INFLUENCE OF SOME METALLURGICAL VARIABLES ON FRACTURE TOUGHNESS OF DUPLEX S.S. WELDMENTS

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The effect of ferrite content from 60 to 85% on fracture toughness of various duplex stainless steel welded joints has been studied. It was observed that an increase in this ferrite content leads to lower fracture toughness values. Moreover, a significant influence of other variables such as the directionality of ferrite areas or the number of inclusions present in the weld metal on the variation of toughness with the testing temperature or the fracture mechanism has been found.

INTRODUCTION

As stated by Baeslack and Lippold (1) the ferrite/austenite balance has a critical influence on the properties of duplex stainless steels. As the proportion of ferrite rises, both strength and stress corrosion cracking resistance increase while the fracture toughness decreases. The optimum of properties will be achieved when nearly equal proportions of austenite and ferrite are present in the microstructure. Moreover, Erauzkin and Irisarri (2) have shown that the influence of ferrite content on fracture toughness is more pronounced at lower temperatures where this phase tends to cleave while austenite fractures by microvoid coalescence in the whole temperature range.

The aim of this paper is to investigate the effect of ferrite content on the fracture toughness of different duplex stainless steel welded joints.

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EXPERIMENTAL PROCEDURE

The material chosen for the present study was a 13,5 mm thick hot rolled and solution annealed plate of a duplex austenitic-ferritic stainless steel conforming to ASTM A240 type UNS 31803, the chemical composition of which is (%wt) C 0.017, Si 0.41, Mn 1.48, P 0.028, S 0.001, Cr 22.1, Ni 5.6, Mo 3.0, N 0.13 and remainder Fe. The mechanical properties of this plate in the longitudinal direction were as follows: yield stress 553 MPa, tensile strength 782 MPa and elongation 37%.

Different samples of this plate were welded in the transverse direction using gas metal arc welding with pulsed arc and synergic control (GMAW), shielded metal arc welding (SMAW) and electron beam welding (EBW). A more detailed description about this welding procedures is given in a previous report by INASMET (3). Ferrite content on the weld metal was measured by means of quantitative metallography in specimens obtained transverse to the weld beam.

CTOD specimens of 124 x 27 x 13,5 mm were machined from the welded plates with the notch located in the weld metal and tested according to BS 5762 (4) in the temperature range from -60 to +20ºC. The fracture surface of each specimen was examined using a scanning electron microscope to determine the fracture mechanism.

RESULTS AND DISCUSSION

Ferrite content were 60, 72 and 85% for the GMAW, SMAW and EBW samples, respectively. Parent steel possesses a strongly banded microstructure constituted by near equal proportions of austenite and ferrite as it is shown in figure 1.

The mean values of CTOD obtained for the various welding procedures versus temperature are summarized in figure 2. In this figure the plot of CTOD versus temperature for the base material in the L-T orientation from reference (2) is also included to facilitate comparison.

It is observed that in the low temperature range GMAW values are higher than those of parent steel even if the former presents around 10% more of ferrite. SEM examination helps to find an explanation to this apparently anomalous behaviour. In the base material brittle cracks initiated in ferrite easily propagate until an ausstenite band is reached. Then, this crack begins a new stable crack growth in the austenite phasis (figure 3). Nevertheless, the magnitude of these crack jumps in the ferrite are large enough to be qualified as critical events.

Although ferrite content in the weld metal is higher, as it is seen in figure 4, this phase is surrounded by austenite which prevents that unstable cracks reach a noticeable length and limits the extension of cleavage areas (figure 5). Consequentey no critical load drop is observed in the load-clip gauge displacement records. Lower toughness of the weld metal compared to base metal at the top range of temperatures, where both austenite and ferrite fractures by microvoid coalescence (figure 6) can be explained based on the higher inclusion content of the former.

SMAW weld metal exhibits lower toughness in good agreement with its higher ferrite content but, surprinsingly, CTOD values are scarcely affected by the testing temperature. Once again, fracture surfaces examination helps to find an explanation to this behaviour. As it is observed in figure 7 even in those specimens tested at the lowest temperature surfaces are covered by ductile dimples pointing to the action of a microvoid coalescence mechanism. The large number of inclusions present in this joint induce interfacial decohesion at relatively low strains. Coalescence takes place before the cleavage stress is reached because of the high volume fraction of inclusions. This could explain the action of this mechanism even at low temperatures.

EBW specimens possess a poor toughness as expected considering the very large ferrite content (85%). Fracture surface examination reveals signs of cleavage at relatively high temperature. In specimens tested below -10ºC this is not preceeded by any stable crack growth. The very low volume fraction of austenite which could arrest these brittle cracks in ferrite leads to the poor values recorded and to a fracture surface near by enterily covered by cleavage facets (figure 8). A support to this explanation is obtained when these welded joints are heat treated to produce a more balanced ferrite/austenite proportions and a more uniform distribution in the microstructure. This results in a strong rise in toughness up to levels even higher than those in GMAW specimens.

CONCLUSIONS

a) An increase in ferrite content leads to lower fracture toughness values. However, the influence of other variables such as inclusions volume fraction or ferrite distribution must be considered.

b) More marked directionality in the ferrite distribution in base material compared to GMA weld metal can induce lower toughness at low temperatures as the cracks easily propagate through the ferrite before a new stable crack growth begins when an austenite band is reached.

c) The presence of a high volume of large inclusions can induce a change in the fracture mechanism, a weaker effect of testing temperature on fracture toughness and low values in SMA weldments.

d) The very low austenite content which could arrest brittle cracks nucleated in ferrite is claimed to be reponsible of the poor toughness of EBW weldments. A more balanced distribution of these phasses, as obtained by heat treatment rises markedly the weld joint toughness.

ACKNOWLEDGEMENTS

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(3) INASMET Comportamiento frente a la fractura y la corrosión de un acero inoxidable austenoferritico y sus uniones soldadas, 1.988 (in spanish).
(4) BS 5762: 1979 Methods for crack opening displacement (COD) testing. British Standard Institutes.

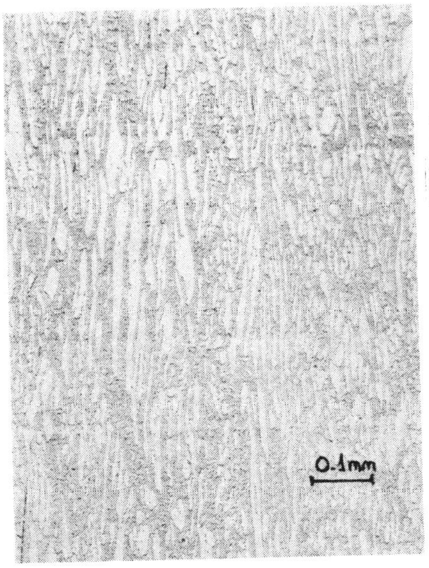

Fig. 1.- Parent steel microstructure (X100)

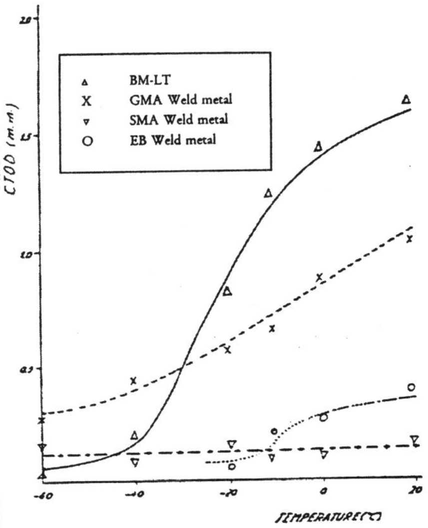

Fig. 2.- CTOD Vs. Testing temperature

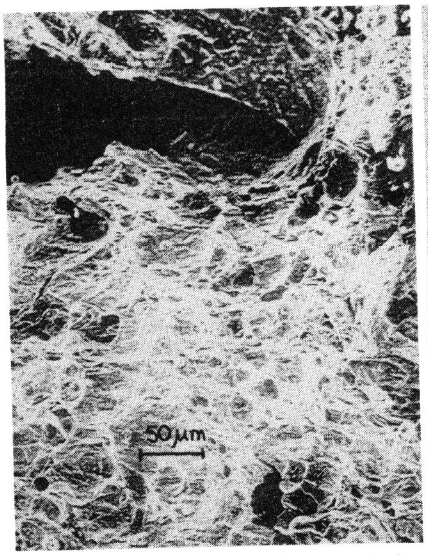

Fig. 3.- Brittle crack arrested at austenite (X200)

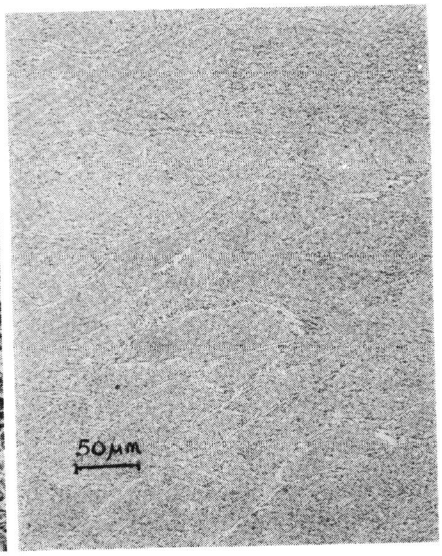

Fig. 4.- GMA weld metal microsctructure (X200)

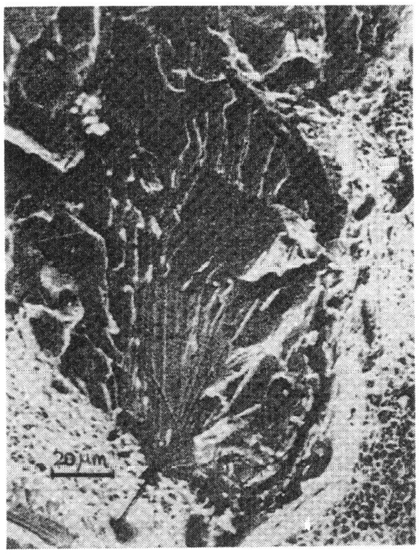

Fig. 5.- Cleavage areas at GMAW metal (X500)

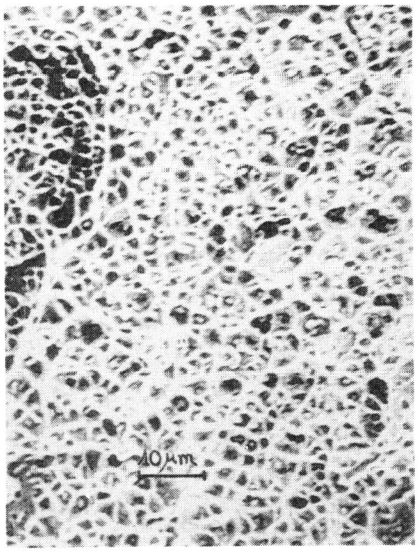

Fig. 6.- Ductile dimples at high temperature range (X1000)

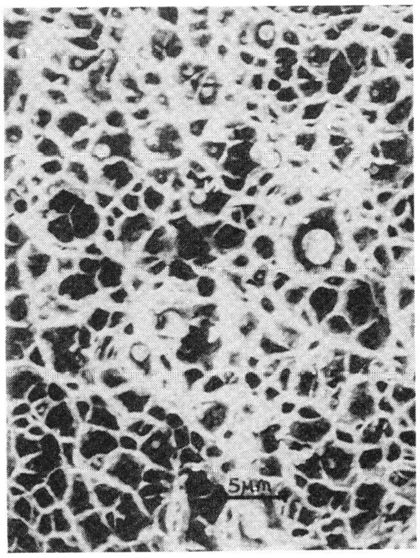

Fig. 7.- Large inclusións in SMAW metal (X1000)

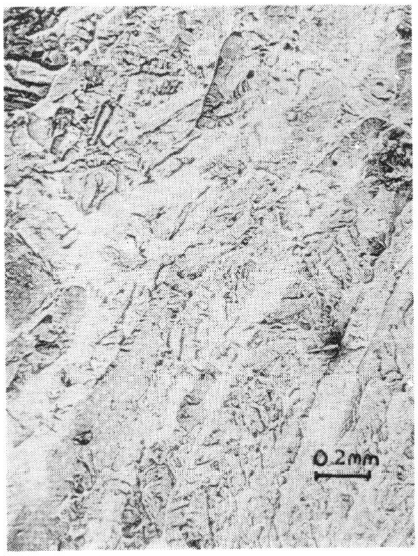

Fig. 8.- Large cleavage areas at EBW metal (X40)