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Important Aspects of Testing Welds

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Abstract. In the treatise presented, the fracture toughness testing of weldments is the matter. Consideration is primarily focused on the effect on testing specific microstructural zones, and elimination of residual stress influences on toughness measurement. Further, the effect of definite weld characteristics on interpretation of test outcomes is surveyed embracing statistical effects appearing from material in homogeneity.

Introduction

Material discontinuities and defects affect weldments adversely. It can extremely influence their mechanical uprightness [1]. A listing of distinct kinds of weld imperfections is presented by the weld quality standards. These consist of rather different defects as arc strikes, cracks, inclusions, lack of fusion, misalignment, porosity, undercuts and additions that can be fixed to diverse ranges:

- Cracks and crack – like imperfections (ie hot and cold cracks, lack of fusion, incomplete penetration, et cetera) that must be prevented or – if they appear – are directly subject to fracture mechanics analysis.
- Geometric discontinuities that increase the local stresses (eg misalignment such as angular distortion or undercuts). This type of defects inclusive of welding residual stresses, may influence crack initiation and crack growth, too, and end failure.
- Material imperfections that function as crack initiation areas (ie slag inclusions), being eminent importance for fatigue life analyses and fatigue strength.
- Imperfections which evidently have no influence on fatigue life and fracture (eg porosity in low stress part of the constituent).

Doing experiments with weld parts

Requisite considerations and parameters for an appropriate role of the test specimens are, as follows: welding process including filler material, base metal composition, joint thickness, preheat and interpass temperatures, heat input, detailed welding procedure, joint configuration, restraint, post-weld treatment, time between welding and testing, environment, test temperature.

Fatigue testing results in state of affairs that the fracture toughness can be crucially dependent on the foregoing factors. Some knowledge of the influences of the miscellaneous parameters is essential so as to achieve conservative limits in testing and constructional assessment. Sometimes hydrogen release heat handling must be realized prior to testing in order to assure same levels of hydrogen in the structure. That is made vital when the period between welding and service beginning is much longer than this between welding and testing.

For specimen preparing, the purpose is to stipulate the fracture toughness as regards of crack initiation or propagating (R – curve) for a precise target region, for example the weld centre line, the heat affected zone, at cetera (marked as weld positional, WP) and / or specific microstructure, eg, coarse grained heat affected zone (marked as SM). Occasionally, eg for narrow laser and electron beam welds, electro – discharge machining with thin diameter wire should be applied for inserting the notch. The example for specific microstructure (SM) notch placing is introduced in Table 1 [2].

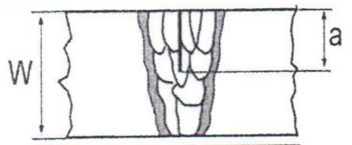
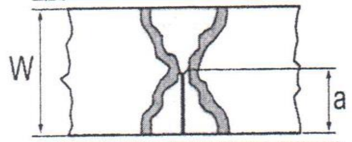
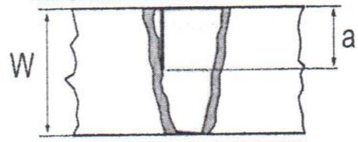
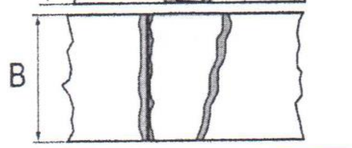
	Specimen orientation	Specimen geometry
	NQ	$B \times B$
	NQ	$B \times B$
	NQ	$B \times B$
	NP	$B \times B$ or $B \times 2B$

Table 1. Specific microstructure notch location, according to [2]

Pre – cracking

Prior to fatigue pre – cracking, it might be essential to adapt the welding residual stresses in specimen prior to testing. There are two incentives for that:

(i) In a fracture mechanics study, the residual stresses are taken into account when calculating the crack driving force in the constituent [1], [3]. From this standpoint, it would be perfect to totally take away the residual stresses in the test specimen.

(ii) As the welding residual stresses demonstrate inhomogeneous pattern through the section, they may affect fatigue crack growth like that the pre – crack front will develop an irregular form.

Even though the residual stresses are partially alleviated and redistributed owing to the extraction of the specimen and the insertion of the crack beginning notch, the remaining residual stresses could be large enough to affect the form of the pre – crack front and the issues of the fracture toughness so as to prevent this, diverse approaches are suggested for the handling of test specimens prior to or in course of pre – cracking (Fig. 1).

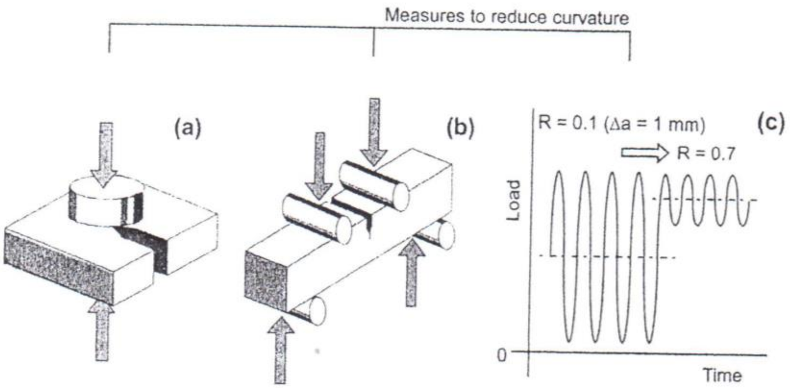


Fig. 1. Methods proposed for redistributing residual stresses prior to and during pre-cracking [1]

Statistical profile of HAZ toughness

Being a result of the scatter in the fracture toughness of weldments and in part of heat affected zone cracks, the definite statistical treatment becomes imperative. As a rule, that is based on the weakest link guiding principle and applies a three - parameter Weibull distribution fit, though even other types of mathematical distributions are used. The so – called VTT – Master Curve procedure included in the test standard ASTM E 1921 is often employed. This particularizes the aforementioned distribution of many replicate test results in the form

$$P = 1 - \exp\left\{-\left[\frac{(K_{mat} - K_{\min})}{K_0 - K_{\min}}\right]^m\right\} \quad (1)$$

where P the failure probability of the test specimens, K_{mat} the fracture toughness via the K factor, K_0 the scale parameter, $K_{\min}$ the shift parameter and m the shape parameter of the distribution. The coefficients K_0, $K_{\min}$ and m are fit parameters, still in the Master Curve concept two these are fixed. For ferritic steels with yield strengths between σ_Y = 275 and 825 MPa, the shape parameter is given by m = 4 and the shift parameter by $K_{\min}$ = 20 MPa $m^{1/2}$. The toughness K_{mat}, is formally specified from the critical J integral, J_{mat}, or CTOD, Δ_{mat}, by the relation

$$K_{mat} = \sqrt{J_{mat} \cdot E/(1 - \nu^2)} \quad (2)$$

or

$$K_{mat} = \sqrt{\beta \cdot \delta_{mat} \cdot \sigma_Y \cdot E/(1 - \nu^2)} \quad (3)$$

where E means Young`s modulus, $\nu$ being Poison`s ratio and β constraint factor that is conservatively chosen as $\beta = 1.5$ for steels with a strain hardening coefficient $N \geq 0.05$. The impact of the material inhomogeneity on statistical treatment is ilustrated in Fig. 2.

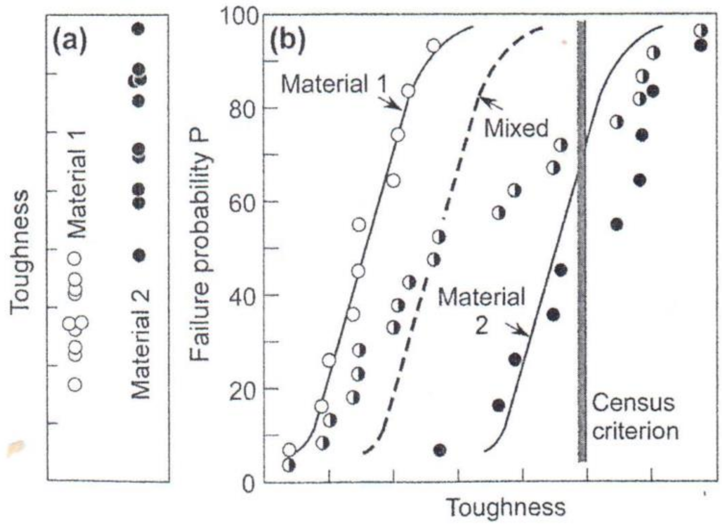


Fig. 2. Ilustration of the mixture effect of two materials with different toughness on the usual toughness distribution applying the censoring criterion [1]

Fatigue crack growth qualities

About the interrelation between fatigue crack, strength mismatch and welding residual stresses it is familiar the opinion that the welding residual stresses are important for fatigue crack propagation owing to their influence on the stress ratio R (= $\sigma_{min}/\sigma_{max}$ or K_{min}/K_{max}). Compressive residual stresses decrease and tensile residual stresses increase the R ratio. The varying residual stress profiles in another zones of the weldment such as the weld centre line or the fusion line are respected liable for crack propagation rates both faster and slower compared with the base metal while the different microstructures of base metal, weld metal and heat affected zone appear to play a minor part in the regime of the $da/dN – \Delta K$ curve. On the contrary, the near threshold range of the curves seems to be more influenced.

The R – ratio is regarded at the crack driving force part of the component rather than at the material part. Residual stresses and strength mismatch have also an influence on the crack tip constraint, and it is known that such effects might play a part in the threshold and lower ranges of the $da/dN – \Delta K$ curves. In a recent investigation on a thermomechanically treated steel used in ship – building was founded the trend indicated in Fig. 3 [4].

Such as, Jones at al examined non – welded C (T) and M (T) samples of aircraft steel, austenitic ductile iron, cast steel and rail steel rigorously and discovered the crack growth rate not only influenced by the cyclic stress intensity factor range, ΔK and the R – ratio still also by the crack length that is an obvious indication of constraint effects.

Conclusion

1. Characteristics in addition to conventional testing are the possibility of notch location choosing in connection with pre – and – post test metallography and the possible necessity for modifying the residual stress state before or during pre – cracking.
2. Usually, no pre – treatment of the specimens is required for welds that have been post weld heat treated for the aims of stress relief. The pre – treatment is also frequently unnecessary for surface notched (B x B) specimens. The ISO test standards

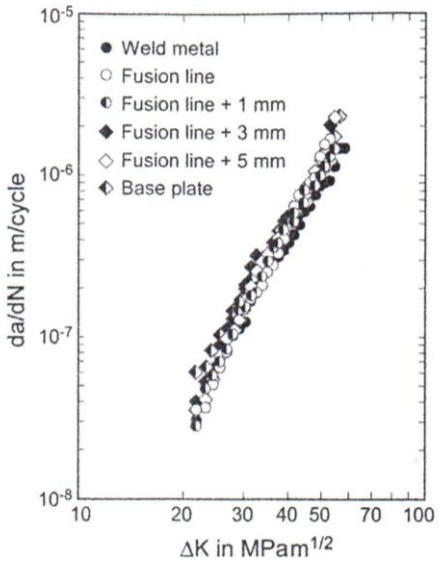


Fig. 3. Range *da/dN* – *ΔK* particulars for base metal, weld metal and HAZ, *R*= 0 [4]

recommend the application of the shortest fatigue crack length authorized in the basic document ISO 12135 to minimize crack front curving and crack deviation, too, from the specified crack zone. If shallow notched specimens are used, ie $a_0/W < 0.45$ ISO 15 653 affords solutions for *J* and CTOD in that the plastic factor solution, η_p , is based on crack mouth opening displacement gained from *J* analyses. These solutions hold for $0.1 < a/W < 0.45$.

3. A minimum of 12 specimens essential for statistical describing the HAZ toughness of structural steels with yield limit up to 450 MPa in the ductile – brittle transition range is announced in BS 7910. Supplementary tests can be necessary to fulfil the metallographical validation criteria. These demands may be released prominently, if the HAZ shows upper shelf behaviour. After revision, the stated standard will incorporate the SINTAP/FITNET procedure as a choice when analyzing fracture toughness outcomes from welds. As the procedure is based on weakest link statistics, the fracture toughness inferred will be a function of crack front length in the structural element being appraised.
4. Some authors did not find any statistically substantial differences in the *da/dN* – *ΔK* despite of differences in materials strength, welding methods and *R* ratio and even variable versus constant amplitude loading can be a result of the high tensile residual stresses in the weld centre. That would have maintained the crack open in course of the complete loading cycle such which no crack closure appeared that could have been influenced by aforementioned considerations.

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