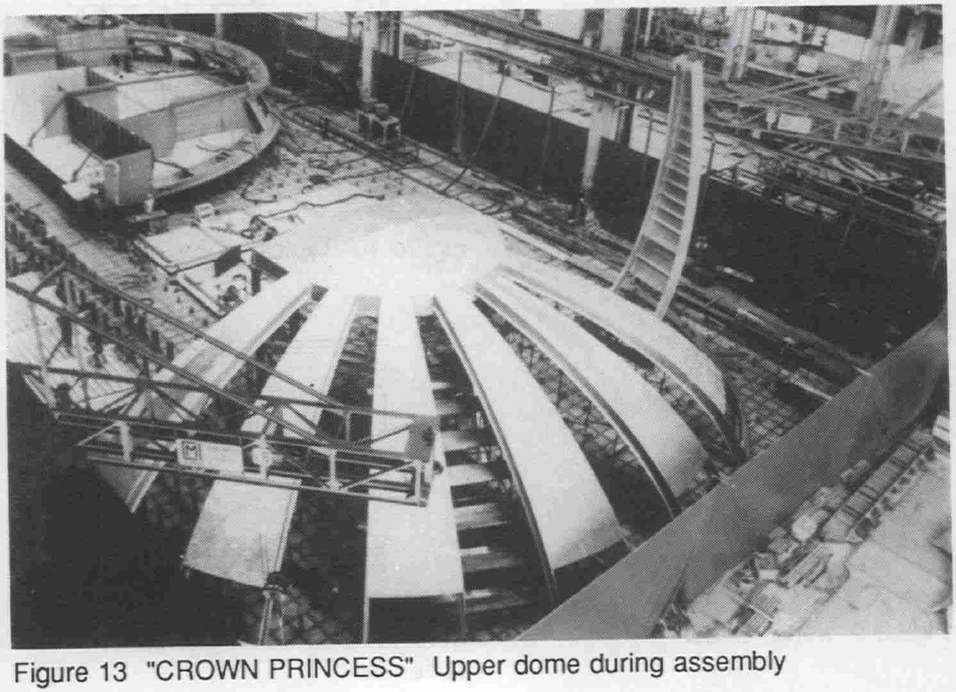
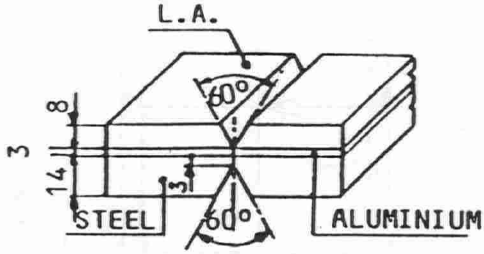


Figure 13 "CROWN PRINCESS" Upper dome during assembly



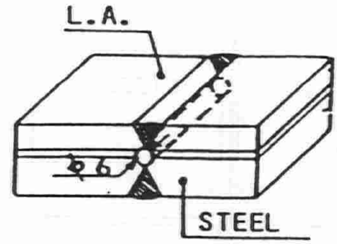


Figure 15 Figure 16
Details of transition joint connection

Figure 17 Transition joint not protruding above deck

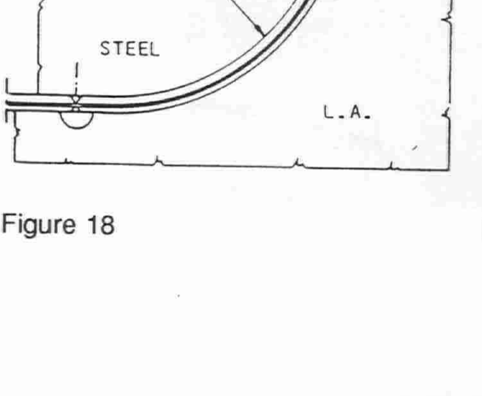


Figure 18

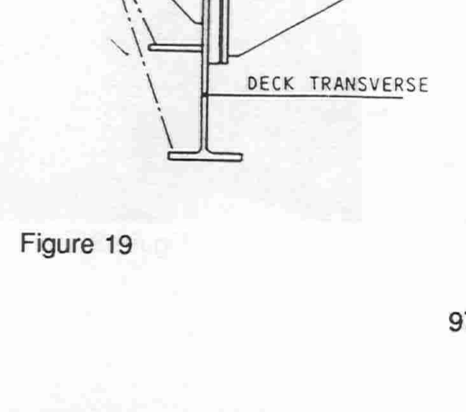


Figure 19

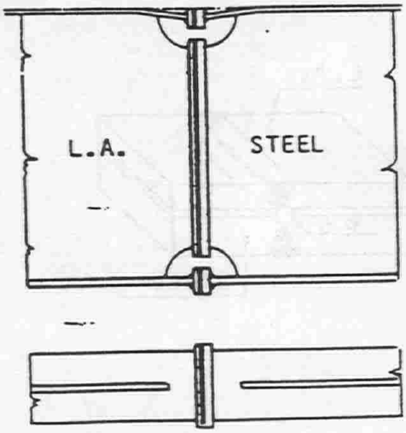


Figure 20

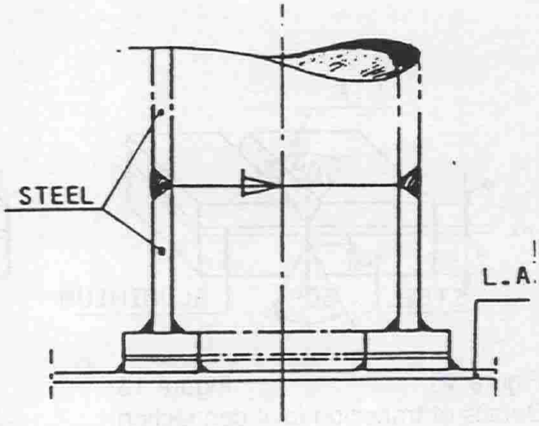


Figure 22

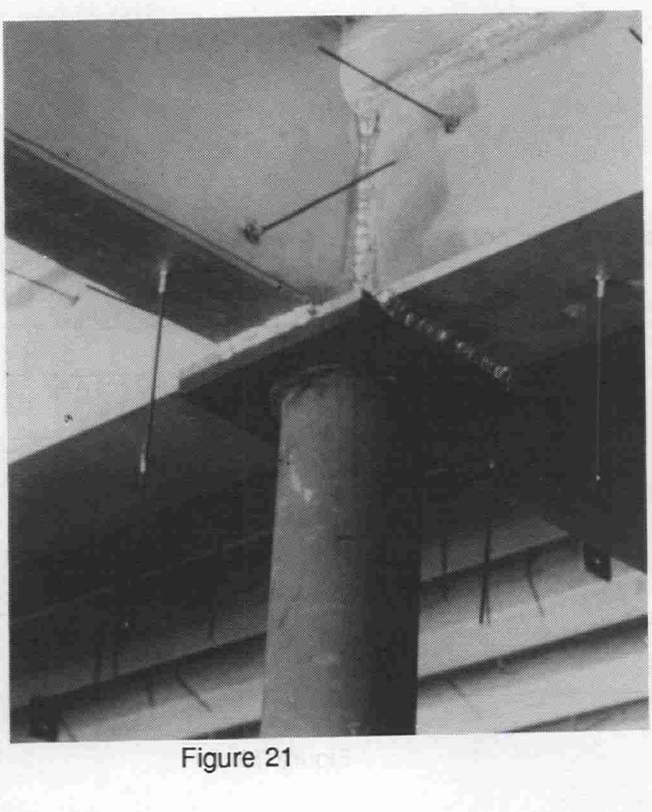


Figure 21

KONSTRUKTION UND FERTIGUNG VON BOOTSCHALEN AUS ALUMINIUM STRANGPRESZPROFILEN

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1. Zusammenfassung

2. Die Ausgangssituation

3. Unkonventionelle Bauweise des Bootrumpfes mit dem Aluminium-Strangpreßprofil

   3.1 Eine geschweißte Profilkonstuktion des Bootrumpfes
   3.2 Unkonventionelle Bauweisen im engeren Sinne,
   d.h. Profilbauweisen ohne Schweißverbindungen

   3.2.1 Renn-Segelyacht "PROFILEN", Beispiel für eine geklebte Aluminium-Bauweise
   3.2.2 Fahrtenyacht "ALUMINIA" als Beispiel für die "durch Kunststoff verriegelte" Profilbauweise

   3.3 Herstellungsablauf im Detail bei einem Aluminium-Profil boot (System Weikert)

   3.3.1 Bau der Form
   3.3.2 Vorarbeiten für die Beplankung
   3.3.3 Durchführen der eigentlichen Beplankung einschließlich des Planken-Vorbiegens
   3.3.4 Schweißarbeiten
   3.3.5 Einspritzen der Polyurethan-Vergußmasse in die Hohlräume der Fügestelle
   3.3.6 Herstellung des Decks, Einbringen von Aufbau, Cockpit und Fundamenten in den Bootskörper

3.4 Zur Theorie der durch abwickelbare Parallelstreifen angenäherten doppel gekrümmten Oberfläche eines Rundspant-Bootes

4. Zur Langzeitbewährung von Aluminium-Profilbooten

5. Schlußbemerkung

6. Literatur Nachweis

1. Zusammenfassung

Seit Jahrzehnten haben sich geschweißte Aluminiumboote einwandfrei bewährt. Es sind im wesentlichen diese Argumente, die eine zunehmende, wenn auch immer noch vergleichsweise kleine Zahl von Schiffseigern überzeugen haben können:

- geringes Konstruktionsgewicht (insbesondere im Vergleich zu Stahl)
- hohe Korrosionsbeständigkeit auch im Meerwasser
- gute Haltbarkeit der Lackierung und damit geringer Unterhaltungsaufwand (im vergleich zu Stahl)
- hohe plastische Dehnungsreserve gegenüber Leckschlagen bei einem Unfall oder Manövrierfehler (besser als GFK)
- metalltypisch gleichbleibende hohe Steifigkeit und Festigkeit der Konstruktion (besser als GFK)
- keine Feuchtigkeitsaufnahme, auch wenn das Boot das ganze Jahr über im Wasser liegt (besser als GFK)

Nur wenn man auf den Anschaffungspreis schaut, sind die in üblicher Manier, nach den Regeln des Metallbauhandwerks aus Blechen und Aussteifungsprofilen
geschweißten Aluminiumboote wirklich teuer - und nur auf den Anschaffungspreis schaut tatsächlich immer noch das große Publikum auf dem Bootsmarkt.

Ein Aluminiumboot in der bevorzugten Rundspantbauweise billiger herzustellen, war das Ziel einer Reihe von Erfindern. Aluminium besitzt gegenüber den anderen Gebrauchsmetallen einen entschiedenden Vorteil den es in allen Technikbereichen immer mehr nutzt. Es läßt sich in fast unbegrenzter Formenvielfalt wirtschaftlich
strangpressen - und nichts lag daher naher auch das Blech einer räumlich gekrümmten Bootsschale durch entsprechend gebogene Strangpreßprofile mit integrierten Stringern abzulösen und dabei das immer mit Verzug einhergehende Schweißen weitgehend auf Null zu bringen.

Aluminium-Profilboote wurden bisher in einer Reihe konstruktiver Varianten entwickelt und als Prototypen oder in Kleinserie gebaut. Einleitend werden zwei Ent-wicklungen aus Skandinavien vorgestellt: eine geschweißte und eine geklebte Ausführung. Der Kern des Vortrags bietet die genaue Beschreibung

einer in Deutschland im vorigen Jahrzehnt zur Anwendsreife entwickelten Profilkonstruktion der Bootsschale. Diese besteht aus schmalen, teils elastisch, teils plastisch in die Bootskontur gebogenen Strangpreßprofilen. Die Profile sind an den Längskanten ineinander gehakt und mit einem aushärtenden Kunststoff fest und wasserdicht miteinander verriegelt.
Schweißnähte sind nur noch erforderlich, um die großen Baugruppen wie die beiden Schalenhälften mit Steven, Spiegel und Kiel, sowie die Decksaufbauten, Cockpit usw. miteinander zu verbinden. Viele komplizierte und verzugsbedrohte Schweißungen entfallen also. Mit anderen Worten werden eher einzelne Bauteile montiert als metallhandwerklich anspruchsvoll Arbeiten getan - dies ist die Schlüssel zu einer fühlbaren Kostenverminderung bei Aluminium-Profilbooten "nach Bausystem".

Profilboote des Typs "Aluminia" haben sich seit 10 Jahren bestens bewährt, auch im rauhen Einsatz. Im Rah-men eines Forschungsauftrages hat man an der Universität Hannover die mehr als ausreichend hohe Festigkeit der profilverbindung nach System WERIS (=Weikert-Riegel-System) nachgewiesen. Unfallsimulationen an der ProfilBootsschale haben gezeigt: Die Riegelverbindung zwischen den Profilen bleibt dicht wie bei einem geschweißten Boot in Konventioneller Blech-Profilgerippe-Bauweise.

2. Die Ausgangssituation

Warum ist das konventionell hergestellte Aluminiumboot nach wie vor selten anzutreffen, vergleicht man mit solchen aus Stahl und insbesondere solchen aus GFK? Warum zum Beispiel stößt man auf Aluminium immer umso wahrscheinlicher, je größer und luxuriöser eine Fahrtenyacht ist?
Es ist keine Frage: Bei den Segel- und auch Motorboote, die in größerer Serien hergestellt werden und die die Masse der Nachfrage befriedigen, wird auf den Anschaffungspreis geschaut. Vorteile der obengenannten Art spielen hier erst in zweiter Linie eine Rolle.
Das heißt, diese können preislich nicht so ohne weiteres beim Kunden geltend gemacht werden. In dieser Situation leider befindet sich aber Aluminium als Bootsbauwerkstoff.

Gegenüber Schiffbaustahl ist Aluminium, rechnet man auf kg-Basis, wesentlich teurer, ohne (im Falle der konventionellen Bauweise) die Chance zu haben die höheren Materialeinstandskosten durch deutliche Vorteile bei der Fertigung des Bootes kompensieren zu können.
Die hohe Fähigkeit des Blech- und Profilbiegens, des verzugsarmen Schweißens, des Richtens unvermeidlichen schweißbedingten Restverzugs, des Spachtelns, um Restunebenheiten auszugleichen sowie weitere Fähigkeiten, die ein anspruchsvolles Metallhandwerk kennzeichen, bleiben gleichermaßen gefordert bzw. werden bei Aluminium vielleicht in noch höherem Maße

verlangt.

Der kg-preis von glasfaserverstärktem Kunststoff (GFK) liegt zwar von dem des Aluminiums heute mehr weit entfernt; GFK weist jedoch bedeutende handwerkliche Vorteile gegenüber einer geschweißten Metallkonstruktion auf. Angesichts der hohen Kosten für die Form ist die Wirtschaftlichkeit seiner Verwendung allerdings an eine gewisse Seriengröße gebunden. Hinzu kommt daß - wenigstens in Deutschland - die meisten Bootsbauer gut mit diesem Material vertraut sind. Auch ist viel eher die Regel, daß eine Bootswerft, die Stahlbau beherrscht, Aluminiumboote alternativ zu Stahlboote anbietet (siehe insbesondere die Niederlande), als daß eine auf die GFK-Verarbeitung ausgerichtete Werft alternativ das Metallboot, geschweige denn das Aluminiumboot, im Program hat.

Offensichtlich hat Aluminium nur dann eine größere Chance als Werkstoff für den Bootsrumpf höhere Marktanteile zu gewinnen, das heißt vor allem im Bereich der kleineren und mittleren Fahrtenyachten ab 7 bis 10 oder 11 m Lange, wenn die Aluminiumbauweise mit fühlbar, um nicht zu sagen, drastisch verringerten Fertigungskosten auf der Werft einhergeht. Die Lösung dieses Problems die übrigens vor Zeiten schon immer wieder versucht wurde, liegt - wenn überhaupt - in der Stangpreßprofiltechnik.

Anders als die meisten anderen metallischen Konstruktionswerkstoffe, unter ihnen Stahl und Eisen, lassen sich viele Aluminium - Knetlegierungen gut bis sehr gut strangpressen.
Dies gilt insbesondere für die niedriger legierten Varianten des Typs AlMgSi, ein warmaushärtbarer Legierungs- typ, der sich zudem durch hohe Korrosions- und Meerwasserbestandigkeit ausgezeichnet und zu den schweißbaren Al-Legierungen gehört. Darunter befindet sich AlMgSi0,5, der überall mit Abstand am meisten stranggepreßte Aluminiumwerkstoff. Im zustand warmausgehärtet erreicht er Festigkeitswerte, die an die von gewöhnlichem Baustahl (ST37) herankommen (nach DIN 1748 ergeben sich die Mindestwerte in N/mm^2)

für F25 zu : $R_m = 245$, $R_{p0.2} = 195$ und

für F22 : $R_m = 215$, $R_{p0.2} = 160$

Insbesondere für diese Legierung läßt die heutige Strangpreßprofil-Technologie kaum noch Wünsche offen, was die

- Größe und Präzision der Abmessungen
- Gestaltungsfreiheit bei der Festlegung des Profilquerschnitts
- Realisierung geringer Wanddicken und
- Quälitat (Ebenmaßigkeit) der Oberfläche angeht.

Die Fortschritte in der Technologie des Aluminium-
Strangpreßprofils manifestieren sich seit langem und kontinuierlich wachsend in allen Bereichen der Technik. An dieser Stelle seien hierzu nur drei sehr

anschauliche Belege genannt:

- Die Segelmasten und -bäume mit ihren heute zum Teil sehr komplizierten, mehrfunktionalen Querschnitten als unangefochtene Domäne des Aluminium-Strangpreßprofils im maritimen Bereich.

- Die Aufbauten großer Passagierschiffe, um durch wirtschaftlichen Leichtbau die Stabilität dieser Schiffe zu vergrößern und

- der Schienenfarzeugbau, angefangen van Straßenbahnen über U- und S-bahnen bis zu Hochgeschwindigkeitszügen wie der Inter City Express (ICE) der Deutschen Bundesbahn.

Die beiden leztgenannten Anwendungsbereiche haben sich zu einem wichtigen Einsatzschwerpunt für Groß-strangpreßprofile ingeschweißten Strukturen entwickelt. Diese Profile vereinen "Stringer und Blechhaut" in einen, bis zu 800 mm breiten Querschnitt.
Da es sich entweder um ebene Platten oder um eine zylindrische "Röhre" handelt, fallen gerade, automatisch herstellbare Schweißnähte zwischen den Profilen an.

Wenngleich der Wagenkasten eines Schienenfahrzeugs die Form eines zylindrischen Körpers aufweist (die einzigen Krümmungen, die auftreten, sind im Querschnitts-ebene enthalten und damit Bestandteil der Querschnittsgestalt der längslaufenden Strangpreßprofile), und wenngleich es sich bei der Bootsschale eines "Rundspanters" eindeutig um eine zweifach gekrümmte, d.h. nicht ab-wickelbare Oberfläche handelt, so war dennoch eine Herausforderung an den Erfindergeist gegeben, auch eine solche Schale (zusammen mit dem Deck und ggf. den Decks-aufbauten) als die Herstellungskosten senkende Aluminiumprofilkonstruktion darzustellen.

3. Unkonventionelle Bauweisen des Bootrumpfes mit dem Aluminium-Strangpreßprofil

Im weiten Sinne mögen hierunter alle Konzepte verstanden sein, den Rumpf ganz oder zumindest weitestgehend aus Strangpreßprofilen ("Integralprofile", siehe vorangehenden Abschnitt) zusammenzusetzen d.h. auch die Konzepte, die voll auf dem Schweißen beruhen.

3.1 Eine geschweißte Profilkonstruktion des Bootrumpfes

Bild 1 zeigt den nach einem Entwurf von Pelle Petterson in Schweden gebauten Motorsegler "ALU QUEEN". Das 1984 fertiggestellte Schiff ist 15.4 m lang (ü.a.) und 4.0 m breit. Die Masthöhe beträgt 20 m. Das Schiff wird angetrieben von einem 62 kW-Motor von Volvo Penta, der ihm eine Dauergeschwindigkeit van ca. 9 kn verleiht. Die Segelfläche beträgt 76 m2 (Großsegel 44 m^2, Fock 32 m^2).

Beim Rumpf handelt es sich um eine vollständig ge-schweißte Aluminium-Konstruktion.
Die Bootsschale (Rumpfbeplankung) ist aus (die Längsaussteifungen oder Stringer bereits enthaltenden) Integralprofilen gebildet. (Bild 2).
In diesen Figur bedeuten

1. Spantprofil
2. Plankenprofil
3. Schweißnaht
4. Innenauskleidung
5. Wärmedämmaterial

Die für die Plankenprofile verwendete Legierung ist 6351, warmausgehärtet (die 4-ziffrige internationale Bezeichnung steht für eine Legierung aus den USA, die in der Zusammensetzung weitgehend AlMgSi1 entspricht: die Bezeichnung ist im Legierungsregister der Aluminium Association (AA), Washington DC enthalten).
Die Profile schließen die Bodenplatte mit dem Kiel - beide wie das Deck und der Kajütaufbau aus Aluminium-blechen geschweißt - ein.
Die Profile der Schale laufen nicht in einem Stück vom Bug bis zum Heck durch; das heißt sie sind in mehreren Abschnitten (im allgemeinen drei) in Längsrichtung gestoßen. Diese Maßnahme bedeutet hier nur wenig Mehraufwand und ist sozusagen systemkonform, jedoch einer der Unterschiede zur nicht geschweißten Profilbauweise, siehe weiter unten.

Es ist die große Breite des einheitlich für die Rumpfschale verwendeten Integralprofils (Bild 2 zeigt es rechts mit unverformtem Querschnitt, das heißt so wie es aus der Strangpress kommt), die für diese Maßnahme verantwortlich ist, ebenso wie für die weiteren Arbeitsschritte, die aus dem "ebenen" Profil die zweifach gekrümmte, der Schalenkontur angepaßte "Planke" machen. Diese Arbeitsschritte sind gleichfalls nicht mit denen identisch, die bei der nicht geschweißten Aluminium-Profilbauweise eine Rundspanters vorkommen.

Das plastische Vorformen (Biegen) der Profile geschieht in zwei Schritten, um die doppelte Flächenkrümmung zu erreichen:

- Zuerst erfolgt das plastische Verformen der Profilwand aus der Ebene heraus mit Hilfe einer Art von hydraulisch betätigtem Hammer- und Drückwerkzeug, wobei der Biegeradius der profilwand (d.h. in Profilquerschnittsebene) entsprechend den verschiedenen Spankrümmungen über der Plankenlänge variabel erzielt wird).

- Darauf wird das so vorgeformte Profil in einer Drück-rollen-Bank über seine "schmale Kante" plastisch vorgebogen, (im Bild 4 unten rechts) so daß es in etwa der relativ geringen Krümmung in Längsrichtung folgt.(-d.h. grob gesehen in Ebene einer Wasserlinie). Kleinere Abweichungen gleicht man am Mall elastisch aus.

Schließlich erfolgt das Besäumen der so zweifach gebogenen Planke, und zwar nur an einer ihrer beiden Längsseiten. Das heißt die Plankenbreite (oder -höhe) ist über der Länge nicht konstant.
Die Profilplanke verjüngt sich von Schiffsmitte zu den Enden insbesondere zum Heck hin. Ein Verbiegen um die "hohe Kante" des Profils findet hier nicht statt (anders als bei der später erläuterten nicht geschweißten Profilbauweise)

Die Idee, einen geschweißten Bootkörper aus Aluminium auf Basis des Strangpreßprofils zu entwickelen und zu bauen, stammt von Gränges Aluminium - Finspang, Schweden. Mit Hans Wester Mekaniska AB war mit der Realisierung ein Bootsbauer beauftragt, der schon jahrelange Erfahrungen mit geschweißten Aluminium Booten in der konventionellen Blech-Gerippe-Bauweise hat. Die Profilbauweise bedeutete hier insofern einen Fortschritt in der Fertigung, als Schweißnahtanhäufungen reduziert wurden und beim Verschweißen der sehr stabilen Integralprofile weniger Verzug auftrat. Jedoch setzt auch die geschweißte Profilbauweise das Können und handwerkliche Geschick des versierten Metallbootsbauers voraus. Der Prototyp "ALU QUEEN" jedenfalls steht da als einer der Ergebnisse in dem Bemühen, dem Aluminium-Strangpreßprofil neue Anwendungsfelder zu schaffen und hierin praktische Erfahrungen vom Bau bis zum Langzeitverhalten zu sammeln.

3.2 Unkonventionelle Bauweisen im engeren Sinne, d.h. Profilbauweisen ohne Schweißverbindungen

Wenn man auch das Integralprofil aus Aluminium bei der "ALU QUEEN" bereits als Fortschritt in der Bootsfertigung ansehen darf, so ist damit das Potential der Strangpreßprofiltechnik noch nicht ausgeschöpft, unter anderem wenn es darum geht, sich von den speziellen Anforderungen des konventionellen Metallbootsbaus wenigstens teilweise zu lösen.

Die zusätzlichen Möglichkeiten (das heißt außer der "Integralbauweise" die Haut und Stringer vereint) liegen bei der Profiltechnik nun aber gerade darin, Füge-Alternativen zum schweißen "an den Profil-Längskanten" zu schaffen; Alternativen, die wegen fehlender Wärme-einbringung verzugsfrei arbeiten. Die Profilquerschnittsgestaltung im Fügebereich schafft hierbei gleichzeitig mehrere günstige Voraussetzungen. Sie sorgt dafür:

- daß die (zum Beispiel auf dem Mall) zu fügenden Profilkanten auch in Krümmungsbereichen genau und bequem zueinander positioniert werden können

- daß man benachbarte Profile sowohl in einer Ebene als auch im (kleinen) Winkel am Spantgerüst übereinandersetzen (verhaken, verkrallen, einhängen) kann, und daß

- gleiche Zuverlässigkeit bezüglich Festigkeit (und Dichtigkeit) wie beim Schweißen erreicht wird. Das gilt sowohl für konventionelle Alternativen wie zum Beispiel Kleben, als auch für neue Fügeverfahren, die prinzipiell an das Strangpreßprofil gekoppelt sind, wie das Verhaken und Verriegeln von Profillängskanten durch Einspritzen von aushärtbaren Kunststoffmassen in einen geschlossenem Hohlraum den die Fügepartner an der Fügestelle bilden.

Somit seien unter "unkonventionellen Bauweisen des Aluminium Bootsrumpfes im <u>engeren</u> Sinne" nur diejenigen Profilbauweisen verstanden, die einen Bootsrumpf in Rundspantenausführung <u>weitestgehend</u> ohne Schweißverbindungen ermöglichen.

Die Einschränkung "weitestgehend" ist, bezogen auf den gesamten Bootskörper, angemessen. Zunächst einmal sind (wenigstens bei den bisher in Europa entwickelten, in der Summe schon beachtlichen Aluminiumprofil-Bauweisen, die in Prototypen von Fahrten- und Rennyachten verwirklicht wurden, die aber hier nicht alle ausführliche Erwähnung finden können) folgende Baugruppen stets bzw. häufig als geschweißte Blechkonstruktion ausgeführt:

- die den Kiel aufnehmende, mehr oder weniger große <u>Bodenplatte</u>

(immer)

- der <u>Kiel</u> (feststehend oder Hubkiel) selbst (immer)

- der <u>Kajütaufbau</u> (ganz oder teilweise)

- der <u>Spiegel</u> (im wesentlichen ein Blechzuschnitt, ggfls, mit angeschweißten Versteifungen versehen)

- das <u>Cockpit</u> (immer).

Das heißt die unkonventionelle Profil-Bauweise bezieht sich typischerweise auf:

- die beide gekrümmten, zueinander spiegelbildlichen <u>Rumpf-Halbschalen</u> mit dem Anschluß der Spante

- das <u>Deck</u>, ebenfalls gebildet aus zwei spiegelbildlichen Partien, die in der Längsmitte zusammenstoßen

- den <u>Anschluß des Decks</u> an die Bootschale.

Auch die Aufbauten können ein Dach haben, das als Profilkonstruktion ausgeführt ist.

Zum zweiten sind - und das auf jeden Fall - durchgehende Schweißnähte als dichte <u>und</u> feste Verbindung zwischen den genannten Baugruppen unverzichtbar; im einzelnen

- zwischen Bodenplatte bzw. Kielprofil und den untersten Profilen der Halbschalen

- zwischen Vordersteven (Einfaßprofil, Bugplatte) und den Stirnseiten der Schalenprofile

- zwischen Spiegel und Stirnseiten der "Profilschalen"

- zwischen den Halbschalen des Decks (schweißnaht in Längsmitte)

- zwischen Deck und Kajütaufbau

- zwischen Deck und Cockpitt

Die durchgehenden und relativ einfach realisierbaren "Montage Schweißnähte" stellen jedoch kein Risiko in Hinblick auf untolerierbar großen Schweißverzug dar. Bei den folgenden Konstruktionsbeschreibungen sollen daher diese Verbindungen gegenüber den nicht geschweißten (das heißt denen zwischen den Profilen) in den Hintergrund treten.

Von zwei Arten der nicht geschweißten Profilbauweise von Rundspant-Rümpfen soll im folgenden die Rede sein; Bauarten, die etwa mit Beginn der 80er Jahre entwickelt wurden und die sich als Prototyp bewährt bzw. (im Falle Weikert) in einer Reihe von Nachbauten manifestiert haben:

- Kleben der Profillängskanten in Bootsschale und Deck

- Verriegeln der Profillängskanten durch Einspritzen von aushärtbarem Kunststoff in den geschlossenen Hohlraum der Fügestelle.

Das erstgenannte Verfahren wurde erstmalig und bisher wohl einzig beim Bau der Schwedischen Renn-Segelyacht "PROFILEN" (Gränges Aluminium) angewendet, siehe 3.2.1.
Das zweitgenannte Verfahren ist

a Gegenstand einer aktuellen Deutschen Entwicklung (Weikert/Elze b. Hannover), die ab 3.2.2. beispielhaft und ausführlich beschrieben werden soll, und war
b über längere Zeit in Österreich bis zu fertigen Prototypen verfolgt worden (Yachtbau Pinica/Wienerherberg), und zwar in einer Modifikation des Verfahrens (siehe Bild 29), die wesentlich auf Schraubverbindungen beruhte.

Die beiden weiter unten im Detail vorgestellten Konstruktionen ("PROFILEN" und "ALUMINIA") haben eine Reihe von Merkmalen gemeinsam:

- Die Profile sind im Vergleich zur Spantlänge (bzw. zur Länge des Rumpfes) ausgesprochen schmal. Meist liegt ihre Rasrehöhe deutlich unter 100 mm (im Falle der Yacht "PROFILEN" maximal ca 100 mm).

- Die Bootsschalen sind karweelbeplankt mit Profilen, die im Prinzip alle den gleichen Querschnitt aufweisen können. Aus verschiedenen Gründen wirde die Schale aber meist mit zwei unterschiedlichen Profilquerschnitten dargestellt.

- Die Profile (Planken) "laufen am Rumpf durch"), das heißt sie sind in Längsrichtung nicht "Querschnitt gegen Querschnitt" gestoßen.

- Der Profilquerschnitt bzw. seine Höhe bleibt über der Länge unverändert, bedingt dadurch, daß die speziell gestalteten Fugekanten erhalten bleiben müssen. Aus der unveränderlichen Profilhöhe folgt, daß die (abgewickelte) Länge aller Spante im oberen Bereich, das heißt dort, wo die Planken vom Bug bis zum Heck durchlaufen, gleich ist. Diese unverzichtbare Randbedingung wirkt sich aber üblicherweise nicht störend beim Bau von Rundspant-Booten aus.

- Die parallel laufende Fügelinien zwischen den Profilen bleiben optisch sichtbar bestehen, das heißt werden nicht zugespachteld. Diese etwa den Wasserlinien entsprechenden Fügelinien zeichnen sich unter dem Außenanstrich nur geringfügig ab. Sie werden kaum als störend empfunden, ja betonen eher eine gelunge Rumpfkontur.

- Die (zumindest für die Bootsschale verwendeten) schmalen Strangpreßprofile weisen im Querschnitt eine optisch nicht bzw. nur schwer erkennbare Krümmung der Wandkontur nach außen auf, Bilder 4 bis 7. Diese leichte, gewissermaßen in den Profilquerschnitt "einkonstruierte", konvexe Krümmung bleibt über der plankenlänge unverändert bestehen. Eine "Kosmetik" mit Spachtel erfolgt nicht. Die "einkonstruierte" Krümmung orientiert sich vor allem nicht an irgendwie bevorzugten Spantkrümmungen.

Die zuletzt gemachten feststellungen mögen nicht nur den Laien überraschen, so daß auf diesen Punkt etwas näher eingegangen werden soll. Ohne weiteres würde man ja glauben, daß sich aus derartigen Profilen nur mal die Kreis-zylinderschale mit durch die Profilquerschnitts-krümmung vorgegebenem Radius optisch einwandfrei, das heißt ohne störende Knicke zusammensetzen ließe, zumal, wenn es sich um glänzend lackierte, jede Störung der Homogenität der Kontur schonungslos reflektierende Oberflächen handelt.

Wie wenig eine solche Ansicht mit der Realität im Einklang ist, beweist der aus schmalen Profilen zusammensesetzte Rundspant-Rumpf der zum Beispiel in Bild 7 gezeigten Fahrtenyachten vom Typ "ALUMINIA" (Weikert). Bei diesen Booten mit 8 bis 9.2 m L.ü.A. treten in Spantebene Krümmungsradien der Spante bzw. des Risses von "unendlich" bis deutlich unter 1m auf. Die Krümmer der Wand der einzelnen Profile in Spantebene weicht also meist mehr oder weniger stark von der Krümmer de Bootsumrisses in dieser Ebene ab, beispielsweise dort, wo die Spante gar keine Krümmung aufweisen.

Damit sich "für das Auge" eine hinreichende Homogenität der aus Streifen bestehenden Rundspantenschale einstellt, ist hinreichende "Schmalheit" der Profile die wesentliche Voraussetzung. Das heißt derartige Profile könnten so gesehen ohne weiters im Querschnitt vollkommen eben sein. Verlangt man aber die ebene Profilwand "nach Zeichnung", besteht allerdings die herstellungsbedingte Gefahr, daß Profile mit "Einfallstellen" (natürlich innerhalb der in DIN festgelegten Toleranzen) geliefert werden.

Auch wenn diese "Wölbungstoleranz der Wand im Profilquerschnitt" bei schmalen Profilen nur Bruchteile eines Millimeters beträgt, die kleine "Konkavheit" in einer insgesamt konvexen, glänzend lackierten und damit reflektierenden Schale fällt leicht auf, ähnlich wie eine flache Delle. Das primäre Ziel der in den Profilquer-schnitt einkonstruierten konvexen Wandkrümmung liegt also (wenigstens bei Weikert) darin, konkaven Einfall-stellen am Profil zuverlässig vorzubeugen.

Im falle der schwedischen Entwicklung ("PROFILEN") ist die "einkonstruierte" konvexe Krümmung im Profilquerschnitt so stark ausgeprägt, daß die einzelnen, gleichmäßigen Rundungen der übereinandergesetzten Planken (wenn auch nur ganz leicht) insbesondere am Bug und Hech sichtbar werden, ohne daß man dies aber unbedingt als störend empfinden muß.

3.2.1 Renn-Segelyacht "PROFILEN"' Beispiel für eine geklebte Aluminium-Bauweise

Die Daten der "PROFILEN" (Bild 3), die 1981 in Schweden nach einem Entwurf von P. Norlin gebaut wurde, lauten:

L.ü.A.	9.83 m
B.	3.3 m
Gesamtgewicht	3.5 t
Segelflxche laut IOR	53 m2
Ratung laut IOR	24.5
Kielgewicht	1 t
Mastlänge	16 m

Für Deck und Bootsschale kommen insgesamt 5 verschiedene Profile aus legierung vom Typ AlMgSi (z.B. AlMgSi0.5) warmausgehärtet) zur Anwendung (Bild 4a). Das Hohlprofil im Unterwasserbereich ist 60 mm hoch, hat außen eine gekrümmte Wand und ist mit PU ausgeschäumt. Dank dieser geringen Höhe ist das {infolge seiner Lage am Rumpf, siehe Abschnitt 3.4) notwendige plastische Vorbiegen des profils "über die hohe Kante", daß heißt vor Anlegen an das Mallgerüst sehr erleichert. Die nach oben anschließenden offene Profile der Bootsschale (Bild 4b) haben eine Rasterhöhe von 101 mm. Der Wand-Krümmungsradius dieses Profils beträgt 608 mm (außen).
Die Wanddicke beträgt lediglich 1,8 mm. An den Kreis-zylinderförmig gestalteten Klebeflächen der profil ist eine Längsriffelung "mit angepreßt" um für eine zusätzliche Verankerung des Klebstoffs (Ciba-Geigy AV 144) zu sorgen. Die Ausbildung der Fügestelle als Kreis-zylinder dient zudem als eine Art "Montage-Gelenk". Die stranggepreßte Spantverbinder (Bild 4a) haken in den inneren Kreis-zylinder der Fügestelle formschlüssig ein.

Diese Verbindungsstücke sind mit ihrem Steg am Spant über Kehlnähte verschweißt. Den Übergang zum Deck bildet eine Fußreling-Profil.
Die T-förmigen Decksprofile (Rastermaß 40 mm) haben eine Wanddicke von nur 1 mm. Sie sind nach dem Nut-Feder-Prinzip an ihren Längsseiten verklebt. Die Profile liegen mit dem unteren Flansch auf den decksbalken auf und sind mit diesen durch quasi punktförmige Kehlnähte verbunden. Das Dach des Kajütaufbaus ist ebenfalls in dieser Bauweise dargestellt; alles übrige an diesem Aufbau besteht aus (geschweißten) Aluminiumblechen. Die Wanne des Cockpits ist eine geschweißte AL-Blechkonstruktion. Die Kombination Deck, Cockpit und Kajütaufbau wiegt nur 150 kg und die gesamte Aluminium-Rumpfkonstruktion ein-schließlich dieser Baugruppe 700 kg.
Bild 4 gibt ein Stadium während der Herstellung des Bootskörpers wieder.

Der Außenanstrich der Rumpfschale beschränkt sich auf das Unterwasserschiff. Oberhalb der Wasserlinie ein-schließlich Deck sorgt eine dekorative Eloxalschicht von 25um Dicke auf den Profilen für ein ansprechendes Äußeres der "Aluminiumhaut". Damit wurde ein weg eingeschlagen, der beim Bootsrumpf aus Aluminium bisher wohl nie üblich war.

Der 3/4-Tonner "PROFILEN" mit seiner sehr leichten Aluminium-Rumpfkonstruktion hat seit 1981 mit ansehnlichem Erfolg an mehreren Regatten teilgenommen; das Boot überstand die harten Belastungen aber nicht immer unbeschä-digt (Kritikern, die es bei neuen Konzepten ja immer besonders zahlreich gibt, ist in diesem Zusammenhang der gedanke unbehaglich, daß beim Rammstoß "zwischen den Spanten" die "Klebnaht" aufreißen kann, ohne daß ein metallischer, hakender Formschluß senkrecht zur Fügestelle als zusätzlicher Sicherheitsfaktor dient).

3.2.2 Fahrtenyacht "ALUMINIA" als Beispiel für die"durch Kunststoff verriegelte" Profilbauweise

Hochseetüchtige "Profilyachten vom Typ "ALUMINIA", Bilder 5 bis 7, wurden seit 1983 in verschiedenen Größen angeboten und gebaut.
Die Daten dieser Boote sind in nachstehender Tabelle 1 zusammengefaßt.
Die Linienrisse für diese einzige in Deutschland betriebene Profilboot-Entwicklung stammen von den Bootskonstrukteuren Hein + Hübner aus Bremen.
Dank ihres niedrigen Gewichts und der Breite von 2,5 m sind diese Aluminium-Yachten trailerbar (Bild 6).

Typ der ALUMINIA	87	94	111
Länge ü.A. (m)	8,7	9,4	11,15
Breite ü.A. (m)	2,5	2,5	3,25
Tiefgang (m)	0,6/1,8	0,6/1,85	1,5/1,8
Masthöhe ü CWL (m)	11,45	11,65	15,25
Trailergewicht (kg)	1400	1800	4800
Fläche Großsegel m2	18	20	31,4
Fläche Fock m2	19	20,5	34,2

Tabelle 1

Weitere Konstruktions-bzw. Ausstattungsmerkmale dieser Bootsbaureihe sind :

- Geschweißte Bodensektion mit Kiel- Ruder- und Püttingfundamenten und teilweise integrierten Tanks

- Deckshaus als Aluminium-Profilkonstruktion, Cockpit aus Al-Blech

- Strömungsgünstiger Flossenhubkiel (Festkiel) aus Al gegossen mit isoliert angebrachtem Kielflügelballast

- Ruderkonstruktion der Kimmruderanlage als Aluminium-schweißkonstruktion

- Alle Boote mit 7/8 Rigg. Mast an Deck stehend und mit Mastlegevorrichtung einhand aufriggbar

- Die Einbau-Dieselmotoren auf Aluminium-Fundament iso-liert montiert.

Die Boote segelten ausgiebig auf Binnengewässern wie auf hoher See. Sie zeigten sehr gute Fahrteigenschaften und erwiesen sich im Korrosions- und Festigkeitsverhalten als einwandfrei. Auch eine 11m-Yacht wurde inzwischen gebaut. Gründliche Versuche an der Universität Hannover, unter anderem mit dem Ziel, die Festigkeit der mit aushärtbarem Kunststoff verriegelten Profilverbindung (Bild 8) zu bestimmen, ließen die hohe Sicherheit der Verbindung erkennen.

Kern- und Angelpunkt für eine durchdachte Profilbau-weise ist die Gestaltung des Profilquerschnitts an den Fügekanten, Bild 8, oben rechts. Diese Gestaltung ist hier für alle Profile in Schale, Deck und bei der Fußreling und für alle Profil-Rastermaße gleich.
Für die Profile wird einheitlich die Knetlegierung AlMgSi0,5 F22 (warmausgehärtet, Festigkeitswerte nach DIN 1748) verwendet. Diese Aluminiumlegierung ist vom Germanischen Lloyd als seewassergeeignet eingestuft.
Die urheberrechtlich geschützte Profilgeometrie verein-igt folgende Funktionen auf sich:

- Haut und Längsversteifung (Stringer) bilden eine Einheit (Prinzip der Integralbauweise)

- Definierte Zuordnung benachbarter Profile (Einhaken) in der Ebene wie unter einem Winkel (Bereich etwa bis 15^0) mit Hilfe einer Art "Montage-Gelenk"

- Erzeugen eines starken metallischen Formschlusses senkrecht zur Verbindung in Profilebene, um "öffnenden" Zugkräften zuverlässig entgegenzuwirken

- Schaffen eines geschlossenen Hohlraumes mit großer Adhäsionsfläche zwischen Metall und dem in den Hohlraum gespritzten aushärtbaren Kunststoff

- Zuverlässige Aufnahme von Biegemomenten in Querschnittsebene nach aushärten der Kunststoffmasse

- Schaffen der Gegebenheit, Spantverbinder auf den Stringer aufzuschieben, so daß Schweißverbindungen direkt an der Profilschale entfallen bzw. zwischen Spant und Verbinder überhaupt verzichtbar werden.

In Bild 8 bedeuten :

1. aufgeschobener und mit (3) verklebter Spantverbinder. Er besitzt im allgemeinem an einem Ende eine ausgefräste, umgebogene Lasche, die an den Spant genietet ist.
2. mit PU-Harz ausgegossener Hohlraum (Kammer).
3. an der Bootsschale höherliegendes Strangpreßprofil.
4. mit einem Steg in den Hohlraum eingreifendes Strangpreßprofil. Der Steg sichert die Übertragung von Momenten in den Aluminium-Kunststoff-Verbund.

In dem Bild werden Profile verschiedenen Rastermaßen für kleinere und größere Boote erkennbar. Die dünnwandiger Ausführung gilt für Schale und Deck kleinerer Boote bzw. Deck auch der größeren Boote. Ein weiteres Rastermaß der "leichten" Ausführung ist 45 mm. Eine "schwere" Ausführung der Profile gilt für die Schale größerer Boote. Rastermaße sind an den gezeigten Profilen: 60 mm und 90 mm. Andere Krümmungsradien als 1000 mm (stets beim kleineren Rastermaß) und 2000 mm (beim größeren Rastermaß) kommen nicht vor.

Bild 8 demonstriert unten im Querschnitt die ge-schweißte Verbindung zwischen einem Blech (z.B. der Bodenplatte) und einem Integralprofil der Bootsschale.

Die hier dargestellte Profilbauweise (System Weikert) zielt ab auf Boote von 7,5 bis etwa 14 m Länge; gleich, ob in Serie oder einzeln gefertigt. Dem Bauprinzip sind aber keine aus heutiger Sicht definierbaren Grenzen nach oben gesetzt. Es ist insbesondere nicht nur auf Segel-yachten beschränkt. Vom Standpunkt der Wirtschaftlichkeit kommt diese Profilbauweise an den GFK-Bootsbau heran, wobei der "AL-Profilbootsrumpf" (mit seinem auf die "Oberfläche Bootskörper" bezogenen Gewicht von nur 12 bis 15 kg/m^2) leichter ist als der einer üblich großen Yacht aus Massiv-GFK auf Polyesterharz (UP)-Basis.

3.3 Herstellungsablauf im Detail bei einem Aluminium-Profilboot (System Weikert)

3.3.1 Bau der Form

Bekanntermaßen benötigt man als Ausgangpunkt für die Herstellung eines Bootes eine Form, die nach dem Linienriß des Bootskonstrukturs anzufertigen ist.

Bei der Aluminium-Profilbauweise stellt man diese Form nicht wie die üblichen Formen für GKF-Boote her. Sie besteht vielmehr aus einer Mallspantenkonstruktion, wie sie im Metallbootsbau üblich ist, die Form kann aus Holz (Sperrholz) oder Aluminium gefertigt sein. Das zweck-mäßige Baumaterial hierfür hängt von der Anzahl der Boote ab, die von dieser Form abgenommen werden sollen. Für geringe Stuckzahlen bis ca. 10 Einheiten ist eine Holz-form ausreichend. Zur Herstellung der Form ist die Kenntnis notwendig, welchen Abstand die im Schifsfkörper verbleibenden Aluminium-Spantprofile haben und an welcher Stelle genau sie positioniert sein sollen. Das heißt die Lage dieser Spantprofile muß bereits im Linienriß des Bootskontrukteurs angegeben sein.

Der Linienriß wird nach üblichen Methoden auf den Maßstab 1:1 vergrößert und abzüglich der Dicke der Außenhaut auf das Sperrholz übertragen. Hiernach werden die Mallen ausgeschnitten und im richtigen Abstand kieloben auf einer sauber justierten Unterlage montiert. Dieses jedoch gehört zur normalen handwerklichen Arbeit eines Bootsbauers. Bild 9 zeigt das Mallengerust von der Innenseite.

3.3.2 Vorarbeiten für die Beplankung

Bei der Herstellung eines Schiffrumpfes aus Aluminium-Profilen beginnt man mit dem Überziehen der Holz- oder Aluminium-Mallen mit den Spantprofilen, die im Schiff verbleiben. Diese Spantprofile werden oben an der Form, also im Kielbereich des Schiffes, befestigt und von Hand über die Schablonen gebogen und unten wiederum fixiert. Danach beginnt man mit dem Anlegen des Fußrelingsprofils, das den Übergang zwischen Seite und Deck des Bootes bildet. Dieses Profil erhält vor dem Anlegen an die Form die entsprechenden Ausstanzungen für den Wasserab-lauf. Das Relingsprofil wird wie alle weiteren Profile, mit Hilfe von vorher aufgeschobenen Spantverbindern ("Knaggen") an den Spantprofilen befestigt. Die Spantverbinder (siehe auch Bild 8, rechts oben) werden an die Spante angenietet. Hierfür verwendet man Aluminium-Niete.
Sitzen die Relingsprofile einwandfrei parallel zur Bord-wand fest, wird der

Vorsteven (ein Al-Blechzuschnitt mit der erforderlichen Dicke) und der Spiegel (ebenfalls ein Al-Blech, zugeschnitten entsprechend dem Linienriß) im Winkel an die Relingsprofile angesetzt und mittels Schmelzschweißen verheftet.

3.3.3 Durchführen der eigentlichen Beplankung einschließlich des Planken-Vorbiegens

Man beginnt mit den breiteren Profilen im Bereich des Überwasserschiffs. Zunächst wird das an das Fußreling Profil anschließende Plankenprofil abgelängt und an seinen Enden auf den vorderen und achterlichen Winkel geschnitten. Daraufhin wird die erforderliche Anzahl Spantverbinder auf das Profilgeschoben, wobei auf die korrekte Einschubrichtung am Spantverbinder zu achten ist. Daraufhin steckt man das Profil in die Öffnung
(Nut) am Relingsprofil ein, und zwar achterlich beginnend. Liegt das Profil einwandfrei an den Spantenprofilen an (hier wird die Planke noch rein elastisch, und zwar um ihre Hochachse gebogen), werden die Spantverbinder sowohl am Plankenprofil als auch an der Spantprofilseite mit Metalkleber eingestrichen und an die Spantprofile angenietet, Bild 11. Am Bug und Heck (Steven und Spiegel) wird elektrisch angeheftet. Das nächste Plankenprofil montiert man in gleicher Weise, wobei es zunehmend schwieriger wird, die Plankenprofile einzupassen und zu fixieren. Als vorteilhaft erweist sich, vor dem endgültigen einsetzen der Planken einen sehr dünnen Dichtungsstreifen aus Silikonmaterial hinter den dafür vorgesehenen Vorsprung am Profil einzuspritzen. Diese Maßnahme verhindert undichte Stelle beim späteren Einbringen des PU-Harzes. Nach dem Aufplanken der erste Profile auf der Steuerbord- und Backbordseite, Bild 10 (es sollten möglichtst beide Seiten gleichmäßig, das heißt max. im abstand von 3 oder 4 Plankenprofilen hochgeplankt werden), zeigt sich, daß die Plankenprofile nich mehr einwandfrei an den Spantenprofilen anliegen. Es bildet sich ein Luftspalt zwischen Spantprofil und eingesetztem Plankenprofil, der unterschiedlich breit ist. Dies nimmt man als Zeichen dafür, daß nun mit dem Vorbiegen der Plankenprofile begonnen werden muß. Die Intensität der Vorbiegung ist im Verhältnis zur Größe des Luftzwischenraumes vorzunehmen.

Dieses Vorbiegen erfolgt plastisch "über die hohe Kante des Profils" zwar in einer einfachen 2-Rollen-Biege-
maschine, deren Rollenform der Kontur des Plankenprofils genau angepaßt ist. Der Biegeradius des Plankenprofils wird durch entsprechende Zustellung der Maschine (von Hand oder hydraulisch) erzeugt. Die Intensität dieser Zustellung der Rollen variiert im allgemeinen über der Profillänge, was derzeit von Hand (mit einige Übung voraussetzendem "Gefühl") beherrscht wird, was aber ohne weiteres auch automatisch und rechnergesteuert erfolgen könnte.
Zu erwähnen ist noch die Tatsache, daß dieses Vorbiegen nicht 100-prozentig exakt zu sein braucht. Eine (in Grenzen mögliche elastische) "Feinjustie-

rung" der Planke am Mall gleicht Abweichungen vom theoretischen Wert aus, wobei sich der (im vergleich zu Stahl) niedrige E-Modul von Aluminium vorteilhaft auswirkt.

Das Aufplanken der vorgebogenen Profile geschieht in gleicher Weise wie das der geraden, das heißt nicht vorgebogenen Profile. Der Bootsbauer wird schnell feststellen, daß die Plankenprofile immer stärker gebogen werden müssen, also immer engere Biegeradien bekommen, je weiter die Beplankung zum Kiel hin fortschreidet. Vom Bootsbauer ist vor allem zu ermitteln, ab wann die breiteren Profile (d.h. die mit dem größeren Rastermaß) durch die schmaleren abgelöst werden müssen, denn
letztere sind leichter über die hohe Kant zu biegen.
Auf alle Fälle sollte der Wechsel auf die schmaleren Profile spätestens kurz Erreichen des Unterewasserschiffes erfolgen, da diese Profil infolge der mit ihnen verbundenen engeren Längsverrippung eine größere Steifigkeit und Festigkeit des Schiffsbodens erzielen.

3.3.4 Schweißarbeiten

Die auf dem Mall oben liegenden Planken sind an die Bodenplatte bzw. das Kielschwein anzupassen. Hierdurch werden die beiden Bootshalbschalen sorgfältig erst mit dem Spiegelblech und dem Vorsteven, dann mit der Bodenplatte durchgehend verschweißt. Die Schweißnähte sind anschließend von außen zu verputzen. Bild 12 zeigt die soweit fertiggestellte Konstruktion vom Bug her und Bild 13 mit Blick auf Spiegel und Bodenplatte.

3.3.5 Einspritzen der Polyurethan-Vergußmasse in die Hohlräume der Fügestellen

Dieser Arbeitsgang erfolgt stets nach Erledigung der Schweißarbeiten. Vor dem Einspritzen der Vergußmasse in die Hohlräume der Planken an den Fügestellen ist die Außenhaut der profilschalen mit dem im Bootsbau üblichen Zwei-Komponenten-Zwischenanstrich (Farbfüller) zu streichen, und zwar dreimal. Im übrigen hatten die Planken - wie die Spantprofile - schon vor dem Einbau eine Grundierung erhalten, so daß nach aufbringen des Füllers der größte Teil der Anstricharbeit getan ist. Der Zwischenanstrich dichtet die Profilverbindung soweit ab, daß die Vergußmasse beim nachfolgenden Einspritzen nicht unkontrolliert aus den Fugen austritt. Vor dem Einspritzen werden im abstand von ca 1 m die Einspritslöcher gebohrt, was mit einer Tiefenbegrenzung am Bohrer geschieht.
Für das Ausspritzen der Hohlräume benötigt man eine 2K-Dosiermaschine mit automatischem Mischkopf, wobei ein bestimmter Mindestdruck aufgebracht werden muß. Das PU-Harz ist hinsichtlich seiner Fließfähigkeit und Abbinde-

zeit genau eingestellt und in dieser "Spezialeinstellung" nicht über den Handel, sondern derzeit nur direkt vom Hersteller zu beziehen. Injiziert wird mit der Spritzpistole so lange, bis flüssiges Harz aus der banacharten Bohrung austritt. Nach Absetzen der Spritzpistole wird die Bohrung mit einem Stopfen aus Kunststoff verschlossen. In dieser Weise verfährt man bei allen übereinander in Spantebene liegenden Bohrungen und geht dann zu den Löchern über, an denen das Harz "vom ersten Durchgang" ausgetreten ist, usw. Mit dieser Verfahrensregel stellt man sich sicher, daß die Profilkammern blasenfrei ausgefüllt werden. Für das Aushärten benötigt das PU-Harz ca. 15 stunden bei Zimmertemperatur.

3.3.6 Herstellung des Decks, Einbringen von Aufbau, Cockpit und Fundamenten in den Bootskörper

Nachdem die Rumpfschale soweit fertiggestellt ist, kan sie (nach Lösen der Spantprofile von den Mallen) zweckmäßig mit Hilfe eines Brückenkrans von der Form abgehoben werden. Danach wird die Rumpfschale in den am Brückenkran befestigten Gurten gedreht, Bild 14. Nach dem Einrichten in die Schwimmlage beginnt man die Beplankung des Decks mit Profilen in der gleichen Weise, wie sie anhand der Bootsschale bereits beschrieben wurd. Der Kajütaufbau (das Deckhaus), Bild 15, kann ebenfalls und wenigstens teilweise aus Profilen zusammengesetzt werden, ebenso das Cockpit. Beide können aber auch eine vergefertigte Al-Blechkonstruktion sein, die als Ganzes mit dem Bootskörper verschweißt wird. Selbstverständlich ist das Deck auch in Holz- oder Kunststoffausführung möglich.

Kiel- Ruder- und Maschinenfundamenten sowie die Versteifungen für die Püttinge sind in üblicher Aluminiumkonstruktion auszuführen und mit der Bodenplatte zu verschweißen. Falls dazu entsprechende Halterungen an der Profilhaut vorgenommen werden sollen sind hierfür bereits beim Beplanken entsprechende Zusatzprofile einzuschieben. An der Beplankung darf nachträglich nicht mehr verschweißt werden.

3.4 Zur Theorie der durch abwickelbare Parallelstreifen angenäherten, doppel gekrümmten Oberfläche eines Rundspant-Boot

Den Ausgangspunkt bilden Planken, deren Wandkontur im Quer-schnitt geradlinig ist bzw. angesichts der geringen Plankenbreite praktisch geradlinig wirkt (Bild 8).

Sind die Winkel, die diese Planken in Spantebene zur Nachbarplanke bilden, hinreichend klein, so entsteht der Eindruck eines insgesamt stetig gekrümmten Linienverlaufs (Bilder 7 und 8.) Die physiologische Grenze, ab der dieser Eindruck entsteht, kann aber nicht Gegenstand der folgenden Analyse sein.

Diese beschäftigt sich vielmehr mit den Grundlagen, aus denen sich vor allem die Notwendigkeit des plastischen Vorbiegens schmaler, ebener Profile um ihre "hohe Kante" (und zwar in Abwickelungsebene) ableiten läßt.

Die doppelt gekrümmte Oberfläche des Rundspantbootes läßt sich mit den Krümmungen von zwei senkrecht in einem Oberflächenpunkt schneidende Linie beschreiben; hier: Linie in Spantrichtung und Linie senkrecht dazu (das heißt etwa Wasserlinie). Diese Krümmungen sind im algemeinem von Punkt zu Punkt veränderlich. Läßt man nun in Spantrichtung den angesprochenen "Multi-Knickeffekt" (Sehnenzug mit kleinen Winkeln zwischen Nachbarprofilen gleichbleibender Breite) zu, dann läuft die Näherung der doppelt gekrümmten Oberfläche auf gebogen Parallelstreifen hinaus, die etwa in Wasserlinie-Ebene liegen und abwickelbar sind. Das heißt die geradlinige Querschnittskontur der Streifen (Planken) bleibt auch nach Anlegen an des Mallen- oder Spantengerüst erhalten, jedoch ändern sich die Krümmungsradien eines Streifens stetig über die Streifenlänge, ebenso der Winkel
(alpha), den die gerade Linie der Profilaußenkontur mit der Senkrechten bildet, Bild 16. Die so erzeugte Streifenoberfläche ist - da abwickelbar - nur noch einfach gekrümmt, ähnlich wie die Oberfläche eines Kegels. Die Streifenoberfläche ist eine abwickelbare Fläche von der allgemeinsten Art, das heißt sie stellt mathematisch eine Torse dar, bei der (anders als beim Kegelmantel) der Winkel über der Länge (s) des Streifens veränderlich ist. Das heißt, wenn man einen ursprünglich geraden, ebenen Parallelstreifen an die Kontur des Mallengerüsts etwa entlang einer Wasserlinie anlegt, so macht der Streifen je nach Lage am Rumpf gleichzeitig bis zu drei verschiedene Verformungen durch:

- Torsion um die Streifenlängsachse

- Biegung um die "schmale Kante", das heißt um die Hoch-achse des Streifenquerschnitts

- Biegung um die "hohe Kante", das heißt um die Querachse des Streifenquerschnitts.

Bei Aluminium-Planken geringer Breite (bzw. Höhe), siehe das Beispiel "ALUMINIA" ist diese Torsion und ebenso die Biegung "um die schmale Kante" problemlos rein elastisch und von Hand möglich. Gründe hierfür sind, daß sich der Winkel alpha, bezogen auf die Länge (s) nur wenig verändert, und die Torsionssteifigkeit des offenen, daß heißt keine geschlossenen Hohlräume aufweisenden Profilquerschnitts gering ist. Auch die Biegesteifigkeit um die Hochachse des Profilquerschnitts ist nur gering, wobei hinzu kommt, daß sich die Biegeradien in Längsrichtung und normal zu den Tangentialebenen am Rumpf immer als recht groß erweisen.

Dem rein elastischen Biegen um die hohe Kante werden allerdings - bedingt durch das viel größere Flächenträgheitsmoment um die Querachse des Profilquerschnitts sowie durch dessen Höhe - sehr bald Grenzen gesetzt, Bild 19, das heißt dann, wenn man sich beim Aufplanken dem Kielbereich (der Bodenplatte) nähert und dabei immer kleinere Krümmungsradien auftreten. Ab einer gewissen Grenze wird man also um die hohe Kante bleibend vorbiegen, was in der Ebenen, das heißt in der Abwicklung der Planke und damit getrennt vom Mallengerüst geschieht.

Der Einfachheit halber seien die grunlegenden Zusammenhänge hierzu am streifenförmigen Ausschnitt aus dem Mantel eines Kreiskegels (das heißt einer Torse mit .. = K = constant) demonstriert, Bild 17. Der Streifen aus dem Kegelmantel stellt überdies bereichsweise eine sehr gute geometrische Näherung dar, eben weil die Torsion eines Längsstreifens am Rumpf so gering ist.

Um einen ebenen Parallelstreifen der Länge l und Breite b in der gemäß Bild 17 gezeigten Weise einem Kegelmantel (halber Öffnungswinkel alpha) anzupassen, muß man den Streifen in der beschriebenen zweifachen Weise biegen. Will oder muß man das Biegen um den Radius R (d.h. um die "hohe Kante" des Streifens) direkt am Kegelmantel vermeiden, dann hat dieses Biegen (Vorformen) des Streifens in Abwicklungsebene als vorgeschalteter Arbeitsgang zu geschehen (Bild 17 rechts oben). Legt man die so plastisch vorgeformte "Planke" (bei Blech ein entsprechender Zuschnitt) an den Kegelmantel an, braucht nur noch senkrecht zur Streifenebene, das heißt um den Radius rho = f(y) gebogen zu werden.
Rho im Punkte P (Bild 17) ist also der kleinste auftretende Biegeradius senkrecht zum Streifen (Profil, Blechzuschnitt) und nicht etwa r.

Da P gleichzeitig auf der Linie eines Kegelschnitts liegt, der den geraden Kreiskegel in P senkrecht schneidet, stellt rho gleichzeitig den Krümmungsradius dieses Kegelschnitts in Punkt P dar. Wie sich auf rechnerischem Weise leicht zeigen läßt, liegt das Mittelpunkt des Krümmungskreises an P mit Radius rho stets auf der Achse des geraden Kreiskegels (hier Y-Achse). Dies ist unabhängig davon, ob der Kegelschnitt sich als eine

- Ellipse (bei .. < 45^0), wie hier gezeichnet
- Parabel (.. = 45^0) oder
- Hyperbel (.. > 45^0)

herausstellt. Aus dieser Tatsache folgt (sie Bild 17, oben) einmal

r = rho * cos(alpha), d.h. rho $\geq$ r

und zum anderen wegen

(rho * R)/2 = r/2 * cos(alpha) + rho * sin(alpha)

die Beziehung: 1/r + cos(alpha)/rho + sin(alpha)/R

die man auch mit:

$1/r^2 = 1/rho^2 + 1/R^2$

bzw. 1/r = $(1/rho^2 + 1/R^2)$ ausdrücken kann.

Die Gesamtkrümmung des Streifens im Punkt P ist also kappa = 1/r, die sich aus den beiden zueinander senkrechten Komponenten 1/rho und 1/R vektoriell zusammensetzt.

In erster Linie sollen uns nur die Dehnungen (ε) interessieren, die die Randfasern des Streiffens beim Vorbiegen um der Radius R erfahren. Es sei angenommen, daß unabhängig von verschiedenen Methoden des plastischen Vorbiegens (Biegen von Hand, "Breitquetschen" eines der Ränder durch Drückrollen, Streckbiegen etc.) die Mittellinie des Streifens in erster Näherung ihre Länge (L_0) beibehält, Bild 27b. Die gestreckte Länge des Außenrandes ist dann
l = l0 = δl

und damit die Dehnung der Außenfaser bei
R + b
(sie entspricht im absoluten Betrag der Stauchung l_0 - δl der Innenfaser bei R):

$\varepsilon + (l - l_0)/l) = \delta l/l_0$

Aus der Biegungen:

l0 = δl = φ * (R+b)

l0 - δl = φ * R

l0 = φ * (R+b/2)

ergibt sich ε = 1/(2 * R)/(b+1)

R läßt sich aus dem Linienriß eines Bootes über die Beziehung

R + r/sin(alpha)

ermitteln. Dabei ist r hinreichend genau der Krümmungsradius der Wasserlinie an der betreffende Stelle des Bootes und der zugehörige "halbe Öffnungswinkel des Kreiskegels", siehe Skizze nach Bild 18.

Als Beispiel für das Folgende sei der Querschnitt in Längsmitte eines Bootes vom Typ "ALUMINIA, L.ü.A. = 8.6 m, gewählt. In Bild 19 oben ist der Verlauf von r und alpha über der bezogenen Höhe Y/H aufgetragen und unten der aus alpha und r errechnete Wert für R. Ebenfalls aus dem unteren Diagramm gehen die für das (plastische) Vorbiegen der Planke notwendigen Randdehnungen hervor, wobei die Plankenbreite (Streifenbreite) b als Parameter auftritt. Deutlich werden vor allem die beiden in Kapittel 3.3 bereits angedeuteten Sachverhalte, daß

- ein plastisches Vorbiegen wegen Überschreiten der 0,2-Dehn-grenze des Werkstoffs schon vor Erreichen der Konstruktions-Wasserlinie (CWL, hier bei y = o,3H) erfolgen muß und

- der Übergang auf das kleinere Profil-Rastermaß dieses Vorbiegen sehr erleichtert.

4. Zur Langzeitbewährung von Aluminium-"Profilbooten"

Seglerische Langzeit-Erfahrungen mit Al-Profilboote haben heute etwa 10 Jahre erreicht. Die bisherige sehr gute Erfahrung mit derartigen in Deutschland gebauten Booten macht eine Lebenserwartung wahrscheinlich, die der von konventionell gefertigten Aluminiumbooten mindestens entspricht.

Das Hauptaugenmerk bei verschiedenen bisher durchgeführten, die Entwicklungsarbeit begleitenden Versuchen galt daher dem Verhalten des Bootsrumpfes beim lokalen Unfall-stoß. So wurden in Österreich bereits 1982 Vergleichsversuche an großen zylindrischen, stirnseitig durch Blech gefaßten Prüfkörpern aus GFK, Stahl, Aluminium (Blechhaut, durch Profilgerippe versteift, geschweißt) und in Al-Profilbauweise durchgeführt. Die Profilbauweise, Bild 20 (den Aufbau der Zylinderschale aus Al-Profilen mit einer Rasterhöhe von 160 mm, Legierung AlMgSi0,7, warmausgehärtet, Verbindung geschraubt und mit Kunststoff ausgegossen, zeigt Bild 20b), erwies sich dabei am widerstandsfähigsten. Sie blieb wie alle metallischen Prüfkörper jener Versuchsreihe nach der (massiven) plastischen Deformation wasserdicht.

Als sehr gut in dieser Hinsicht ist auch die gemäß Bild 8 gefügte Bootsschale zu beurteilen. Bild 21 zeigt, daß mit einem Stempel geringen Durchmessers eine eng begrenzte, direkt neben einer Verbindungsstelle der Profile liegende (und aus beide Gründen besonders ungünstige) örtliche Beanspruchung deutlich in den 48/stischen Verformungbereich hinein vorgenommem wurde. Auch hier blieb die Schale dicht. Im "Ernstfall" kann man also mit einer

solchen "Delle" weiter segeln, um später einen fähigen Reparaturbetrieb auf zu suchen, der den Schaden "in Ruhe" behebt, wenn man dies nicht gar selbst tut.
Bild 22 zeigt, wie hier optimal vorzugehen ist: man verwendet die Original-Profilabschnitte, schweißt diese (nach entfernen der Kunststofffüllung in der Fügestelle im Kantenbereich der Öffnung) ein und spritzt anschließend mit PU-Harz aus.
Die Profilbauweise gemäß dem Riegelsystem WERIS war Gegenstand von Festigkeits- und Verformungsversuche an der Universität Hannover im Rahmen eines Forschungsauftrages. Auch die heraus vorliegende Ergebnisse bestätigen die außergewöhnliche Belastbarkeit der Profilschale, ohne daß die Fügestelle undicht würden. Vielmehr erweisen sich die Verbindungen zwischen den Profilen als von größerer Festigkeit als die dazwischenliegenden Wandpartien.

5. Schlußbemerkung

Unterzieht man die bisher unternommene Entwicklungsarbeiten zur kostensparende Leichtbauweise des Bootrumpfes auf Basis des Aluminium-Strangpreßprofils einer genaueren Betrachtung - und dieser Beitrag soll ein Schritt in diese Richtung sein -, dann kann man sich schwer des Eindrucks erwehren, daß heute eine "neue Qualität im Aluminium-Bootsbau" und zwar zu erschwinglichen Preisen vor der Tür steht.

Sieht man einmal vom günstigen Preis-Leistungs-Verhältnis ab, welches das Al-Strangpreßprofil hier wie in anderen Bereichen der Technik schafft, so erreicht die Profilbauweise vor allem, daß spezifische Kenntnisse der Metallverarbeitung in einem so großren Umfang, wie vom "konventionellen" Metallbootsbau her bekannt, nicht mehr gefordet werden.

Die Al-Strangpreßprofil-Technik hat sich über Jahrzehnte soweit entwickelt, daß der Gestaltung von "integralen" Profilen, die die verzugsfreien "kalten' Fügeverfahren bei einer Metallkonstruktion ermöglichen, nur noch in der Phantasie des Gestalters Grenzen gesetzt ist. Profilquerschnitte in Breiten bis zu 800 mm, enge Toleranzen in allen Abmessungen, geringe Wanddicken, glatte, dekorativ ansprechende Oberflächen und die hohe Festigkeit der (zum Teil eigens für das Strangpressen optimierten) Aluminiumlegierungen machen das Strangpreßprofil zu einem Konstruktionselement, das heute nur wenig Wünsche offenläßt. Wie demonstriert werden konnte, läßt sich ein Profilbausystem auch den Erfordernissen einer gekrümmten Geometrie erfolgreich anpassen, wie wir sie bei einem Rundspantboot vorfinden.

6. Literatur nachweis

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6. Koser, J.: Betriebsfestigkeit von Aluminiumkonstruktionen am Beispiel eines Yachtrumpfes
Aluminium 63 (1987) 1, S. 48/52

Bild 1. "ALU QUEEN" - Entwurf Pelle Petterson

Bild 3 "PROFILEN" - Entwurf P. Norlin

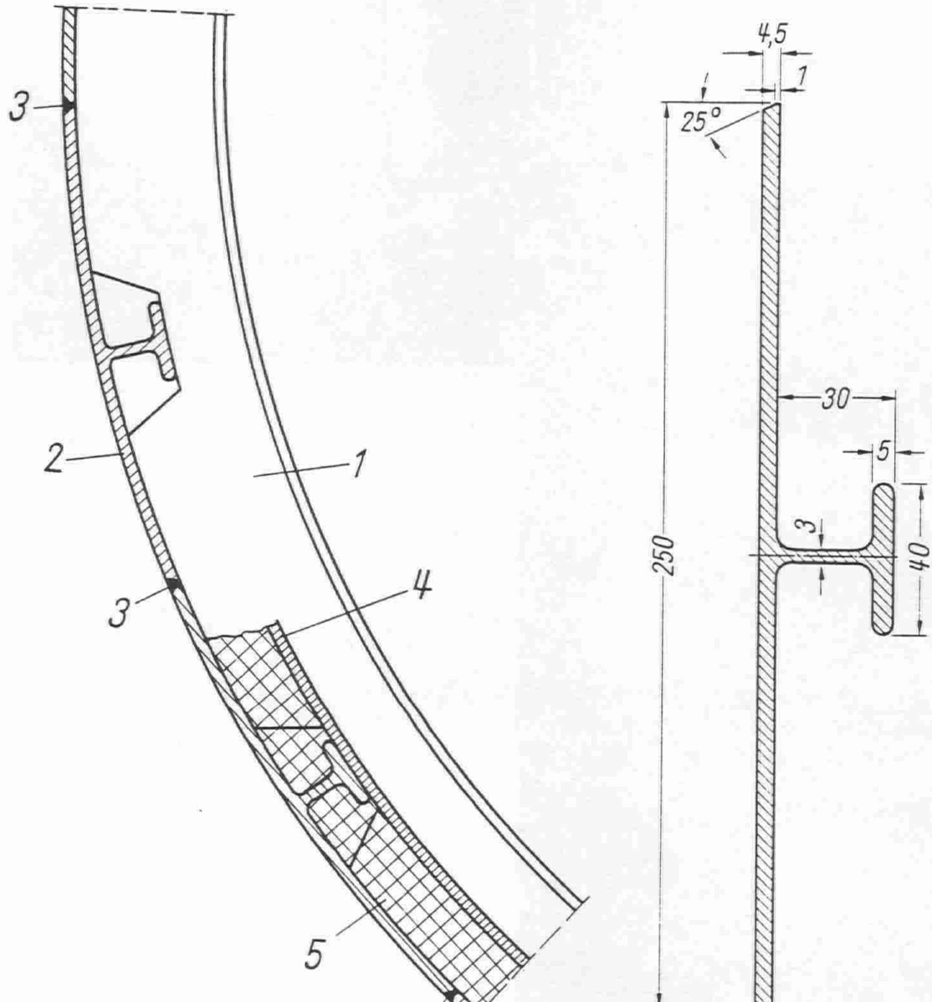
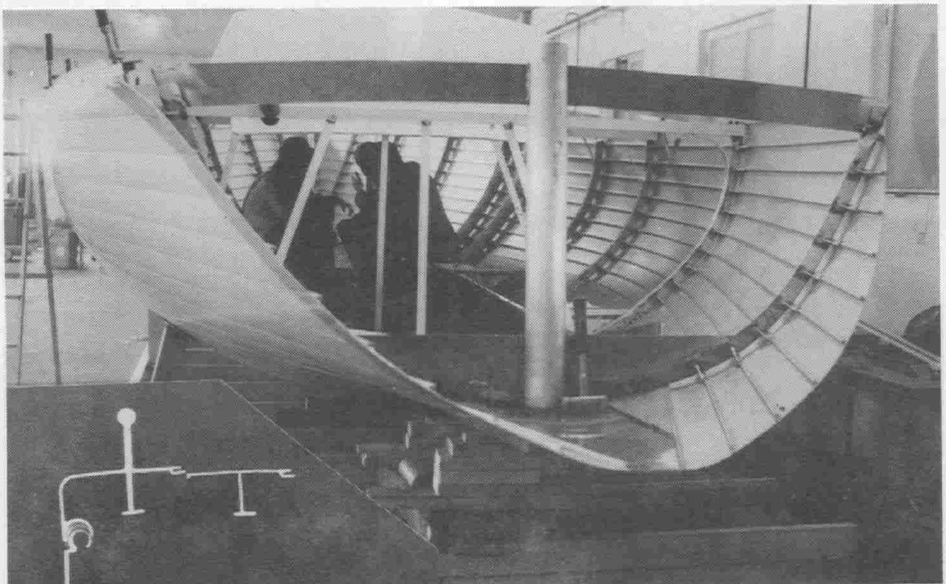
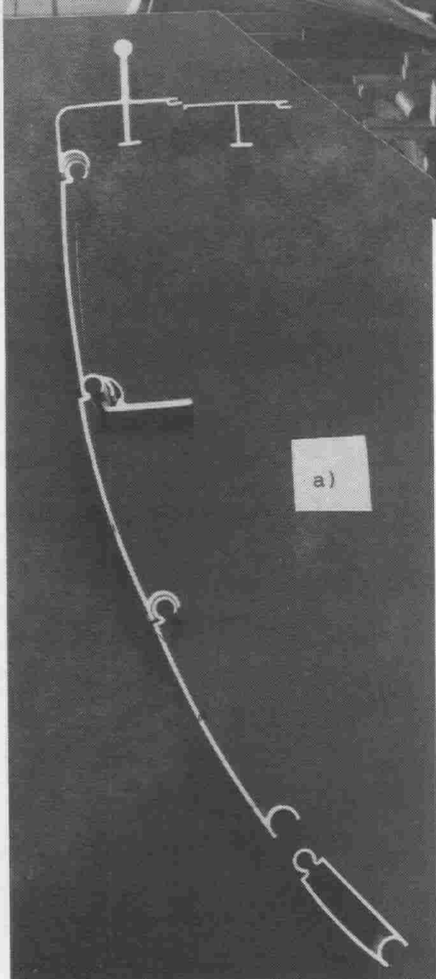
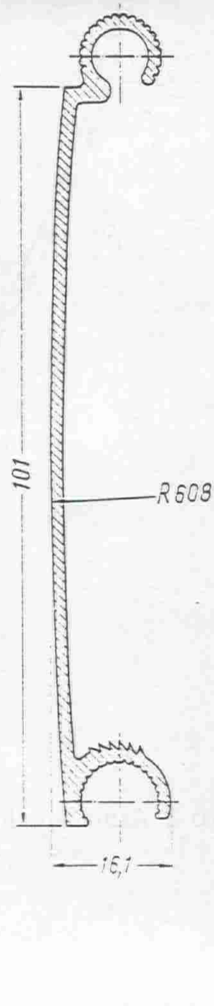


Bild 2 Aluminium Integral-Profil





"Profilen"



b)

Bild 4 Vorgeformte Aluminium Intergral-Profil

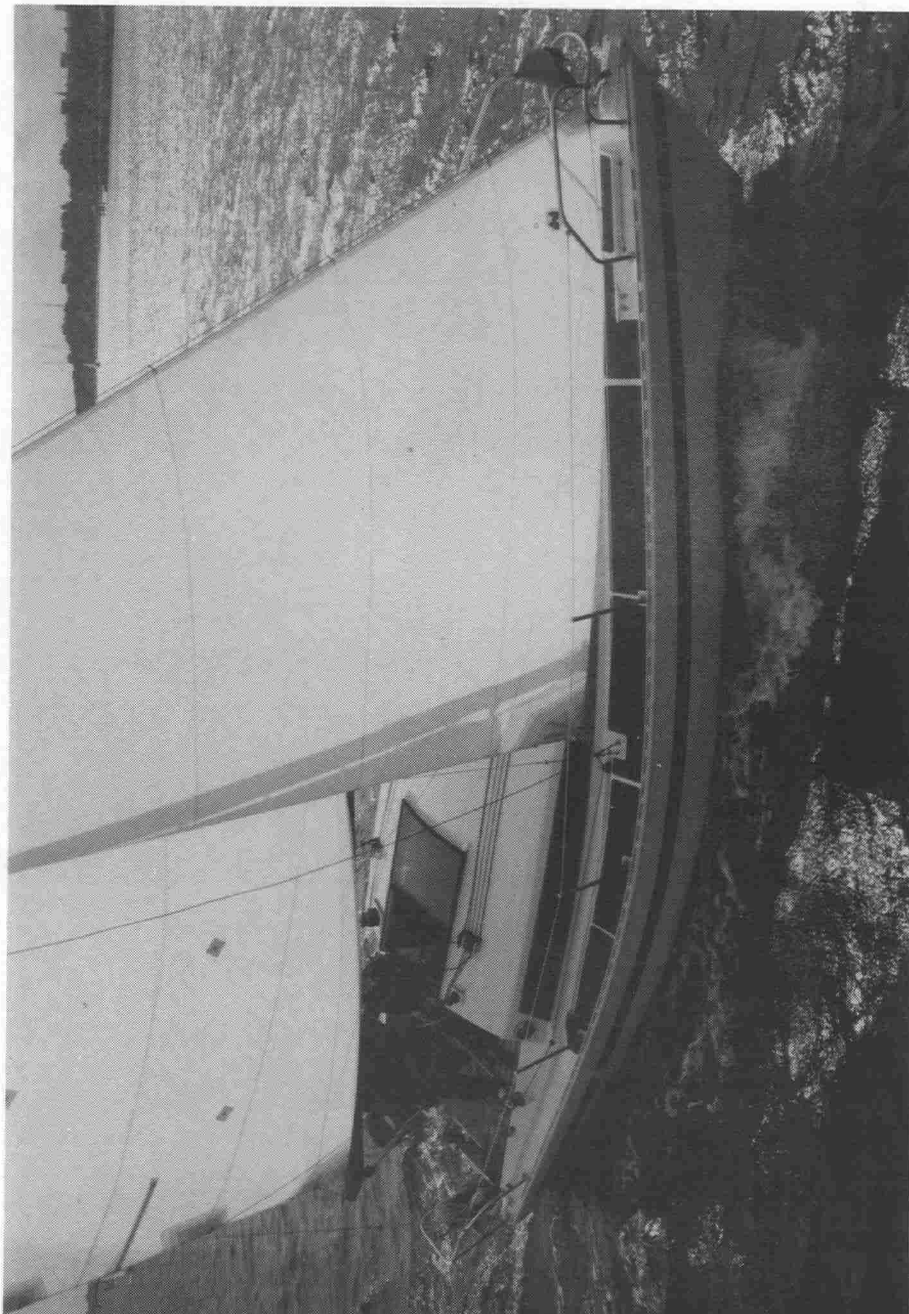


Bild 5 "ALUMINIA"

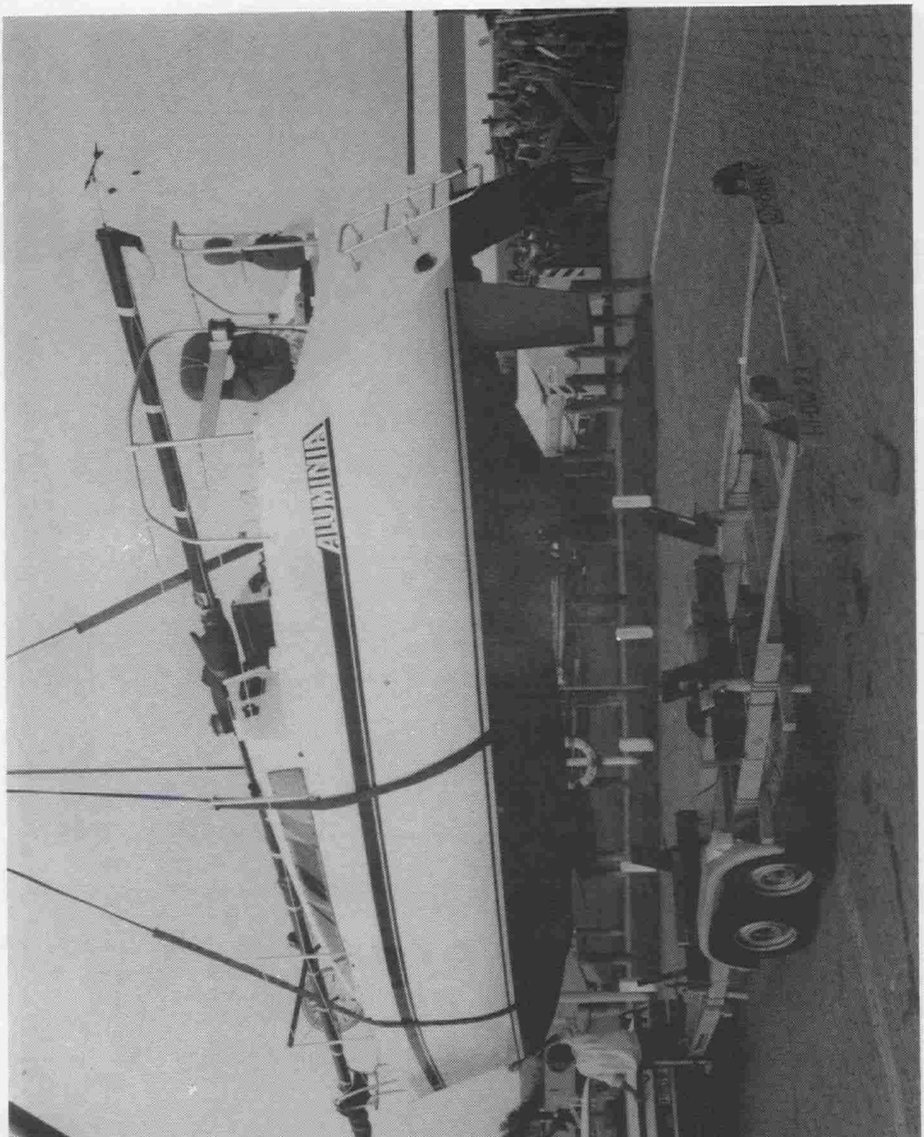


Bild 6 "ALUMINIA"

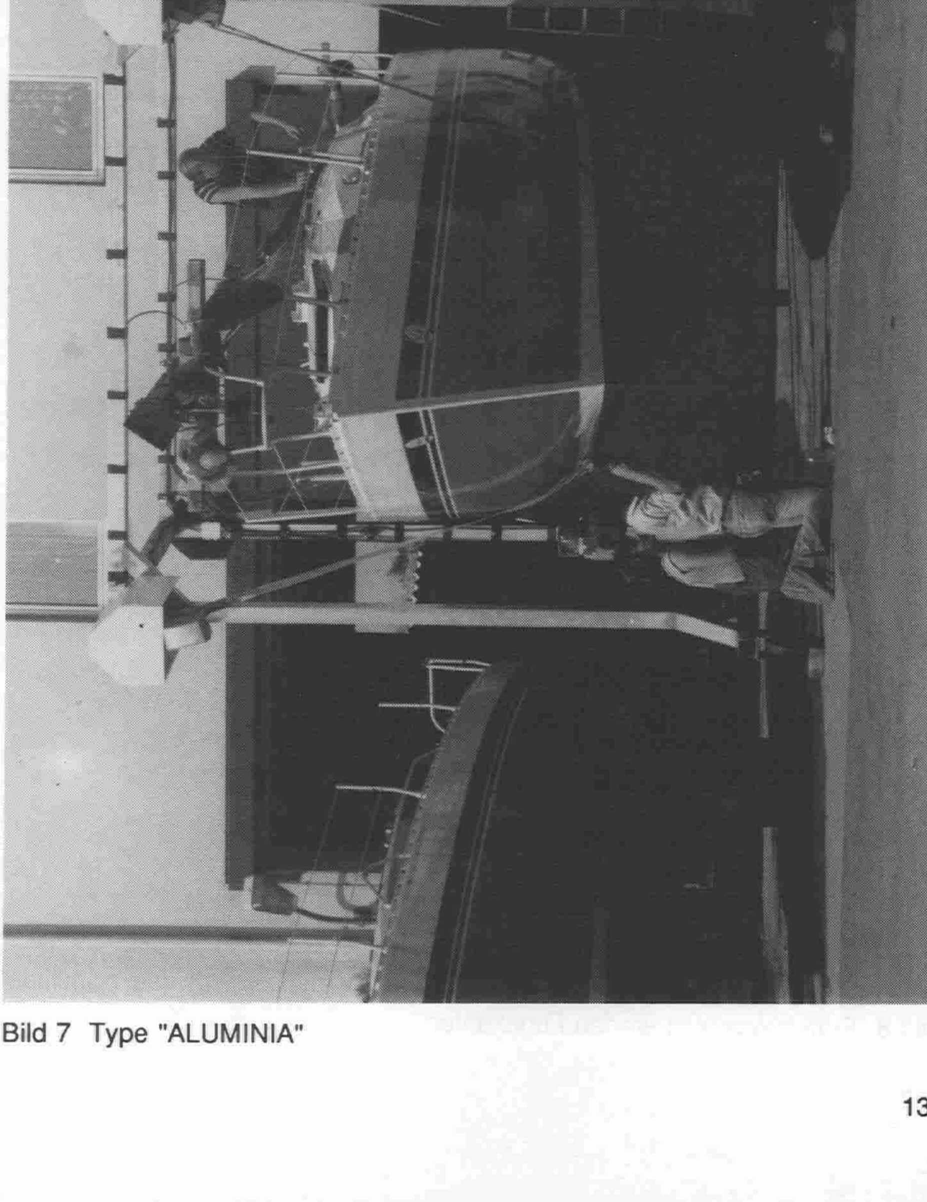


Bild 7 Type "ALUMINIA"

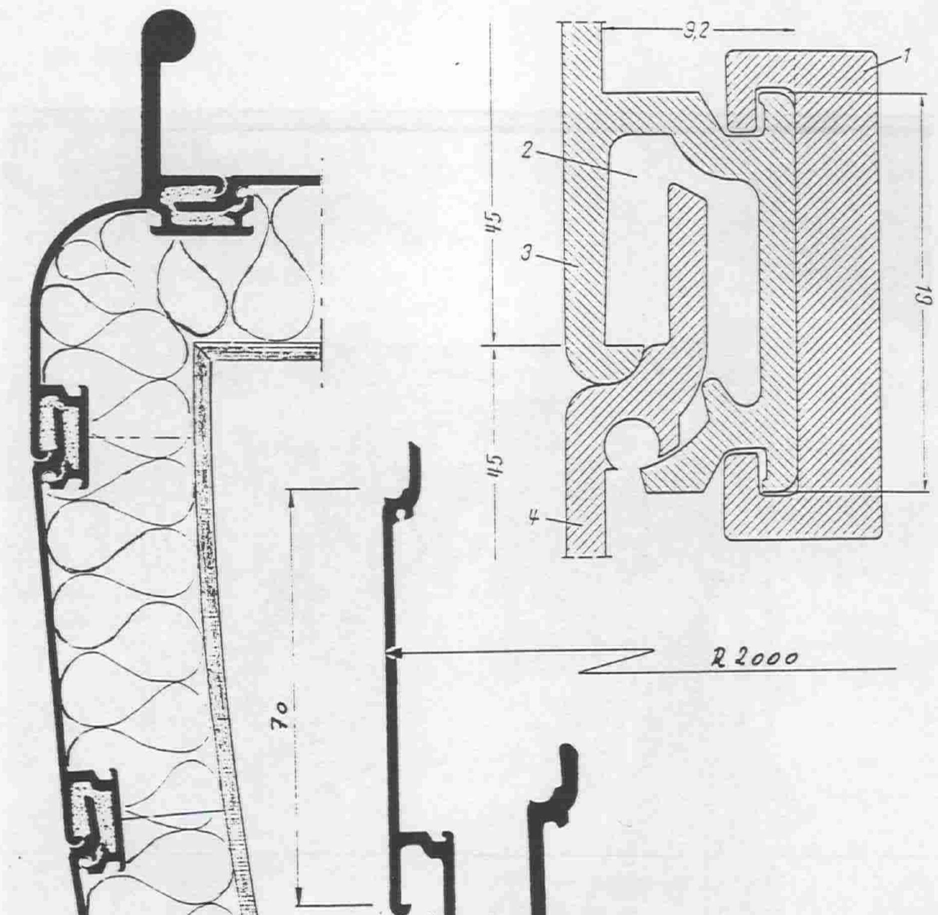


Bild 8 Profilquerschnitt an den Fugekanten

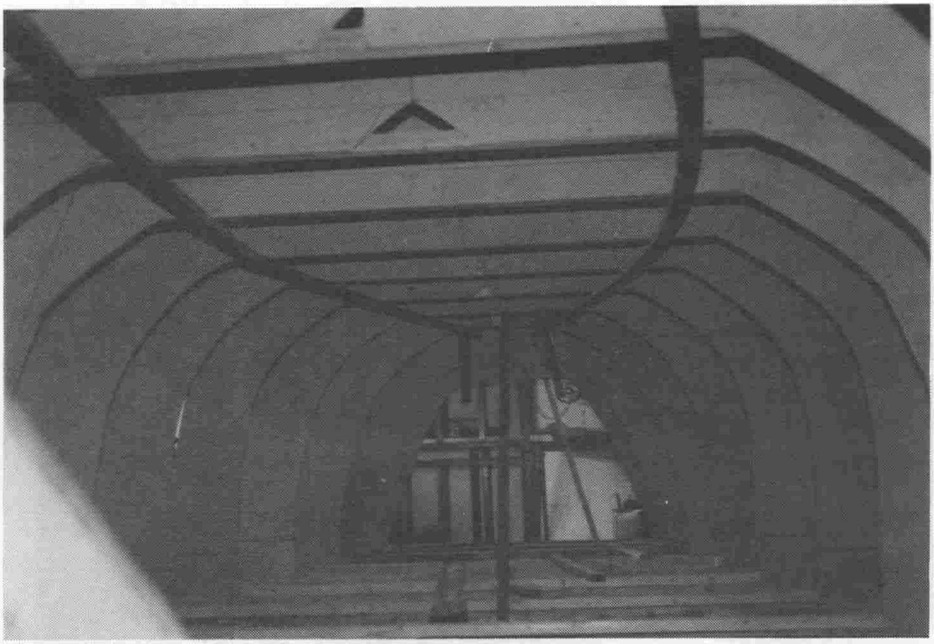


Bild 9 Mallengerüst von der Innenseite

Bild 10 Aufplanken

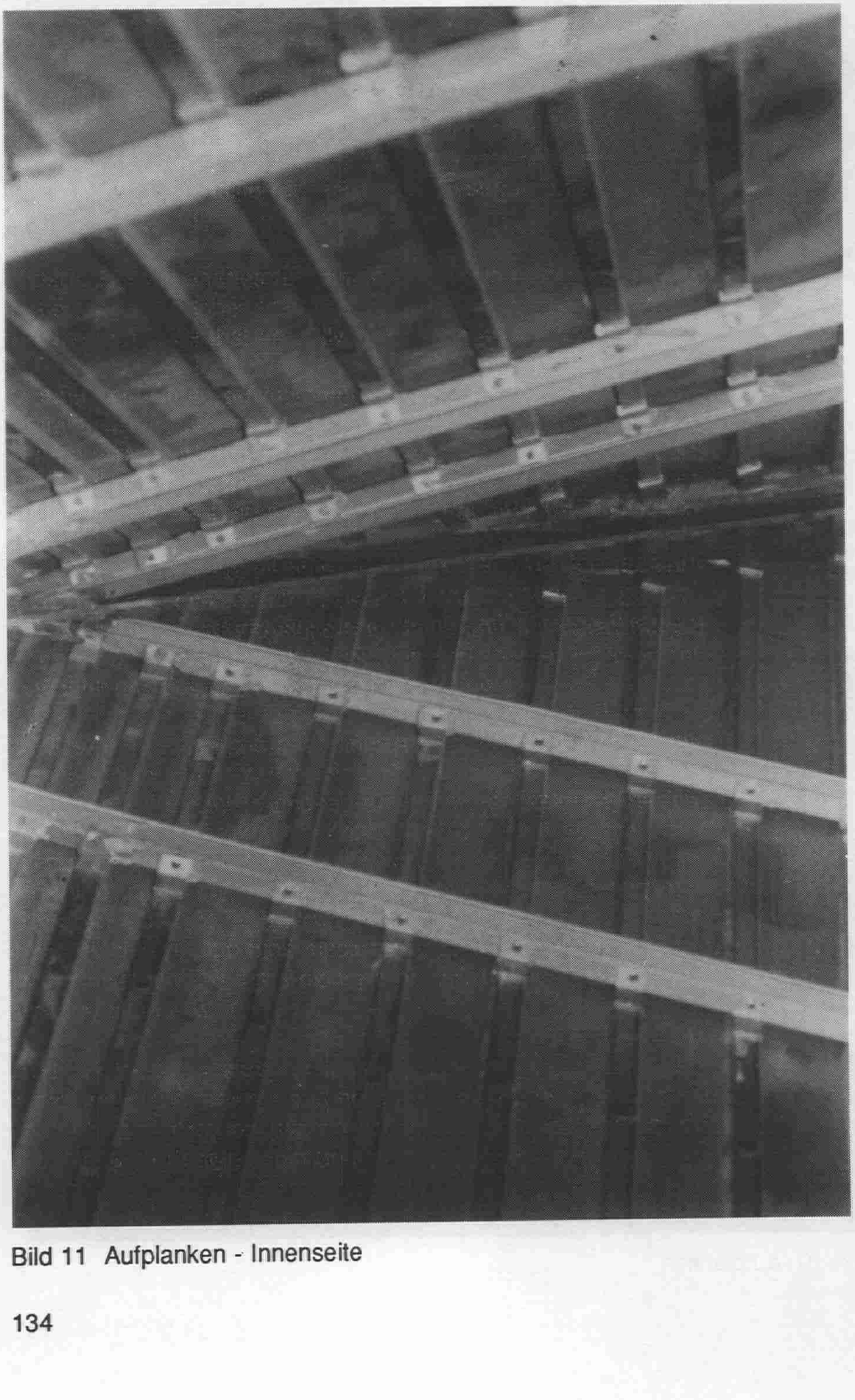


Bild 11 Aufplanken - Innenseite

Bild 12 Fertiggestellte Konstruktion - Bugseite

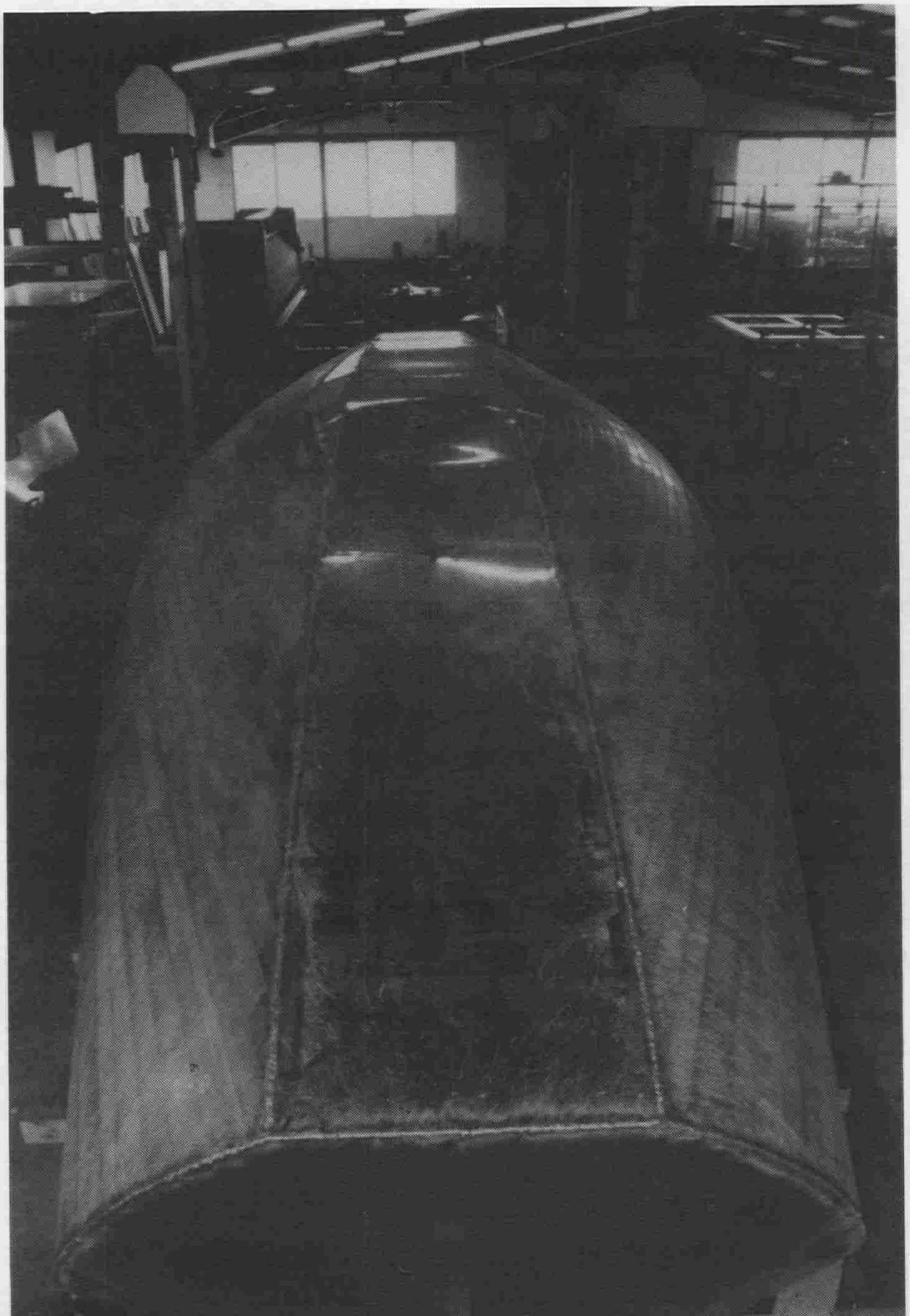


Bild 13 Fertiggestellte Konstruktion - Spiegel und Bodenplatte

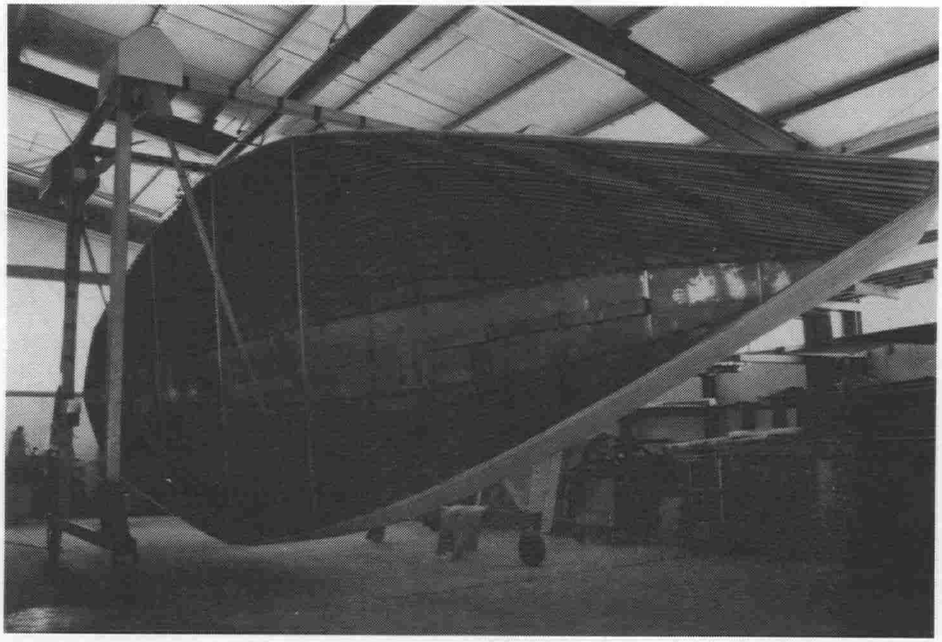


Bild 14 Drehen der Bootsschale

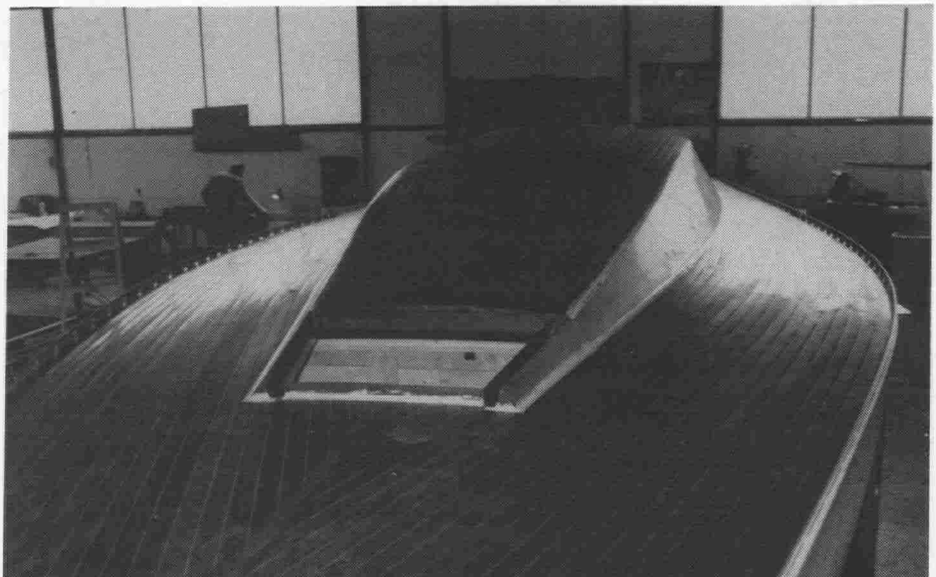


Bild 15 Kajütaufbau

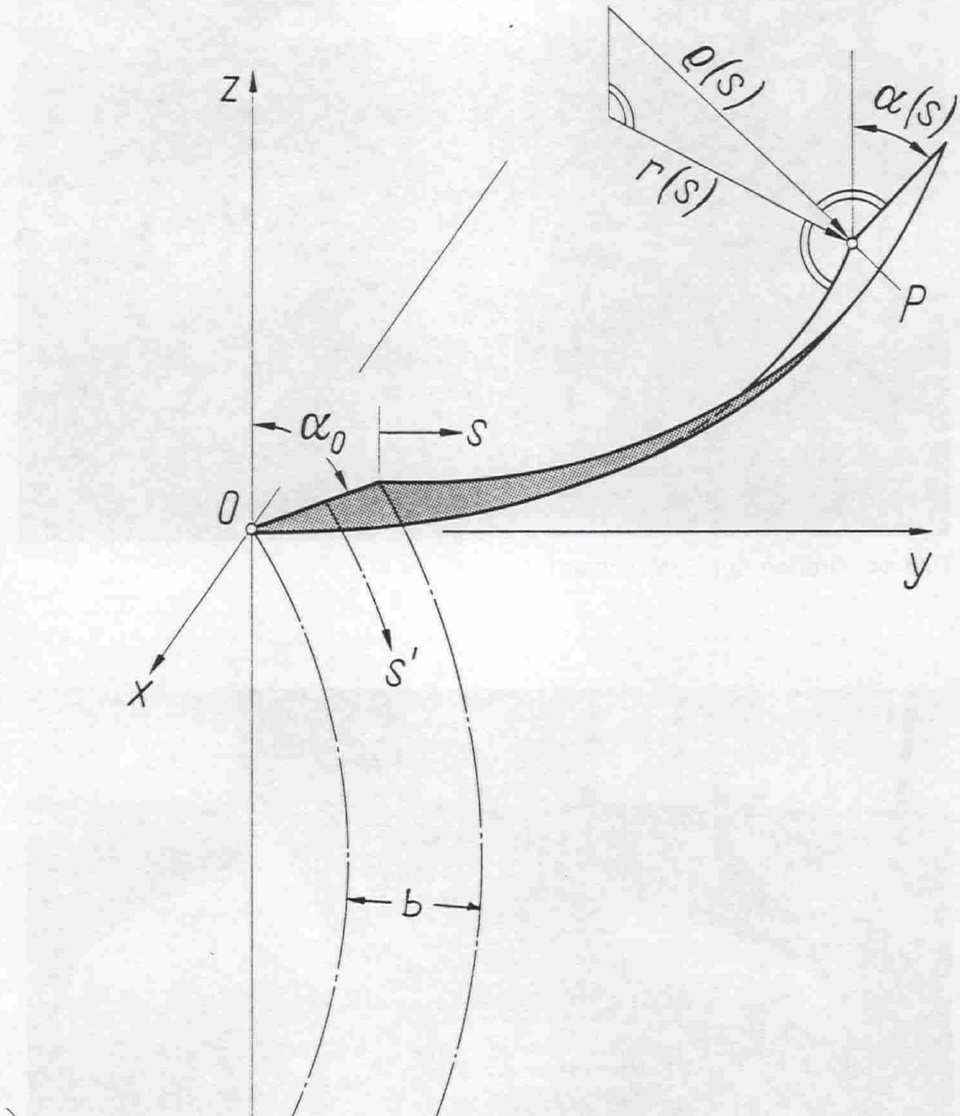


Bild 16

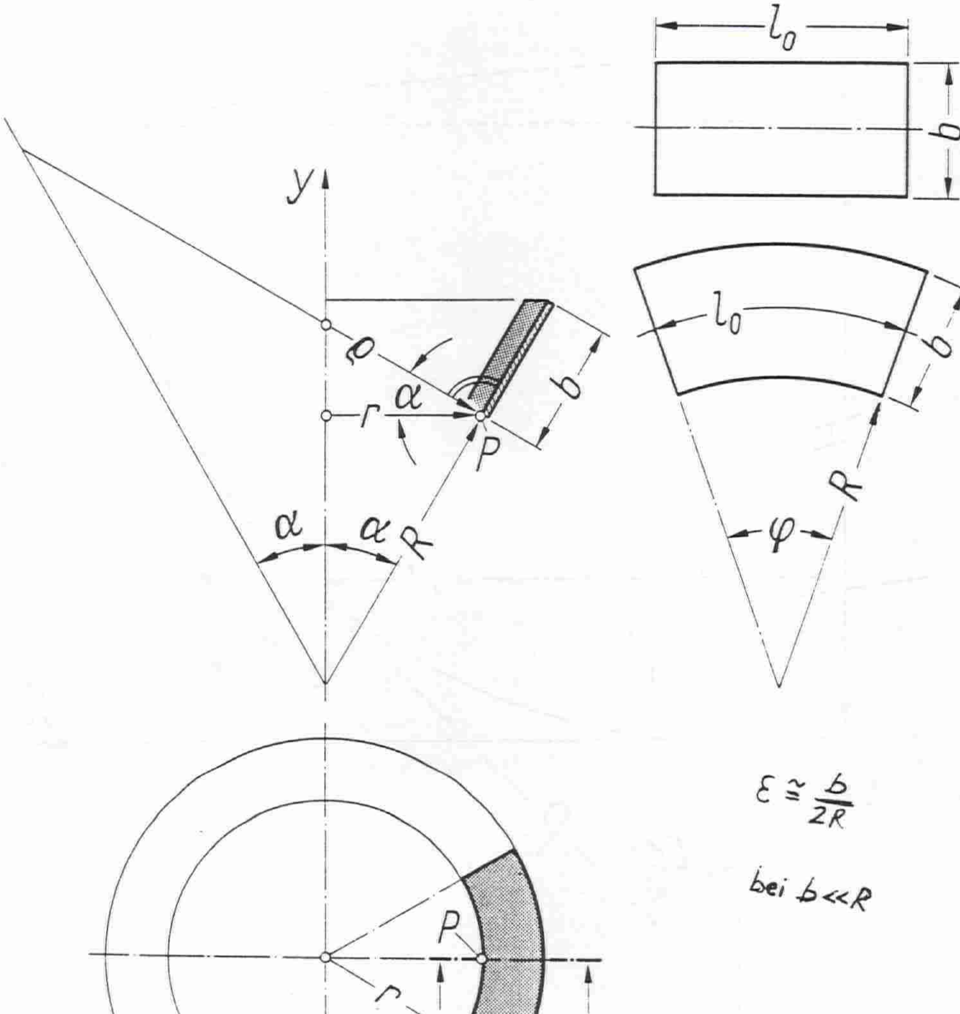


Bild 17

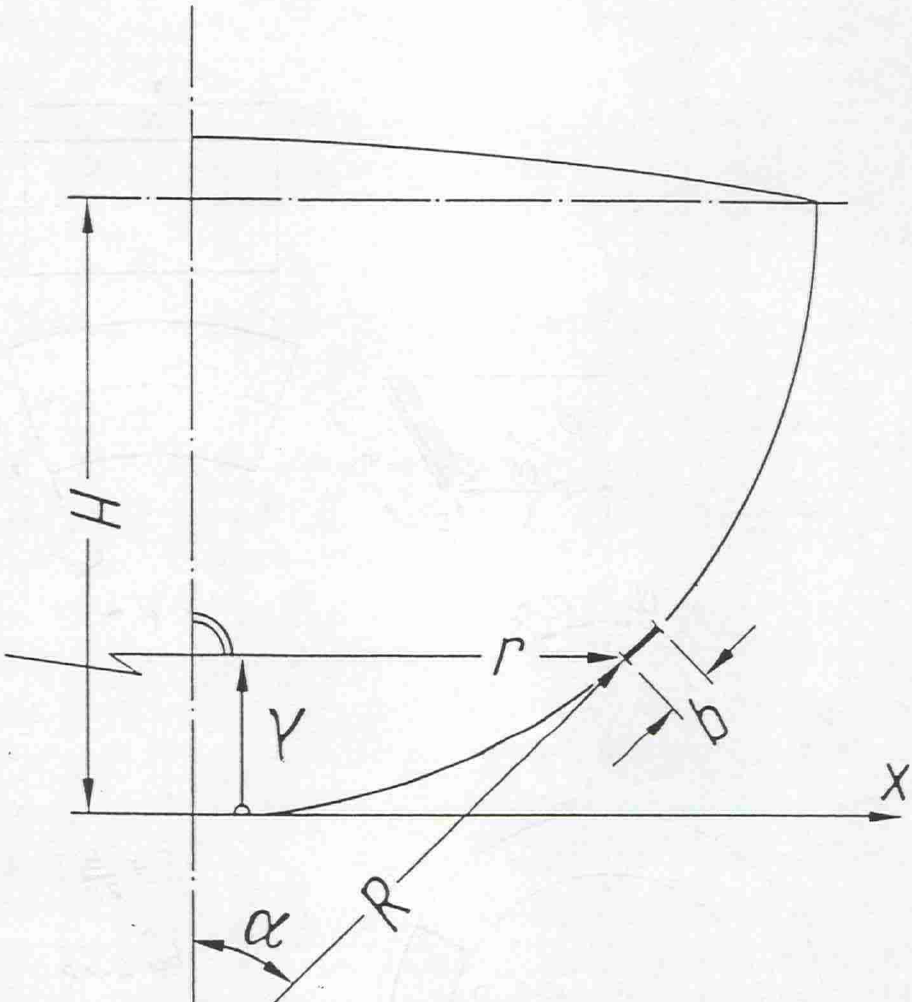


Bild 18

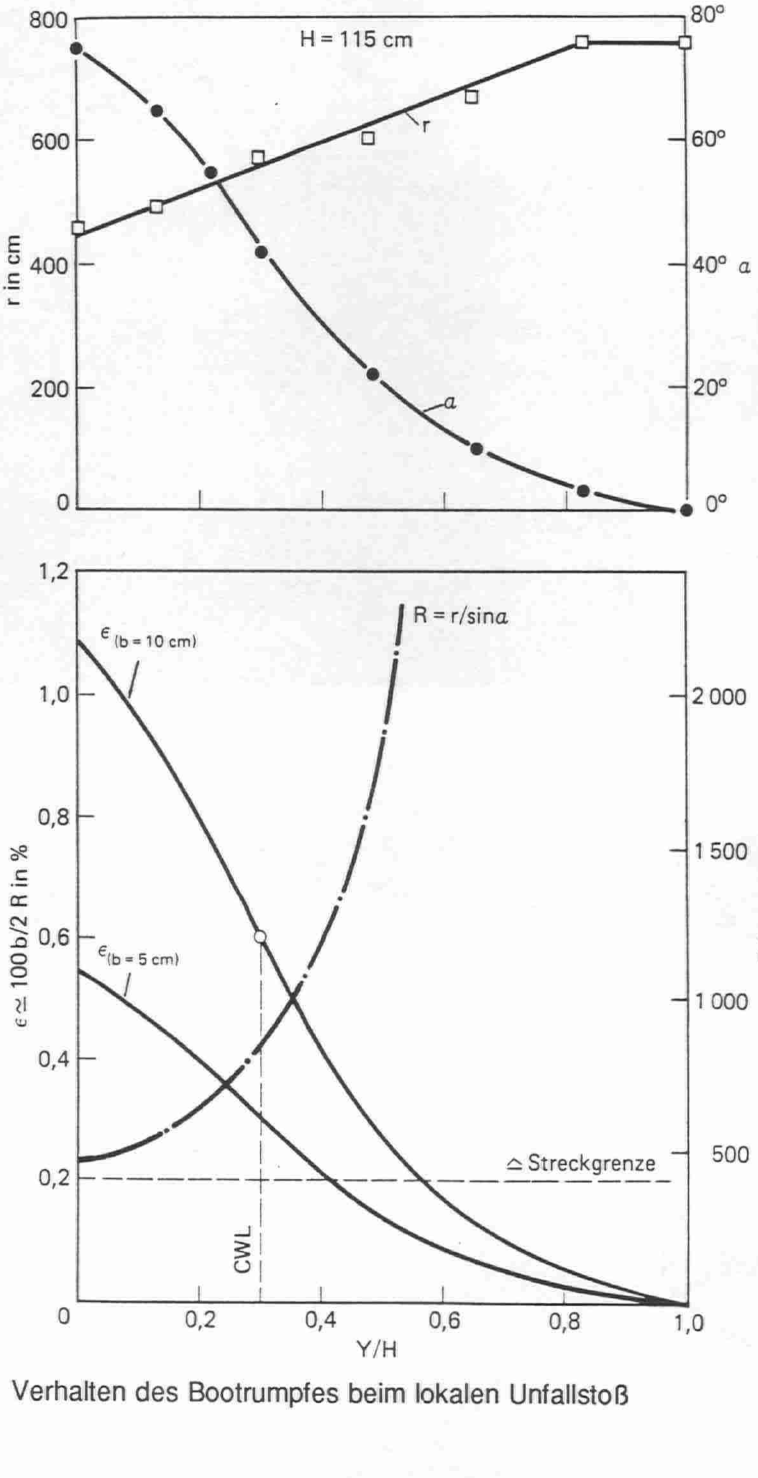
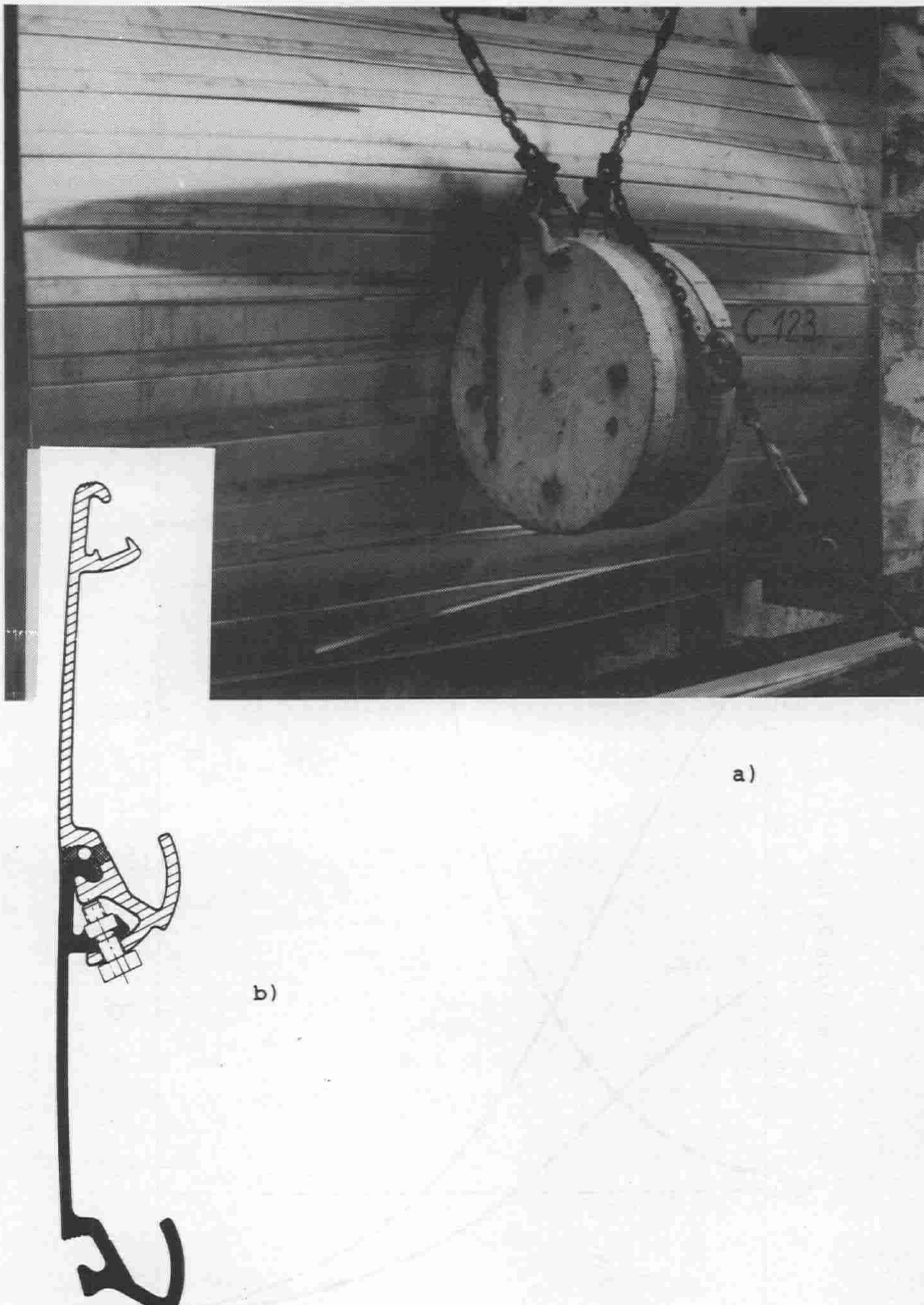


Bild 19 Verhalten des Bootrumpfes beim lokalen Unfallstoß



a)

b)

Bild 20

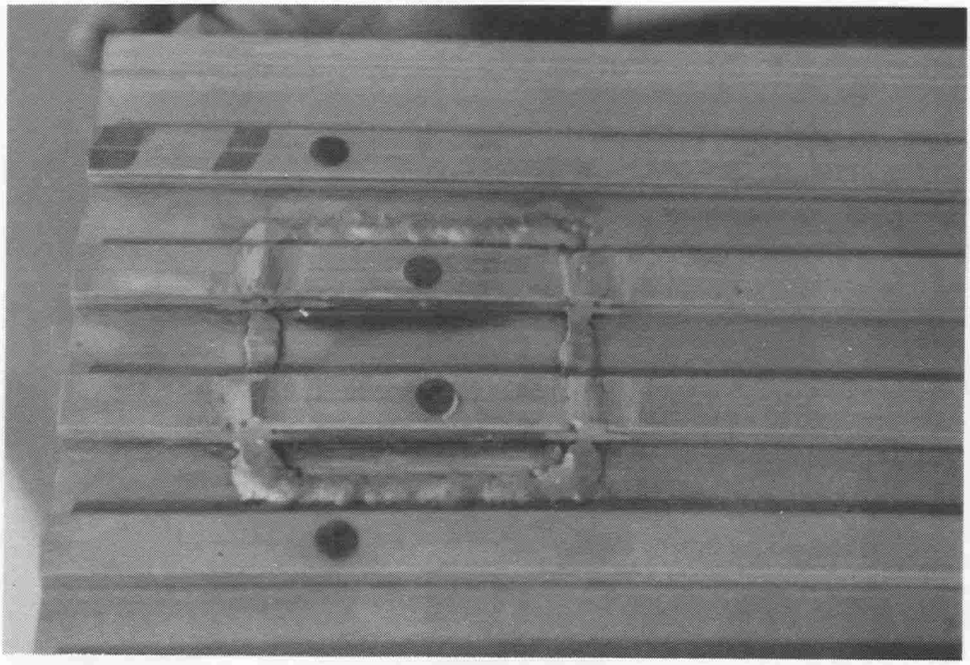


Bild 22 Reparatur

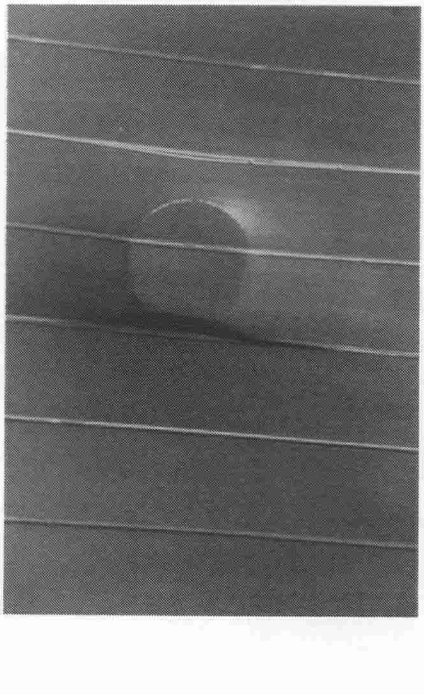


Bild 22 Reparatur

WHAT IS WRONG WITH WELDED ALUMINIUM BOATS TODAY

SOME CRITICAL NOTES

W.J. ALLDAY

With the rapid growth of the fast-ferry market there are now more aluminium vessels in service than ever before. The size of the vessels is also increasing rapidly with 74 m catamarans in service and new ones of 100 m and more planned.
Aluminium is a well established boatbuilding material, the main marine constructions alloys being basically unchanged since the 1930s and welding techniques having been steadily refined since the 1940s.

It has been described as the ideal boatbuilding material and, while this might be a little exaggerated, it has many properties to recommend it for high speed craft in particular.

The marine alloys, primarily the 5000 series alloys such as 5083 in Europe and 5086 in the United States and the 6000-series alloys, 6061 and 6082, are easily welded using well tried techniques and equipment and give no significant cracking problems either during welding or due to stress corrosion.
They have good corrosion resistance, even when immersed in salt water and are tough and ductile with excellent strength to weight ratio.

With the wealth of experience available in the design, build and operation of high speed aluminium craft, why are we still hearing of problems with cracking, corrosion and weld quality?
Let us consider these problems one at a time.

The problems with cracking are almost without exception due to fatigue. It takes a very incompetent designer to produce a construction that fails due to static loads and the impact resistance of an aluminium structure is such that it will takes a very large impact without the metal fracturing.
Because of its high strength to weight ratio, aluminium is mostly used in vessels where light weight is of critical importance. Its position in this field is being challenged by the advanced composite materials and it is almost as if a race has been developed between the proponents of these materials to

produce the lightest structure in the pursuit of speed.

This search for minimum weight now seems to have passed the point at which safety is jeopardized, with increasing problems with cracking in aluminium and some fairly drastic delamination in composite craft.
The most common cause of fatigue in aluminium hulls is construction and propeller and machinery induced vibration.

To prevent fatique occuring to start with you got to get the design loadings correct but equal important to that you got to get the details right, because that are these details that more often than not destroy a well planned design. A lot of common welded details have an extremely low fatique resistance.

If you consider a fabricated I-beam, often seen in yacht-building where the hullplating forms one flange of the I-beam itself. A fabricated I-beam made from strips with continuous fillet welds could be considered having a resistance against fatigue of 100%.
If this is manually welded i.s.o. automatic welded with stops and starts the fatigue strength drops to 73%. If you make it with intermittend fillet welds, which is quite common in boat construction to reduce buckling the strength reduces further to 66% and if it is made with scallops between the intermittend welds, which seems the Classification Societies very fond of, the fatigue strength reduces to 56%.
If you start welding non load carrying fillet weld onto the edge of the beam and you keep away from the edge the the fatigue strength drops to 56%.
If you start on the edge of the beam it reduces right down to 41% of the original.
Boats are full of details like this. Their are longitudinals and webframes, interconnecting and you have got flanges welded together. all these reduces the fatigue strength drastically. At least butt welds should be full penetrated.
Most of the Classification Societies are far more concerned about buckling then they are about fatigue.
The designs to prevent buckling is full of little brackets, tripping brackets and all such of things.
All these little brackets are disastruous for fatique. Besides that they give high stress concentrations.
During fitting out cable trays, pipe clips etc. are added and with these new stress concentrations are introduced.
The designer should specify oin the drawings where the highly stressed locations are, so the buoilder has no excuse he doesnot know what he is doing in the construction.

When large, powerful, diesel engines, driving large propellers through long shafts, are installed in a light weight structure, there are many possibilities for forced and resonant vibrations in the structure of sufficient magnitude to cause fatigue failure.

Great care needs to be taken at the design and building stage to ensure the structure supporting these rotating masses is sufficiently stiff and massive to prevent any chance of resonance and that the rotating masses themselves are not prone to torsional and other resonances.
The propellers can subject the surrounding structure to large pressure pulses, which are often the cause of cracking in the adjacent bottom plating.

Much time and expense is often spend on isolating the passenger compartment from machinery noise and vibration, even to the extent of floating the entire superstructure on isolation mounts.
If this is considered necessary, then it is also surely necessary to isolate the hull structure from these same destructive forces.
Usually the only sure way to prevent these fatigue cracks is to reinforce the structure, using thicker insert plates in way of the propellers and shaft logs, for example.
This, however, adds weight and if it means the loss of revenue from one of two passengers or drop of one half knot in maximum speed or a small percent increase in fuel consumption, these tend to take precedence.

There are ferries running in which the plating above the propellers has to be repaired at frequent intervals with considerable loss of revenue and repair costs, but the stiffening up of the structure is not considered, due to the increase in weight, equivalent to about two passengers.
They normally carry a greater weight of water in the bilges due to the leaks!

Other areas in high speed craft that are prone to cracking are the slamming areas forward and the cure is the same.

Fatigue cracking should not be a mayor problem if the repetitive loads are carefully assessed during the design stage and the structure designed to reduce the stress levels below those likely to cause fatigue.
Attention should be paid to the elimination of stress raisers, to the continuity of the structural members and to the quality of construction.
None of this is new but it is surprising how often this is forgotten.

A properly designed structure will probably, but not certainly, be heavier than some of today's troublesome craft, but the increased reliability in service will pay for itself in many ways.

The corrosion resistance of the marine aluminium alloys in sea water is excellent when used by themselves and quality material of the correct alloy and grade is specified and used.

It is only when other metals are introduced that problems can arise with galvanic corrosion. The use of other metals should be avoided wherever possible, and it is surprising how many other metals, traditionally used on boats can be eliminated with a little thought and planning at the design stage.

It will never be possible to eliminate all non-aluminium metals, but some thought can reduce the likelihood of galvanic corrosion to a large extent.
Copper alloys are one of the main culprits, but they can be removed from their traditional position in sea water systems and valves by turning to the chemical industry.

This industry manages to contain chemicals much more aggressive than salt water at much higher pressures than those normally found in boat systems by the use of valves that are fully compatible with aluminium.

Careful selection of materials and well thought out insulations between aluminium and other metals should reduce corrosion to negligible proportions, but care must be taken that poorly carried out maintenance does not negate all the original precautions against galvanic corrosion.
Once again there is nothing new here, just the applications of well-tried principles.
There should be no problem in producing good quality welds in aluminium. The MIG process, which is used for the majority of the welding on marine craft, has been around since the 1940s and has been refined into a process capable of producing first class welds in aluminium, provided certain simple and well documented precautions are taken.

MIG welding equipment is now available in a wide variety of types and sophistication.
It is most important to choose equipment suitable for the job in hand, which meet not be of the most sophisticated type, but it is well worthwhile purchasing good quality.
It is sad that many companies think nothing of investing many thousands or tens of thousands of pounds in cutting and forming equipment, but will not buy anything but the most basic of welding equipment.
It is the quality of the welding that can make or break the reputation of a welding fabricator.

The photographs show sections and nick breaks (where a short length of weld is weakened by sawing into the reinforcement and breaking open through the wakened plane to reveal internal defects) taken from a critical weld in a 30 m aluminium boat. There were over 15 m of critical weld of this quality.
The builder was not a small lowcost yard, but one well known for the building

of large aluminium vessels.

The defects visible in the photographs include lack of fusion, lack of penetration, gross porosity and mis-alignment, all defects likely to greatly reduce the fatigue strength of the welded joint.

The course of this unfortunate state of affairs are many.

The worst lack of penetration is where there is now weld on one side, the inside of the joint, as shown in photo 3.
In this position there was inadequate access for the welding torch to allow a weld to be made on the inside.

Many people contributed to the occurrence of this defect. The designer had no option for geometrical reasons in calling for the welding of a joint without access for making the inside welds, however, he should have paid attention to it on the drawings and specified a permanently backed butt weld with the appropriate edge preparation.
The limited access should have been noticed at the planning stage and the correct weld preparation and procedure called for. The welding supervisor should have noticed it and the welder should have called the supervisor's attention to the fact that he could not weld the inside. Finally the inspector should have seen it and called for a repair.

The other defects can be caused by a combination of lack of supervision, lack of welder training and inadequate inspection.

The welding of aluminium is no more difficult today then it has ever been. In fact many people consider it easier to weld than steel. It is just different and a different approach is necessary.

The important considerations for making good aluminium welds are:

a Cleanliness, the removal of oil, grease moisture, and the oxide film from the vicinity of the weld is vital.
b Preparations: the correct edge preparation and fit up for the joint is critical.
c Joint access: MIG-welding torch is bulkier than a stick electrode and access to the welds must be considered at the design and planning stages.
d Welder training: welders must be trained and tested on the configuration of joints they are going to weld. Unqualified welders should not be allowed on the job.
e. Inspection; Inspection standards are much too poorly defined.

Contracts often contain clauses to the effect that welding should be "to the highest commercial standard", whatever that means.
Even classification society standards are littered with such undefined phrases as "to the surveyors satisfac-tion", "adequate" and "to a satisfactory standard". Such standards only lead to arguments about what quality is actually required.

The MOD (Navy) manages to lay down a weld inspection standard that specifies the level of defects that can be allowed for structures for differing service environments.
Why can there be no international weld standard for aluminium passenger ferries that lays down precise quality requirements?
Everyone would then know what they were trying to
achieve. The surveyors could still be given the initiative to relax the rules, for instance, where repairs were likely to cause more defects than they would remove.

After 40 years of welded aluminium boat constructions the industry is still suffering from the same old problems. One of the main reasons for this is the lack of trained welding engineers in the industry.
Often large welded boat fabricators have no one in management with any welding qualifications or experience.
With luck the foreman will have welding training and experience but all too often the welder is the only one with any qualifications and:
who will then supervise him ?

BS/AA	ISO	Mg	Si	Mn	Cu
5154A	AlMg3,5	3,1-3,9	-	0,1-0,5	-
5454	AlMg3Mn	2,4-3,0	-	0,5-1,0	-
5086	AlMg4	3,5-4,6	-	0,2-0,7	-
5083	AlMg4.5Mn	4,0-4,9	-	0,4-1,0	-
6082	AlsilMgMn	0,6-1,2	0,7-1,3	0,4-1,0	-
6061	AlMg1SiCu	0,8-1,2	0,4-0,8	-	0,15-0,4

Table 1 Specification of the Main Marine Aluminium Alloys

BS = British Standard

AA = Aluminium Association

ISO = International Standards Organisation

Description of Joint	Configuration of joint	Relative Strength
Fabricated I-beam, continuous fillet welds, no stops or starts		100 %
Fabricated I-beam, manual weld with stops and starts		73 %
Fabricated I-beam, a. Intermittent fillet b. With scallops		a. 66 % b. 56 %
Non load carrying fillet welds > 10mm from edge of member		56 %
Non load carrying fillet welds on edge of member		41 %

Table 2 The relative strength of some welded joints

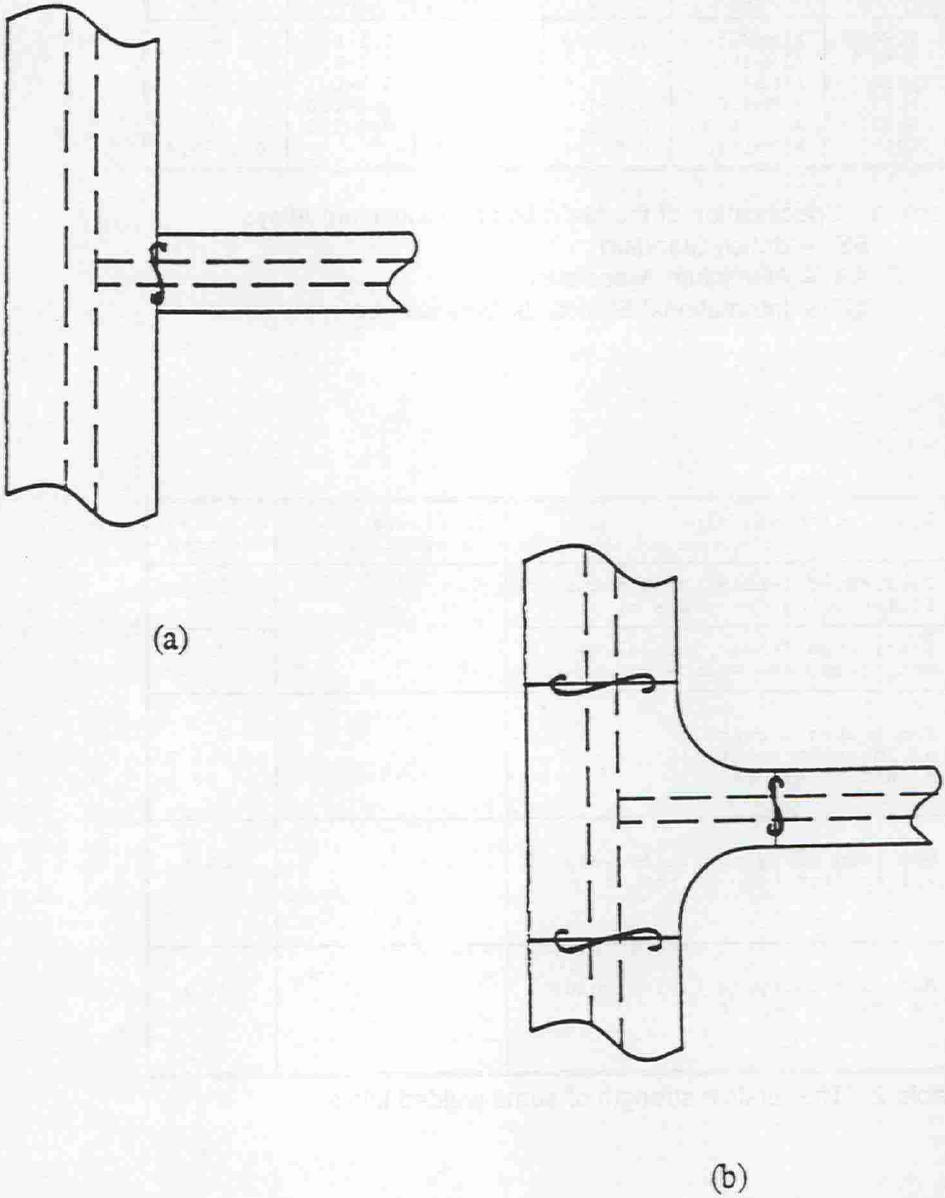


Figure 1
Bad and good methods of joining the flanges if two I-beamsubject to fatigue loading.
Relative strength (a) 47 %, (b) 100%

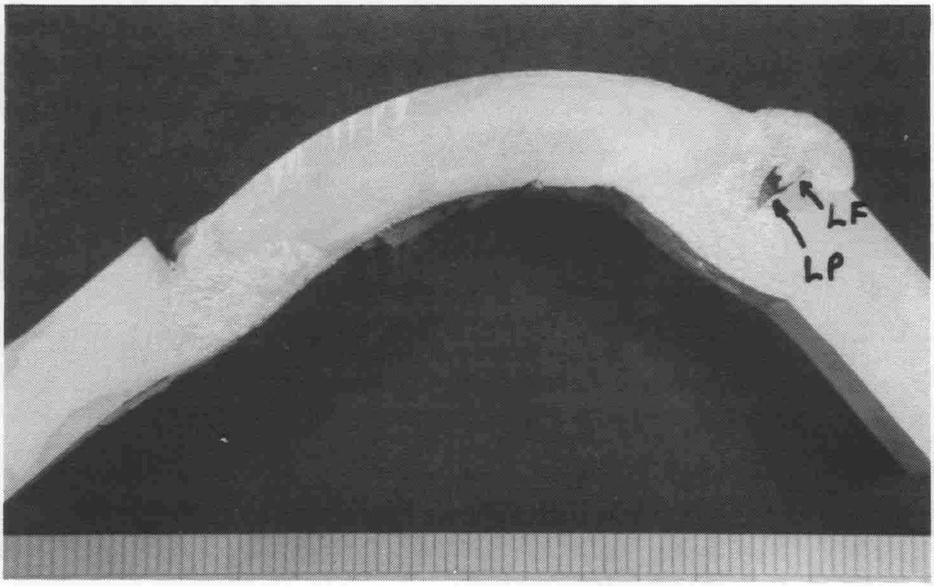


Figure 2
A section through two butt welds. The weld on the right contains lack of fusion (LF), of penetration (LP) and a cavity.
The weld on the left has been welded from one from one side only due to lack of access to the other side. It contains lack of penetration, lack of fusion and misalignment. Plate thickness 10 mm.

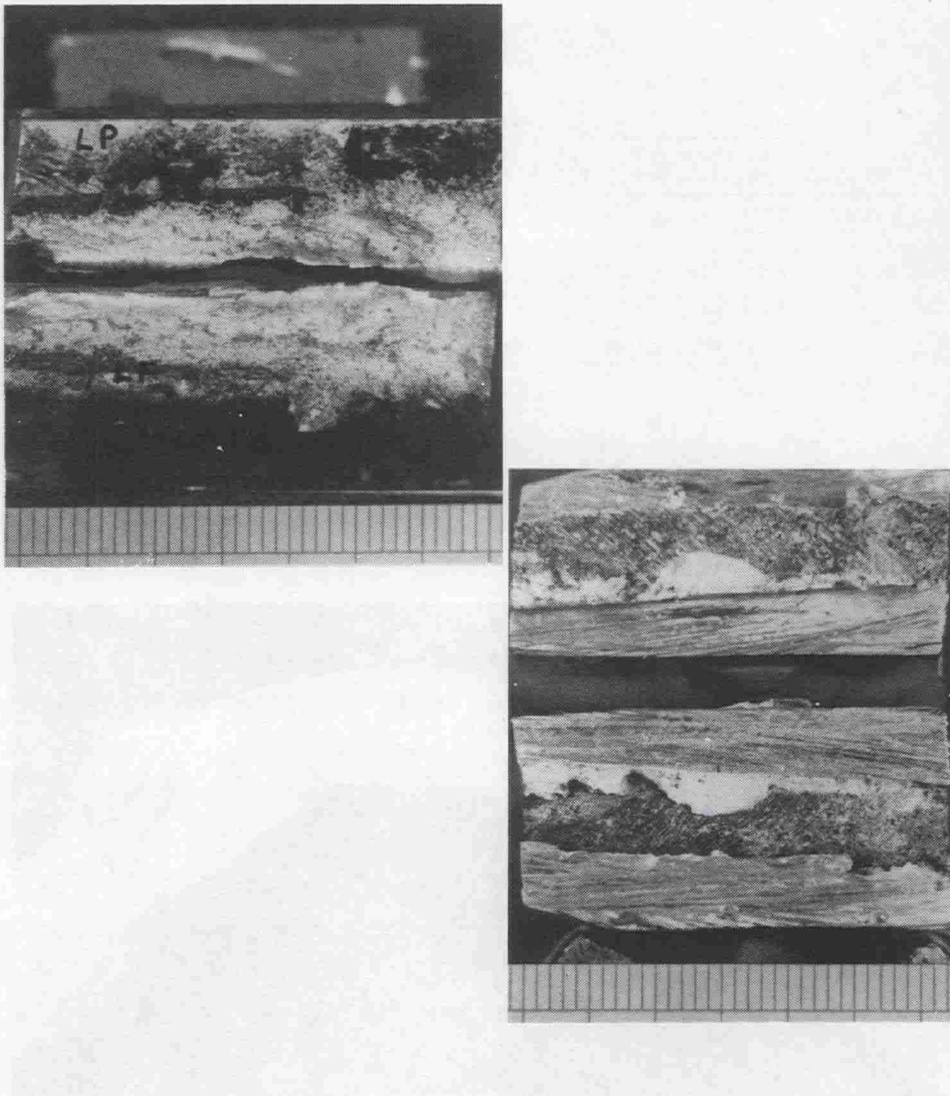


Figure 3 Nick break samples taken from the welds adjacent to those shown in figure 1.

a) Left hand weld with lack of fusion (LF), lack of penetration (LP). No saw cuts were needed to break this sample.

b) Right hand weld with lack of fusion and penetration. The saw cuts (S) made to break the sample can be seen at top and bottom.

Corrosion of Aluminium in Sea Atmospheres

Hubert Wetzel

Alusuisse

Table of Content

1. Introduction

In the following we will explain something about the chemical stability respectively corrosion behaviour of aluminium - in particular in sea atmospheres.
At the end of the paper you should see which aluminium alloys are best for the use in sea atmospheres.
For a good understanding let first have a short look on:
- what is corrosion?
- what forms of corrosion are possible?
- what is the difference between a manifestation of corrosion and a corrosion damage.

Then there are some examples of how to minimize corro-sion problems with only little changes in the corrosion.

2. What is Corrosion

As to be seen on figure 1 corrosion is the reaction of a material resulting in a measurable change of this material. (figure 1). This reaction can lead to a protective passive layer or to a manifestation of corrosion without damage.
In the worst case the metal is substantially attacked. Here we have a corrosion damage, because the function of the part is not given anymore.

In this sense we must always remember that the definition of corrosion includes both the environment and the metal aluminium.
Accordingly, the corrosion resistance of aluminium
varies with the environment, and is not a fundamental property of the metal, as is specific gravity, tensile strength and electric conductivity.
Since the corrosion resistance depends on so many environmental factors as for example temperature, humidity of the air, raining frequency and durance, environmental pollution, salt content of the air etc. corrosion resistance will never be a simple property value you can find in a catalogue.

3. Forms of Corrosion

Corrosion can occur under different forms.
In very strong electrolytes - for example sodium hydroxide - aluminium is corroded by a uniform attack.
If there are halogenides present - especially chloride as the most common halogenoid - the form of corrosion will be pitting corrosion. An example how pitting corrosion looks like in the cross section is to be seen in figure 2.
Based on distinct metallurgical conditions, some alloys reveal other forms of corrosive attack such as intergranular corrosion, stress corrosion cracking (SCC) and exfoliation corrosion, shown in the figure too.

As regards these types of corrosion the attack follows the grain boundaries or segregation bands which are electrochemically different to the bulk material. If they are anodic, that means the bulk material is nobler, only the grain boundaries are corroded.

The difference between intergranular corrosion and SCC is that in the case of SCC a mechanical stress is needed in addition to start the corrosion.

The particular danger with intergranular corrosion and SCC is, that they can occur without obvious corrosion products resulting in a sudden breakdown of the corroded part.

While all aluminium alloys can be corroded in a uniform, pitting or trough-shaped manner, only a few can be susceptible to intergranular corrosion and only the zinc- and/or copper containing alloys can be susceptible to SCC and exfoliation corrosion, when they get the wrong thermal treatment.

Competent aluminium manufacturers have the knowledge to produce even this high-strength alloys in a condition which guarantees resistance to SCC.

After this general look on what corrosion is, we will have a closer look on the corrosion behaviour of aluminium.

4. Corrosion of Aluminium

4.1 The Aluminium oxide layer

It is appropriate to start a report on the corrosion behaviour of aluminium with a discussion of the surface film of aluminium oxide, for it is the properties of this film that provide aluminium with its resistance to corrosion.

When a fresh aluminium surface is created and exposed to air, it oxidizes rapidly, and acquires a compact, adher-ent, protective film of aluminium oxide (common termed alumina) which tends to resist further oxidation. On a fresh rolled aluminium sheet the film is extremely thin -about 2.5 nm, a tenmillionth of an inch.

Aluminium oxide is relatively inert, and it is this inactivity that the good corrosion resistance of aluminium depends on.
When the oxide film dissolves, as it does in the pres-ence of certain chemicals, dissolution of the metal occurs (i.e. the metal corrodes uniformly). Alternatively, when the film is damaged under condition that present normal self-healing, localized corrosion ensues.
This corrosion may take the form of pitting or intergranular attack, depending on the circumstances.

In figure 3 the oxide film is stable over a pH range of about 4.5 to 8.5

However, the pH value alone does not determine the solubility of the film, because the presence of certain anions and cations, as well as negative hydroxide (OH) and positive hydrogen (H) ions, exerts an influence. For example, aluminium is rapidly attacked in sodium hydro-xide solutions not far from the neutral point (pH 7), whereas it is resistant to ammonium hydroxide even at pH 13.

Other exceptions include the resistance of aluminium to concentrated nitric acid at Ph 1 and glacial acetic acid at pH 5.

Because of the thinness of the natural oxide film and its non-crystalline nature its composition and structure and the influence of alloying ingredients on its morphology and properties are very important for the corrosion behaviour.

The normal air-formed surface film on aluminium consists essentially of amorphous aluminium oxide (AL203) in various degrees of hydration (AL203-xH20), depending on its history, especially the conditions of relative humidity and the temperature of formation.

On aluminium alloys that contain magnesium the film may contain magnesium oxide (MgO) in an amount proportionally larger than the percentage of magnesium in the alloy, with the result that its resistance to acidic solutions is lowered.

The resistance to slight alkaline solutions - like seawater -, however, is increased.

5. Atmospheric Corrosion

When aluminium is exposed to a moist atmosphere or is immersed in water, the oxide film becomes thicker.

The rate of growth increases with temperature and humidity.

Most aluminium alloys have excellent resistance to atmospheric corrosion and consequently aluminium is widely used for structural and architectural purposes.

Figure 4 shows a typical corrosion rate curve for aluminium in the weather.

Initially the rate of corrosion is relatively rapid, after which it decreases to a very low and almost linear value.
The shape of the curve is similar whether the amount of corrosion is measured by weight loss, depth of pitting or loss of tensile strength.

The aluminium requires no protection from weather, or protective maintenance.

The originally shiny surface changes with the time and becomes dull, grey (like stone) or even black (in some smoke pollutes city atmospheres).
If it is desired to retain the initially bright surface, a protection is necessary like anodizing (that means thickening the natural oxide film) or coating with organic films.

5.1 Types of atmospheres

In the corrosion technology atmospheres are usually classified as rural, industrial, marine or marine-in-dustrial, although it should be realized that these are generic types only, and that there are wide variations in the corrosivity within one kind. (figure 5).

5.1.1. Rural atmospheres

In rural atmospheres, the corrosion of aluminium is hardly detectable.

5.1.2. Industrial atmospheres

In industrial atmospheres most aluminium alloys have good corrosion resistance, although the acid condition on the surface due to sulphur from burned fuels does produce pitting and surface roughening.

5.1.3. Marine atmospheres

In marine atmospheres

Pure metal AL99.5	(AA 1150)
AlMn	(AA 3003)
AlMg	(AA 5754, AA 5083)
AlSi	(AA 4083)
AlMgSi	(AA 6061, AA 6063, AA 6351)

exhibit good corrosion behaviour, and some are widely used for superstructures on boats, ships and oil platforms. (figure 6).

Alloys that contain more than about 0.5% copper have a rather poor resistance to corrosion in marine atmo-spheres and requires surface protection to avoid corrosion.

6. Corrosion in sea water

Aluminium was first used for marine craft by both Jackson and the Wellman Artic expeditions of 1894 in the form of sledges and aluminium boats.
In 1895 for example the aluminium-hulled yacht "DEFENDER" won the International Cup Race.
Some of the early examples suffered extensive corrosion due to unfavorable alloy composition (for example AlCu6 alloy) or galvanic corrosion, which were not well understood at the time.

From 1930 to 1938 an English firm built 139 crafts of Al-Mg alloys. The 55 ft cruiser "DIANA II" was over 50 years and the 65 ft patrol craft "INTERCEPTOR" was over 30 years in service in sea atmospheres. In figure 7 is shown the weight losses of plate specimen in sea water.

Easily is to be seen that pure aluminium, the Al-Mn, the Al-Mg and the Al-MgSi alloys exhibited good corrosion resistance.

The weight loss of mild steel was up to 100 times higher as for aluminium alloys.

There is a negligible thinning due to uniform corrosion and the bulk weight loss corrosion rate amounts to less than 5 micrometer per year (0.2 mpy) or one-twentieth that of mild steel in seawater.

Corrosion takes the form of pin-point pitting.

A typical maximum pit depth over 5 years would be 1.2 mm (50 mils).

Marine fouling does not promote the corrosion of aluminium alloys; on the contrary, there is some evidence to suggest that it is actually protective.
AlMgSi alloys (AA 6061, AA6063) are somewhat less resistant to seawater. The density of pitting is higher, the pits tend to be larger.
However, there is no general thinning and the weight loss corrosion rate is in the order of 12 mm per year (0.5 mpy).

The stronger aircraft alloys (Al-Cu) and Al-ZnMgCu) types) have rather poor corrosion resistance to sea water, and in the unprotected state a 6 mm (0.25 in) plate will perforate in a few years.

The available information clearly indicates that selected aluminium alloys, especially the Al-Mg alloys have a high degree of resistance to corrosion by seawater, even submarine structures built of them will have a long service life.

7. Galvanic corrosion

As mentioned is of particular importance with the use of aluminium in sea atmospheres that there is no contact with any nobler material

Figure 8 shows the galvanic series of metals. The metals above aluminium are less noble, the metals below are electrochemically nobler than aluminium. When aluminium is in sea water in contact with a dissim-ilar metal other than Mg, Zn, Cd, or CR in the presence of on electrolyte, it tends to corrode more rapidly than it would if it were exposed by itself to the same environment.

Zn tends to protect aluminium, while Cd and Cr are almost neutral.

Ti is the next best, then stainless steel, steel, and then lead.

Copper, nickel and their alloys should be avoided.

The same negative influence have cobalt, tin, mercury, silver, gold and platinum, but these alloys are not very common in the industry.
Antifouling paints as well must not contain copper or like in former times even mercury!

The severity or galvanic action depends on the corrosion current density at the anode surface, and this, in turn, depends on several factors in addition to the degree of separation in the next table, which shows the galvanic series of metals in sea atmospheres. (figure 9).

The influencing factors are for example

- Electric resistance of the metal path and in the solution: the higher the resistance the lower the galvanic corrosion is
- Cathode/anode area ratio:
  the bigger the anode and the smaller the cathode the lower is the galvanic corrosion current

An aluminium rivet in a steel sheet, for example, (figure 10) will be soon consumed. A steel rivet in an aluminium sheet accepts only a small amount of current which is trying to flow from a large area of aluminium.
Thus there is less total corrosion and very much less loss of aluminium.

8. Crevice corrosion

Crevice corrosion is of practical importance for thin metal parts or - in cases surface appearance is important -. The production of bulky corrosion products in a confined space can exert a strong disruptive force and lead to the distortion of assemblies.

In the figures 11 - 15 can to be seen how constructive details will lead to crevice corrosion and how crevice corrosion can be minimized with small changes in the construction.

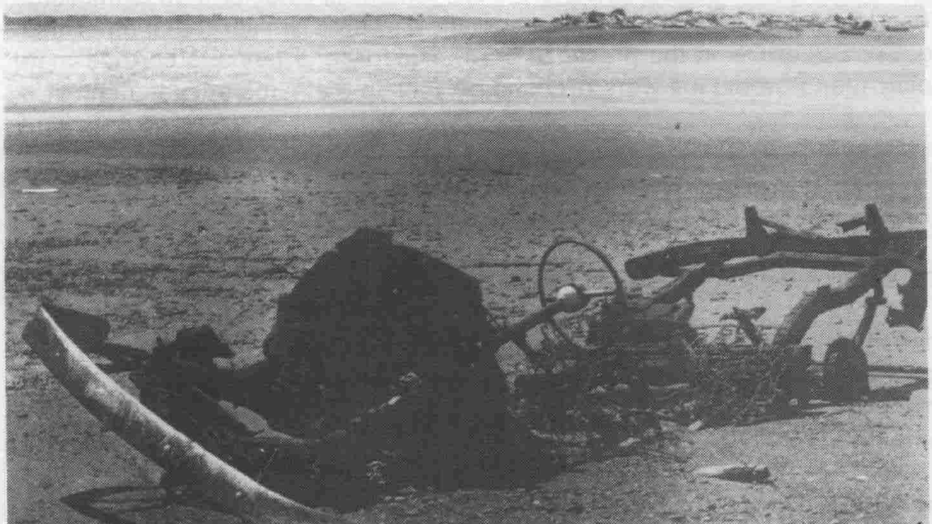


Figure 1 Corrosion

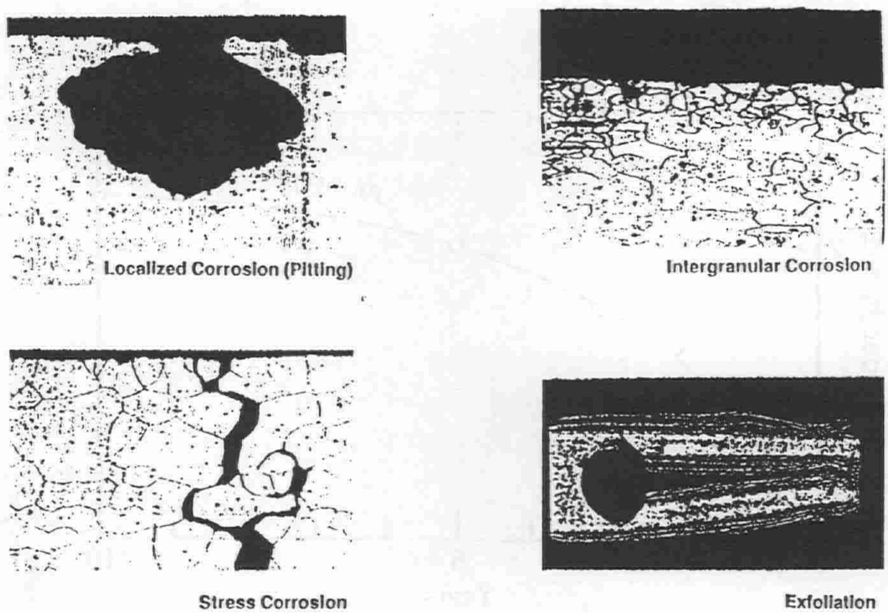


Figure 2 Forms of corrosion

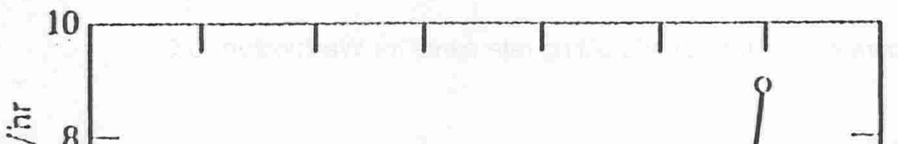


Figure 3 Influence of pH on solubility of aluminium oxide film

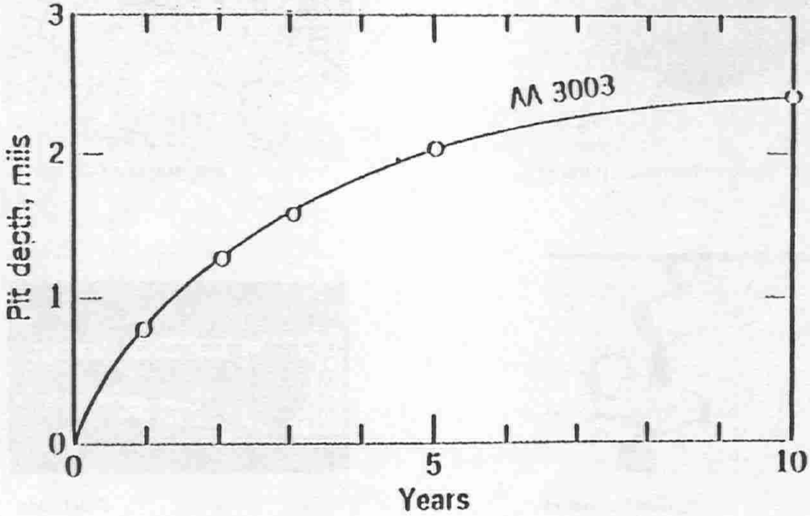


Figure 4 Atmospheric pitting-rate curve for Washington, D.C.

Material - Corrosion rates					
Location	Atmosphere	Aluminium	Copper	Lead	Zinc
Phoenis, Arizona	Desert	.0	1.3	2.3	2.5
State College, Pa.	Rural	.3	5.8	4.0	10.5
Key West, Florida	Marine	1.0	5.0	5.5	5.3
La Jolla, Calif.	Marine	7.0	13.0	4.0	17.0
New York, N.Y.	Industrial	7.8	11.0	4.3	47.5

Figure 5 Atmospheric corrosion: Corrosion rates at 10 years

PLATE	Al 99,5	AA1150
	AlMn	AA3003
	AlMg3	AA5754
	AlMg4,5Mn	AA5083
EXTRUSION	AlMgSi0,5	AA6060
	AlMgSi1	AA6082

Figure 6 Aluminium alloys for the use in sea atmospheres

Material - Average weight loss (g/dm2)					
Location	Al99.5 - AlMn - AlMg		AlMgSi		Mild Steel
	Serie 1	Serie 2	Serie 1	Serie 2	
Harbor Island N.C.	.64	.52	.85	1.19	50.80
Halifax N.S.	.68	.47	.85	1.49	75.18
Esquimalt B.C.	.89	.81	1.91	1.83	116.10

Figure 7 Average weight losses on plate material in seawater

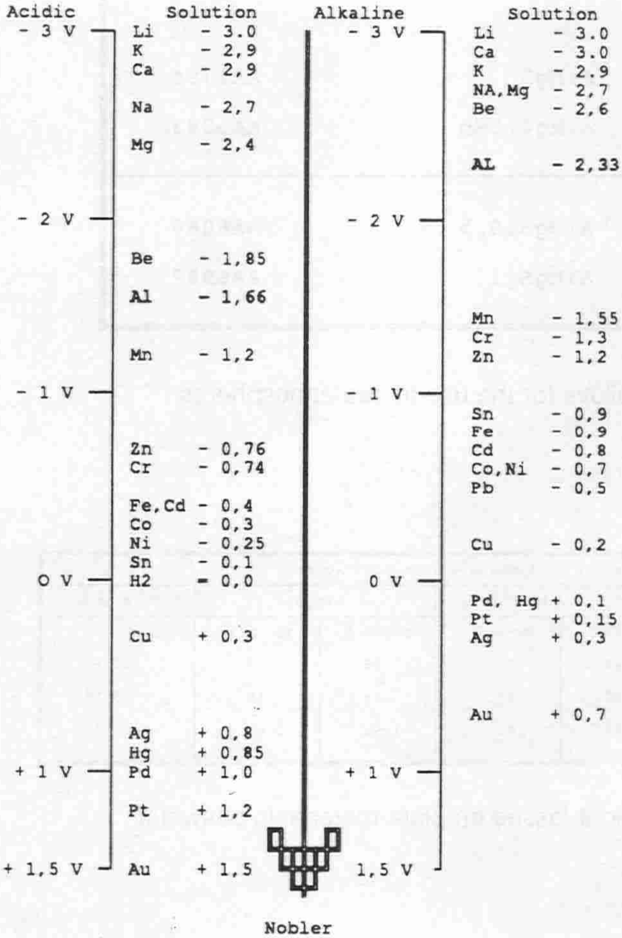
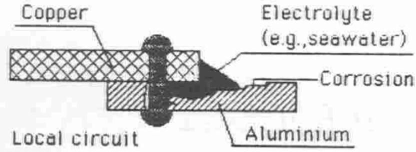


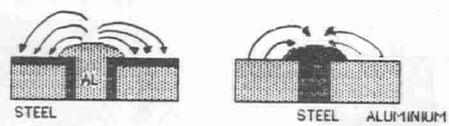
Figure 8 Galvanic series of metals

SEA-WATER GALVANIC SERIES

Corroded end (anodic)	Magnesium
	Magnesium alloys
	Zinc
	Aluminum alloys 7072, Alclad 7075, Alclad 3003
	Aluminum alloys 5083, 5086
	Aluminum alloys 1100, 3003, 5052, 6061, 6063 Alclad 2014, 2017, 2024
	Cadmium
	Aluminum alloy 7075
	Aluminum alloys 2014, 2017, 2024
	Mild steel, cast and wrought iron
	Lead-tin solders
	Lead
	Tin
	Brasses
	Copper
	Bronzes
	Monel, Inconel
	Nickel
Protected end (cathodic)	



Galvanic cell Al-Cu



Influences of cathode/anode areas in sea water

Figure 9 Galvanic Corrosion

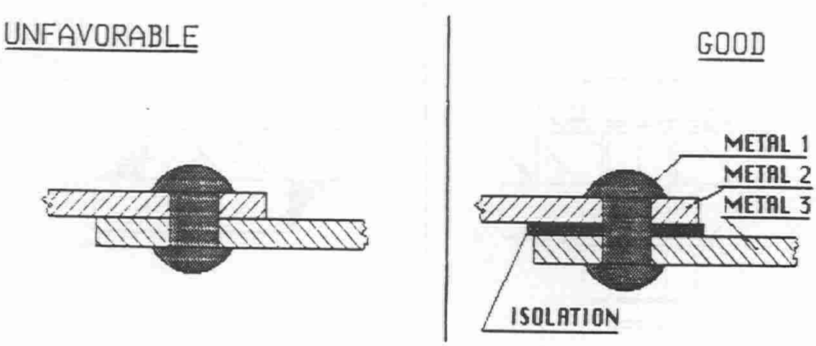


Figure 10 Construction Details: Rivet connections

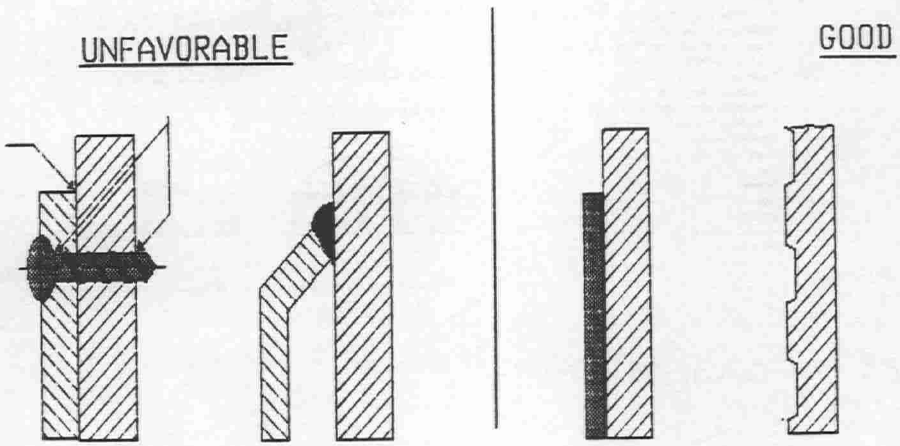


Figure 11 Construction Details: Model number plates

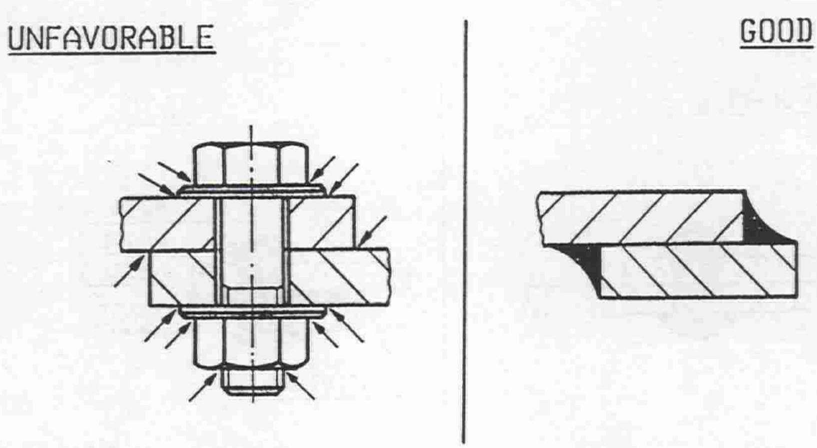


Figure 12 Construction Details: Screw - Weld connection

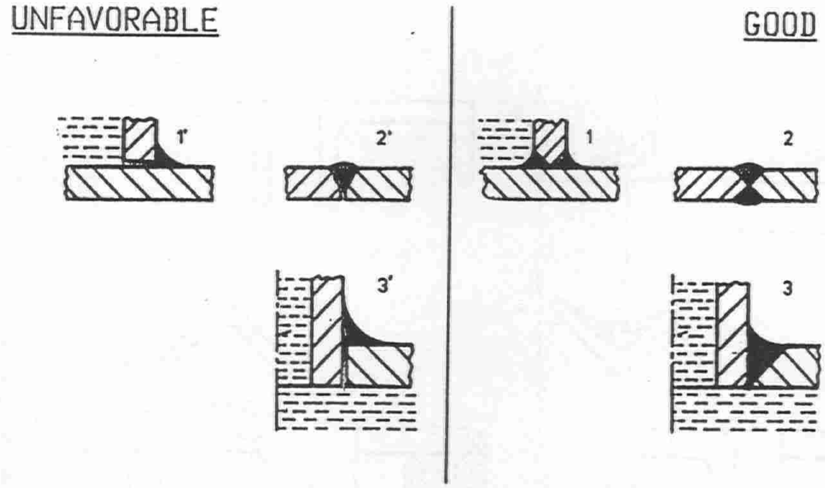


Figure 13 Construction details: Weld connections

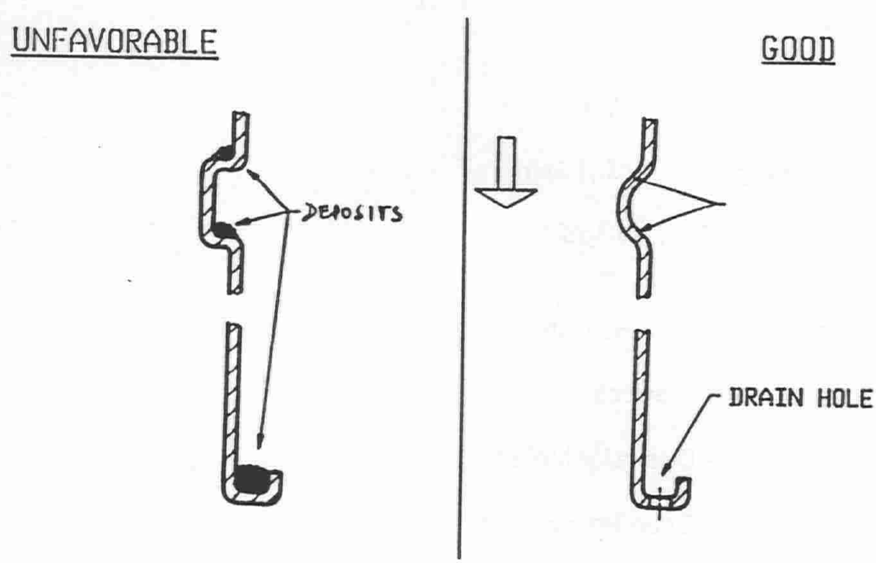


Figure 14 Corrosion under deposits

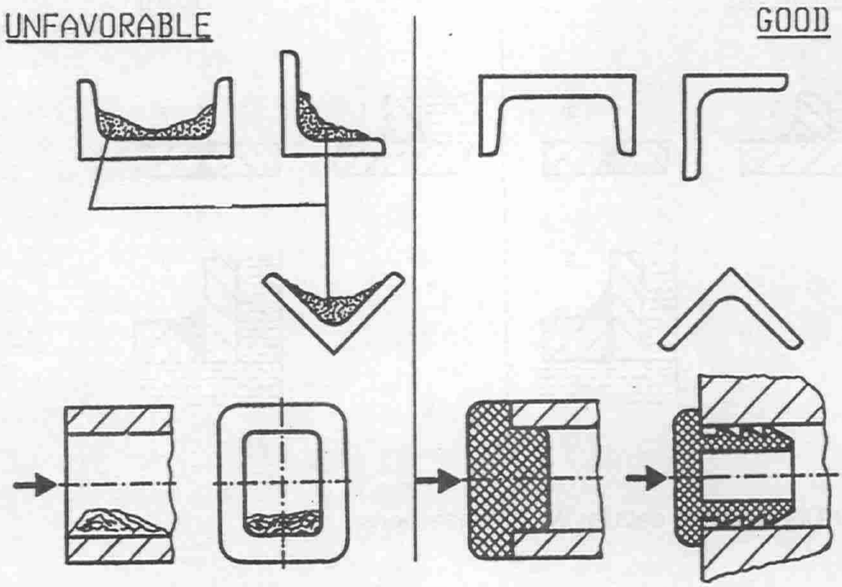


Figure 15 Corrosion under deposits

Allloys Al99.5 , AlMn

AlMg3 , AlMg4.5Mn

AlMgSi0.5 , AlMgSi1

Construction Avoid: - Horizontal areas

- Crevices

- Dissimilar Metals

- Open Hollow Sections

Figure 16 Summary

KORROSIONSVERHALTEN VON ALUMINIUMWERKSTOFFEN IM MEERWASSER

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1. Abstract

The aluminium alloys AlMg4,5Mn and AlZn1 roll-bonded AlMn1Mg1 have exhibited good corrosion resistance as well in artificial sea water as after 4.5 years exposure to the natural corrosive environment of the Island Helgoland (North Sea).

Both the thin spray-coated Zn-layer and the roll-bonded AlZn1-cladding have been effective as cathodic protection and thus proven as useful methods of corrosion control.

2. Einführung

Aluminium und seine Legierungen werden mit Erfolg in Bereichen eingesezt, in denen sie durch Meerwasser und Meeresklima stark beansprucht sind. Die besonderen physikalischen, korrosions-chemischen und technologischen Eigenschaften der Aluminium-werkstoffe haben auch im Schiffbau und in der Meerestechnik weitere technische Fortschritte ermöglicht. Bild 1 zeigt eine Großboje für die Meeresforschung, deren Rohrschwimmkörper (ca. 2,5 m diam.) aus der Legierung AlMn4,5Mg zusammengeschweißt wurde (Gewicht ca. 38 t).

Das geringe spezifische Gewicht (2,7 g/cm^3) bei relativ hohen mechanischen Festigkeiten erlauben dem Konstrukteur leichte Bauweisen, die sich beispielweise günstig auf die Schwerpunktlage und Stabilität, sowie auf den Tiefgang und die erreichbaren Fahrgeschwindigkeiten und Zuladung auswirken.

Die Widerstandsfähigkeit van Aluminium gegenüber Korrosion, elektrochemisch auch mit dem Begriff "Passivverhalten" gekennzeichnet, wird von isolierenden Oxidschichten bewirkt, die sich an Luft und in Wässern spontan bilden und eine Schutzwirkung haben. Der Aufbau einer an feuchter Luft entstandenen Schutzschicht ist in Bild 2 schematisch dargestellt. Demnach gibt es zwei übereinanderliegende Teilschichten: eine nahezu porenfreie Grund- oder Sperrschicht aus amorphen Al_2O_3, deren Dicke von der thermomechanischen Vorgeschichte des Werkstoff abhängt, sowie einer porösen, wasserhaltigen Deckschicht. Im bestimmten Säuren (pH $<4,5$) und Laugen (pH $>8,5$) sind die Oxidschichten löslich und Aluminium wird flächenmäßig angegriffen (1).
Im Meerwasser kann die Oxidschicht örtlich durchbrochen werden und es entstehen lochförmige Korrosionsstellen (Loch- oder Muldenkorrosion). Aluminium geht dabei in Form von Ionen in Lösung und Elektronen werden freigesetzt.
Diesen Teil des Korrosionsvorganges nennt man "anodische Teilreaktion". Die

notwendige Voraussetzung für Lochkorrosion ist aber daß noch andere elektrochemische Vorgänge gleichzeitig an der Aluminiumoberfläche ablaufen, die sog. "kathodischen Teilreaktionen", welche die freigesetzten Elektronen verbrauchen. Die Summe dieser beiden Teilreaktionen ergibt einen elektrischen Spannungszustand, das "Potential".
Ob Aluminium in einem wässrigen Medium lochförmig angegriffen wird oder nicht, ob bei mechanischer Verletzung durch Kratzer seine oxidischen Schutzschichten neu gebildet werden, hängt von der Größe dieses Potentials ab. Man nennt die zugehörigen Potentialgebiete dann "Lochkorrosion"- und "Passivbereiche" (2).

Tabelle 1 zeigt Potentialbereiche für verschiedene Korrosionsarten, wie sie im Laborversuch in künstlichem Meerwasser bei 22 ^{0}C konstanter Prüftemperatur ermittelt wurden. Hiervon kommt es jedoch unter natürlichen Bedingungen zu Abweichungen, zum Beispiel unter dem Einfluß von Bewuchs, Temperaturschwankungen und Meerwasserbewegung (3,4).

3. Korrosionsversuche im Meerwasser

In Langzeitversuchen (bis zu 4,5 Jahren) wurden auf dem Korrosionsprüfstand auf Helgoland (Nordsee) unter natürlichen Meerwasserbedingungen das Verhalten der Legierungen AlMg4,5Mn und der beidseitig mit AlZn1 walzplattierten AlMn1Mg1 untersucht.
Tabelle 2 enthält die chemische Zusammensetzung der durchweg als 8 mm starke Bleche hergestellten Werkstoffe.
Bei der AlMg4,5Mn handelt es sich um die im Schiffbau überwiegend verwendete Legierung, während die walzplattierte AlMn1Mg1 infolge ihres hervorragenden kathodischen Schutzes als KAL-ZIP (R)-Bleche in der Bautechnik (Dacheindeckungen, Wandverkleidungen), wenn auch in der meist weniger aggressiven Binnenlandatmosphäre, seit Jahren mit Erfolg eingesetzt wird (5)

Beide Werkstofftypen wurden in verschiedenen Behandlungszuständen sowie geschweißt im Korrosionsprüfstand ausgelagert (Tabelle 3). Die Schweißverbindungen wurden als 60^{0} V-Nähte nach dem MIG-Verfahren (halbautomatisch) unter Verwendung des Schweißzusatzwerkstoffes AlMg4,5Mn (diam. = 1,6 mm) hergestellt.

Die Sensibilisierung des Werkstoffes AlMg4,5Mn für interkristalline Korrosion (IK) erfolgte durch 168-stündige Simulationsglühung bei 150 ^{0}C. IK-anfälliges Gefüge kann bei der Weiterverarbeitung durch falsche Wärmebehandlung entstehen, z.B. beim Schweißen durch zu hohe Vorwärmtemperaturen (T.170 ^{0}C) über längere Zeiten.

Für ergänzende Untersuchungen zum kathodischen Korrosionsschutz wurden zusätzlich Proben mit einer ca. 0,1 mm dicken Feinzinkschicht durch Aufspritzen (METCO-Verfahren) hergestellt.

Schiffsbleche aus AlMg4,5Mn werden ungeschützt, d.h. ohne Zinkspritzschicht eingesetzt. Daß so eine Schutz-sicht selbstverständlich auch an ihnen positiv wirkt beweist der Sonderfall einer Großboje, zu der Hoogovens Aluminium entsprechendes AlMg4,5Mn-Blech lieferte, und die acht Jahre im Wasser der Nordsee lag, ohne Schaden zu erleiden.

Die Korrosive Prüfumgebung des Prüfstandes umfaßt die sog. Spritzwasserzone (SWZ), die Wechseltauchzone (Ebbe und Flut; WTZ) und die Dauertauchzone (DTZ).
Die Änderungen der Festigkeitseigenschaften und das Korrosionsverhalten durch Bestimmung der Lochtiefe, Lochanzahl pro Flächeneinheit sowie flächenbezogenen Masseverlust wurden nach Auslagerungszeiten zwischen 0,5 und 4,5 Jahren ausgewertet.
Zum Vergleich und für Polarisationsmessungen wurden Korrosionsversuche unter simulierten Meerwassereinflüssen im Labor durchgeführt.
Eine ausführliche Darstellung der Versuche, deren Auswertung und Diskussion gibt F.J. Reker in (3).

4. Ergebnisse und Diskussion

Das Korrosionsverhalten läßt, wie die Auslagerungen an der Helgoländer Mole zeigten, z.T. feine Unterschiede erkennen. Während eine aufgespritzte Zinkschicht beinahe stetig mit der Zeit abgetragen wird, gehen der flächenbezogene Massenverlust oder die lochförmige Korrosion bei plattierten und ungeschützten Blechen im Laufe der Zeite nicht gleichmäßig vor sich.
Tabelle 4 zeigt als Beispiel die ermittelten maximalen Lochtiefen in Abhängigkeit von Legierungsvariante, Beanspruchungszone und Auslagerungsdauer.

Nach 4,5 Jahren Dauertauchen betrug demnach die größte gemessene Lochtiefe an ungeschützten AlMg4,5Mn-Blechen nur 0,26 mm.
Die Festigkeitseigenschaften aller Proben hatten sich nicht verändert, die Spritzzinkschichten (Opferanode) waren noch ebenso wirksam als kathodischer Schutz wie die AlZn1-Walzplattierschichten.

In den ersten etwa eineinhalb Jahren verursacht die Einwirkung von Meerwasser örtlich verstärkte Lochkorrosion. Dann stabilisiert sich das Korrosionsgeschehen, bei ungeschütztem Blech verlangsamt sich sogar die Korrosionsgeschwindigkeit.
Ursache hierfür ist, wie Laboruntersuchungen zeigten, daß Auftreten und Wachstum örtlicher Korrosionsstellen nur dann erfolgen, wenn sich ein Potential einstellt, das im entsprechenden Korrosionsbereich liegt.

Die im Laborversuch ermittelten kritischen Potentiallagen der einzelnen Legierungsvarianten sind in Tabelle 5 dargestellt.

In der Praxis werden die Kritischen Potentialgrenzen nur zeitweise in Abhängigkeit von der Bewegung des Meeres und des Bewuchses überschritten, d.h. mit Dauer der Exposition verringert sich zwar das Wachstum örtlicher Korrosionsstellen, aber der Angriff kommt nicht zum Stillstand. Deshalb ist bei ständiger Einwirkung von Meerwasser ein Korrosionsschutz erforderlich.

Die Potentialabhängigkeit der Loch-Korrosion von Aluminiumwerkstoffen ist bekannt. Die durchgeführten Untersuchungen haben eindeutig ergeben, daß durch Absenken des Potentials unter die bekannten kritischen Potentialwerte örtliche Korrosion völlig verhindert werden kann und bereits entstandene Korrosionsstellen repassiviert werden ("Selbstheilung").

Überraschend war die Tatsache, daß mit vergleichsweise geringen Schutzströmen von den Opferanoden auch blanke AlMg4,5Mn-Bleche, die durch unsachgemäße Wärmebehandlung anfällig gegen interkristalline Korrosion sind, verläßlich geschützt werden können. Potentialmessungen in künstlichem Meerwasser ergeben Werte von ca. -800 mV GKE für interkristalline Korrosion, die auf selektivem Angriff zusammenhängender intermetallischer Phasen Al_3Mg_5 bzw. Al_3Mg_2 zurückzuführen ist, sowie Werte zwischen -750 und -720 mV GKE für Lochfraß, abhängig von Wärmebehandlung und Oberflächenbeschaffenheit. Die Potentiale der Plattier- bzw. Spritzschichten liegen zwischen -855 und -805 mV GKE bzw. zwischen -1130 und -1050 mV GKE (Tabellen 1 und 5).
Die Dauerversuche vor Helgoland und die sie begleitenden Labortests haben die hervorragende Schutzwirkung walzplattierter AlZn1-Schichten auf Blech aus AlMn1Mg1 auch im Meerwasser und Meeresklima nachgewiesen.
Die Potentialabsenkung durch aufgespritzte Zinküberzüge als Opferanode auf AlMg4,5Mn brachte neue Erkentnisse für den aktiven Korrosionsschutz.

Bereits die ungeschützte, blanke Oberfläche der Schiffbaulegierung AlMg4,-5Mn - ähnlich verhalten sich die Legierungen AlMg3 und AlMg2Mn0,8 nach (6) - läßt an einen Einsatz in maritimer Umgebung ohne zusätzlichen Korrozionsschutz denken. Bei kleineren Sport- und Freizeitbooten wurde dieses auch mit Erfolg praktiziert.
Vorausgesetzt werden muß dann, daß in jedem Fall Kontakt- und Spaltkorrosion ausgeschlossen werden können. Weiterhin ist die ungeschützte Al-Oberfläche regelmäßig so zu reinigen und trocknen, daß sich eventuell vorhandene, lokal korrodierte Bereiche wieder passivieren können.

Da diese Bedingungen nicht immer sicher gegeben sind, erfordern insbesonders größere Konstruktionen für den Einsatz im Meerwasser zusätzliche Korrosionsschutzmaßnahmen, die sich mit beiden folgenden praktikablen

Möglichkeiten anbieten:

1. Passiver Korrosionsschutz: der Zutritt des Korrosionsmediums (Wasser) zur Metalloberfläche wird durch eine Beschichtung verhindert.

2. Aktiver Korrosionsschutz: durch kathodische Polarisation wird direkt in den Korrosionsprozeß eingegriffen, d.h. die anodische Teilreaktion an der Al-legierungen werden unterbunden.

In den hier untersuchten Fällen wurde dieses durch die Walzplattierlegierung AlZn1 bzw. durch die aufgespritzte Zn-Schicht erreicht, an denen sich die anodischen Teilreaktionen abspielen ("Opferanoden").
Im vergelich zu Stahlkonstruktionen sind die für Aluminium zum kathodischen Schutz benötigten Stromdichten niedriger, da bereits die gute Korrosionsbeständigkeit der blanken Oberfläche eine zusätzliche Schutzwirkung ausübt, d.h. der größte Teil der Oberfläche ist durch die natürliche Oxidschicht passiviert (6).

4. Zusammenfassung

Die Legierungen AlMg4,5Mn und AlZn1-walzplattierte AlMn1Mg1 zeigten sowohl unter Laborbedingungen in künstlichem Meerwasser als auch im Langzeitverhalten bis 4,5 Jahre bei natürlicher Meerwasserumgebung gute Korrosionsbeständigkeit. Das Aufspritzen von Zn und die Walzplattierung mit AlZn1 erwiesen sich als wirksame aktive Korrosionsschutzmaßnahme.

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Kritische Grenzpotentiale für Bleche und stranggepreßte Profile in künstlichem Meerwasser, 22 oC bezogen auf gesättigte Kalomelelektrode (GKE)

Werkstoff	Beschreibung	Lochfraßpotential in mV (GKE)	Grenzpotential - selektive Korrosion in mV (GKE)
AlMg4,5MN	Blech	-750 bis -705	
AlMnMg1	Blech	-750 bis -705	
AlMg4,5Mn	Blech sensibilisiert		- 800 (I.K.)
AlMgSi0,5	Strangpreßprofil	-750 bis -730	
AlMgSi1	Strangpreßprofil	-750 bis -730	
AlMgSiCu	Strangpreßprofil	-750 bis -730	
AlZn1	Walzplattierschicht	-855 bis -805	
AlZn4,5Mg1	Strangpreßprofil	-890 bis -820	
AlZn4,5Mg1	Strangpreßprofil warmausgehärtet: quer zur Preßrichtung		-900 bis -875 (Schichtkorrosion)
AlZn4,5Mg1	Strangpreßprofil kaltausgehärtet: quer zur Preßrichtung		-1000 bis -975 (Schichtkorrosion)
AlZn5Mg1,7	Strangpreßprofil	-845 bis -820	

Tabelle 1

Chemische Zusammensetzung der untersuchten Legierungen

Legierung	AA Bezeichnung	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
AlMg4,5 Mn	5083	0,25	0,30	0,022	0,73	4,56	0,094	0,056	0,009
AlMn1Mg1	Alclad 3004	0,25	0,39	0,11	1,17	0,93	0,018	0,16	0,014
AlZn1 *	7072	0,034	0,22	0,011	0,010	0,004	0,001	1,26	0,001
ALMn1Mg1	Alclad 3004	0,22	0,33	0,12	1,09	0,99	0,024	0,085	0,013
AlZn1 *	7072	0,10	0,33	0,010	0,010	0,034	0,01	1,04	0,012

* Plattierwerkstoff

Tabelle 2

Verschiedene Zustände der untersuchte Legierungen nach Tabelle 1		
Variante	Legierung	Zustand
1	AlMg4,5Mn	weich, geschweißt
2	AlMg4,5Mn	stabilisiert, geschweißt und verzinkt
3	AlMg4,5Mn	stabilisiert, geschweißt
4	AlMn1Mg1	F 22, beids. plattiert mit legierung AlZn1, (4 - 8%), geschweißt und verzinkt
5	AlMg4,5Mn	korrosionssensibilisiert
6	AlMg4,5Mn	korrosionstabilisiert
7	AlMn1Mg1	F 22, beids. plattiert mit legierung AlZn1, (4 - 8%)
8	AlMn1Mg1	F 22, beids. plattiert mit legierung AlZn1, (4 - 8%)

Tabelle 3

Maximale Angriffstiefe L_{max} (nach DIN 50905) der Lochkorrosion nach Auslagerung im Korrosionsprüfstand auf der Insel Helgoland (Nordsee)

Zustand nach Tabelle 3	Werkstoff	Zone	Lochkorrosion Grundwerkstoff		Wärmeeinflußzone	
			Lmax in mm	Zeit in d	Lmax in mm	Zeit 1) in d
1	AlMg4,5Mn	SWZ	0,27	1403	0,25	1619
		WTZ	0,21	1024	0,05	152
		DTZ	0,26	1619	0,24	1024
3	AlMg4,5Mn	SWZ	0,26	1024	0,12	1403
		WTZ	0,19	1024	0,09	1024
		DTZ	0,26	1024	0,15	1024
5	AlMg4,5Mn	SWZ	0,23	1024	--	--
		WTZ	0,03	524	--	--
		DTZ	0,24	1403	0,17	1024
6	AlMg4,5Mn	SWZ	0,27	1024	--	--
		WTZ	0,05	152	--	--
		DTZ	--	--	--	--
7	AlMn1Mg1	SWZ	0,27	1403	--	--
		WTZ	0,25	1403	--	--
		DTZ	0,26	1024	0,25	1024
8	AlMn1Mg1	SWZ	0,23	1024	--	--
		WTZ	0,27	1403	--	--
		DTZ	0,21	1024	0,15	1024

1) Auslagerungszeit: 1619 Tage (= 4,4 Jahre).
Werden kürzere Zeiten angegeben, so bedeutet dieses, daß bis zur Auslagerungszeit von 4,4 Jahren keine meßbaren Lochvertiefungen gefunden wurden.

Tabelle 4

Potentialgrenzen für lokale lochfürmige Korrosion
nach 100-stündiger Polarisation in künstlichem Meerwasser,
22 °C.
Die mV-Werte sind auf die gesättigte Kolomelektrode (GKE) bezogen.

Zustand	Potential in mV *
1 Oberfläche gewalzt, weichgeglüht	-750 bis -735
1 Oberfläche gewalzt, weichgeglüht	-740 bis -720
2 Oberfläche gewalzt, stabilisiert	-745 bis -730
2 Bereich WEZ (Wärmeinflußzone)	-745 bis -720
3 Bereich WEZ (Wärmeinflußzone)	-745 bis -710
4 Zinkschicht	-1130 bis -995
5 Oberfläche gewalzt, sensibilisiert	-735 bis -725
5 Bereich WEZ, sensibilisiert	-760 bis -740
5 Bereich WEZ, sensibilisiert	-750 bis -740
6 Oberfläche gewalzt, stabilisiert	-745 bis -730
7 Oberfläche gewalzt AlZn1	-855 bis -845
7 Oberfläche poliert AlZn1	-845 bis -835
7 Oberfläche gewalzt AlMg1Mn1 F22	-715 bis -705
8 Oberfläche gewalzt AlZn1 weich	-815 bis -805
8 Oberfläche geschliffen AlMg1Mn1 F22	-740 bis -730
8 Oberfläche gewalzt AlZn1 weich	-820 bis -800
8 Bereich WEZ, geschliffen, weich	-735 bis -725

* Der höhere Wert zeigt an, bei welchem Potential lokale Lochkorrosion aufgetreten ist;
der niedrigere wert steht für Potentiale ohne erkennbare Korrosionserscheinungen

Tabelle 5

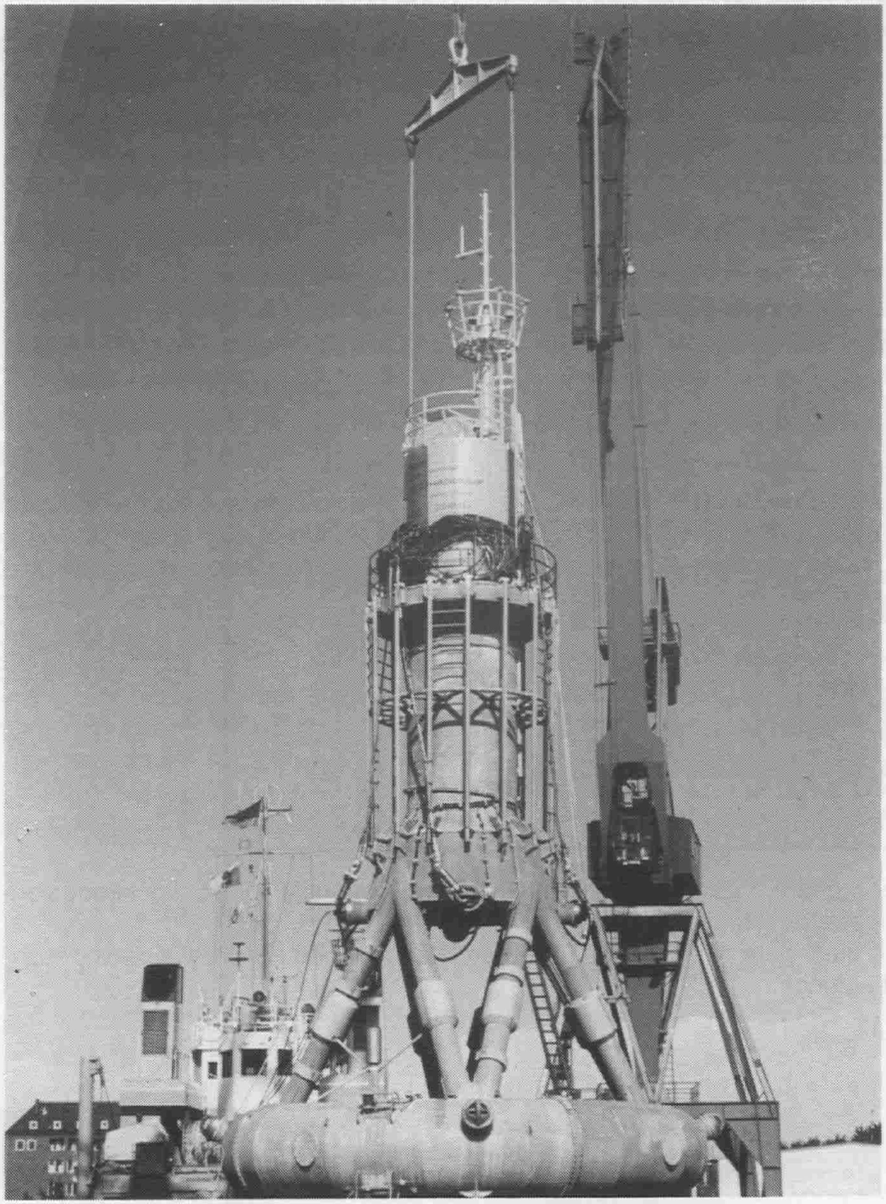
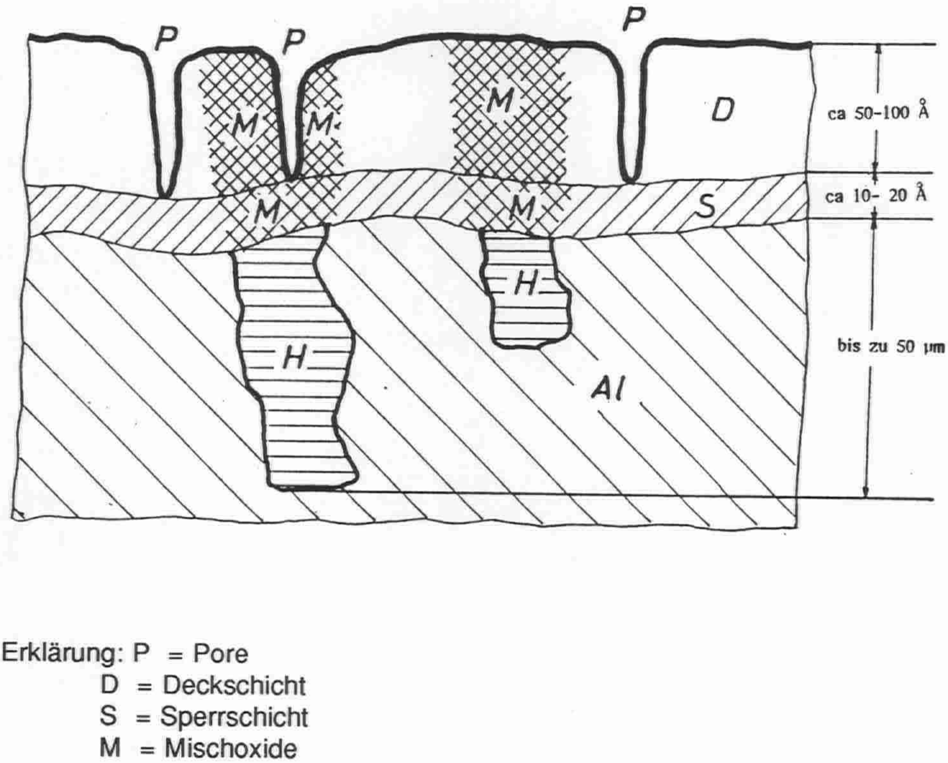


Bild 1 Großboje für die Meeresforschung
Rohrschwimmkörper ca. 2,5 m Durchmesser
aus geschweißten Blechen der Legierung AlMg4,5Mn
Gewicht ca 39 t.
Gesamthöhe 24 m, davon 10,4 m unter Wasser
(Foto: Fa Hagenuk, Kiel)



Erklärung: P = Pore
D = Deckschicht
S = Sperrschicht
M = Mischoxide
H = Heterogenitäten
(Einschlüsse, Ausscheidungen)
Al = Aluminium - Grundmetall

Bild 2 Schematischer Aufbau einer Oxidschicht auf Reinaluminium.
(an feuchter Luft bei Raumtemperatur gewachsen)

CONSTRUCTION IN ALUMINIUM

DIPL.ING. M. KRAMM

Table of Content

1. Introduction

The basic principle of a construction is the translation of someones idea into a design in which one or more materials will be used.
Consequently calculations have to be made, finally resulting in a drawing.

The preliminary conditions of most designs are i.a.:

- restricted weight
- restricted costs
- resistant against external influences
- restricted bending
- surface conditions
- safety requirements
- rules and regulations

With use of aluminium there are two lines to reach a final design:

a. A construction or part of a construction, designed in steel has a too heavy weight.
   The designer must find out if aluminium could be the answer to solve this.

b. The designer starts from the beginning with a specialized aluminium design.

In developing a construction the following combination of semi-products can be used:

a. A construction made out of single sheets
b. A construction made out of single profiles
c. A combination of plates and shapes
d. A mixed construction of shape and casting
e. A mixed combination of sleet and forging

Suppletion of this list is easily done, just because many other materials can be added.
In principle it will be possible to use different Al-alloys.

2. Aluminium-alloys

It's the designer's duty to choose the right material out of a list of many possibilities.

The aluminium-industry, producing semi-products, has very good information concerning this material where the properties of the varying alloys and the technical possibilities are described; they give data of the chemical composition, the physical values and the standardi-zation-numbers of other countries.
A certain basic knowledge however is necessary to use this information in the correct way.
Several items will be explained.
In the wrought aluminium alloys there is a difference between the non heat-treatable and the heat-treatable alloys. The heat-treatable alloys have within this group differences, due to the fabrication-process, the stretching, the heat-treatment and the quenching.
Next table gives a rough insight into the wrought aluminium alloys. Small changes in the chemical composition can give a big variety of their temper.

Wrought Aluminium Alloy			
Non heat-treatable Alloy		Heat-treatable Alloy	
Series	Composition	Series	Composition
1000 3000 5000	AlFeSi AlMn AlMg AlMgMn	2000 6000 7000	AlCuMg AlMgSi AlZnMg AlZnMgCu

Table 1

3. The advantages of aluminium

= High to very high strength
= Low specific weight
= Excellent corrosion-resistant
= Good plasticity
= Good weldability
= Good formability
= Good decorativity
= Good electric conductivity

furthermore

= An increase of strength with decrease of temperature
= A financial high scrap-value
= Germs-resistant
= A positive influence on the internal transport costs

4. Disadvantages of aluminium

= High investment
= Low modulus of elasticity
= Low melting point
= Decrease of strength in welded zones
= Corrosion-sensitive in combination with other materials
= Sensitive to crevice-corrosion
= Sensitive to stress-corrosion.

5. Choice of alloy

The designer must choose the correct alloy, in harmony with the given order and taking special conditions into account.
A civil architect will always take an alloy out of the 6000-series with 0.5 Si as eloxated material for covering a frontwall of a building.
The shipbuilding confines to the 5000- and the 6000-series as seawater-resistant.
The electrotechnic industry found another alloy and the producers gave these alloys soundfull names.
When high-strength materials have to be chosen for barriers alongside highways in combination with a good-looking, smooth surface a Si-content of 0.1 will be taken in the 6000-series
Bodies of railwaycars will be fabricated out of AlMgSi0.5. An increased strength will be gained by adding some more Si.
In high loaded parts AlZnMg can be used, protected by a good coating.
The choice for military material, e.g. parts for movable bridge elements could be AlMgZn.
This is a high strength alloy - keeping in mind that this alloy is sensitive to corrosion and sensitive to cracking in the welded zones.
In bolted and riveted constructions AlZnMgCu is a correct choice. In military condition a sufficient maintenance is expected to be available.

When the designer made his choice, he can start his design, taking into account the following items:

- Low-alloyed rolled material in the ranges of lower plate-thicknesses is available with a large breadth.
- High-alloyed material in the ranges of lower plate-thicknesses is available in small width.

The manufacturer can give all necessary information.

Very important is the alloy AA5083, with 4.5% Magnesium and approx. 1% Mn.

The yieldstress in plate condition is 270 N/mm^2 and in shape'it is just 140 N/mm^2.
Many mistakes are already made, using this alloy.

6. <u>Constructions, made out of plate.</u>

With bending of the aluminium the minimal radius must be in accordance with manufacturer's data. Haircracking in the tensionside, cause of intergranulair corrosion, can be eliminated.
Marking should be done with a pencil or marker and not with a steel-marker.
Cutting can be done with automatic scissors, saw or plasmacutting.
Welding, riveting or bolting are the normal types of connection.
Just as an exception the material will be glued. Tackwelding of thin aluminium material just for small constructions for a non-water-, air- or gastight connection.

A new technique to connect thin sheets is the press-connection system, called as "clinching".
With a cutting-device a slot is made in both two connecting materials (figure 1).
After making this slot the pressed-out material will be squeezed on the lower surface of both sheets (figure 2). This connection method is a fast, cheap and good technique.

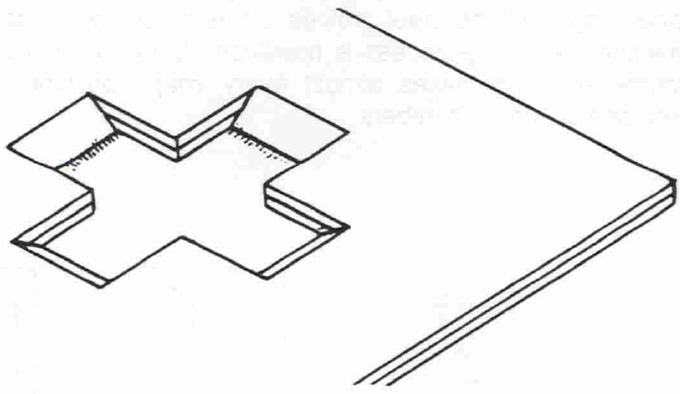


Figure 1

No extra material and preparation of the connection is required. The upper and lower sheet, however, will be "damaged". The connection is not water-tight.

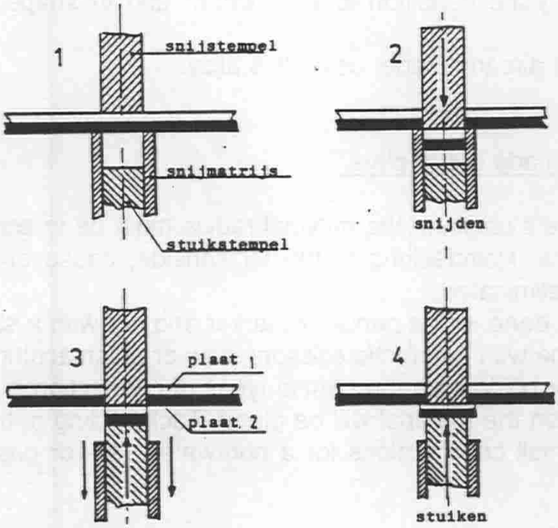


Figure 2 Clinching-connection

7. Aluminium Profiles

In constructions the profiles are the most important components. Figure 3 gives a few examples of steel and aluminium profiles.
The shaped flanges of the steel profiles are required by the rolling-process. With aluminium the rolling-process is needless, due to the extrusion method. This production-method makes almost every shape possible, even hollow profiles with one or more chambers.

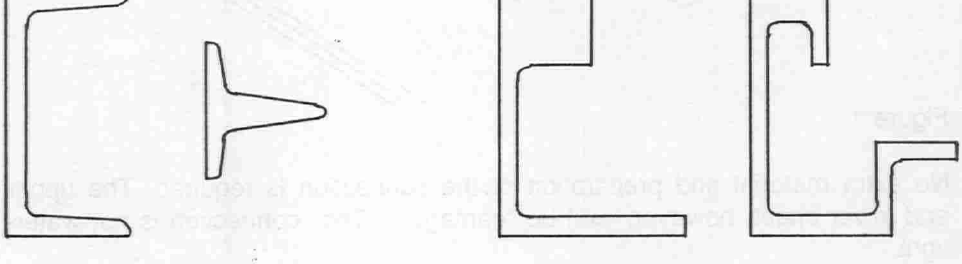


Figure 3 Steel profiles Aluminium Profiles

In conversion a steel construction into an aluminium performance we can use the following conversion-formula:

$W_{al} = W_{st} * k$ in which

W_{al} = the section modulus of the Al-profile
W_{st} = the section modulus of the Steel-profile
k = conversion factor.

The conversion factor k will be determined by the aluminium alloy and the condition of the material

$$k = \frac{635}{R_m + R_{p0,2}}$$

R^m = ultimate strength - N/mm^2
$R_{p0.2}$ = yield strength - N/mm^2

Table 2 gives the k-values of a number of specific alloys in combination with Fe 410 - the normal shipbuilding steel with ultimate strength = 410 N/mm^2.

A check must be done on the bending of the construction.
When a section modulus and a moment of inertia has been calculated, we have to keep in mind that bending is 3 times stronger compared to steel.
The modulus of elasticity of Al is 70 kN/mm^2 compared with 210 Kn/mm^2 for steel.
It is necessary to take the own weight of the construction in the bending-calculations.
It should be well-known that a moment of inertia times multiplied by 3 is not the same as a loading multiplying by 3.

Conversion factor k					
AA	Alloy		Rm	Rp0.2	k
5754	AlMg3	F18	180	80	2,44
5083	AlMg4,5Mn	F27	270	140	1,55
6063	AlMgSi0,5	F22	215	160	1,69
6082	AlMgSi0,9	F28	275	200	1,34
6082	AlMgSi 1	F31	310	260	1.11
7020	AlZnMg 1	F35	350	290	0,99

Table 2

Aluminium is quite expensive. For a relative cheaper construction the mass of the material should be divided in such a way that the compression and tension-forces are equal. Then the function of the material is 100%. Figure 4 shows two different profiles with the same mass.
The section modulus and the moment of inertia of the lower profile are significant higher.
The calculations for shear and torsion are the same in comparison with steel.
Fatigue calculations, however, should be done from $1x10^6$ cycles.

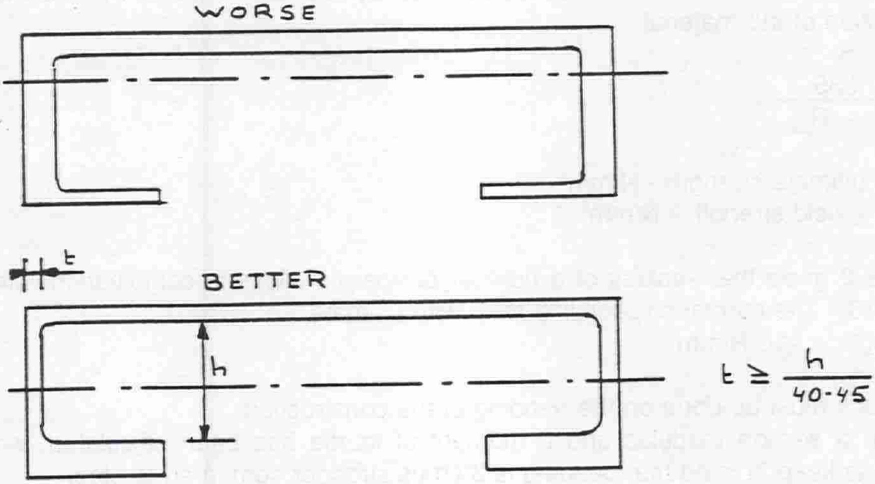


Figure 4 Distribution of Mass

7.1 The relation between pressure and wall thickness

Very important to the wall-thickness of a profile is the specific pressure in the extrusion process. The avail-able pressure should be divided by the surface of the container. These values are variable and depend on the manufacturer.
A disadvantage are the very large friction forces in the "direct" process. The billet, heated to 550 °C is pressed by the plunger through the die, (figure 5) The internal pressure of the billet is also directed to the side of the container. The friction-forces of the moving billet are a loss of energy, caused by the plunger.
This leads to the "indirect" method. In this case not the billet is pressed in the direction of the die; the plunger is open and the material is pressed through the die, through the plunger. The friction absorbes no energy, so these problems have been solved.

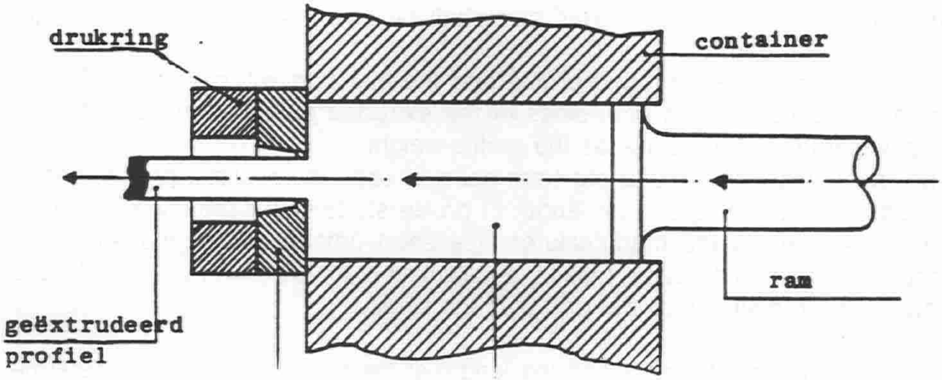


Figure 5 Direct method

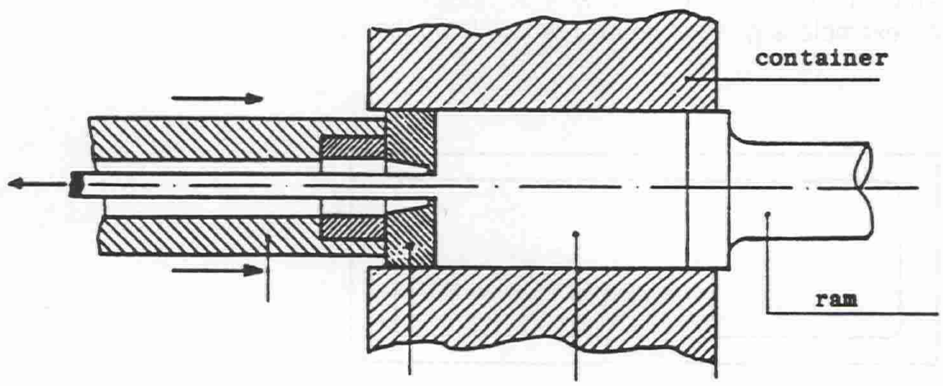


Figure 6 Indirect method

With this method profiles can be produced with a very thin wall thickness.
The surface area, measured in cm^2 or mm^2 and the minimum wall thicknesses are dependent of the extrusion press and type of the aluminium alloys.
Still it is a fact that easy and difficult producible profiles exist. Naturally hard aluminium alloys are more difficult to extrude and require a bigger wall thickness. Heat-treatable alloys however can be produced with smaller wall thicknesses. There are many very small decorative profiles with an area of 8 mm^2 and a thickness of 1 mm.

7.2 The relation between billet-weight and profileweight

Every billet has a remainder in which during extrusion all the oxide remaining will be collected. This part shall be cutout after most of the billet has been extruded.
The first part of the extruded profile and the last part will be removed, thus there is a scrap-part on both sides of the extruded profile. Consequently the billet weight is not the same as the profile weight.
The manufacturer will calculate from case to case the realistic profile length.
A consumer, ordering a large length of profile starts with submitting a draft of the profile-area to the manufacturer. If a short amount of lengths has been required the manufacturer makes a calculation for the multiple length and deduct the remaining (oxide) part plus the scrap.

In this way the billet-weight and the length of the press-block can be determined.

7.3 Open profiles

An open profile is not necessarily admissible to one side.
An example is given in figure 7 where the opening is quite small.

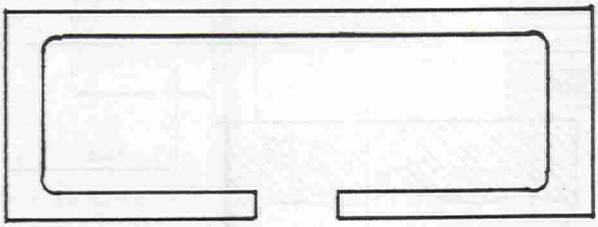


Figure 7 Open profile

A critical situation arises when the innerspace closed. The innerspace, just connected in a small area, is under full pressure and can crack just in the die. Examples are found in mast-profiles. (figure 8). The big chamber is fully closed and the small chamber has a small opening.
For the designer this is a big problem because the innerpart is supported by a very small connection-piece. In uncertain cases an installation for a two-chamber-production will be used.
Figure 9 shows a profile with a big depth.

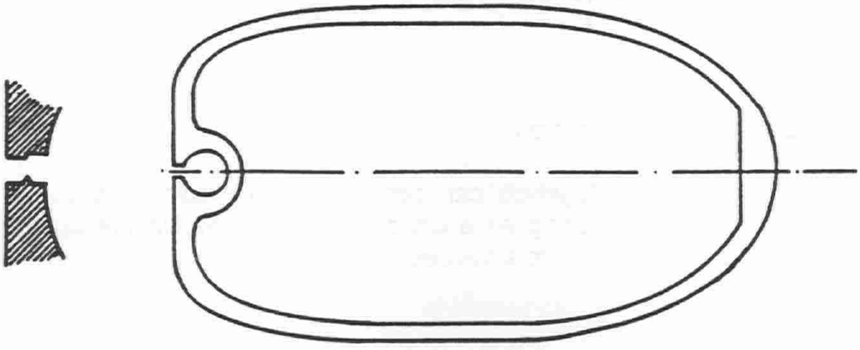


Figure 8 One- or two chamber profile

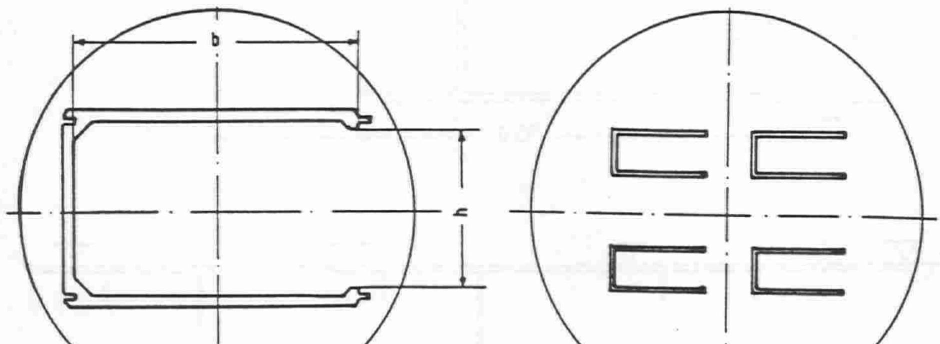


Figure 9 U-shaped profile

In reviewing this profile it is of a great importance of the pressability if the complete diameter of the die can be used. Smaller profiles can accept other propor-tions than bigger profiles because the pressure on the innersurface is lower. Taking this rule into account a bigger shaped construction is easy understandable.
A construction with closed upper and lower surface, can easily be designed (figure 10-a)

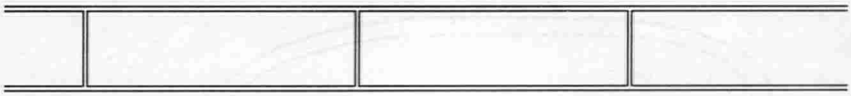


Figure 10-a Design of a closed profile.

Finally, due to the problems, which can occur in the extruding process a profile has been designed looking as a double T-profile wherein the upper- and the lower leg asymmetrical are extended. (figure 10-b)

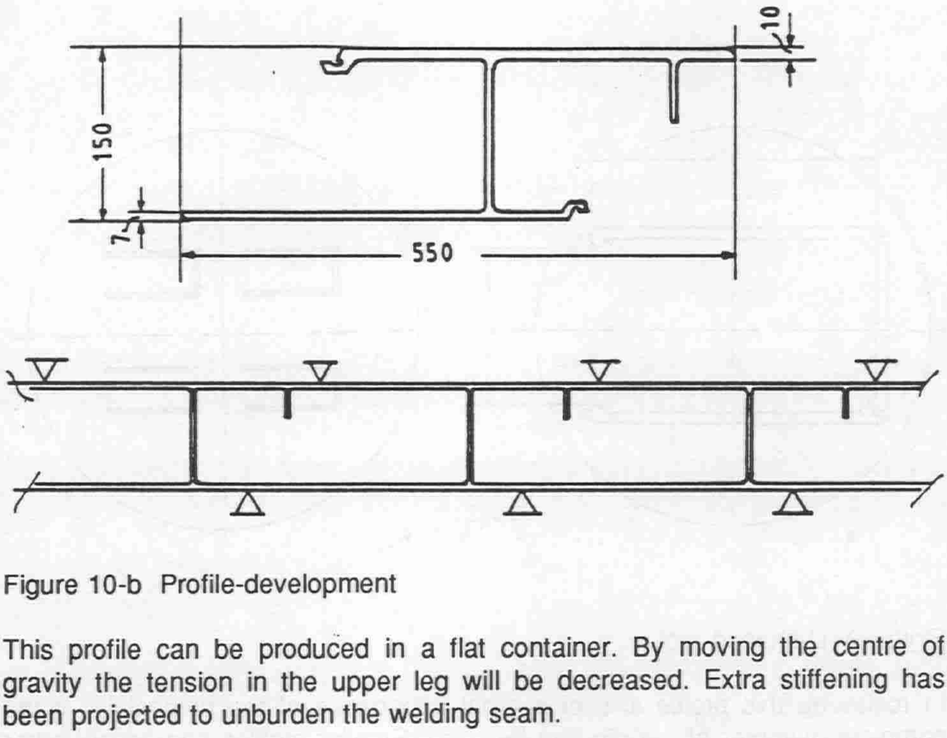


Figure 10-b Profile-development

This profile can be produced in a flat container. By moving the centre of gravity the tension in the upper leg will be decreased. Extra stiffening has been projected to unburden the welding seam.

With all these profiles we have to look to the circumferential circle. To be mentioned is the diameter in which the profile fits. The biggest circle for round containers is approximately 520 mm. A flat container is also usable with round corners. In this way extrusion-profiles with the following dimensions will be possible:

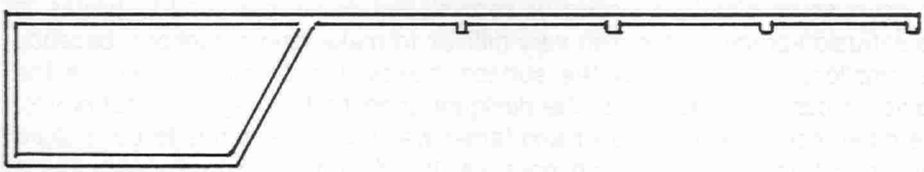
800 x 60 mm
750 x 80 mm
720 x 120 mm
650 x 150 mm
600 x 180 mm

In all cases the wall-thickness and the kind of alloy have some influences.

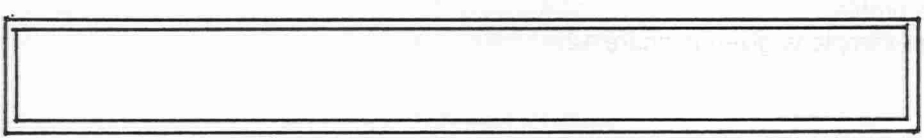
7.4. Hollow sections and their specific problems

In the industry hollow sections are preferred because these profile are quite stable and needs hardly any stretching. Any precautions needs to be taken care off yet. The extrusion process is more expensive in comparison with the open profiles. The designer has to calculate the extension of the specific order. The initial costs will be specific lower for a big quantity of material; Further, the industry wants a minimum weight for an order.

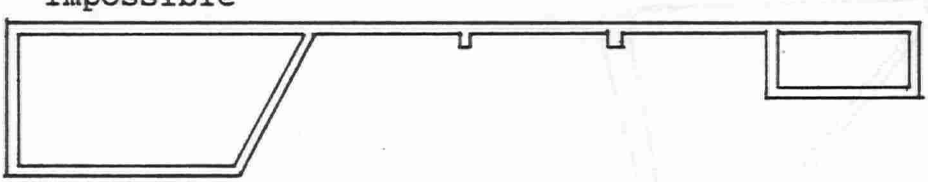
Figure 11 shows several examples of hollow profiles were the grade of difficulty for extrusion has been given.



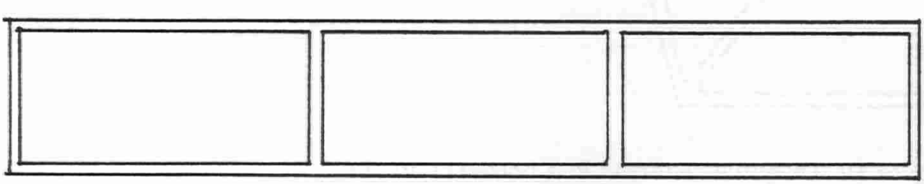
Very difficult



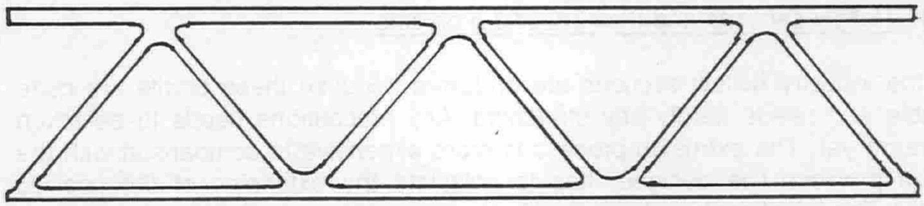
Impossible



Good



Very good



Ideal

Figure 11 Hollow extrusion profiles and the grade of difficulty.

An asymmetric size in a closed or semi-closed profile can lead to waves in the extrusion-process. It is also very difficult to make long chambers, because the smallest deformation of the surface makes it impossible to stretch the profile. In cases of uncertainty the designer chooses for a symmetrical profile. The difference between smaller and larger wall thicknesses has to be bridged with good transitions. It is also possible that during the extrusion-process a diagonal stiffening in a hollow chamber will help to keep the correct form of the profile.
An example is given in figure 12.

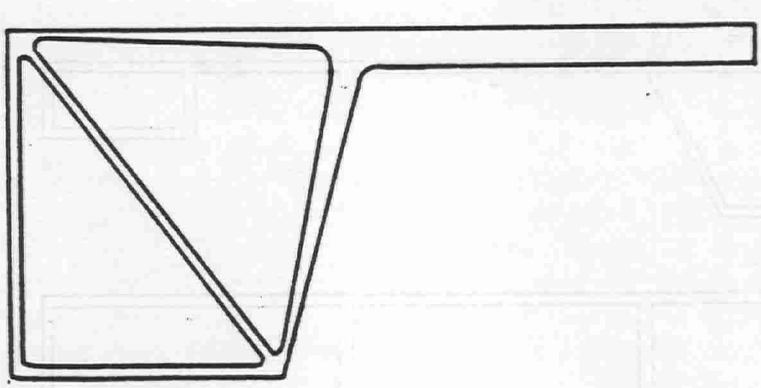


Figure 12 Diagonal stiffening in a hollow chamber.

7.5 Difficult extrusionable profiles

Alloys out of the 2000, 5000 and 7000 series give, especially in the extrusion-process, many problems.
It is quite impossible to produce a thin wall profile out of AA 5083 with 4.5% magnesium.
For a hollow profile, extruded through a combination of dies, the material will be led through the various channels in the dies to the mandrel and the streams are welded together. The "welding" seams are hardly visible. The mentioned alloys are apparently welded but this is not always reliable. Under high tension this can lead to cracks in these seams.
With alloys out of the series 1000, 3000 and 6000 these problems do not exist.
Figure 13 gives examples of extruded profiles with a very small wall-thickness, made out of alloy 6083.
These profiles are very difficult to extrude, because many problems occur to stretch these later.
These profiles have a width of 600 to 800 mm and a thickness of 3 mm. The surface is not flat and must be straightened with the result that the legs will turn. After correcting the legs, the surface is not flat anymore.
Extrusion of profiles out of AA 5083 is impossible because this hard alloy can not be pressed through the dies. The minimum wall thickness must be 8 - 10 mm.

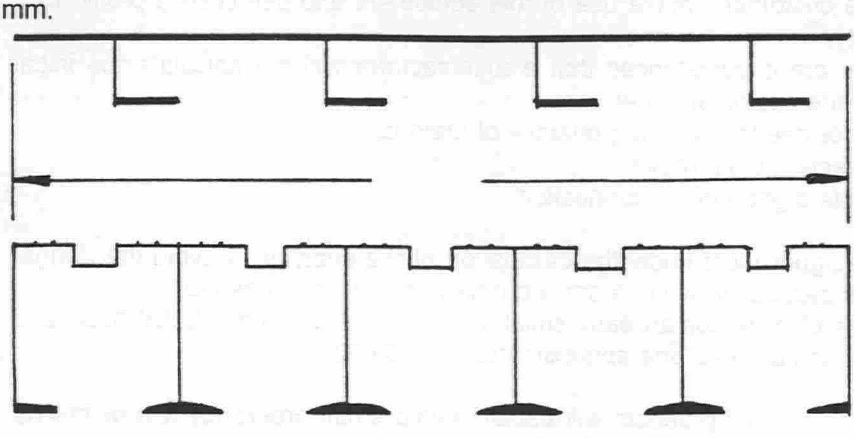


Figure 13 Large profile with small wall thicknesses.

Mostly a big extrusion-profile is supported by two points after leaving the extrusion-press. The aluminium material is at that moment still soft and weak so it can bend by its own weight. In such circumstances a supporting leg could be designed and extruded. The client or the factory can remove this supporting leg in a later state.
Figure 14 shows a section-area in which an extra supporting leg has been applied.

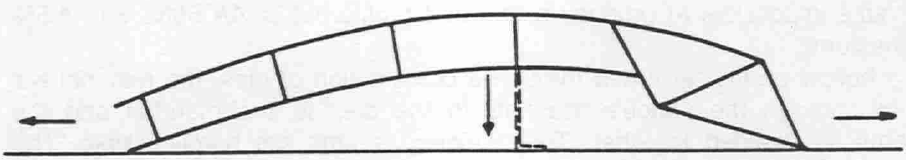


Figure 14 Profile with supporting leg

7.6. Economic limitations

In the factories' catalogue only these profile are
shown, that are freely available. When the customer needs a special profile, he must carry a part of the development costs. These costs will be calculated to the customer with an extra 3% of the nett-value of the delivery. When sufficient orders will be given, the customer becomes a certain owner of the special equipment (dies). The manufacturer can then not - without authorization of the customer - make use of this equipment and sell such a profile to a third party.
But there are circumstances that a manufacturer will not calculate the initial costs to one customer, when

-. the order needs a very big quantity of material
-. he expects a big turnover
-. he wants a good client-connection.

Every designer must know the calculation of the supplier to avoid the danger of a miss calculation when a small quantity of profiles is needed.
The costs of a die for an easy small section are approximately Dfl 300.- and for a big, complicated one approximately Dfl 60,000.

A supplier of semi-products will usually avoid small orders for a new profile, due to the complicated steps that have to be taken:

The die must be designed
The drawing must be digitized in the computer
Steel for the die must be ordered
Fabricating the die
Hardening of the material
First try-out
Post-treatment of the die
Second try-out

Fabrication process
Preparation of the extrusion press
Heating the tools to 550 °C
Preparation of the billets
Billets heating to extrusion-temperature
Extrusion
Dismount the extrusion press
Stretching
Cutting to length
Levelling
Artificial aging
Controlling shape, surface, mechanical properties
Packing and shipping.

For the own stock such big quantities shall be fabricated so that orders of a small quantity can be handled.

7.7 Variations in design and technical tricks

This subject is so extended that we can call this a bottomless barrel. Despite experience of many years the designer can learn and has to learn.
The field of applications should be compared with other constructions and disciplines.
A perpendicular connection between two round tubes must - if possible - be avoided, because such a connection is very expensive. With a lower loading the pipes' end can be presses and subsequently welded as a flat bar. See figure 15.

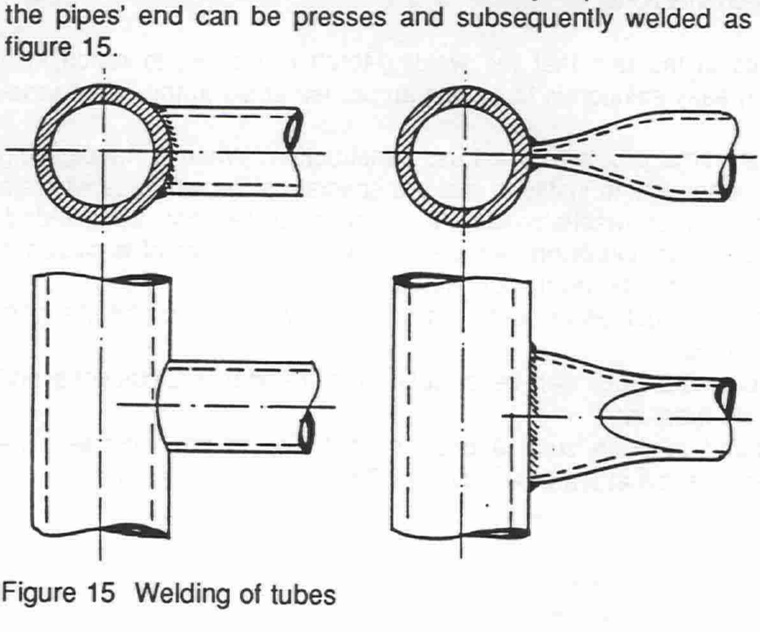


Figure 15 Welding of tubes

Because a square tube will be produced in the same way as a circular tube the prices shall be equal per weight.
When the pipe-connection is not perpendicular the connection with aluminium tubes is more difficult compared with the steel tubes.

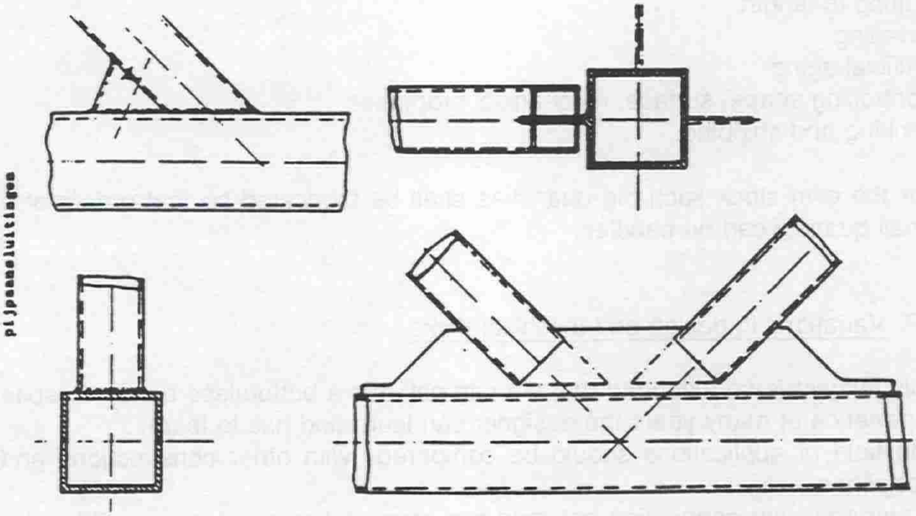


Figure 16 Pipe-connections

The difficulty lies in the fact that the welding-torch is too big to reach in a sharp corner. An easy solution is to design an obtuse angle in the same tube-construction.
We can find the same problem in a truss-construction. When it handles big quantities it is economical to justify to make a special profile with legs wherein the junctions are better reachable and the junction-plates can be avoided. Some truss-bars are compression members, so the weakest point is midways the length. The ends can be freely connected.
Sometimes a profile must be foreseen on one end with a coverplate, e.g. in balconies or in lamps.
The needed "screwchannels" can be calculated in the static calculations and will have a double meaning.
It is recommended to open such a channel to have an open profile. The openings-corner must be at least 60^0. (figure 17a)

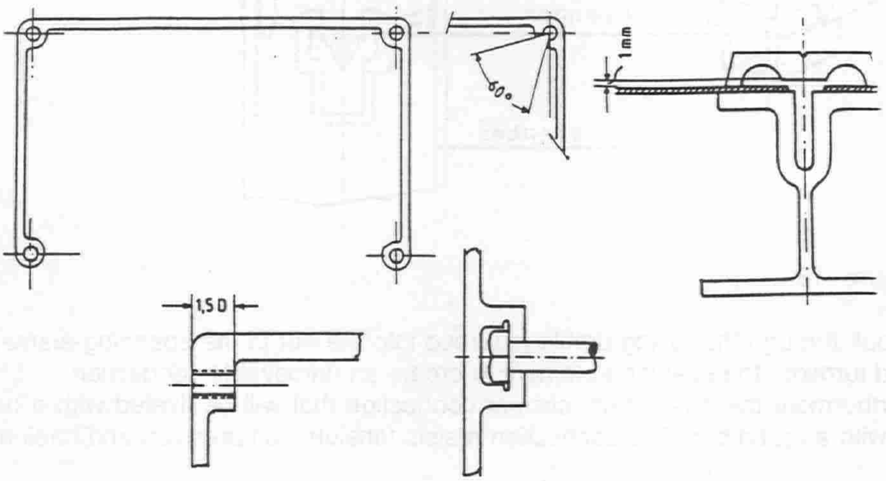


Figure 17

If a bolt-hole, perpendicular to the extrusion direction is needed it is profitable to strengthen the sec-tion with a wall thickness = 1.5 times the bolt-diameter. (figure 17b). A second solution could be a welded doubler. An other solution is a continuous blind hole, usable for a self-tapping screw.(figure 17c)
Many parts have continuous channels with the width of a six-sided bolt. In the drawing the corners are chamfered just to avoid tension-concentrations.(figure 17d).

By studying the several catalogues for semi-products, for e.g. handrails for bridges, windows, doors etc. we can find many times very good solutions for corner-connections.
In the auto-, and railwaycar-industry there are many inventive ideas. In the program of handrails very good connection parts have been invented too.
Figure 18 gives an idea of such a connection.

Here is a special element, foreseen with a nut, moved into a vertical sceptre. By pressing the upperpart with
a wrench, the spanning-element is turned-out and fixed in the hollow profile.

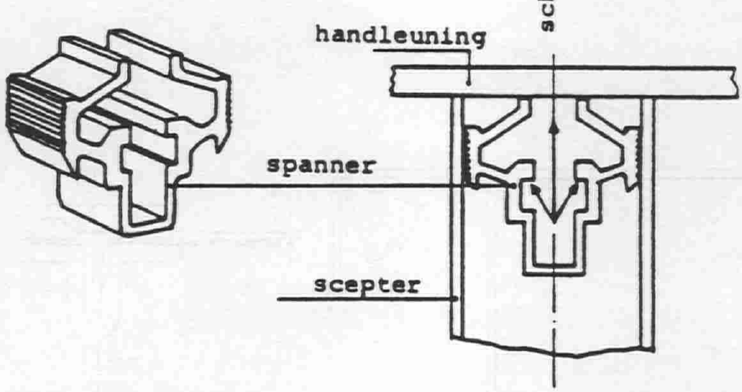


Figure 18

A bolt through the railing-profile is turned into the nut in the spanning-element and turnsout the spanning-element to create an unmovable connection. Furthermore there is a semi-circular connection that will be fixated with a ball or with a round bar. The connection resists tension, compression and torsion.

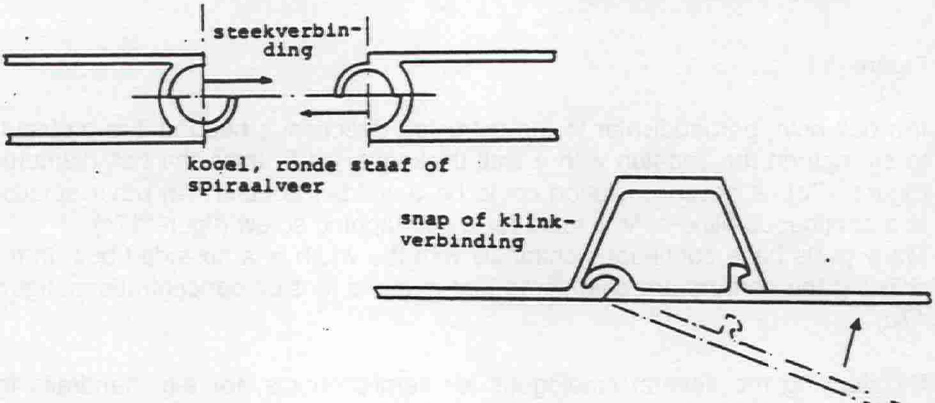


Figure 19

Very reliable is the click-connection. Dismounting after mounting is not possible. (figure 19)
With slip connections a very strong warning must be given that this connection is not reachable with small tolerances. The experience is that after 200 mm distance moving is not possible anymore. Many designers learned this lesson already.

7.8 <u>Heat-effect during welding</u>

As already mentioned in the vicinity of the welding-seam the tensile-strength decreased due to welding. The effect of this phenomenon is different with the various alloys.
Table 3 shows minimum values for the tensile-strength of MIG-welded shapes and plates.

The table learns that the natural hard materials show hardly any difference. The well-known construction-alloy AlMgSi1, with very good values for $R_{p0,2}$ looses in the condition R31 50% or more.

Plate			
AA nr	Alloy	Rm	Rpo,2
5754 5083	AlMg3, All conditions AlMg4,5 All conditions	180 280	80 130
Profiles			
5754 5083 6063 6063 7020	AlMg3 F18 AlMg4,5 F 27 AlMgSi0,5 F22-25 AlMgSi1 F31 and F28 AlZn4,5Mg1 F35	190 270 215 90 >280	80 130 160 120 >205

Table 3

It is the designer's duty to work with this material and to calculate with these - by welding - decreased values.
However there is a possibility to design the welding seam in a low-tension position, e.g. in the vicinity of the neutral zone. Figure 20 gives some examples

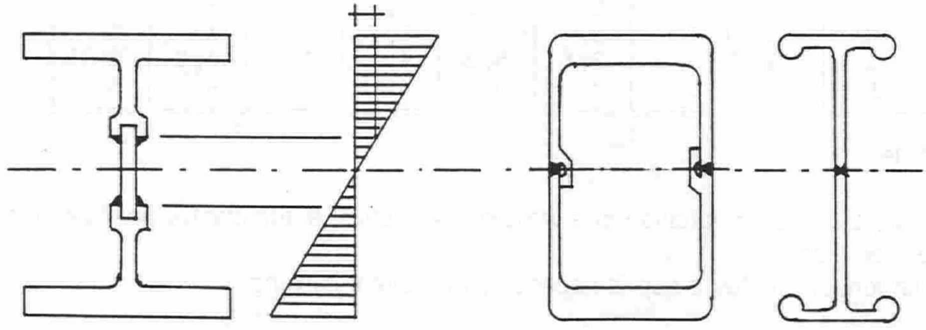


Figure 20 Welding of profiles

Especially with big extrusion-profiles we will pay attention to the weldingpool-support. In the same profile the connecting members can be made out of material with a very small wall thickness, without the danger that the welding will harm the profile-construction.

Fig 21 gives a weldingpool-support with the dimensions in table 4.

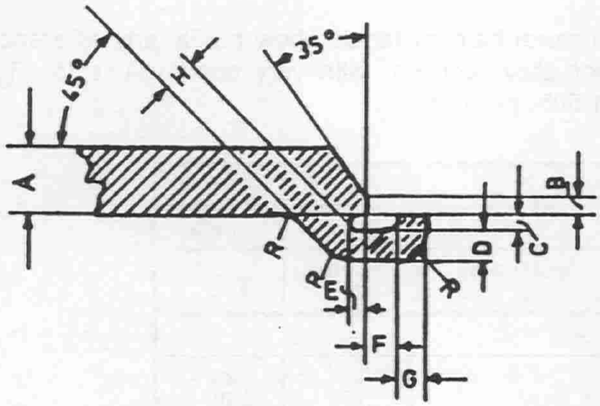


Figure 21 Weldingpool-support

A	2,5	3	3,5	4	5	6	8	10
B	1	1	1	1	1,5	1,5	2	2
C	1	1,5	1,5	1,5	2	2	2	2,5
D	2,5	3	3	3	3	3,5	3,5	4
E	1	1	1,5	1,5	2	2	2	2,5
F	2,5	3	3	3,5	3,5	4	5	5
G	3	3	3	3	3,5	3,5	4	4
H	3	3,5	3,5	5,5	4	4	4,5	5
R	3	3	3	3	4	4	4	5

Table 4

Figure 22 gives a variation of a weld-support which automatically positions the both profiles.
With longer profiles a gap is necessary to prevent sticking.

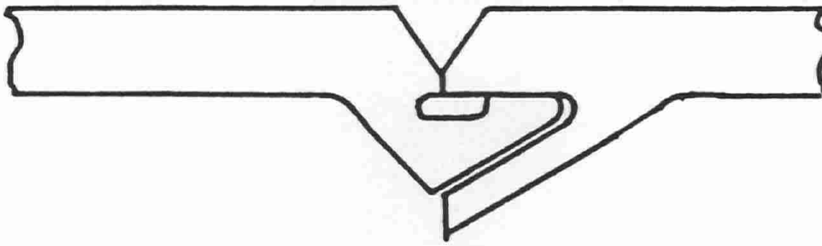


Figure 22 Welding support

Figure 23 shows another variation of a weld-support, specially made for big-size profiles. The welding seams are positioned on both sides of the neutral axes and gives a possibility to adjust the dimensions during mounting. Instead of a X-seam where in the root always grinding must be done, we created two V-seams. This means one production-phase less.

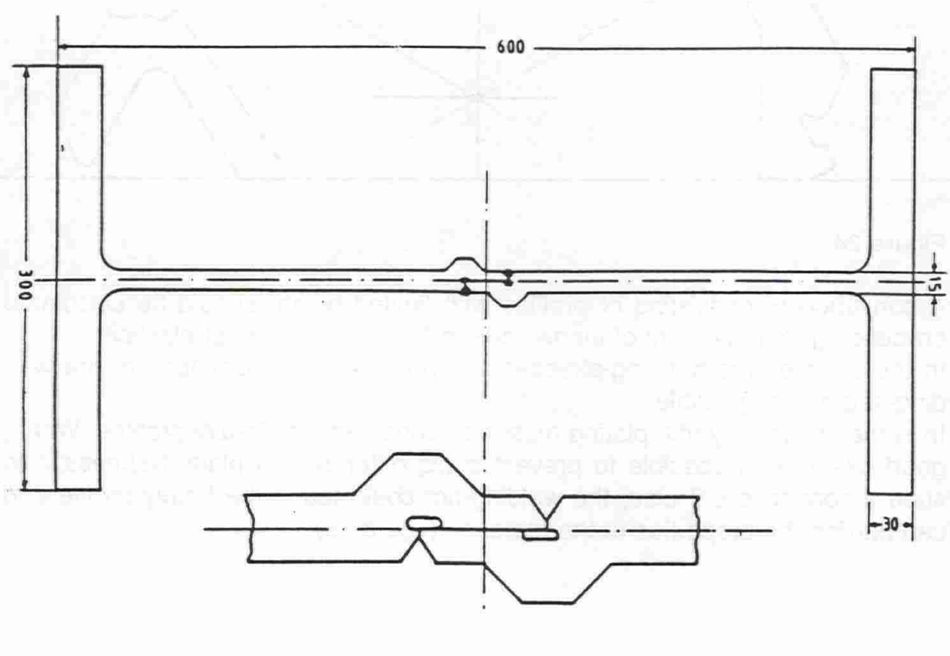


Figure 23

During the extrusion precautions must be taken to prevent damaging of the - at that moment - quite weak material of the welding seam. An extra leg in the design, used as a support during extrusion can prevent this. (figure 24)

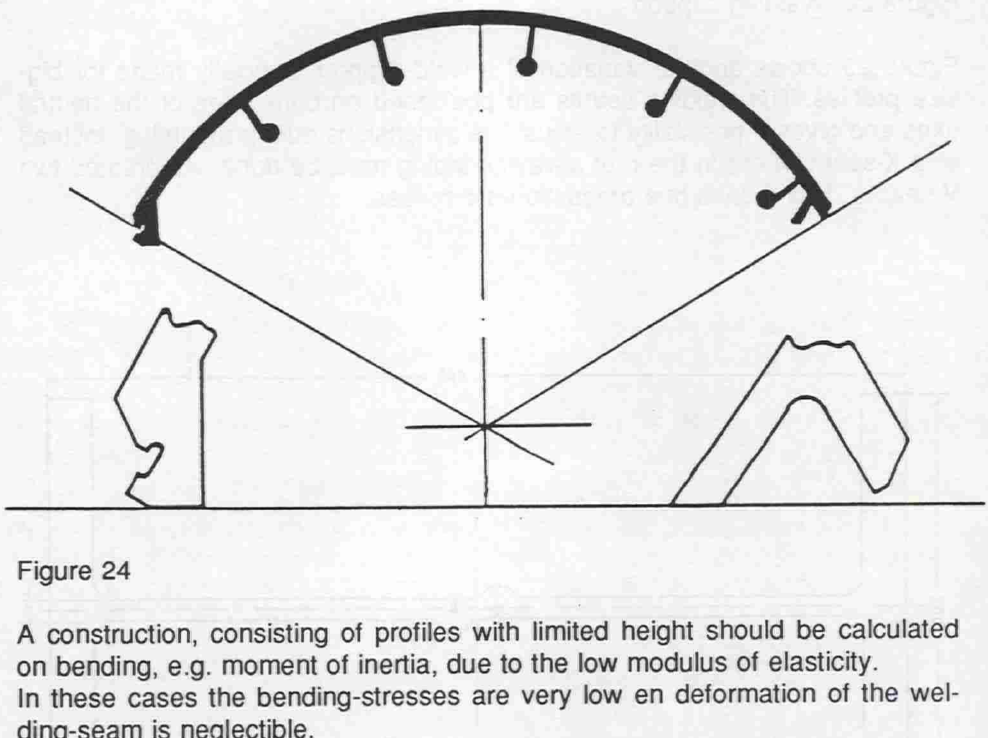


Figure 24

A construction, consisting of profiles with limited height should be calculated on bending, e.g. moment of inertia, due to the low modulus of elasticity.
In these cases the bending-stresses are very low en deformation of the welding-seam is neglectible.
In some cases very thin plating must be connected with heavy profiles. With a good design it is possible to prevent a big difference in plate-thicknesses in such a connection. If else, the welding-arc could touch the heavy profile and can burden the properties of the material. (figure 25)

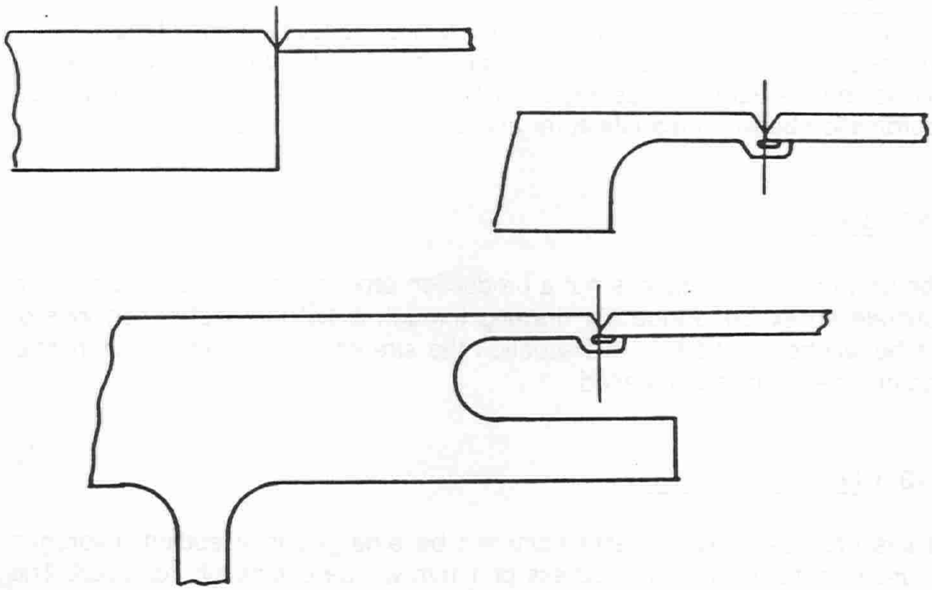


Figure 25. Examples of welding seams.

7.9 Integrating in stead of welding

In principle the most favourite way of designing an extrusion profiles is to integrate all possible functions. I.e bolt-guidance, connection-possibilities, extra legs, etc.
It is more economic to remove some parts in a later state instead of welding special facilities. This retards the production and shall give extra heat-effects.

7.10 Quenching

In general the heat-treatable aluminium alloys shall be quenched immediately after the extrusion process. This can be done by air. The profiles will bend slightly by this. Some alloys must be quenched with water; this can cause some other problems.
When the wall thickness is quite large some difficulties can occur in penetrating the cooling to the heart of the material.
This is the reason that some manufactures mention a lower strength-value for the same material.

Profiles with variable wall thicknesses do not cool down with the same speed and will become warped. These deviations can be partly remedied by stretching.

7.11 Stretching.

The cutout to length and stretched profiles must be levelled sometimes.
This costs sometimes more efforts than the original extrusion. This levelling will be then a very big cost-factor in the total price of a profile, so a good coordination between manufacturer and designer is necessary.

7.12 Drawing

The drawing of aluminium is not a production process and will just be done to calibrate an extruded tube. By drawing through a slot the final dimensions of a tube will be reached. In this situation the strength of the material is increased but the strain is decreased.

7.13 Chemical machining

In this process a part of aluminium will be emerged in a sodium hydrogen solution. In 10 minutes a thickness of 1 mm will be chemically removed. The remaining surface, covered with lack or tape is clean and needs no further manufacturing.
Instead of a thin-wall profile with welded strengthening this method gives us variable wall thicknesses with a homogeneous structure. It is also possible to create a thickening of a location, that cannot be done by extrusion, to make an extrusion-design with a bigger wall thickness and to remove the superfluity of the material with chemical machining.

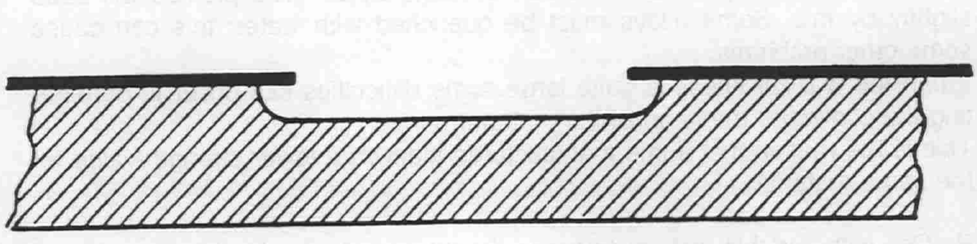


Figure 26 Chemical machining

7.14 Bimetal extrusion

For a fixed connection between steel and aluminium, there are three well-proven methods:
- roll-cladding
- explosion-welding
- double extrusion

Especially in the USA the roll-cladding is preferable.
In a very big roller steel and aluminium strips will be rolled under a very high specific pressure.

Explosion-welding is mentioned in chapter 10

Double extrusion is quite complicated and shown in figure 27.
In this process two coils of strips (80 x 3) will be used. Both strips, heated to press-temperature and cleaned in argon gas atmosphere are guided into a special die. Together with the aluminium both strips are extruded through a final die and leave the press as a double profile.
With this method it is possible to provide several kinds of profile with an other metal. In shipbuilding these profiles are not wellknown.
These profiles are quite favourite in the field of the electric industry, due to a good conductivity (aluminium or copper) and wearing-resistant (steel)

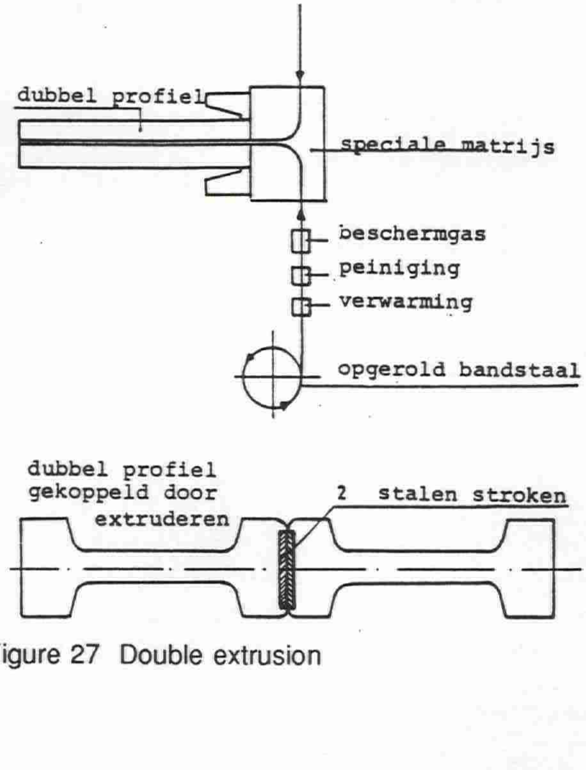


Figure 27 Double extrusion

A NEW GENERATION "M2' ASSAULT AND BRIDGE BUILDING CRAFT

P.H.NOORDENBOS and
J. PINKSTER

DAMEN SHIPYARDS

With courtesy to the Royal Institute of Naval Architects
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Coastal Defence and Assault Vessels 1986

Table of Content

SUMMARY

The design of a new concept for a small fast aluminium assault craft also to be used as a rafting unit or bridge as developed by Damen Shipyards Holland.
Also included is a detailed full scale strength and stability analysis, as well as photographs showing the final concept in use.

1. INTRODUCTION

During the second World War the allied armed forces were equipped with small assault craft of the "M2" (wood) and the larger "M4" (aluminium) type. The former were used for assault purposes as well as for building rafts and bridges, whereas the latter were used mainly for rafting and bridge building.
During the last decades the engineering corps development programs focused their attention on larger - with regard to loading capacity - bridges for Military Load Class 60* requirements, both in a fixed or in a floating configuration. In the shadow of these developments the smaller assault craft was generally speaking left out and remained as it was.

> * Military Load Classes (MLC.) are specified in Stanag 2021 (NATO Standardization Agreement);
> i.e. MLC 60 equals a load of 60 times factor 0,9 = 54 tons, for tanks etc. For army vehicles Stanag 2021 also specifies the maximum axle loads for each MLC.

When doing a market research study in 1983 on the requirements of a new small fast assault and bridgebuilding craft, an overseas yard asked for assistance in the design and construction of prototypes of a similar craft for their own armed forces.
The new concept that resulted from the merger of both requirements, has a length of 5.4 m and answers the demands of countries having a specific need for such small portable craft for transportation and inspection purposes on rivers and estuaries and for the occasional flood relief work in peacetime.
For military actions the craft can be used as an assault craft and carry one infantry platoon and 2 or 3 engineers. The rafting capabilities were specified for a vehicle of MLC.6 and the bridge should be able to carry vehicles up to MLC.8.
Clearly, such a design could not be conceived overnight and intensive contact with several army engineering corps was therefore necessary. This resulted in system design requirements which included many conflicting areas.

In the early design stage several construction materials were considered such as, wood, polyester and aluminium from which the latter proved to be the most suitable and as result a first prototype was built.
The tests with this prototype indicated that it was not possible to utilize existing construction elements for the final design.
It was therefore necessary to re-design each part, based on special aluminium extrusions after which a second prototype had to be constructed.

This second prototype was subject to a detailed full strength and stability analysis which successfully proved the technical feasibility of the complete design concept.
A series of photographs showing the final version as an assault craft and as part of a rafting combination. (figure 7 and 8) underline the foregoing.

2. HISTORICAL REVIEW OF THE "M2" ASSAULT CRAFT AND HER RAFTING CAPABILITIES

During the design stage of the new Assault Craft also has been looked into the history of the so-called wooden "M2" Assault Craft as used by the allied forces during World War II. The design originated from the Unitated States Army and the craft proved their capabilities on numerous occasions during military actions. One of them was the crossing of the Moselle River north of Nancy by the Third Army on 5th September 1944.
The record and flexibility of the "M2" must have impressed the Royal Netherlands Army so well that the construction of 500 "M2" Assault Craft together with the wooden tracks and accessories was ordered. The craft were used from 1950 until 1970 and after that period were phased out until 1980.

The design was almost a copy of the U.S. Army design and the main particulars can be seen in figure 2.
The material used was a marine grade plywood with metal fittings.
The rafting capabilities of the "M2" were designed to be sufficient for the first crossing of a waterway by Engineers and Infantry. When coupled stern to stern they formed one pontoon or in boating terms a so-called "double ender" with the possibility to fit an outboard motor (OBM) on each bow section.
The carrying capacity of the rafts were usually up to Class 5 (5000 kg) for a single vehicle on a raft made of 3 pontoons (6 craft) and 8 tracks with the necessary accessories.
In an emergency case the capacity could be increased to 8000 kg. The tracks were also made of marine plywood and could be coupled with stainless steel pins. Main particulars of the tracks are also given in figure 1.

For rolling on and rolling off, the raft needed a fixed support on the riverbeds so that the outer tracks could spread the wheel loads of the vehicle and so ascertain enough transverse stability. Later on in section 6 it is to be seen that the ro-ro mode results in the heaviest loading condition for a raft.

"M2" Assault Craft

Length o.a.	4,10 m
Beam o.a.	1,80 m
Depth	0,69 m
Weight	200 kg
Outboard motor	25 hp
Material	marine plywood
Buoyancy when turned over	very little 0-5 kg
Way of storing	stacked upside down with a maximum of 12 boats
Maximum Carrying cap.	
- as assault craft	15 men (without OBM)
- during rafting	1350 kg

"M2" Tracks

Length	3,65 m
Width	0,92 m
Thickness	0,18 m
Weight	180 kg
Material	marine plywood

Figure 1 Main particulars "M2" Assault Craft and Tracks

The tracks were fitted on the boats by steel clamps and the track couplings had a longitudinal reinforcement by means of wooden side rail curbs with a cross section of 10 x 15 cm and a length of 3,65 m. The side rail curbs were usually fitted on the inner side of the trackway to guide the tires of the vehicles.
Bridgebuilding could be done by coupling the rafts together with sufficient shore anchors and lines to keep the whole bridge in its designed position, in line with the shore supports for the end of the tracks.
With a riverstream of more than 1.0 m/sec or in rough weather conditions the carrying capacity was downgraded.
The maximum configuration of a single raft was 7 pontoons (14 craft) with a total capacity of 12.000 kg divided over equal loads, or vehicles of not more than 5000 kg each.
The maximum advised bridge span was 57 m and for this span 18 pontoons (36 craft) were needed. The use of the bridge was a temporary one and only meant for assault purposes.

3. DESIGN REQUIREMENTS FOR A NEW GENERATION ASSAULT AND INSPECTION CRAFT WITH RAFTING AND BRIDGEBUILDING CAPABILITIES

The design requirements that could be compiled after merging the requirements as described in section 1, can be summarized as follows:

3.1 Operational profile:

Operational areas could range from very shallow rivers to estuaries and along the beach and the craft had to be unsinkable with sufficient positive buoyancy under all conditions even when turned over or damaged. The operational profile also included the possibility of beaching and the subsequent leaving the craft via the bow. Other important design criteria resulting from the operational profile were low maintenance in general and the possibilities of quick repairs during frontline operations.

The bilges of the craft had to be selfdraining when moored during a rain season.

3.2 Size:

The size of the craft had to be such that transportation in a 3 ton army vehicle or in a C 130 aircraft would be possible. Length, beam and depth should allow nesting upside down.

3.3 Portability

The craft's weight had to be limited to slightly above 200 kg to facilitate portability by 6 or 8 men. Two ways of portability had to be envisaged, i.e. upside down on the shoulders (with a smooth gunwale top), or by hand (with a portaging rail).

3.4 Loading capacity

The craft should be able to carry a fully equipped infantry section of 10 - 12 men with 2 or 3 engineers as crew members. For transportation purposes the craft should be able to carry a payload of 1800 kg, divided over a minimum floor area of 6,7 m^2.

3.5 Propulsion:

Depth, gunwale and internal lay-out had to be designed to allow four men to paddle the craft.

When using outboard motors, positioning of two 40 h.p. motors at the stern or one 40 h.p. motor at the bow had to be achieved (preferably without special brackets).

3.6 Rafting capabilities

The rafting capabilities could be specified as follows:

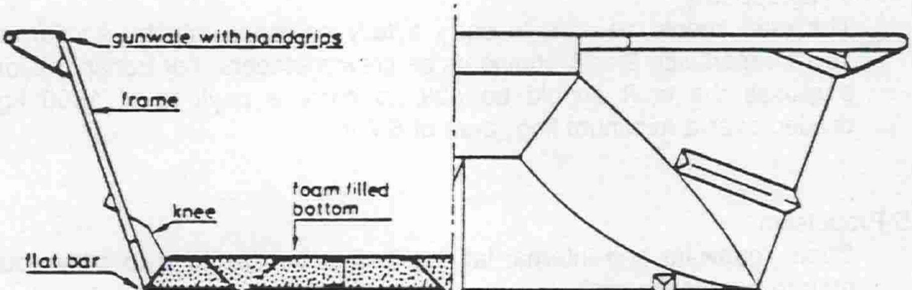
- a loading capability of: MLC.6 or a 3 ton army vehicle with single or twin rear tires, or a Landrover with a standard army trailer,
- a raft configuration: not to exceed 4 craft,
- the trackways: to be light and interchangeable with the ramps,
- the design: to be such that no special shore supports would have to be constructed for the ramps.

3.7 Bridge building capabilities:

The single rafts should be capable of being coupled together to form a bridge with a capacity for vehicles of MLC.8. Bridge span in riverstream would be a matter of further investigation.

4. THE FIRST DESIGN AND PROTOTYPE

After compiling the fore mentioned requirements at the end of 1983, the time available for detailed design work and construction of the prototype was running short and so the choice was made for a completely fabricated aluminium construction method as shown in figure 2.
The main reasons for this method were, as we look at it now, not so well balanced as they should have been. Also the fact that the craft were not used by "boating people" but by engineers, hating all loose items, were underestimated. However those involved in small boat designing will probably recognize these points.



Length o.a.	5,45 m
Beam o.a.	2,23 m
Depth	0,61 m
Weight	247 kg
Outboard motor	one at the stern or one at the bow
Material	aluminium alloy
Buoyancy when turned over	200 kg positive
Maximum Carrying cap.	
- as assault craft	16 men with OBM
- during rafting	1800 kg

Figure 2 Cross section and main particulars of the first prototype

The craft itself was not the main factor for the end users to send us back to the drawing board as we will show later on.

The only observation was that the bow of the craft in its loaded catamaran configuration, caused two bow waves, which curled up at the centerline of the craft and were then reflected causing spraywater over the sides.

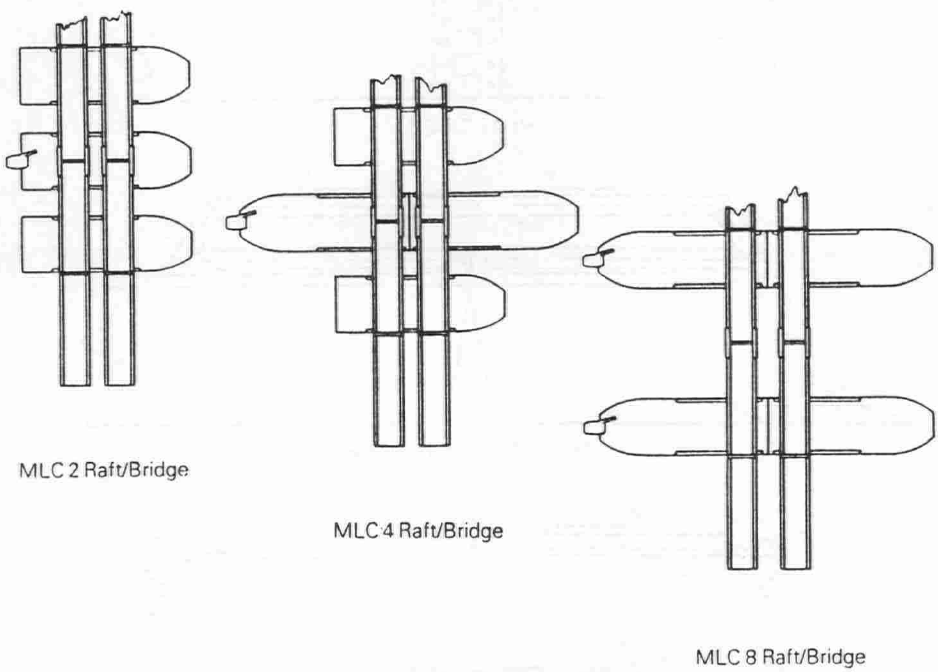


Figure 3 Three different rafting configurations with their maximum load class

Nearly all the design requirements from section 3 could be met, but it was the weight and assembling time of all the accessories needed for rafting, which caused most of the user's observations during the various tests in 1984.

When looking into the design of the raft we selected three onfigurations to place the craft under the tracks and three stern to stern coupling methods for further investigation. The three configurations to place the craft under the tracks can be seen in figure 3 and the three coupling methods of the stern in figure 4.
The transverse stability tests as described in section 6 proved that the so-called "catamaran" configuration could cope with MLC.6 with hinged outer ramps and without any special riverbed supports. The "single" and "trimaran" configuration could cope with MLC.2 respectively MLC.4.
The selection between the three configurations for the coupling of the sterns caused most of the problems. During normal operation the longitudinal loads on the raft are more important than the transverse loads, but during rolling on and rolling off the transverse loads are more serious to cope with (this is dealt with in detail in section 7).

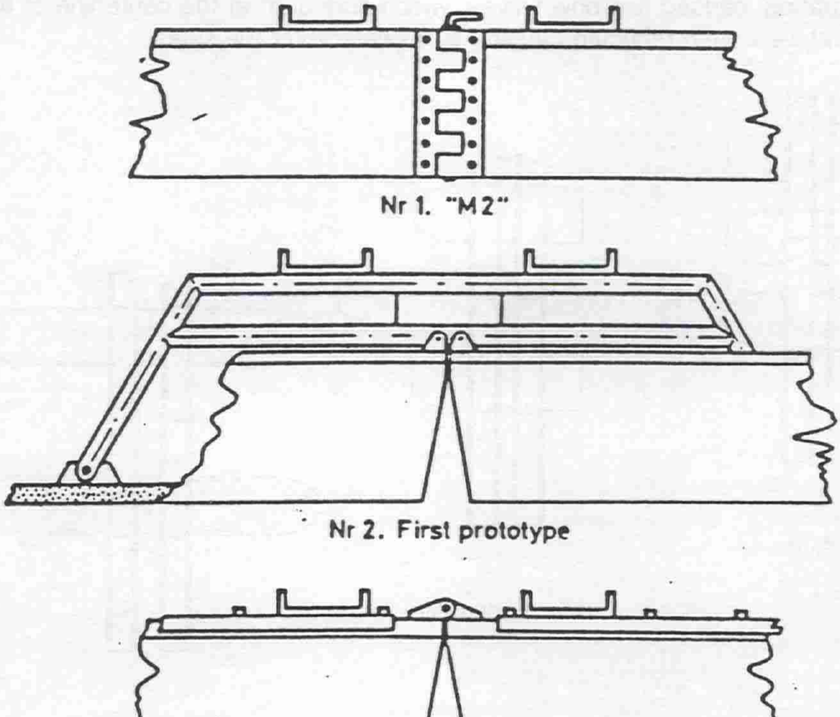
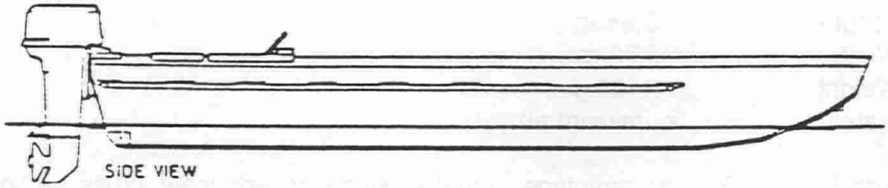


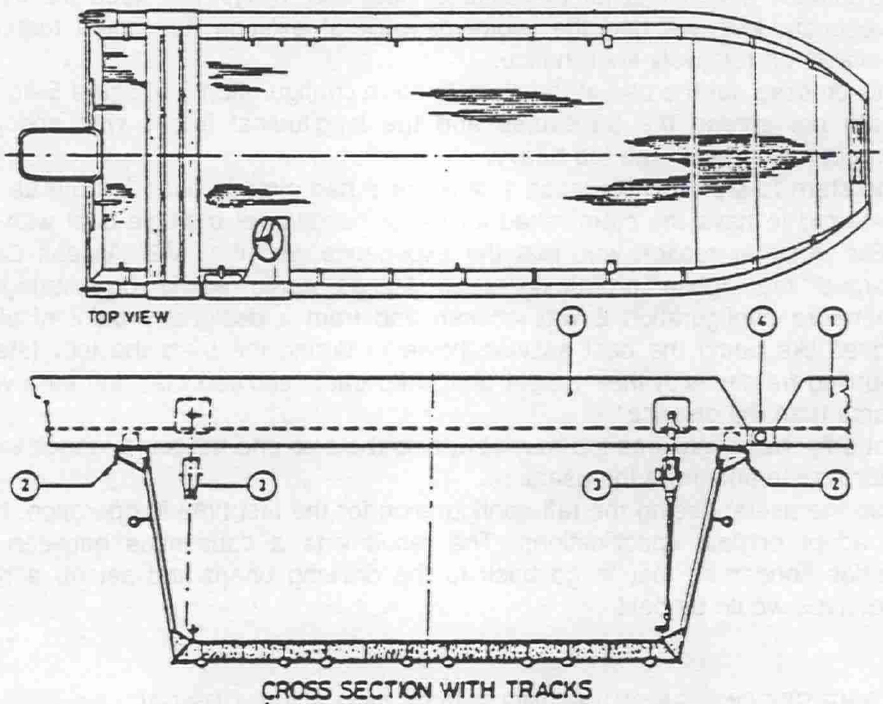
Figure 4 Three different stern to stern coupling methods

We already stated that for the sake of time and in trying to keep the initial investment low, we had the prototype built of existing aluminium material available on relatively short notice.
This crossed out the use of the stern to stern configuration 3 of figure 5 as we could not spread the transverse and the longitudinal forces well enough, without making the craft too heavy.
The stern to stern configuration 1 of figure 5 had already been left out as we preferred to have the stern raked for better handling of a single boat with an OBM. Another reason was that the experience with the "M2" Assault Craft learned that these protruding stern fittings could easily be damaged. Therefore configuration 2 was chosen and from a designer's point of view looked like being the best answer, however during the trials the four (steel) coupling frames with their weight of 130 kg each, showed that "the cure was worse than the disease".
Not only the weight was too much but also the size and the sharp edges were causing remarks from the users.
Also the users, seeing the raft configuration for the first time in operation, had to adapt original specifications. The result was a consensus between all parties concerned that to go back to the drawing board and set up a new prototype would be best.

5. THE SECOND ENGINEERING PHASE AND FINAL DESIGN

It was during the second half of 1984 that we could start with the engineering phase of another prototype.
We knew the major and minor observations from the operators with regard to the craft and rafting equipment but we had also made an even longer list of points that we wanted to change or redesign ourselves.
One target we had set ourselves was an overall weight reduction of 10% for the craft. We will come to the other points later on in this section when clarifying the cross-section of the new design as shown in figure 5.





Length o.a.	5,40 m
Beam o.a.	1,80 m
Depth	0,62 m
Weight	225 kg
Outboard motor	two 40 h.p. at the stern or one at the bow
Material	aluminium alloy
Buoyancy when turned over	200 kg positive
Way of storing	stacked upside down with a maximum of 12 boats
Maximum Carrying cap.	
- as assault craft	16 men with OBM
- during rafting	1800 kg

Damen Tracks

Length	3,65 m
Width	0,76 m
Weight	110 kg
Material	aluminium alloy

Figure 5. Second prototype - Final version with side view, cross section and main particulars.

5.1 The major changes

The change of the bow wave in the catamaran configuration was a point which had to be solved first as any change would influence the hull lines and consequently the stability.
After extensive discussions with representatives from Marin Tanktest Laboratories at Wageningen, we decided to change the bow lines to only one chine and change the slope of the bottom lines.
Another major change to be made, was with regard to the stern to stern coupling method. We decided to choose the method of figure 4 no.3 and re-design and optimalize all structural members of the craft and the rafting equipment.
Subsequently all together 12 new aluminium extrusions had to be made. Some of them so difficult that a lot of engineering had to be undertaken by the manufacturers of the moulds and the extrusions. Points of discussion were the quality and the lifespan of the complicated moulds and the tolerance on the thickness of the plating.
The most difficult extrusions were the bottom sections, where each section would have a width of 360 mm and four separate channels (two for foam and two for the rubbing strakes).
The moulds of these sections cracked several times or gave a much wider thickness variation than allowed according to DIN 1748 which we had set as a standard. Finally the suppliers were able to improve the moulds such that a reasonable life span and a good quality was achieved.

5.2 The second prototype

The results of all these different actions can best be discussed with the cross section of the second prototype as shown in figure 5.

- The craft's weight could be reduced to 225 kg.
- A portaging rail was added under the gunwale to facilitate lifting and walking with the craft with stretched arms.
- the beam was reduced to 1.80 m. by reducing the width of the gunwale and a little less slope of the sides.
- Nesting was improved by fitting four knees with a nylon top plate to support the next craft.
- The stern plating was redesigned to carry two OBM's.
- The non-skid painting of the floor plates could be replaced by a non-skid

pattern in the aluminium bottom sections.

- The reduced width of the gunwale also improved the paddling of the boat. For night operations the gunwales were filled with foam to reduce the contact noises.

The cross section of figure 5 also shows the changed method for fastening the tracks where:

1 = Aluminium track with male and female hinged coup-lings (4) and notches in the bottom plating to fit over the aluminium gunwale saddles.

2 = Gunwale saddle with aluminium blocks. The saddle fits around the gunwale with a securing device and spreads the loads of the tracks. The coupling between the saddle and the craft and the saddle and the track is such that the cross section acts as if it were closed. The aluminium saddles are light and long enough to adjust the width between the tracks for any kind of army vehicle within the range of MLC.8

3 = Standard nylon straps for fastening the tracks to the craft. The welded hooks on the top of the chines do not obstruct the crew and on the other hand provide enough fastening facilities for all loose items such as paddles, fuel tanks, etc.

4 = Hinged coupling of tracks when used as ramps. The ends can also be coupled fixed with an aluminium C-channel fastened over the curb rail sides of the tracks.

5.3 Final tests and production

The production of the second prototype took of course much longer than the first but extensive stability and strength tests could start by mid 1985. The method of testing and the results are further described and detailed in section 6, 7 and 8.

Figure 6 The new craft used for assault purposes

Figure 7 Four Damen assault craft in a catamaran configuration for an MLC.6 raft

6. TRANSVERSE STABILITY MULTI-HULL CRAFT

The transverse stability is mainly determined by the metacentric height GM (see figure 8) where:

$GM = KM - KG$

$GM = KB + BM - KG$

and $BM = \frac{I_{TOT}}{V}$

with $I_{TOT} = N.I + O.A.a^2$

while

$$I = 2\int_0^L y^2.dA$$

$$A = 2\int_0^L y.dx$$

$$V = 2N\int_0^L \int_0^{B/2} \int_0^T dx.dy.dz$$

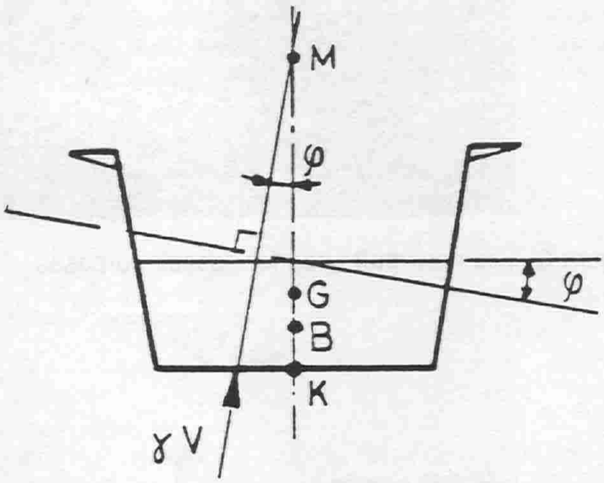


Figure 8
Transverse stability and metacentric height
(single raft N = 3, O = 2)

In general with multi-hull craft, the product $A.a^2$ is far greater than the term I and therefore is a determining factor in the magnitude of GM.
The values KB and BM depend on the craft's dimensions whereas the value of KG is more weight related.
By ro-ro operations the transverse stability of the complete system should be well evaluated for the given range of vehicles concerned.

In figure 10 an example is shown of a step by step evaluation of the transverse stability of a similar system during roll on and roll off operations. The system used in this example represents the catamaran configuration (figure 4) with the exception that the four basic float-ing units have been simplified in smaller dimensions, form and weights in order to show the possible presence of critical situations. The vehicle wheel base length was assumed to be 4.5 m.
The following magnitudes were considered when evaluating the transverse stability (not all of these are shown in figure 10).

- front axle load component
- resulting heeling moment component
- rear axle load component
- resulting heeling moment component
- resulting total axle load component (P)
- resulting ditto heeling moment component (MP)
- vertical centre of buoyancy of the system (heeling angle = 0)
- metacentric radius of the system (heeling angle = 0)
- metacentric height above the baseline of the system (heeling angle = 0)
- vertical centre of gravity of the system (heeling angle = 0)
- metacentric height of the system (heeling angle = 0)
- static angle of heel of the system (0)
- starboard draft of the system (T_{SB})
- average draft of the system (T_{avg})
- portside draft of the system (T_{PS})
- increase in starboard draft of the system (DT_{SB})
- total displacement of the system (D)
- average displacement of the starboard floating unit of the system (D_{SBA})
- average of the portside floating unit of the system (D_{PSA})

From the example in figure 9 can be seen that the portside draft of the system enters an area of negative values on two different occasions i.e. at distances of 3 m and 14.5 m of the front axle contact point taken from the initial point of rafting.
The presence of such negative areas is hypothetical as the system ceases to be a multi-hull system upon the occurrence of such a negative value; i.e. the system becomes that of a mono-hull system with a second similar hull system hanging out on one side at a given distance.
This is an unstable condition as I_{TOT} has diminished greatly (by constant system volume displacement) and the system will therefore rapidly capsize.

It is evident to all that scenarios which could cause such situations should be tracked down on paper and be avoided at all costs during the operational lifespan of such systems. Avoiding such disastrous situations may be realised by

1) avoiding the scenarios which lead the system into unstable areas e.g. change the vehicle to be loaded (i.e. reduce MLC.) and/or increase the total empty weight of the system,
2) change the configuration of the system in such a way that the unstable areas become stable ones e.g. by increasing the breadth between the outer floating units. As soon as the operational profile of the above system changes and a riverbed support is allowed (whereby fixed tracks throughout are employed) the loading capacity can be increased.

The safe operational areas for such systems could be presented as per figure 10 after many such scenarios (e.g. given wheel base and variable axle loads) have been evaluated for a given system.

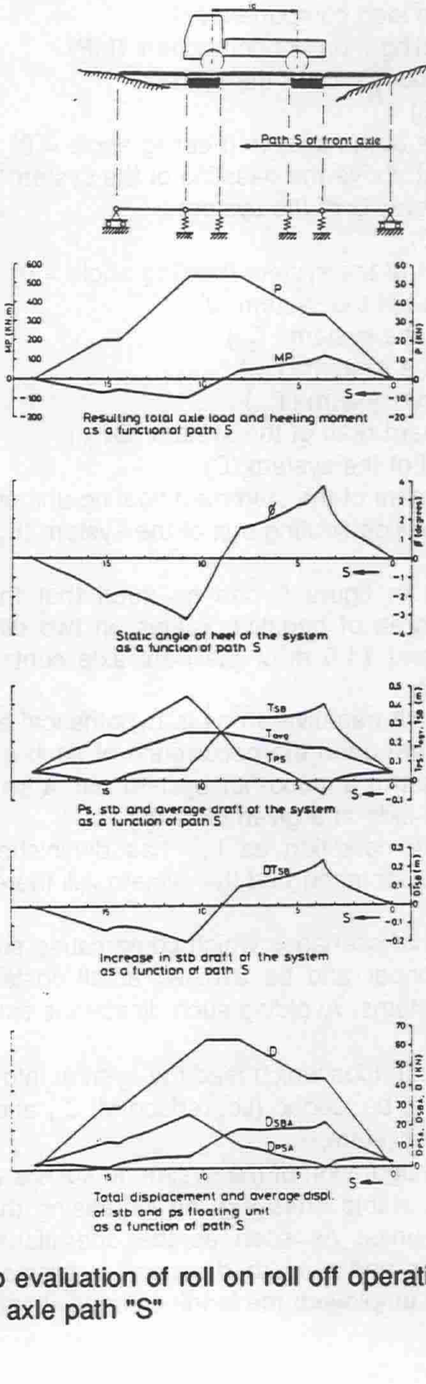
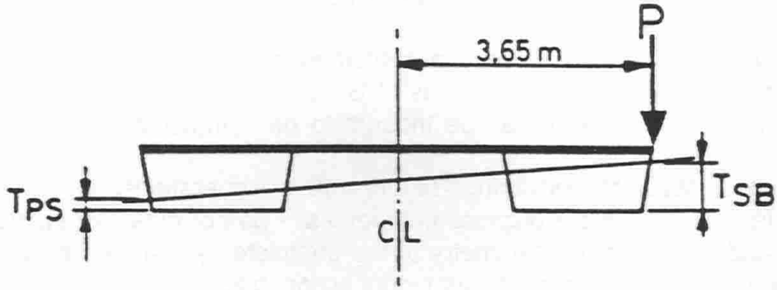


Figure 9 Step by step evaluation of roll on roll off operation as a function of vehicle front axle path "S"



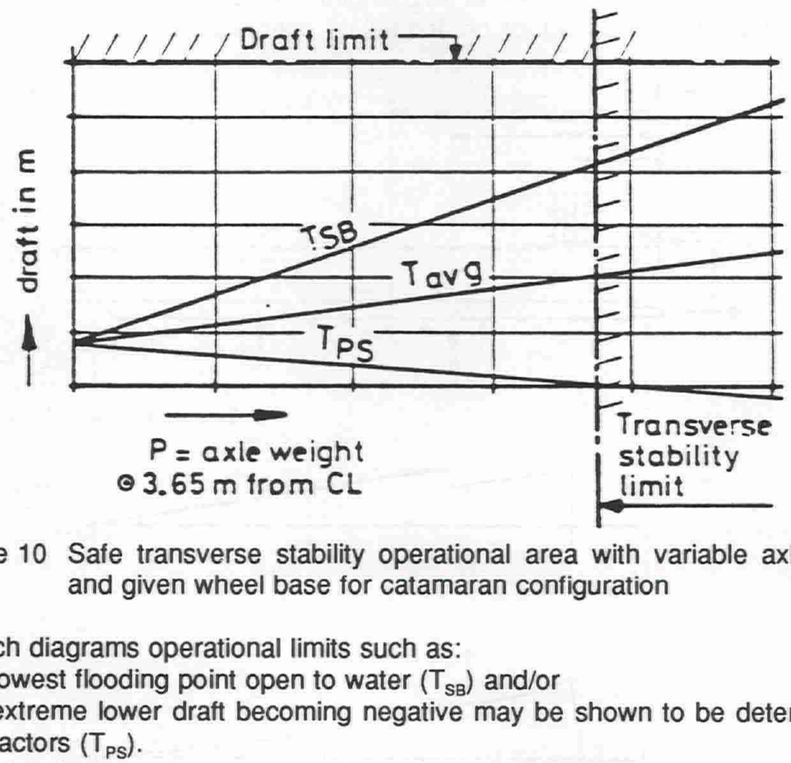


Figure 10 Safe transverse stability operational area with variable axle load and given wheel base for catamaran configuration

In such diagrams operational limits such as:

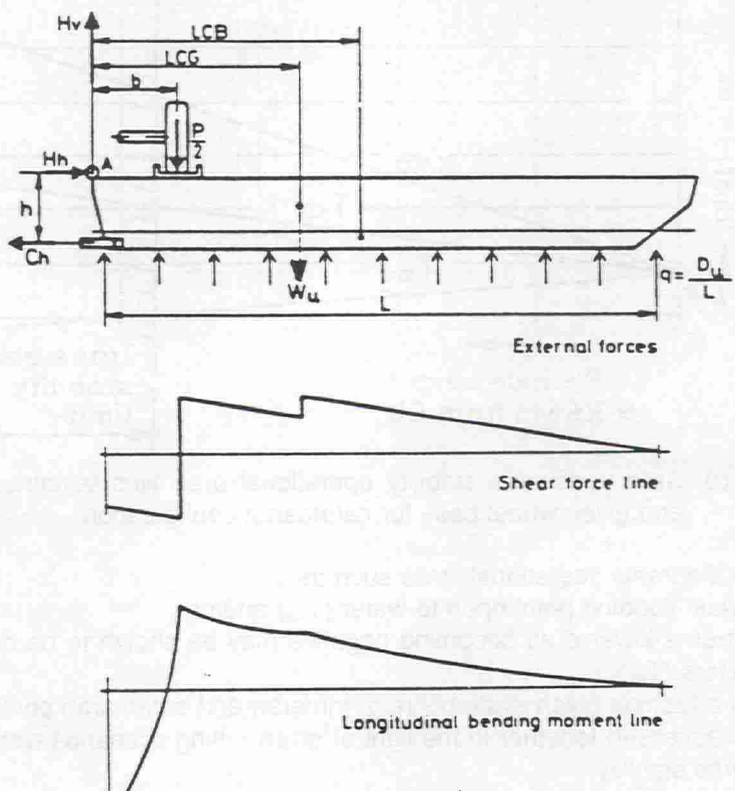
1 - lowest flooding point open to water (T_{SB}) and/or
2 - extreme lower draft becoming negative may be shown to be determining factors (T_{PS}).

In such a fashion given system - (e.g. trimaran and catamaran configurations) may be assessed together in the light of given rafting scenarios with regard to transverse stability.

7. STRENGTH CONSIDERATIONS

The catamaran configuration shown in figure 3 will be considered.
In a state of equilibrium before roll on takes place the system has eight (sub)components with regard to external forces acting on the system namely:

a - 4 displacement (buoyancy) forces (1 per unit)
b - 4 unit weights
Each of these external forces have their own unique point of action in the system. For the displacement this is LCB and for the unit weights this is LCG. Furthermore the system may be thought to be symmetrical about two axes; i.e. X and Y.
In such a state of equilibrium before roll on operations, in general, unit weights - (and therefore displacement forces) - do not differ largely from each other and regarding the symmetry of the complete system one may conclude that the four hinges and the four connection bars - all to be found at the transom of the units - have then virtually no induced reaction forces.
These induced reaction forces at the hinges and connection bars become apparently significant during roll on and roll off operations.



$\Sigma F_V = 0 \; : Hv = D_u - W_u - P/2$

$\Sigma F_H = 0 \; : Ch = Hh$

$\Sigma M_A = 0 \; : Ch = (D_u \cdot LCB - W_u \cdot LCG - P/2 \cdot b)/h$

Figure 11 Hinge and connection bar reaction forces during roll on roll off operations

7.1 Induced hinge and connection bar forces during roll on and roll off operations.

During roll on and roll off operations the following longitudinal bending moment line may be drawn up for one of the two catamaran units on the side where the rafting takes place - see figure 11.

The terms used to deduce these forces are also mentioned in figure 11.
During roll on operations the sign and magnitude of these forces may vary strongly with the axle load (P) and momentaneous displacement of the floating unit under consideration (Du)-(all other parameters remaining almost constant in the formulae).

The maximum incurred values could for some scenarios be unacceptably high and thereby form an operational limit for a given system.

8. FULL SCALE STRENGTH AND STABILITY ANALYSIS

In 1985 full scale strength and stability tests were carried out with the catamaran configuration as shown in figure 4 during which the roll on operation of an MLC.6 vehicle was simulated with the aid of weights.
The following section describes the measurement configuration and shows representation of these stresses for measurement run no. 3. Stresses were measured with the aid of 24 strain gauges.

8.1 Simulation of the roll on operation of an MLC.6 vehicle

The total front and rear axle loads (and points of contact) used in the different measurement runs are shown in figure 12. Variable wheel bases (l_a) were simulated in order to investigate extremes.

8.2 The measured tensile, compressive and shear stresses

One of the strain gauges showed that there was a local peak stress present on the top of the gunwale during measurement runs 3, 4 and 5. This compressive stress, in combination with a local high shear force, resulted in a local deformation of the upper gunwale area behind the hinge concerned. See figure 13.

This plastic deformation was however short of duration, as it had largely disappeared within 24 hours. This local deformation problem was solved with an extension of the baseplate supporting the hinge concerned, thus reducing

the local shear force by approximately 40%.
An extra frame was also placed in the vicinity of the hinge.

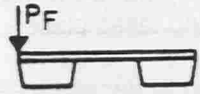
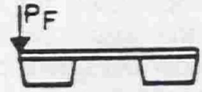
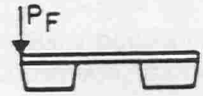
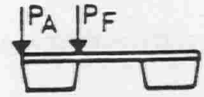
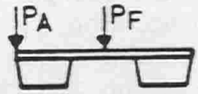
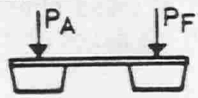
Measurement run numbers	P_A (KN)	P_F (KN)	Situations
1	—	2 x 10	
2	—	2x 15	
3	—	2 x 17	
4	2x5	2 x 17	
5	2x10	2 x 17	
6	2x10	2 x 17	

Figure 12 Simulation of a roll on operation of a 5.4 tons (54 KN) truck having a front axle load PF of 3.4 tons (34 KN) and a rear axle load PA of 2.0 tons (20KN) with the aid of weights.

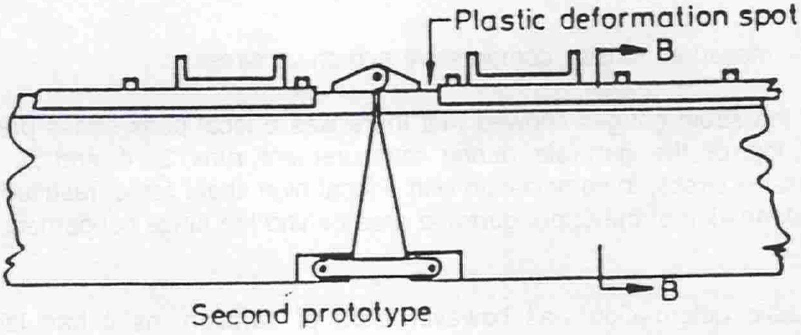


Figure 13 Hinge with local plastic deformation during simulation

Further tests with a vehicle carried out at a later date proved these solutions to be correct and effective and later on for the final production line the gunwale extrusion profile thickness (i.e. moment of inertia) was also increased.

The other measured tensile, compressive and shear stresses showed that no alarming values were met.

8.3 Three dimensional representation of measured stresses during the simulation runs

Figure 14 shows a three dimensional representation of the measured longitudinal and shear force stresses and interpolated tendency values between these discrete values for the cross section monitored during the simulation run number 3. This cross section was situated just in front of the track (see figure 13 B-B).
It is important to be aware of the fact that the peak values presented are interpolated values, which have been deduced from the discretely measured values; in reality these values will be lower, due to the fact that more material is available at these construction corners i.e. gunwale and bilge areas than is the case at the measurement points.

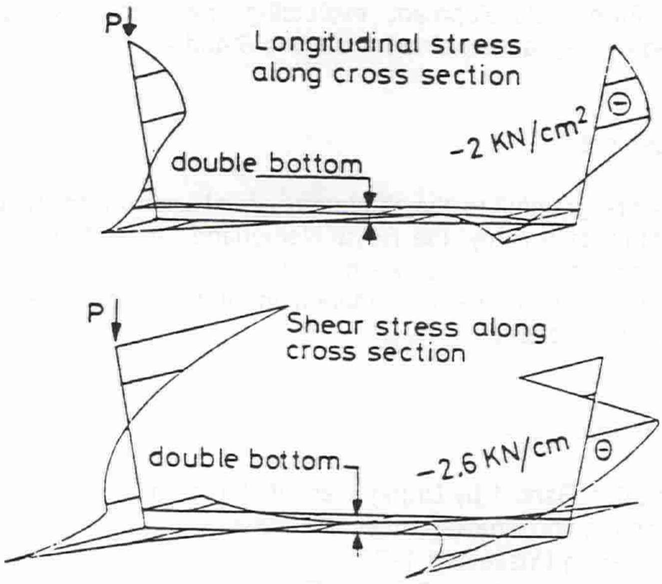


Figure 14 Three dimensional graph of maximum measured stresses during simulation.

0 = Compression.
Permissable longitudinal stress = 12 KN/cm^2 Permissable shear stress = 7 KN/cm^2

Also good notice should be taken with regard to the positive effects that the track, horizontally placed across the measured cross section, has on both the tensile and the shear stresses. Positive in that respect is, that these stresses are reduced due to the presence of the track. This is due to the fact that the track across the gunwale forms an integral part of the cross section as described in detail in section 5.

9. CONCLUSIONS

The assault and inspection craft and the different rafting configurations meet the design and operational requirements very well.
The operational limitations with the catamaran rafting configurations for Classes in excess of MLC.6 during roll on and roll off operations will at first be formed by the transverse stability requirements and secondly by the strength requirements.
Such multi-hull configurations for rafting should be accompanied by good user's handbooks in which a wide range of roll on and roll off scenarios are being dealt with.
A computer simulation model for these multi-hull configuration is now undergoing further development evaluating the transverse stability and strength step by step as explained in section 6 and 7.

Acknowledgement.

The authors are greatfull to the Staffmembers of Limbongan Timor Shipyard, The Royal Malaysian Army, the Royal Netherlands Army Corps of Engineers and to all sub-contractors concerned, for their valuable comments and assistance, resulting in the implementation of the design as a whole, as presented with this paper.

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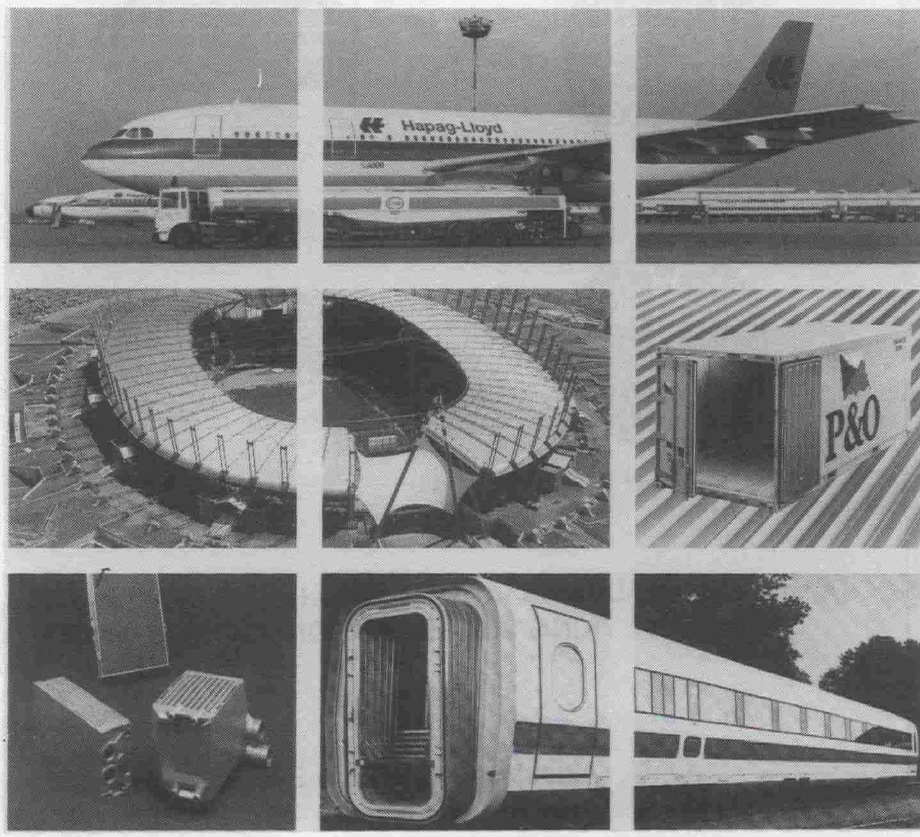
  Vught, Netherlands

Symbols

GM	Metacentric height (transverse)
KM	Metacentric height above base line
BM	Metacentric radius
KB	Vertical centre of buoyancy above base line
KG	System centre of gravity above base line
I	Waterline moment of inertia of a single floating unit about its own longitudinal symmetry axis
A	Waterline area of a single floating unit
a	Distance centroid of "A" to longitudinal symmetry axis multi-hull craft configuration
N	Number of floating units in multi-hull craft configuration under consideration
O	Number of outer floating units in multi-hull craft configuration under consideration
V	Displacement volume multi-hull craft configuration
L	Waterline length of floating unit
y	Elementary waterline breadth floating unit
B	Maximum breadth floating unit
T	Draft floating unit
ϕ	Static angle of heel
g	Specific gravity water
b	Horizontal distance between axle load and hinge on stern
LCG	Longitudinal centre of gravity of floating unit measured from hinge on stern
LCB	Longitudinal centre of buoyancy of floating unit measured from hinge on stern
Du	Momentaneous displacement of floating unit
Wu	Weight of floating unit
q	Uniformly distributed momentaneous displacement (Du) over craft waterline length
H_v	Total vertical hinge reaction force floating unit
H_h	Total horizontal hinge reaction force floating unit
C_h	Total horizontal connection rod reaction force floating unit
h	Vertical distance between connection rod reaction force and hinge on stern of floating unit
P	Total momentaneous axle load acting on multi-hull craft configuration
P_A	Total momentaneous rear axle load acting on multi-hull craft configuration
P_F	Total momentaneous front axle load acting on multi-hull craft configuration

Die Summe guter Erfahrungen



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