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SOME OBSERVATIONS ON C.O.D.-TESTING (WITH PARTICULAR REFERENCE TO IIW-DOC. X-901-78)

by Prof.ir. J.J.W. Nibbering*

Part I.

1. Introduction.

C.O.D.-testing has become a rather established procedure for estimating the fracture toughness of materials under static load conditions. As always occurs, the test has its merits and shortcomings.
In this paper it will be shown that most of the latter either are less important than often is suggested or are due to unsuitable, but easily to change, items of the test-procedure. Simplifications are possible and will render the test more acceptable both from a practical and a theoretical point of view. One point to be discussed is the accuracy of the $C.O.D._{tip}$ when calculated from a measurement made at some distance of the tip. Another one is the usual treatment of welded specimens prior to fatigue-loading in order to get rid of the residual stresses (side-compression). In between observations will be made which stand against statements given in IIW-doc. X-901-78 prepared by a French Working Group /1/.

2. Test specimen and test procedure.

In principle the C.O.D.-test is simple, straight-forward and - from a theoretical point of view - sound.
But the test procedure given in /2/ is complex, not well defined and concerns types of specimens ill-suited for the purpose.

2.1. The first shortcoming of the Standard /2/ is that the dimensions of specimens and the depths of notches are not specified in a unique way. As far as the writer can see there is hardly never need of a "subsidiary" type of specimen. It should be left out of the Standard or be only admitted in well-defined exceptional cases.

2.2. Weak defining occurs also with respect to the depth of the notches: 0.45 W - 0.55 W or even "by agreement".
The inclusion of Table I with a range of a/W from 0.1 to 0.7 (!) is confusing. It may tempt people to choose depths of notches far too small. On the other hand, it will be argued in 3 that a notch depth of 0.5 W is much too large. It impairs the accuracy of the test result without need.

2.3. In section 6 "Test procedure" the required fatigue-loading is indicated in a manner which is not easily understood by people less familiar with fracture mechanics.
What everybody knows about is the bending formula $\sigma = \frac{M}{W}$.
When one would calculate the nominal stress-value in the notched section (net-section) of the preferential specimen (a/W = 0.5) for $K_f \leq 0.63.\sigma_y.\sqrt{B}$ (see 6,1,1, in /2/) the result would be $M/W_{net} \rightarrow \sigma_y$ $((W_{net} = 1/6\ B.(1/2\ W)^2)$.

Now first of all this is a really high value, which might give rise to crack-blunting. On the other hand it has the advantage that the effect of eventual residual welding stresses on fatigue-cracking will become

* Delft and Ghent University.

negligible. (Of course in that case σ_y should be the yield point of the weld metal!).
If we keep the loading as above ($M = W_{net} \times \sigma_y$) the K_f-value will be different for different notch depths. Then the question emerges why not only one (or two at the maximum) notch depths has been stipulated. Theoretically there is little ground for coupling notch depth to plate thickness. From a practical point of view one might argue that the thicker a plate, the bigger the risk that certain defects and cracks escape N.D.T.-inspection.
But for a fracture-mechanics test this is inconsequent reasoning.
For, the C.O.D.-value found in the test should be used as a basis for calculating critical crack lengths for the structures under consideration. When there is a need for large critical crack lengths, because of unapproachable structural details, or inadequate N.D.Testing, the required critical C.O.D.-values should be taken larger accordingly.

2.4. Stable crack development should rather be looked upon as a favourable phenomenon. In a way it is comparable to plastic zone formation. Both phenomena lead to relaxation of stresses in structures. Parts of the load will be shirked to other places in redundant structures. Apart from that, the C.O.D.-test is concerned with the danger of initiation of brittle fracture in steel. In case of ductile tearing crack length and not C.O.D. is the obvious parameter. The Standard /2/ should be more straight-forward on this point.
A more difficult phenomenon is "pop-in" or arrested brittle cracking. In welds or H.A.Zones it should always be considered as a favourable event. It proves that, although at a weak spot of the weld a brittle crack may start, the general toughness of the weld is good enough to arrest a running brittle crack. There is one condition: the load on the specimen at pop-in should be high (at least $M \geq W_{net} \times \sigma_y$) in order to be sure that the crack does not arrest as a consequence of load relaxation.

3. A closer look to specimen configuration.

In /2/ the preferred depth of the notch a in relation to width of specimen W is $a/W \simeq 0.5$. As $W \simeq 2B$ this results in a notch depth equal to plate thickness. In 2.3 it has already been argued that a standard depth is desirable. This combined with a standard width would eliminate some of the before mentioned complications.
Nobody will deny that C.O.D.-testing is particularly relevant for thick plates. (Below 25 mm thickness the Charpy-test will do rather well for quality control). This means that the notches in C.O.D.-specimens according to /2/ will often be very deep. This, combined with the fact that the notch tip is situated at half width, leads to great inaccuracies when the C.O.D.-tip is calculated on the basis of measured C.O.D. at the edge of the specimen. First of all the smaller the distance a between measured C.O.D. (V_g) and C.O.D.-tip (δ) in relation to the distance between measured C.O.D. and point of zero deformation (R), the greater the accuracy of δ, (Figs. 1 and 2).

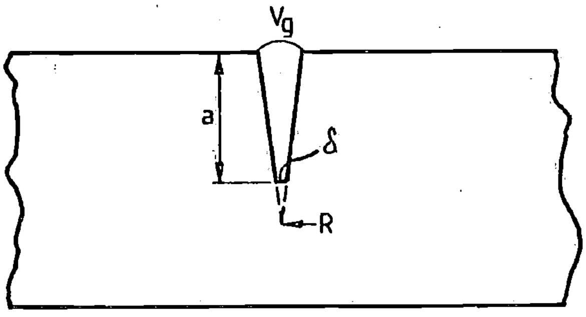


Fig.1

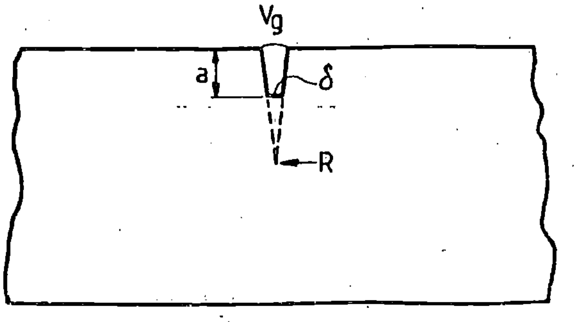


Fig.2

For, when a becomes zero, δ becomes equal to V_g.
But more important is that the calculation of δ in terms of V_g depends very much on the position of R in the left case and little in the right case. Now the deeper the notch the more the position of R will shift during the test when the situation changes from elastic, to elasto-plastic and fully plastic.
Finally the material at the tip of a shallow notch will be loaded more in conformity with what will occur in practice, than that at the tip of a deep notch (stretching instead of jackknifing).

It is thought that at the maximum two types of specimens are necessary.
For: $t \leqq 40$ mm: $a = 10$ mm
$W = 75$ mm

$t \geqq 40$ mm: $a = 20$ mm
$W = 100$ mm.

In the Delft Ship Structures Laboratory C.O.D.-measurements are often made as in Fig. 3 with a dial gauge. The notch preparation takes somewhat more work, but it allows a measurement close to the notch tip.
The clip gauges (Fig. 4) are also different from what is recommended in /2/. The reliability is high, and the gauges are cheap. The supports of the gauges are only connected to the specimen immediately adjacent of the notch where the material is unstressed. Measuring with a dial gauge is a good method for people in industry where analog recorders are not always available.
In laboratories the combination of a dial gauge with a "bridge" gauge allows a very accurate estimate of the rotation point R (Fig. 1).

4. The French document IIW X-901-78.

With the foregoing a good deal of the critical observations given in the French document /1/ have been put aside. Most surprising in that document is that the Charpy-V-test is presented as the "better" substitute.
In the I.I.W. the shortcomings of that procedure - especially for thick welded plates made with a number of runs - have been repeatedly put forward in many committees. One could perhaps agree to accept the test when screening over the whole thickness is carried out - which means quite a number of Charpy-bars - provided that the lowest energy-values of the bars meet a high requirement. Averageing of results is absolutely unreliable.

For the time being a lot of arguments with respect to the C.O.D.-tests could be postponed by looking at the results in terms of transition temperature. For, many scatter problems mentioned in connection to C.O.D.-testing stem from the fact that the minimum required values are often situated in the transition range of the material. But for very thick plates the solution will lead to relatively higher critical temperatures than for thinner plates because the transitions occur at higher C.O.D.'s. (The explanation is that the transition temperature depends also on the transition from plane strain to plane stress).

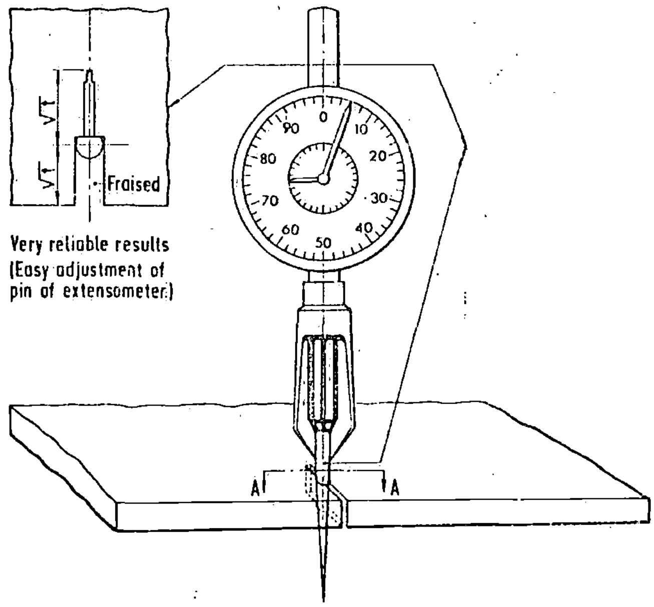
Another procedure in which the advantage of full-plate thickness in the C.O.D.-testing is maintained and which avoids the problem of calculating a critical crack-length from C.O.D., is fatigue-loading at low temperature /3/. It has the additional advantage that as many points of the specimen are tested, as there are numbers of cycles.

Literature.

/1/ 'Étude critique de la méthode de l'écartement de fissure (C.O.D.)'. IIW-doc. X-901-78, May 1978, presented by French Delegation.

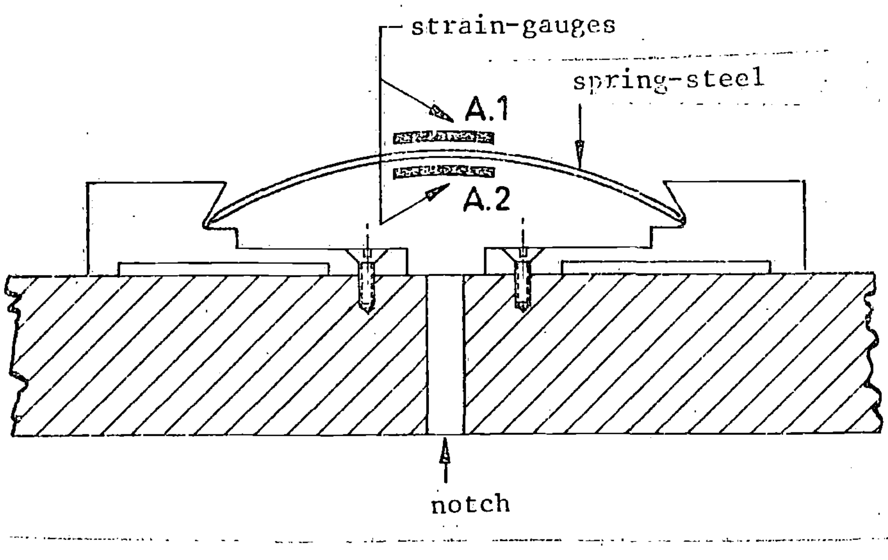
/2/ 'Methods for Crack opening displacement (COD) testing'. British Standards Institution, BS 5762: 1979.

/3/ Final report of IIW Working Group 2912 'Brittle fracture tests for weld metal'. Welding in the World, Vol. 13, No. 7/8, 1975.



Fraised
Very reliable results
(Easy adjustment of
pin of extensometer)
A
A

Fig. 3.



strain-gauges
spring-steel
A.1
A.2
notch

Fig. 4.