Constraint Effect on Fracture Behaviour on Strength Mis-matched Weld Joints

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ABSTRACT: *The differences in mechanical properties amongst different welded joints' regions obviously affect the strain distribution around the crack tip during the fracture test and, hence, influence the toughness value. The strength mis-match and width of welded joint have an effect on the stress-strain distribution in the vicinity of the crack tip. Both can contribute to a higher constraint in the weld metal. It was found that the width of the welded joint as constraint parameter has an effect on the limit load, maximum load and achieved fracture toughness values of a welded joint. In the case of strength overmatched welded joints, the limit and maximum loads increase with constraint (welded joint width) decrease. On the contrary, in the case of strength under-match welded joints the limit and maximum loads decrease and the constraint (welded joint width) decreases.*

INTRODUCTION

The integrity of welded structures depends on the load carrying capacities of their welded joints. Hence, today a number of engineering approaches are being developed, with the aim of ensuring the safe service of welded structures. These methods are based on fracture toughness testing. The differences in mechanical properties amongst different weld joints' regions obviously affect the strain distribution around the crack tip during the fracture test and, hence influence the toughness value. The strength mis-match and the width of a welded joint have an effect on the stress-strain distribution in the vicinity of the crack tip, because both can contribute to a higher constraint in the weld metal. The aim of the work performed was an estimation of the constraint effect on fracture behaviour of over and under-matched welded joints. Different levels of constraint effect on fracture toughness were achieved by using different widths of welded joints.

MATERIALS AND WELDING

A high strength low alloyed HSLA steel (t=30 mm), corresponding to the grade HT50, was used as the base metal (BM) in a quenched and tempered condition (Q+T). The welding preparation for the X- grooved multipass welded joints is shown in figure 1. The Flux Cored Arc Welding process (FCAW), with 82% Ar + 18% CO_2 as shielding gas, was used and two different consumables were selected. The first one ensured global overmatching with the weld metal, denoted by OM, and second one ensured global under-matching with the weld metal, denoted by UM. Three different over-matched and under-matched welded joints were produced with three different weld metal widths (2H=6, 12 and 18 mm) as shown in Table 1. The cooling times from 800° to 500°C (? $t_{8/5}$) were approximately 9secs, with heat inputs 1.8-2.0 MJm^{-1}, whilst the preheating/inter-pass temperature was 100°C.

The mechanical properties, Table 2, of the welds were determined by round tensile specimens (d_0=? 5mm), extracted from the root and the cap region of the X-groove welds in a longitudinal direction. The chemical compositions of the base metal and both the weld metals are listed in Table 3.

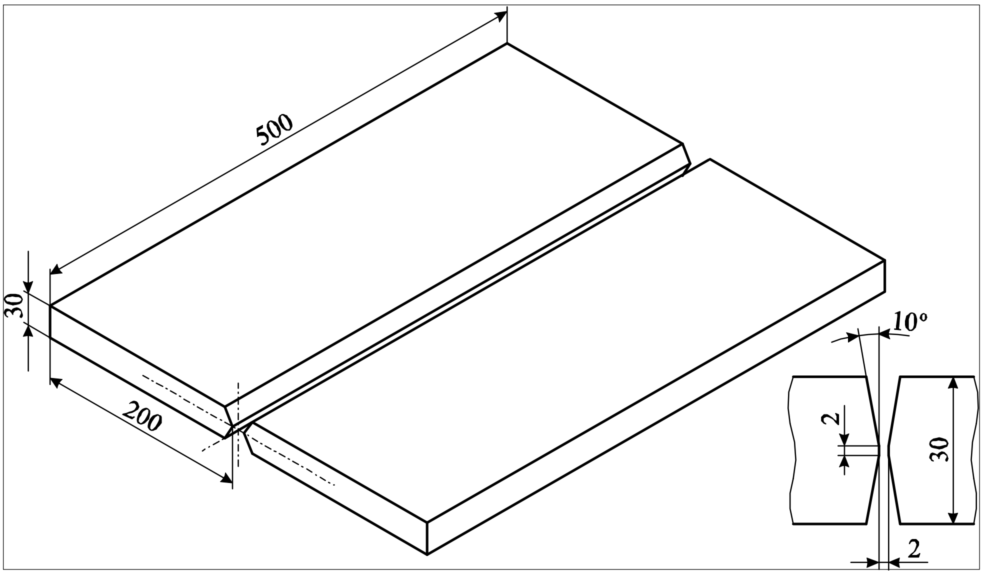


Figure 1: Welding preparation

TABLE 1: Overview of tested configuration of over- and under-matched welded joints with notch position in the centre of the weld metal symmetry

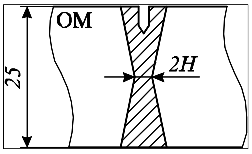
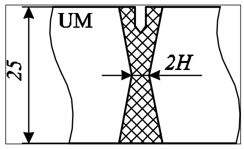
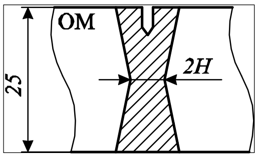
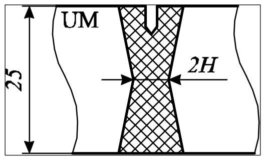
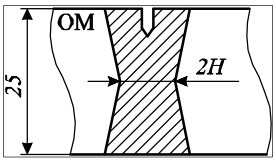
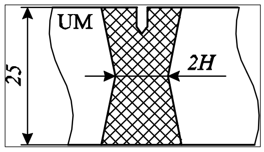
Weld metal width	OM over-matched weld joint	UM under-matched weld joint
A (2H=5..9)		
B (2H=10..14)		
C (2H=16..20)		

TABLE 2: Mechanical properties of base metal and weld metals at room temperature

Material	E GPa	$R_{p0,2}$ MPa	R_m MPa	M $R_{p0,2}/R_m$	Charpy Cv $J/80mm^2$
Overmatching	183.8	648	744	1.19	111, 92, 98 at +26°C 52, 51, 42 at -50°C
Base metal	202.9	545	648	-	122, 134, 137 at +26°C 55, 47, 42 at -50°C
Undermatching	206.7	469	590	0.86	99, 98, 92 at +26°C 44, 34, 40 at -50°C

TABLE 3: Chemical composition of base metal and consumable in weight percentages

Material	C	Si	Mn	P	S	Cr	Mo	Ni
FILTUB	0,040	0,16	0,95	0,011	0,021	0,49	0,42	2,06
NIOMOL	0,123	0,33	0,56	0,003	0,002	0,57	0,34	0,13
VAC 60	0,096	0,58	1,24	0,013	0,160	0,07	0,02	0,03

EXPERIMENTAL PROCEDURE

The single edge notched bend (SENB) specimens were used for estimation of the fracture behaviour of the different welded joints' widths, Figure 2. Two groups of specimens with crack tip in the symmetry line of the weld metal were tested, one with surface notch and one with through-thickness notch. The specimens were fatigue pre-cracked in accordance with BS 7448 ?1?. The fatigue pre-crack length was the same *a/W=0.32* for all specimens. The testing temperature was room temperature +26?C and the single specimen method was used. The DC potential drop technique was applied for stable crack growth monitoring. The CTOD values were directly measured with a $?_5$ clip gauge, developed by GKSS ?2?. The measuring points were marked on the specimen surface, Figure 2.
Figures 3.a) and 3.b) show the plots normal load (F/F_{YM}) vs. CTOD($?_5$), for over- and under-matched weld metals, respectively. Note, that Figure 3 shows only one typical example of the specimens' fracture behaviour for each weld width A, B, C listed in Table 1. Since the toughness is high at room temperature the differences between shallow notched and through-thickness notched specimens are insignificant (see the Charpy impact toughness listed in Table 2).
The limit load FYM was determined according to ETM-MM 96 [3] for the crack along the weld metal.

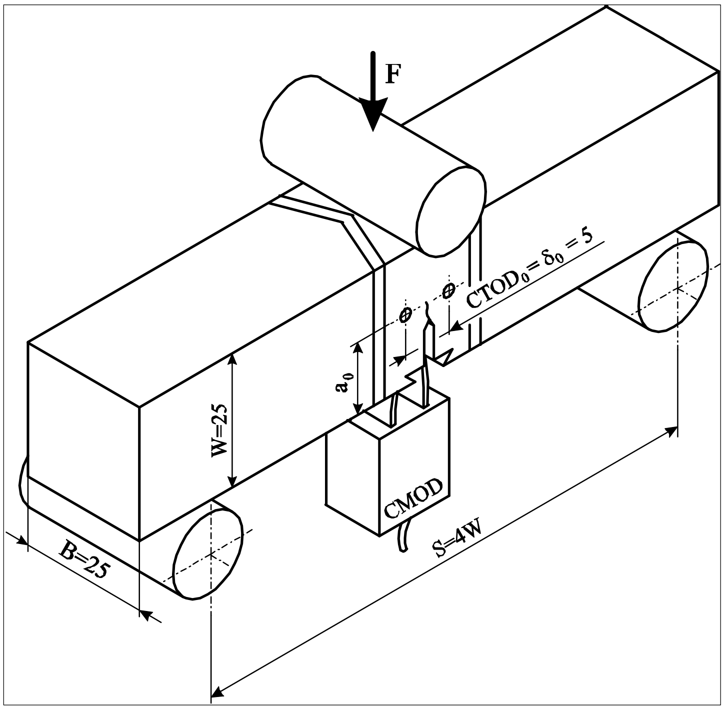
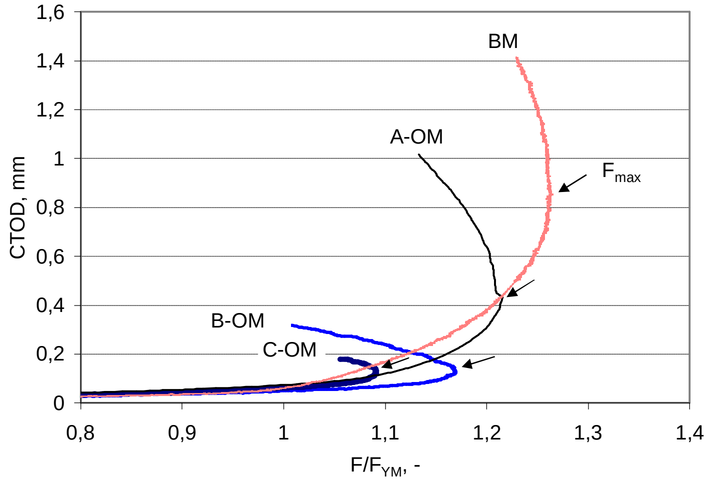
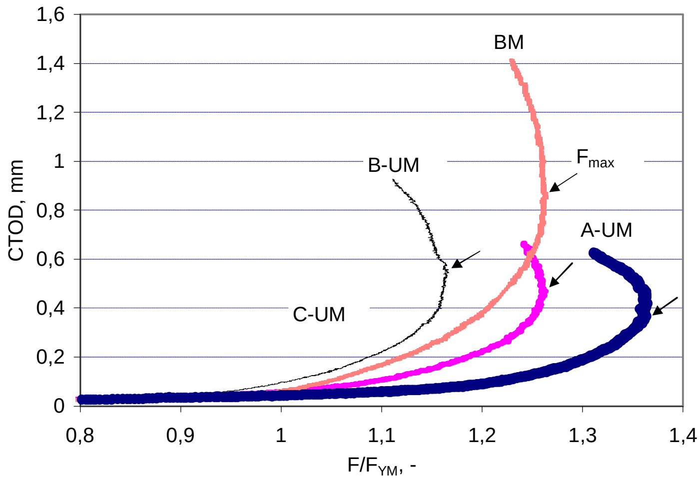


Figure 2: CTOD fracture toughness specimen.



a) overmatched weld joints



b) under-matched welded joints

Figure 3: Crack driving force curves obtained during test.

ANALYSIS AND DISCUSSION

Figure 3.a) shows lower load capacity (F/F_{YM}) and lower $CTOD(?_5)$ values for the overmatched weld joint than the base metal (BM). The maximum load capacities (F/F_{YM}) and $CTOD(?_5)_m$ decrease by increasing the width of weld metal. In the case of the under-matched weld metal, Figure 3.b), the maximum load capacities F/F_{YM} and $CTOD(?_5)_m$ are strongly related to the

current width of the weld metal. Therefore, in the case of a narrow under-matched weld joint (A-UM) a higher load capacity F/F_{YM} is achieved than in the case of base metal (BM). The maximum load capacity decreases by increasing the width of the weld metal. The main difference between the over and under-matched welded joints' Crack driving force-CDF curves is the behaviour at the maximum sustained load F_{max}. Thus in the case of an overmatched weld joint, the loading capacity significantly decreases, more than in the case of an under-matched welded joint. This event is more pronounced by increasing the relative width of the overmatched weld metal, and vice versa in the case of the under-matched weld metal. Since, the $CTOD(?_5)_m$ values at maximum sustainable load F_{max} of both weld metals are lower than the $CTOD(?_5)_m$ value of the base metal, one can concluded that the effect of the base metal on the yielding and hardening plays an important role in the fracture behaviour of the specimen. In this experimental testing of the bend specimens were conducted with over- and under-matched welded joints of different widths and numerical crack propagation analyses using the cohesive zone model of these specimens.

Figure 4 shows the equivalent stress (von Mises) distribution at maximum sustainable load F_{max} for each specimen. In the case of the overmatched welded joint the yielding portion of the base metal decreases by increasing the width of the weld metal, meanwhile in the case of the under-matched welded joint the yielded portion of the base metal slightly increases. Therefore, the yielding of the base metal enables higher deformation at maximum sustainable load F_{max} for an under-matched welded joint.

Figure 5 shows the equivalent strain at maximum sustainable load F_{max} for each specimen. In both cases the reduction of base metal deformation appeared by increasing the width of the weld metal. In the case of the overmatched welded joint, this event causes reduction of deformation and consequently the decreasing of CTOD fracture toughness value. Meanwhile in the case of the under-matched welded joint, the higher portion of soft weld metal contributed to higher CTOD values. Therefore, lower constraint is achieved:

-at overmatched welded joint with narrow weld metal gap and

-at under-matched welded joint with broad weld metal gap.

CONCLUSION

It was found that the width of the welded joint as a constraint parameter has an effect on the limit load, maximum load and achieved fracture toughness values of a welded joint. In the case of strength overmatched weld joints, the limit and maximum loads increase with constraint (weld joint width) decrease. On the contrary, in the case of a strength under-match welded joint the limit and maximum loads decrease and constraint (weld joint width) increases. On the basis of the work performed and introduction of correction term, it is possible to explain fracture path and behaviour deviations during the fracture processes of the welded joint.

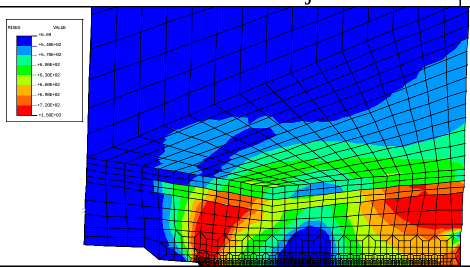
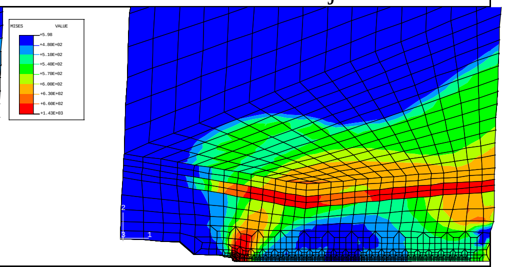
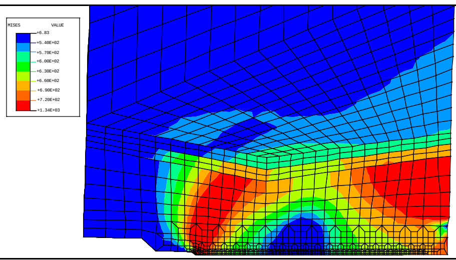
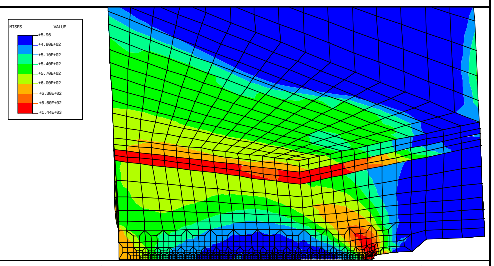
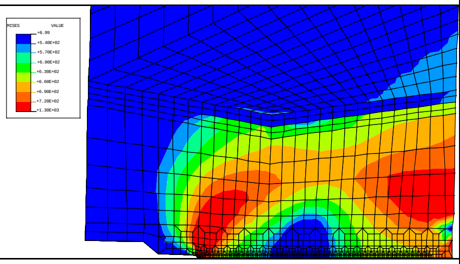
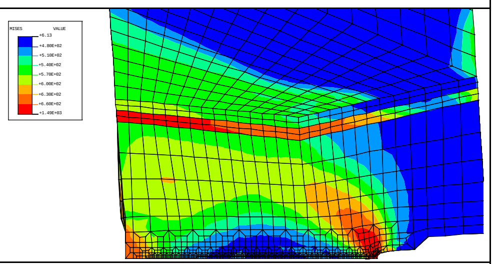
	Overmatch welded joint	Undermatch welded joint
A		
	Yield of weld metal with penetrating to the base metal	Significant yield penetration to the base metal
B		
	Small yield penetration to the base metal. Most yield confined to the weld metal	Yield of the weld metal with significant penetration to the base metal
C		
	Yield confined to the weld metal	Significant yield of the weld meal with penetrating to the base metal

Figure 4: Equivalent stress (von Mises) distribution at F_{max}

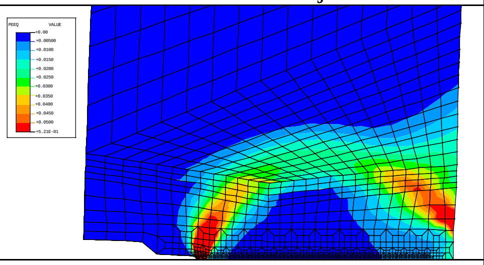
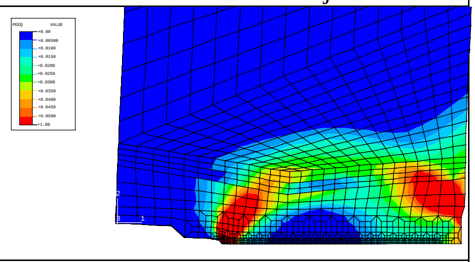
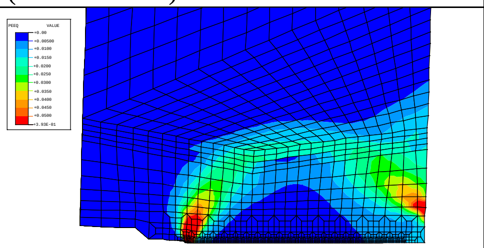
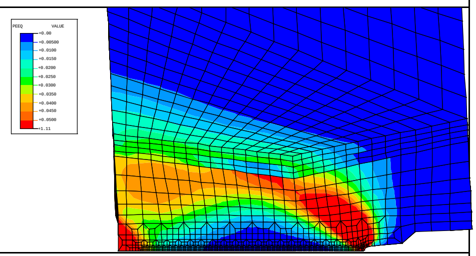
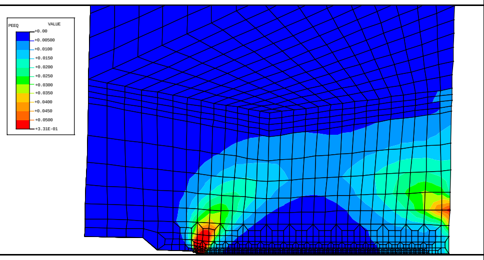
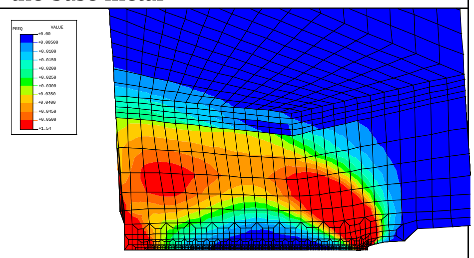
	Overmatched weld joint	Under-matched weld joint
A		
	Deformation penetration to the base metal (low constraint)	Deformation penetration to the base metal
B		
	Reduction to deformation penetration to the base metal	Reduction to deformation penetration to the base metal
C		
	Deformation confined at crack tip, no effect on base metal	Deformation confined to the weld metal (low constraint)

Figure 5: Equivalent stress (von Mises) distribution at F_{max}

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