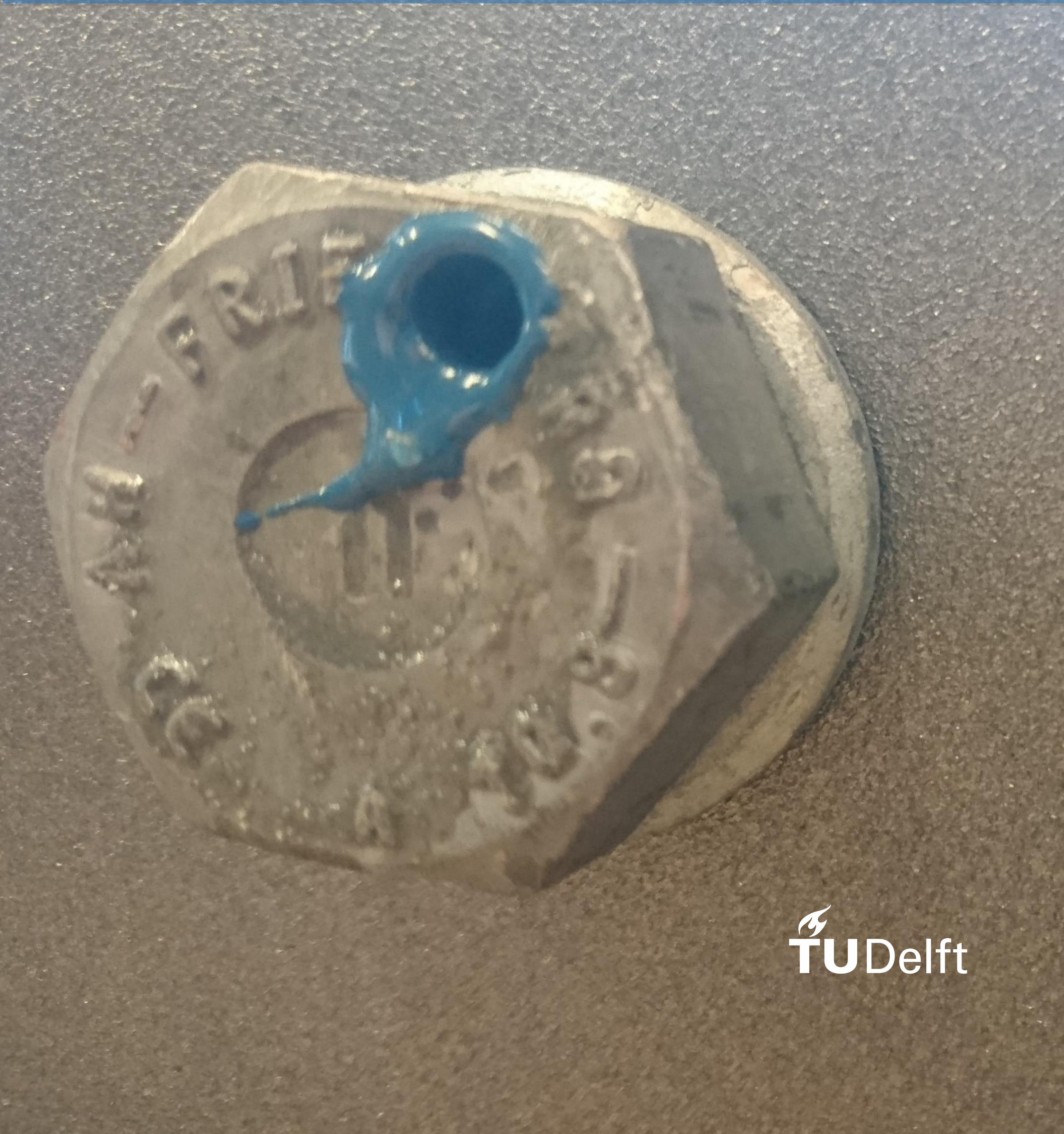
Assessment of Epoxy Resins for Injected Bolted Shear Connections

Axel Koper



TU Delft

Assessment of Epoxy Resins for Injected Bolted Shear Connections

An experimental research on double lap shear connections with injected bolts

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1 Preface

This thesis is submitted for the requirements of the Structural Engineering master track at the Faculty of Civil Engineering and Geo Sciences of the Delft University of Technology. The topic of the thesis is an investigation into resin products for application in injected bolted connections in civil engineering steel structures. The research is mainly focused on alternative resin in a double lap shear application.

I started to work on this thesis in 2016 mainly focusing on investigating the admittedly limited research base of the topic of resin applications in civil engineering practice. Throughout the year, I have tested resins in the Stevin Laboratory of TU Delft. For this I would like to express my gratitude to the lab staff and more specifically J. Hermsen and F.J.P. Schilperoort for helping me to perform the tests in the Stevin Laboratory.

Also, I would of course like to extend my gratitude towards the members of my assessment committee, Prof. dr. M. Veljkovic, ir. P.A. de Vries, Drs. W.F. Gard and in particular dr. Çopuroğlu for joining my committee at a later stage.

Furthermore, I would like to thank G. van Bolderen, M. Mureau, C. Hagen and C.A. van Hoogdalem. Working on my thesis in parallel with them in the Office of Stevin II 1.34 has given me a lot of support. Of course, I also want to thank my parents for supporting me during this thesis but also throughout my time as a student at the TU Delft.

Axel Koper

Delft, May 2017

2 Abstract

The purpose of this thesis is to assess potential alternative epoxy resins in injected bolted shear connections for a civil engineering application. Research has focused on the application of injection bolts with various resins in a double lap shear connection.

In current practice only one resin is allowed to be used due to regulation by RWS. This is RenGel SW404/HY2404 resin [1]. To assess possible alternatives different products have been selected that have potential for use in this application. To verify their performance, short duration double lap shear tests have been performed in the Stevin Laboratory. The curing temperature of the resin was varied in testing to assess the influence this has on performance, and gain further insight in the importance of material properties of resins for injection bolts.

Secondly the stress distribution of the resin layer has been investigated by developing an analytical model using 1 dimensional Timoshenko beam theory. This model was calibrated using results from lab tests and verified against FEM results and other experiments.

From this research, it is concluded that only Edilon Dex R2K resin is a possible alternative resin. The injection procedure is simplified with this product but it suffers from large scatter in results in this research. The found characteristic short term strength is 156 MPa when cured at 16 degrees Celsius. Curing temperature had no influence for RenGel SW404/HY2404 between 8 and 24 degrees. Dex R2K did have a positive dependency in this range. Lastly the research into the effect of bolt length shows a trend that the connection capacity remains the same or increases slightly for L/D ratios above 3.

From this research, it is recommended to gain further insight in the mechanical behavior of injection bolt connections through FEM analysis. Furthermore, development of alternative washer designs and research into optimized injection procedures are recommended. Lastly the occurrence of air inclusions in the resin layer as noticed in this research is something to be investigated in future research.

Table of Contents

3 List of symbols and acronyms

A	Area
l	Length of connection plate package
d	Bolt shank diameter
E	Young's Modulus
ϵ_{plate}	Strain of plate
Δl_{plate}	Elongation of plate
l_{CBG}	Length between measurement location and CBG
σ_{plate}	Stress in connection plate
$f_{b,resin}$	Bearing stress of resin
$f_{b,resin,short}$	Short duration bearing stress of resin
F	Force
k	Spring stiffness
μ	Slip factor
ν	Poisson ratio
π	Pi constant (3.14)
T_g	Glass transition temperature of resin
$F_{b,Rd,resin}$	Bearing strength of injection bolt
β	Coefficient for thickness ratio of connection plates
$t_{b,resin}$	Effective bearing thickness of resin
k_t	Coefficient for limit state
k_s	Coefficient for the hole clearance
m	Difference in mm between the normal and oversized hole size
t_1	Thickness of center plate
t_2	Thickness of cover plate
σ_1	Stress in resin at center plate
σ_2	Stress in resin at outer plates
$\emptyset$	Diameter
L/D	Ratio between length of plate package and bolt diameter
A_s	Effective area in shear for Timoshenko model
G	Shear modulus
I	Second moment of inertia
q	Distributed line load
ϕ	Rotation of bolt in Timoshenko model
v	Vertical deflection of bolt in Timoshenko model
w	Foot displacement of springs in Timoshenko model
V	Shear force in Timoshenko model
M	Moment in Timoshenko model
r	Radius of bolt shank
μ	mean
σ	Standard deviation

CBG	Center of Bolt group
IBC	Injected Bolted Connections
HSFG	High Strength Friction Grip
BVP	Boundary-Value Problem
PE	Plate Edge
ECCS	European Convention for Constructional Steelwork
RTM	Resin Transfer Molding
VARTM	Vacuum Assisted Resin Transfer Molding
PDS	Product Data Sheet
LVDT	Linear Variable Differential Transformer

4 List of Figures

5 List of Tables

6 Introduction

In civil engineering applications steel structures are generally assembled on site from smaller elements to make up the main load bearing structure. It is common practice to use mechanical fasteners such as bolts to join the elements of a steel structure on site. Welding members is only done in specific applications due to the complexity of creating high-quality welds on-site. The joints and connections between the individual elements make up a significant contribution to the total cost of the structure. Therefor the design of joints focuses on the transfer of high loads with low erection costs.

Figure 1 Example of bolted connection in steel structure [2]

Bolted connections in steel structures are fabricated with hole clearances to make assembly on site possible. This leads to some slip occurring in the joints before significant loads can be carried. In specific applications, such as oversized or slotted holes in the connection or the possibility of fatigue and load reversals, connections can be considered slip-critical. [3] These joints must behave rigidly and the mechanical fasteners must provide a slip-resistant connection.

Conventional methods to execute slip-resistant connections is to apply rivets, fitted bolts or preloaded HSFG bolts. Rivets are no longer being applied in modern practice due to the labor-intensiveness. In the Netherlands, an alternative for these methods is the application of injection bolts, which were developed in the 1970s to replace riveted connection in existing structures. [4]

> *“ Injection Bolts are bolts in which the cavity produced by the clearance between the bolt and the wall of the hole is completely filled up with a two-component resin. Filling of the clearance is carried out through a small hole in the head of the bolt. After injection and complete curing, the connection is slip resistant.” [5]*

An illustration of an injection bolt is shown in Figure 2. This is a sawed-through test specimen. The blue material is the cured resin which serves to create a slip-resistant connection.

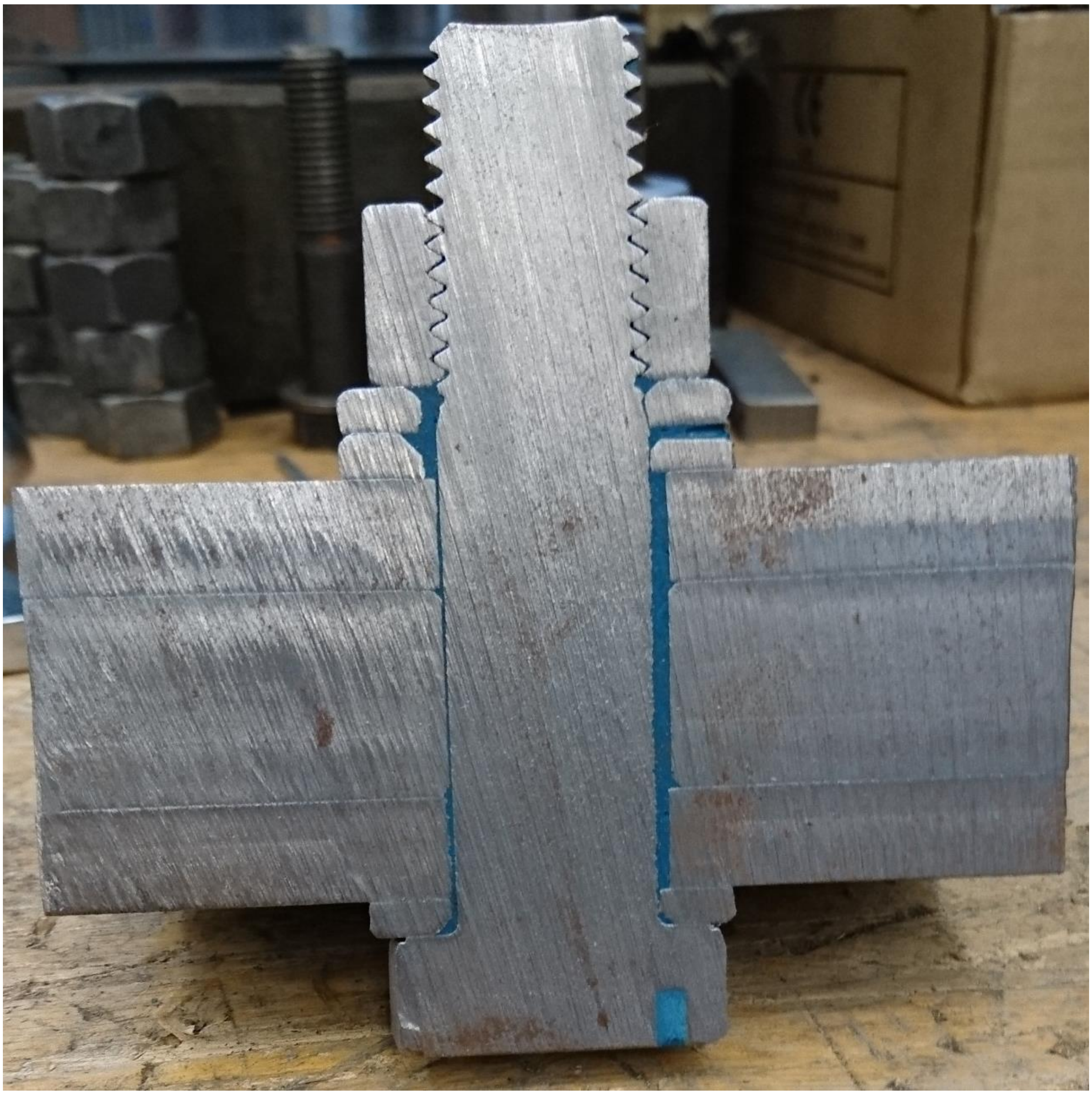


Figure 2 Sawed-through injection bolt connection

6.1 Problem definition

Since the development in the 1970s the use of injection bolts has increased. To achieve economic and safe design rules more research on the application of these bolts is necessary. In current practice the type of resin used is limited to one specific product which was tested in the previous research into the topic. [5] [6] This product is the RenGel SW404/SY2404 epoxy resin. The availability of this product is not guaranteed as the resin applied is not developed specifically for injection bolts. Furthermore, from literature limited information is available about the required properties of epoxies for use in IBC. Finally, since the development of injection bolts in other fields such as aerospace many innovations have taken place on composite structures [7]. Development of new resin products for other applications is ongoing.

The research that has been performed on injection bolts thus far has been based on the testing of actual bolted connections. It is currently unknown by which mechanisms in the resin the deformations that are measured in these connections are caused. To verify the performance of alternative resins, European recommendations specify a testing procedure [8]. Because connections with injection bolts are subject to creep these tests are costly and time consuming, having a runtime that can be more than 1 year [9].

The performance of connections with injection bolts is highly dependent on the bearing stresses that occur in the resin. This is among other things influenced by the ratio between the bolt diameter and the thickness of steel plates. With a relatively long bolt bending deformation leads to an uneven bearing stress distribution in the connection. [5] The exact behavior and stress distribution in the resin layer is not well understood.

From the above-mentioned considerations, the main goals of this thesis are laid out in the following three aspects:

- Investigate the possibilities for application of different resins in injection bolts.
- Try to find a relation between the resin material properties and their performance in the application of injection bolts.
- Analyze the resin stress distribution and influence of the bolt length

6.2 Research questions

From the three goals set out above the following questions relating to these three aspects will be answered in this thesis:

Feasibility of application

- Can alternative resins be injected using the current practice injection procedure?
- Which material properties of a resin product are important for application in IBC?

Mechanical performance of resin products in IBC

- How does the mechanical performance of alternative resins compare to current practice?
- Which properties influence the performance of resins in IBC?

Modelling of stress distribution

What influence does the bolt length have on the resin stress distribution in an IBC?

6.3 Research approach

First the theoretical background on injection bolts will be reviewed and a look into the chemical and material properties of resins. From this literature review a first selection will be made on the important parameters in the selection of alternative products to be further investigated. Based on the results found in this initial research alternative products on the market will be selected as possible alternatives. For this selection of alternative products also input from the suppliers is considered and the information supplied by them.

Taking the information from literature as a basis, a model is developed to assess the stress distribution that is expected in an injected bolted connection. This is done based on an analytical approach to the problem.

The following step is the main body of work of this research project. Testing of the resin products in injected bolted connections. This is done by testing double lap shear connections with injection bolts in the Stevin Laboratory.

Finally, the results obtained from the double lap shear tests are processed to gain more information on the required material properties of resins for this application. Based on this a further step is taken to design a test that could predict performance of resin products in an injected bolted connection.

Finally, the test results obtained will be used to draw a conclusion about the selected and tested alternative epoxy resins products in this research topic.

An overview of the steps taken in this research project are shown in the diagram on the following page.

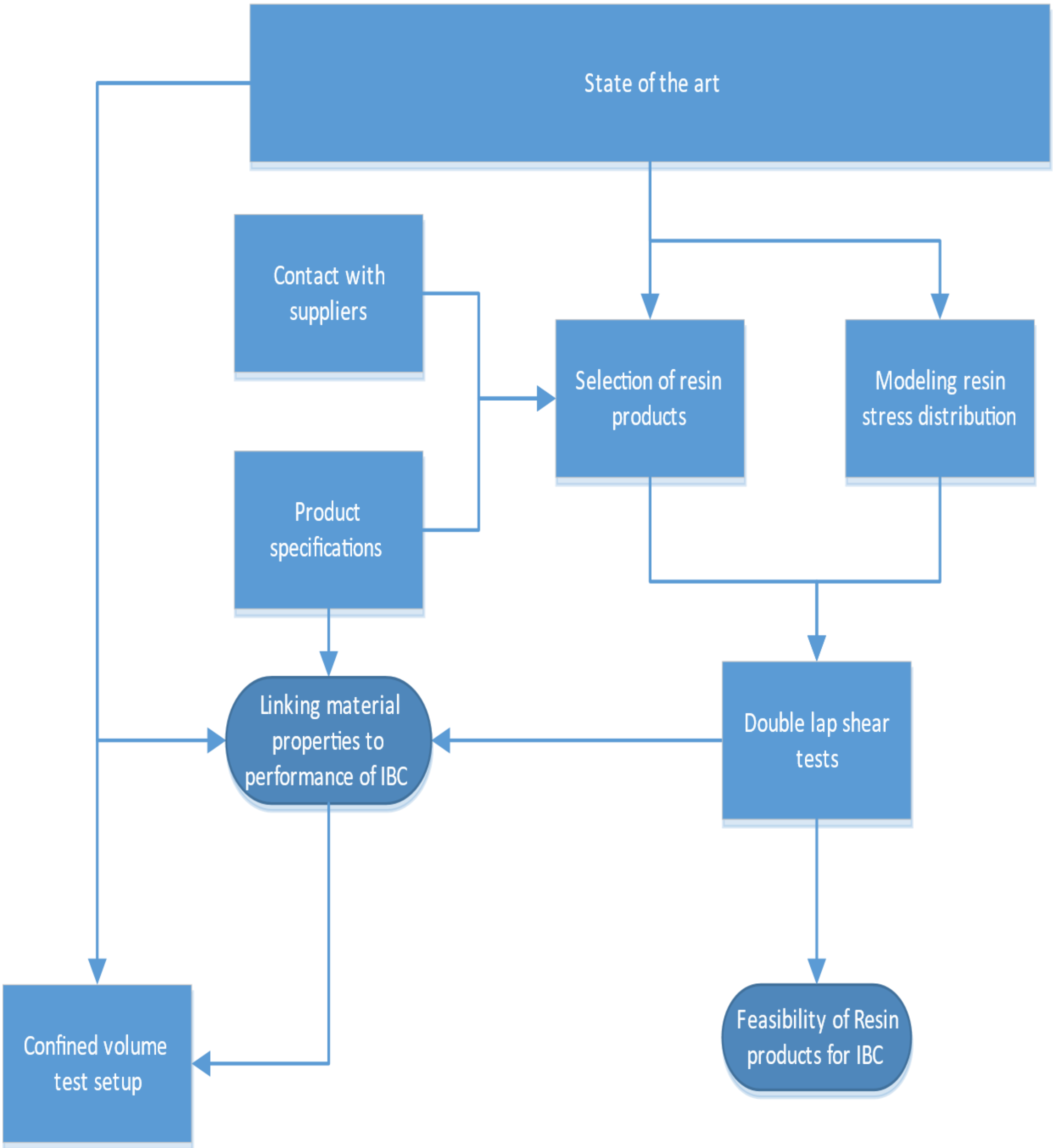


Figure 3 Overview of work flow of this research project

7 State of the Art

7.1 Examples of application of injection bolts

7.1.1 Repair of riveted connections using Injection bolts

Injected bolts are applied successfully to repair old riveted bridge structures. Riveting is no longer a common connection method due to the labor intensiveness, so skilled laborer's and material is hard to find. To repair riveted structures alternative slip-resistant fasteners are thus considered. Using HSFG bolts is not a viable option for old bridges due to the corrosion and paint layers, because this leads to low friction between the plate surfaces. Riveting is excluded to the lack of skilled labor. The remaining repair methods are fitted bolts and injection bolts. The high cost associated with fitted bolts makes injection bolts a good alternative in this application.

A successful application of injection bolts to repair a riveted structure is performed on the Schlossbrücke Oranienburg. [9] A cross-section detail of the bridge design is shown in Figure 4. An image of the corrosion of the steel structure and the repair executed with injection bolts is shown in Figure 5.

For this project, long duration creep tests were performed to investigate the design bearing stress allowed on the resin. An allowable design bearing stress of 150 MPa is reported. The influence of temperature on creep for injection bolts is reported to be only of moderate influence on the results. [9]

Numerical analysis of a riveted connection repaired using an injection bolt has shown that the load transfer of surrounding rivets increased. This is attributed to the low stiffness of the resin. Execution quality of the injection has a large influence on this load transfer in a repaired connection. [10]

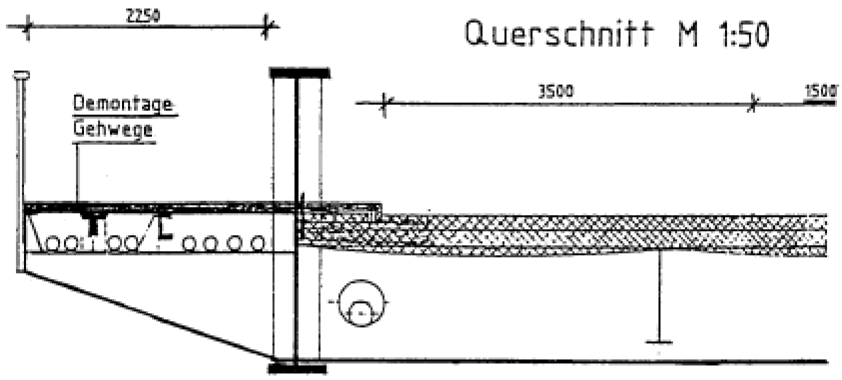
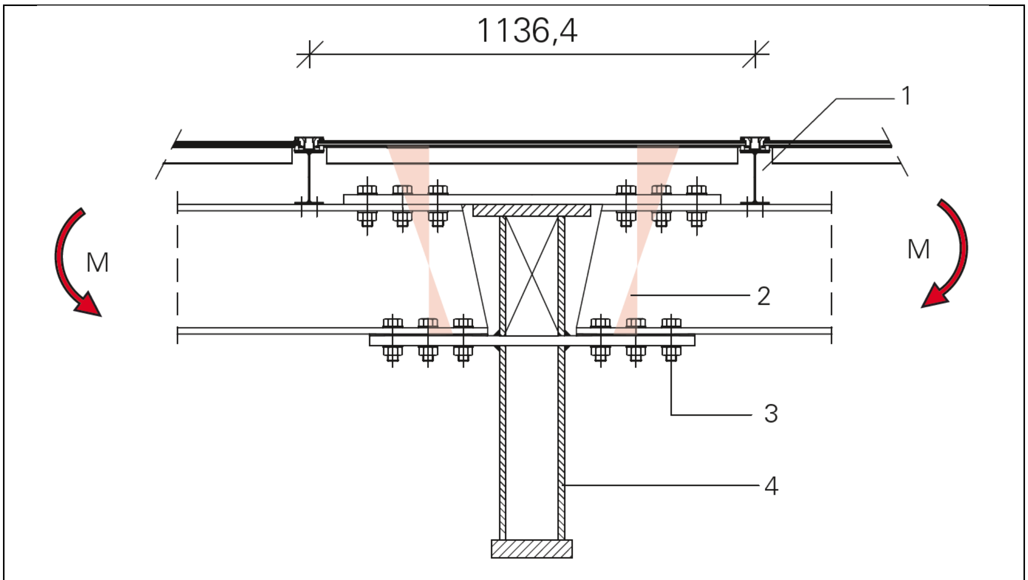


Figure 4 Cross-section of Schlossbrücke in which injection bolts were used for repair [9]

Figure 5 Corrosion of steel structure and subsequent repair with injection bolts [9]

7.1.2 Glass roof structure Amsterdam Centraal station

Injection bolts have been successfully applied for compact connections in a glass roof structure near Amsterdam Centraal station. [11] In this project, the rotations introduced with normal bolted connections were too large. Injection bolts have been applied successfully in this application to limit rotations in the connections of the glass roof structure. The connection in which injection bolts were the solution are shown in Figure 6. [11]



1	Glasdrager IPE 140 A
2	Horizontale verplaatsing door boutgatspeling
3	M27 10.9, gerold
4	Spant samengesteld uit platen

Figure 6 Connection in glass roof structure for which injection bolts were applied [11]

For this project research has been carried out in the Stevin Laboratory of the TU Delft on the bearing resistance of the resin. Short duration loading and long duration loading has been considered in this research. [11] [12]

A test specimen for this research is shown in Figure 7. The result of this research has been reported in a separate publication [12]. Here the results from the test procedure according to EN-1090 is reported [8]. From this research the design bearing stress of RenGel SW404/HY2404 resin can be taken as $f_{b,resin} = 200\ MPa$ and for short duration high loads the bearing stress of the resin can be taken as $280\ MPa$. [12] This higher resistance of the resin layer for short duration loading is already remarked in previous research as well [13].

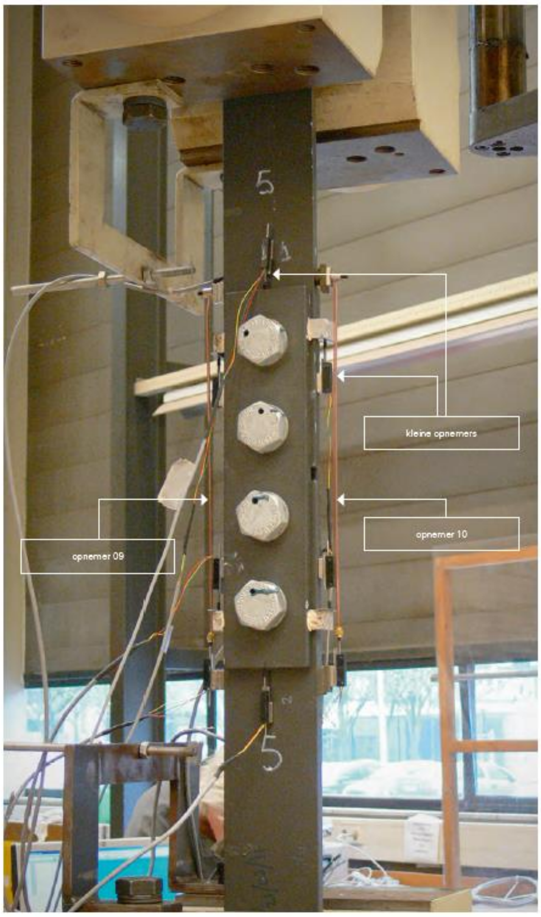


Figure 7 Test specimen to investigate bearing stress of resin for glass roof structure of Amsterdam Centraal station

7.2 Resins

7.2.1 Chemical background of epoxy resins

Polymers are chemicals with a chain of repeated elements in their molecular structure. Epoxy resins are a class of polymers which contain an epoxide group. These epoxy resins are a viscous liquid substance before curing of the resin takes place. The viscosity of the uncured epoxy resin product is dependent on the length of molecule chains, i.e. the pre-polymerization degree. [14] [15]

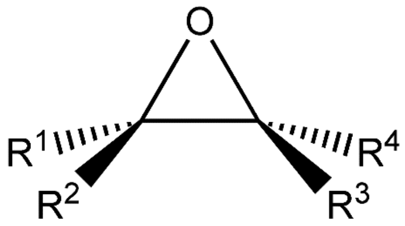


Figure 8 Epoxide group that characterizes epoxy resins [16]

When an epoxy resin is applied, the resin must be cured. Curing is a chemical reaction that forms the final structure of the resin. Epoxies are available in practice as one component or two component products. One component epoxies create the final structure through a process called homo-polymerization. Two component products reach their final state through copolymerization. In this process of curing the resin, the individual chains of molecules react to form a 3-dimensional network of bonds. This reaction between individual molecules is called cross-linking. Through this cross-linking of molecules, the resin transforms from a liquid to a solid. An illustration of the chemical structure of a resin after curing with a hardener has taken place is shown in Figure 9. [15] [14]

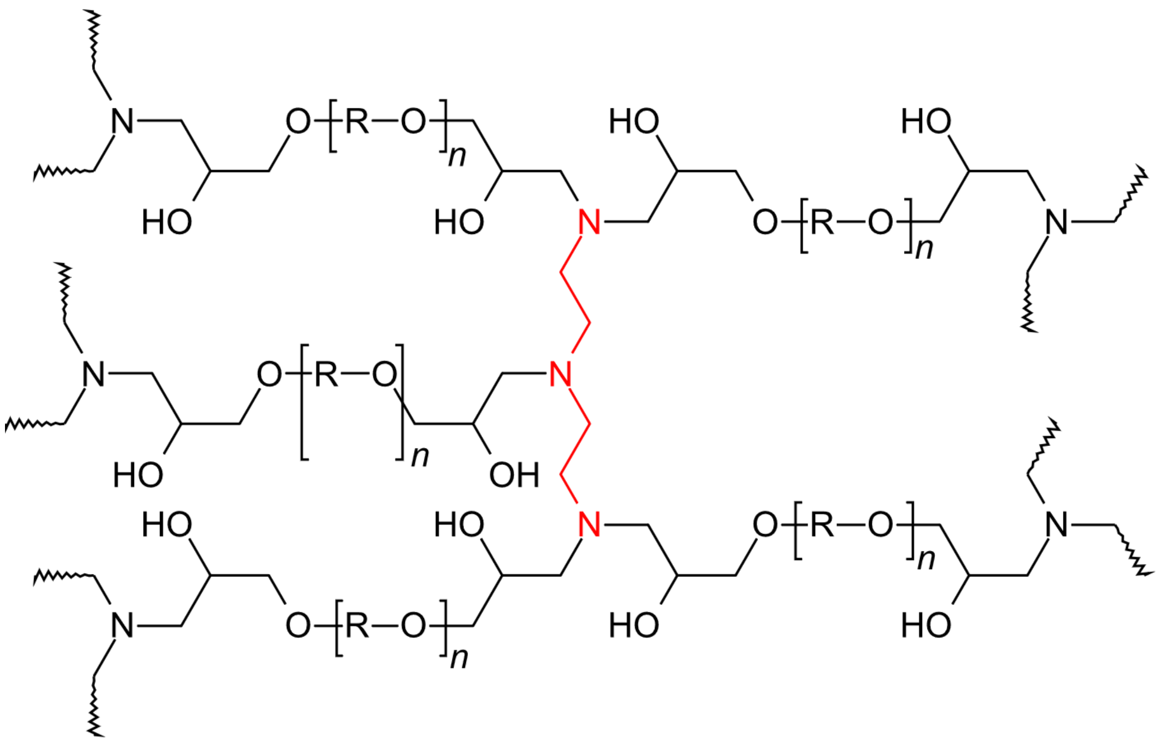


Figure 9 molecular structure of copolymerized resin with hardener (in red) [17]

In homo-polymerization the resin chains react with each other to form the final resin structure. A two-component resin product consists of a resin mass combined with a hardener. This hardener is a reactive chemical which initiates the reaction between the polymer chains of the resin molecules. Through the application of a hardener the degree of cross-linking can be engineered to gain different properties of the final cured resin product. [14] [15]

7.2.2 Curing aspects of Epoxies

One of the most important aspects of an epoxy resin is the behavior during curing. When the resin and hardener is mixed the chemical reaction that causes the curing is started. The viscosity of the resin mixture will start increasing from the moment of mixing until finally the resin reaches a solid state.

For practical applications the speed of this increase in viscosity after mixing is important. This is reported as pot life for a resin product. The definition of pot life is the amount of time it takes for the initial viscosity of the mixed resin to double (or quadruple for low viscosity products <1000 cPs) [18]. Another term to describe the speed of reaction is the working time. This is the time it takes for a resin to have a viscosity such that it cannot be applied anymore. Working life of a resin product is thus dependent on the specific application. [14] [15] [18]

The chemical reaction that occurs during curing of epoxy resins is exothermic. This means the resin gives us heat when curing. When a large amount of resin is mixed and in a contained volume the exothermic reaction can cause a snowball effect whereby the reaction heats up the resin mass which increases the speed of the reaction causing the resin to cure extremely quickly and is potentially hazardous. [19]

7.2.3 Influence of temperature on epoxy resins before and during curing

Temperature is a very important parameter for epoxy resin products and their application. The temperature of the epoxy resin itself before curing influences the viscosity of the mixed product. The viscosity of the resin will be lower at higher temperatures due to higher molecule mobility. The temperature of the epoxy resin also influences the speed of the curing reaction. At higher temperatures the pot life of the resin product decreases.

The final material properties of the cured resin product are dependent on the cross-link density. At high temperatures the cross-linking reaction between the hardener and resin mass will be more complete ensuring a high cross-link density.

7.2.4 Material properties of epoxy resins after curing

The material properties achieved by an epoxy resin are dependent mostly on the epoxy chemicals used and the curing conditions. An important aspect of epoxy resins after curing is the glass transition temperature T_g. Cured resins show a dramatic change in material properties above a certain temperature. This temperature signifies the change between a glass and rubber like state. This is illustrated in Figure 10. [14] Resins with high cross-link densities such as epoxy resins have high glass transition temperature. [20] The achieved glass transition temperature of the epoxy also depends on the temperature during curing. [20]

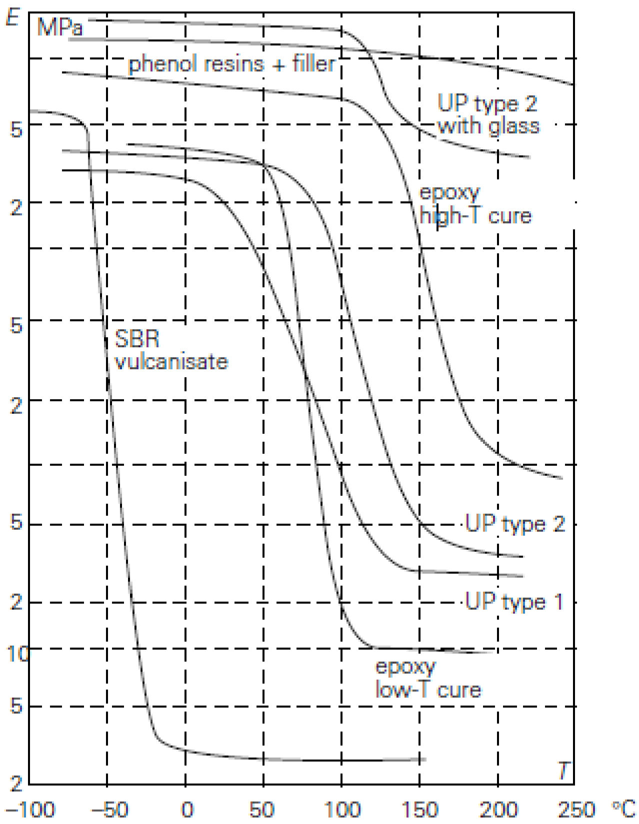


Figure 10 Glass transition temperature of various resins [14]

7.2.5 Defects in epoxy resin

7.2.5.1 Voids

The occurrence of voids in the resin layer is the most important type of defect that can occur in the resin layer. They greatly influence the strength and stiffness of the resin material. The occurrence of voids can be caused by several issues. First is shrinking of the epoxy during curing. When the epoxy is injected in a closed volume and left to cure, the volume of the epoxy will shrink due to the curing process. [15] The amount of shrinkage is dependent on the resin product. Due to this shrinkage voids will occur in a closed volume. [21] Void 1 in Figure 11 occurs due to shrinkage before the rubbery state is reached [21]. This void rises to the top of the resin mass due to the buoyancy of the air. Voids also occur after the rubbery state. These are caused by peak residual stresses that are generated by the shrinkage effect. [21]

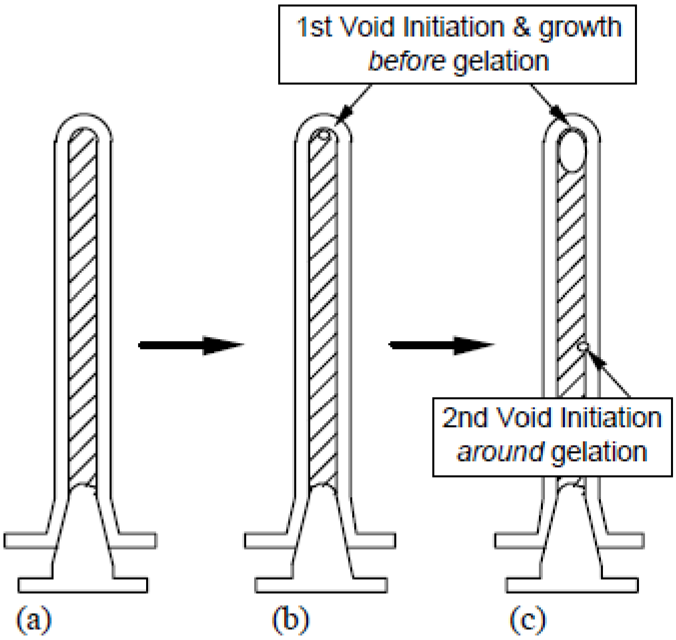


Figure 11 initiation of voids during curing of resin in closed volume [21]

Voids can also be introduced through the application of resin. A lot of research has been done on the production process and injection procedures for composite structures. An elaborate review of void formation, and the effect on the material properties for carbon fiber reinforced plastics is done by Xueshu Liu [22]. From this overview, the temperature of the mold, the used injection pressure and the type of resin used influences the occurrence of voids in carbon fiber reinforced plastics, when using a Resin Transfer Molding process (RTM) [22]. In this process it was found that for high injection pressures micro-voids were formed and at low pressures macro-voids are formed. [22]

7.2.5.2 Inhomogeneous mixing

Resin products consisting of a hardener and a resin mass in a two-component system can suffer from defects due to the improper mixing of the components. An incorrect mixing ratio can lead to an under-cured resin matrix with a low cross-link density, or if too much hardener is added this does not react with the resin mass, due to full curing already having occurred before the hardener is used up. Furthermore, the hardener must be uniformly distributed throughout the mixture. Inhomogeneous distribution of hardener can locally result in a wide scatter of performance with the solid resin layer and introduce stress peaks [23].

7.2.6 Material properties

The material properties of epoxy resins in IBC which are most interesting relate to the strength and stiffness of the resin after curing. Furthermore, the viscosity and pot life are of interest for the injection procedure of the bolts. Lastly the time-dependent behaviour of the resin is of importance.

7.3 Resin products applied in injection bolts

Currently the only resin product allowed for injection bolts in the projects of the Dutch ministry of infrastructure is RenGel SW404 with HY2404 [1]. Also referred to in literature as Araldite SW404/HY2404 [24]. From research on injection bolt connections with this resin performed in relation to the Amsterdam Centraal project the long duration bearing stress of this resin can be taken as $f_{b,resin} = 200\ MPa$ and the short-term bearing resistance of $f_{b,resin,short} = 280\ MPa$. [11] [12]

The young's modulus of this resin ranges between $9\ to\ 9.5\ GPa$. The strength of this resin in a uniaxial compression test is reported to be $110 - 125\ MPa$. [24] From numerical analysis on this resin applied in injection bolts the stiffness values found range from $3.2 - 5\ GPa$. [10] [25]

Results from double lap shear tests with repeated loading are reported for the Amsterdam Centraal project in Figure 13. [11] The effective bearing stress values here far exceed the supplied material strength from the manufacturer specification. [24]

7.3.1.1 Compressibility

The resin layer in an injection bolt is confined laterally when loaded. The test procedure to determine the compressive strength of resin is outlined in ISO 604 [26] this is a uniaxial compression test [26]. In Figure 12 results on Polycarbonate tested in compression with different types of confinement is shown from other research [27]. A clear effect on stiffness and strength is observed for this polymer depending on the confinement conditions.

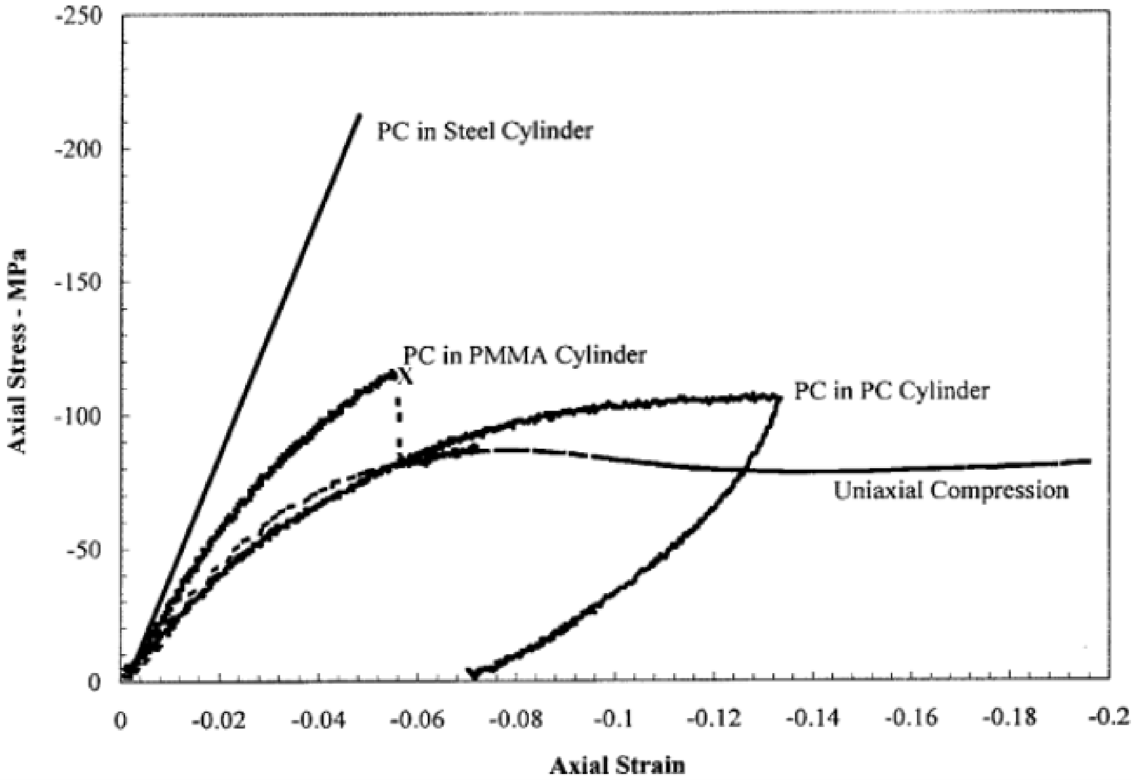


Figure 12 Compression tests on Polycarbonate with different types of confinement of the specimen [27]

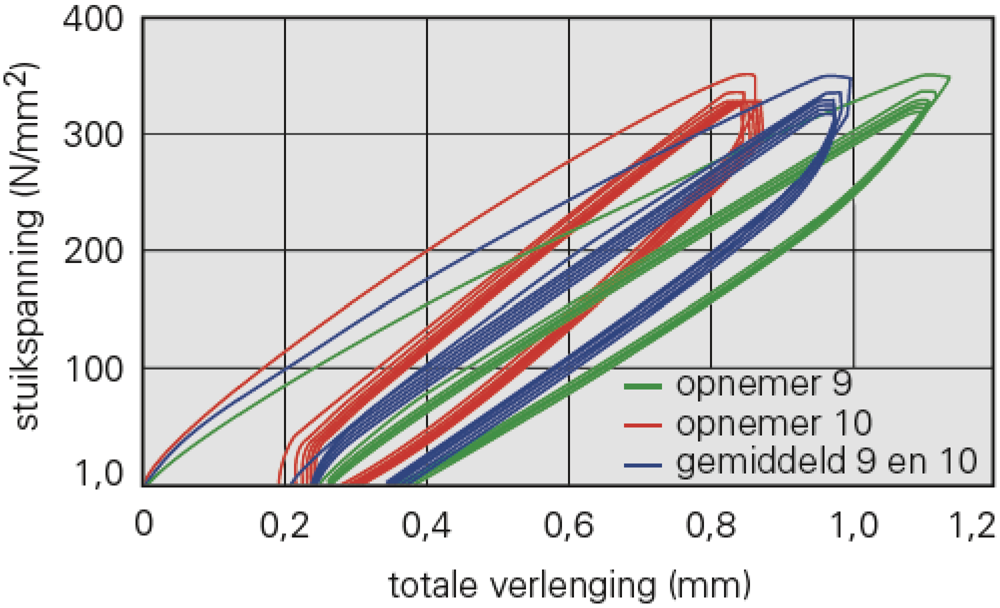


Figure 13 Repeated loading on double lap shear joint with RenGel resin [11]

7.3.2 Alternative resin application for injection bolts

In current research Sikadur 30 resin is investigated as a possible resin for use in injection bolts. From Figure 16 results of test injections on Perspex mock-up samples with Sikadur 30 and RenGel SW404 can be seen. [28] The washers in the injection bolts have been optimized to ensure proper flow of resin around the bolt shank. The different washer designs investigated in this research are shown in Figure 14. [28]

Figure 14 Bolt head washer designs investigated in research on Sikadur 30 and RenGel resin IBC in FRP structures [28]

In this research testing is performed on double lap shear specimens with FRP plate material. The orientation of the bolts in the specimens is controlled to be concentric with the bolt hole clearance using an installation jig which is shown in Figure 15 [28].

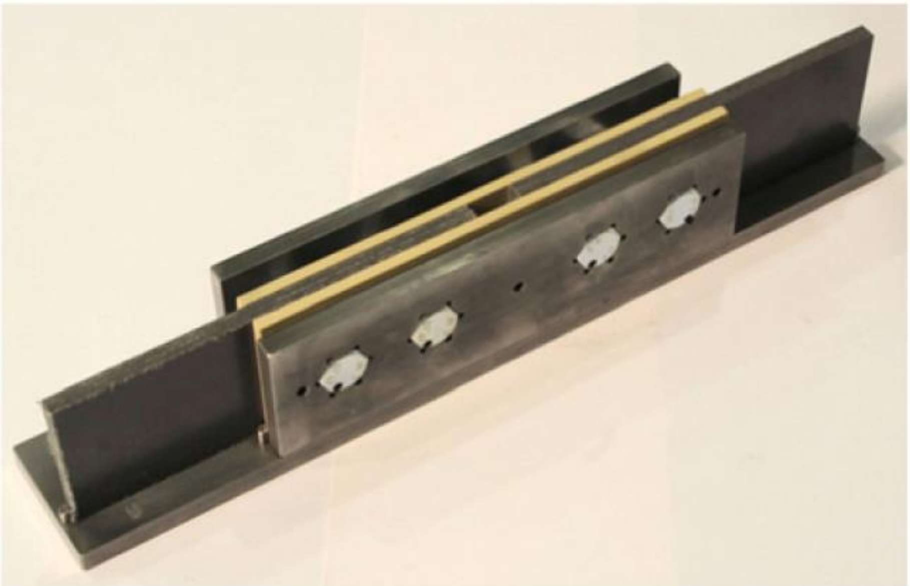


Figure *15* Installation jig to control bolt position in plate assembly [28]

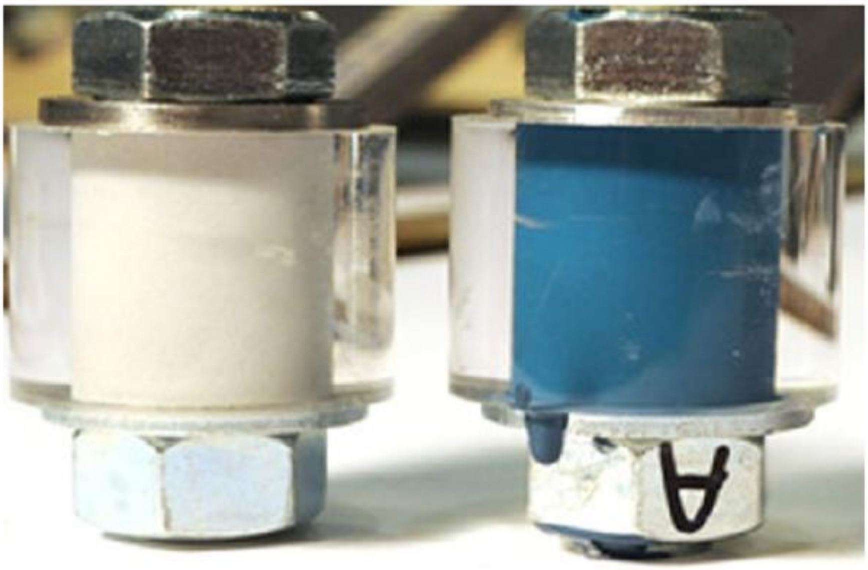


Figure 16 Sikadur 30 and RenGel SW404 Perspex mockup samples to check filling of bolt [28]

Strength values found for Sikadur 30 resin in this research are very comparable to RenGel SW404/HY2404 Resin as illustrated in Figure 17. [29]

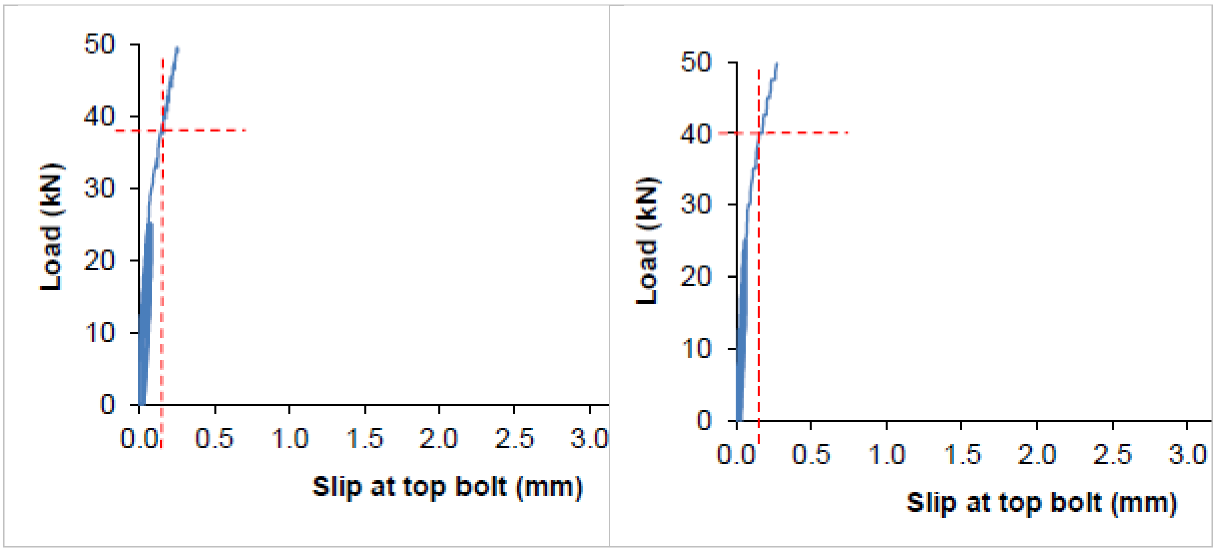


Figure 17 Left: test result on RenGel SW404/HY2404 Right: Test result of Sikadur 30 resin [29]

7.3.2.1 Other tested epoxy resins

From research done in the Stevin Laboratory two other resin systems were investigated. [30] These are Araldite GY250 with XB2571 hardener and Araldite CW214 with XB2571 hardener. These resin systems are reported to have such low viscosity clay had to be used to prevent resin flowing out of the air escape groove and injection hole in the bolt head. Furthermore, they showed no improvements over earlier mentioned RenGel SW404/HY2404. Strength values achieved with these resin systems were lower than RenGel SW404/HY2404. [30]

An update on research and application of Injection bolts is published as this research was ongoing. Here Sikadur 33 and Sika AnchorFix are reported as injection resins for use in the repair of a roof structure suffering reversal movements due to a suspended crane. [31] From this publication it is mentioned that Sika AnchorFix was the most suitable resin for this application. The curing time was a lot shorter than the Sikadur 33 resin which meant the crane had to be taken out of service for a shorter time period. [31] It is also mentioned that the curing of Sika AnchorFix was more reliable. It is reported though that the short duration resistance of the Sikadur 33 resin according to the specification of EN 1090 was 20% higher than Sika AnchorFix [31] [8]. Also in this application reference is made to alternative washers that facilitate the injection procedure instead of the hole in the bolt head as is specified in EN 1090 [8] [31]

7.3.3 Other injection materials

Parallel to this research carried out on epoxy resins for use in injection bolts the use of grout has been investigated by M.P. Nijgh [32]. In this research similar strength values are reported for grout injected connections as for resin injected connections. The successful injection though was dependent on the washer positioning around the bolt head. [32] Furthermore, air inclusions were observed in the grout. This is attributed to the use of super-plasticizer in the grout mixture. Results of short duration static tests done on grout specimens in this research with different hole clearances is illustrated in Figure 18. [32]

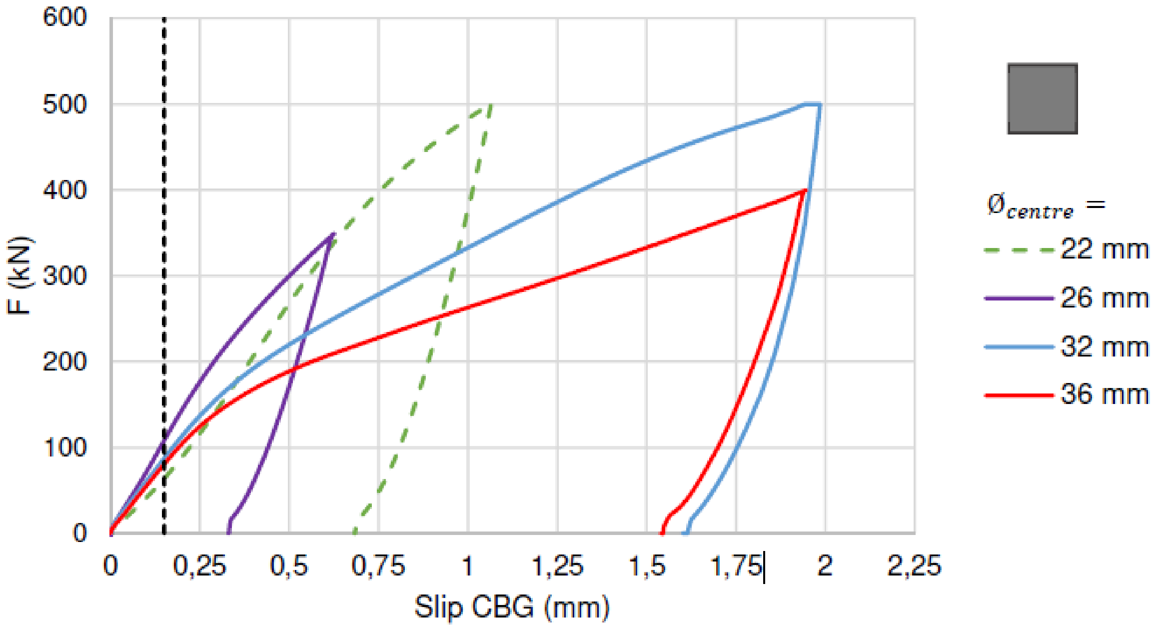


Figure 18 Test results on grout injected bolted connections with different hole clearances [32]

7.4 Injection methods for resins

Injection bolts can be injected successfully using hand-driven and air driven injection guns. Injection is successful when the resin completely fills the void between the bolt shank and bolt hole [5]. The product should also not run in between the plate surfaces during injection [5]. From research in the Stevin Laboratory it was found that injection with hand-driven equipment does not pose any problems for short bolt lengths. [33] For longer bolt lengths issues were seen in this research with hand-driven equipment. Resin flowed out of the rear of the cylinder due to deformation caused by the high pressure applied. [33]

In this research air-driven injection equipment was also investigated for the injection. This proved to be an effective method of filling the injection bolts also for long lengths. [33] Results of the injection time required on M27 bolt specimens with a clamping length of 170 mm are reproduced here in Table 1. [33] It is recommended to use high pressures when injecting long bolts in this research to limit the injection time per bolt. [33]

Table 1 Injection times with various pressures for M27 injection bolts with 170 mm clamp length [33]

Applied pressure [Bar]	Time to inject bolt [s]
7	80
7	284
13	25
10	130
13	29

7.4.1.1 Injection methods in other applications

Resin products are widely applied in the fabrication of composite structures in practice. In the fabrication of composites two main methods are currently applied:

- Resin transfer moulding (RTM)
- Vacuum assisted transfer moulding (VARTM)

An illustration of these injection methods is shown in Figure 19. The main advantage of VARTM is the removal of the top mould. This steel element is associated with high tooling costs and is replaced by a vacuum bag in the VARTM process. Resin flow in these production methods is modelled in work by X. Song [34]. The model developed by Song is used for optimizing flow velocity to reduce the porosity of the resulting composite.

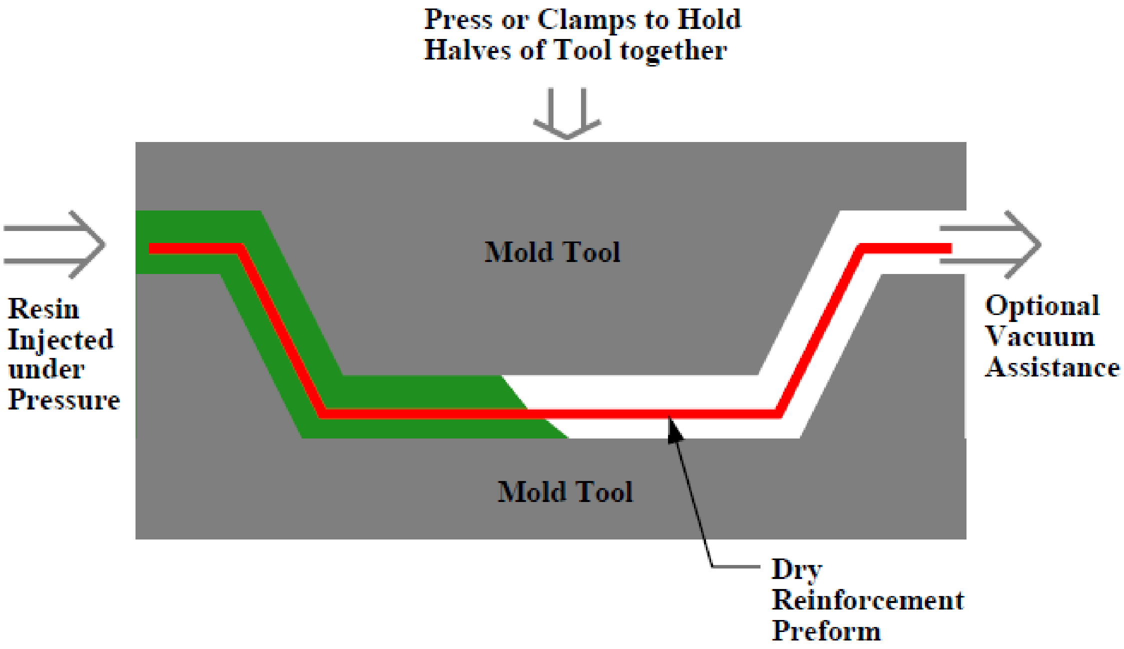


Figure 19 Illustration of RTM for composite fabrication [34]

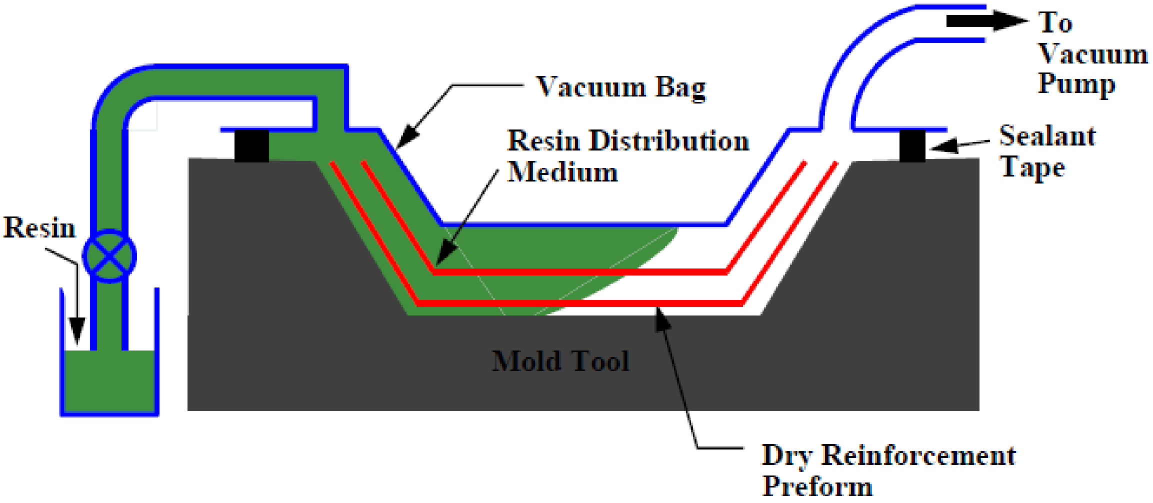


Figure 20 Illustration of VARTM production process for composite structures [34]

7.5 Other considerations for Injection bolts

7.5.1.1 Curing time and temperature

The time necessary for curing to take place in an injection bolt is roughly 20 hours. This is sufficient for regular construction methods because the connection is not immediately fully loaded. In specific applications such as repairs on bridges which are in use this curing time cannot be reached before the connection is loaded. [35]

In the Stevin Laboratory tests have been done on the effect of temperature on curing time in injection bolts. [35] The conclusions of this research are that specimens which are heated after injection show good resistance of around 182 MPa already 3 or 4 hours after curing. It is remarked though that heating directly after injection causes the resin to flow out of the injection bolt. Therefore, it is recommended to wait around 20 minutes after injection before the connection is heated. [35]

Relating this to the background on epoxies explained in Curing aspects of Epoxies the viscosity of the resin decreases due to the applied increase in temperature. [14] [15] [18] The timeframe of 20 minutes coincides with the pot life of RenGel SW404/HY2404 as supplied by the manufacturer. [24].

7.5.1.2 Presence of water during injection

Injection bolts are applied during fabrication of a steel structure on site. This means the structure is exposed to weather influences. With this background research has been carried out in the Stevin Laboratory to investigate the influence water presence has on the strength of injection bolts. [30] In this research specimens were flushed with water immediately before injection. This had a significant influence on the bearing strength of the connection. The results of this test series are shown in Figure 21. In this figure the specimens marked “w” were flushed with water immediately before injection. [30]

It is noted in this research that this is not a realistic situation for practical application. Therefore, a second series of tests was performed, where specimens were assembled and left exposed to elements such that water could penetrate the connection. The specimens were injected when one day of dry weather occurred after a period of rain. [30] In this approach no differences in strength were observed between dry and wet specimens. Therefore, it is recommended from this research to wait at least one day after rain before injection of pre-assembled injection bolts takes place. [30]

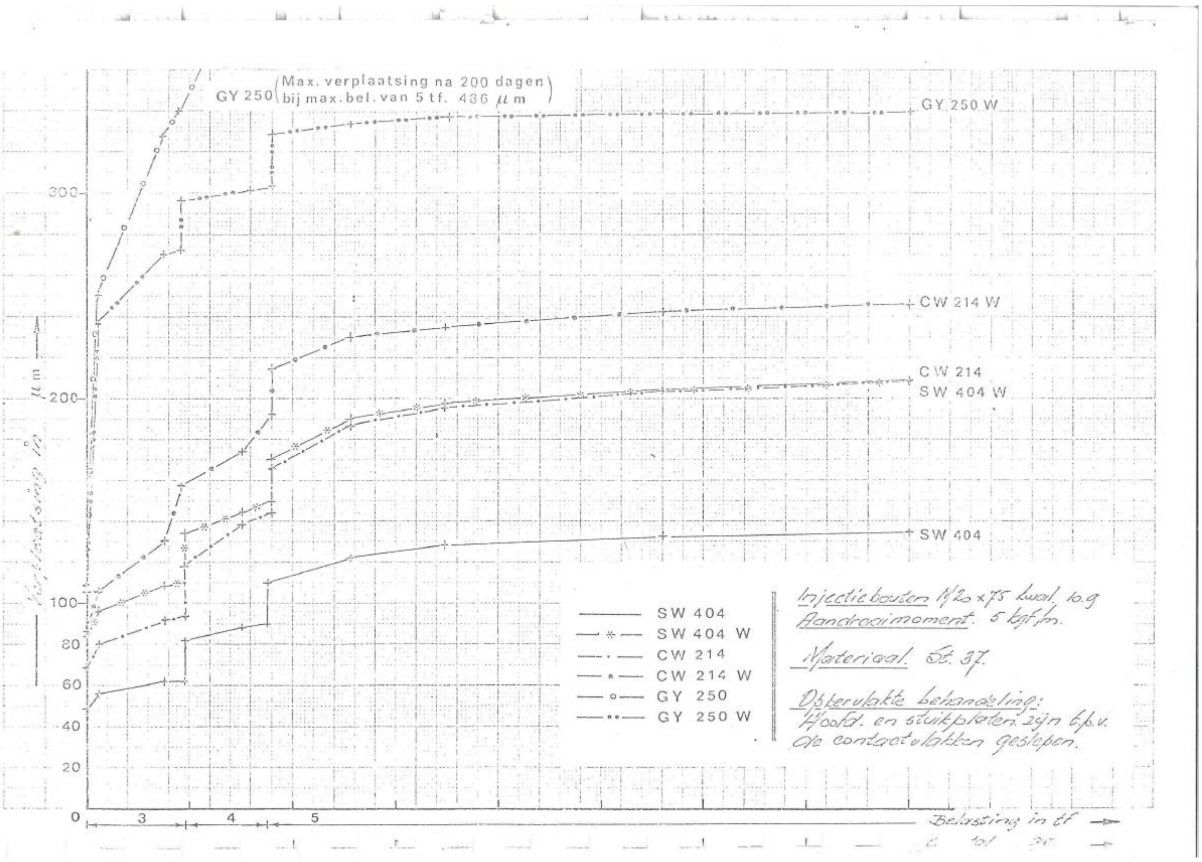


Figure 21 load-slip results of 3 resin products in double lap shear tests in wet and dry application [30]

7.5.1.3 Combination of preload and injection

Research into the combination of a preloaded and injected connection has been done by various authors [36] [37] [38] [39] [40]. In Figure 22 Results of Rugelj are shown [40]. In blue a connection with a combination of preload and injection is shown, in black a connection with just preload and in green just injection. The dots in corresponding colour as above show the characteristic value of these tests. [40] The dot in red is the calculated capacity of a connection with injection and preload according to EN 1993-1-8. [41] This is lower than the tested value at a displacement of 0.15 mm. From this research it is concluded that the calculated capacity according to EN 1993-1-8 is reached at a slip of 0.2 mm. [40]

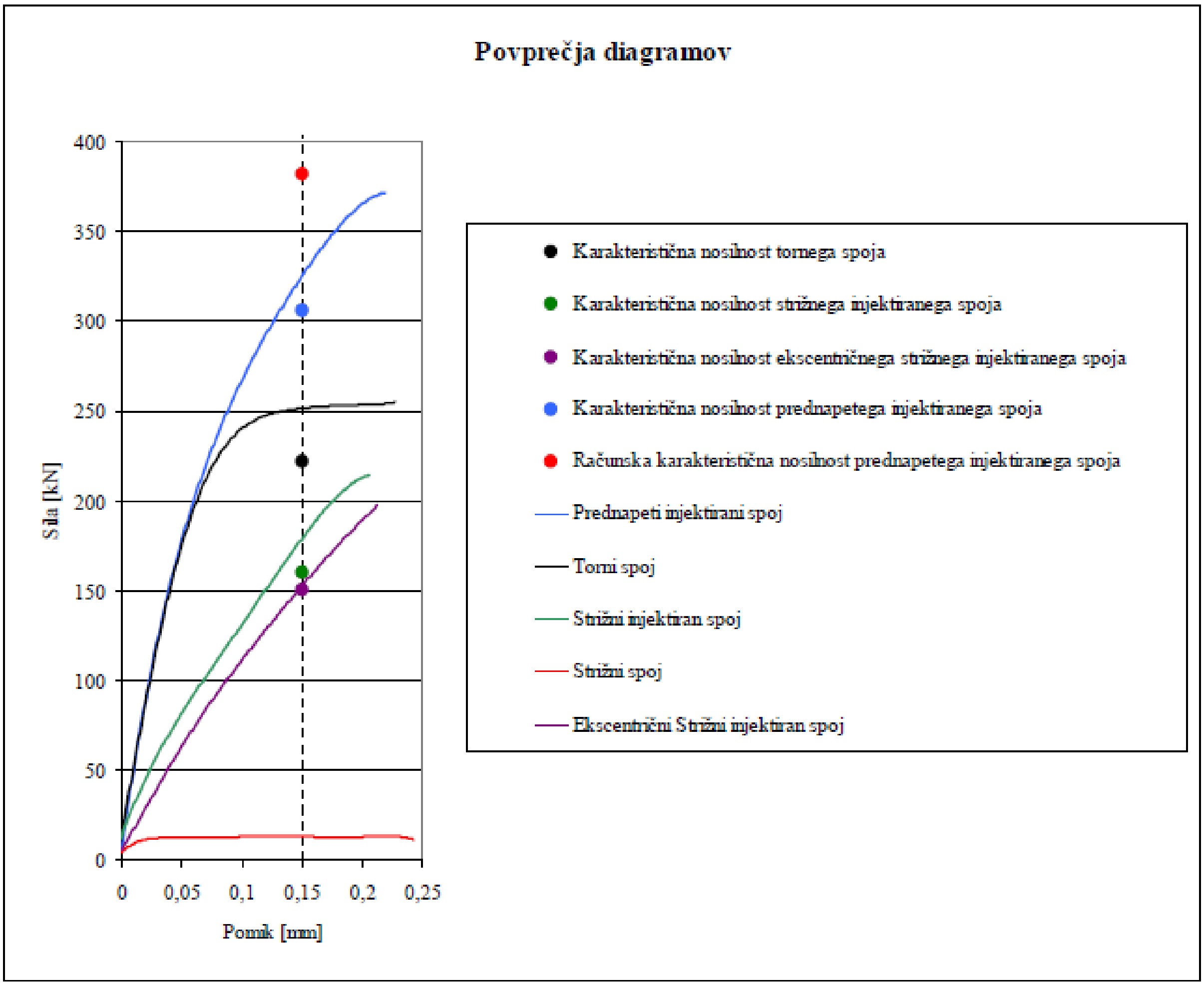


Figure 22 load slip results of tests with injection, preloaded and injection-preloaded bolt connections [40]

It is noted though that the fatigue resistance of this combination is a point of discussion. Experimental research has shown that the fatigue resistance of connections with preload and injection is lower than preload alone [42]. Recent numerical analysis of connections with preload and fatigue though indicates higher fatigue strength [39].

7.5.1.4 Demountability

At the end of the service life of a steel structure it can be disassembled to recycle the steel structure. With this in mind, research has been done by Smits and Bouman on separating liquids in an injection bolt application [43]. Recently the demountability of injected bolted connections has been researched extensively by Nijgh [32]. From this research and earlier research an injection bolt can be disassembled if a release agent is used. Without this precaution during assembly it is very difficult to disassemble the bolt. [32]

7.5.2 Creep

Resins show time-dependent behavior under loading. [44] The creep behavior of resins is dependent upon the load placed on it as is evidenced by research. Further the temperature of the resin layer also impacts the creep behavior [9] This is illustrated in Figure 23. As mentioned earlier the influence of temperature for the applied resin in this test (RenGel SW404/HY2404) is moderate. [9] The average creep at ambient temperatures was found to be 0.19 mm in this research while 0.24 mm was found at 70 degrees Celsius and a bearing stress of 250 $^{N}/_{mm^2}$. [9]

The creep response of crosslinked polymers depends mostly on the crosslink density and the temperature of the polymer [45]. A higher crosslink density will increase the dimensional stability of the product and lower the creep rate [45]. A high crosslink density is associated with a high glass transition temperature [20].

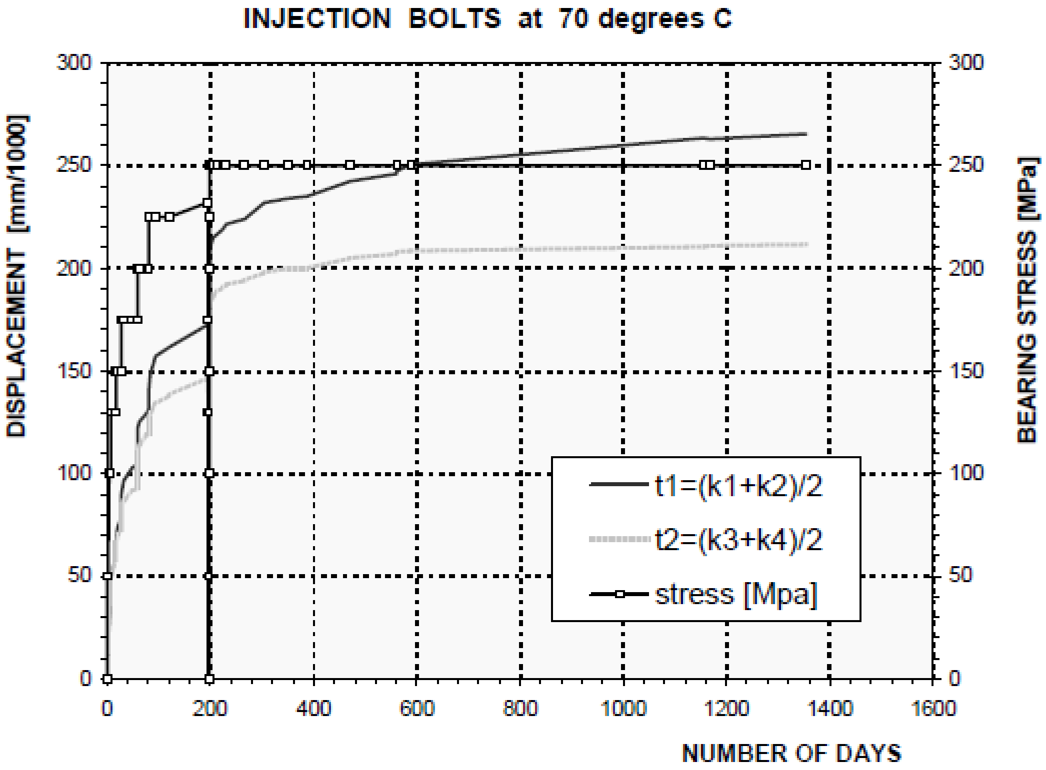


Figure 23 displacement over time of injection bolt at 70 degrees Celsius [9]

7.5.3 Durability of Injection Bolts

The properties of epoxy resins are subject to degradation over time due to ageing processes. This can be initiated through exposure to water, high temperatures and other aggressive fluids. [46] This is documented in research into composites and adhesive joints. [46] [47] The combination of both water presence and high temperatures on degradation processes is not yet well understood. [47] These degradation processes could be of influence on the durability of an injection bolt if the connection is exposed to them. An advantage of injection bolts is the corrosion protection. [5] In the ECCS recommendations it is mentioned that internal corrosion of the steel structure is prevented by the resin completely filling the cavity of the bolted connection. [5]

7.6 Regulations and standards

7.6.1 Injection bolts

Regulations regarding the use of injection bolts in a structural engineering context are specified in EN-1993-1-8 and EN-1090 [8] [41]. The regulations from standard EN1993-1-8 are related to the calculation rules that can be used in the design and checking of injection bolts in structures. The regulation from EN-1090 specifies the material and detailing of components for application as an injection bolt in a structure.

7.6.2 Regulations regarding detailing and materials

In Figure 24 a cross-section of an injection bolt fastener system is shown in a double lap shear connection. The different components of the injection bolt assembly are shown in Figure 25. This consists of the injection bolt, nut and the washers for the head and nut side.

7.6.3 Bolt

The bolts that can be used as injection bolts are all fasteners of steel grade 8.8 and 10.9 that are allowed for use in preloaded and non-preloaded connections. The details and regulations for fasteners are found in EN 14399 and EN 15048 [48] [49]

For application as an injection bolt a hole must be made in the head of the bolt to facilitate the injection of the resin material. The dimensions of this injection hole are specified in EN 1090 Annex K. This is shown in Figure 26. [8]

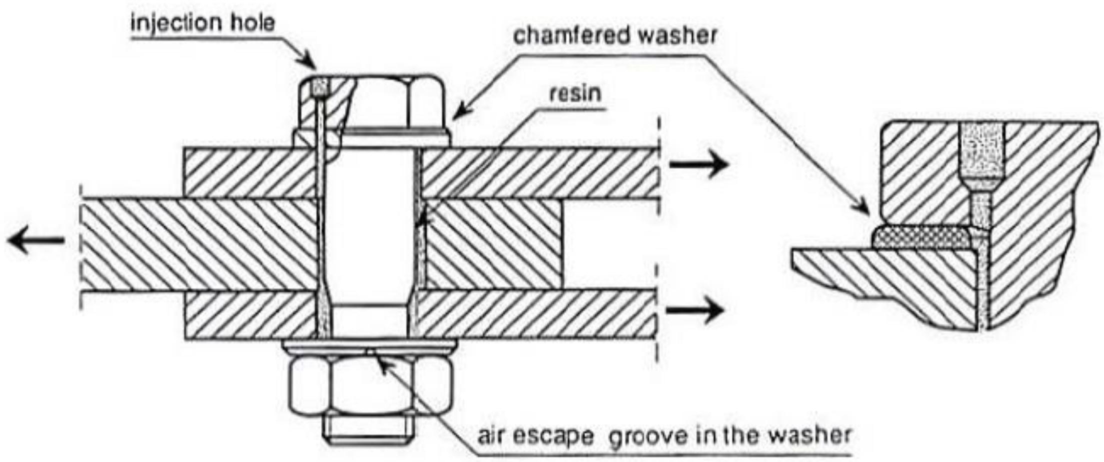


Figure 24 Cross-sectional overview of an injection bolt fastener system [5]

Figure 25 Injection bolt assembly components

7.6.4 Washers

To apply the injection of resin in the connection special washers must be used for the assembly. The washer design that can be used for injection bolts is also outlined in annex K of EN-1090 [8]. This washer design has a chamfered side on the head side to allow the resin to flow from the injection hole around the bolt shank and into the hole clearance between the shank and the bolt holes in the plates. The washer on the nut side has a groove machined into it. This allows air to escape from the cavity between the bolt shank and bolt hole during injection to allow complete filling of the injection bolt. The geometries of the chamfered side and machined air escape groove are shown in Figure 27. For an example of these washers refer to Figure 25.

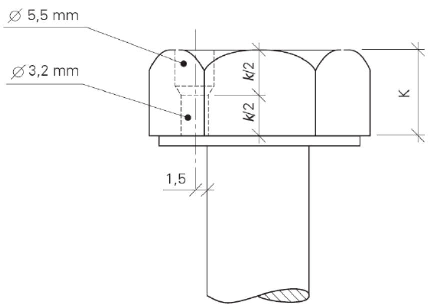


Figure 26 Specified dimensions of injection hole in bolt head from EN 1090 annex K [8]

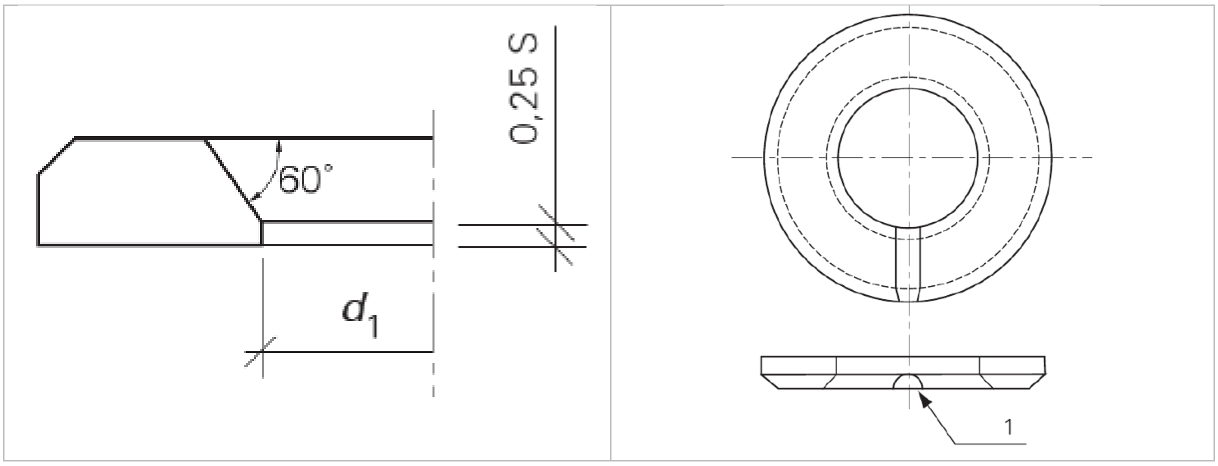


Figure 27 left: chamfered washer on head side right: air escape groove washer on nut side [8]

7.6.5 Bolt holes in steel plates

The bolt holes to be used for IBC are the same as regular bolted connections. The dimensions for these holes are specified in the EN 1090 in section 6.6.1. The nominal dimensions of the bolt hole must be 2 mm larger than the bolt diameter for bolt sizes up to M27. For larger bolts the clearance is increased to 3 mm. These clearances are necessary to take tolerances during fabrication and erection into account for assembly on-site. [8]

7.6.6 Resin

The material used for injecting the bolt is specified in EN 1090. A two-component epoxy resin must be used. The pot life of this product is required to be at least 15 minutes according to the guidelines. The exact resin to be used is not specified in the codes. The result of the injection with the product is specified. All cavities in the connection should be filled and resin should not flow out of the bolt after the injection is stopped. [8]

7.6.7 Design and calculation of Injection bolts

Design and calculation of injection bolts is guided by the calculation rules and methods explained in the EN 1993-1-8 [41]. In the calculation of bolted connections, the connection class as outlined in Table 3.2 of EN 1993-1-8 determines the calculation method. Non-preloaded connections fall in Category A connections. Category B and Category C connections are preloaded. Injection bolts are allowed to be used for all three categories of connections. [41]

7.6.7.1 Static design resistance

The design shear load on an IBC should not exceed either the shear resistance of the bolt or the design bearing resistance of the resin. For a preloaded injection bolt connection in category B or C the load should not exceed the design slip resistance of the bolt plus the bearing resistance of the resin at the relevant limit state. The design ultimate shear load should furthermore not exceed the design shear resistance of the bolt and the bearing resistance of the bolt. [41]This is shown concisely below:

$$F_{Rd,A} = \min(F_{b,Rd,resin}, F_{v,Rd})$$

$$F_{Rd,B/C} = \min(F_{s,Rd} + F_{b,Rd,resin}, F_{v,Rd}, F_{b,Rd})$$

The design bearing resistance that can be taken into account in an IBC is concisely defined in EN 1993-1-8 as follows:

$$F_{b,Rd,resin} = \frac{k_t \cdot k_s \cdot t_{b,resin} \cdot \beta \cdot f_{b,resin}}{\gamma_{M4}}$$

Where:

$F_{b,Rd,resin}$	Is the bearing strength of an injection bolt
β	Is a coefficient depending on the thickness ratio of the connected plates
$f_{b,resin}$	Bearing strength of the resin
$t_{b,resin}$	Effective bearing thickness of the resin
k_t	Coefficient for the limit state (1.0 for SLS and 1.2 for ULS)
k_s	Coefficient for the hole clearance $(1.0 - 0.1 \cdot m)$
m	The difference in mm between the normal and oversized diameter to be used for k_s

The coefficient k_t considers the difference in the short term allowable bearing stress compared to the long term bearing stress of the resin, where creep of the resin layer plays an important role. The value 1.2 is chosen by engineering judgement. [31]

The values to be used for coefficients β and $t_{b,resin}$ are shown in Table 2. These coefficients consider the connection geometry. The stress occurring in the resin layer depends on the ratio of the thicknesses of the cover and center plate in the connection as exemplified in Figure 28.

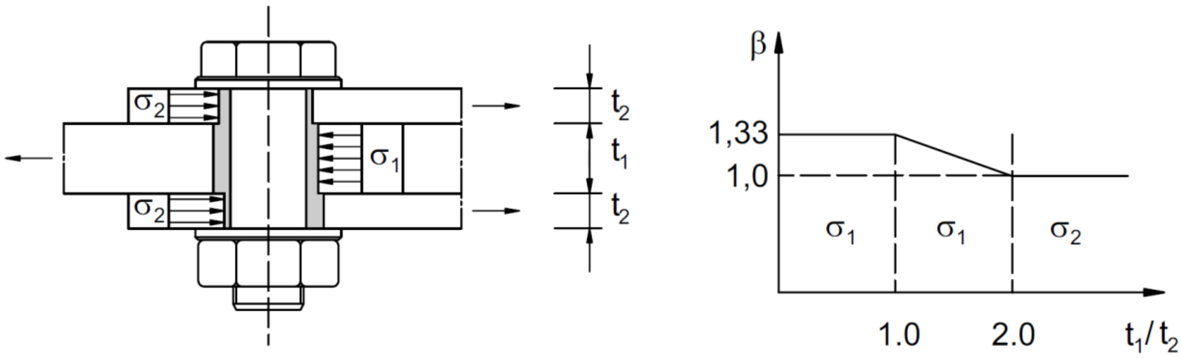


Figure 28 Resin layer stress in IBC depending on the ratio of plate thicknesses [41]

Table 2 coefficients β and $t_{b,resin}$ depending on t_1/t_2 for use in calculation of design bearing resistance [41]

t_1 / t_2	β	$t_{b,resin}$
≥ 2,0 1,0 < t_1 / t_2 < 2,0 ≤ 1,0	1,0 1,66 - 0,33 (t_1 / t_2) 1,33	2 t_2 ≤ 1,5 d t_1 ≤ 1,5 d t_1 ≤ 1,5 d

The coefficient $t_{b,resin}$ considers the total thickness of the plate package. The stress distribution in the resin layer does not remain uniform for larger values of the L/D ratio. This is caused by bending deformation of the bolt. Only an effective length of the resin layer can be taken into account for the calculation for long joints. This is illustrated in Figure 29.

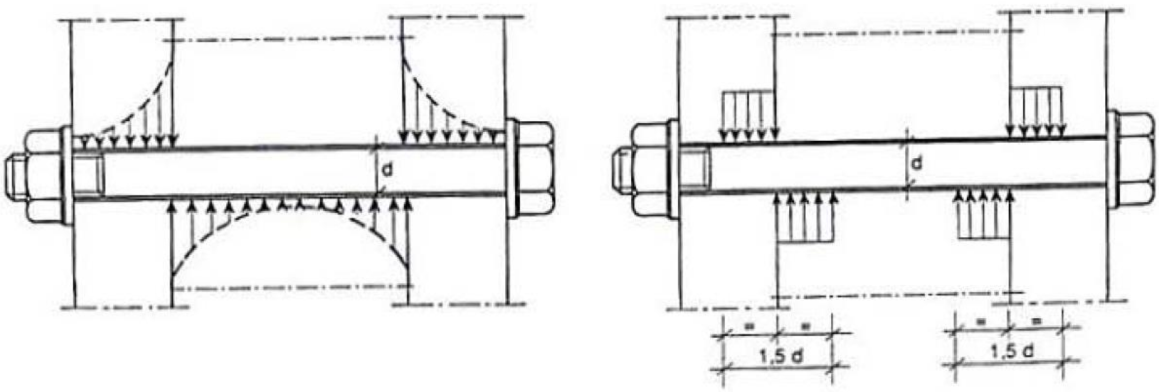


Figure 29 actual and effective resin stress distribution take into account in long joints with IBC [5]

7.6.8 Resin test procedure for injection bolts

The procedure for testing the allowable bearing stress on the resin product in IBC is outlined in annex G of EN 1090 [8]. This procedure outlines the test of slip factor determination of preloaded connections but should also be used for injection bolts. The resin must be tested in double lap shear connections with specimen geometry according to Figure 31. The specimen on the left must be used with M20 bolts and Ø22 mm holes. The specimen on the right must be applied with M16 bolts in Ø18 mm holes. [8]

For injection bolts the specimen must be assembled such that the resin layer loaded in compression is maximized. [8] This is the most unfavorable loading position since the resistance is determined at a set displacement. With a thicker resin layer the strain in the resin is lower to reach the displacement and a lower strength value results. An illustration of the resulting bolt position and resin layer is shown below:

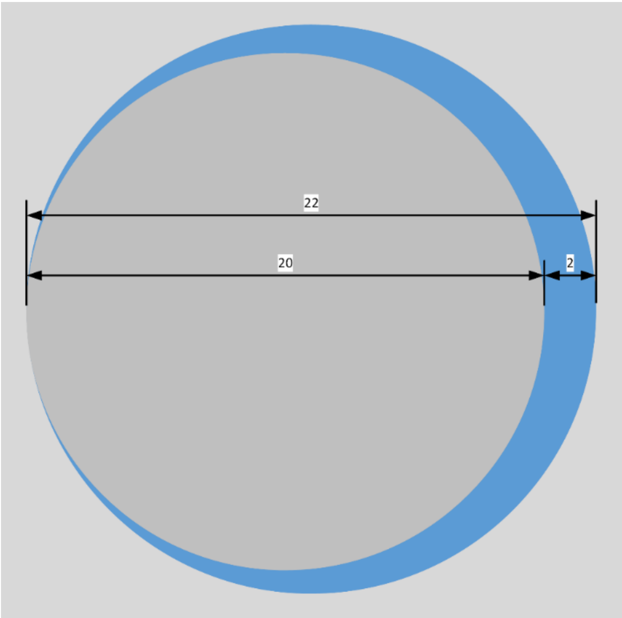


Figure 30 Resin layer in most unfavorable position of bolt for test procedure of EN 1090

Furthermore, the surface treatment of specimens must be the same as will be applied in the application for which testing takes place. Also Resin curing time must be explained. Either by referring to recommendations or through a description of the real procedure. [8]

Test procedure outlines initially 5 specimens must be tested. 4 test specimens must be tested in the regular way which is a load controlled tensile test, with a loading speed such that total test time ranges between 10 and 15 minutes. The slip in the connection should be measured through the relative slip between the center and cover plates of the specimen in the heart of the connection. This is indicated in Figure 31 as points a and b. The test is considered finished when an average slip at these points a and b on both sides of the connection of 0.15 mm is measured. Each connection gives a separate slip force at 0.15 mm. [8]

The fifth specimen in the test protocol should be loaded to 90% of the average slip force of the previous 4 specimens (so 8 results). For this fifth specimen, the slip in the connection 5 minutes after this 90% value is reached should be recorded. If the change in displacement 3 hours after applying the load is less than 0.002 mm the specimen should be loaded as the previous four specimens. [8]

If the 0.002 mm value is crossed an extended creep test should be done on the connection to verify long term bearing stress. [8]

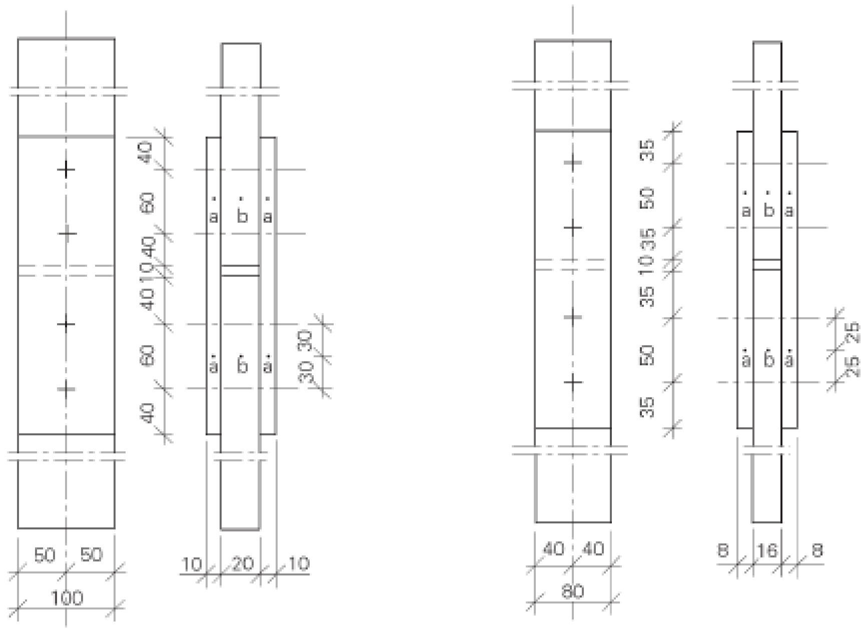


Figure 31 Prescribed specimen geometry for testing of allowable resin bearing stress in injection bolts [8]

The extended creep procedure specifies 3 specimens (6 connections) should be tested. The load should be chosen using the result from the short duration creep test on the fifth specimen as mentioned above and any already performed extended creep tests. Secondly the force for this creep test can also be selected based on the specific application for which testing is carried out. [8]

In the long duration creep test it must be verified that the slip in the connection for the service life of the structure, 50 years unless otherwise specified, shall not exceed 0.3 mm. For the assessment of results a displacement- time diagram shall be plotted with time on a log scale. In this graph the displacement may be extrapolated linearly to determine that the specimen meets the 0.3 mm slip requirement at the service life time. This is shown in Figure G.2 of EN1090. Reproduced here below in Figure 32. Here three results are shown with the linear extrapolation of the curves of specimen 1 and 2 shown in a dashed line [8].

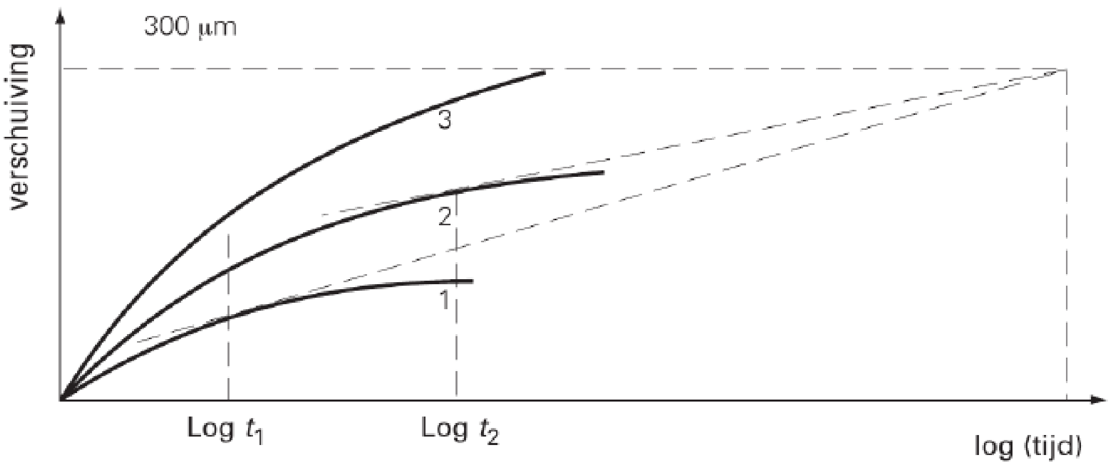


Figure 32 load-log time diagram of extended creep test procedure from annex G EN 1090 [8]

7.6.9 Other relevant regulations for injection bolts

To set the stage regarding the state of regulation and research into other load cases than mentioned above in Design and calculation of Injection bolts are discussed here. These load types are not applied in this research but it gives an idea of the state of the art regarding injection bolts in a broader application.

7.6.10 Fatigue loading for Injection bolts

The structural resistance of connections loaded by fatigue loads is governed by the standard EN 1993-1-9 [50]. The main determinant of fatigue loading is the detail category of a connection. [50] This number represents the constant amplitude stress range for which the design value of the resistance in number of cycles is $2 \cdot 10^6$ for that type of connection. The detail category for fatigue loading of IBC in double lap shear joints is shown in Table 3 below against those for normal bolted connections.

Table 3 Fatigue detail category of double lap shear joints with regular- and injection bolts

	NON-PRELOADED	**PRELOADED**
REGULAR BOLTED CONNECTION	50	112
INJECTION BOLT CONNECTION	90	112

7.6.11 Pre-tensioned connections

As discussed previously shear connections with bolts can be either preloaded or non-preloaded. In category B/C connections preload takes care of (part) of the load transfer. This is done through friction between the contact surfaces of the connected steel plates. This is illustrated in Figure 33.

The design resistance of this type of connection is discussed in EN 1993-1-8. Important for load transfer is the contact surface between the plates. This is taken into account in the slip factor μ which depends on the surface treatment of the steel plates in the connection. [41]

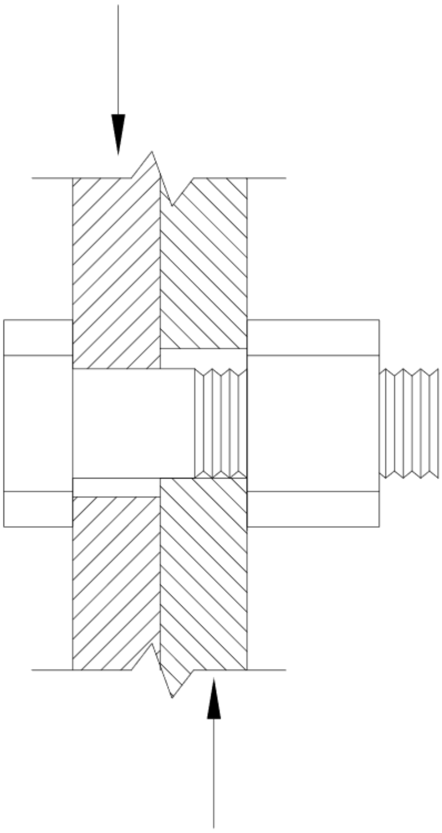


Figure 33 Load transfer of shear connection through bearing (left) and friction due to pretension (right) [51]

8 Material and Methods

In this chapter the procedure for performing of tests and the used materials are explained to answer the research goals of this Master thesis. First the selected alternative resins will be discussed.

8.1 Resin Selection

From the review of the state of the art reported on in Chapter 7 it was found that limited knowledge is available about possible alternative resins for the injection bolt application. From a review of the chemical properties and background on epoxy resins the following properties were identified as important parameters for this application:

- The viscosity of the resin mixture
- The pot life of the resin product
- The glass transition temperature of the resin product after curing
- The curing shrinkage of the resin product
- Mechanical properties of the resin after curing.

Also, successful application of a resin product in IBC in other research is considered for the selection of alternative resins. (Note: at the time of resin selection the author of this research was unaware of the use of Sika AnchorFix and Sika Sikadur 33 for injection bolts as reported on by Gresnigt [31])

Due to the limited knowledge about the optimal range of the aforementioned parameters for this application suppliers of resin products were contacted directly to discuss the possibilities. From this contact with manufacturers and by considering the done research on resins for injection bolts products were selected for testing.

An overview of the used products for this experimental program and some general remarks about their basic properties is given here. For the resin products used in this research detailed information from the PDS is attached in Appendix 16.

8.1.1 RenGel SW404/HY2404

The currently applied epoxy resin in practice RenGel SW404 with HY2404 is used as a reference for all tests. This resin is the benchmark against which the alternatives can be measured. This product has a bright blue color after mixing. For detailed product specifications refer to the attached PDS in Appendix 16. [36] In Figure 35 the two resin components are shown. In Figure 34 a Perspex mockup sample of an injection bolt with RenGel Resin is shown.

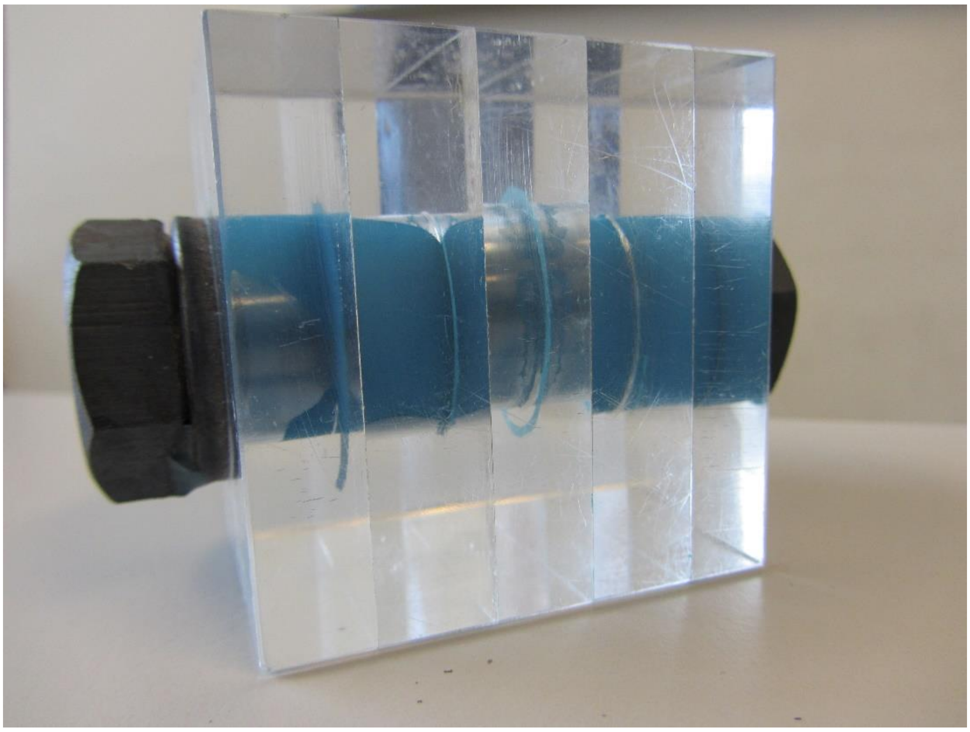


Figure 34 Perspex mockup sample with RenGel SW404/HY2404 resin

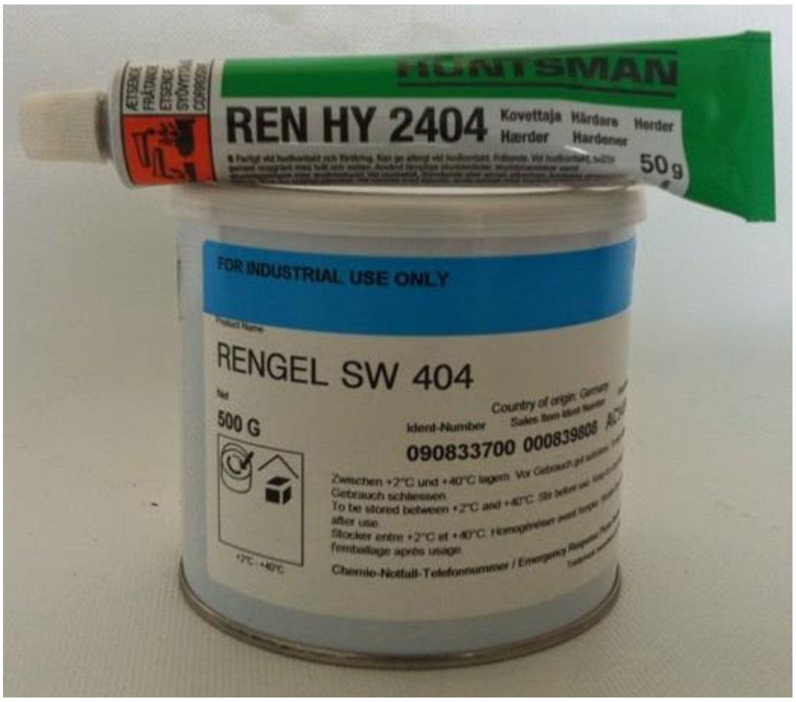


Figure 35 RenGel SW404 resin with HY2404 hardener

8.1.2 Sika Sikadur-30 Resin

Sikadur-30 is one of the alternative resins tested in IBC's in this research. This product has a grey color after mixing. In Figure 36 the resin applied in an IBC is shown. For detailed product specifications refer to the attached PDS in Appendix 16. [52]

Figure 36 Sikadur-30 resin in demounted IBC

8.1.3 Sika Injection 451 Resin

Sika Injection 451 is another alternative resin used in the testing procedure. This resin product is transparent with a slight yellow hue to it after mixing. The viscosity is far lower than the other products appearing almost water-like after mixing. The viscosity mentioned in the PDS of this resin is 100 $mPa \cdot s$. [53] For more detailed product information refer to Appendix 16 where the PDS is attached [53]. In Figure 37 the two components of the resin packaging are shown.

Figure 37 Sika Injection 451 components

8.1.4 Edilon Dex R2K resin

Edilon Dex R2K resin is a product used for structural bonding of anchors in concrete structures. [54] This resin has a very dark grey color after mixing. This product is supplied in a double caulk tube with the correct resin component ratio. This resin is mixed with a special nozzle that fits on this double caulk tube packaging. A special injection gun is used for this double cylinder caulk tube. For detailed product specifications refer to the PDS of this resin attached in Appendix 16. [54] The mixing nozzle, injection gun and resin packaging is shown in Figure 38 and Figure 39.

Figure 38 Edilon Dex R2K injection gun

Figure 39 Dex R2K double caulk tube packaging and mixing nozzle

8.1.5 Edilon Dex G 20 Resin

Edilon Dex G 20 is the second product from manufacturer Edilon)(Sedra tested as a possible alternative for RenGel SW404/HY2404. This resin is normally applied through pouring [55]. Contrary to Edilon Dex R2K this resin is mixed manually and supplied as two separate components. The viscosity of this resin is 11 $Pa \cdot s$ at 25 degrees as stated in the PDS of the product. [55] Refer to the full details of this product in the PDS attached in Appendix 16. [55] This resin product has a light gray color after mixing. The resin packaging is shown in Figure 40.

Figure 40 Two components of Edilon Dex G 20 resin product

8.2 Other used material

To perform testing in the Stevin laboratory on injection bolts several materials were used. These are discussed below.

8.2.1 Fasteners

The bolts used for this experimental program are HV 10.9 bolts modified for use as injection bolts. A hole is drilled in the head according to the dimensions specified in EN 1090-2. These hole dimensions are shown in Figure 41.

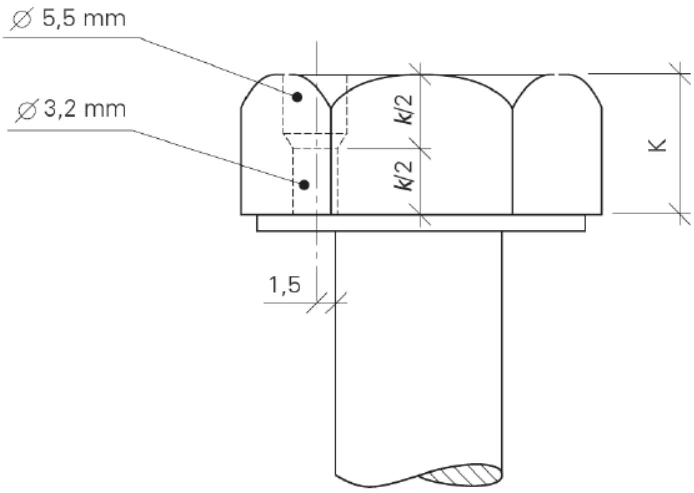


Figure 41 hole in bolt head for IBC [8]

The washers used are also according to EN 1090-2 for use in IBC applications. The washer at the bolt head side has a chamfered side which allows resin to flow from the hole in the bolt head around the shank of the bolt and into the bolt hole. The washer at the nut side has a machined groove to let air escape from the connection during injection.

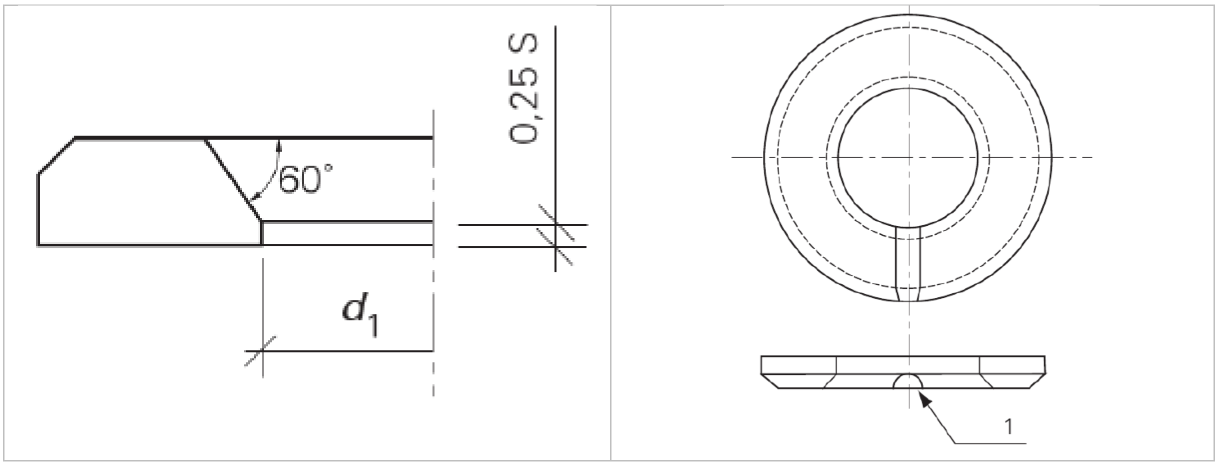


Figure 42 chamfered washer and air escape groove washer overview [8]

The nuts are standard HV 10.9 nuts with oversized thread to work in conjunction with the galvanized thread of the bolts. A full fastener assembly is shown in Figure 43.

Figure 43 Fastener assembly of injection bolt with bolt, washers and nut

8.2.2 Plate Material

All plate material used in the experimental program is steel. The steel grade used was S355. The plates in the testing program were reused from preload slip factor tests performed in the Stevin laboratory. The dimensions of specimens were conform the guidelines laid out in NEN-EN 1090-2. [8] An overview of the used plate dimensions is shown in Figure 44.

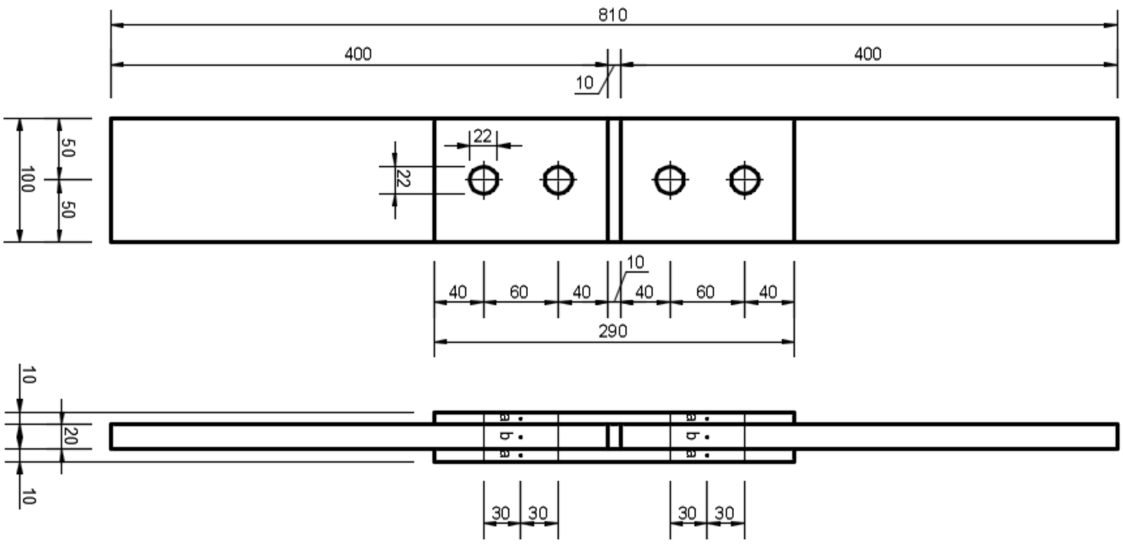


Figure 44 Plate dimensions double lap shear test specimen

For the tests on the resin stress distribution with long bolt lengths leftover plate material from the lab was re-used. This was cut to size to be used as a test specimen. An overview of the steel plate dimensions used in the long bolt tests is shown in Figure 45 and Figure 46.

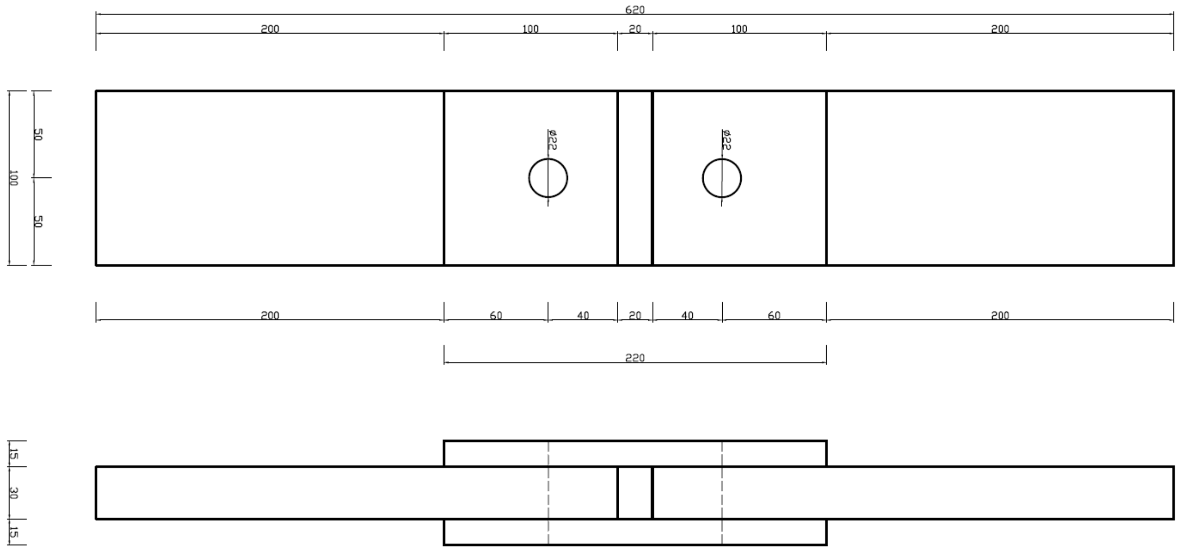


Figure 45 Plate dimensions for long bolt test l/d ratio 3

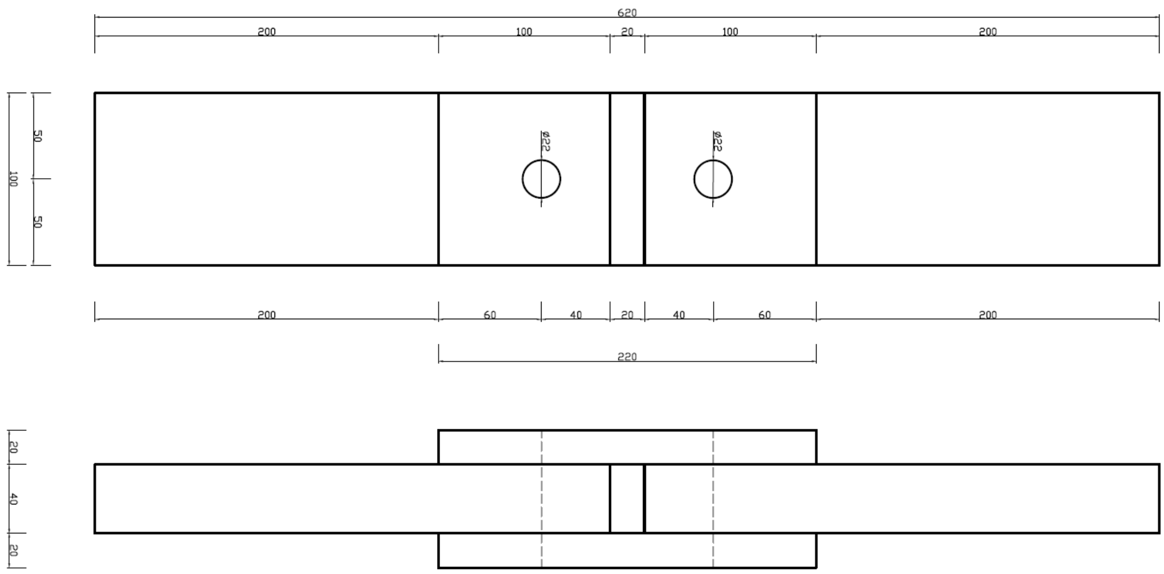


Figure 46 Plate dimensions for long bolt test l/d ratio 4

The plate material used in testing had varying surface treatments. This meant the slip factor μ varied between specimens. A qualitative overview of the different faying surfaces is given in the following table:

Surface treatment	Indication of slip factor [56]
Grit blasted	0.5
Zinc spray-metallized	0.4
Epoxy coating	Very low

8.3 Tools

For the assembly of specimens some general and specific tools were used. These are discussed in order.

8.3.1 Injection gun

For the injection, a hand operated injection gun is used. This allows the operator to get a better feel of the resin flow during the injection through the applied pressure. The used resin products are two component epoxy resins. They are mixed according to the manufacturer specifications as supplied in the PDS of the respective product, using a scale. The resin is then poured into a caulk tube which can be used in the injection gun. An injection nozzle is screwed onto this caulk tube that fits in the hole in the bolt head. The tube is sealed at the back using a plastic end cap. images of the caulk tube, plastic caps and injection nozzles as well as the used injection gun are shown in the figures below:

Figure 47 Hand-Driven injection gun used to inject bolts

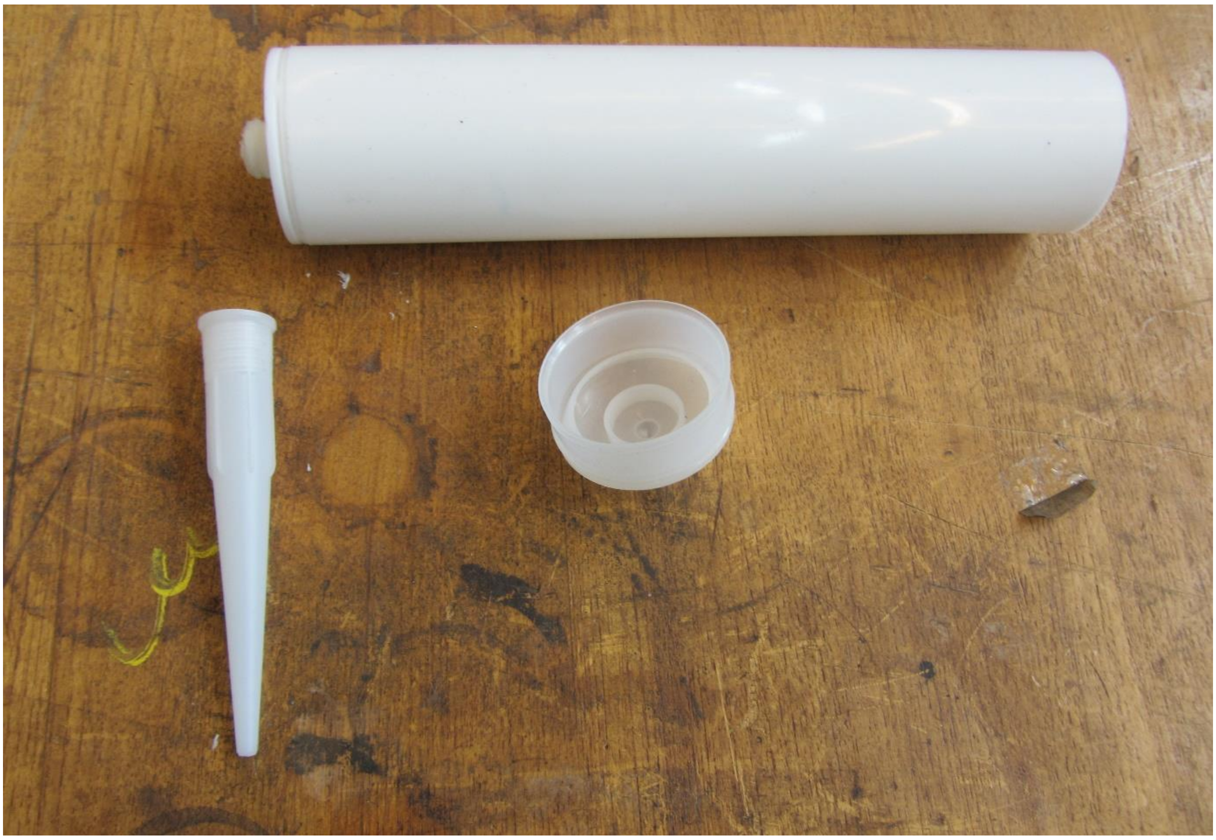


Figure *48* Caulk tube with injection nozzle and tube end cap

For the Dex R2K resin a different injection gun was supplied. This injection is also hand driven. The Dex R2K caulk tube is placed directly in this injection gun and a mixing nozzle is attached to the tube. To correctly inject the bolt a standard injection nozzle is cut to size to fit on the mixing nozzle of the Dex R2K product, since this had a too large opening to fit inside the hole in the head of the bolt. The mixing nozzle is already shown in Figure 39.

8.3.2 Other general tools

To assemble the fastener systems for the IBC specimens some other general tools were used. These include various wrenches as well as a torque wrench to apply a specific preload in the nuts during the injection and curing of specimens. Furthermore, modelling clay was used to close the air escape groove and hole in the bolt head for resins which flowed out of these openings after finishing the injection procedure. The used clay for closing the openings of the IBC is shown in Figure 49.

Figure 49 Modelling clay used for closing air escape groove and bolt head hole

9 Test procedure and setup

The tests performed in this research are double lap shear tests on IBCs. Two test setups in the Stevin II laboratory of the TU Delft are used to perform the tests. In both machines the specimen is placed vertically and fixated with hydraulic clamps at the top and bottom of the center plate of the specimen. The load on the specimen is applied by a hydraulic jack located in the bottom of the machine. The maximum load of machine 1 is 500 kN (hydraulic clamp capacity), used for all tests on standard specimen dimensions. The other machine used for double lap shear tests on specimens with thicker plates has a maximum load of 600 kN. An overview of specimens in the testing rigs is shown in Figure 50.

Figure 50 Test specimens in test rigs for double lap shear tests

9.1 Specimen assembly and fabrication

Specimens used for testing in this research are assembled in the Stevin Laboratory of the TU Delft. The method used for assembling the specimens to ensure proper test results is discussed now in detail.

To assemble a specimen the center- and cover plates are placed on a flat working surface in the lab and the bolt holes drilled in the plates are aligned for assembly. The bolts to be used in the specimen are checked visually to see no debris is inside the injection hole in the bolt head. If this was the case any metal shrapnel from drilling was removed before continuing assembly.

The bolt, nut and washer assembly is then placed in the bolt holes of the steel plate and tightened loosely by hand. After this step, the washers are checked to verify that the washers of the bolt head side and nut side are placed in the right place and with the flat side of the washer facing the steel plates.

Following the guidelines for testing of annex G EN-1090 the center plates of the double lap shear connection are pushed together manually to create the most unfavorable position of the bolt in the bolt hole. [8] This procedure guarantees the maximal resin layer thickness is placed in the compressed side. The resulting bolt shank positioning inside the bolt hole and resulting resin layer is illustrated in Figure 51.

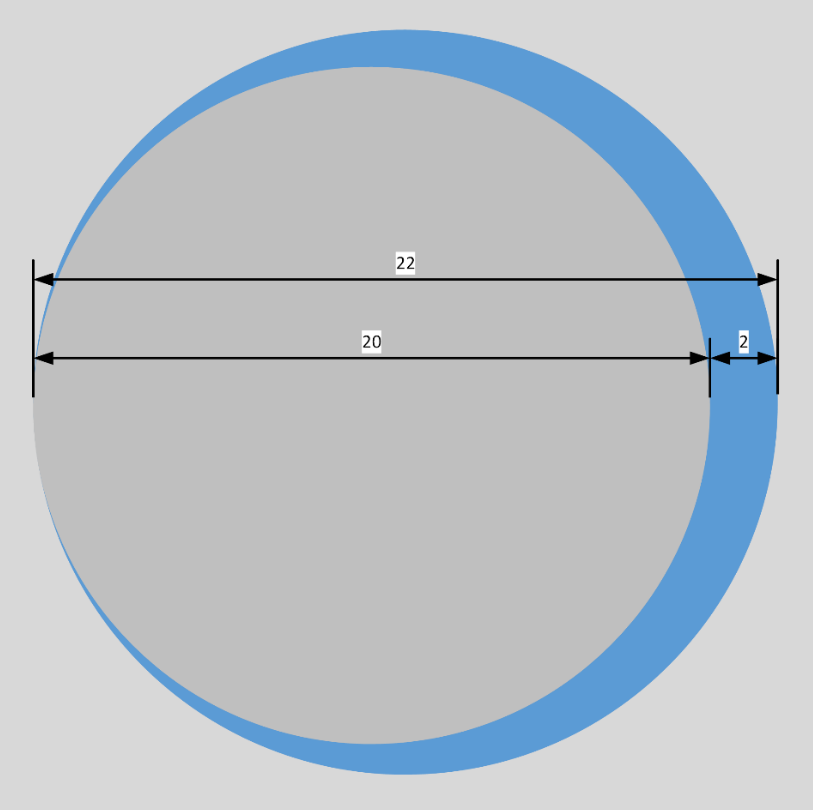


Figure 51 unfavorable bolt shank position in bolt hole for IBC testing

After the plates are pushed together the assembly of the fastener system is checked for correct orientation of the components. The injection hole in the bolt head should be placed at the top. The air escape groove of the washer on the nut side is also placed facing upwards.

The nuts are tightened using a torque wrench to prescribed torque. This is done to prevent the steel plates of the specimen to move during handling. It also prevents the resin penetrating from the bolt hole into the contact surfaces of the steel plates in the connection. The used assembly torque is varied throughout this research. These will be discussed in the test overview of Section 9.6.

After specimen assembly was completed the specimens were either placed in a refrigerator at a set temperature or injected directly. Specimens for which temperature is controlled were left in the refrigerator for at least 24 hours before injection to ensure they reached the desired temperature. The refrigerator used for this is shown in Figure 52. The refrigerator is temperature controlled and is double-checked using a thermometer attached to a laptop to verify the correct temperature.

Figure 52 Refrigerator used for controlling curing temperature of specimens

9.2 Specimen injection

Following the assembly and cooling of specimens the specimen is injected with resin for testing. For the injection procedure, the specimen is again placed on a flat working surface with the bolts horizontal. The hole in the bolt head for injection is again placed on the top side of the connection to prevent air inclusions.

For the injection, the two resin components are mixed in the ratio as supplied in the manufacturer specifications. The quantity of resin mixed for injection is enough to fill all the bolts of a specimen. The preparation of resin is done by weighing the two components of the resin in small mixing cups using a scale. These are then mixed by hand until a homogeneous resin mixture is created.

For the injection a caulk tube is prepared by cutting off the top and screwing an injection nozzle onto it. The resin mixture is poured into the caulk tube taking care to keep the tip of the injection nozzle closed. After pouring the resin into the tube it is tapped on the working surface to compact the resin and remove air in the tube as much as possible. Then a plastic end cap is inserted in the top of the caulk tube to seal the tube at the rear.

The caulk tube assembly is placed in the hand-driven injection gun. The piston of the injection gun is pushed until all air in the tip of the injection nozzle is gone and some resin flows out of the tip of the nozzle. The resin is then injected through the hole in the bolt head until the operator sees resin flowing out of the air escape groove washer on the nut side of the specimen. During injection the pressure applied using the injection gun is high, care must be taken to not apply too much pressure as deforming the plastic end cap results in resin flowing out of the rear of the caulk tube.

9.2.1 Dex R2K injection

For the Edilon Dex R2K resin the injection procedure was changed slightly. This product is supplied as a complete system. For this resin a specific hand-driven injection gun is used with a supplied mixing nozzle, that mixes the two resin components during injection. To use this product in the IBC application a standard injection nozzle is cut to size to fit on the mixing nozzle supplied with the resin. This to ensure a proper seal of the hole in the bolt head and enable injection of the bolt.

For the mixing procedure of this resin the manufacturer application guidelines are followed [57]. When starting with application the first amount of resin from the mixing nozzle is discarded until the resin mixture is a homogeneous dark grey in color. Injection is only started after this initial unmixed resin is discarded from the nozzle. [57]

9.3 Specimen preparation for testing

Before testing is started a last step in preparing the specimen is done. The brackets to mount the LVDTs used for measurements during testing are attached to the specimen. This is done by clamping the bracket with screws on the plates of the specimen and by screwing the mounting bracket onto specially tapped holes in the side of the steel plate specimens. When the specimen is placed in the testing rig the nuts of the fasteners are loosened and then retightened loosely hand-tight. This is done to remove the preload that was introduced during the assembly and curing of the specimens.

9.4 Test procedure and measurement setup

The measurement setup for the double lap shear tests is taken from the guidelines of annex G of EN 1090 [8]. The load-slip curve of the specimen must be recorded during testing. The slip in the connection is measured in the CBG at both sides of the connection to account for any rotation of the plates during testing. Additional measuring of the slip on the PE of the cover plate is done in this research. In total 12 LVDTs are used to measure the displacements. The LVDTs used are high precision with a measurement range of 2 mm and an accuracy of 1 micron. This measurement setup is reused from earlier testing on double lap shear connections using friction grip connections [56]. An illustration of the mounting brackets and LVDT setup from the earlier testing program is shown in Figure 53.

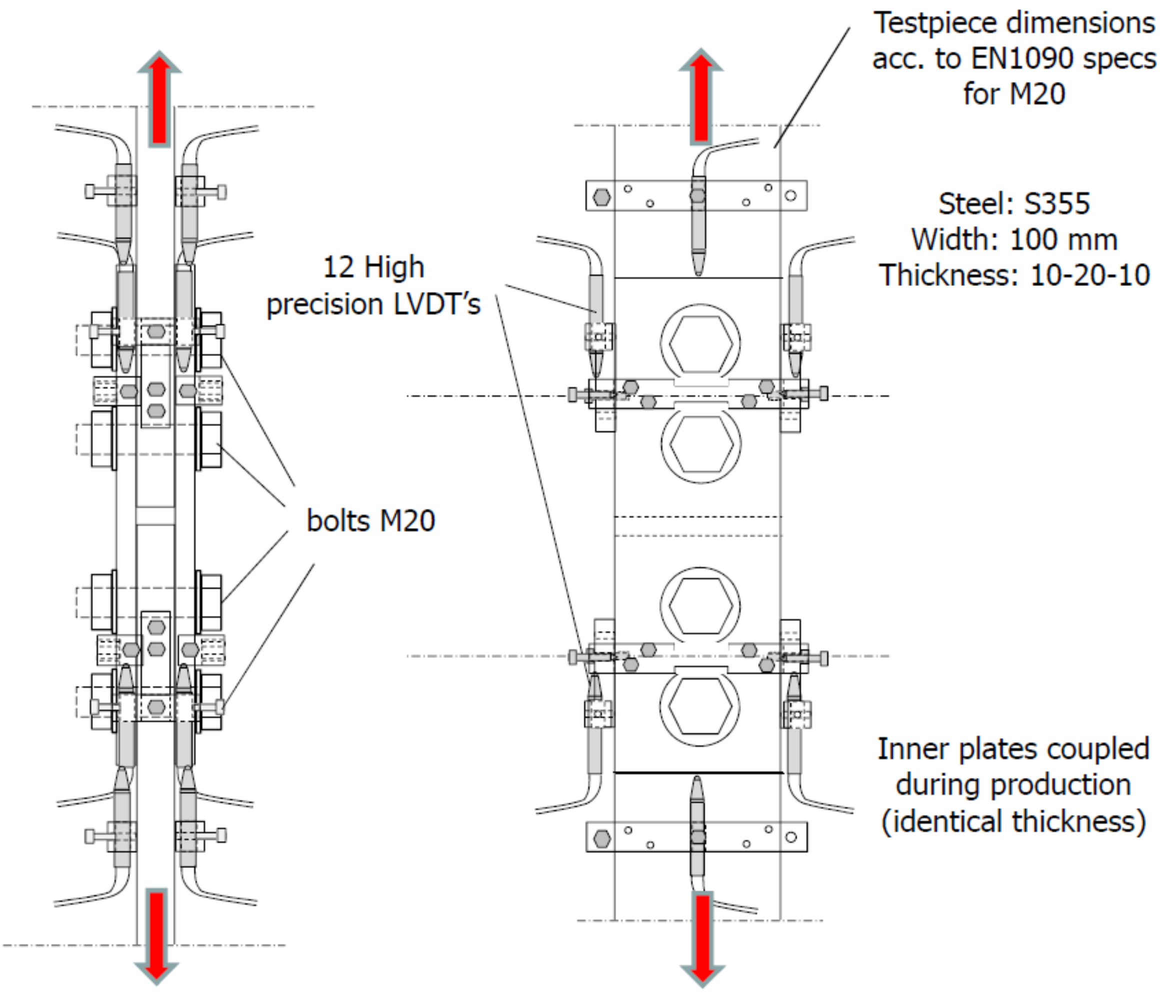


Figure 53 LVDT measurement bracket setup [56]

Testing performed on specimens for bolt length influence was done in a different tensile machine. For these specimens the measurement setup consisted of 4 LVDTs measuring the slip of the connection only at the plate edges of both connections. An image of the LVDTs mounted to the specimen is shown in Figure 54. The distance of the LVDT mounting bracket to the plate edge is controlled during assembly to be 35 mm using a steel spacer block when tightening the LVDT bracket to the plate.

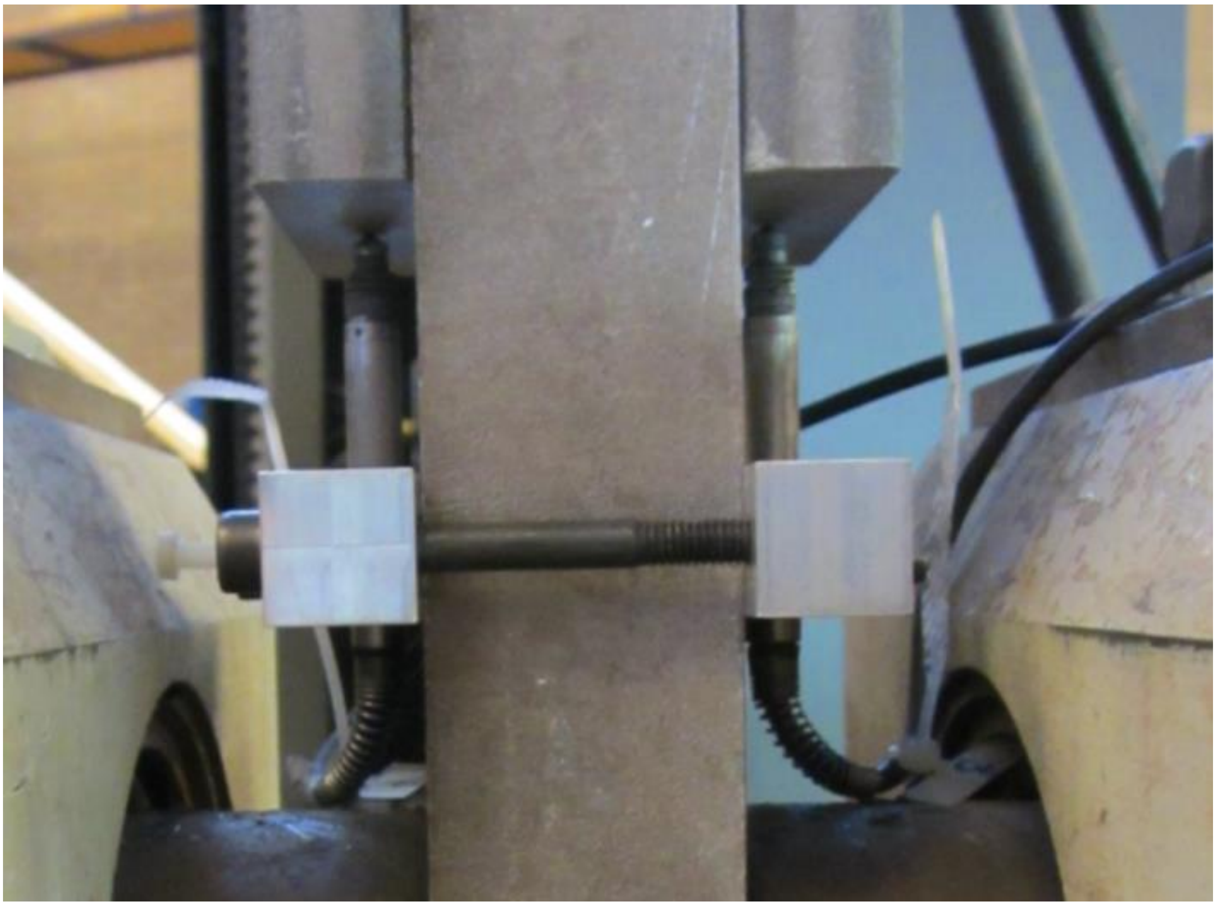


Figure 54 LVDTs measuring slip at PE of LD4 specimen

The load placed on the specimen is measured by the tensile test rig itself. Combining the measurements from the LVDTs and the force from the tensile test setup results in two separate load-slip curves for the top and bottom connection of every specimen.

9.5 Loading procedure

As stated before the guidelines from annex G of EN-1090 are followed. The specimen is loaded in tension with a force controlled protocol. The test is considered finished when a relative slip between inner- and outer plates of 0.15 mm in both connections of the specimen occurs. Which is the average of the displacement at both sides of the connection measured in the CBG.

In this research three distinct load procedures are used to test the specimens. All procedures start from the guidelines of EN-1090. The total time of the test procedure to reach the 0.15 mm slip value should be between 10 and 15 minutes. [8]

The initial load procedure is shown in Figure 55. The load rate for this test to reach the 0.15 mm slip value is at 0.3 $kN/_{s}$. After the test result according to the guideline of EN-1090 is found, the load is removed and a small compressive force is introduced before loading the specimen again to 90% of the load that was found at the 0.15 mm slip value. This load is then kept constant for a minimum of 6 hours before the specimen is unloaded and removed from the test setup. This provides information on the time-dependent behavior of the resin under high loads.

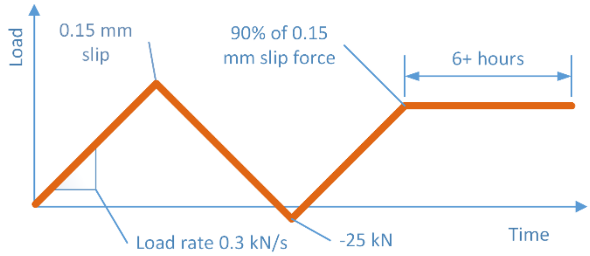


Figure 55 Initial load procedure for double lap shear tests

The second load procedure that was used in this research is shown in Figure 56. Again, the test is started according to the EN-1090 guidelines. The load rate of this test procedure is 0.2 $^{kN}/_{s}$ to conform to the loading time specified in EN-1090. After the 0.15 mm slip at the CBG is reached the load rate is increased to 1.0 $^{kN}/_{s}$. The load is increased until the maximum load of the test setup, 500 kN, is reached. This provides information on the resin behavior when it is overloaded according to EN-1090.

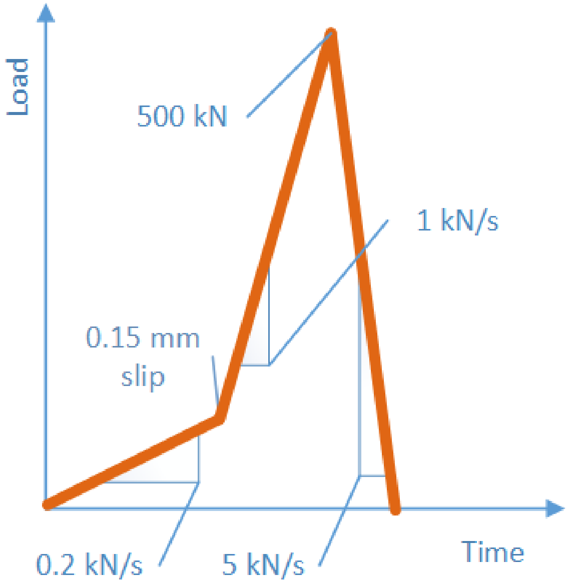


Figure 56 second load procedure with 0.15 mm slip protocol and overload

The final load procedure that is used in this research program is the exact protocol of EN-1090 guidelines. This is shown in Figure 57. Here the load rate is again 0.2 $^{kN}/_{s}$ but no additional testing is done after the 0.15 mm slip value is reached. The specimen is simply unloaded and removed from the test setup.

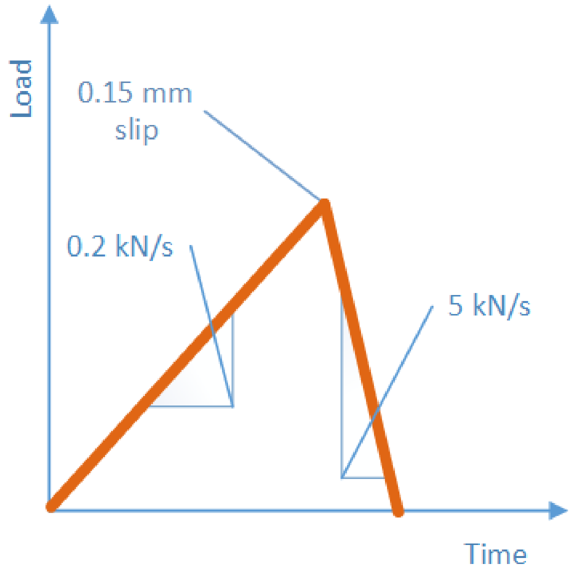


Figure 57 Third load procedure for double lap shear tests

9.6 Overview of performed tests and investigated parameters

Testing in this research has taken place in several test series. Each test series has a different focus and number of specimens tested. An overview of the number of tested specimens for each series of tests is shown in Table 4. Due to the large variation in parameters throughout this testing program a coding system to identify specimens is set up that indicates the values of the varied parameters. The used code shorthand is set out in Table 5. Each of the test series and the parameters varied in the series is discussed in more detail in the following sections. The aim of each series and how it relates to the research goals laid out in the introduction and problem definition is shown graphically in Figure 58.

Table 4 Number of tests performed in each test series

Test series	**Test series identifier**	**number of specimens**	**Aim of the series**
initial feasibility tests	In	5	*Feasibility of application*
temperature dependency tests	T1	12	*Mechanical performance of resin products*
temperature dependency retests	T2	6	*Mechanical performance of resin products*
temperature dependency retests 2	T3	4	*Mechanical performance of resin products*
spread of Dex R2K	DS	4	*Mechanical performance of resin products*
Bolt length influence 1	BL1	4	*Stress distribution of resin layer*
Bolt length influence 2	BL2	4	*Stress distribution of resin layer*

Table 5 Coding system for specimens

Test series	Resin types	specimen dimensions	temperature	plate surface	assembly torque	load procedure	Specimen number*
In	RenG	LD2	8	Zn	hand	init	1
T1	dG20	LD3	16	Ep	100 Nm	slipmax	2
T2	dR2K	LD4	24	Gb	30 Nm	slip	3
T3	Sd30		amb		60 Nm		4
DS	Inj451						
BL1							
BL2							

*for specimens with the same parameters an alphanumerical number is added to identify each specimen uniquely

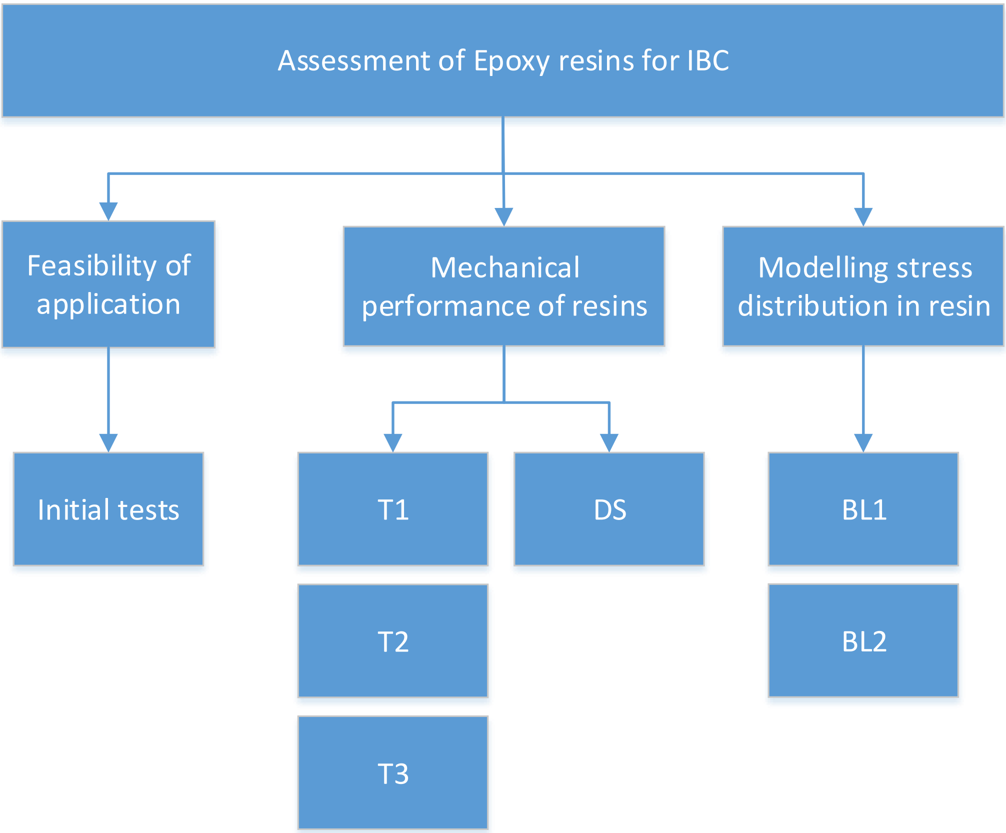


Figure 58 Aim of test series in research project

9.6.1 Initial feasibility tests (in)

The first test series in this research is the initial feasibility testing. The purpose of this series is to investigate the injectability of the different resin products. It is also used as a startup for the research into IBC and thus also served as a way of gaining experience with the injection procedure for the lab staff in the fabrication of specimens. Testing on these specimens is done to get a first indication of the behavior under load of the resin product for short duration and long duration loads. An overview of the test specimens in this series with the applied resin is given here.

Table 6 Test specimens of initial test series with applied resin

Test specimen ID	Resin used
in_RenG_LD2_amb_Zn_hand_init	RenGel SW404/HY2404
in_dG20_LD2_amb_Zn_hand_init	Edilon Dex G20
in_dR2K_LD2_amb_Zn_hand_init	Edilon Dex R2K
in_inj451_LD2_amb_Zn_hand_init	Sika Injection-451
in_sd30_LD2_amb_Zn_hand_init	Sika Sikadur-30

9.6.2 Temperature dependency tests (T1)

The second test series in the research program focused on the curing temperature of the resin as the main parameter. Testing in this series is done to get formal information on the resistance at 0.15 mm slip at the CBG. For information on this load procedure refer to Figure 57 in Section Loading procedure. An overview of the tests in this series with the main parameters can be seen in Table 7.

Table 7 Test specimens of temperature dependency test series with applied resin and temperature

Test specimen ID	resin used	temperature
T1_RenG_LD2_8_Zn_100Nm_slip	RenGel SW404/HY2404	8
T1_dG20_LD2_8_Zn_100Nm_slip	Edilon Dex G20	8
T1_dR2K_LD2_8_Zn_100Nm_slip	Edilon Dex R2K	8
T1_sd30_LD2_8_Zn_100Nm_slip	Sika Sikadur-30	8
T1_RenG_LD2_16_Zn_100Nm_slip	RenGel SW404/HY2404	16
T1_dG20_LD2_16_Zn_100Nm_slip	Edilon Dex G20	16
T1_dR2K_LD2_16_Zn_100Nm_slip	Edilon Dex R2K	16
T1_sd30_LD2_8_Zn_100Nm_slip	Sika Sikadur-30	16
T1_RenG_LD2_24_Zn_100Nm_slip	RenGel SW404/HY2404	24
T1_dG20_LD2_24_Zn_100Nm_slip	Edilon Dex G20	24
T1_dR2K_LD2_24_Zn_100Nm_slip	Edilon Dex R2K	24
T1_sd30_LD2_24_Zn_100Nm_slip	Sika Sikadur-30	24

9.6.3 Temperature dependency retests (T2)

In this test series, the tests from the first series on temperature is repeated partially. This is due to errors in the execution of the first series of tests. To get more information in this series the load procedure was changed to the slipmax version in which the specimen is loaded to the max of the testing equipment. For more detailed information on the loading procedure of this test series refer to the section Loading procedure and Figure 56 specifically.

Furthermore, additional testing is done in this series with plate material using an epoxy coating surface treatment with a low slip factor μ. This gives information on the influence of friction in the performed tests.

Again, the tests of this series are tabulated in Table 8

Table 8 Temperature dependency retests with the surface treatment, temperature and resin per specimen

Test specimen ID	resin used	temperature	faying surface
T2_RenG_LD2_8_Zn_100Nm_slipmax	RenGel SW404/HY2404	8	Zinc
T2_RenG_LD2_8_Ep_100Nm_slipmax	RenGel SW404/HY2404	8	Epoxy coat
T2_dR2K_LD2_8_Zn_100Nm_slipmax	Edilon Dex R2K	8	Zinc
T2_dR2K_LD2_8_Ep_100Nm_slipmax	Edilon Dex R2K	8	Epoxy coat
T2_RenG_LD2_16_Zn_100Nm_slipmax	RenGel SW404/HY2404	16	Zinc
T2_dR2K_LD2_16_Zn_100Nm_slipmax	Edilon Dex R2K	16	Zinc

9.6.4 Spread of Dex R2K test series (DS)

The purpose of this test series is to investigate the spread that occurs in results with Dex R2K specimens with a larger set of results. For these specimens, the torque applied during the specimen assembly procedure was changed to 30 Nm. This is varied to remove any influence of friction between the plate surfaces on the results. The tested specimens in this series are shown in Table 9.

Table 9 Test specimens used to investigate spread and temperature behavior of Edilon Dex R2K

Test specimen ID	resin used	temperature	assembly torque
DS_dR2K_LD2_16_Zn_30Nm_slipmax_1	Edilon Dex R2K	16	30 Nm
DS_dR2K_LD2_16_Zn_30Nm_slipmax_2	Edilon Dex R2K	16	30 Nm
DS_dR2K_LD2_16_Zn_30Nm_slipmax_3	Edilon Dex R2K	16	30 Nm
DS_dR2K_LD2_16_Zn_30Nm_slipmax_4	Edilon Dex R2K	16	30 Nm

9.6.5 Temperature dependency retests 2 (T3)

In this test series testing was only performed on Edilon Dex R2K resin. The purpose here is to complete the investigation into curing temperature dependency with the adapted procedure to eliminate friction from the results. The load procedure used is again the slipmax variant as illustrated in Figure 56. The specimens tested are shown in Table 10.

Table 10 Test specimens for temperature dependency retests 2

Test specimen ID	resin used	temperature	assembly torque
T3_dR2K_LD2_8_Zn_30Nm_slipmax_1	Edilon Dex R2K	8	30 Nm
T3_dR2K_LD2_8_Zn_30Nm_slipmax_2	Edilon Dex R2K	8	30 Nm
T3_dR2K_LD2_24_Zn_30Nm_slipmax_1	Edilon Dex R2K	24	30 Nm
T3_dR2K_LD2_24_Zn_30Nm_slipmax_2	Edilon Dex R2K	24	30 Nm

9.6.6 Bolt length influence 1

This test series investigates the behavior of IBC with a thicker plate package in relation to the bolt diameter. Two different values for the $\frac{l}{d}$ ratio are tested in this series. Due to the different specimen dimensions used in this series, a different tensile testing machine was used to perform tests. The resin product used in this series is RenGel SW404/HY2404. The specimen curing in this series is done in the ambient temperature of the lab. The plates used for these specimens are fabricated from leftover steel plates from the Stevin II laboratory of the TU Delft. The surface treatment of this plates is grit-blasted. An overview of the performed tests can be found in Table 11.

Table 11 Tests performed for the Bolt Length influence test series 1

Test specimen ID	resin used	l/d ratio specimen	temperature	assembly torque
BL1_RenG_LD3_amb_Gb_30Nm_slip_1	RenGel SW404/HY2404	3	ambient	30 Nm
BL1_RenG_LD3_amb_Gb_30Nm_slip_2	RenGel SW404/HY2404	3	ambient	30 Nm
BL1_RenG_LD4_amb_Gb_30Nm_slip_1	RenGel SW404/HY2404	4	ambient	30 Nm
BL1_RenG_LD4_amb_Gb_30Nm_slip_2	RenGel SW404/HY2404	4	ambient	30 Nm

9.6.7 Bolt length influence 2

This series is performed to gain more confidence in the test results from the first series on Bolt length influence. These tests are performed by sand blasting the specimens from the first series on bolt length influence until they are clean and the plates are reused for these tests. The only parameter that was changed between this series and the previous one on bolt length influence, is the applied torque during specimen assembly, this was raised to 60 Nm. A final test specimen overview can be found in Table 12.

Table 12 Overview of second series on the influence of bolt length on resin stress distribution

Test specimen ID	resin used	l/d ratio specimen	temperature	assembly torque
BL2_RenG_LD3_amb_Gb_30Nm_slip_1	RenGel SW404/HY2404	3	ambient	60 Nm
BL2_RenG_LD3_amb_Gb_30Nm_slip_2	RenGel SW404/HY2404	3	ambient	60 Nm
BL2_RenG_LD4_amb_Gb_30Nm_slip_1	RenGel SW404/HY2404	4	ambient	60 Nm
BL2_RenG_LD4_amb_Gb_30Nm_slip_2	RenGel SW404/HY2404	4	ambient	60 Nm

9.7 Curing time research

All specimens tested in this research have had a curing time of at least 24 hours at the specified temperature. The test program carried out in the Stevin laboratory of the TU Delft was more extensive than just the tests of this research. Experiments relating to the curing time of resin products in IBC was carried out in the laboratory as well [58]. Due to the large relevance of these tests for this research topic the results of this series are also discussed in the results section shortly.

The approach to testing and assembling of specimens of the series of tests performed by J. Li is the same as reported above for this research [58]. Two different load procedures were used in this research into the effect of curing time. These are reproduced here in Figure 59 and Figure 60.

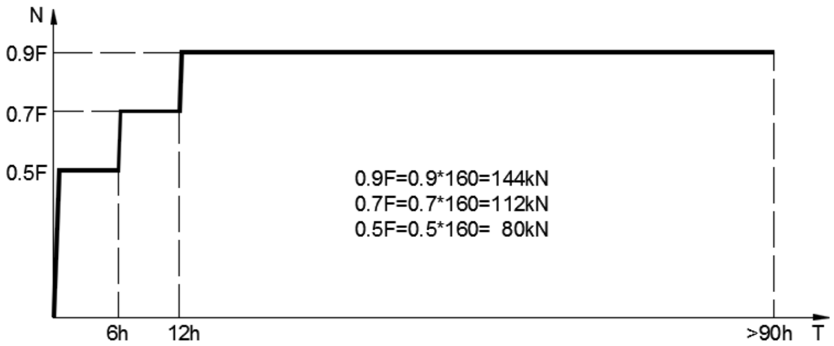


Figure 59 Short3-1 load procedure from curing time research

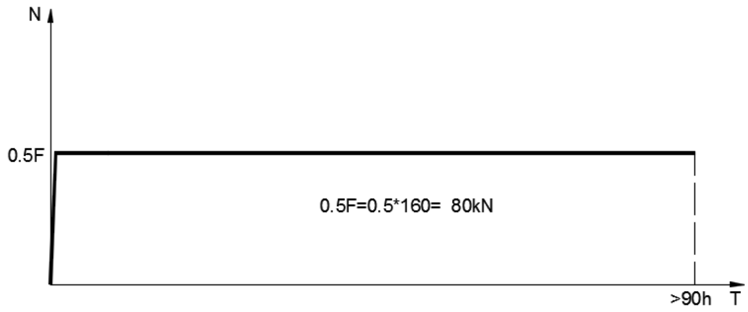


Figure 60 Short3-2 load procedure from curing time research

10 Results

10.1 Initial feasibility of alternative resins

To verify the feasibility of the resin products mentioned in section 8.1, one specimen was tested for each product, according to the procedure mentioned in section 9. After testing of these specimens, they were disassembled for a visual inspection. This will be discussed first, then the results of the connection tests will be discussed.

10.1.1 Visual inspection

10.1.1.1 Voids in injection bolt specimens

Research is done on injection bolt specimens in relation to voids in the resin layer. For this an injection bolt is cut from a steel specimen and placed inside a CT scan. This allows us to visualize the resin layer in three dimensions through differences in density. In Figure 61 the result of a CT scan on an injection bolt is shown. Here the presence of an air inclusion can be seen in the resin layer in white (indicated with the yellow arrow.).

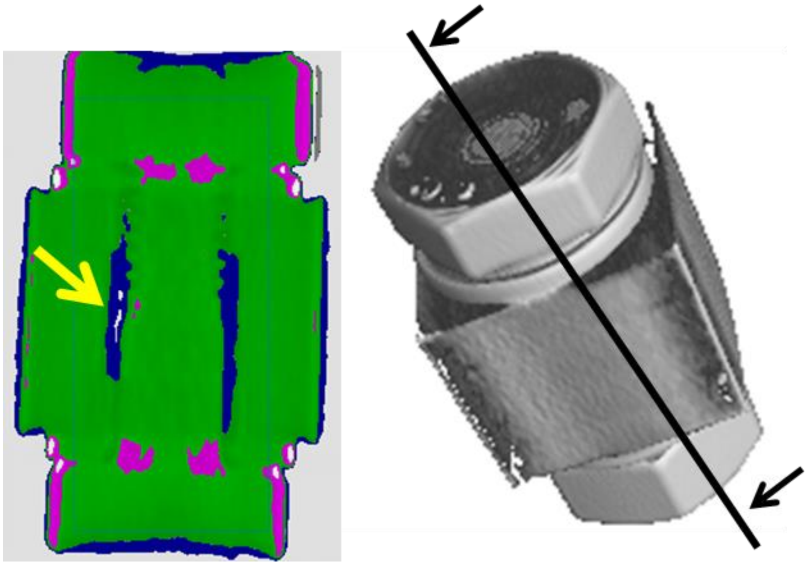


Figure 61 CT-scan of injection bolt specimen with void in resin layer [59]

From other research Perspex mock-ups are often used to assess resin injection. In this research, no Perspex mock-up samples were created. To assess the injection procedure specimens from this test series are disassembled and the resin layer in the steel plates is checked for proper filling of the bolt hole clearance. As mentioned in research by Nijgh [32] the bolts are not easily disassembled since no products were applied to facilitate this. To disassemble the specimens a hydraulic press in the Stevin laboratory is used to push the bolts out of the specimens. This procedure is shown in Figure 62.

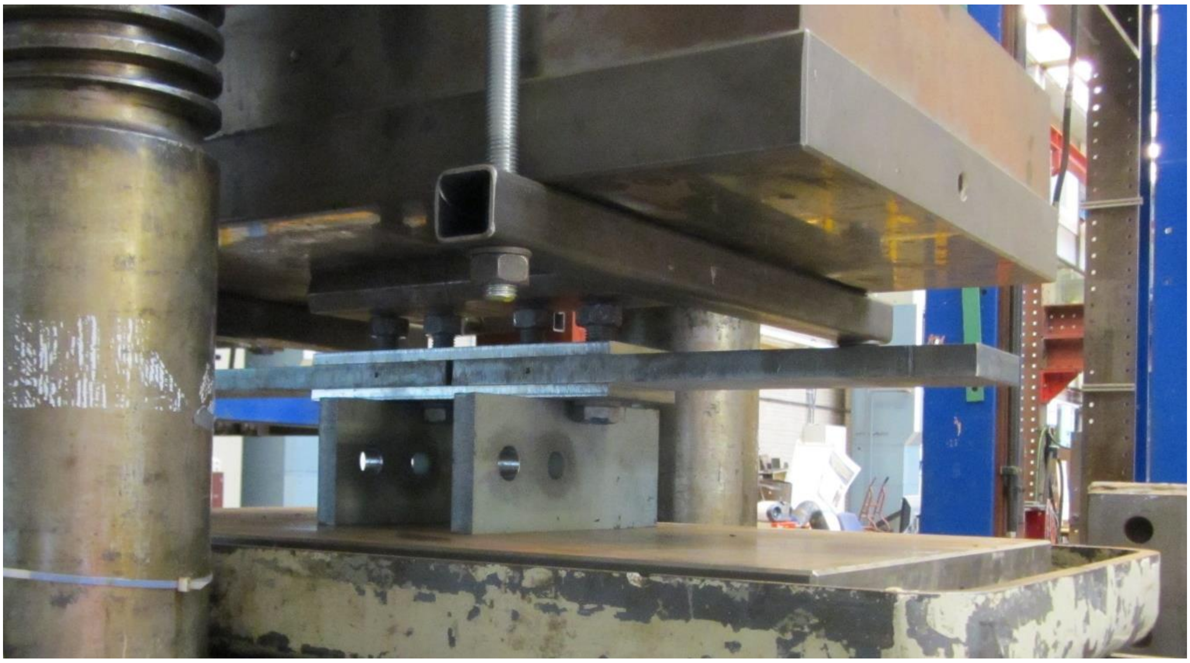


Figure 62 Use of hydraulic press to push bolts out of specimen

Due to the large force required to push the bolts out of the specimen the surface area of the resin layer is slightly damaged in some cases. The cross-section of the resin layer though remained relatively intact and proved valuable for inspection.

Images of the visual inspection for each resin product are shown below. As a general remark from previous research using Perspex mock-ups no air inclusions were observed. Using this inspection method of the resin cross-section it can be observed that air inclusions were found in the resin layer for each resin product including the currently successfully applied resin RenGel SW404.

From the positioning of the air inclusions inside the cross-section of the layer these inclusions would not have been visible using the Perspex mock-up samples where only the outer surface of the resin against the plate surface is visible.

10.1.1.2 RenGel SW404/HY2404

This resin product has been proven to work from extensive previous research. [11] [40] [9]. The visual inspection of this resin is shown for comparison with alternative resin products. The filling of the bolt hole clearance was successful but some air inclusions in the resin can be seen in the images of Figure 63.

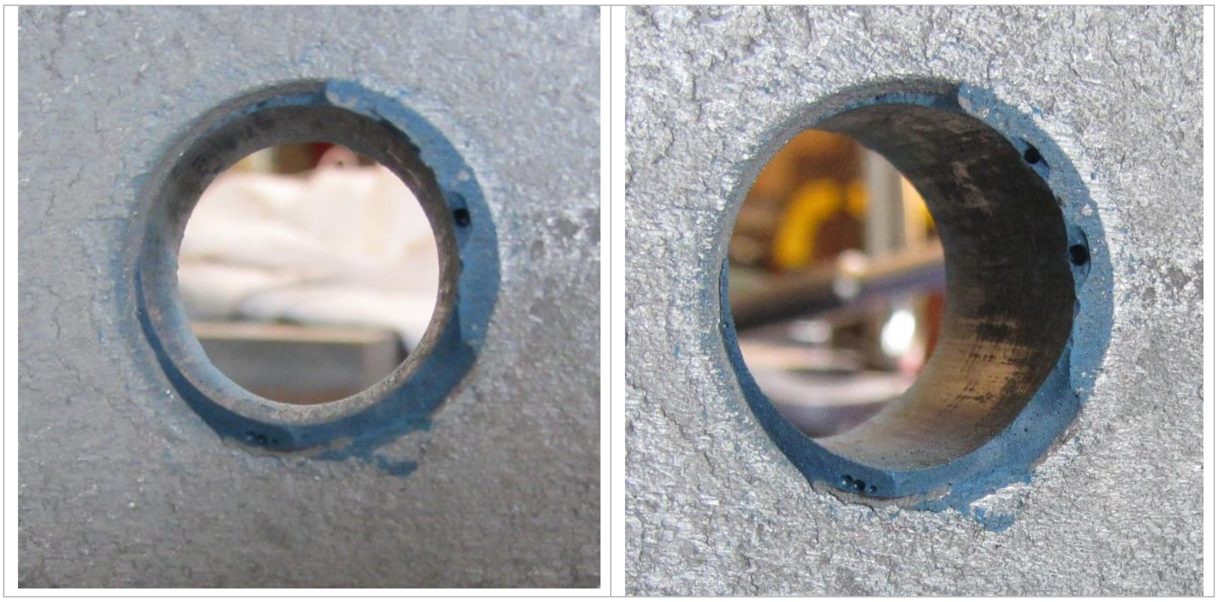


Figure 63 Visual inspection of RenGel in bolt holes after disassembly of specimen

10.1.1.3 Edilon Dex G 20

Clay had to be used to prevent this resin product from leaking out of the air escape groove and injection hole in the bolt head after finishing the injection procedure. After disassembly, the resin showed to have properly filled the bolt hole clearance without penetrating in between the steel plates. Again, some air inclusions were observed though in the resin layer.

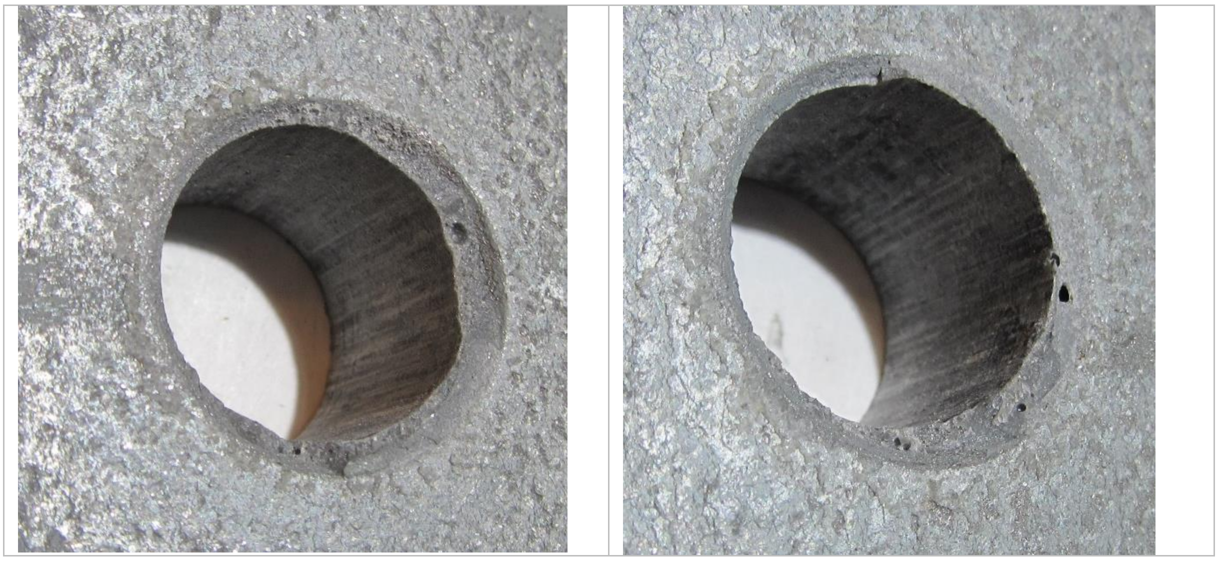


Figure 64 Visual inspection of resin layer of Dex G 20 product

10.1.1.4 Edilon Dex R2K

From the inspection of the resin layer this product also properly filled the bolt hole without penetrating the plate surfaces. The resin did not run out of the air escape groove or injection hole in the bolt head after injection. Once more some air inclusions are visible.

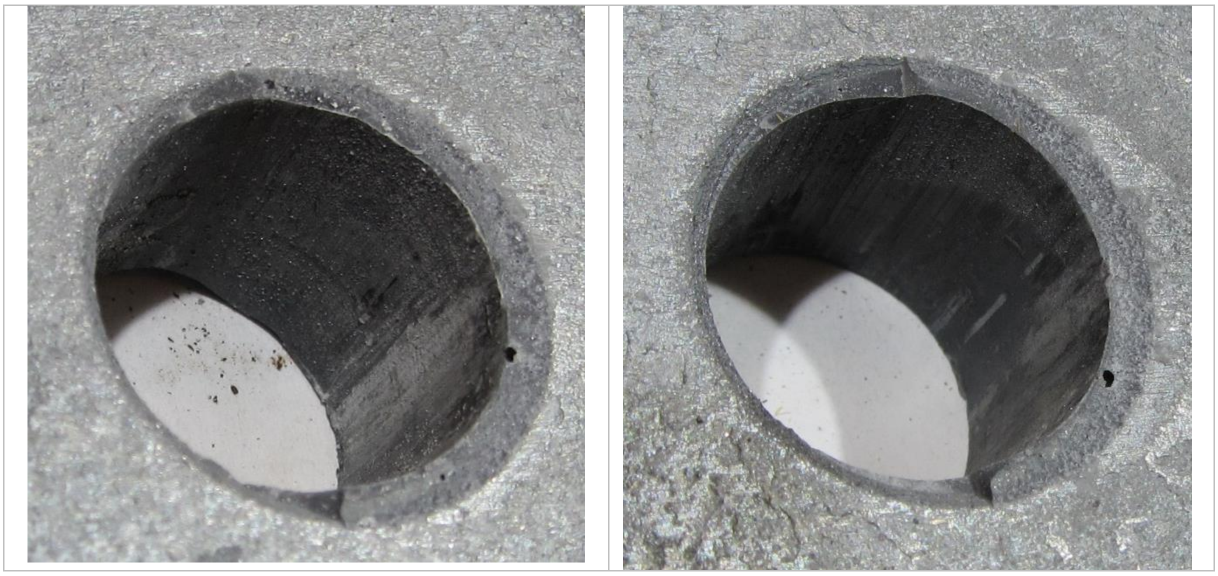


Figure 65 Visual inspection of Dex R2K resin in bolt holes

10.1.1.5 Sika Injection 451

This resin did not properly fill the bolt hole clearance due to excessively low viscosity. The resin leaked out of the bolt hole and in between the steel plates of the connection. This caused a glue-like bond between the plates. The bolt hole clearance was partially filled and residue of the resin can clearly be seen on the plate surfaces in Figure 66.

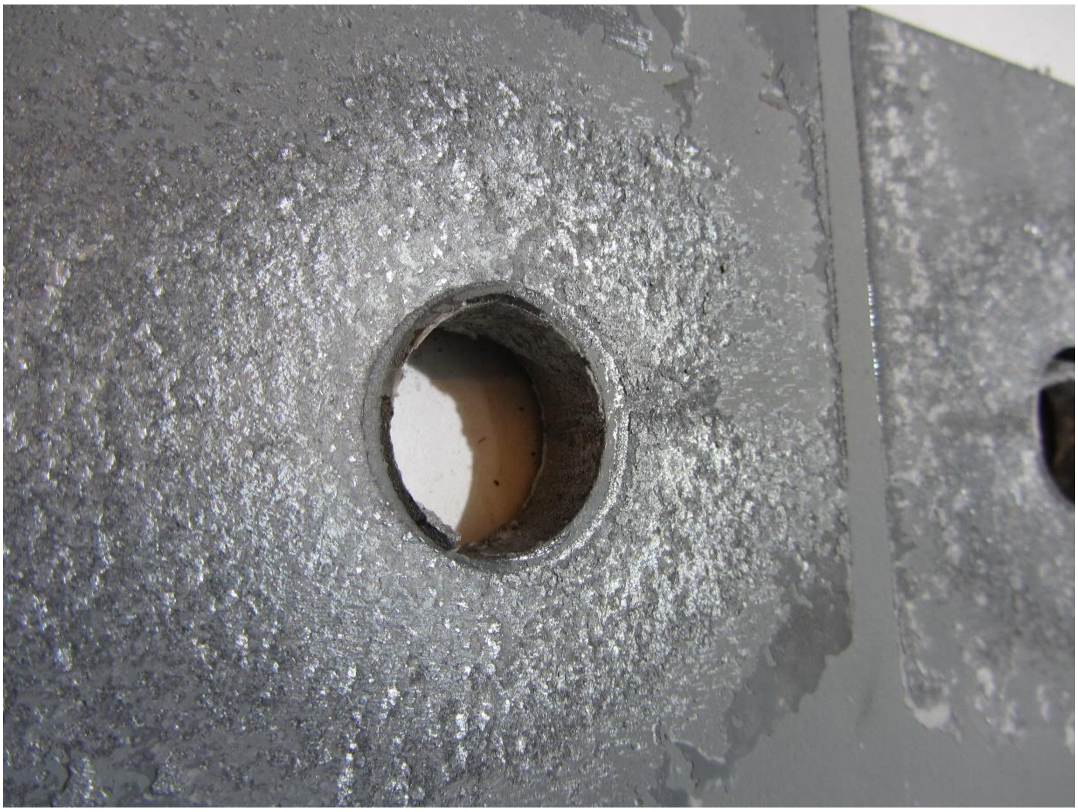


Figure 66 Visual inspection of Sika Injection 451 specimen

10.1.1.6 Sikadur 30

The resin correctly filled all the bolt holes. For reference an image of one of the cover plates is shown. Here it can be seen that the bolt shank positioning is correct and the most unfavourable position of the bolt shank is realised according to the EN 1090 test specifications [8]. Again, air inclusions can be seen in the resin layer. The resin layer and cover plates are shown in Figure 67.

Figure 67 Visual inspection of disassembled Sikadur 30 specimen

10.1.2 Results of initial connection tests

The results of these connections tests are shown in Figure 68 and Figure 69. First the load displacement of the connection is shown for the initial loading. Secondly the creep of the connection is compared after loading to 90% of the found 0.15 mm slip value. For clarity, the average of the two connections of the specimen is shown. The full results are tabulated in Table 13.

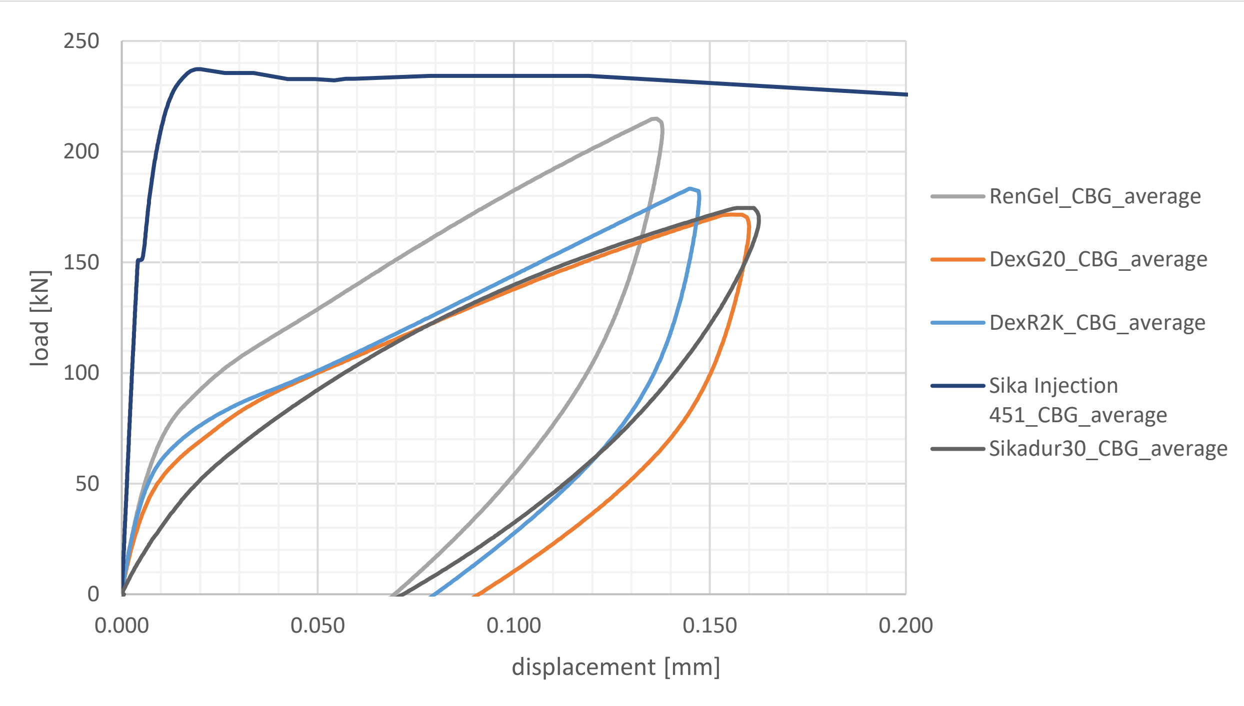


Figure 68 load-displacement results of initial tests on selected resin products

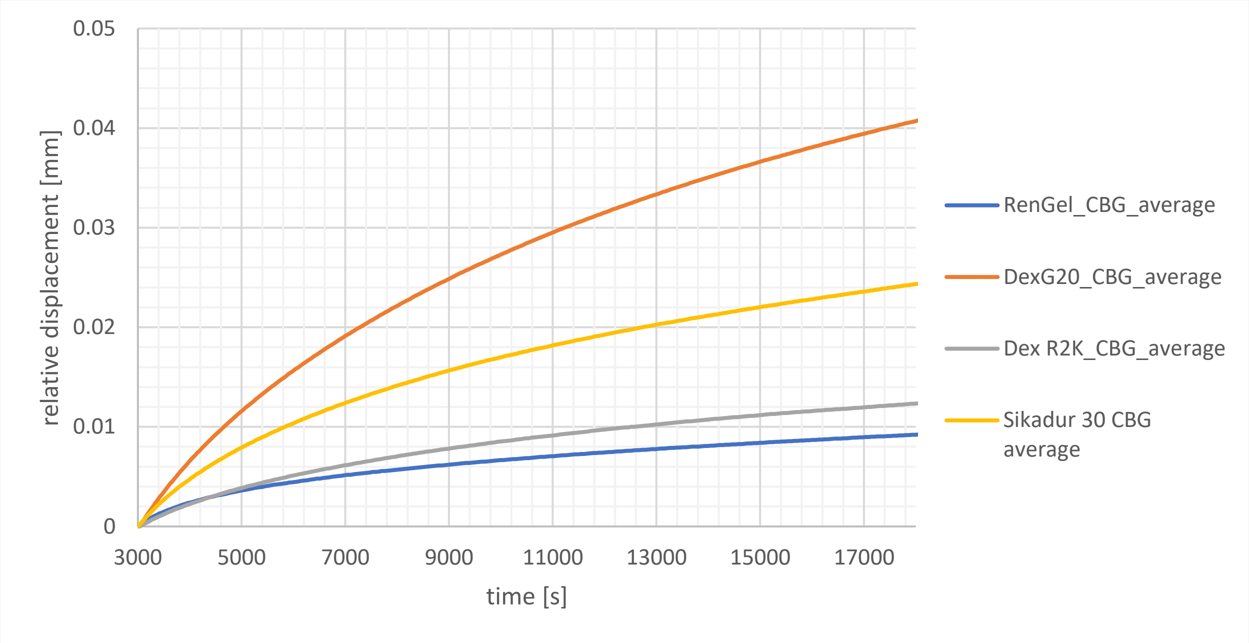


Figure 69 creep of injection bolt loaded to 90% of 0.15 mm value of initial tests

Table 13 Results initial connection tests

Product name	Force for 0.15 mm slip [kN]
Araldite (RenGel SW404/HY2404)	215
Sika injection 451	-
Sikadur 30	175
Edilon DEX G 20	170
Edilon DEX R2K	185

What can be seen is that the Sikadur 451 specimen behavior is not correct. Due to the excessive leaking of resin in between the plates a glued connection was created. This caused a very stiff response of the specimen followed by a sudden slip of around 2 mm which is equal to the bolt hole clearance. The other specimens which did show a correct filling all behave similarly. There is an initial stiff response followed by a linear behaviour until the 0.15 mm displacement limit.

What can be remarked on these tests is that the test of the Dex R2K and RenGel specimens was unloaded after the first connection reached the 0.15 mm slip instead of both specimens. Therefor the average of those tests in Figure 68 does not reach 0.15 mm. This series was intended to gain experience with the injection procedure and verify the application of resin products in IBC so this is not considered an issue.

To initially gather more information on the alternative resin product behaviour the specimens were unloaded and then reloaded to 90% of the value found at 0.15 mm slip in the initial loading. This load was then kept constant and creep of the connection was checked in time. This is illustrated in Figure 69. Since this specimen is loaded up to 0.15 and then unloaded before starting the creep test this test does not follow the formal procedure of EN 1090 but it does serve to get some information on the time dependent behaviour of the resin. What can be observed is that the RenGel and Dex R2K specimens show very similar creep while the Sikadur 30 and Dex G 20 show severe creep at this load. This is tabulated as well in Table 14.

Table 14 Creep results initial connection tests

Resin product	Creep deformation [mm]	Relative deformation* [%]
RenGel SW404/HY2404	0.009	0.0
Dex G20	0.042	349.9
Dex R2K	0.011	18.4
Sikadur 30	0.025	169.3
*compared with RenGel SW404/HY2404 creep behavior		

10.2 Temperature dependency tests

Based on the results of the initial test series the research is continued for RenGel SW404/HY2404, Edilon Dex R2K, Edilon Dex G20 and Sika Sikadur 30 resin. Sika injection 451 is discarded due to the resin not properly filling the bolt hole clearance and penetrating the steel plate surfaces.

The investigation into the dependency on curing temperature of the resin was executed in several series of tests due to errors in execution of the test or assembly of specimens. In this section first the execution errors and issues will be discussed. Thereafter the results of performed tests without issues will be reported for analysis.

10.2.1 First series on temperature dependency (T1)

These specimens were erroneously assembled hand-tight the same as the initial test series instead of the prescribed 100 Nm. In this test series, some specimens did not give good results due to issues with the injection of specimens and because of errors in the execution of the test procedure, aside from the aforementioned 100 Nm mistake. The specimens with issues are summarized here in Table 15.

Table 15 *Issues with test specimens of first series on temperature dependency*

Test specimen ID	issue
T1_RenG_LD2_8_Zn_100Nm_slip	Too little resin mixed for injection. One connection of this specimen unusable.
T1_sd30_LD2_8_Zn_100Nm_slip	Injection failed for 2 bolts. Both in one connection. One connection unusable results.
T1_RenG_LD2_16_Zn_100Nm_slip	Nuts not loosened before testing started
T1_dR2K_LD2_16_Zn_100Nm_slip	Nuts not loosened before testing started
T1_sd30_LD2_16_Zn_100Nm_slip	Both connections unusable due to failed injection
T1_sd30_LD2_24_Zn_100Nm_slip	One connection unusable due to failed injection.

The issues with the injection of Sikadur 30 resin will be discussed in more detail due to the important information that could be gained from this.

10.2.2 Temperature dependency retests (T2)

To be able to draw conclusions on the curing temperature dependency the tests with issues summarized above in Table 15 were repeated. To limit the total number of tests performed in this research it was decided to stop further testing on the Edilon Dex G 20 resin. The strength values found in the first series on temperature dependency were a lot lower than the other products and this product also showed the worst time-dependent behavior in the indication gained from the initial test series. In addition to the retests on the temperature dependency also two additional tests were performed with a different plate surface preparation. These will be discussed in more detail below.

10.2.3 Third series on temperature dependency (T3)

From the results on the different plate surface preparation specimens of test series T2 combined with the results using the adapted assembly procedure of series DS this series was done to draw a clear conclusion on the dependency of curing temperature for Dex R2K resin. One specimen in this series had an issue in this series:

Test specimen ID	Issue
T3_dR2K_LD2_24_Zn_30Nm_slipmax_1	LVDT mounting bracket loose

10.2.4 Results

From the first series of tests Sikadur-30 showed issues with the injection procedure across all specimens. The position of the washer was found to influence the resin injection for this product. The bolts for which injection was not possible in this research were removed from the specimen and the typical pattern found for these bolts is shown in Figure 70. These issues arose in all specimens of the first series and based on this behavior the resin was discarded as an alternative.

Figure 70 Sikadur-30 failed injection at bolt head washer interface

The initial test series results are tabulated in Table 16. Based on the results of T1 the Edilon Dex G 20 product was also discarded as an alternative. The strength values in this series were lower than the other products and the creep behavior of Dex G 20 in the initial tests was also unfavorable compared to the other products.

Table 16 Results of first temperature dependency series (T1)

	Temperature [Celsius]	force 0.15 mm top CBG [kN]	force 0.15 mm bottom CBG [kN]	Average [kN]	Average effective Bearing stress resin [N/mm^2
RenGel	8	197	-	197	246,25
	16	227	203	215	268,75
	24	200	197	199	248,125
Dex g 20	8	151	139	145	181,25
	16	154	158	156	195
	24	159	175	167	208,75
DEX R 2 k	8	229	182	206	256,875
	16	234	178	206	257,5
	24	172	141	157	195,625
Sikadur 30	8	-	124	124	155
	16	-	-	-	-
	24	-	154	154	192,5

10.2.5 Friction influence

During this research assembly of specimens was done with 100 Nm torque applied to the nut during assembly. From the results found in the load-slip graphs a stiff initial response of the specimens was seen. In the second test series done on temperature dependency this stiff response was investigated by varying the plate surface preparation. An epoxy coated specimen was used which has a very low factor as shown in research by P.A. de Vries [56]. In Figure 71 the results of specimens cured at 8 degrees with RenGel are shown in which the only variation is the plate surface preparation. From this it is concluded that the 100 Nm assembly procedure results in some load transfer through friction between the plate surfaces. This despite the loosening of nuts before testing. It is theorized here that the resin behaves stiff enough after curing to retain the preload in the specimen.

Based on this result the assembly procedure was changed to apply only a 30 Nm torque on the nut during assembly to remove this friction influence in the results.

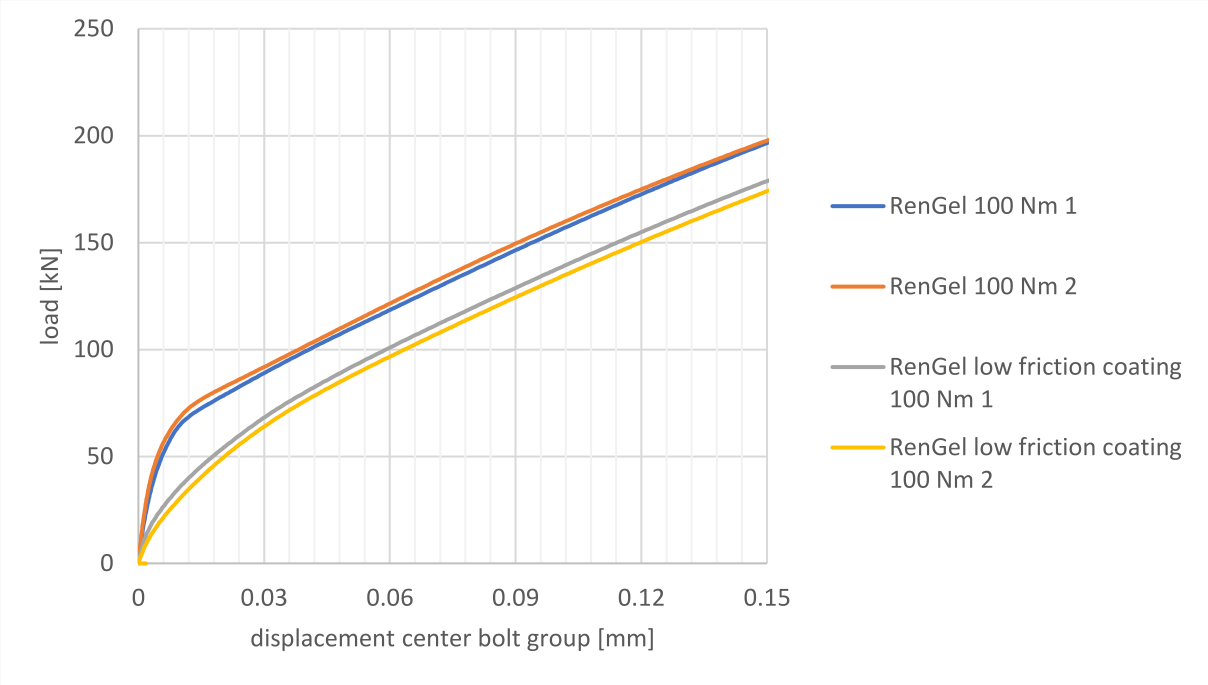


Figure 71 Load-slip of RenGel specimen with 100 Nm assembly torque with normal Zinc coated and epoxy low friction coating

10.2.6 Overload behavior

The test results reported concern the 0.15 mm slip value of EN 1090 [8]. In this research, the behavior for higher loads of the resin products is also investigated as described in Figure 56. The load-slip diagram of test results on Dex R2K at 24 degrees and RenGel at 16 degrees is shown in Figure 72. From this test procedure, the connections maintain a nearly linear behavior even when loaded far beyond what is specified in EN 1090. [8] What can be seen in Figure 72 is that the force increases up to a displacement of 0.6 mm. This is four times the short-term displacement limit from EN-1090.

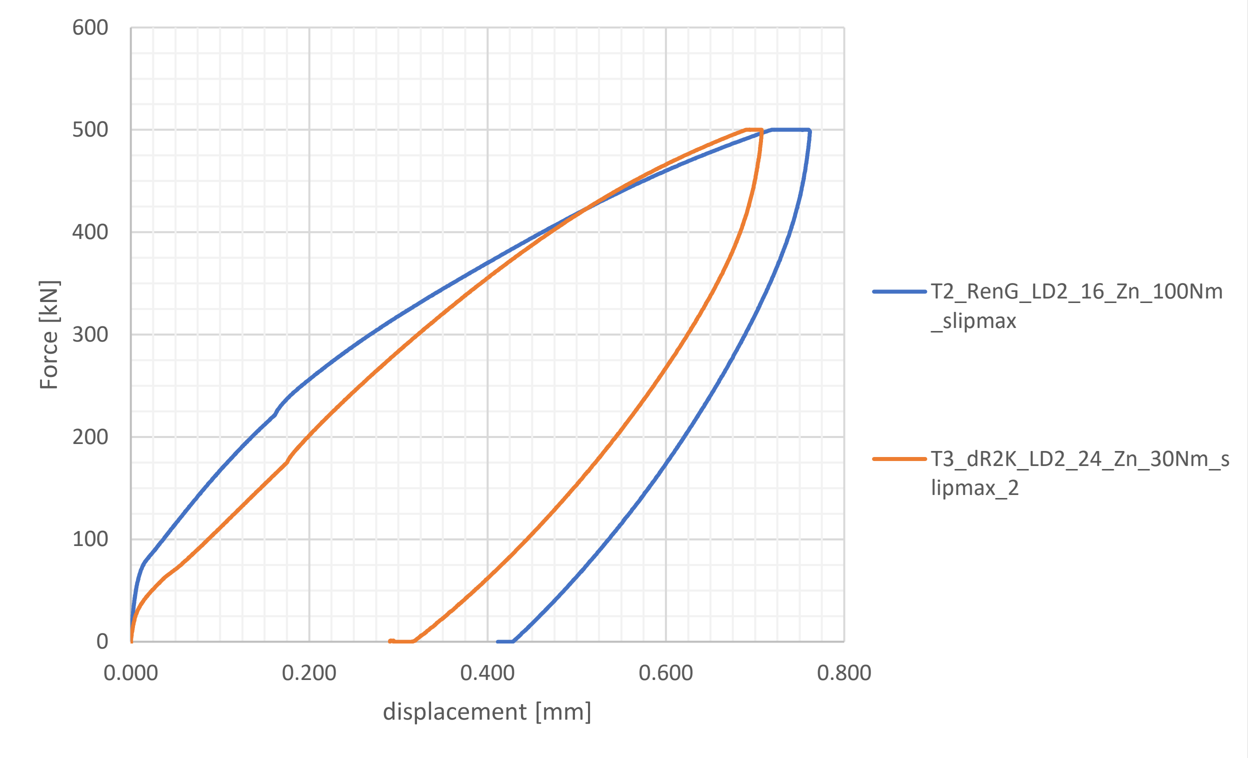


Figure 72 Overload behavior of test specimens with RenGel and Dex R2K resin

10.2.7 Curing temperature dependency

The conclusions of this test series when combined with the results obtained in the series on the spread of Dex R2K (DS) are summarized in the following three graphs: Figure 74, Figure 73 and Figure 75. The number of results for RenGel is limited but these specimens showed very small spreads in the tests performed in these series. From the tests performed the conclusion is that RenGel SW404/HY2404 shows no dependency on the curing temperature in this practical range between 8 and 24 degrees.

Edilon Dex R2K showed large scatter in results in this test series. From the results, it is concluded that a small positive dependency on curing temperature exists for this resin product. This is illustrated in Figure 74. This positive dependency is also seen when the stiffness of the connection is investigated in the 0.05-0.15 mm slip range as evidenced in Figure 75. This range removes any initial stiff response by friction. Note though that this influence was already greatly diminished by applying the lower preload of 30 Nm during assembly.

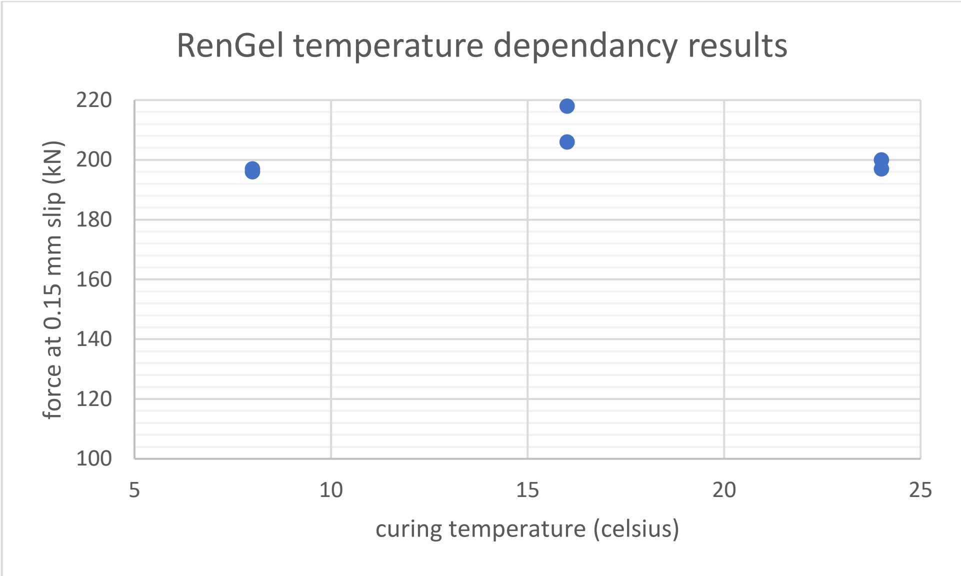


Figure 73 Curing temperature dependency of RenGel SW404/HY2404 results

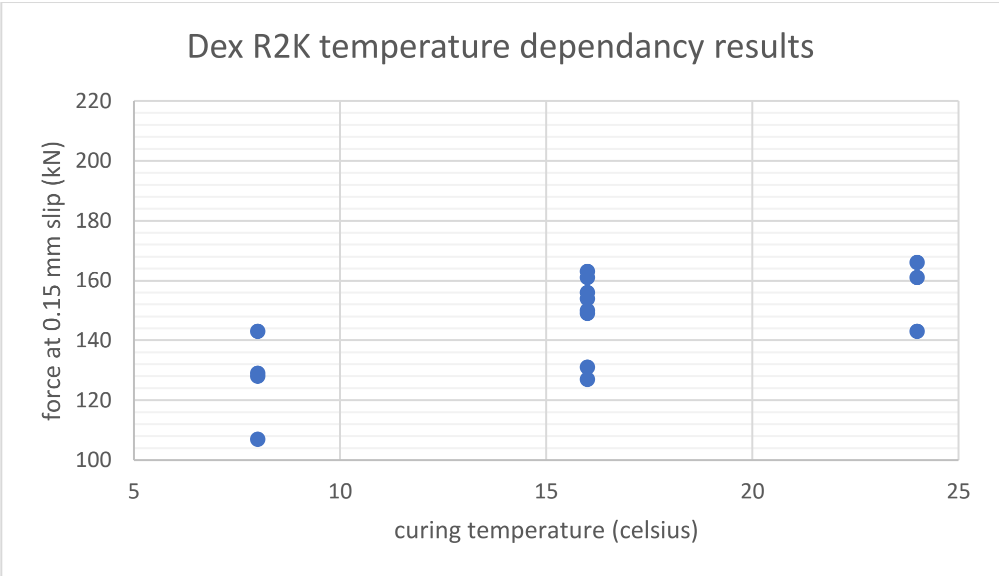


Figure 74 Curing temperature dependency results of Edilon Dex R2K

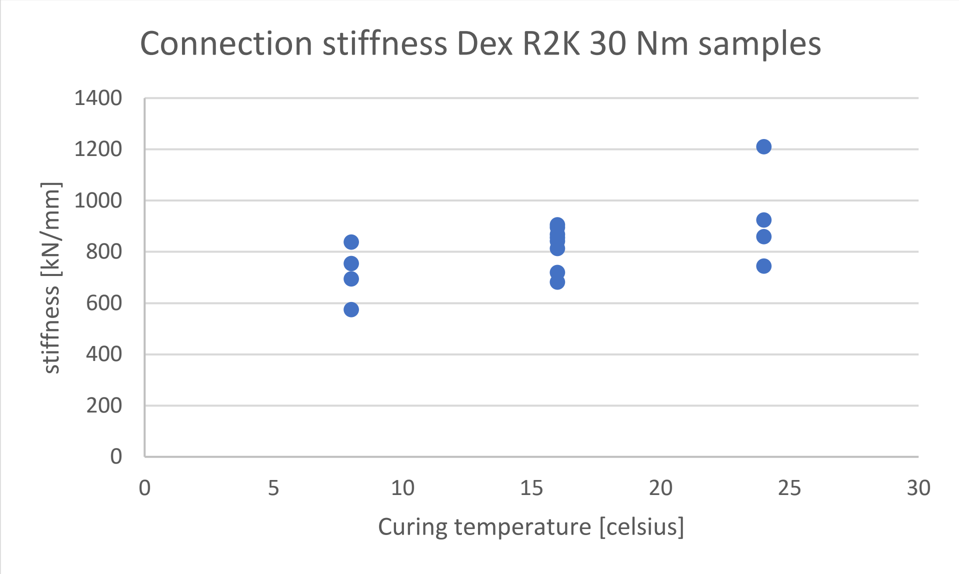


Figure 75 Stiffness of connection measured in the range 0.05-0.15 mm slip for Dex R2K resin

10.3 Spread of Dex R2K

In this series of tests 4 specimens were tested using Edilon Dex R2K resin at 16 degree and a 30 Nm preload during assembly. The load displacement result of the four specimens is shown in Figure 76. These results are also tabulated in Table 17. In this series one specimen suffered from an issue. For that specific specimen one connection gave an unusable result in this case. This is also noted in Table 17.

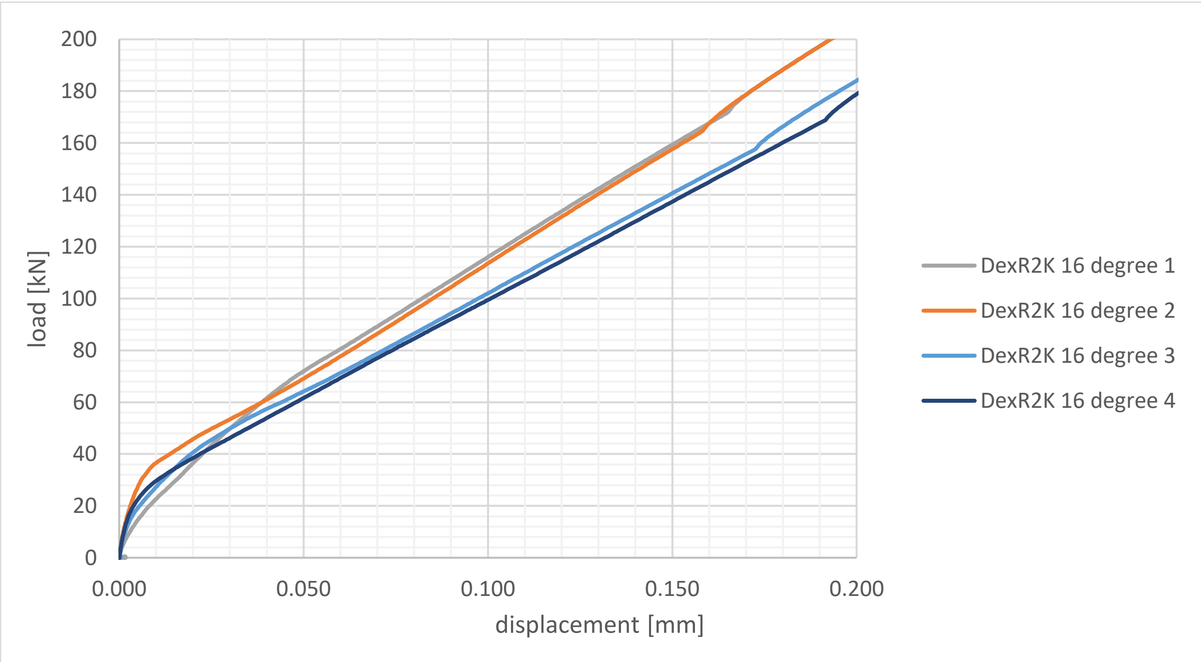


Figure 76 Load displacement graphs of Dex R2K specimens at 16 degrees

Table 17 Test results of spread Dex R2K test series

Test specimen ID	connection	resistance at 0.15 mm [kN]	resin effective stress [N/mm^2]	Connection stiffness * [kN/mm]
DS_dR2K_LD2_16_Zn_30Nm_slipmax_1	1	163	203.75	855.96126
DS_dR2K_LD2_16_Zn_30Nm_slipmax_1	2	156	195	895.52593
DS_dR2K_LD2_16_Zn_30Nm_slipmax_2	1	161	201.25	868.03147
DS_dR2K_LD2_16_Zn_30Nm_slipmax_2	2	154	192.5	905.96659
DS_dR2K_LD2_16_Zn_30Nm_slipmax_3	1	150	187.5	719.7442
DS_dR2K_LD2_16_Zn_30Nm_slipmax_3	2	131	163.75	813.02313
DS_dR2K_LD2_16_Zn_30Nm_slipmax_4	1**	-	-	-
DS_dR2K_LD2_16_Zn_30Nm_slipmax_4	2	127	158.75	841.77556
*connection stiffness determined in the range of 0.07 to 0.15 mm slip of CBG ** LVDT bracket was loose during testing. Results unusable.				

The spread of the Dex R2K specimens of this test series and the specimens tested using the same 30 Nm preload method from test series T3 is illustrated in Figure 77. What can be seen is that the spread of this product is very large. This in contrast to the spread found using RenGel SW404/HY2404 illustrated in Figure 73. This analysis of the spread is done using the results with the 30 Nm Preload assembly so scatter caused by friction effects is not a factor in the results displayed here.

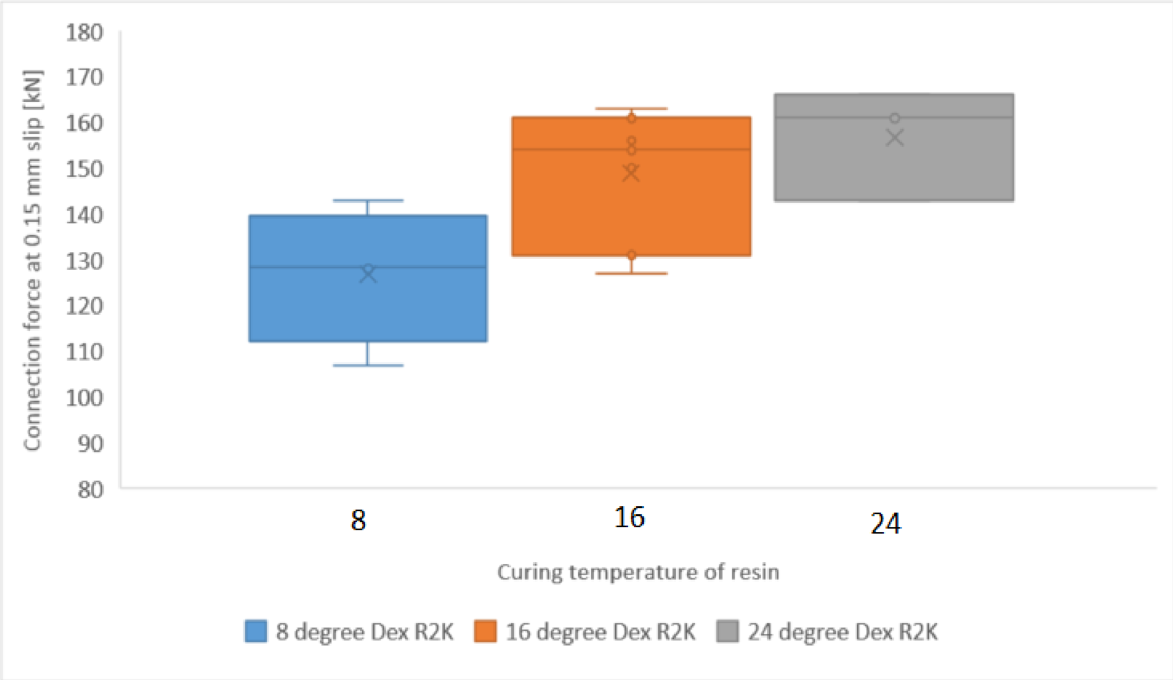


Figure 77 Box plot spread of Dex R2K temperature dependency and Dex R2K spread results

From Figure 77 a positive dependency on the curing temperature can be observed for this resin product as mentioned earlier. From the specimens tested at 16 degrees for which 7 results were available the characteristic value is determined, this is shown in Table 18.

Table 18 determination of characteristic value from DS test series

Mean value of results	186	MPa
Standard deviation	17.8	MPa
Characteristic value (95% lower limit, $\mu - 1.64 \cdot \sigma$)	156.805245	MPa

10.4 Bolt length influence

10.4.1 First test series

Two tests are done on specimens with an L/D ratio of 3. The results of these tests are shown graphically in Figure 78. The relevant results from these tests are also shown in Table 19. As with all test specimens the bolts were removed using a hydraulic press. The visual inspection of the specimens is illustrated in Figure 79.

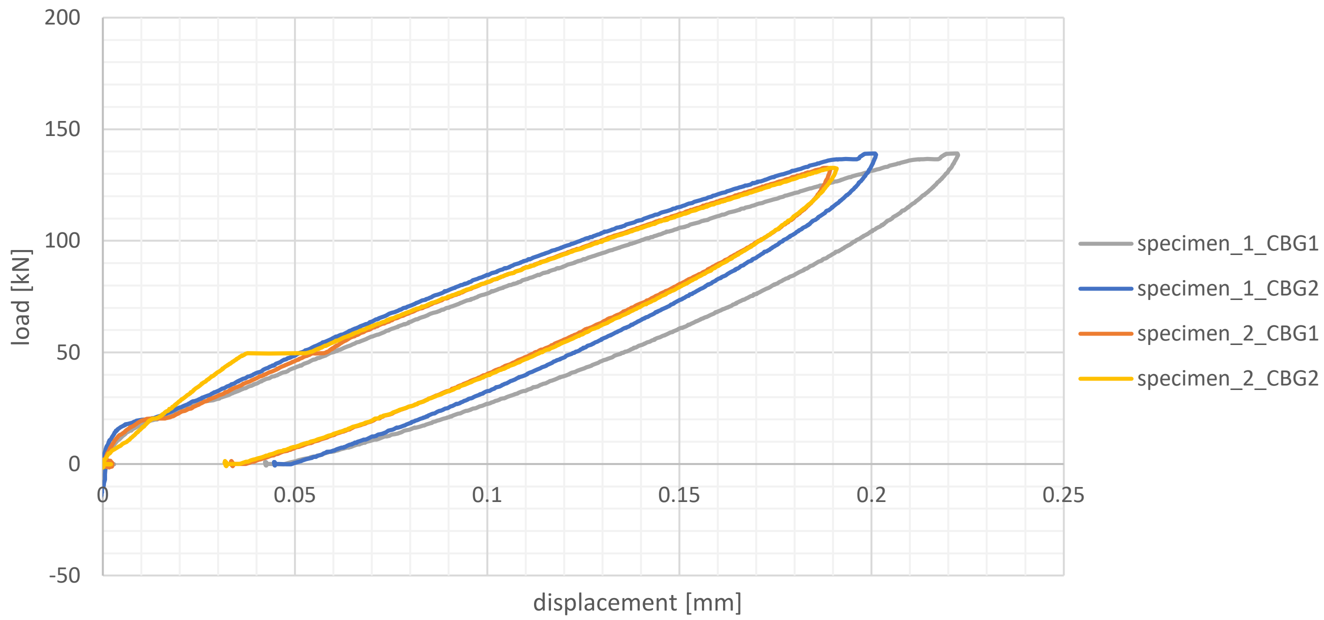


Figure 78 Results of first series with specimens of L/D ratio 3

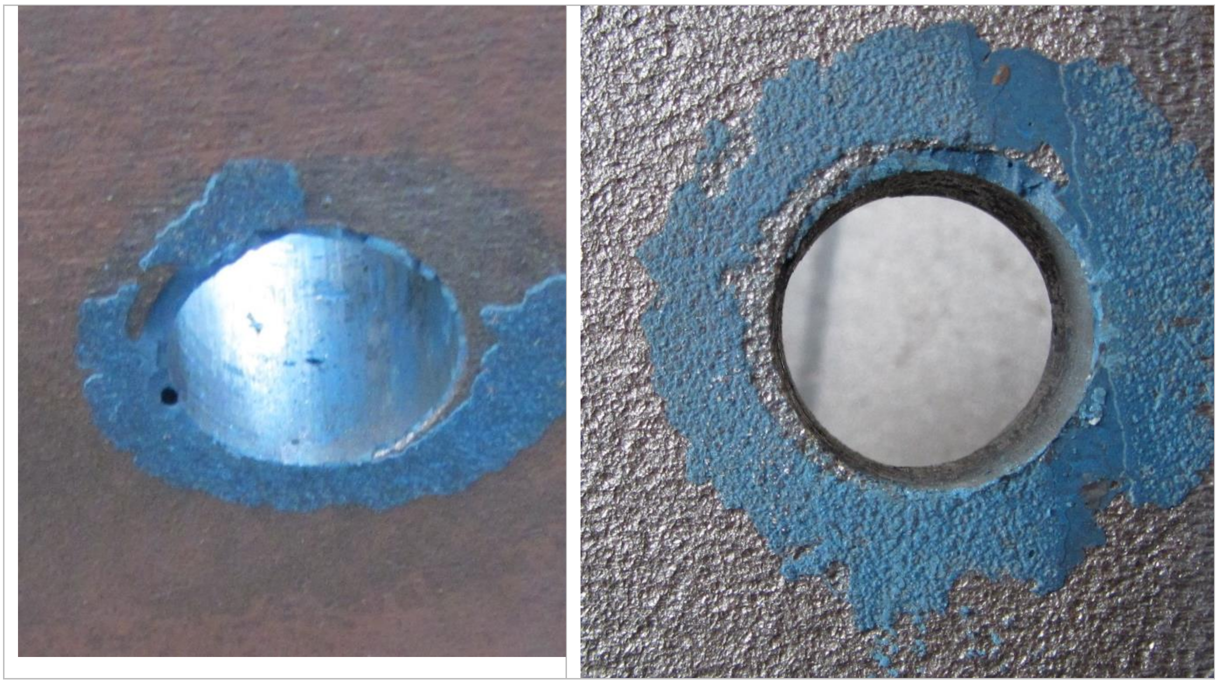


Figure 79 Visual inspection of disassembled L/D ratio 3 specimens of first series

Table 19 Summary of test results on L/D ratio 3 specimens of first series

Test specimen ID	Connection	Resistance at 0.15 mm [kN]	resin effective stress [N/mm^2]	Connection stiffness * [kN/mm]
BL1_RenG_LD3_amb_Gb_30Nm_slip_1	1	105	175	602
BL1_RenG_LD3_amb_Gb_30Nm_slip_1	2	115	191	639
BL1_RenG_LD3_amb_Gb_30Nm_slip_2	1	112	186	635
BL1_RenG_LD3_amb_Gb_30Nm_slip_2	2	111	185	619
*connection stiffness determined in the range of 0.07 to 0.15 mm slip of CBG				

The results of the specimens with an L/D ratio of 4 in the first series are shown in the same manner as for the L/D ratio 3 specimens. In Figure 81 The visual inspection of the resin layer in the specimens is shown after disassembly. In Figure 80 The test results are shown graphically and finally these results are summarized in Table 20.

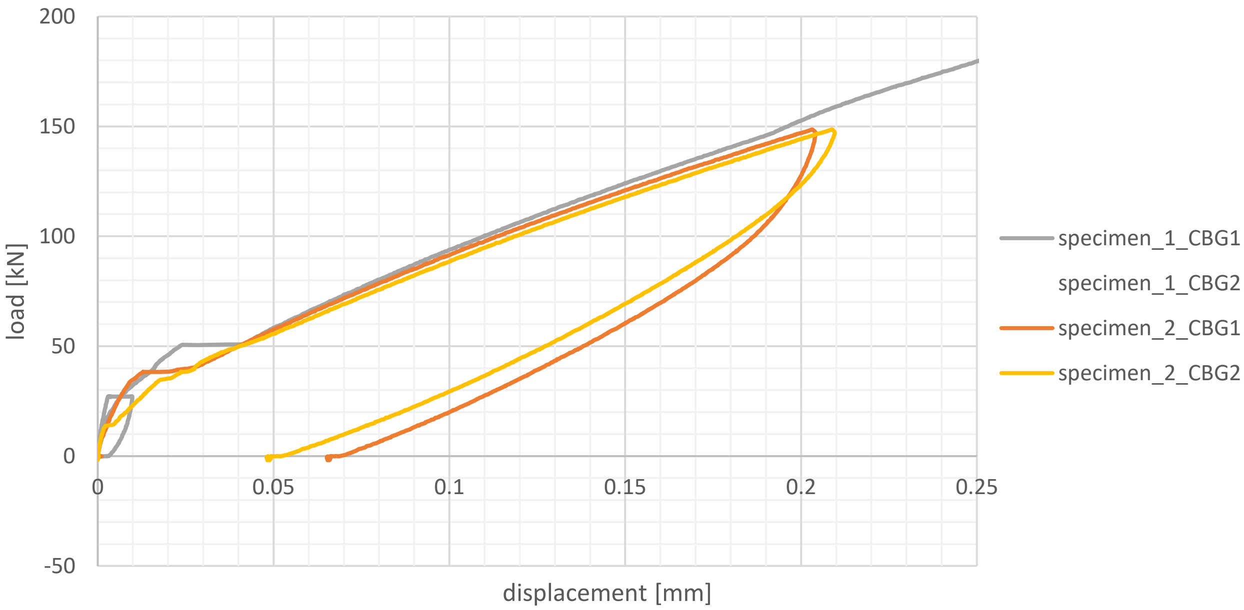


Figure 80 Results of first test series on specimens of L/D ratio 4

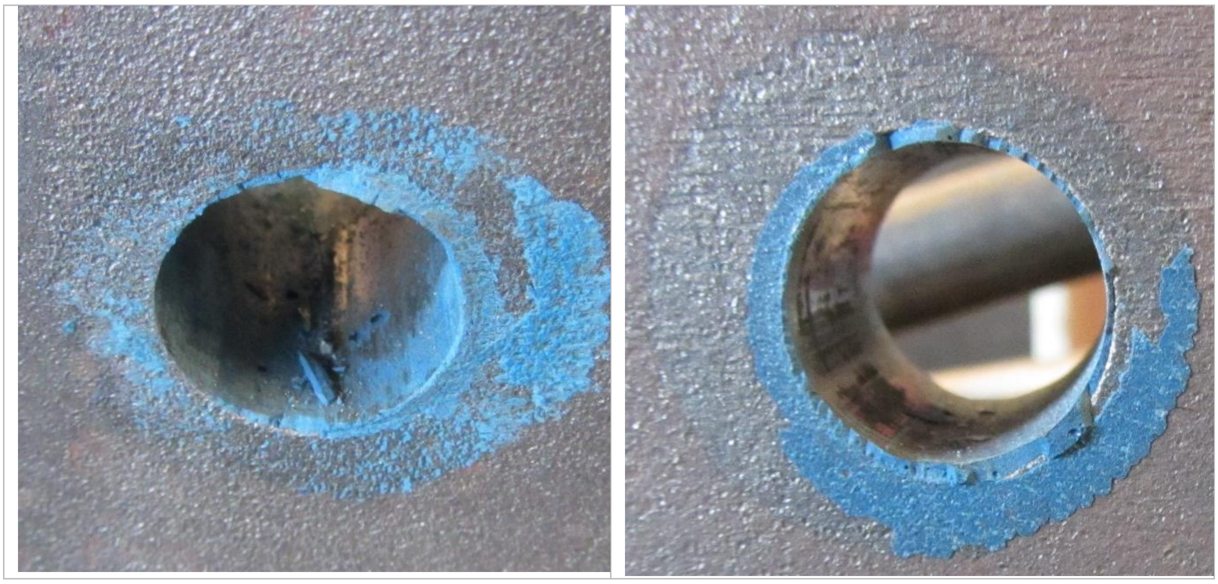


Figure 81 Visual inspection of resin layer of L/D ratio 4 of first series

Table 20 Summary of test results on L/D ratio 4 specimens in first series

Test specimen ID	Connection	Resistance at 0.15 mm [kN]	resin effective stress [N/mm^2]	Connection stiffness * [kN/mm]
BL1_RenG_LD4_amb_Gb_30Nm_slip_1	1	124	155	640
BL1_RenG_LD4_amb_Gb_30Nm_slip_1	2	119	148	643
BL1_RenG_LD4_amb_Gb_30Nm_slip_2	1	121	151	615
BL1_RenG_LD4_amb_Gb_30Nm_slip_2	2	118	147	612
*connection stiffness determined in the range of 0.07 to 0.15 mm slip of CBG				

From the visual inspection as illustrated in Figure 81 and Figure 83 it was observed that resin penetrated from the bolt hole in between the steel plates. The test results shown in Figure 78 and Figure 80 show the influence of this with jumps in the displacement. The small resin layer in between the steel plates caused a glue bond which audibly broke during testing. This resulted in sudden slip in the connection when the resin bond failed. The resin flowing in between the plates is attributed to the 30 Nm preload applied to prevent friction is too low for the longer plate packages to close the gap between the plates.

It is noted though that after breaking of the resin bond all force must be transferred by bearing. Further The bond already breaks at relatively low force so the influence of this resin layer between the plates is thought to be minor on the 0.15 mm slip resistance.

Furthermore, some air inclusions were observed in the resin layer from the visual inspection after disassembly. These can also be seen in Figure 81 and Figure 83..

10.4.2 Second test series

A second test series is performed to investigate the influence of the L/D ratio. These tests were done by cleaning the plate material from the first series through sand blasting the surfaces of the plates and cleaning the bolt holes with a drill of the same size as the bolt hole. In this second series, the preload applied during assembly, injection and curing of the specimen was changed from 30 Nm to 60 Nm.

Again the results are represented graphically in Figure 82, an overview of the results can also be found in Table 21. Finally, the visual inspection of the specimens in this second series is shown in Figure 83.

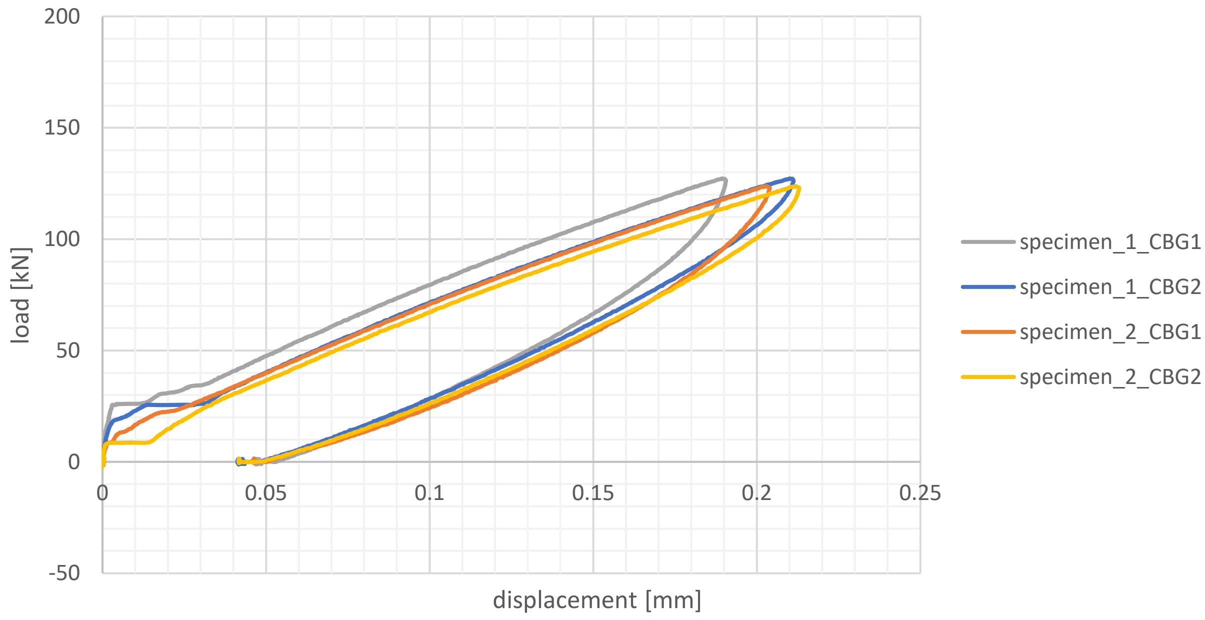


Figure 82 Test results of L/D ratio 3 specimens in second series

Table 21 Overview of test results of second test series on L/D ratio 3 specimens

Test specimen ID	Connection	Resistance at 0.15 mm [kN]	resin effective stress [N/mm^2]	connection stiffness* [kN/mm]
BL2_RenG_LD3_amb_Gb_60Nm_slip_1	1	108	179	587
BL2_RenG_LD3_amb_Gb_60Nm_slip_1	2	99	164	569
BL2_RenG_LD3_amb_Gb_60Nm_slip_2	1	98	164	576
BL2_RenG_LD3_amb_Gb_60Nm_slip_2	2	94	157	563
*connection stiffness determined in the range of 0.07 to 0.15 mm slip of CBG				

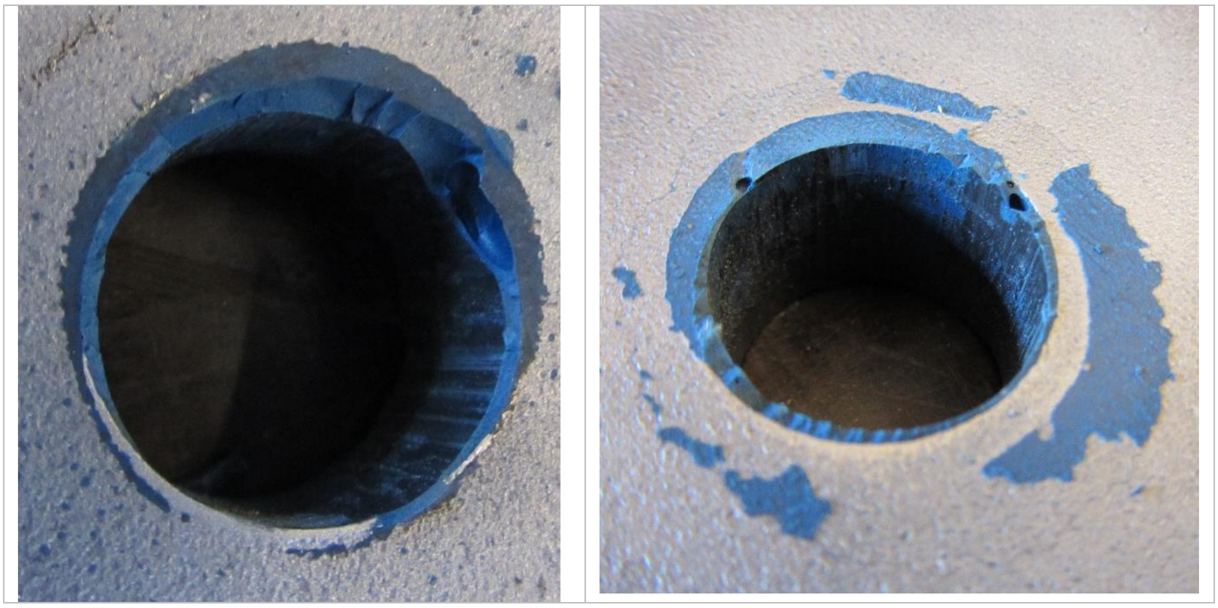


Figure 83 Visual inspection of specimens in the second series on L/D ratio 3

Tests on specimens with an L/D ratio of 4 were also repeated in this second series using the same method of 60 Nm preload during assembly and cleaning the surfaces by sand blasting them and drilling the bolt hole to clean it. As before the results are shown graphically in Figure 84, after testing the specimens were disassembled and the resin layer in the bolt holes was investigated. This is shown in Figure 85. Finally, the relevant test data is tabulated in Table 22. Note that in this case a sudden jump in displacement occurred in the 0.07 to 0.15 mm range which is used to determine the connection stiffness. So for one specimen these values are not calculated.

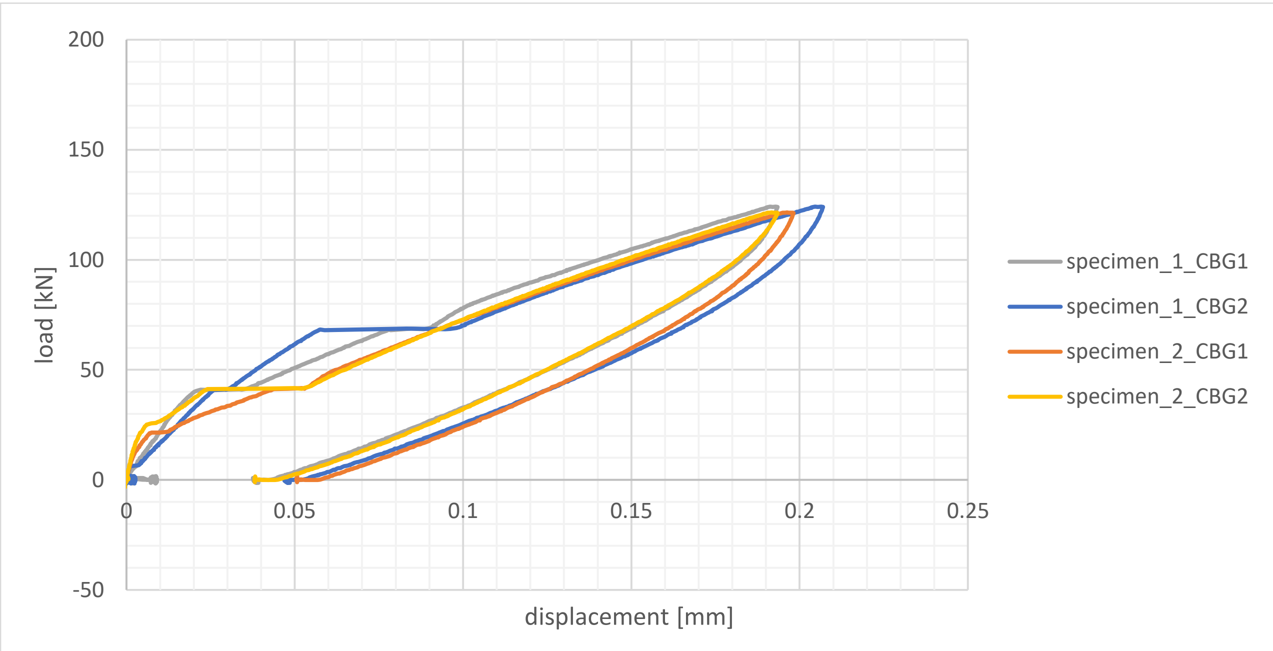


Figure 84 Results of L/D ratio 4 specimens in second test series

Table 22 Overview of test results of L/D ratio 4 specimens in second series

Test specimen ID	Connection	Resistance at 0.15 mm [kN]	resin effective stress [N/mm^2]	connection stiffness* [kN/mm]
BL2_RenG_LD4_amb_Gb_60Nm_slip_1	1	105	131	-**
BL2_RenG_LD4_amb_Gb_60Nm_slip_1	2	98	123	-**
BL2_RenG_LD4_amb_Gb_60Nm_slip_2	1	100	125	563
BL2_RenG_LD4_amb_Gb_60Nm_slip_2	2	101	126	597

*connection stiffness determined in the range of 0.07 to 0.15 mm slip of CBG
** connection stiffness of this specimen is not calculated due to sudden jump in displacement in the 0.07-0.15 mm range

Figure 85 Visual inspection of resin layer after disassembly of L/D ratio 4 specimens in second series

10.4.3 Visual inspection

Again, the resin has run between the plate surfaces of the connection. This resulted once more in jumps in the displacement during testing when an audible breaking of the resin layer bond occurred. Increasing the preload of specimens during assembly in this case was not sufficient to prevent this from occurring. It is thought the plate preparation could be a reason for the leaking of resin between the plates as this did not occur in the previous test series. Finally, in this second test series large air inclusions are visible in all specimens during the visual inspection.

10.4.4 Measurement setup discussion

The results in this section are reported at the CBG. These specimens were tested in the second test machine setup. Therefore, as explained in section 9 the slip was measured using 4 LVDTs which measure at the plate edge of the cover plate. To determine from this measurement data the slip in the CBG the elastic elongation of the center plate must be considered.

This is done by calculating the strain in the center plate and using the length between the LVDT measurement bracket and the CBG to determine the total deformation of the plate. This is then subtracted from the measurements at the PE to determine the CBG measurement which can be compared against the previous results which did measure directly at the CBG.

An illustration of this procedure is shown below using the BL1_RenG_LD3_amb_Gb_30Nm_slip_2 specimen as an example. The plate geometry of this specimen is reported already in Figure 45. The young's modulus used for the plate is 210.000 N/mm^2. Further the sensitivity in the results for this calculation is checked by varying the length over which the plate deformation is taken into account by +/- 20% and the impact of the calculated resistance.

$$\sigma_{plate} = E \cdot \epsilon_{plate}$$

$$\sigma_{plate} = \frac{F}{A_{plate}} = \frac{F}{100 \cdot 30}$$

$$\epsilon_{plate} = \frac{F}{100 \cdot 30 \cdot E}$$

$$\Delta l_{plate} = \frac{F \cdot l_{CBG}}{100 \cdot 30 \cdot E}$$

$$l_{CBG} = 60 + 35 = 95\ mm$$

$$\Delta l_{plate} = \frac{F \cdot 95}{100 \cdot 30 \cdot 210.000} = 1.5 \cdot 10^{-7} \cdot F$$

In Table 23 The sensitivity analysis of the plate deformation length is shown for BL1_RenG_LD3_amb_Gb_30Nm_slip_2. Here the resistance at 0.15 mm slip for the CBG is shown with the length over which the plate elongation is considered varied by 20% up and down from the actual length of 95 mm. As can be seen the large variation in plate elongation length has a minor influence on the calculated resistance at 0.15 mm. therefore it is concluded that this method of processing the results to the CBG of the specimen is valid.

Table 23 sensitivity analysis of plate deformation length for calculated CBG displacement of specimen LD3_2

Length of plate deformation l_{CBG}	Resistance at 0.15 mm slip for connection 1 and 2 [kN]	Difference in resistance compared to l_{CBG} of test specimen geometry [%]
95	111.635	-*
	111.183	-*
76	109.755	-1.68
	109.226	-1.76
114	113.833	1.97
	113.268	1.46
*THIS CORRESPONDS TO THE SPECIMEN GEOMETRY		

10.4.5 Comparison of test series results

Both test series showed the same behavior of resin leaking between the plates despite a change in preload. Comparing the results of the two test series is done in Figure 86. What can be observed is that the apparent spread is larger for the test results with an L/D ratio 3 than those specimens with an L/D ratio of 4. Furthermore, in the first test series we see a trend of increasing capacity between L/D ratio 3 and 4 while this trend is not observed in the second series.

The average strength values of the specimens decreases roughly 20% between the first and second test series. From the visual inspection of the specimens the second series showed large air inclusions. The first series air inclusions were also seen but smaller than those of the second series. Despite these air inclusions though the spread in results that was observed in the first and second series does not change. This is especially well illustrated in the L/D ratio 4 specimens where both the first and second series of tests has a small spread.

This could be explained by the fact that specimens are assembled in one batch for each series leading to a maintained spread between the specimens of one series.

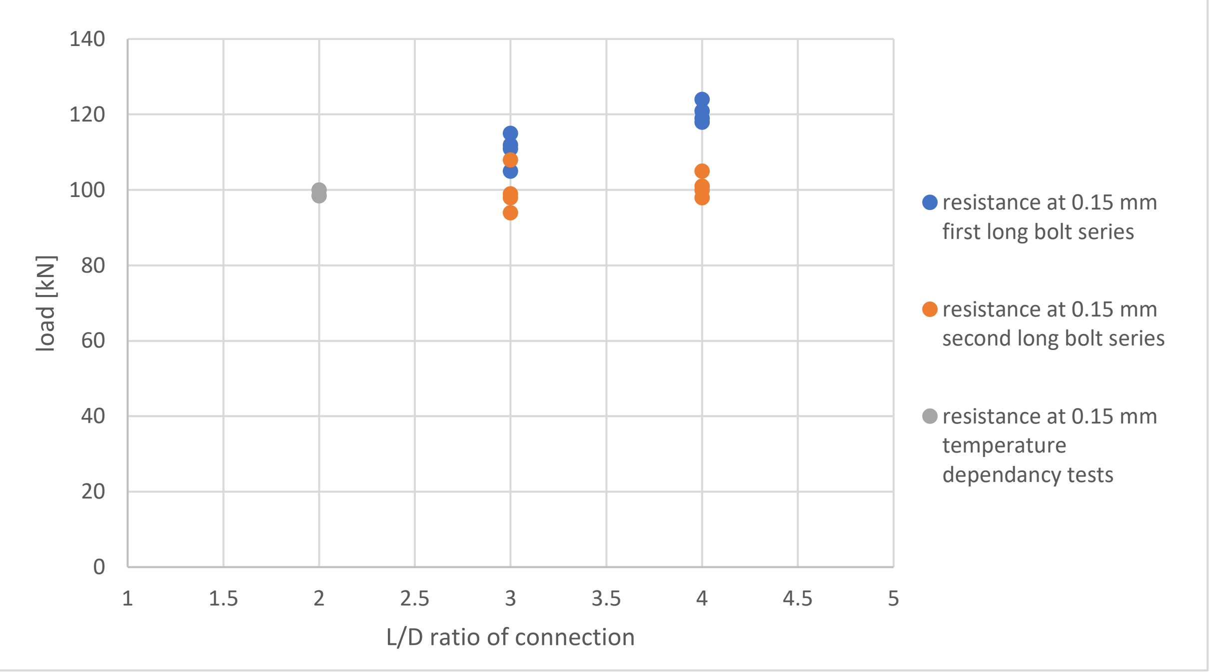


Figure 86 Comparison of test results of bolt length influence series with previous test results

Comparing these results against the calculation method of EN 1993-1-8 [41] and effective bearing length of 3 is prescribed for the calculated resistance. This means the connection capacity according to the Eurocode is constant for L/D values of 3 and higher. In these tests, we see that this could be conservative as indicated by the first series. In the second series, the constant resistance for L/D values larger than 3 is reproduced here.

10.5 Curing time research

As mentioned in the test series overview of section 9.6 the research done in the Stevin laboratory on the influence of curing time is discussed here shortly. These tests were performed by J. Li. An overview of the performed tests is shown below in Table 24. The load procedures mentioned in this table have been shown graphically already in Figure 59 and Figure 60 in section 9.7.

Table 24 Tests performed in curing time research

Test step	**Bolt type**	**Bolt size**	**Hole Clearance**	**Load type**	**Resin type**	**Curing temperature**	**Curing time (hours)**	**Number of specimens**		
								1st batch Short 3-1	**2nd batch Short 3-2**	**3rd batch Short 3-2**
Step 3	**Non-preloaded**	**M20**	**2mm**	**Short 3**	**RenGel SW404/HY 2404**	**Ambient temperature**	**6**	**1**	**1**	**1**
							24	**1**	**1**	**1**
					EDILON Dex-R2K		**6**	**1**	**1**	**1**
							24	**1**	**1**	**1**
Total								**4**	**4**	**4**
								12		

From the work by J. Li above the Curing time was found to not be of great influence on the results. Both resin products showed little creep behavior in this test series. What was found though was that Dex R2K resin had larger absolute displacements than the RenGel product.

10.6 Linking material properties to performance

From all the test results in this research the following analysis of the material properties as it relates to the performance in injection bolts can be done.

10.6.1 Viscosity of mixed resin product

The main determinant of the resin injectability found in this research is the viscosity of the resin after mixing. From the range of products tested here an indication of the viscosity of product necessary for injection in injection bolts can be given. A definitive lower bound of the viscosity can be given by the Sika Injection 451. This resin viscosity was decisively too low for this application.

The injection of Sikadur 30 on the other hand was not possible. This product has no supplied viscosity in the PDS to reference. [52] What can be mentioned is that this product was the only one which did not behave as a liquid after mixing. It cannot be poured and is best characterized as a paste rather than a liquid.

Both Edilon resin products showed proper filling of the bolt hole cavity in this research. The Dex G 20 specimens though did have some small leaking of resin from the injection port and air escape washer after injection. This was solved with modelling clay.

Finally, a remark is made about the RenGel SW404/HY2404 product currently applied in practice. In the PDS it is remarked that this resin mixture shows thixotropic behavior. [24] Thixotropic fluids have a time-dependent viscosity. Their apparent viscosity lowers when the fluid is stressed through stirring for example. This implies that this resin product has a lower viscosity during the injection when it is stressed and flowing and becomes more viscous after injection is stopped. This could be a favorable property of the product as this facilitates good filling of the cavity while limiting any leaking of resin after injection is stopped.

Table 25 Summary of supplied viscosities and result of application for IBC

Product	**Supplied viscosity**	**Result of application in injection bolts**	**remarks**
Sikadur 30	Not supplied in PDS	Issues with injection around washer of bolt head	Paste. Does not flow as a liquid
Sika Injection 451	$100\, mPa \cdot s$ at 23 degrees	No proper filling of bolt hole cavity. Leaked between plates	
Edilon Dex R2K	$35\, Pa \cdot s$ (measured after 2 minutes at 26 degrees Celsius)	Proper filling	
Edilon Dex G20	$11\, Pa \cdot s$ (measured at 25 degrees)	Proper filling but some leaking from injection port. Clay needed	
RenGel SW404/HY2404	$55 - 80\, Pa \cdot s$ of resin. $3.5 - 5.5\, Pa \cdot s$ of hardener	Proper filling	Thixotropic: Apparent viscosity lowers when agitated

10.6.2 Mechanical properties of resin products

The resin products applied in this research have mechanical properties supplied in the PDS. These mechanical properties which are supplied are derived using different test methods. A comparison between the supplied mechanical properties and the effective bearing stresses found in the double lap shear tests of injection bolts with the specific product is shown in Table 26. What can be concluded from this comparison is that the relation between the supplied compressive strength of the resin products does not show a clear correlation with the performance in the IBC application.

Table 26 comparison of supplied mechanical properties in PDS with bearing stress in injection bolts

Product	**Supplied compressive strength**	**Bearing stress in injection bolts**	**remarks**
Sikadur 30	$54\ MPa$	155-193 MPa (T1)	ASTM- D695
Sika Injection 451	$70 - 80\ MPa$	-	Test method unspecified
Edilon Dex R2K	$100\ MPa$ after 24 hours	158-204 MPa (DS)	ISO 604
Edilon Dex G20	$> 90\ MPa$	180-209 MPa (T1)	EN 196-1
RenGel SW404/HY2404	$110 - 125\ MPa$	248-269 MPa (T1)	ISO 604

11 Modelling of resin stress for long bolts

To gain a better understanding of the mechanical behavior of the resin products in injection bolts an analytical model was developed to model the stress distribution that occurs in the resin layer when the injection bolt connection is loaded. In this chapter the development and results of the model are discussed.

11.1 Model overview and assumptions

The model developed in this research is based on an injection bolt in a double lap shear connection. This aligns with the state of the art in terms of numerical modeling of injection bolts. [10] [32] Furthermore the test procedure and guidelines explained in the standards of EN 1090 and EN 1993-1-8 are related to double lap shear connections. [8] [41]

Of interest in the development of this model is the behavior of the resin layer stress in longer connections. This is taken into account in the guidelines of EN 1993-1-8 through an effective bearing stress. The analytical model attempts to model the stress peak distribution as seen in the left of Figure 87.

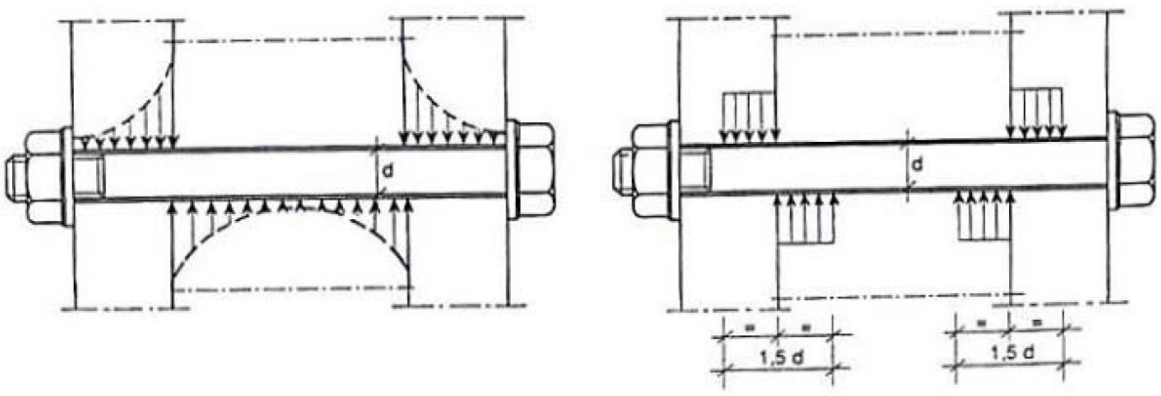


Figure 87 Resin layer stress distribution in long injection bolts [5]

An analytical modelling approach was followed to investigate the resin layer stress for this research. As stated in the ECCS recommendations the cause of the uneven bearing stress as illustrated in Figure 87 is caused by bending of the bolt for longer connections. [5]

Based on the considerations above the analytical model schematization of an injection bolt in a double lap shear connection is derived and presented in Figure 88.

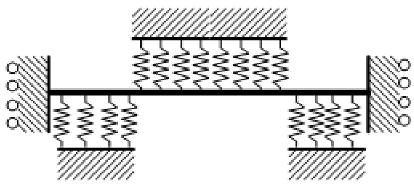


Figure 88 Analytical schematization of resin-injected bolt of double lap shear connecti*on*

The most important points of this schematization are discussed separately below.

11.1.1.1 Deformation of bolt

To model the stress that occurs in the resin layer the bending of the bolt should be taken into account according to the ECCS recommendations [5]. For this deformation of the bolt a beam model is used. The L/D ratio of the connection is the most important parameter for this beam model. The cut off for the effective bearing thickness of the resin layer as laid down in EN 1993-1-8 is at an L/D ratio of 3. For such low span to depth ratios an analytical approach should take into account both the bending and shear deformation of a beam. Therefore, the analytical modeling of deformations of the bolt is done using Timoshenko Theory [60] [61].

11.1.1.2 Deformation of steel plates

Due to the lower stiffness of resin products compared to the steel plates it is assumed for this analytical model that the plates are rigid. No deformation of the plate and bolt hole is considered in this analytical model.

11.1.1.3 Resin layer

To comply with the tests as performed in this research project the bolt is assumed to be placed in the bolt hole in the most unfavorable position as illustrated in Figure 89. Therefore, only resin is located at the compressed side.

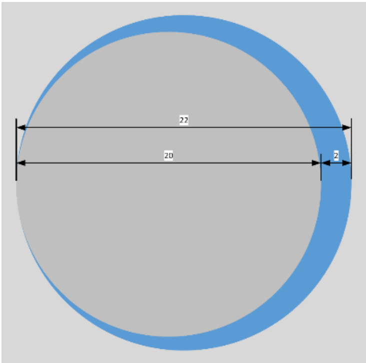


Figure 89 Assumed unfavorable positioning of bolt in the bolt hole

The resin layer in the injection bolt is connected at the outer edge to the bolt hole in the steel plate and at the inner edge to the bolt shank. To model this resin layer, a set of distributed springs is chosen which are placed at opposite sides of the bolt shank for the cover and center plates respectively. The distributed springs are attached to a fixed support which represents the bolt hole and steel place which as explained above are assumed to be rigid.

The spring characteristic used for the resin layer in this model is assumed to be linear elastic. This is based on the test results presented in this research which shows the connections have a nearly linear load slip behavior even far beyond the maximum slip value of 0.15 mm from EN 1090. This model does not consider the visco-elastic properties of the resin which cause creep for longer time durations.

11.1.1.4 Bolt head, washer and nut

The model boundary is placed at the outer edges of the cover plate. The bolt head and nut are taken into account in this analytical model through the boundary conditions. It is assumed that through the bolt and nut being tightened and in contact with the plate surface they prevent rotation of the bolt shank occurring in the boundary. Thus, the boundary of the model is a clamped support at the outer edges of the cover plates. Further it is assumed that no vertical forces are transferred from the bolt head and nut to the bolt shank. Thus no vertical forces can be transferred to the boundary.

11.1.1.5 Loading of model

To compare the model results to experimentally derived values the loading applied to the model corresponds to the short duration resistance of the connection according to the test procedure of Annex G EN 1090. This means a slip between the cover and center plates of 0.15 mm must occur.

The force in a double lap shear specimen is introduced through the steel plates of the connection. The loading of this model is done in a displacement controlled manner to guarantee the slip value of the procedure. The plates which are assumed to be rigid in the model are taken into account by the rigid support of the distributed springs. A prescribed displacement of this rigid support is used to load the model and generate the resin stress in the bolt.

11.2 Derivation of analytical relations

From the schematization as shown in Figure 88 Timoshenko theory has been used to derive a set of analytical equations which govern the deflection of the bolt shank following the examples of A. Simone [62]. For a full explanation of the derivation of these analytical equations please refer to Appendix A

.

$$GA_s \cdot \left(\frac{d^2v}{dx^2} - \frac{d\phi}{dx}\right) = -q + k \cdot (v - w)$$

$$-EI \cdot \frac{d^2\phi}{dx^2} = GA_s \cdot \left(\frac{dv}{dx} - \phi\right)$$

These two equations are a set of linear coupled differential equations. To solve a set of differential equations boundary conditions are necessary. These have already been explained above so are only shown here briefly. Again, refer to the appendix for a full description of the derivation.

Table 27 Overview of boundary conditions of the model

	$x = 0$	$x = t_1 + 2 \cdot t_2$
Shear force V	0	0
Rotation of beam ϕ	0	0

11.3 Solving analytical model

To solve the set of equations presented in section 11.2 no closed form solution could be found by hand. Therefore, MATLAB is used to derive a solution to the set of equations. To solve a set of linearly coupled differential equations, the built-in solver application of MATLAB BVP4C is used. [63] [64] An example solution for a similar problem is given in research. [65] A full derivation and application of MATLAB solver BVP4C to solve the model presented here is discussed in Appendix A

11.3.1 Model parameters

The model presented above is applied in first instance with parameters that align with the test specimen geometry outlined by EN 1090 [8]. These geometrical values are:tabulated in Table 28.

Table 28 Model parameters used in analytical modelling

Parameter	Value	Unit
Hole clearance	2	mm
Bolt size	M20	mm
Young's modulus of steel	210.000	N/mm^2
Connection slip	0.15	mm
Poisson ratio of steel	0.28	-
Ratio plate thicknesses t_1/t_2	2	-

As shown in the analytical relations that govern the deflections of the bolt the parameters relating to the cross-section of the bolt shank must be defined. For this use is made of the mechanical relations relating to a circular cross-section. Note that it is assumed that no threaded parts are inside the connection.

$$I = \pi \cdot \frac{r^4}{4}$$

Further the shear modulus must be determined, for this the following holds:

$$G = \frac{E}{2 \cdot (1 + \nu)}$$

The used young's modulus and Poisson ratio are tabulated above in Table 28. The parameter k of the distributed spring stiffness is dependent on the chosen value of the Young's modulus of the resin product. This parameter is used to calibrate the model and will be discussed in the next section. For reference the relation between k and E_{resin} is derived here per unit length:

$$\sigma = E_{resin} \cdot \epsilon$$

$$\epsilon_{resin} = \frac{\Delta l}{l}$$

$$F = \sigma \cdot A = \sigma \cdot 1 \cdot D_{bolt}$$

$$F = E_{resin} \cdot \frac{\Delta l}{l} \cdot 1 \cdot D_{bolt}$$

$$F = \frac{E_{resin} \cdot D_{bolt}}{hole\ clearance} \cdot \Delta l$$

$$\Delta l = v + w$$

$$F = k_{resin} \cdot (v + w)$$

$$k_{resin} = \frac{E_{resin} \cdot D_{bolt}}{hole\ clearance}$$

11.4 Model analysis and calibration

The model behavior is analyzed in this section with an initial estimate for the resin Young's modulus from literature of $E_{resin} = 500\ N/mm^2$. [10] This is related to the resin product RenGel SW404/HY2404. Due to the results found in earlier test series on Dex R2K showing large spread the tests on bolt length were only performed for RenGel so the modelling is done using this resin. The calibration explained in this chapter on test results can also be performed for Dex R2K resin.

The model is used to derive a solution to the specified slip of 0.15 mm for connections with an L/D ratio up to 10. To achieve this the plate package length was increased at every step while the bolt dimensions were kept constant. The ratio between center and cover plates was also kept constant in this analysis.

11.4.1 Qualitative analysis of resin stress distribution

The main varied parameter in the initial run of the model concerns the L/D ratio. As the bolt bending deformation is assumed to largely be responsible for the uneven stress distribution it is expected that the resin stress shows larger peak stresses as the L/D ratio increases and a near constant behavior for low L/D ratio where the force is mostly transferred through shear. The resulting stress distribution over the length of the connection is illustrated in the following 3 figures:

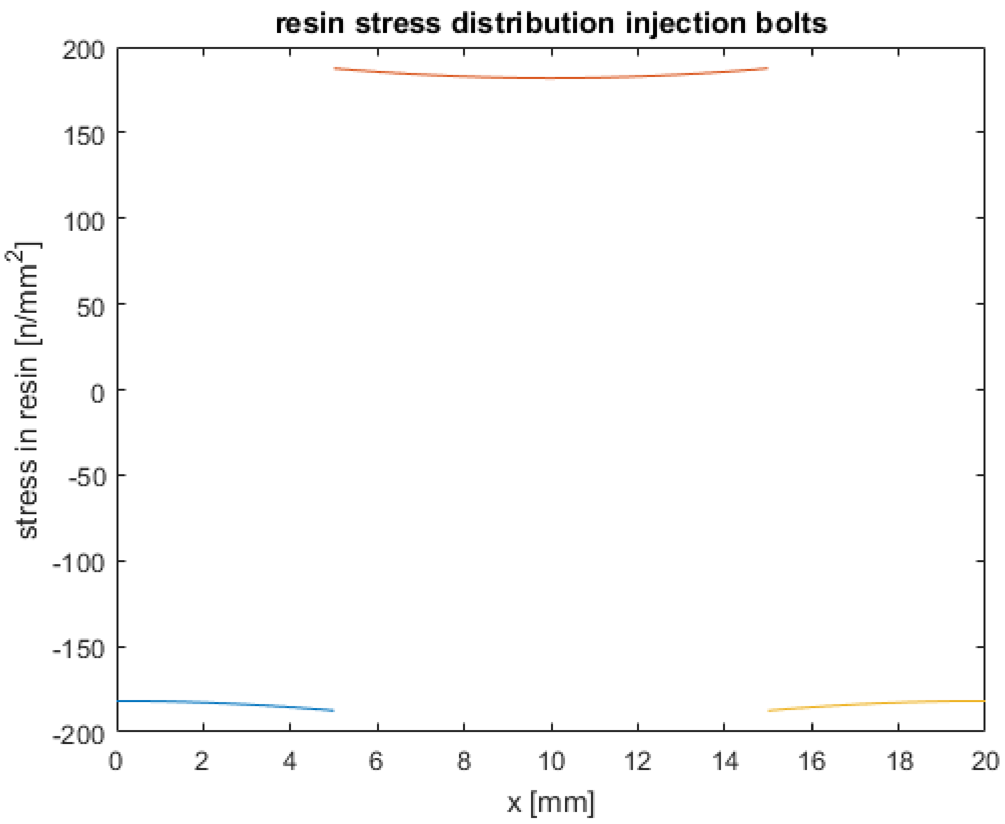


Figure 90 Resin stress distribution over length of connection for L/D ratio of 1

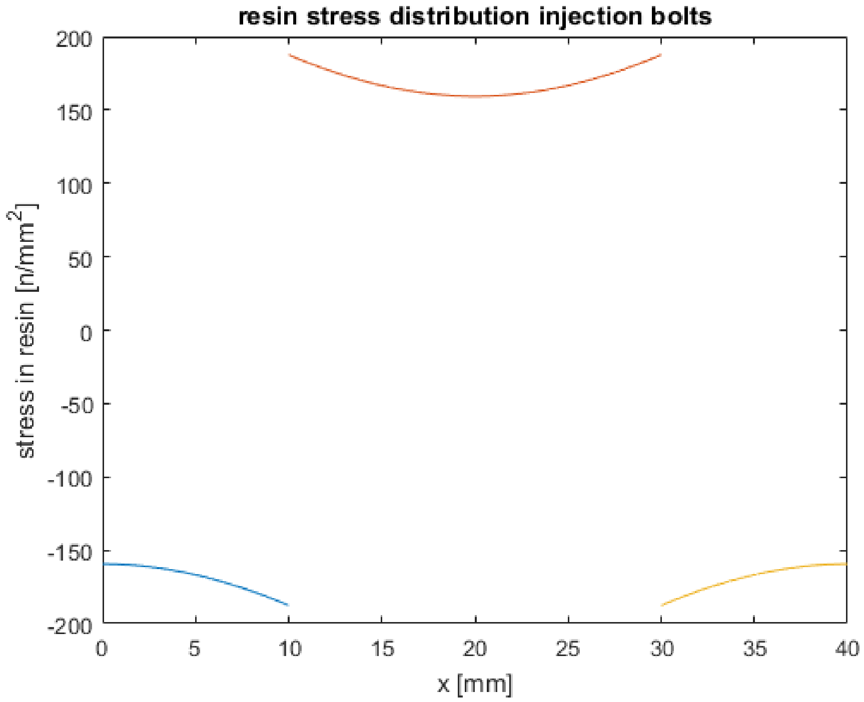


Figure 91 resin stress distribution over length of connection for L/D ratio 2

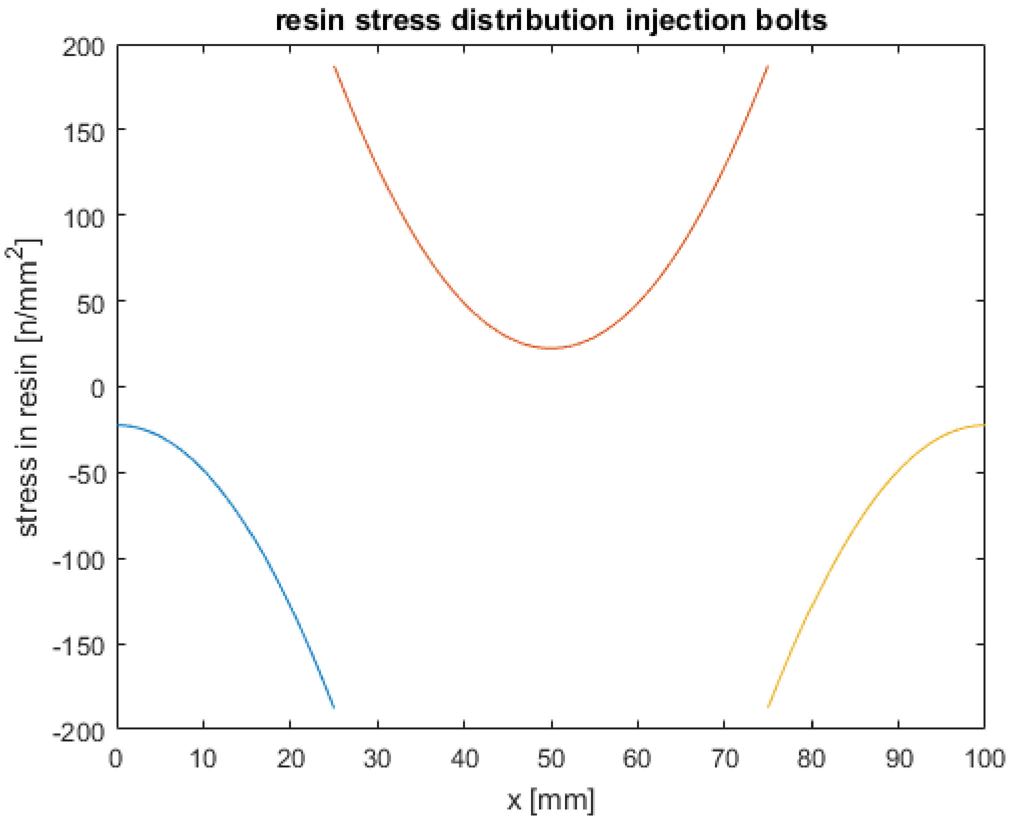


Figure 92 Resin stress distribution for L/D ratio 5

From this initial run, erroneous behavior was seen for L/D ratios larger than 6. The resin stress calculated by the analytical model had tension in the center of the center plate and outer of the outer plates. To remedy this behavior in the model the resin distributed spring stiffness was given a bi-linear characteristic that does not allow any tension. This assumes no tensile forces can be transferred in the resin layer due to adhesion to the bolt hole surface. The resulting resin stress distribution using this bi-linear spring stiffness is shown for an L/D ratio of 7 in Figure 93.

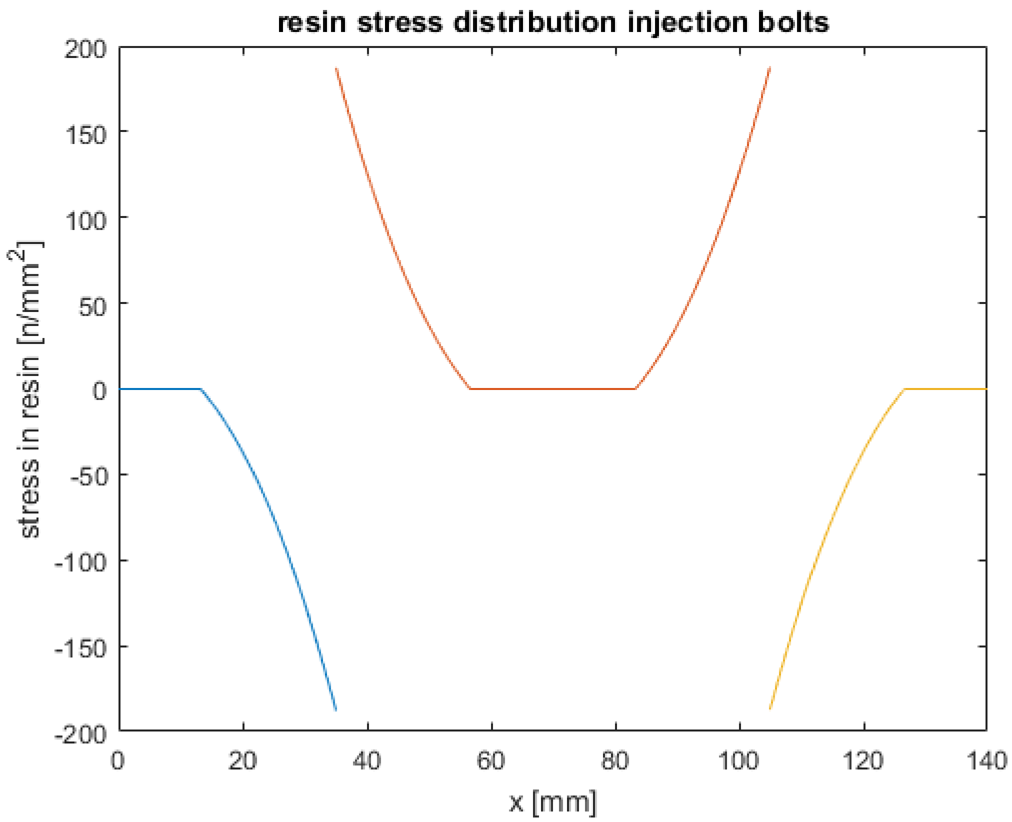


Figure 93 Resin stress distribution with bi-linear spring stiffness to eliminate tension

From the resin stresses shown in Figure 90 through to Figure 93 the trend of the model behavior appears to follow what is expected to happen in these connections. As already mentioned the tensile stresses occurring in the resin layer had to be solved manually using a tensile stress cutoff in the resin spring stiffness.

What can be remarked is that the resin stress trend appears to correlate well with what is expected the absolute values show a peculiar behavior. The peak stress that is found in the resin layer occurring in the interface between center and cover plates is independent of the L/D ratio. The value that is found here is directly related to the applied displacement of 0.15 mm in the model. This is calculated below:

$$w = 0.15\ mm$$

$$w = w_1 + w_2 = 0.075 + 0.075\ mm$$

$$\sigma = E_{resin} \cdot \epsilon_{resin}$$

$$\sigma = 5000 \cdot \frac{w_1}{hole\ clearance}$$

$$\sigma = 5000 \cdot \frac{0.075}{2} = 187.5\ MPa$$

What happens is the model is that this calculated value appears as an absolute maximum and the average stress drops through a lowering of the resin stress away from the center and cover plate interface. This is illustrated in the following graph shortly:

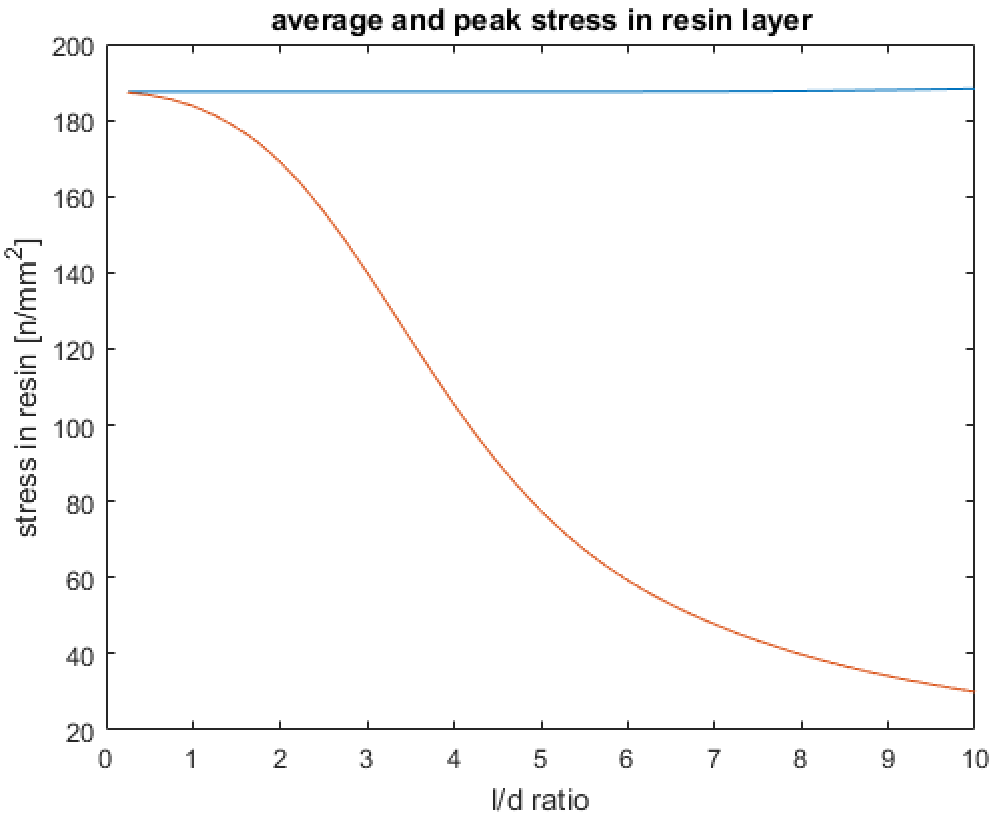


Figure 94 Relation between peak and average stress of resin layer in analytical model

A further analysis of the model behavior is the force balance of the connection. As stated in the model overview the bolt in the connection is assumed to be in force equilibrium without vertical reaction forces occurring in the bolt head and nut interface at the outside of the cover plates. This also to verify the solution derived using the BVP4C package in MATLAB is correct. From Table 29 the solutions found have a very small residual that is probably caused by the solution method in BVP4C.

Table 29 Force balance residuals of model results

L/D ratio	**Force outer plates [kN]**	**Force center plate [kN]**	**Residual [kN]**
1	36.7499	36.7498	$1.88 \cdot 10^{-5}$
2	67.5796	67.5794	$1.88 \cdot 10^{-4}$
3	83.9395	83.9388	$7.24 \cdot 10^{-4}$
4	84.2799	94.2783	0.0017
5	77.4595	77.4567	0.0028
6	71.0809	71.0774	0.0036
7	66.7959	66.8113	0.0154
8	63.6808	63.6986	0.0178
9	61.4812	61.498	0.0169
10	60.0516	60.0602	0.0086

Following this initial run, the connection resistance at the 0.15 mm slip value from EN 1090 according to the analytical model can be plotted. This is shown in Figure 95. What can be seen from this result is that the model shows a peak capacity at an L/D ratio of 3.5. In the current regulations the maximum capacity of an IBC is reached at an L/D ratio of 3 and the capacity remains constant afterwards. This result implies that the peak capacity is reached for slightl higher L/D ratios. Remarkably this model suggest that the resistance at 0.15 mm for higher L/D ratios does not remain constant but actually drops.

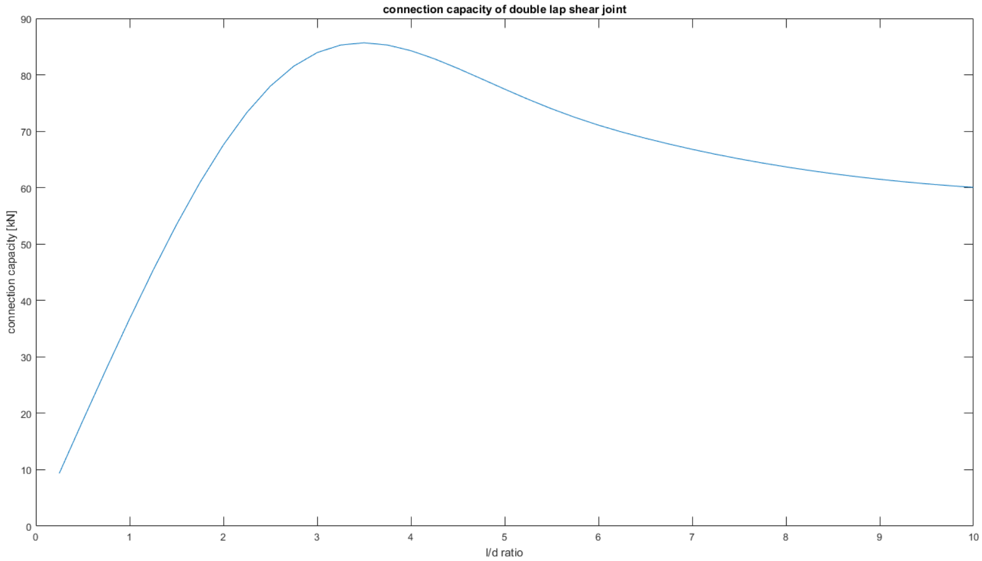


Figure 95 Connection resistance at 0.15 mm for different L/D ratio values

11.4.2 Calibration of model using test results

For the initial analysis an E modulus found from literature is used. This is compared against the values found in the Temperature dependency tests performed for this research on RenGel SW404/HY2404 resin. The test results are then used to calibrate the model through adaptation of the Young's modulus of the resin. This procedure resulted in an adapted resin Young's modulus of 7500 N/mm^2.

A comparison between the test results of temperature dependency and the analytical model calculated resistance with this calibrated Young's modulus is shown in Figure 96

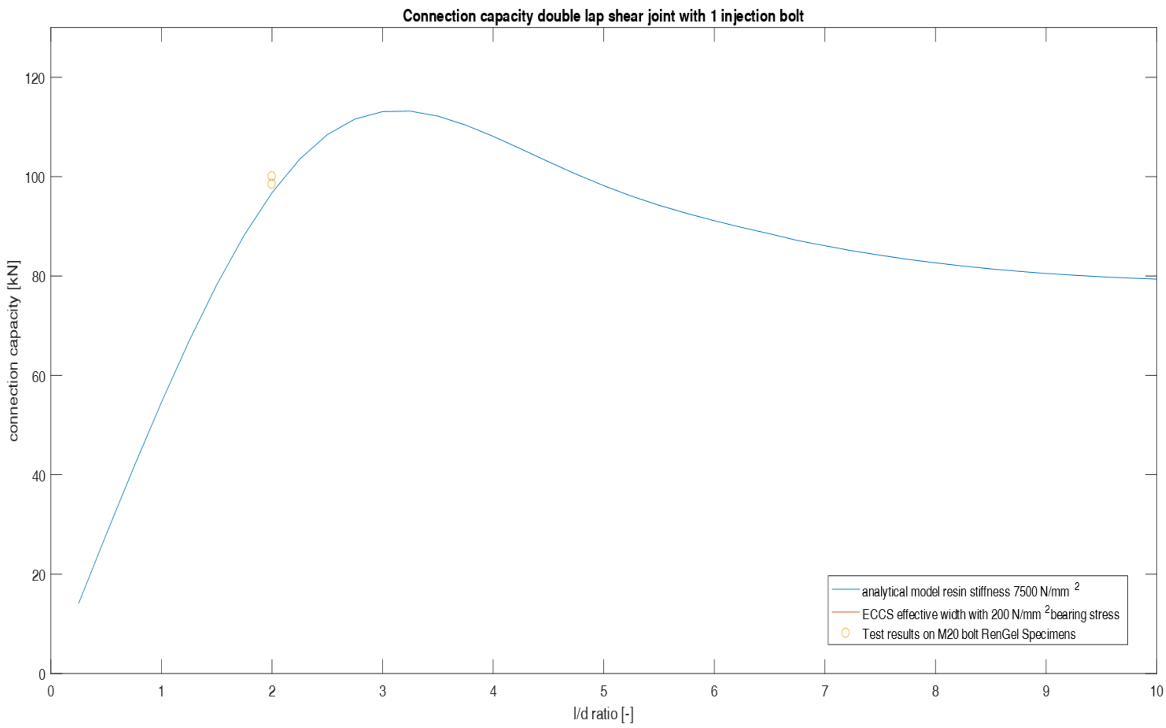


Figure 96 Model results using calibrated Young's Modulus

11.5 Verification of model

11.5.1FEM model

To verify the calibrated model behavior for this research this author cooperated with M.P. Nijgh who developed a FEM model for injection bolts. [32] The stress distribution of the models is compared by normalizing them. An overview of this comparison between the two models is given in Figure 97. From this verification it is concluded that the bolt bending is accurately calculated in the analytical model for all L/D ratios [32]. As can be seen in Figure 97 the analytical model solution diverges from the FEM results for L/D values around 4. The agreement between the models gets worse as the L/D ratio increases further with the analytical results dropping to zero not occurring in the FEM model.

From this verification of the model it is concluded that the analytical model does not work for L/D ratios larger than 4.

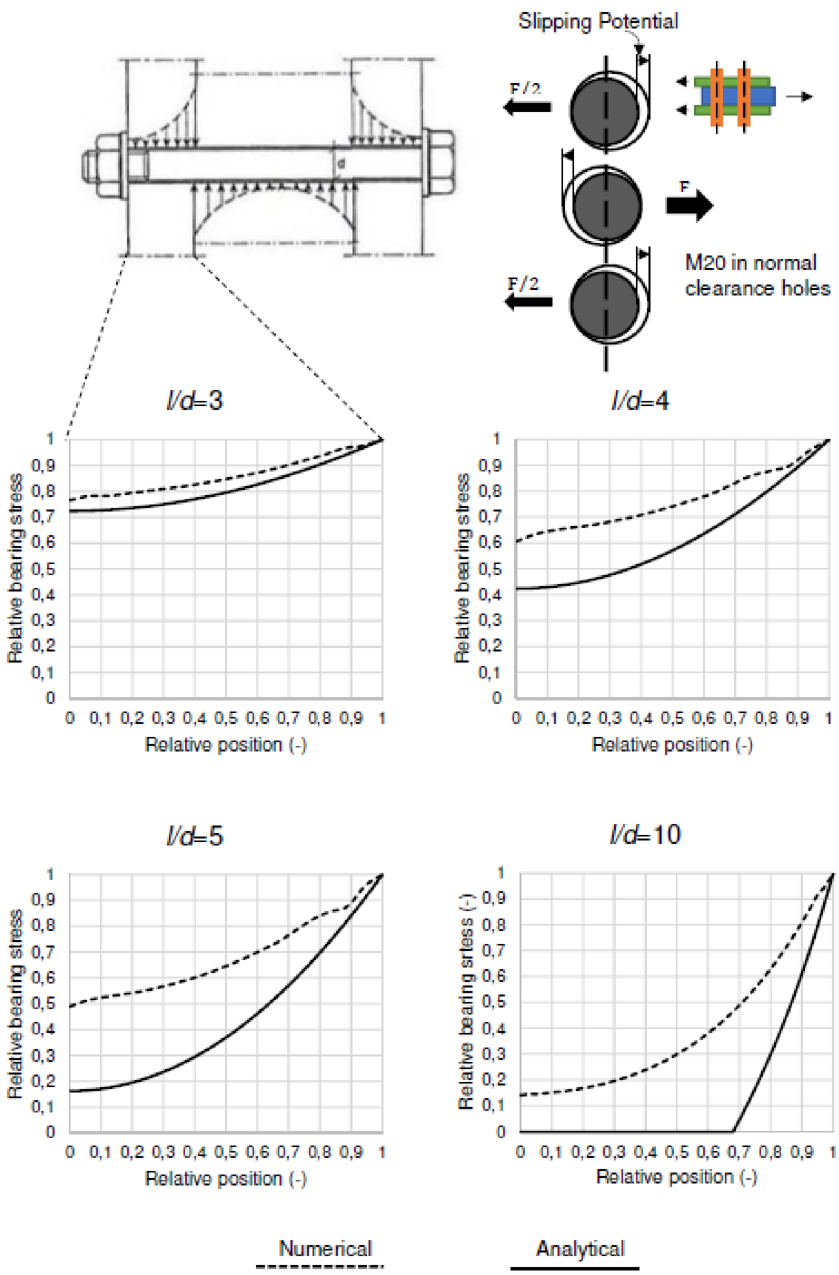


Figure 97 Comparison between FEM results and analytical model [32]

11.5.2 Verification against test results

The model is also checked against the test results obtained on long bolt specimens tested in this research. For this again the calibrated analytical model is used. An overview of both long bolt test series results is shown in Figure 98. The model is calibrated using the test results on L/D ratio 2. These are shown in aforementioned graph for reference.

What can be seen is that the test results of the first test series appear to have a good agreement with the calculated maximum capacity of the analytical model. This is not the case for the second series of tests. As mentioned in the discussion of these test results the air inclusions observed could influence the differences between the results of each series. Comparison of these test results with the analytical model is inconclusive. The differences between the model and test results are large and different for the two series. The apparent Young's modulus that was calibrated using the L/D ratio 2 specimens depends on the porosity of the resin layer and could vary between these series of tests.

What can be said from the comparison with these test results is that the tests indicate the model behavior above L/D values of 3 is incorrect. The capacity is at least maintained above L/D 3 and does not decrease.

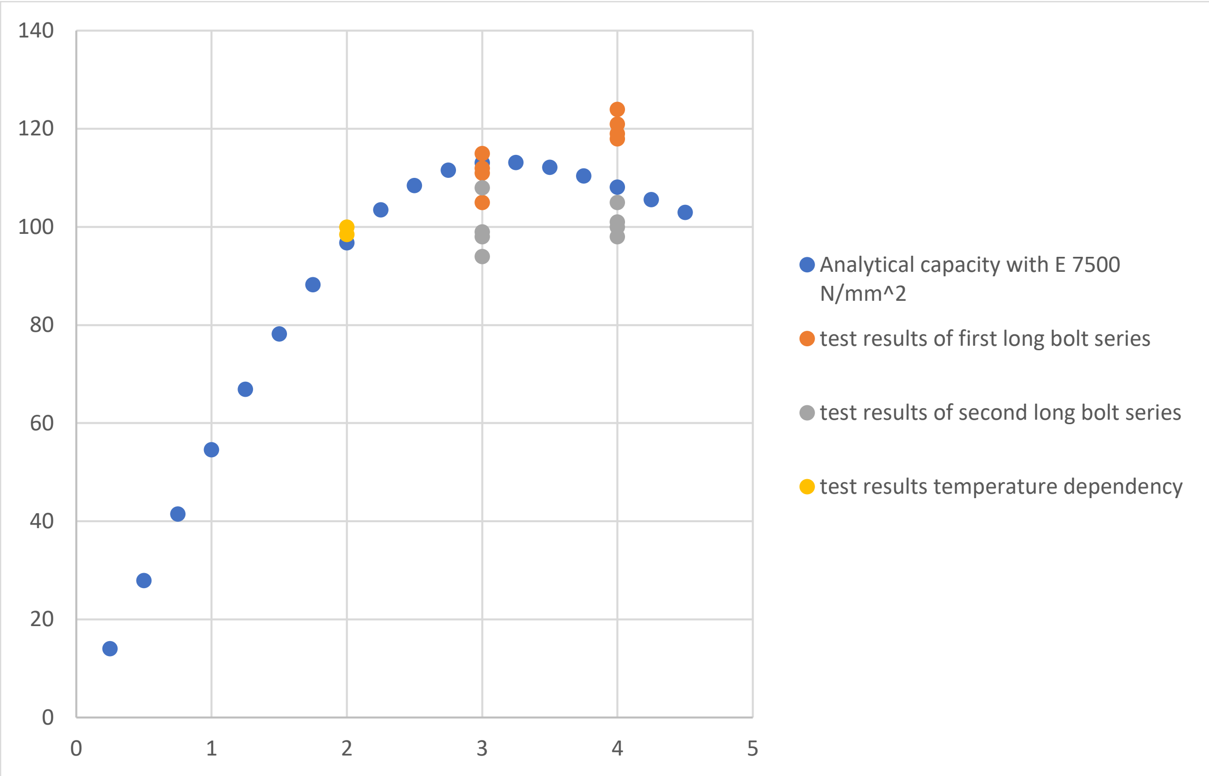


Figure 98 Comparison between test results on L/D ratio and analytical model

11.5.3 Parameter study

To investigate the model behavior in more detail the model parameters are varied and the influence on the results is investigated here. After the verification against the FEM results of Nijgh the range of L/D ratio shown here is up to an L/D ratio of 4 due to the range of validity of the model.

11.5.4 Bolt hole clearance

The influence of the bolt hole clearance on the calculated capacity is investigated. What can be seen is that the peak capacity calculated from the model moves to higher L/D ratios for larger hole clearances but the absolute capacity calculated drops as the hole clearance increases. As the percentage increase in hole clearance drops the largest drop of capacity is seen between a hole clearance of 2 and 3 mm.

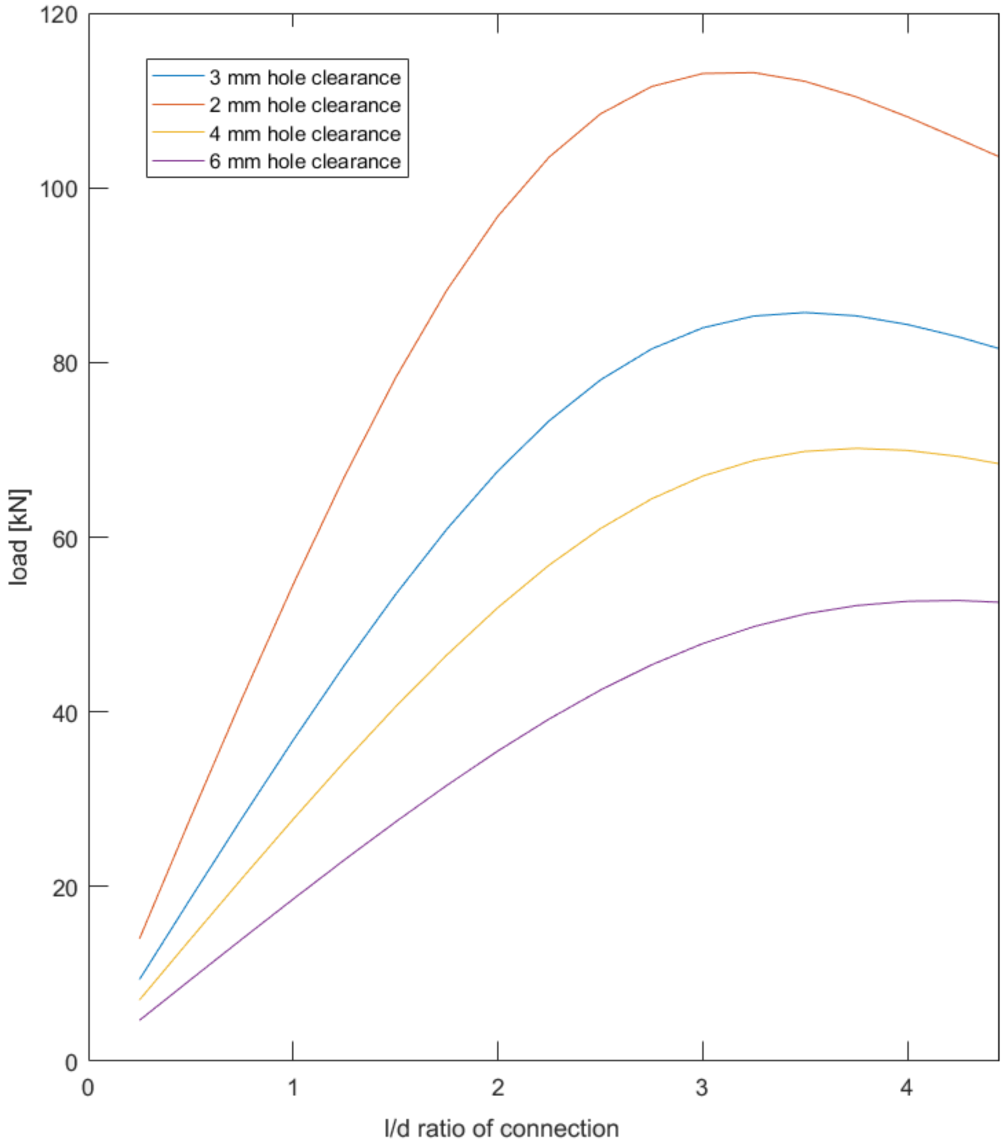


Figure 99 Calculated connection capacity for a single M20 injection bolt with varying hole clearance

12 Discussion

12.1 Linking resin material properties to performance

From the results in this research no clear relation could be drawn between the supplied mechanical properties of the resin and the performance of injection bolts. The compression of resin when confined, as illustrated in the State of the Art in Figure 12, could provide a better link between the resins mechanical properties and the performance in this application. Due to time and budget constraints testing of the confined compressive values of resin was not performed in this research. A design for a setup to perform such testing on specimens fabricated with the same procedure as injection bolts is supplied in the appendix of this research.

12.2 Injection procedure and occurrence of air inclusions

The washers used in this experimental program were according to the specifications of EN 1090-2. The positioning of the washer influenced the injection procedure for Sika Sikadur 30. From other research the washer design is optimized for injection. This washer design is a possible cause for the feasibility of Sikadur 30 and for the spread observed by workers for the required injection pressure during assembly.

The injection procedure and testing was explicitly chosen to follow the research base on injection bolts performed thus far. The injection was done in this research using a hand driven injection gun so the pressure applied during injection is not controlled accurately. From the visual inspection method executed in this research, air inclusions were observed in the resin layer for most specimens. This is not reported in other research using Perspex mockups as an inspection method. From a CT scan of an injection bolt also air inclusions are identified in the resin layer.

The air inclusions were observed across all different resin products used in this research except for Sika Injection 451 which was not applied successfully. This includes the currently applied resin RenGel SW404/HY2404. It is unknown whether the occurrence of air inclusions in this research is caused by the injection procedure applied or that these air inclusions have simply not been detected with the Perspex injection samples used for visual inspection in other research.

12.3 Scatter in the experimental results

From this research a significant scatter in the results was obtained. During the research the influence of friction was identified as a possible cause for this scatter. This influence was decreased through specific testing and a subsequent adaptation of the assembly procedure. Despite the adaptations to decrease friction influence on the results a large scatter in results, especially for Edilon Dex R2K resin, remained. The reason for this scatter is not known but possible causes have been identified.

One of the main aspects identified as a cause of possible scatter is the injection procedure. The specific aspects are the positioning of the washer at the bolt head side during injection, the occurrence of voids in the resin layer and the applied pressure with the hand-driven injection gun.

Furthermore, the mixing of resin components is identified as a possible cause for scatter. Due to the small volumes applied in injection bolts inhomogeneities in the mixing of the two components could influence the found results. For Edilon Dex R2K specifically, the mixing takes place in the mixing nozzle supplied by the manufacturer. This mixing of small resin volumes in the mixing nozzle could be a cause of scatter in the results.

To determine the resistance values of the tested resins in this research accurately, a larger set of tests must be performed, to gain better insight in the scatter and characteristic values that can be taken into account.

12.4 Analytical modelling

The analytical model developed and presented in this report is intended to investigate the stress peaks that occur in the resin layer because of bolt bending in an IBC. As discussed this model shows good agreement with the numerical model developed by Nijgh on IBC concerning the bolt deformation in the connection. The stress in the resin layer that is calculated from the analytical model shows worse agreement with numerical results. Issues were seen in this modelling approach with resin stress initially dropping below zero which had to be corrected. Also, the stress peak being constant in the model results show that this model is not accurately representing the real connection behavior.

The analytical model does not take local deformation of the plates into account. The deformations in the resin layer are very small. The deformation of the plate could be a reason for the model behavior not following the FEM and experimental results. Furthermore, the occurrence of voids means the resin spring stiffness varies locally, this is not taken into account in the analytical model either.

12.5 Limitations of research

One of the research questions in this study is the application of alternative resin products for injection bolts. The choice of resins which were selected for use in this research was based on limited research. The resin products that were considered for the selection procedure were two-component epoxy resins.

The choice of Sikadur 30 resin was supported by current research [28]. RenGel SW404/HY2404 resin was tested as a baseline product proven in previous research and successful practical applications. The remaining resin products were selected based on the product data sheets supplied by the manufacturers and through direct communication with the suppliers to determine possible alternatives. The selection of these products was not supported by other research. Furthermore, in the selection procedure of the resins in this research, the author was not aware of the research and application of Sika AnchorFix and Sikadur 33 resins for injection bolts as reported on by Gresnigt. [31]

The testing procedure chosen for this research has been based on the guidelines of EN 1090. This aligns with the previous research done on this topic explained in the State of the art. The tests performed were short duration tests with static load procedures. This means the conclusions of this research cannot be extended to other load cases in which further research is required. The time-dependent creep of the resin layer was briefly investigated in additional loading on test specimens in this research, but the duration of this test was too short to draw meaningful conclusions on the long duration behavior of tested resins. Tests on the creep behavior of connections with varying bolt hole sizes is ongoing at TU Delft using RenGel and Dex R2K resins.

The washer design was not varied in this research. The product Sika Sikadur 30 showed good results in IBC from other research using optimized washer designs [28]. This research did not consider alternative washers for resin products.

The variation in the geometry of the connection in this research has been limited to the L/D ratio of the connection. For this ratio only the plate package thickness l has been varied. The effect of bolt size has not been studied in this research. Other variations in the connection geometry such as the ratio between the center and cover plate thickness $t_1/t_2$and hole clearance have not been considered in this experimental research. The hole clearance was analyzed as a parameter in the analytical model. Experimental research into the effect of bolt size is ongoing at TU Delft currently. The effect of the size of the hole clearance has been studied recently in TU Delft research performed by Nijgh [32].

Finally, as mentioned in the State of the art injection bolts may be applied in combination with a preload. This combination of preload and injection for bolted connections was not considered in this research although research in this combination is ongoing at TU Delft as well.

In this research, the effect of the curing temperature on the resin bearing resistance of injection bolts is tested. From the State of the art the glass transition temperature of the resin is identified as an important material property for the strength and stiffness of resin products. In this research, no testing has been performed at elevated temperatures for alternative resins to investigate this material parameter. The currently applied resin RenGel SW404/HY2404 has been tested at high temperatures in previous research and showed good performance [9] .

13 Conclusions and recommendations

13.1 Conclusions

In current practice RenGel SW404/HY2404 is the resin of choice for injection bolts. In this research Edilon Dex G 20 and Edilon Dex R2K were injected successfully. Sika Injection 451 resin had a too low viscosity for injection, causing it to run in between the plate surfaces of the connection. Sika Sikadur 30 had a too high viscosity leading to issues with injection around the bolt head washer. In all resin products air inclusions were observed after disassembly of test specimens.

From the review of properties in this research the viscosity of the resin mixture, pot life, glass transition temperature and curing shrinkage are found to be the most important properties of resins for IBC application. The viscosity of feasible products ranged from 11.000 to 55.00-80.000 $mPa \cdot s$. The viscosity of Sika Injection 451 (100 $mPa \cdot s$) was far too low. Sika Sikadur 30 is a paste and not a liquid so no exact viscosity can be given. The pot life and glass transition temperature of a product should be as high as possible. Curing shrinkage should be minimized for this application. Edilon Dex R2K negated pot life considerations, the resin was mixed in the nozzle during injection itself. This simplifies the procedure.

From testing double lap shear connections in this research the characteristic value of Edilon Dex R2K bearing stress in short term loading is found to be 156 MPa when cured at 16 degrees. The spread of this product was large.

In short duration creep tests the deformation of Edilon Dex G 20 was 3.5 times larger than the currently applied product RenGel SW404/HY2404. Dex R2K had 18% higher creep deformation than RenGel. Edilon Dex G 20 was discarded as an alternative, due to this creep behavior.

When overloaded, connections with injection bolts showed near linear behavior up to 0.6 mm deformation. Four times the short duration deformation limit from EN 1090. The curing temperature had no influence, in a practical range of 8 to 24 degrees Celsius, for the currently applied product RenGel SW404/HY2404. Edilon Dex R2K did show a dependency on the curing temperature in this range.

The mechanical properties of the resins tested in this research, as they are supplied by the manufacturers in their respective Product data sheets, did not show a clear correlation with their performance as an injection material for injected bolts.

The influence of bolt length on the resistance of an injection bolt connection is investigated in this research. Modeling the resin stress occurring for these connections was done using an analytical 1D approach. The model can be calibrated for different resins using the Young's modulus. The validity of the model ended at an L/D ratio of 4 or higher [32].

The model showed a peak resistance at an L/D ratio of 3 and decreasing for higher values. This peak resistance coincides with the maximum effective length of L/D ratio 3 specified in EN 1993-1-8. Experimental verification using RenGel SW404/HY2404 showed no decrease in resistance for L/D values between 3 and 4. One series even showed an increase in resistance between L/D 3 and 4.

13.2 Recommendations

- Material properties of resin
    - Compressibility of resin as a predictor for performance
    - More well-defined range of applicable viscosities
- Optimized washer design for injection
    - Recheck of Sikadur 30
- Optimize injection process
    - Applied pressure
    - Vacuum assistance injection procedure
- Modelling
    - Resin flow model from RTM to adapt for injection bolts
    - Extensive FEA to determine resin stress occurring in the layer
    - Improve analytical model to take plate deformation into account
- Different load cases
    - Long duration tests
    - Elevated temperature
- Bolt size effect on L/D ratio
- Behavior in repeated loading
    - Plasticity of resin layer
- Investigate the occurrence of voids in resin layer
    - CT-scan method

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15 Appendix A: Solution of Analytical Timoshenko model using BVP4C MATLAB routine

15.1.1 Deriving the governing equations of analytical model

To solve the schematized analytical model from Figure 100 the Timoshenko beam theory is applied [60] [61]. To take the foot displacement of the distributed springs into account the governing equations will be derived. This is done according to the methods explained in chapter four of the CIE4190 course reader on slender structures [62].

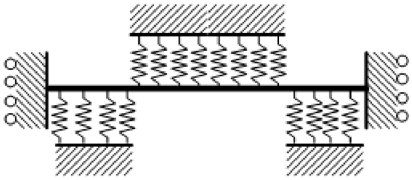

Figure 100 overview of analytical model schematization

Kinematic equations

First, the derivation is started by deriving the kinematic equations following the starting assumptions for the Timoshenko theory. That is plane sections remain plane but contrary to the Euler-Bernoulli theory they do not remain perpendicular to the neutral axis [62]. The assumptions for positive directions are shown in Figure 101.

$$S_x(x,y) = -\phi(x) \cdot y$$

$$S_y(x,y) = v(x)$$

$$\epsilon_{xx} = \frac{dS_x}{dx} = -y \cdot \frac{d\phi}{dx}$$

$$\gamma_{xy} = \frac{dS_x}{dy} + \frac{dS_y}{dx} = -\phi + \frac{dv}{dx}$$

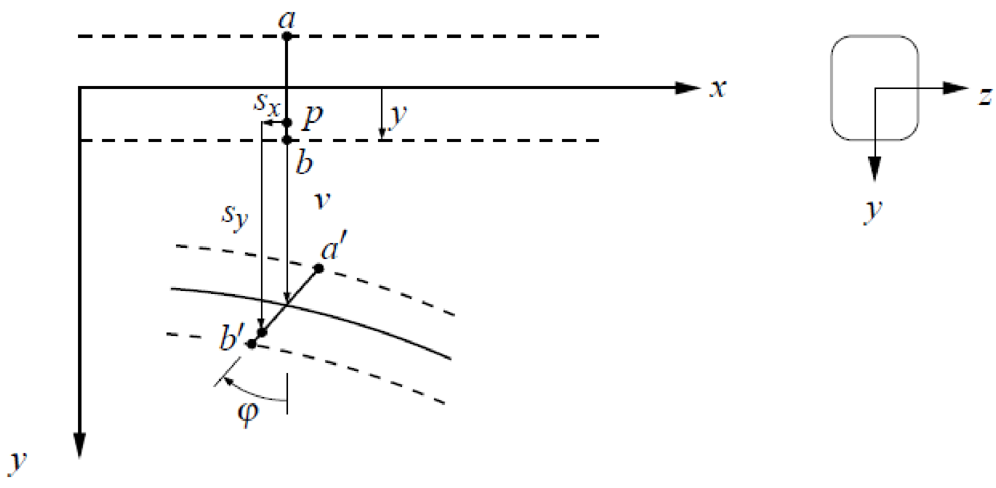

Figure 101 Assumed directions for derivation of kinematic equations [62]

$$\tan(\theta) = \frac{dv}{dx}$$

$$Rd\theta = ds$$

$$\frac{ds}{d\theta} = R$$

$$\frac{1}{R} = \kappa = \frac{d\theta}{ds}$$

We assume that the rotations of the beam stay small. Therefore, the following approximation holds:

$$\sin(\theta) \approx \tan(\theta) \approx \theta$$

$$ds \approx dx$$

And thus:

$$\kappa = \frac{d\theta}{dx}$$

$$\theta = \frac{dv}{dx}$$

$$\kappa = \frac{d^2v}{dx^2}$$

This solves the kinematic equations for the Timoshenko theory.

Equilibrium equations

What follows is the equations that relate to the force equilibrium of the model. The positive force directions are indicated in Figure 102. This figure shows an infinitesimal segment of the beam for which the equilibrium conditions must hold. For this model second order terms of derivatives are neglected [62]. The force related to the distributed springs of Figure 102 has a term with v and w. These are the displacements of the beam itself and the foot of the spring layer respectively. The positive conventions of this is shown in Figure 103.

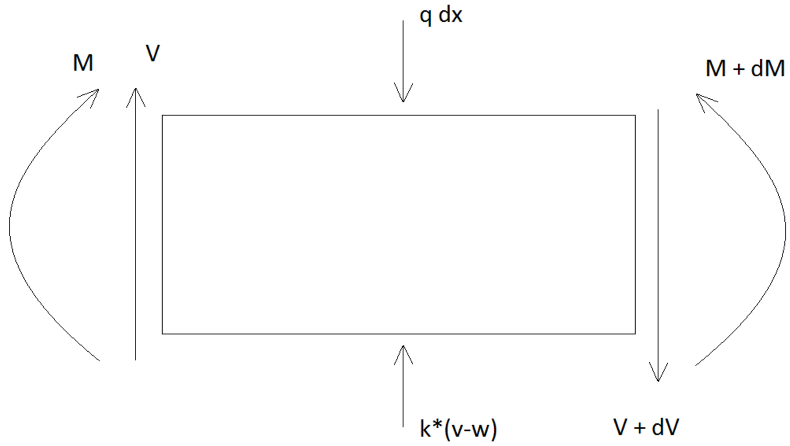

Figure 102 positive force directions equilibrium equations

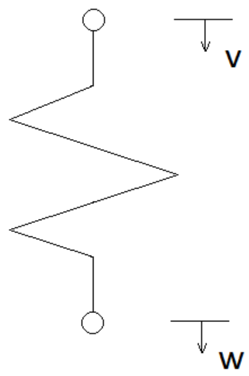

Figure 103 positive displacements distributed springs

Now we can derive the equilibrium conditions of the model:

$$\sum M = 0$$

$$\sum M = M = dM - M - V \cdot dx = 0$$

$$\sum M = dM - V \cdot dx = 0$$

$$dM = V \cdot dx$$

$$\frac{dM}{dx} = V$$

$$\sum F_y = 0$$

$$\sum F_y = V + dV - V + \left(q - k \cdot (v - w)\right) \cdot dx = 0$$

$$dV + qdx - kdx \cdot (v - w) = 0$$

$$\frac{dV}{dx} + q - k \cdot (v - w) = 0$$

$$\frac{dV}{dx} = -q + k \cdot (v - w)$$

Constitutive equations

Last to complete the derivations of the governing equations is the constitutive equations. These relate the displacements and deformations to the stresses that occur in the material. For this reference is made to [62]. Hereby E is the young's modulus of the material, G the shear modulus, A_s the effective area in shear and I the second moment of inertia of the cross-section.

$$dM = \sigma_x \cdot y \cdot dA$$

$$\int dM = M = \int \sigma_x \cdot y \cdot dA$$

$$\int \sigma_x \cdot y \cdot dA = \int E \cdot \epsilon_{xx} \cdot y \cdot dA$$

$$\int E \cdot \epsilon_{xx} \cdot y \cdot dA = -\int E \cdot y \cdot \frac{d\phi}{dx} \cdot y \cdot dA$$

$$-\int E\cdot y\cdot\frac{d\phi}{dx}\cdot y\cdot dA=-E\cdot\frac{d\phi}{dx}\cdot\int y^2\cdot dA=-E\cdot I\cdot\frac{d\phi}{dx}$$

$$M=-EI\cdot\frac{d\phi}{dx}$$

$$\frac{dM}{dx}=-EI\cdot\frac{d^2\phi}{dx^2}$$

Again, making use of the assumption of small rotations we can find the following:

$$\gamma=\tan\frac{dv}{dx}\approx\frac{dv}{dx}$$

$$\tau=G\cdot\gamma$$

$$\tau=\frac{V}{A_s}$$

$$\gamma=\frac{V}{G\cdot A_s}$$

$$\gamma=-\phi+\frac{dv}{dx}$$

$$V=GA_s(\frac{dv}{dx}-\phi)$$

Combining all the above equations we can find the governing equations for the problem:

$$\frac{dM}{dx}=V=-EI\cdot\frac{d^2\phi}{dx^2}$$

$$-EI\cdot\frac{d^2\phi}{dx^2}=GA_s\cdot\left(\frac{dv}{dx}-\phi\right)$$

$$V=GA_s(\frac{dv}{dx}-\phi)$$

$$\frac{dV}{dx}=GA_s\cdot\left(\frac{d^2v}{dx^2}-\frac{d\phi}{dx}\right)=-q+k\cdot(v-w)$$

So, to summarize we find two second order dependent differential equations which govern the deflection of the bolt shank loaded by a set of distributed springs which represent the resin layer of the injection bolt. Furthermore the q term represents an external distributed load but this is not used further in the modelling but was left included for completeness.

$$GA_s\cdot\left(\frac{d^2v}{dx^2}-\frac{d\phi}{dx}\right)=-q+k\cdot(v-w)$$
$$-EI\cdot\frac{d^2\phi}{dx^2}=GA_s\cdot(\frac{dv}{dx}-\phi)$$

The equations above govern the deflection of the analytical model. To formulate a solution to these equations the boundary conditions must be considered. Due to the discontinuities in the loading that occur at the interface between center and cover plate the solution must be derived in three solution fields. To take this into account interface conditions between the different solution fields are needed. The boundary conditions and interface conditions are summarized below in Table 30. An overview of the solution fields is also given in Figure 104.

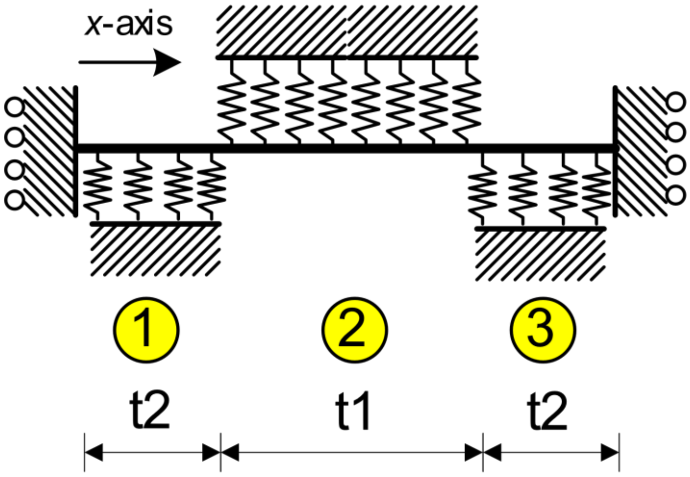

Figure 104 analytical model with solution fields in yellow

Table 30 Overview of boundary conditions analytical model

Boundary conditions analytical model			
Left boundary ($\boldsymbol{x = 0}$)	Interface 1 ($x = t_2$)	Interface 2 ($x = t_1 + t_2$)	Right boundary ($x = t_1 + 2 \cdot t_2$)
$\boldsymbol{V = 0}$	$M_1 = M_2$	$M_2 = M_3$	$V = 0$
$\boldsymbol{\phi = 0}$	$V_1 = V_2$	$V_2 = V_3$	$\phi = 0$
	$\phi_1 = \phi_2$	$\phi_2 = \phi_3$	
	$v_1 = v_2$	$v_2 = v_3$	

15.1.2 Solving the governing equations

To solve the governing equations derived above using the boundary conditions from Table 30 MATLAB is used. The system of differential equations is known as a boundary-value problem. To solve this the BVP4C solver routine built into MATLAB is used. This will give a numerical approximation to the analytical solution. To apply this solver a specific format of the differential equations and boundary conditions must be used. Reference is made here to previous research on analytical modelling of Timoshenko beams using the BVP4C solver as an example. [65] [63] [66]

15.1.3 Reduction of order and solution fields

The BVP4C solver can only deal with first order differential equations. [66] The Timoshenko equations consist of two coupled second order differential equations. Therefore, a reduction of order must be applied on both main variables v and ϕ. For this the example supplied in Appendix A of [65] is followed. This is shown below:

$$f_1 = \phi$$

$$f_2 = \frac{df_1}{dx} = \frac{d\phi}{dx}$$

$$\frac{d^2\phi}{dx^2} = \frac{df_2}{dx}$$

$$v_1 = v$$

$$v_2 = \frac{dv_1}{dx} = \frac{dv}{dx}$$

$$\frac{d^2v}{dx^2} = \frac{dv_2}{dx}$$

Using the newly defined variables f_1, f_2, v_1, v_2 we can now write the governing equations as:

$$EI \cdot f_2' + GA_s \cdot (v_2 - f_1) = 0$$

$$f_2' = -\frac{GA_s}{EI} \cdot (v_2 - f_1)$$

$$GA_s \cdot (v_2' - f_2) = -q + k \cdot (v_1 - w)$$

$$v_2' = \frac{-q + k \cdot (v_1 - w)}{GA_s} + f_2$$

In the solution script the reduced order variables are all stored in a separate solution vector y. This is structured as follows:

$$y = [\, f_1 \quad f_2 \quad v_1 \quad v_2 \,]$$

As mentioned earlier the solution must be derived in three solution fields. The implementation of splitting the three fields is shown here below in X. The que for BVP4C to know the edge of a solution field is a repeated entry in the vector with x coordinates of the solution.

```
function v = xinitial
    %XINITIAL makes linearly spaced 3 field mesh of the bolt
    v1 = linspace(0,t2,n/3);
    v2 = linspace(t2,t1+t2,n/3);
    v3 = linspace(t1+t2,t1+t2+t2,n/3);
    v  = [v1 v2 v3];
end
```

Figure 105 implementation of splitting solution field

15.1.4 Applying boundary conditions

To apply the BVP4C solver the boundary conditions as determined before in Table 30 must be rewritten in the reduced order variables and the residuals must be computed. BVP4C works by minimizing the residuals of the solution and the boundary condition as specified by the user. First, the boundary conditions in the reduced order variables will be derived. To indicate the different fields and order of derivative term two subscripts are used here. The first index refers to the field of the variable. The second index denotes the order of derivative the term represents.

The left and right boundary as applied in reduced order variables gives the following:

$$on\ x = 0$$

$$V_1 = GA_s \cdot (v_{1,2} - f_{1,1}) = 0$$

$$\phi_1 = f_{1,1} = 0$$

$$on\ x = t_1 + 2 \cdot t_2$$

$$V_3 = GA_s \cdot (v_{3,2} - f_{3,1}) = 0$$

$$\phi_3 = f_{3,1} = 0$$

The interface conditions between the different fields in the reduced order variables gives the following:

$$on\ x = t_2$$

$$V_1 = V_2$$

$$GA_s \cdot (v_{1,2} - f_{1,1}) = GA_s \cdot (v_{2,2} - f_{2,1})$$

$$\phi_1 = \phi_2$$

$$f_{1,1} = f_{2,1}$$

$$M_1 = M_2$$

$$-EI \cdot f_{1,2} = -EI \cdot f_{2,2}$$

$$v_1 = v_2$$

$$v_{1,1} = v_{2,1}$$

In similar fashion the interface between the second and third solution field gives the following:

$$on\ x = t_1 + t_2$$

$$GA_s \cdot (v_{2,2} - f_{2,1}) = GA_s \cdot (v_{3,2} - f_{3,1})$$

$$f_{2,1} = f_{3,1}$$

$$-EI \cdot f_{2,2} = -EI \cdot f_{3,2}$$

$$v_{2,1} = v_{3,1}$$

From the documentation of the BVP4C solver when using a multiple field approach the boundary conditions must be stored in two separate matrices. One containing all the conditions at the left side of each field and the second matrix with all the conditions at the right side of the fields. [66] [67] These matrices are denoted as YL and YR in the script for this problem. Lastly the boundary conditions must be computed as residuals, all terms are moved to one side such that the value is zero when the boundary condition is met exactly. This is shown for one boundary condition below:

$$-EI \cdot f_{1,2} = -EI \cdot f_{2,2}$$

$$-EI \cdot (f_{1,2} - f_{2,2}) = 0$$

This implementation of residuals and boundary condition matrices can be seen in the code snippet of Figure 106.

```
    function res = bc(YL,YR)
        %BC Function that finds the residuals of the BCs of the bolt

        res = [GAs*(YL(4,1)-YL(1,1)) %V1(0)=0  force balance on the bolt
               YL(1,1)          %phi1(0)=0          clamped end
               YR(3,1)-YL(3,2) %w1(t2)=w2(t2)   matching conditions 1,2
               -EI*(YR(2,1)-YL(2,2)) %M1(t2)= M2(t2)
               GAs*(YR(4,1)-YR(1,1))-GAs*(YL(4,2)-YL(1,2)) %V1(t2)=V2(t2)
               YR(1,1)-YL(1,2) %phi1(t2)=phi2(t2)
               YR(3,2)-YL(3,3) %w1(t2)=w2(t2)   matching conditions 2,3
               -EI*(YR(2,2)-YL(2,3)) %M1(t2)= M2(t2)
               GAs*(YR(4,2)-YR(1,2))-GAs*(YL(4,3)-YL(1,3)) %V2(t2)=V3(t2)
               YR(1,2)-YL(1,3) %phi1(t2)=phi2(t2)
               GAs*(YR(4,3)-YR(1,3)) %V3(t1+2*t2)=0   force balance
               YR(1,3)          %phi3(t1+2*t2)=0
              ];
    end
```

Figure 106 implementation of boundary conditions and residuals

15.1.5 Implementing numerical solver mesh size

Now we can apply the BVP4C solver to find a solution to the governing equations. BVP4C finds a numerical approximation to the analytical solution on a mesh of points along the length. Due to the solution being sought in three fields it is necessary that the number of mesh points n is a multiple of three. From the documentation of BVP4C it can be found that the mesh size n will be automatically adjusted when the desired accuracy of the solution cannot be found. [66] This adjusted mesh size is not necessarily a multiple of three so a manual catch is put in the script when this happens to guarantee n is a multiple of three. This is shown in the code snippet below in Figure 107. This implementation guarantees the accuracy of the solution is maintained and that the solution mesh is a multiple of three so a discrete number of points fits in each field.

```
sol = bvp4c(@ex1ode,@bc,solinit,options);

if size(sol.x,2) ~= n
      disp('mesh size adjusted!');
      disp('mesh size:');
      disp(size(sol.x,2));
      disp('n:');
      disp(n);

      %triple mesh size for new attempt
      n = n*3;

      %run solver again using the enlarged mesh
      xinit = xinitial;
      yinit = [0.00 0.00 0.00 0.00];

      solinit = bvpinit(xinit,yinit);
      options = bvpset('Stats','on','RelTol',1e-7,'NMax',n);

      sol = bvp4c(@ex1ode,@bc,solinit,options);

      %report wether the new solution follows n.
      disp('new n:');
      disp(n);
      disp('mesh size new:');
      disp(size(sol.x,2));
end
```

Figure 107 Mesh size check implementation BVP4C

15.1.6 Full MATLAB implementation BVP4C solver

For clarity the full script used to determine the deflections with the BVP4C solver is shown here on the next pages:

```
function [LD,AVGstress,ConnCap, Sols] =
bolt_bending_timoshenko(max_ld,nr_steps,mesh_size)
    %function to solve euler bernoulli theory bending of bolt

    %close all; clear all;

    EI = 1*16.449336*10^8;
    q = 0;
    w1 = -0.075; %mm
    w2 =  0.075; %mm
    Bolt_Clearance = 3; %mm
    dbolt = 20;
    rbolt = dbolt/2;
    As = 0.9*pi*(rbolt)^2;
    G  = 210000/(2*(1+0.28));
    GAs = G*As;
    disp(GAs);
    E_Resin = 7500; % N/mm^2
    k_linear = (E_Resin*dbolt)/Bolt_Clearance;
    k = k_linear;
    %GAs = 1*10^14;

    n = mesh_size; % number of points over x coordinate for
solution.
             % multiple of 3.

    connection_capacity = zeros(1,nr_steps);
    avg_stress = zeros(1,nr_steps);
    ld_matrix=zeros(1,nr_steps);
    sol_comb = cell(1,nr_steps); %cell array with solution at every
iteration
    sol_comb(:) = {0};          % 4 rows per step for full sol

    for j = 1:nr_steps
            ld_ratio=(max_ld/nr_steps)*j;

            t1 = 0.5*ld_ratio*dbolt; %mm
            t2 = 0.25*ld_ratio*dbolt; %mm

            xinit = xinitial;
            yinit = [0.00 0.00 0.00 0.00];

            solinit = bvpinit(xinit,yinit);
            options = bvpset('Stats','on','RelTol',1e-7,'NMax',n);

            sol = bvp4c(@ex1ode,@bc,solinit,options);

            if size(sol.x,2) ~= n
                disp('mesh size adjusted!');
                disp('mesh size:');
                disp(size(sol.x,2));
                disp('n:');
                disp(n);

                %triple mesh size for new attempt
```

```
                n = n*3;

                %run solver again using the enlarged
mesh
                xinit = xinitial;
                yinit = [0.00 0.00 0.00 0.00];

                solinit = bvpinit(xinit,yinit);
                options =
bvpset('Stats','on','RelTol',1e-7,'NMax',n);

                sol =
bvp4c(@ex1ode,@bc,solinit,options);

                %report wether the new solution follows
n.
                disp('new n:');
                disp(n);
                disp('mesh size new:');
                disp(size(sol.x,2));
            end


            x = sol.x;
            y = sol.y;
            sol_comb(j) = {sol};

            i=size(x,2);

            y_center_plate      = y(3,(i/3)+1:(2*i/3));
            x_center_plate      = x(1,(i/3)+1:(2*i/3));
            Sigma_center        =
(E_Resin/Bolt_Clearance)*(y_center_plate(1,:)-
w1).*(heaviside(y_center_plate(1,:)-w1));
            sigma_avg_center    = mean(Sigma_center);
            avg_stress(j) = sigma_avg_center;
            ld_matrix(j) = ld_ratio;
            connection_capacity(j) =
sigma_avg_center*t1*dbolt*0.001;
%             for ld_ratio = 4;
% %                 plot(x,-y(3,:));
% %                 hold on;
% %                 plot(x,-y(1,:));
% %                 figure;
%                   plot(x_center_plate,Sigma_center);
%                   figure;
%             end
```

```
    end

%     plot(ld_matrix,connection_capacity);
%     hold on;
%     plot(ld_matrix,avg_stress);
%
%     disp(max(connection_capacity));
%     disp(avg_stress);

    LD = ld_matrix;
    AVGstress = avg_stress;
    ConnCap = connection_capacity;
    Sols = sol_comb;

    return;


    % ---------------------------------------------------
-------------------------

    function dydx = ex1ode(x,y,region)
        %EX1ODE ODE function for Example 1 of the BVP
tutorial.
        %   The components of y correspond to the
original variables
        %   as  y(1) = w, y(2) = phi, y(3) = kappa, y(4)
= z

        % y = [ f1 f2 v1 v2] = [ phi phi' v v']
        dydx = zeros(4,1);
%         dydx(1) = y(2);
%         dydx(2) = y(3);
%         dydx(3) = y(4);

        dydx(1) = y(2);
        dydx(3) = y(4);

        dydx(2) = -(GAs/EI)*(y(4)-y(1));

        switch region
            case 1    % x in [0 t2]
                %dydx(4) = (-q+k*(y(3)-w2))/GAs + y(2);
                dydx(4) = (((-q+(k*(y(3)-w2)))*(1-
heaviside(y(3)-w2)))/GAs)+y(2);
```

```
                case 2     % x in [t2 t1+t2]
                    %dydx(4) = (-q+k*(y(3)-w1))/GAs + y(2);
                    dydx(4) = (((-q+(k*(y(3)-
w1)))*(heaviside(y(3)-w1)))/GAs)+y(2);
                case 3     % x in [t1+t2 t1+t2+t2]
                    %dydx(4) = (-q+k*(y(3)-w2))/GAs + y(2);
                    dydx(4) = (((-q+(k*(y(3)-w2)))*(1-
heaviside(y(3)-w2)))/GAs)+y(2);
                otherwise

error('MATLAB:threebvp:BadRegionIndex','Incorrect region
index: %d',region);
            end
        end

        %-------------------------------------------------------
----------------------

        function res = bc(YL,YR)
            %BC Function that finds the residuals of the BCs
of the bolt

            res = [GAs*(YL(4,1)-YL(1,1)) %V1(0)=0  force
balance on the bolt
                   YL(1,1)          %phi1(0)=0
clamped end
                   YR(3,1)-YL(3,2) %w1(t2)=w2(t2)   matching
conditions 1,2
                   -EI*(YR(2,1)-YL(2,2)) %M1(t2)= M2(t2)
                   GAs*(YR(4,1)-YR(1,1))-GAs*(YL(4,2)-
YL(1,2)) %V1(t2)=V2(t2)
                   YR(1,1)-YL(1,2) %phi1(t2)=phi2(t2)
                   YR(3,2)-YL(3,3) %w1(t2)=w2(t2)   matching
conditions 2,3
                   -EI*(YR(2,2)-YL(2,3)) %M1(t2)= M2(t2)
                   GAs*(YR(4,2)-YR(1,2))-GAs*(YL(4,3)-
YL(1,3)) %V2(t2)=V3(t2)
                   YR(1,2)-YL(1,3) %phi1(t2)=phi2(t2)
                   GAs*(YR(4,3)-YR(1,3)) %V3(t1+2*t2)=0
force balance
                   YR(1,3)          %phi3(t1+2*t2)=0
                  ];
        end
```

```
    %-------------------------------------------------------
--------

    function v = xinitial
        %XINITIAL makes linearly spaced 3 field mesh of
the bolt
        v1 = linspace(0,t2,n/3);
        v2 = linspace(t2,t1+t2,n/3);
        v3 = linspace(t1+t2,t1+t2+t2,n/3);
        v  = [v1 v2 v3];
    end

end
```

16 Appendix B confined volume compressive test setup design

Top plate of confined volume compressive test setup design

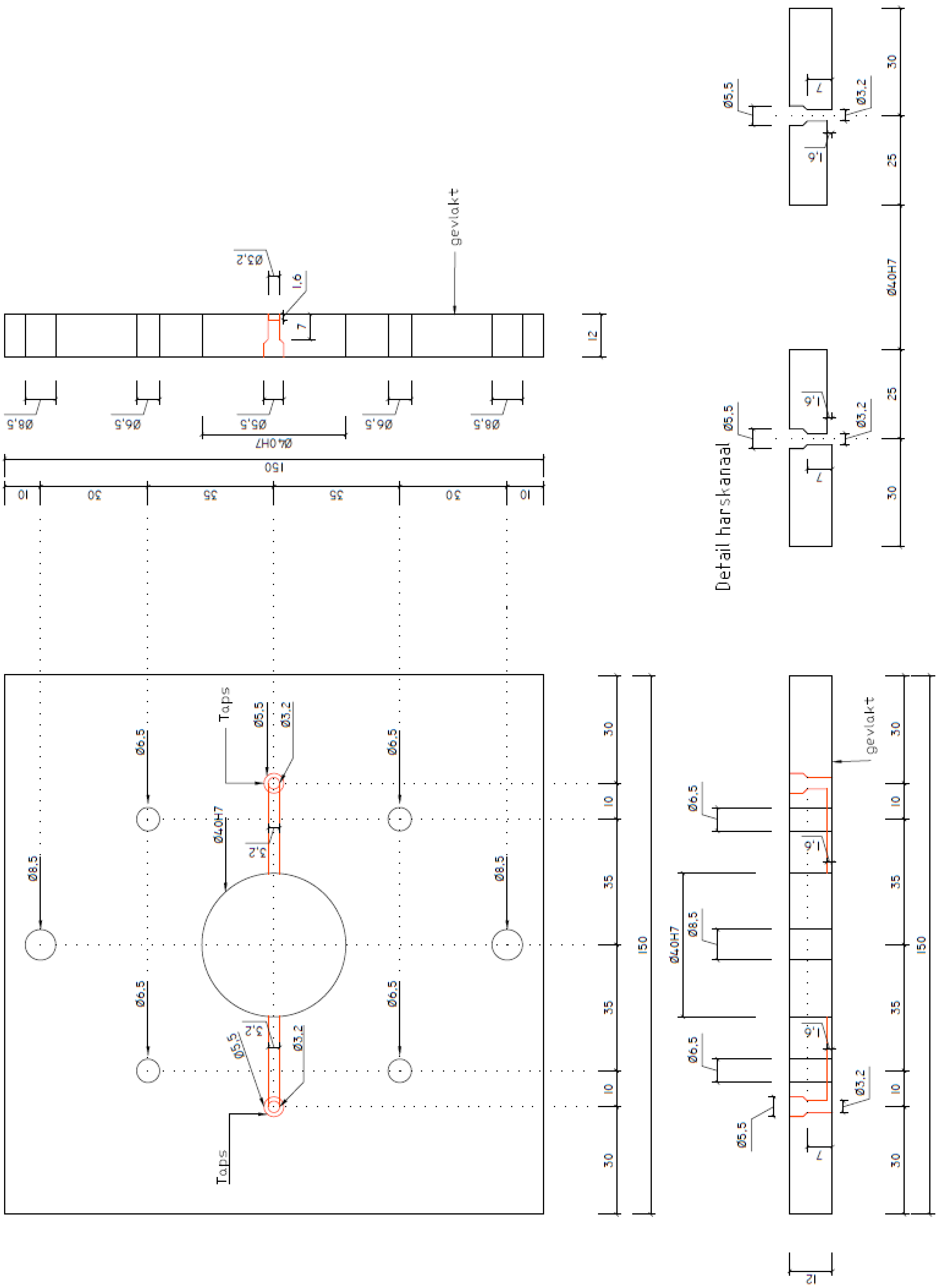

Figure 108 *Top plate of confined volume compressive test design with resin injection channels according to EN 1090*

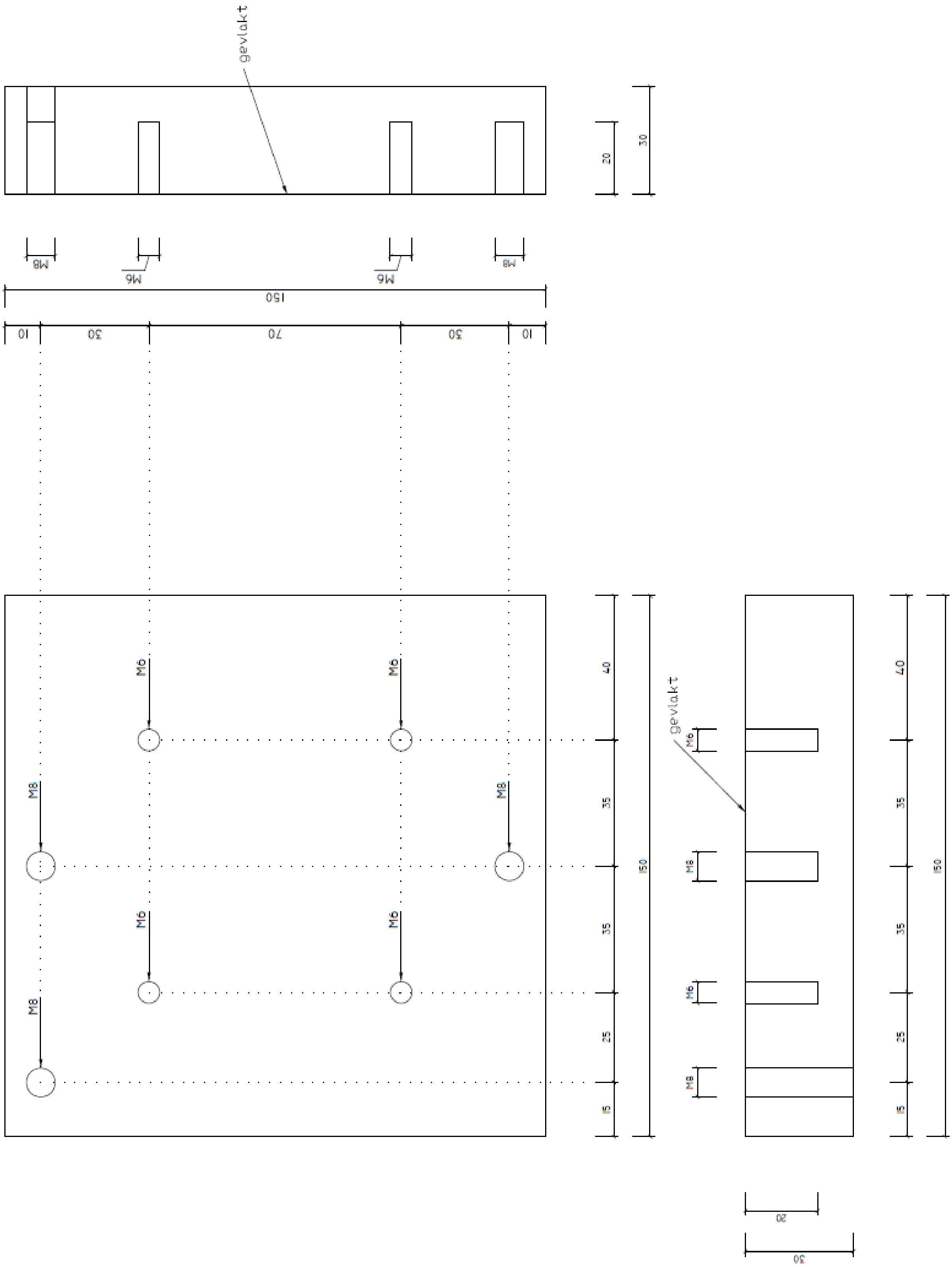

Figure 109 *Bottom plate of compressive test confined volume design*

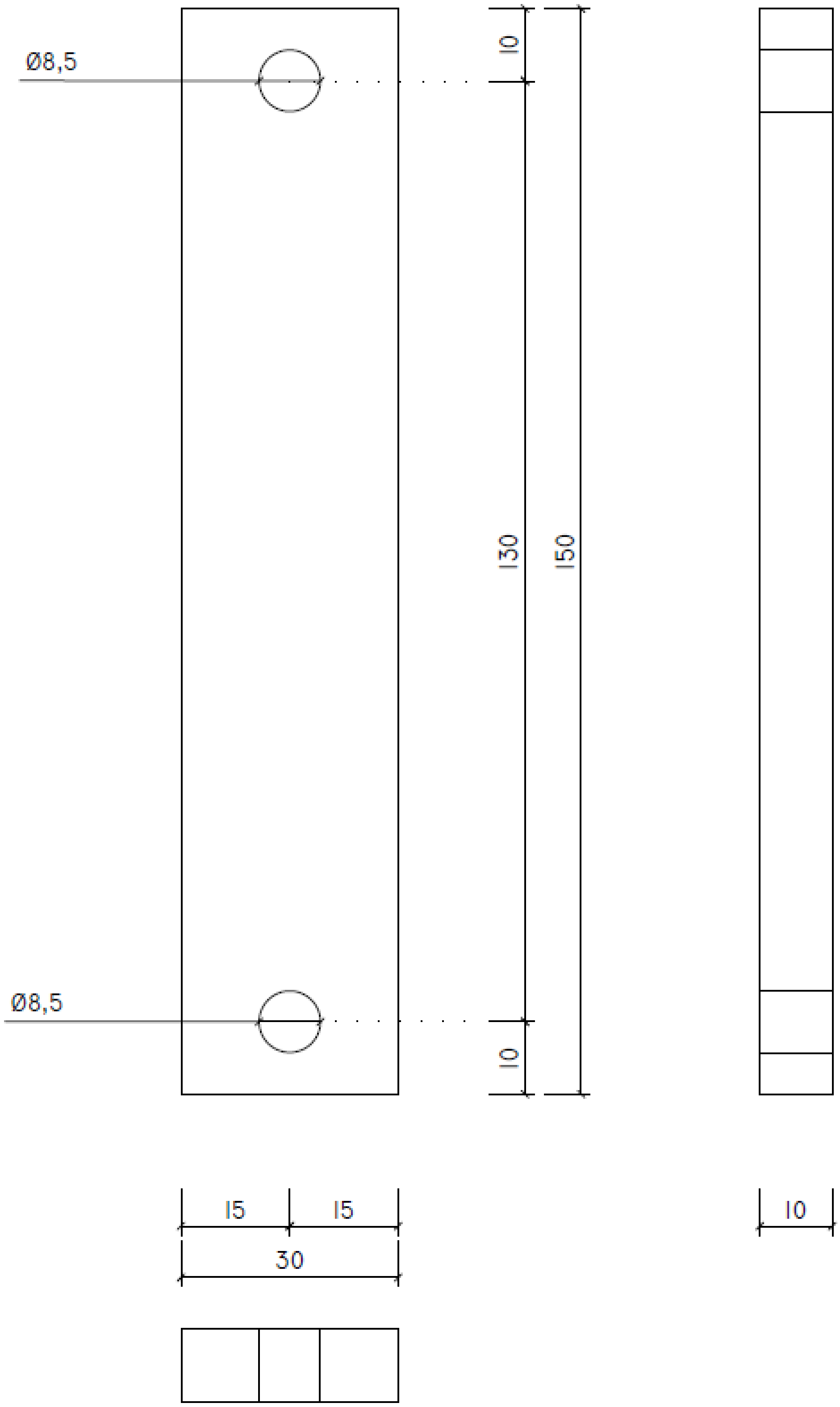

Figure 110 *Strip to clamp cylinder during curing of resin for compressive test*

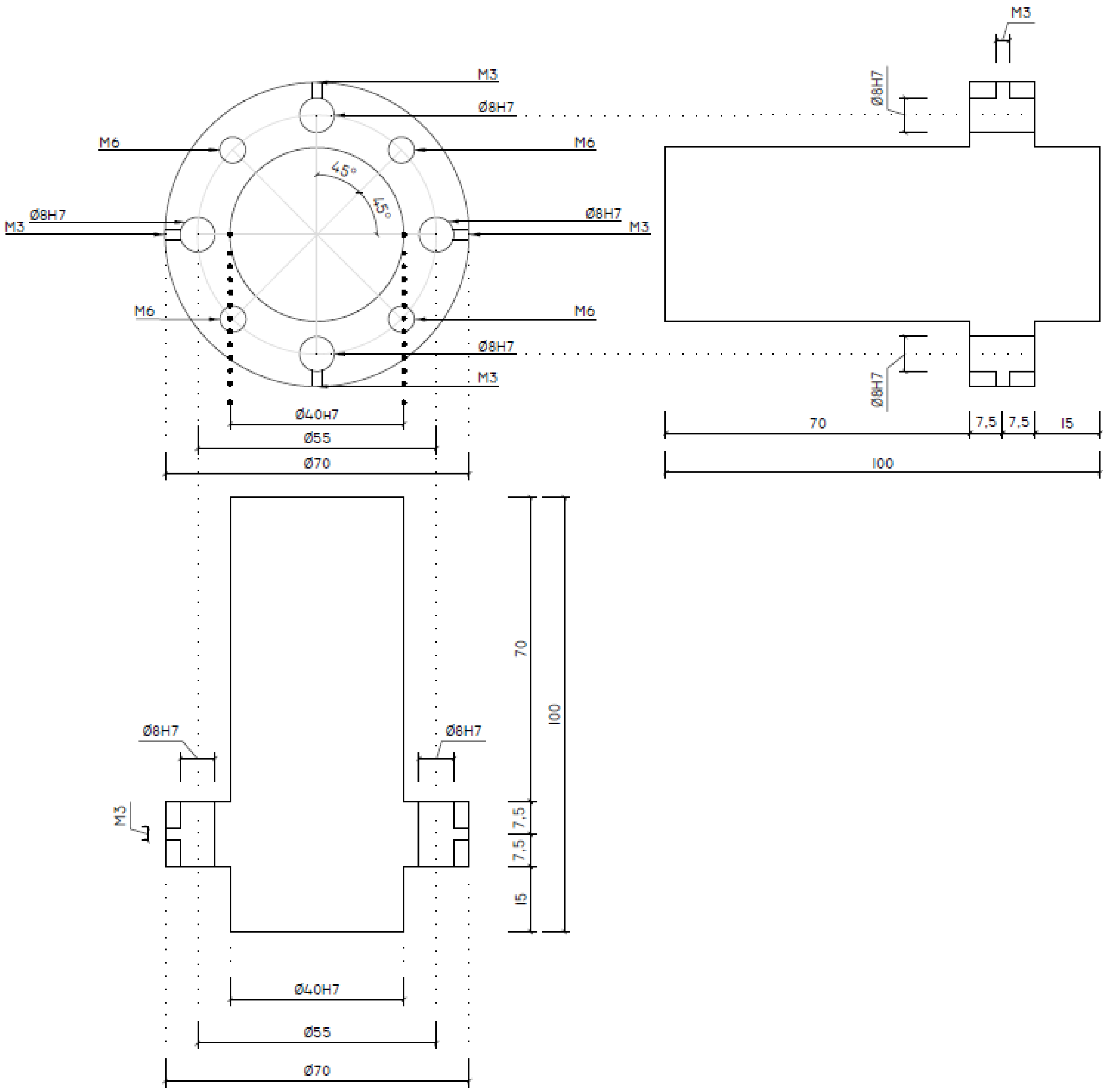

Figure 111 *Cylinder of compressive test setup with mounting points for LVDTs*

17 Appendix C: Product data sheets of used Resins

17.1 RenGel / Araldite SW404/HY2404

Gelcoat Resin

Araldite® SW 404 Resin with HY 2404 Hardener

Filled epoxy system, abrasion resistant

Key Properties

- Easy to apply with brush or spatula, or by pouring
- Easy to use
- Covers sharp edges
- Cures rapidly at room temperature
- Outstanding mechanical strength
- Very hard, abrasion-resistant surfaces
- Very strong edges

Applications

- Foundry patterns
- Copy-milling models
- Foaming and concrete-casting moulds
- Tools and tooling aids

Typical product data

Property		Araldite SW 404	Hardener HY 2404
Appearance		blue, medium-viscosity liquid	yellow, transparent, low-viscosity liquid
Viscosity at 25 °C	mPa s	55,000 - 80,000	3,500 - 5,500
Density at 25 °C	g/cm^3	1.85 - 1.95	1.0 - 1.05

Processing

Mix ratio	Parts by weight
Araldite SW 404	100
Hardener HY 2404	10

Resin / Hardener mix at 20 - 25 °C

Viscosity		slightly thixotropic
Pot life (500 g batch)	min	25 - 30
Gel time, thin layer	min	40 - 45
Demouldable after	h	12-16

Properties

After cure for 7 days at 20 - 25°C

Property	Standard	Unit	Value
Density	-	g/cm^3	1.8 - 1.9
Shore D hardness	ISO 868	-	85 - 90
Compressive strength	ISO 604	N/mm^2	110 - 125
Flexuralstrength	ISO 178	N/mm^2	95 - 105
Flexuralmodulus	ISO 178	N/mm^2	9,000 - 9,500
Impact strength	ISO 179	kj/m^2	7.5 - 9.5
Deflection temperature	ISO 75	°C	70 - 75
Cold water absorption, 24h/23°C	ISO 62	mg	5.5 - 7.0
Boiling water absorption, 30 min	ISO 117	mg	30 - 40
Abrasion resistance (S/33 sandpaper strips, 500 P load)	NEMA	mg/100 rpm	8 - 15

Storage

The resin and hardener described in this instruction sheet have the shelf lives shown provided they are stored in a dry place at 18°C - 25°C and in the original sealed containers.
Resin which has solidified in storing owing to low temperatures can be re-conditioned by heating it to 70 - 80°C for about an hour and stirring it thoroughly. The resin must be allowed to cool to room temperature before the hardener is added.

Handling precautions

Caution
Ciba Specialty Chemicals' products are generally quite harmless to handle provided that certain precautions normally taken when handling chemicals are observed. The uncured materials must not, for instance, be allowed to come into contact with foodstuffs or food utensils, and measures should be taken to prevent the uncured materials from coming in contact with the skin, since people with particularly sensitive skin may be affected. The wearing of impervious rubber or plastic gloves will normally be necessary; likewise the use of eye protection. The skin should be thoroughly cleansed at the end of each working period by washing with soap and warm water. The use of solvents is to be avoided. Disposable paper - not cloth towels - should be used to dry the skin. Adequate ventilation of the working area is recommended. These precautions are described in greater detail in Ciba Specialty Chemicals publication No. 24264/3/e Hygienic precautions for handling plastics products of Ciba Specialty Chemicals and in the Ciba Specialty Chemicals Material Safety Data sheets for the individual products. These publications are available on request and should be referred to for fuller information.

Ciba Specialty Chemicals
Performance
Polymers

All recommendations for the use of our products, whether given by us in writing, verbally, or to be implied from the results of tests carried out by us, are based on the current state of our knowledge. Notwithstanding any such recommendations the Buyer shall remain responsible for satisfying himself that the products as supplied by us are suitable for his intended process or purpose. Since we cannot control the application, use or processing of the products, we cannot accept responsibility therefor. The Buyer shall ensure that the intended use of the products will not infringe any third party's intellectual property rights. We warrant that our products are free from defects in accordance with and subject to our general conditions of supply.

17.2 Sika Sikadur 30

Product Data Sheet
Edition 9.23.2014
Sikadur® 30

Sikadur® 30

High-modulus, high-strength, structural epoxy paste adhesive for use with Sika® CarboDur® reinforcement.

Construction

Description	Sikadur® 30 is a 2-component, 100% solids, moisture-tolerant, high-modulus, high-strength, structural epoxy paste adhesive. It conforms to the current ASTM C-881 Type I, IV Grade 3, Class C and AASHTO M-235 specifications.
Where to use	■ Adhesive for bonding external reinforcement to concrete, masonry, steel, wood, stone, etc. ■ Structural bonding of composite laminates (Sika® CarboDur® CFRP) to concrete. ■ Structural bonding of steel plates to concrete. ■ Suitable for use in vertical and overhead configurations. ■ As a binder for epoxy mortar repairs.
Advantages	■ Long pot life. ■ Long open time. ■ Tolerant of moisture before, during and after cure. ■ High strength, high modulus, structural paste adhesive. ■ Excellent adhesion to concrete, masonry, metals, wood and most structural materials. ■ Fully compatible and excellent adhesion to Sika® CarboDur® CFRP composite laminate. ■ Paste consistency ideal for vertical and overhead applications of Sika® CarboDur®. ■ High abrasion and shock resistance. ■ Convenient easy mix ratio A:B=3:1 by volume. ■ Solvent-free. ■ Color-coded components to ensure proper mixing control.
Coverage	Type S 512 CarboDur®: approx. 50 LF/gal.; Type S 812 CarboDur: approx. 32 LF/gal.; Type S 1012 CarboDur®: approx. 22 LF/gal.
Packaging	1 gal. units.

Typical Data *(Material and curing conditions @ 73°F (23°C) and 50% R.H.)*

RESULTS MAY DIFFER BASED UPON STATISTICAL VARIATIONS DEPENDING UPON MIXING METHODS AND EQUIPMENT, TEMPERATURE, APPLICATION METHODS, TEST METHODS, ACTUAL SITE CONDITIONS AND CURING CONDITIONS.

Shelf Life	2 years in original, unopened containers.
Storage Conditions	Store dry at 40°-95°F (4°-35°C). Condition material to 65°-85°F (18°-29°C) before using.
Color	Light gray
Mixing Ratio	Component 'A': Component 'B' = 3:1 by volume.
Consistency	Non-sag paste.
Pot Life	Approximately 70 minutes @ 73°F (23°C) (1 qt.)

Tensile Properties (ASTM D-638)

7 day	Tensile Strength	3,600 psi (24.8 MPa)
	Elongation at Break	1%
	Modulus of Elasticity	6.5 X 10⁵ psi (4,482 MPa)

Flexural Properties (ASTM D-790)

14 day	Flexural Strength (Modulus of Rupture)	6,800 psi (46.8 MPa)
	Tangent Modulus of Elasticity in Bending	1.7 X 10⁶ psi (11,721 MPa)

Shear Strength (ASTM D-732) **14 day** Shear Strength 3,600 psi (24.8 MPa)

Bond Strength (ASTM C-882): Hardened Concrete to Hardened Concrete

2 day (moist cure)	Bond Strength	2,700 psi (18.6 MPa)
2 day (dry cure)	Bond Strength	3,200 psi (22.0 MPa)
14 day (moist cure)	Bond Strength	3,100 psi (21.3 MPa)
	Hardened Concrete to Steel	2,600 psi (17.9 MPa)
2 day (moist cure)	Bond Strength	3,000 psi (20.6 MPa)
2 day (dry cure)	Bond Strength	2,600 psi (17.9 MPa)
14 day (moist cure)	Bond Strength	

Heat Deflection Temperature (ASTM D-648)

7 day	[fiber stress loading=264 psi (1.8 MPa)]	118°F (47°C)

Water Absorption (ASTM D-570) **7 day** (24 hour immersion) 0.03%

Sika®

PRIOR TO EACH USE OF ANY SIKA PRODUCT, THE USER MUST ALWAYS READ AND FOLLOW THE WARNINGS AND INSTRUCTIONS ON THE PRODUCT'S MOST CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET WHICH ARE AVAILABLE ONLINE AT HTTP://USA.SIKA.COM/ OR BY CALLING SIKA'S TECHNICAL SERVICE DEPARTMENT AT 800.933.7452 NOTHING CONTAINED IN ANY SIKA MATERIALS RELIEVES THE USER OF THE OBLIGATION TO READ AND FOLLOW THE WARNINGS AND INSTRUCTIONS FOR EACH SIKA PRODUCT AS SET FORTH IN THE CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET PRIOR TO PRODUCT USE.

C140

Construction

Compressive Properties (ASTM D-695) - Compressive Strength, psi (MPa)

	40°F* (4°C)	73°F* (23°C)	90°F* (32°C)
4 hour	-	-	5,500 (37.9)
8 hour	-	3,500 (24.1)	6,700 (46.2)
16 hour	-	6,700 (46.2)	7,400 (51.0)
1 day	750 (5.1)	7,800 (53.7)	7,800 (53.7)
3 day	6,800 (46.8)	8,300 (57.2)	8,300 (57.2)
7 day	8,000 (55.1)	8,600 (59.3)	8,600 (59.3)
14 day	8,500 (58.6)	8,600 (59.3)	8,900 (61.3)
28 day	8,500 (58.6)	8,600 (59.3)	9,000 (62.0)

Compressive Modulus **7 day** 3.9 x 10^5 psi (2,689 MPa)

*Material cured and tested at the temperatures indicated.

How to Use

Surface Preparation

The concrete surface should be prepared to a minimum concrete surface profile (CSP) 3 defined by the ICRI surface-profile chips. Localized out-of-plane variations, including form lines, should not exceed 1/32 in. (1 mm). Surface must be clean and sound. It may be dry or damp, but free of standing water and frost. Remove dust, laitance, grease, curing compounds, impregnations, waxes, foreign particles, disintegrated materials, and other bond inhibiting materials from the surface. Existing uneven surfaces must be filled with an appropriate repair mortar (e.g., Sikadur® 30 with the addition of 1 part oven-dried sand). The adhesive strength of the concrete must be verified after surface preparation by random pull-off testing (as defined by ACI 503R, ASTM C1583) at the discretion of the engineer. Minimum tensile strength, 200 psi (1.4 MPa) with concrete substrate failure.

Concrete - Blast clean, shot blast or use other approved mechanical means to provide an open roughened texture.

Steel - Should be cleaned and prepared thoroughly by blast cleaning to a white metal finish.

CarboDur® - Wipe clean with appropriate cleaner (e.g. MEK).

Mixing

Pre-mix each component. Proportion 1 part Component 'B' to 3 parts Component 'A' by volume into a clean pail or appropriately sized mixing container. Mix thoroughly for 3 minutes with Sika paddle on low-speed (400-600 rpm) drill until uniform in color. Mix only that quantity which can be used within its pot life.

To prepare an epoxy mortar: slowly add up to 1 part by loose volume of an oven-dried aggregate to 1 part of the mixed Sikadur® 30 and mix until uniform in consistency.

Application

For bonded, external reinforcement: Apply the neat mixed Sikadur® 30 onto the concrete with a trowel or spatula to a nominal thickness of 1/16" (1.5 mm). Apply the mixed Sikadur® 30 onto the CarboDur® laminate with a "roof-shaped" spatula to a nominal thickness of 1/16" (1.5 mm). Within the open time of the epoxy, depending on the temperature, place the CarboDur® laminate onto the concrete surface. Using a hard rubber roller, press the laminate into the epoxy resin until the adhesive is forced out on both sides. Remove excess adhesive. Glue line should not exceed 1/8 inch (3 mm). The external reinforcement must not be disturbed for a minimum of 24 hours. The epoxy will reach its design strength after 7 days.

For interior vertical and overhead patching: Work the material into the prepared substrate, filling the cavity. Strike off level. Lifts should not exceed 1 inch (25 mm).

Limitations

- Minimum substrate and ambient temperature is 40°F (4°C).
- Do not thin. Addition of solvents will prevent proper cure.
- Use oven-dried aggregate only.
- Maximum glue line of neat epoxy is 1/8 inch (3 mm).
- Maximum epoxy mortar thickness is 1 inch (25 mm) per lift.
- Minimum age of concrete must be 21-28 days, depending upon curing and drying conditions.
- Porous substrates must be tested for moisture vapor transmission prior to mortar applications.
- Not an aesthetic product. Color may alter due to variations in lighting and/or UV exposure.

PRIOR TO EACH USE OF ANY SIKA PRODUCT, THE USER MUST ALWAYS READ AND FOLLOW THE WARNINGS AND INSTRUCTIONS ON THE PRODUCT'S MOST CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET WHICH ARE AVAILABLE ONLINE AT HTTP://USA.SIKA.COM/ OR BY CALLING SIKA'S TECHNICAL SERVICE DEPARTMENT AT 800.933.7452 NOTHING CONTAINED IN ANY SIKA MATERIALS RELIEVES THE USER OF THE OBLIGATION TO READ AND FOLLOW THE WARNINGS AND INSTRUCTIONS FOR EACH SIKA PRODUCT AS SET FORTH IN THE CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET PRIOR TO PRODUCT USE.

KEEP CONTAINER TIGHTLY CLOSED. KEEP OUT OF REACH OF CHILDREN. NOT FOR INTERNAL CONSUMPTION. FOR INDUSTRIAL USE ONLY. FOR PROFESSIONAL USE ONLY.

For further information and advice regarding transportation, handling, storage and disposal of chemical products, users should refer to the actual Safety Data Sheets containing physical, ecological, toxicological and other safety related data. Read the current actual Safety Data Sheet before using the product. In case of emergency, call CHEMTREC at 1-800-424-9300, International 703-527-3887.

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17.3 Sika Injection 451

Construction

Product Data Sheet
Version No.: 06/10

Only to be applied by a Sika Approved Applicator

Sika® Injection-451

Low viscosity Epoxy Injection resin

Product Description	Sika® Injection-451 is a special solvent free, very low viscosity, high strength structural epoxy injection resin.
Uses	Sika® Injection-451 is suitable for closing, sealing and bridging of dry and damp cracks and cavities, where structural bond strength is required to restore structural integrity. It is suitable for use in concrete, brick and natural stone substrates, particularly in civil engineering structures, i.e. bridges, tunnels and shafts.
Characteristics / Advantages	• Very low viscosity (especially at low temperatures) • Very good adhesion on dry and damp surfaces in most mineral substrates (i.e. concrete, masonry and natural stone etc) • Excellent barrier against water infiltration and corrosion promoting media • Due to its low viscosity it can penetrates into cracks >0.2 mm in width • No subsequent shrinkage in dry conditions • Solvent-free
Approval / Standards	Tested and approved according to ZTV-ING (RISS)
Product Data	
Colours	Component A: Yellowish - Transparent Component B: Brownish
Packaging	Component A: 0.78 and 13.26 kg Component B: 0.22 and 3.74 kg
Storage Conditions / Shelf-Life	12 months from date of production if stored in unopened, undamaged original and sealed packaging, in dry conditions at temperatures between +5°C and 25°C.
Technical Data	
Chemical Base	Solvent free, 2-component Epoxy resin
Density	Component A: ~1.14 kg/l (at 20°C) Component B: ~0.87 kg/l (at 20°C)
Viscosity	Of Mixture: At +8°C: ~ 350 mPa·s At +15°C: ~ 180 mPa·s At +23°C: ~ 100 mPa·s At +35°C: ~ 70 mPa·s
Curing Time	Fully cured: 7 days (at +23°C)
Mechanical / Physical Properties	
Compressive Strength	70 -80 N/mm²
Tensile Strength	~50 N/mm²
Bond Strength	*On Water Saturated Concrete:* After 5 days storage in water: 2.6 N/mm² (failure in concrete)
System Information	
Application Conditions/ Limitations	
Substrate Preparation	Surfaces and cracks need to be clean, free of loose and friable particles, dust and any other bond-breaking substances. Any dirt must be blown out using clean compressed air.

Sika® Injection-451 1/3

Substrate Temperature	+8°C min. / +30°C max.
Ambient Temperature	+8°C min. / +30°C max.

Application Instructions

Mixing Ratio	78 : 22 parts by weight (refer to Application Instructions/Mixing)

Mixing

- The material is supplied in containers pre-batched according to the required mixing ratio of 78 : 22 parts by weight
- Empty components A and B completely into a mixing vessel and mix until homogeneous.
- When required, smaller quantities can be measured out and mixed in the correct proportions. The table below illustrates some different mixing ratios that may be convenient.
- Mix the components together thoroughly but without excessive aeration, using a low-speed mechanical stirrer (max 300 rpm) for at least 3 minutes until a fully homogeneous mixture is obtained. Make sure that the material on the container walls and bottom is also mixed in thoroughly (use a spatula or pour again into another clean container and remix).
- After mixing, fill the material into the pump's feed container, stir briefly and use **within the pot life**

Partial Unit Mixing Guidelines:

Component A by weight	Component B by weight	Component A + B mixed by weight
0.78 kg	0.22 kg	1.0 kg
3.00 kg	0.85 kg	3.85 kg
5.00 kg	1.41 kg	6.41 kg
8.00 kg	2.26 kg	10.26 kg
10.00 kg	2.82 kg	12.82 kg

Application Method / Tools

Injection pumps for single component products, such as Sika® Injection Pump EL-1, EL-2, Hand-1 or Hand-2.

Cleaning of Tools

Clean all tools and application equipment with Sika® Colma-Cleaner to remove any residue immediately after use. Do not leave Sika® Colma-Cleaner in the injection pump. Hardened/cured material can only be removed mechanically.

Potlife

(for 1kg)

+ 8°C	+ 10°C	+ 20°C	+ 30°C
~ 90 min	~ 80 min	~ 65 min	~ 10 min

The potlife is also dependent on the amount of material that has been mixed, higher volumes will decrease the potlife.

Once the pot life has elapsed, the material reacts very quickly with strong exothermic heat development including smoke generation.

Therefore, only mix that amount of material which can be used within the specified pot life.

Notes on Application / Limitations

The injection process is divided into three phases:

Injection:
The time during which the injected material under pressure flows from the pump to the desired moisture/water containing areas.

Induction:
The time from mixing until the reaction starts.

Reaction in dry or damp conditions:
The period during which the mix viscosity increases and the hardening process takes place

Construction

Value Base	All technical data stated in this Product Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.
Local Restrictions	Please note that as a result of specific local regulations the performance of this product may vary from country to country. Please consult the local Product Data Sheet for the exact description of the application fields.

Safety Instructions

Protective Measures	• Wear protective gloves and eye protection during work • A full Material Safety Data Sheet is available from Sika on request
Important Notes	• Residues of material must be removed according to local regulations. Fully cured material can be disposed of as household waste under agreement with the responsible local authorities. • Detailed health and safety information as well as detailed precautionary measures e.g. physical, toxicological and ecological data can be obtained from the safety data sheet.

Legal Notes

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17.4 Edilon Dex G 20

Productinformatieblad

edilon)(sedra Dex®-G type 20/40/80

1 OMSCHRIJVING

edilon)(sedra Dex-G is een hoogwaardig groutsysteem voor het duurzaam ondersabelen van machines en constructies onder zware dynamische mechanische belastingen. De uitstekende hechting op vochtige ondergronden en de hoge aanvangsdrukvastheid maakt dit groutsysteem bij uitstek geschikt voor toepassingen waar snelheid is geboden. Het **edilon)(sedra Dex-G** groutsysteem is beschikbaar in drie typen, waarbij de componenten zorgvuldig op elkaar afgestemd zijn.

edilon)(sedra Dex-G type 20 (2 componenten): aanbevolen voor giethoogtes van 0 – 20 mm.
edilon)(sedra Dex-G type 40 (3 componenten): aanbevolen voor giethoogtes van 20 – 40 mm.
edilon)(sedra Dex-G type 80 (3 componenten): aanbevolen voor giethoogtes van 40 – 80 mm.

Op verzoek:
edilon)(sedra Dex-G Fast kan worden geleverd door ons katalysatorpakket **edilon)(sedra Catalyst for Dex-G Component 4** toe te voegen.

2 TOEPASSING

edilon)(sedra Dex-G is speciaal geschikt voor het ondersabelen van machinefundaties, spoorconstructies, **edilon)(sedra EDF** rughellingplaten, lichtmasten etc. Andere toepassingen zijn het spanningsvrij verlijmen van ankerbouten, draadstangen, lasplaten en betonijzers, boutkoppen en ankerbussen in betonconstructies en / of het repareren van betonconstructies. edilon)(sedra Dex-G kan tevens gebruikt worden voor het verlijmen van staalplaten en strips aan beton en het verlijmen van **edilon)(sedra Resilient ERS Strips** in het **edilon)(sedra Embedded Rail System**.

3 KENMERKEN & VOORDELEN

Kenmerken	Voordelen
• Uitstekende hechting op vochtige en natte ondergronden	+ Gebruiksomstandigheden zijn nauwelijks kritisch + Ook in regenachtig weer toepasbaar + Onderwaterapplicaties zijn mogelijk
• Hoogwaardige mechanische eigenschappen • Uitstekende elektrische isolatie	+ Waarborgt ook onder zware en dynamische belastingen en perfecte verticale uitlijning van machines, constructies en spoorstaven + Goede vermoeiingsweerstand
• Zeer geringe volumetrische krimp	+ Grotere laagdiktes kunnen in één gieting worden aangebracht + Waarborgt een perfecte uitlijning
• Verpakt in nauwkeurig afgemeten en op elkaar afgestemde eenheden	+ Eenvoudige verwerking zonder weging + Altijd de juiste mengverhouding
• Lage viscositeit (Dex-G type 20)	+ Vereenvoudigt het gebruik in nauwe ruimtes + Bespaart kosten
• Uitermate bestand tegen olie en de meeste chemicaliën	+ Garandeert een duurzame ondersteuning en fixatie
• Goede bestendigheid tegen trillingen en dynamische belastingen	+ Bij uitstek geschikt voor ondersabelen van edilon)(sedra DFS rughellingplaten en van motoren

4 AANDACHTSPUNTEN

Aandachtspunt	Toelichting
• Voor een optimale hechting dienen de oppervlakken voorbehandeld te worden	• Betonnen oppervlakken met lossingsmiddelen en curing compounds kunnen een gereduceerde hechting tot gevolg hebben
• De standaard uithardingstijd van Dex-G is 24 uur	• Dex-G Fast heef een kortere uithardingstijd en wordt aangeraden om te gebruiken bij temperaturen tussen de +10 en + 25 °C

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edilon)(sedra

5 SAMENSTELLING

edilon)(sedra Dex-G is een oplosmiddelvrij zelfnivellerend groutsysteem op basis van speciale epoxyharsen en hoogwaardige minerale vulstoffen.

Raadpleeg voor meer informatie het **edilon)(sedra Dex-G Veiligheidsinformatieblad**.

6 VERPAKKING

Afhankelijk van het producttype wordt **edilon)(sedra Dex-G** geleverd in twee dan wel in drie afzonderlijk verpakte componenten; component 1 (hars), component 2 (harder) en eventueel component 3 (afgestemde hoeveelheid minerale vulstoffen).

Catalyst for Dex-G Component 4 is leverbaar in afzonderlijke flessen.

De standaard unitgrootte van **edilon)(sedra Dex-G type 20** is 2.5 en 10 kg product.
De standaard unitgrootte van **edilon)(sedra Dex-G type 40** is 15 kg product.
De standaard unitgrootte van **edilon)(sedra Dex-G type 80** is 20 kg product.

7 OPSLAG & HOUDBAARHEID

edilon)(sedra Dex-G dient in het magazijn en op de plaats van uitvoering droog, goed afgesloten en op een tegen de zon beschutte plaats te worden opgeslagen. De opslagtemperaturen dienen te liggen tussen de **+ 5 °C** en **+ 30 °C**.

In de originele goed afgesloten verpakking en onder de boven omschreven omstandigheden heeft **edilon)(sedra Dex-G** een houdbaarheid van maximaal **24** maanden.

8 CHEMISCHE & FYSISCHE EIGENSCHAPPEN

Dex-G type		20	40	80	
Eigenschap	**Norm**	**Waarde**	**Waarde**	**Waarde**	**Eenheid**
Dichtheid uitgehard product	ISO 1183-1-A	**1.61± 0.05**	**1.75 ± 0.05**	**1.90 ± 0.05**	g/cm³
Kleur gemengd product		**Grijs**	**Grijs**	**Grijs**	
Kleur component 1		**Beige**	**Beige**	**Beige**	
Kleur component 2		**Zwart**	**Zwart**	**Zwart**	
Kleur component 3		**–**	**Beige**	**Beige**	
Viscositeit component 3 bij + 25 °C	ISO 3219	**–**	**–**	**–**	Pa·s
Viscositeit gemengd product (1+2) bij + 25 °C	ISO 3219	**11**	**11**	**11**	Pa·s
Mengverhouding in gewicht component 1 : component 2		**100 : 20.05**	**100 : 20.05**	**100 : 20.05**	
Mengverhouding in gewicht gemend product (1+2) : component 3		**–**	**100 : 50**	**100 : 100**	
Verwerkingstijd bij + 25 °C (viscositeit 200 Pa·s)	ISO 10364	**30**	**30**	**35**	minuten
Warmtegeleidbaarheid λ10 – λ40 tussen + 10 °C en + 40 °C	EN12667	**0.430**	**–**	**–**	W/(m.K)
Volumeweerstand	DIN VDE 0100-610 DIN VDE 0303-30 (IEC 60093)	> **1000 (Droog)** > **1000 (Nat) (0.1 N NaCl)**			MΩm

- Proefstukken zijn gemaakt door beide componenten grondig te mengen.
- Testresultaten zijn bepaald met uitgehard product na 7 dagen bij een temperatuur van + 23 °C, tenzij anders aangegeven.
- De toegepaste proefstukken en testmethoden kunnen worden gewijzigd zonder voorafgaande kennisgeving.

Productinformatieblad
edilon)(sedra Dex-G

Referentie: **DATA Dex-G (NL) 070504 rev 09**
Pagina: 2 van 7

edilon)(sedra

9 MECHANISCHE EIGENSCHAPPEN

Dex-G type		20	40	80	
Eigenschap	**Norm**	**Waarde**	**Waarde**	**Waarde**	**Eenheid**
Buigtreksterkte Proefstukafmetingen: 40 x 40 x 160 mm	EN 196-1	56.7	30.8	32.7	MPa
Druksterkte Proefstukafmetingen: 100 x 100 x 40 mm	Op basis van EN 196-1	> 90	> 126	> 140	MPa
Elasticiteitsmodulus	ISO 178	> 4500			MPa
Afschuifsterkte	ASTM D1002	> 15			MPa
Buigsterkte	ISO 178	> 39			MPa
Rubberhardheid na 24 uur	ISO 7619-1	75 ± 5			Shore D
Rubberhardheid na 7 dagen	ISO 7619-1	80 ± 5			Shore D
Oppervlakteslijtageweerstand (TWA)	ISO 9352	< 440			µl / 1000 omw.
Hechtsterkte op staal (S235 JR Sa 2.5)	ISO 4624	> 35			MPa
Hechtsterkte op beton (droog)	EN 1542	> 1.5 (betonbreuk)			MPa
Hechtsterkte op beton (vochtigheid 6%)					
Hechtsterkte op beton (onder water)					

- Proefstukken zijn gemaakt door beide componenten grondig te mengen.
- Testresultaten zijn bepaald met uitgehard product na 7 dagen bij een temperatuur van + 23 °C, tenzij anders aangegeven.
- De toegepaste proefstukken en testmethoden kunnen worden gewijzigd zonder voorafgaande kennisgeving.

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10 OPPERVLAKTE-VOORBEHANDELING

De duurzaamheid van het systeem waarin **edilon)(sedra Dex-G** toegepast is, is direct afhankelijk van de kwaliteit van de oppervlaktevoorbehandeling vlak voor toepassing. Voor een optimale hechting dienen de oppervlakken in ieder geval schoon te zijn.

edilon)(sedra Dex-G dient direct na het voorbehandelen van de oppervlakken aangebracht te worden.

Betonnen oppervlakken:
Ten aanzien van betonnen oppervlakken zijn de volgende eisen van toepassing:

- Minimaal C20/25 kwaliteit volgens EN 206
- Ten minste 7 dagen oud
- Aanhechtsterkte betonnen oppervlak > 1.5 MPa volgens EN 1542

Voor het verkrijgen van een optimale hechting aan betonnen oppervlakken dient te allen tijde het betonnen oppervlak voorbehandeld te worden. Het betonnen oppervlak dient te worden ontdaan van de cementhuid, curing compound, lossingmiddelen en vervuilingen zoals olie, vuil en vet. Geschikte methodes hiervoor zijn straalreiniging (droog of nat) en slijpen.

Na voorbehandeling dient het oppervlak ontdaan te worden van losse deeltjes en stof.

ATTENTIE: Het gebruik van curing compound en lossingsmiddelen bij betonnen oppervlakken kan een zeer sterk reducerend effect hebben op de hechtingseigenschappen van edilon)(sedra Dex-G.

Reparatiemortel:
Voor het verkrijgen van een optimale hechting aan reparatiemortel gelden dezelfde eisen en voorbehandeling als voor betonnen oppervlakken.

Stalen oppervlakken:
Voor het verkrijgen van een optimale hechting aan stalen oppervlakken dient het oppervlak te allen tijde voorbehandeld te worden. Losse deeltjes, stof, vuil, walshuid, roest en andere verontreinigen moeten worden verwijderd. In het geval van thermisch verzinkte oppervlakken dient het oppervlak tevens vrij te zijn van zinkzouten.

ATTENTIE: Zo snel mogelijk na het voorbehandelen dienen stalen oppervlakken te worden voorzien van edilon)(sedra Dex-G. Stalen oppervlakken dienen volledig droog te zijn voordat de applicatie wordt uitgevoerd. Om in de tijd tussen de voorbehandeling en het aanbrengen van de edilon)(sedra Dex-G roestvorming van het oppervlak te voorkomen, dient het oppervlak droog opgeslagen te worden.

- **Onbehandeld staal:**
  Straalreinigen tot minimale reinheidsgraad Sa 2.5 volgens EN ISO 8501-1.
  Het oppervlak dient een ruwheid Rz te hebben van 50-70 µm.
- **Thermisch verzinkt staal:**
  Aanstralen met een niet-metallisch straalmiddel volgens NEN 5254.

11 GEBRUIKERS-INSTRUCTIES

Raadpleeg voor uitgebreide gebruiksinstructies het **edilon)(sedra Dex-G Gebruikersinstructieblad** en de **edilon)(sedra Installatie Instructies** die van toepassing zijn.

edilon)(sedra

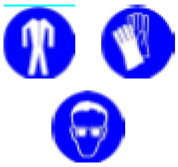
12 VERWERKINGSCONDITIES

Condities	Waarde	Opmerkingen
Oppervlak	**Droog – nat, schoon**	Pas het product alleen toe op voorbehandelde oppervlakken (zie sectie 11). Visueel te bepalen.
Omgeving[1)]	**Droog – nat**	
Relatieve luchtvochtigheid	**Geen beperking**	
Oppervlaktetemperatuur	**+ 5 °C tot + 45 °C**	Geldt voor ieder oppervlak waarop product wordt toegepast. Bij licht bewolkt en zonnig weer is de oppervlaktetemperatuur altijd hoger dan de luchttemperatuur door stralingswarmte van de zon
Producttemperatuur	**+ 15 °C tot + 30 °C**	

- Aanbevolen meetapparatuur: TQC DewCheck of Elcometer 319s

1) **Uitzondering: het hechten van de Resilient Strip in de ERS-goot dient onder droge omstandigheden te gebeuren.**

13 VEILIGHEIDS-MAATREGELEN



Bij het verwerken van **edilon)(sedra Dex-G** dienen de volgende veiligheidsmaatregelen in acht te worden genomen: het dragen van beschermende kleding, rubberhandschoenen en een veiligheidsbril.

Zorg bij de verwerking van **edilon)(sedra Dex-G** voor voldoende ventilatie.

Raadpleeg voor meer gedetailleerde veiligheidsinformatie betreffende de verwerking van **edilon)(sedra Dex-G** het verpakkingsetiket en het **edilon)(sedra Dex-G Veiligheidsinformatieblad**.

edilon)(sedra Dex-G dient opgeslagen te worden in de originele goed afgesloten verpakking.

14 MENGEN

Schud vóór het mengen Component 2 gedurende **1** minuut intensief en giet de volledige inhoud langzaam bij Component 1. Indien **edilon)(sedra Catalyst for Dex-G Component 4** gebruikt wordt, giet dan eerst de inhoud van een flesje in de Component 1 alvorens te mengen met Component 2.

Voor het mengen van **edilon)(sedra Dex-G type 20/40** kan het **edilon)(sedra ediMix 14 mobiele mengstation** worden ingezet. Meng het product twee keer.

Bij **edilon)(sedra Dex-G type 20/40/80** kunnen beide componenten grondig met behulp van een elektrische handmenger gedurende **2** minuten worden gemengd. Hierbij beweegt men de menger in de verpakking heen en weer om zo een homogene grijskleurige massa te verkrijgen.

Voor toepassing van **edilon)(sedra Dex-G type 40/80** dienen Component 1 en 2 eerst gemengd te worden zoals hierboven is beschreven. Voeg daarna de afgepaste hoeveelheid Component 3 langzaam toe. Alle componenten dienen tenslotte nog gedurende **1** minuut te worden gemengd met de ediMix 14 (voor Dex-G type 40) of met de elektrische handmenger (voor Dex-G type 80) tot een homogene massa verkregen is.

Ter bescherming van de edilon)(sedra ediMix14 mobiele mengstations tegen overbelasting, en ter verbetering van de gieteigenschappen, wordt geadviseerd om beide componenten bij een producttemperatuur tussen **+ 15 °C** en **+ 30 °C** te mengen.

Raadpleeg het **edilon)(sedra ediMix 14 Gebruikersinstructieblad** voor gedetailleerde informatie over het gebruik.

Specificaties	Handmenger
Type	Handboormachine of vergelijkbaar
Mengpropeller	edilon)(sedra WK 90
Vermogen	400 W
Snelheid	400-500 tpm
Geschikt voor:	
Dex-G type	**20, 40, 80**

Productinformatieblad
edilon)(sedra Dex-G

Referentie: DATA Dex-G (NL) 070504 rev 09
Pagina: 5 van 7

edilon)(sedra

15 VERWERKINGSTIJD

De verwerkingstijd van **edilon)(sedra Dex-G** is afhankelijk van de producttemperatuur en het gemengde volume.

Onderstaande tabel toont de verwerkingstijd met en zonder toevoeging van **edilon)(sedra Catalyst for Dex-G Component 4 (Dex-G 20 Fast)**.

Producttemperatuur (°C)	Verwerkingstijd Dex-G 20 (minuten)	Verwerkingstijd Dex-G 20 Fast (minuten)
15	40	26
20	35	18
25	30	-
30	20	-

16 UITHARDEN

De minimale uithardingduur van **edilon)(sedra Dex-G** wordt gerelateerd aan de oppervlaktetemperatuur.

Onderstaande tabel toont de uithardingstijden met en zonder toevoeging van **edilon)(sedra Catalyst for Dex-G Component 4 (Dex-G Fast)**.

Oppervlaktetemperatuur (°C)	Uithardingstijd Dex-G 20 (uren)	Uithardingstijd Dex-G 20 Fast (uren)
10	24	10
15	16	7
20	12	3
25	9	2
30 – 45	5	2

17 REINIGING

Gereedschappen dienen direct na gebruik schoon gemaakt te worden met **edilon)(sedra Toolcleaner**. Raadpleeg vóór gebruik eerst het **edilon)(sedra Toolcleaner Veiligheidsinformatieblad**.

18 VERWIJDERINGS-AANBEVELINGEN

De volgende afvalproducten kunnen ontstaan bij verwerken van **edilon)(sedra Dex-G**:

Omschrijving	Soort afval	Afvalcode
Uitgehard product	Geen gevaarlijk afval	-
Verpakking met uitgehard product	Geen gevaarlijk afval	-
Verpakking met component 1 of component 2	Gevaarlijk afval	15 01 10
Verpakking met component 3	Geen gevaarlijk afval	-
Verpakking met component 4	Gevaarlijk afval	15 01 10
Verpakking met niet uitgehard product	Gevaarlijk afval	15 01 10

De afvalproducten dienen met inachtneming van de voorschriften van de plaatselijke instanties in een daarvoor geschikte installatie te worden verbrand of dienen te worden afgevoerd volgens de voorschriften van de Europese Afvalstoffenlijst (EURAL).

19 KLEURBESTENDIGHEID

De kleur van **edilon)(sedra Dex-G** kan veranderen doordat omgevingsinvloeden (chemicaliën, hoge temperaturen, uv-straling) op het materiaal inwerken. Deze kleurveranderingen aan het oppervlak hebben een geringe invloed op de mechanische eigenschappen van het productoppervlak.

Productinformatieblad
edilon)(sedra Dex-G

Referentie: **DATA Dex-G (NL) 070504 rev 09**
Pagina: 6 van 7

edilon)(sedra

070504 rev 08/2004-0404REC15/0314 **Datum uitgifte: 12-03-2014**

Vertaling gebaseerd op het originele edilon)(sedra document (EN) 070704 rev 09

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17.5 Edilon Dex R 2K

Productinformatieblad

edilon)(sedra

EDILON Dex®-R 2K

1 OMSCHRIJVING

0620
edilon)(sedra bv 06
0620-CPD-43262/02
ETA–06/0272
ETAG 0001-5 – Optie 7
M12 – M30

EDILON Dex-R 2K is een CE gecertificeerd, hoogwaardige professionele ankerlijm voor het spanningsvrij verlijmen van constructieve ankers in beton, waarvoor de product goedkeuringsrichtlijn ETAG No.001, part 5 – "Bonded anchors", optie 7 van kracht is.

De **EDILON Dex-R 2K** is toegelaten op basis van diamant geboorde gaten en is geschikt voor het verlijmen van standaard metrische draadeinden in droge, natte en met watergevulde boorgaten.

EDILON Dex-R 2K is een twee componenten oplosmiddel- en styreenvrije ankerlijm, verpakt in een dubbele kokerverpakking van 600 ml en kan worden verwerkt met hand, pneumatische of accu kokerpistolen voor 2K kokers.
Voor iedere applicatie een passende verwerkingsoplossing.

2 TOEPASSING

EDILON Dex-R 2K kent als universeel ankerlijm systeem veel toepassingen in de bouw, spoorbouw en industrie ten behoeve van het structureel en constructief verlijmen van draadeinden, wapeningsstaven, speciale ankerbouten, boutkoppen en ankerbussen in beton.

EDILON Dex-R 2K is geschikt voor het structureel verlijmen van veel verschillende soorten materialen zoals; staal, beton, natuursteen, prefab bouwelementen, enz., waarbij op ondergronden van beton en staal een hoge aanhechtsterkte wordt gerealiseerd.

EDILON Dex-R 2K is speciaal geschikt voor toepassingen onder extreme omstandigheden die in de bouw voorkomen en waarbij het verwerkingsgemak wordt gekoppeld aan een hoge plaatsingsbetrouwbaarheid en een goede duurzaamheid.

3 KENMERKEN & VOORDELEN

Kenmerken	Voordelen
• ETA goedkeuring • Product conformiteitsverklaring AoC-level 1 volgens KIWA EC conformiteitscertificaat 0620–CPD–43262/02	+ Speciaal voor diamant geboorde gaten een goedgekeurd ETAG ankerproduct + Productprestaties en productkwaliteit zijn geborgd
• Hoge plaatsingsbetrouwbaarheid • Spanningsvrij verankeren van betonconstructies • Uitstekende hechting in droge, natte en in water gevulde boorgaten	+ Lage partiële veiligheidsfactor γ_2 = 1,0 + Productprestaties ongeëvenaard + Hoge rekenwaardes + Geschikt voor zeer zware belastbaarheid
• Toepasbaar op vochtige ondergronden • Geschikt voor gebruik in met water gevulde boorgaten • Toegelaten in diamant geboorde gaten	+ Gebruiksomstandigheden zijn niet kritisch + Ook in regenachtig weer toepasbaar + Onderwater applicaties zijn mogelijk + Bespaart tijd
• Geen speciale ankers nodig • Standaard metrische draadeinden met 3.1 certificaat zijn toepasbaar • Geschikt voor horizontale en verticale boorgaten • Ruime boorgat maattoleranties mogelijk • Geschikt voor doorsteek en voorsteek montage • Ook wapeningsstaven en afwijkende ankertypen kunnen eenvoudig worden verlijmd	+ Breed inzetbaar + Biedt een hoge mate van flexibiliteit + Ruime beschikbaarheid van verschillende kwaliteiten draadeinden + Universeel toepasbaar + Bespaart kosten
• Hoogwaardige mechanische eigenschappen • Uitstekende elektrische isolatie • Ultermate resistent tegen olie en de meeste chemicaliën • Zeer geringe volumetrische krimp	+ Garandeert een goede duurzaamheid + Beperkt risico's spanningscorrosie + Goede vermoeiingsweerstand eigenschappen + Verankering in grote gatdiameters en diepe boorgaten ook mogelijk
• Vrij van oplosmiddelen • Reukloos • Bevat hoogwaardige vulstoffen	+ Bevat geen schadelijke styreenachtige stoffen + Goede verwerkbaarheid + Lange houdbaarheid

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Kenmerken	Voordelen
• Twee componenten kokerverpakking • Hoogwaardige statische mengtuit • Gebruiksvriendelijke, schone, veilige en snelle verwerkingsmethode • Vrijwel geen materiaalverlies	+ Direct verwerkbaar + Altijd een perfecte menging + Verhoogt de productiviteit + Aangebroken kokers ook na langere tijd herbruikbaar met een nieuwe statische mengtuit + Zeer economisch, lage kosten per boorgat

4 AANDACHTSPUNTEN

Aandachtspunt	Toelichting
• Verankeringstoepassingen die buiten de ETAG richtlijn vallen, dienen per toepassing te worden beoordeeld door een deskundig constructeur	• Voor constructieve verankeringen in beton mogen uitsluitend ETA goedkeurde producten gebruikt te worden
• In hoge betonsterkte klassen bijv. C50/60 dienen diamant geboorde boorgat wanden te worden opgeruwd voor optimale prestaties	• In het geval van hoge betonsterkte klassen wordt de boorgat wand als het ware glad gepolijst bij het diamant boren

5 SAMENSTELLING

EDILON Dex-R 2K is een oplosmiddelvrij twee componenten lijmsysteem op basis van speciaal samengestelde epoxy harsen en hoogwaardige minerale vulstoffen.

Raadpleeg voor meer informatie het **EDILON Dex-R 2K Veiligheidsinformatieblad.**

6 PRODUCTTOELATING

ETA CE 0620
edilon)(sedra bv 06
0620-CPD-43262/02
ETA–06/0272
ETAG 0001-5 – Optie 7
M12 – M30

EDILON Dex-R 2K European Technical Approval – **ETA-06/0272**

Europese productgoedkeuring met EC conformiteitscertificaat 0620-CPD-43262/01 op basis van de ETAG richtlijn No.001, part 5 – "Bonded anchors" volgens optie 7.

Goedkeuringstesten zijn uitgevoerd op met diamant geboorde gaten in niet gescheurd beton met minimale sterkteklasse C20/25 en maximale sterkteklasse C50/60.

Geteste ankerdiameters M12, M16, M20, M24 en M30 met inlijmdieptes tussen 8.d en 12.d.

Gebruikscategorie 2 – droog en nat beton en in met water gevulde boorgaten.

7 VERPAKKING

EDILON Dex-R 2K wordt geleverd in een twee componenten 600 ml dubbele kokerverpakking, waarbij de mengverhoudingen op elkaar zijn afgestemd.

EDILON Dex-R 2K wordt in de 600 ml kokerverpakking standaard geleverd in een omverpakking van 14 units inclusief 14 statische mengers en injectie slangetjes (195 mm).

8 OPSLAG & HOUDBAARHEID

EDILON Dex-R 2K dient in het magazijn en op de plaats van uitvoering droog, goed afgesloten en op een tegen de zon beschutte plaats te worden opgeslagen. De opslagtemperaturen dient te liggen tussen de **+ 10 °C** en **+ 30 °C**.

In de originele goed afgesloten verpakking en onder de bovenstaand omschreven omstandigheden heeft **EDILON Dex-R 2K**een houdbaarheid van maximaal **18** maanden.

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9 CHEMISCHE & FYSISCHE EIGENSCHAPPEN

Eigenschap	Norm	Waarde	Eenheid	Opmerkingen
Dichtheid uitgehard product	ISO 1183-1-A	1.47 ± 0.05	g/cm³	
Kleur gemengd product		Donker grijs		
Kleur component 1		Licht beige		
Kleur component 2		Zwart		
Viscositeit component 1 bij +23°C	ISO 3219	30	Pa.s	
Viscositeit component 2 bij +23°C	ISO 3219	41	Pa.s	
Viscositeit gemengd product bij +25°C	ISO 3219	35	Pa.s	Gemeten na 2 minuten
Mengverhouding in gewicht component 1 : component 2		100 : 124		
Mengverhouding in volume Component 1 : component 2		100 : 100		
Reactiviteit bij +23°C	ISO 10364	9	minuten	
Specifieke elektrische oppervlakteweerstand	UIC 864-5	> 1×10^6 > 1×10^5	MΩ	Droog Nat
Specifieke elektrische doorslagweerstand	UIC 864-5	> 100.000 > 100	MΩ.m	Droog Nat

- Testresultaten zijn bepaald met uitgehard product na 7 dagen bij +23 °C, tenzij anders aangegeven.
- De toegepaste proefstukken en testmethoden kunnen gewijzigd worden zonder verdere mededelingen.

10 MECHANISCHE EIGENSCHAPPEN

Eigenschap	Norm	Waarde	Eenheid	Opmerkingen
Treksterkte	ISO 527	> 35	MPa	
Elasticiteit modulus	ISO 178	4 900	MPa	
Buigsterkte	ISO 178	> 80	MPa	
Afschuif sterkte	ASTM D1002	> 10	MPa	
Druksterkte na 24 uur	ISO 604	> 100	MPa	
Druksterkte na 7 dagen	ISO 604	> 120	MPa	
Treksterkte staal	NEN ISO 6922	> 25	MPa	
Enkelvoudige Lapnaad sterkte	ASTM D1002	> 10	MPa	
Enkelvoudige Lapnaad sterkte – dik proefstuk Staal S235JR – Sa2.5	SNCF CT IGEV 602A	> 22	MPa	Lijmoppervlak 20 x 30 mm, onder drukbelasting SNCF eis > 19 MPa
Hardheid na 24 uur	ISO 7619-1	85 ± 5	Shore D	
Hardheid na 7 dagen	ISO 7619-1	85 ± 5	Shore D	
Lineaire krimp	edilon M012	Niet waarneembaar		
Hechteigenschappen staal (St.37-2, Sa 2.5)	ISO 4624	> 35	MPa	
Hechteigenschappen beton (C35/45)	ISO 4624	> 5	MPa	Cohesiebreuk beton

- Testresultaten zijn bepaald met uitgehard product na 7 dagen bij van +23 °C, tenzij anders aangegeven.
- De toegepaste proefstukken en testmethoden kunnen gewijzigd worden zonder verdere mededelingen.

Productinformatieblad
EDILON Dex-R 2K

Referentie: DATA Dex-R 2K (NL) 070209 rev 09
Pagina: 3 van 7

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11 ETA PLAATSINGS-GEGEVENS

De onderstaande plaatsingsgegevens van de **EDILON Dex-R 2K** zijn ontleend aan ETA goedkeuringsdocument ETA-06/0272 en gelden voor:

- Diamant geboorde gaten
- Ongescheurd beton met minimale betonkwaliteit C20/25 en C50/60 maximum
- Gebruikscategorie 2 (droog, nat en met water gevulde boorgaten)
- Standaard metrische draadeinden van koolstof staal met staalkwaliteit 4.6 t/m 12.9 en roestvast staal soorten
- Geen beperking door rand- en/of of hart-op-hart afstanden
- Partiële veiligheidsfactor voor plaatsingsgevoeligheid γ_2 = 1,0

ETA-06/0272		standaard			Minimum			maximum		
	d_0 (mm)	h_{ef} (mm)	$N^0_{Rk,c}$ (kN)	N_{Sd} (kN)	h_{ef} (mm)	$N^0_{Rk,c}$ (kN)	N_{Sd} (kN)	h_{ef} (mm)	$N^0_{Rk,c}$ (kN)	N_{Sd} (kN)
M12	16	120	40	**26,7**	95	30	**20,0**	150	50	**33,3**
M16	20	150	60	**40,0**	125	50	**33,3**	180	75	**50,0**
M20	24	180	75	**50,0**	160	60	**40,0**	230	95	**63,3**
M24	28	230	115	**76,7**	190	95	**63,3**	280	140	**93,3**
M30	34	270	170	**113,3**	240	140	**93,3**	330	200	**133,3**

- d_0 = boorgatdiameter
- h_{ef} = effectieve plaatsingsdiepte (standaard, minimum, maximum)
- $N^0_{Rk,c}$ = karakteristieke sterkte C20/25 beton
- N_{Sd} = rekenwaarde trekkracht met γ_{Mc} = 1,5

Verhogingsfactor voor niet-gescheurd beton			
Betonsterkte klasse	**C30/37**	**C40/50**	**C50/60**
Ψ_c	1.14	1.26	1.33

Voor het berekenen van de eigenschappen van ankergroepen en ankers onder invloed van rand- en/of of hart-op-hart afstanden wordt verwezen naar de CUR 25 aanbeveling tweede herziene versie. In de CUR 25 aanbeveling is de anker berekeningsmethodiek overgenomen, die door de European Organisation of Technical Approvals is vastgelegd in de European Technical Appproval Guideline No. 001 voor "Ankers in beton".
Conform de richtlijnen in de ETAG No. 001 wordt door edilon)(sedra voor de anker plaatsingsdiepte een bereik van 8 –12 x anker diameter gehanteerd. In het geval van plaatsingsgegevens die afwijken van de ETA dient men deskundig advies in te winnen.

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12 TOEPASSINGS-GEGEVENS en GEBRUIKSADVIES

Bij toepassing van **EDILON Dex-R 2K** dienen betonnen ondergronden voldoende sterkte bereikt te hebben ten behoeve van de constructieve toepassing.
Ten aanzien van betonnen ondergronden, zijn de volgende specificaties van (nieuw) gestorte betonvlakken in constructieve toepassingen vereist:

- Minimaal C20/25 kwaliteit volgens EN 206
- Tenminste 7 dagen oud
- Aanhechtsterkte betonoppervlak > 1.5 MPa volgens EN1542

Boorgaten dienen conform (bestek-) tekening te worden geboord.
Reiniging van alle boorgaten door: 3x borstelen en 3x uitblazen.
Borstelen met een kunststof borstel en uitblazen met olievrije perslucht dmv een perslucht pistool met een uitblaasopening van minimaal 3 mm diameter.
De verwerkingstijd en de minimale uithardingduur van **EDILON Dex-R 2K** zijn afhankelijk van de producttemperatuur en het gemengde volume. De tabel geeft een indicatie van de verwerkingstijd van het product bij verschillende producttemperaturen. De minimale uithardingduur van **EDILON Dex-R 2K** wordt gerelateerd aan de oppervlaktetemperatuur.

Producttemperatuur [°C]	Verwerkingstijd [min]	Uithardingstijd [uur]
5 - 10	30	48
10 - 20	20	24
20 - 35	5	24

Raadpleeg voor een uitgebreide verwerkingsinstructies het **EDILON Dex-R 2K Gebruikersinstructieblad**.

13 ETA INSTALLATIE GEGEVENS

De onderstaande installatiegegevens van de **EDILON Dex-R 2K** zijn ontleend aan ETA goedkeuringsdocument ETA-06/0272.

ETA-06/0272				Standaard			Minimum			Maximum		
	d_0 (mm)	d_{fix} (mm)	T_{inst} (Nm)	s_{min} (mm)	c_{min} (mm)	h_{min} (mm)	s_{min} (mm)	c_{min} (mm)	h_{min} (mm)	s_{min} (mm)	c_{min} (mm)	h_{min} (mm)
M12	16	14	40	60	60	150	50	50	125	75	75	180
M16	20	18	100	75	75	180	65	65	155	90	90	210
M20	24	22	180	90	90	220	80	80	200	115	115	270
M24	28	26	300	115	115	280	95	95	240	140	140	330
M30	34	33	500	135	135	330	120	120	300	165	165	390

- d_0 = boorgat diameter
- d_{fix} = gatdiameter in bevestigingsplaat
- T_{inst} = Aandraaimoment voor draadeinden klasse 8.8–12.9
- s_{min} = minimale anker hart-op-hart afstand
- c_{min} = minimale anker randafstand
- h_{min} = minimale beton bouwdeeldikte

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14 VERBRUIKS-GEGEVENS

Met één 600 ml 2 componenten kokerverpakking **EDILON Dex-R 2K** ankerlijm kunnen maximaal de onderstaande aantallen ankers worden verlijmd volgens de algemene plaatsingscondities.

Metrisch draadeind		Standaard		Minimum		Maximum	
	d_0 (mm)	h_{ef} (mm)	n_{std}	h_{ef} (mm)	n_{min}	h_{ef} (mm)	n_{max}
M12	16	120	46	95	58	150	37
M16	20	150	28	125	33	180	23
M20	24	180	18	160	20	230	14
M24	28	230	11	190	14	280	9
M30	34	270	7	240	8	330	6

- d_0 = boorgat diameter
- h_{ef} = effectieve plaatsingsdiepte (standaard, minimum, maximum)
- n = aantal ankers per 600 ml kokerverpakking (boorgat wordt niet volledig gevuld)

N.B.: Berekening verbruiksgegevens zonder verliezen en zonder anker / boorgat toleranties

Wapeningsstaaf FeB 500	d_{rib} (mm)	d_0 (mm)	h_{ef} 20xd (mm)	n_{20xd}	h_{ef} 25xd (mm)	n_{25xd}
ø10	11.5	14	200	39	250	31
ø12	13.5	16	240	28	360	22
ø14	14	18	280	21	350	17
ø16	18	20	320	16	400	13
ø20	23	25	400	10	500	8
ø25	28.5	30	500	5	625	4
ø28	32	35	560	3	700	2
ø32	36	40	640	2	800	1.5

- d_0 = boorgat diameter
- d_{rib} = uitwendige rib diameter (rib diameters kunnen variëren tgv nationale normen en producenten)
- h_{ef} = effectieve plaatsingsdiepte – voorbeeld plaatsingsdiepte = 20 x staaf diameter / 25 x staaf diameter
- n_{20xd} = aantal ankers per 600 ml kokerverpakking (boorgat hoeft niet volledig gevuld te worden)

N.B.: Berekening verbruiksgegevens zonder verliezen en zonder anker / boorgat toleranties

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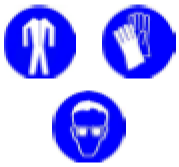
15 VEILIGHEIDS-MAATREGELEN



Bij het verwerken van **EDILON Dex-R 2K** dienen de volgende beschermende maatregelen in acht te worden genomen: het dragen van beschermende kleding, handschoenen en het dragen van een veiligheidsbril. Zorg bij de verwerking van EDILON Dex-R 2K voor voldoende ventilatie.

Raadpleeg voor meer gedetailleerde veiligheidsinformatie betreffende de verwerking van **EDILON Dex-R 2K**het verpakkingsetiket en het **EDILON Dex-R 2K Veiligheids informatieblad**.

EDILON Dex-R 2K dient opgeslagen te worden in de originele verpakking.

16 REINIGING

Gereedschappen dienen direct na gebruik schoon gemaakt te worden met **EDILON Tool Cleaner**. Raadpleeg voor gebruik het **EDILON Tool Cleaner Veiligheidsinformatieblad**.

17 VERWIJDERINGS-AANBEVELINGEN

De volgende afvalproducten kunnen ontstaan bij verwerken van **EDILON Dex-R 2K**:

Omschrijving	Soort afval	Afvalcode
Uitgehard product	Geen gevaarlijk afval	-
Verpakking met uitgehard product	Geen gevaarlijk afval	-
Verpakking met component 1 of component 2	Gevaarlijk afval	15 01 10
Verpakking met niet uitgehard product	Gevaarlijk afval	15 01 10

De afvalproducten dienen met inachtneming van de voorschriften van de plaatselijke instanties in een daarvoor geschikte installatie te worden verbrand of dienen afgevoerd te worden volgens de voorschriften van de Europese Afvalstoffenlijst (EURAL).

18 PRODUCTADVIES
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Voorafgaand aan de keuze voor **EDILON Dex-R 2K** wordt geadviseerd om contact op te nemen met edilon)(sedra om verder advies te krijgen bij uw toepassing. Tevens kunt u gebruik maken van onze jarenlange ervaring in het ontwerpen en toepassen van edilon)(sedra producten.

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