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An Investigation of the Weld Region of the SAE 1020 Joined with Metal Active Gas and Determination of the Mismatch Factor

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In this study, the joining process of SAE 1020 low carbon steel, generally used in the industry, has been completed using the metal active gas (MAG) weld method. The goal of this study was to examine the mismatch between base and weld metal. After the joining process, mechanical properties of the samples of the base metal (BM), the heat affected zone (HAZ), and the weld metal (WM) were investigated, and the crack tip opening displacement (CTOD) test was performed.

Keywords crack tip opening displacement, low carbon steel, metal active gas, mismatch, welding

1. Introduction

The mechanical properties of base metal (BM), weld metal (WM), and heat affected zone (HAZ) in welded joints are different. These differences occurring in welded joints affect the structural performance, life, and fracture behavior of joints. The mismatch in welded structures makes it necessary to take into account the same parameters in using fracture toughness test methods developed for homogeneous materials. Various studies (Ref 1-3) have addressed the fracture behavior of mismatched weld joints. The results show that strength mismatch can significantly affect deformation and fracture behavior of the welded joints under bending and tension loading.

Mismatch of yield strengths of the base and weld metals induces significant effects on the yielding behavior and, hence, fracture process of the weld joints in the elastic-plastic regime. Many structural weld joints are produced with substantial strength mismatch between base and weld metal. The mismatch factor, M:

$$M = \sigma y^{WM}/\sigma y^{BM}$$

is in practice often chosen to be greater than 1.0 (overmatching). The reason for this is that in the weld metal region, weld defects, or cracks are more likely to be present than in the base plate. It is widely believed that weld metal overmatching provides some protection for such defects from applied stress. Overmatching with M of 1.2 to 1.3 with satisfactory fracture toughness is commonly used for many low and medium strength steel weldments (Ref 3, 4). Conversely, in the presence of coarse grained heat affected zones (CGHAZ) having a tendency to brittle fracture, an undermatching weld metal can significantly increase the critical CTOD of a crack in the CGHAZ, as a compared to overmatching weld metal (Ref 1).

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One problem in the investigation of the influence of strength mismatch on fracture behavior of weld joints is the variety of possible parameters, such as:

- Weld type (butt weld, filled weld)
- Weld preparation geometry (e.g., V- or X-butt weld)
- Loading mode (bending or tension)
- Loading direction (transverse or longitudinal to the weld seam)
- Notch position (WM or HAZ)
- Mismatch ratio, M
- Specimen geometry (e.g., $2H/a$, $2H/(W - a)$, $2H/B$, where, $2H$ is the weld width) (Ref 1)

Standard CTOD and J-integral fracture toughness estimation procedures, as described in ASTM E 1290 and BS 7448: Part 1 and ESIS P2 are intended to be applied for homogenous materials and cannot be extended in a straight forward manner to strength mismatch weld configurations where deformation behavior of the specimen (and crack tip region) is not any more similar to the homogeneous case. The deformation behavior is likely to be influenced by differences in tensile properties between the weld and base material. Clearly, there is the possibility of serious errors in the estimation of J-results from load-displacement curves of specimens with strength mismatch weld joints where displacement (measured remotely) may not fully be related to the crack tip driving force (Ref 1-6). Generally, the nearer displacement measurements are made to the crack tip itself, the more reliable they will be.

Generally used defect assignment procedures are based on the assumptions of homogeneous materials and that defects occur in material of uniform mechanical and microstructural properties. In reality, though, the heterogeneity of welded joints influences structural behavior. This effect, however, is not considered in this study (Ref 7).

It is still difficult to define the optimum combination of weld metal strength and toughness for a given defect size in WM or HAZ and application because toughness decreases with increasing yield strength. It is now known that a complete fracture characterization of mismatched weld joints should not be based only on the mismatch ratio, $M = \sigma y^{WM}/\sigma y^{BM}$ (Ref 6, 8).

Table 1 Welding parameters used in the experiments

Welding wire diameter, mm	Welding wire speed, m/min	Welding wire standard	Protective gas, %	Protective gas, L/min	Voltage, V	Current, A
1.2	7.5	SG2 DIN8559	20% CO_2 + 80%Ar	150	24	250

Table 2 Chemical compositions of the SAW 1020 and weld metal

	Composition, wt%									
Materials	C	Si	Mn	P	S	Cr	Ni	Mo	W	V
SAE 1020	0.205	0.164	0.427	0.0089	0.0085	0.100	0.0069	0.0022	0.010	0.0021
Weld metal	0.078	0.510	1.130	0.0150	0.0038	0.026	0.0450	0.0110	0.010	0.0019

Table 3 Mechanical properties of the SAE 1020 and weld metal

Materials	Ultimate strength, N/mm^2	Yield stress, N/mm^2	Elongation ($l_0 = 5d_0$), %
SAE 1020	375	291	25
Weld metal	500	450	22

2. Experimental Results

2.1 Welding Procedure

Experimental specimens were prepared from low carbon steel SAE 1020 of 12 mm thickness by taking into consideration the direction of rolling. These specimens, with V-welding mouths, were welded in accordance with the parameters given in Table 1. Necessary precautions were taken to prevent bending during the welding process. Fatigue precracks of 2 mm length were formed at the end of the V-notch of the single edge notched bending (SENB) specimens. The tests were carried out at room temperature with specimens having fatigue precracks with final a/W ratios of 0.16.

The base material was low carbon steel SAE 1020. The specimens were welded by the metal active gas (MAG) method. Table 2 gives the chemical compositions of SAE 1020 and weld metal.

Tensile test specimens were tested to determine the mechanical properties. Table 3 lists these properties.

2.2 Mismatch Factor

As a result of the tensile test, the mismatch factor, M, was obtained as:

$$M = \sigma y^{WM}/\sigma y^{BM} = (450/291) = 1.54$$

Because the result is greater than 1, the case is overmatching. This is a preferable case in welded joints (Ref 3, 9, 10).

2.3 Charpy Impact Values of the Weld Joints

The test specimens were tested by a Charpy impact test machine, which had a 2 J-friction value and 300 J capacity. Methanol bath was used as a cooling environment. Charpy impact toughness specimens were taken from BM, HAZ, WM (cup), and WM (root) layers for S-curve design. Charpy impact toughness experiments were conducted between –50 and +20 °C, and the results are given in Fig. 1. Figure 1 shows that (a) the base metal has lower toughness than the weld metal, (b) in weld metal, the root region has lower toughness than the cap region, and (c) the HAZ (cap) has lower toughness than the HAZ (root).

Ductile fracture has been observed in the cap region where the ductility value is high, brittle fracture has been observed in the root region, and mixed fracture has been observed in the transition region. It has been determined that the toughness value of the material increases with temperature, and the material tends to have ductile fracture. The plastic deformations will become more frequent in HAZ because of the coarse grain structure; this region is important for the toughness test (Ref 2,11).

2.4 Microhardness Test Results

The test specimens were tested in Carlzeiss Jena microhardness test equipment (Carl Zeiss Jena, Jena, Germany). The surfaces of the specimens were polished sensitively and acted with 5% nital. Microhardness values are measured in three different regions (WM, HAZ, and BM), in five parallel directions with 2.5 mm spacing from the surface (as seen in Fig. 3). A force, P, of 0.8 N was used in this experiment, and the results are shown in Fig. 3.

Figure 3 shows the high hardness values in the weld region tend to decrease in HAZ. Because the cooling rate varied depending on the thickness of specimens, base metal hardness value was reached by a normal decreasing curve in the cap and root surfaces. In X2, X3, and X4 directions, on the base metal side of HAZ, hardness decreased because of the coarse grain structure and then base metal hardness values were reached.

2.5 Three Point Bending (CTOD, δ_5) Test Results

The test shown schematically in Fig. 4 was performed by operating three different apparatuses together. Loading of the material was done by an Instron (model 1114) tensile test instrument. The loading values were transferred to the Y-channel of the recorder.

Strain gage outputs as Weston bridge, on the clip gage were amplified and transferred to the X-channel of the recorder. Clip gage legs were connected in 5 mm, δ_5, distance to the crack tip.

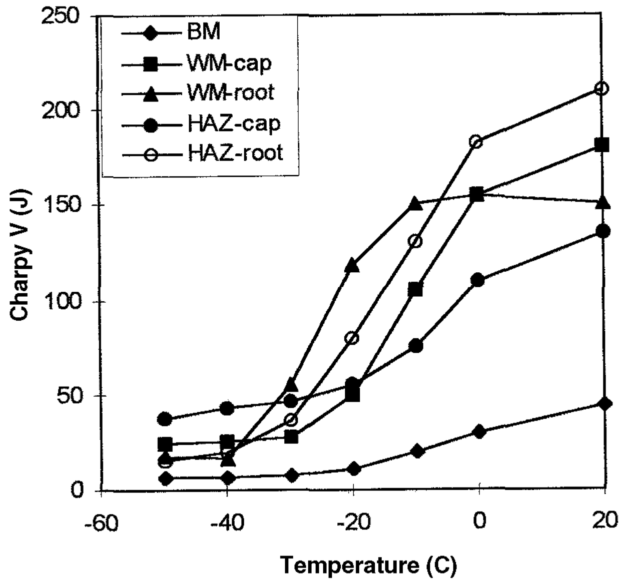

Fig. 1 The change of the Charpy impact values according to temperature

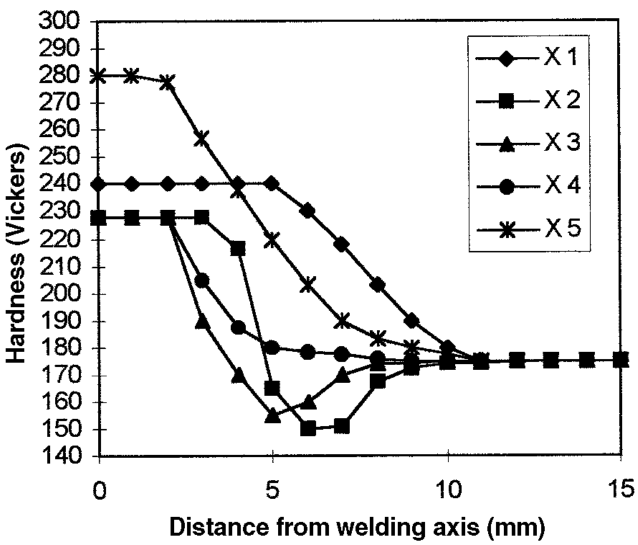

Fig. 3 The change of the microhardness values in five parallel directions

For determining crack progress due to loading, test specimens were observed under stereo microscope.

Load-displacement curves were drawn by measuring crack tip opening displacement on tips of clip gage via loading of the test specimens on tensile test instrument. While drawing these curves, crack tip opening propagation was determined at the same time and CTOD-Δ_a curves were obtained from these curves (Fig. 5-8).

All tests were conducted on static loading conditions, and the cracks that were propagated were unstable. The crack on tip of the notch was propagated under loading up to some value, then stopped. Blunt occurred because of a big plastic deformation on the tip of the crack (Fig. 9). The reason for this blunt is the passing of the crack progress from a low deformation region to high deformation region. This CTOD (δ_5) measuring method is valid only on low deformation region, not on a high deformation region.

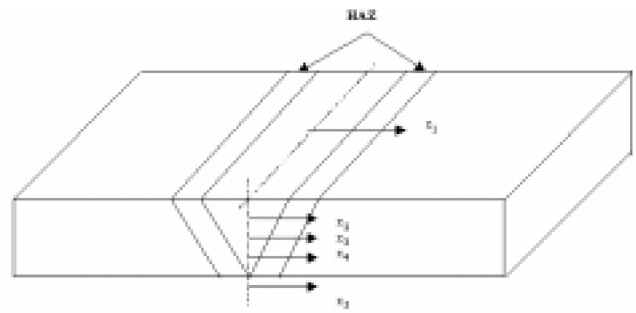

Fig. 2 The directions on the specimens in which microhardness is measured

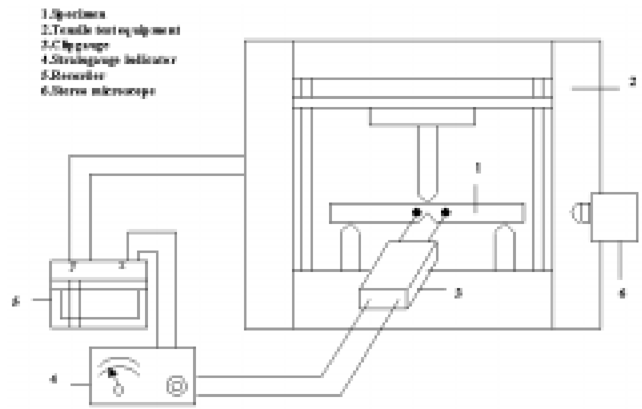

Fig. 4 The schematic representation of the test mechanism

3. Conclusions

The following conclusions can be drawn from the test results:

- It was found that yield stress of weld metal was 450 N/mm^2, base metal yield stress was 291 N/mm^2, and the mismatch factor was M = 1.54. When this value is higher than 1, there is overmatch, and it is a desirable situation for welded joints.
- The notch impact test established that toughness of the material increased with temperature, and, on the cap region, it showed ductile breaking tendency where the toughness value was high and brittle breaking tendency on the root region. It was seen that the base metal had lower toughness value than the weld material, the HAZ (cap) had lower toughness than the HAZ (root), and the root layer had lower toughness of the weld than the cap layer.
- As a result of microhardness measuring, the highest hardness value was calculated as 280 HV80 at the root layer of the weld seam and 240 HV80 at the cap layer, and these values decreased to 150 HV80 at HAZ, then reached to 174 HV80, which was the base material hardness value.

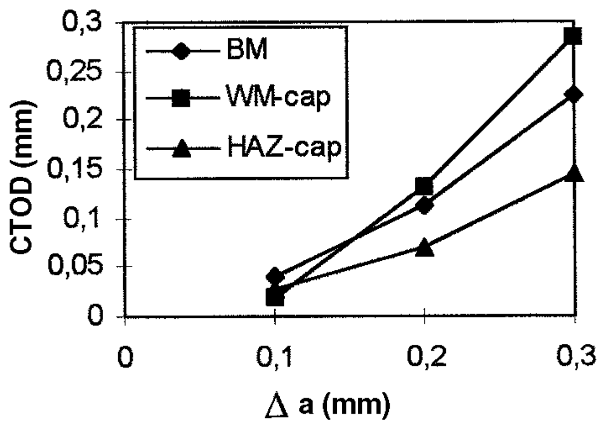

Fig. 5 Crack tip opening displacement (δ_5) R-curves of the base metal, weld metal cap, and heat affected zone cap (a/W = 0.16)

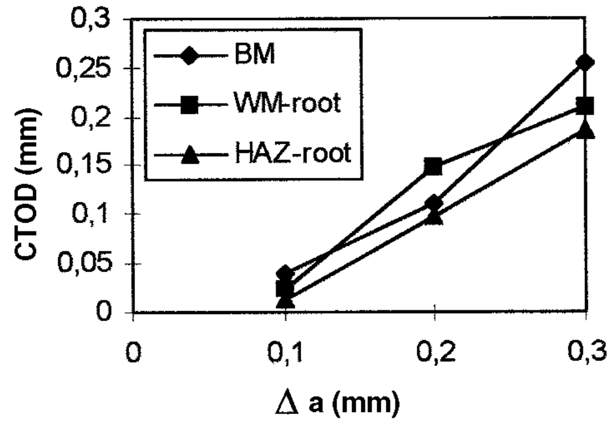

Fig. 6 Crack tip opening displacement (δ_5) R-curves of the base metal, weld metal root, and heat affected zone root (a/W = 0.16)

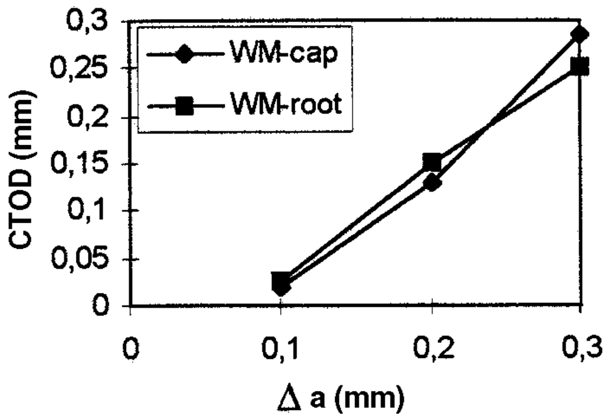

Fig. 7 Crack tip opening displacement (δ_5) R-curves of the weld metal cap and the weld metal root (a/W = 0.16)

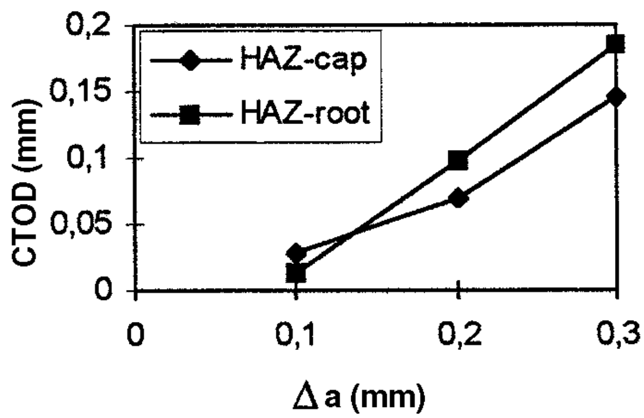

Fig. 8 Crack tip opening displacement (δ_5) R-curves of the heat affected zone cap and the heat affected zone root (a/W = 0.16)

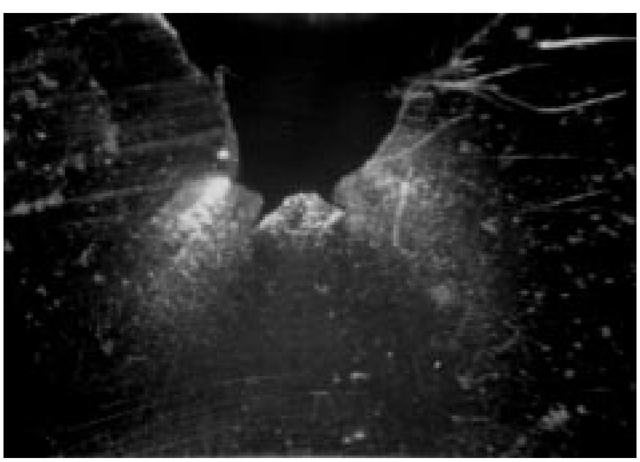

Fig. 9 Ending of propagation and the tip of the crack becoming blunt (30×)

- It was established that on CTOD (δ_5)-R curves of three point bending (SENB) test specimens, the crack at the HAZ progressed faster, depending on loading. At the hard and brittle root layer of the weld material, the crack progressed faster than the cap layer.

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