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Weldability studies of high-strength low-alloy steel using austenitic fillers

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Industrial Summary

A study was undertaken to establish the weldability of high-strength low-alloy steel (0.3C–3Ni–2.5Si–0. 87Cr–0.52Mn–0.29Mo) using austenitic filler metals (309L and 18Cr–8Ni–6Mn) and the gas tungsten arc welding process with a view to securing high toughness in the weldment. Hot and cold cracking tests, carried out to study the cracking tendency in the weldment, showed that these steels are not prone to hot and cold cracking. Weld joints were characterised on the basis of transverse tensile, hardness and impact-toughness properties and microstructural studies. The joint efficiencies of 309L and 18–8–6 austenitic stainless-steel weld deposits were found to be around 72% compared to that of the base metal (with respect to UTS). However, the studies revealed that the toughness of the weld deposit is improved by a factor of nearly 1 1/2 compared to that of the base metal in the case of 309L filler wire, while with 18–8–6 filler wire the toughness of the weld deposit was lower than that of the base metal.

1. Introduction

Welding is a principal method of joining materials. During World War II greater recognition was accorded to this field, as an effective fabrication technique compared to riveting and bolting. Disastrous failures of welded ships at sub-zero temperatures triggered off extensive research into the causes of such failures. Research that was carried out subsequently led to the development of High Strength Steels. These steels presently find wide application in the field of aerospace for parts such as landing gear, mortar casings, etc. [1]. During the fabrication of a complex structure, the steel will be subjected to various forming treatments such as hot and cold rolling, cold bending, welding, etc. It is therefore necessary to know the behaviour of these steels when

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subjected to the above-mentioned processes, the data of which will help in the developing of these steels. Weldability studies carried out using base metal as filler exhibited 80% joint efficiency [3,4]. For some joints, where joint strength is not an important criterion and toughness in the weld joint is essential, there is a need to establish suitable alternative consumables.

A literature survey indicates the use of austenitic stainless steel as filler metals for the welding of heavy structures in ship building, pressure vessels and heavy vehicles, in order to meet the requirement of good impact properties along with adequate strength. The same consumable finds application for the welding of high-strength low-alloy steels to meet the service requirements of armoured vehicles. These stainless-steel filler wires are known for their good resistance to cold cracking and hot cracking [5–7]. This paper reports the results of a detailed study carried out to investigate the weldability behaviour of HSLA steel using austenitic filler metals.

2. Experimental procedure

2.1. Base metal

The chemical composition of the steel selected for the weldability study is given below (wt%).

C	Ni	Si	Cr	Mo	Mn
0.35	3	2.5	0.87	0.29	0.52

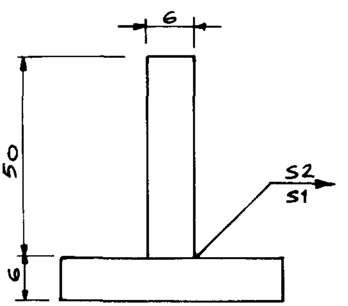
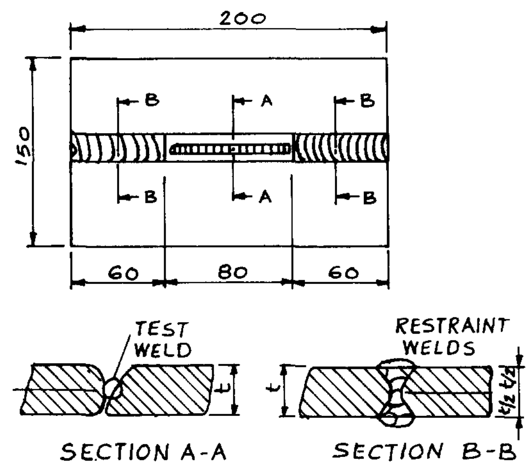
2.2. Weld-metal cracking tests

The T-type weld-cracking test (JIS Z 3153) for hot cracking and the Tekken test (JIS Z 3158) for cold cracking were used to assess the cracking susceptibility of the steel. The T-test was carried out on the basis of JIS Z 3153, this being a restrained fillet-weld test to establish whether the deposited weld metal is susceptible to hot cracking, whilst the Tekken test was carried out on the basis of Japanese standard JIS Z 3158. In general, the oblique Y groove is the recommended configuration for testing heat-affected zones susceptibility to hydrogen cracking. In this test the weld coupon is sectioned in the transverse direction at three locations after a lapse of a post-weld period of at least 48 h in order to ascertain the cracking tendency. The conditions used in the T-type cracking test and the Tekken test are summarized in Table 1.

2.3. Welding procedure

Manual gas tungsten arc (GTA) welds were made using 1.6 mm diameter filler metal of E309L and 18–8–6, the nominal compositions of the filler metal being

Table 1
Experimental conditions of GTA welding used to assess the cracking susceptibility of high-strength low-alloy steel (dimensions: m)

T-type weld cracking test (JIS Z 3153)	Tekken test (JIS Z 3158)
 Leg Length $S_1 = 9$ mm $S_2 = 3$ mm (test bead) Welding parameters 120A, 17 V 1 mm s^{-1} welding speed 1.6 kj mm^{-1} heat input 2 mm arc length Filler wire (austenitic) E309L, 18Cr–8Ni–6Mn Electrode WTh-2.32 mm dia. Shielding gas Pure argon, 0.25 l s^{-1} flow rate.	 Welding parameters as per T-type welds

presented in Table 2. The plates were welded after hardening and tempering treatment. The joint configuration for all of the weldments consisted of a single V-groove with 60° included angle and a root gap of 2 mm and root height of 1.5 mm (Fig. 1). Weld coupons of size 75 × 200 mm were clamped in a jig with the joint line over a channel which could be purged with backing argon gas, as shown in Fig. 2. Welds were made in the flat position using DC straight polarity, the welding direction being perpendicular to the rolling direction for all of the plates. The weld coupons were sectioned, polished and etched, optical microscopy being used to examine the weld microstructure. Hardness, tensile and impact tests were carried out on specimens cut perpendicular to the welding direction. Hardness measurements (HV10) were carried out both across the weldment (covering the weld deposit and the HAZ) and in the

Table 2
Composition of the austenitic filler wires used (wt%)

Element Filler	E309L	18–8–6
Carbon	0.03	0.03
Chromium	22–25	18–20
Nickel	12–15	8–10
Molybdenum	0.05	0.05
Manganese	0.5–2.5	6–8
Silicon	0.9	0.9
Phosphorous	0.04	0.025
Sulphur	0.03	0.025

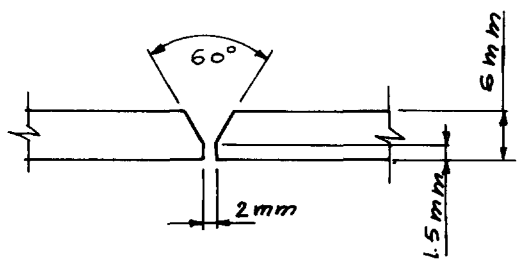


Fig. 1. Schematic diagram of the weld groove.

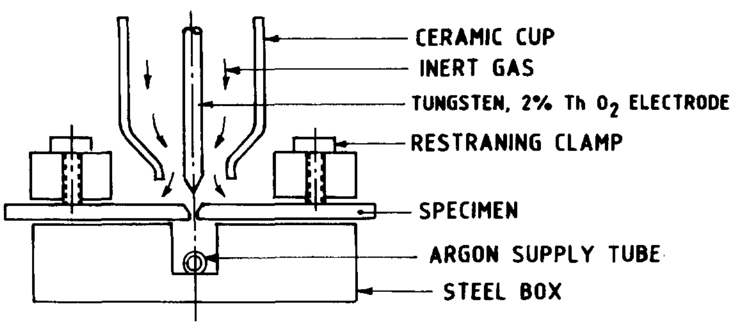


Fig. 2. Cross-sectional view of the clamping fixture.

thickness direction (from the face side to the root side) at the center line of the weld-metal. A scanning electron microscope (ISI:100) was used to study the fracture behaviour.

3. Results and discussion

3.1. Metallographic observations

Specimens of the T-test that were used to test the susceptibility to hot cracking of the weld showed no evidence of any cracks (Fig. 3). Similarly, the specimens of the

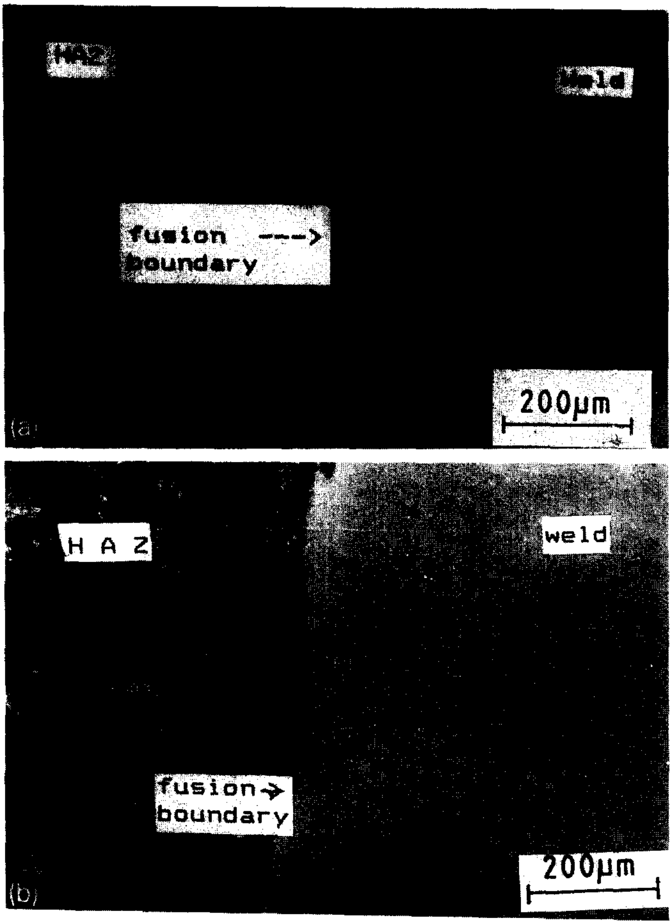


Fig. 3. Microphotographs of sections across the hot cracking specimens: (a) 309L weld deposit; (b) 18–8–6 weld deposit.

Tekken test subjected to micro- and macro- examination showed no cracks at a magnification of 100 × (Fig. 4). This confirms the ability of the base metal, of the heat-affected zone (HAZ) and of the weld-metal to resist cold cracking.

The microstructure of the 1st pass and the 2nd pass are compared in Fig. 5 and Fig. 6 respectively. In Fig. 5, it is observed that the 1st pass contains a larger austenite grain size in respect of 18–8–6 filler. The microstructures in the 2nd pass are comparable in the two cases (Fig. 6)

3.2. *Hardness survey*

It is observed from the results of the hardness test that the 1st pass weld-metal exhibited a greater hardness compared to the 2nd pass weld-deposit (Figs. 7–9). The increase in the hardness found in the first bead over the second bead may be a result of

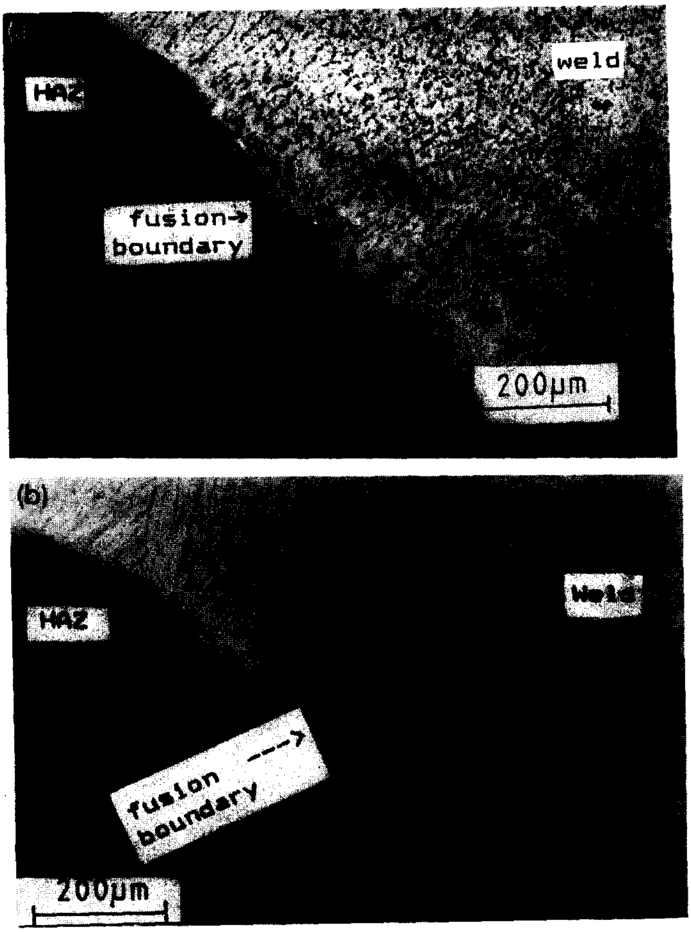


Fig. 4. Sections across the y-groove weld showing no evidence of cracking: (a) 309L weld deposit; (b) 18–8–6 weld deposit.

the difference in chemical composition arising from variation in the dilution levels, which can be due to the formation of martensite on account of the higher dilution levels in the first pass. Similar trends in hardness in two-pass welds was reported by Bosansky et al [8].

The hardness values in the weld metal were low, a characteristic of austenitic steels. A hardness survey carried out covering different regions of the HAZ and the base metal are shown in Figs. 10 and 11, where from these profiles it can be observed that the HAZ has the greatest hardness. There is a dip in hardness while changing over from the HAZ to the base metal. The high hardness observed in the HAZ region can be attributed to the formation of martensite, as the steel is of air-hardenable class. The expected coarsened grain size in the HAZ also would favour the formation of martensite, a shear-type of transformation product. The dip in hardness in the base

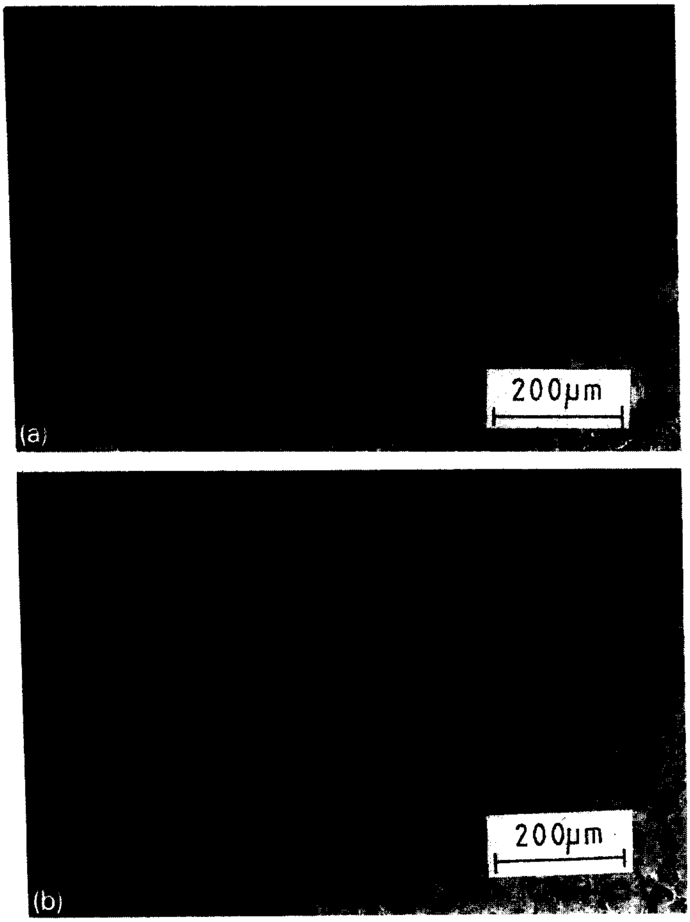


Fig. 5. Microstructure of the centre of the 1st pass weld deposit: (a) 309L; (b) 18–8–6.

metal is possibly due to the nature of the weld thermal cycle leading to tempering of the steel, resulting in the decomposition of martensite in the temperature range 440 to 600°C.

3.3. Tensile test

Strength and ductility data obtained from tensile tests are shown in Table 3. It may be noted that the yield strength of the weld joint is greater in the case of the 18–8–6 weld deposit: however, the latter showed marginally lower ductility, which can be due to a greater tendency of transformation of martensite in the 18–8–6 weld compared to that in the E309L weld, a greater amount of Nickel in the E309L substantiating this view. The joint efficiencies, which are calculated from the ultimate tensile strength of

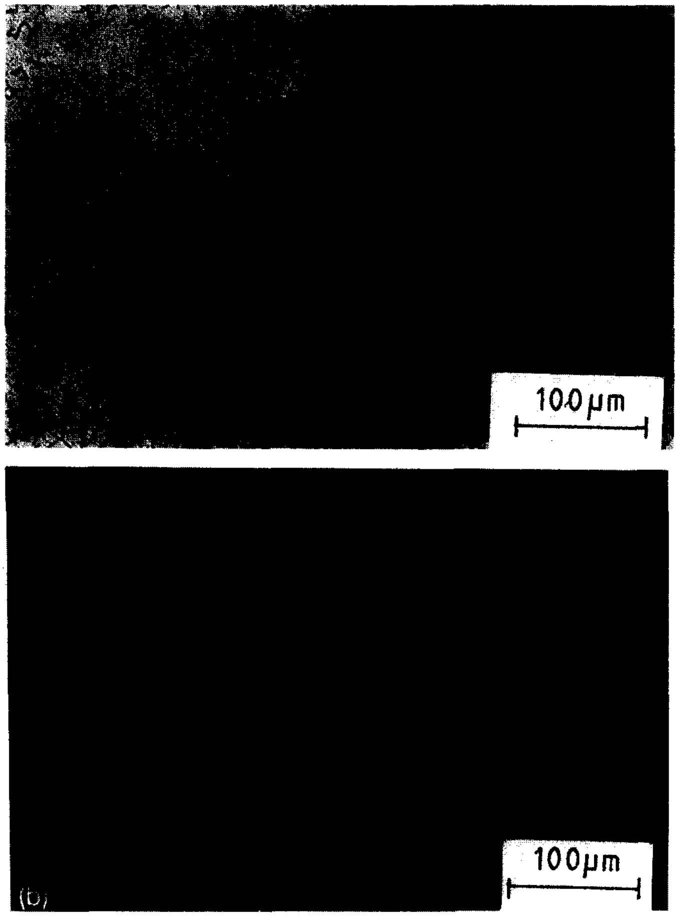


Fig. 6. Microstructure of the centre of the 2nd pass weld deposit: (a) 309L; (b) 18-8-6.

the welded joints (for 309L and 18–8–6 fillers) with respect to the values for the base metal, are found to be around 72%.

It was observed that the tensile strengths of the weld joints for both filler metals are quite low compared to those of the base metal. Fracture occurred, therefore, in the weld metal. Fractographic examination of the failed samples revealed a ductile mode of fracture (Fig. 12). However, the degree of ductility is greater in the case of E309L filler (Fig. 12(a)), which is evident from the larger dimple size in the case of the 309L weld deposit (Fig. 12(a)) compared to that for the 18–8–6 weld deposit (Fig. 12(b)).

3.4. Charpy V-Notch (CVN) impact test

The CVN test results at room temperature are presented in Table 4, from which it may be observed that the toughness in the HAZ region matches that of base metal,

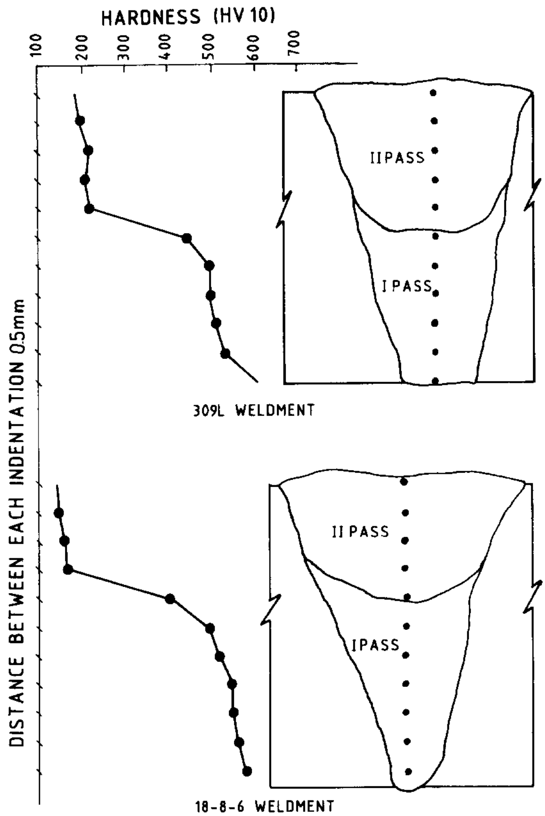


Fig. 7. Hardness survey along the vertical centre-line of the weldment.

whilst the toughness of the weld deposit for E309L is greater than that for 18–8–6 weld deposit by a factor of nearly 1 1/2.

Fractographic observations made on weld impact samples of 309L at the interface of two weld passes are shown in Fig. 13(a), the individual observations on each pass being shown in Fig. 13(b) and Fig. 13(c). The first pass shows dimples of smaller size (Fig. 13(b), whilst the second pass exhibits larger dimples (Fig. 13(c)), which suggests a tendency towards higher ductility in the second pass. This can be attributed to the higher dilution levels experienced by the first pass leading to the formation of martensite, substantiated by the greater hardness of the first pass (Fig. 7 and Fig. 8).

Fractographic observations on the impact-toughness specimens in respect of 18–8–6 weld deposit are presented in Fig. 14, from which fractographs the underlying solidification structure (cellular) is evident (Fig. 14(a) and Fig. 14(b)). Higher magnification pictures of the 1st-pass and 2nd-pass regions show a greater degree of ductile features in the second pass (Fig. 14(c) and Fig. 14(d)). The cellular microstructure features suggest that 18–8–6 filler is prone to weld-metal segregation effects, which could be the reason for the lower toughness of the 18–8–6 weld deposit.

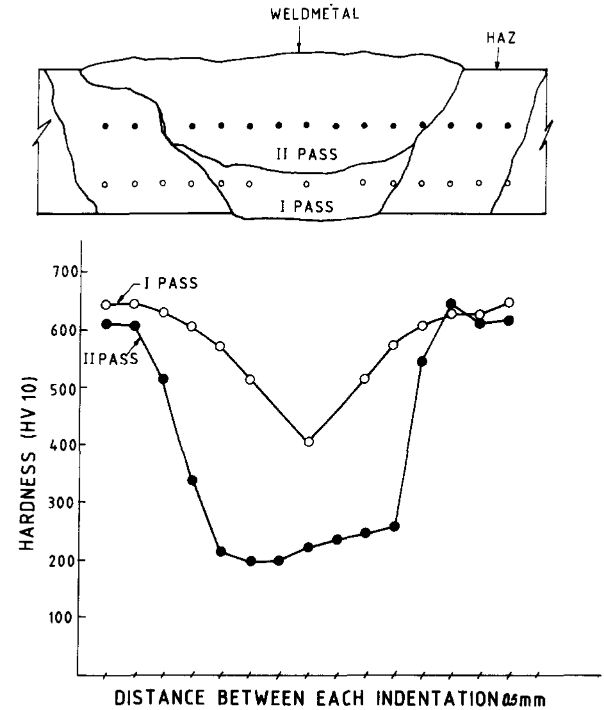


Fig. 8. Hardness survey across the 309L weldment in the 1st and 2nd pass.

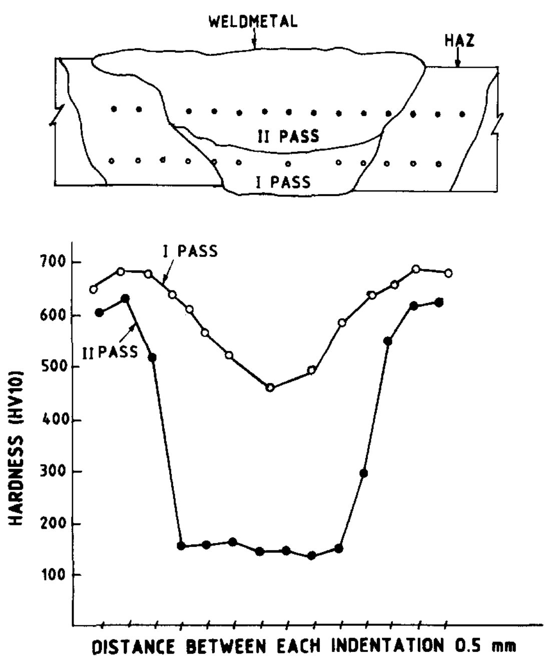


Fig. 9. Hardness survey across the 18–8–6 weldment in the 1st and 2nd pass.

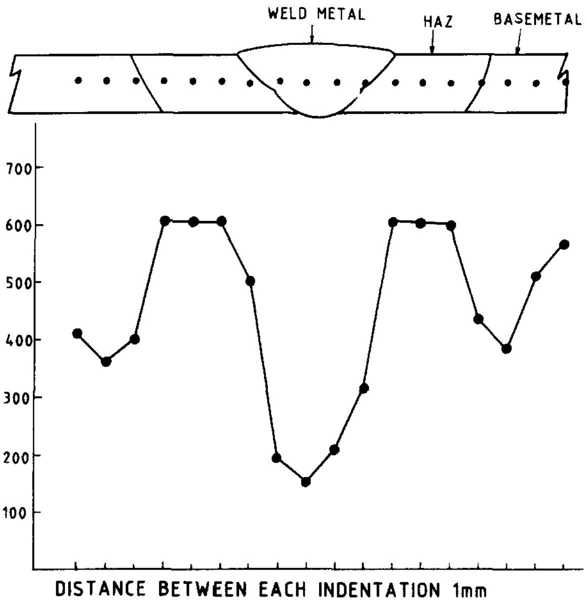


Fig. 10. Hardness survey across the weldment for the 309L weld deposit.

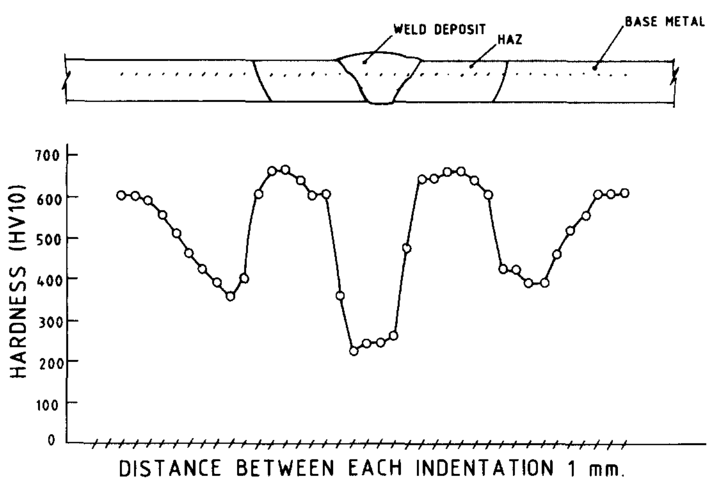


Fig. 11. Hardness survey across the weldment for the 18–8–6 weld deposit.

4. Conclusions

1. Weldability study of high-strength steel using two types of austenitic fillers namely, E309L and 18–8–6, revealed that the weld metal is not prone to cracking.

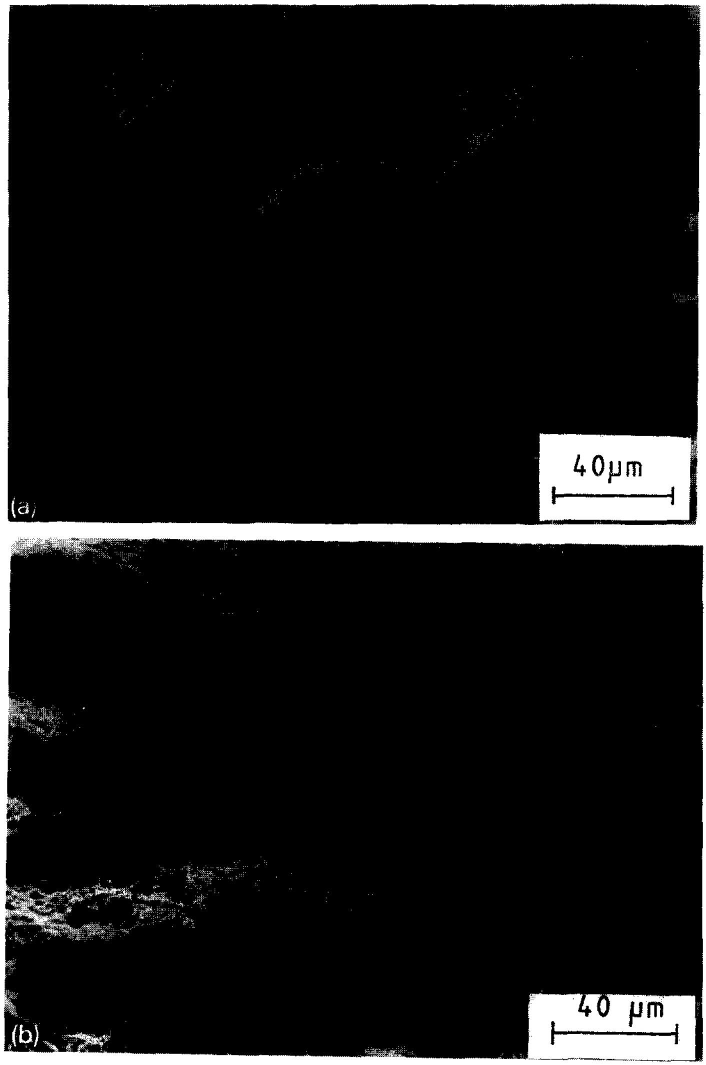


Fig. 12. Fracture surface of tensile sample of: (a) a 309L weld joint; (b) a 18–8–6 weld joint.

2. The hardness of the weld bead in the 1st pass is considerably greater than the hardness of the weld bead in the 2nd pass in two-pass welding.

3. The yield strength of 18–8–6 weld deposit was greater than that for the 309L.

4. The impact toughness of the weld metal is greater than that of the base metal in the case of E309L weld deposit by a factor of nearly 1 1/2, whilst the toughness of the HAZ is close to that of the base metal. However, in the case of 18–8–6 filler the toughness of the weld metal is lower than that of the base metal, which can be due to the greater yield strength of the 18–8–6 weld deposit due to its inability to tolerate

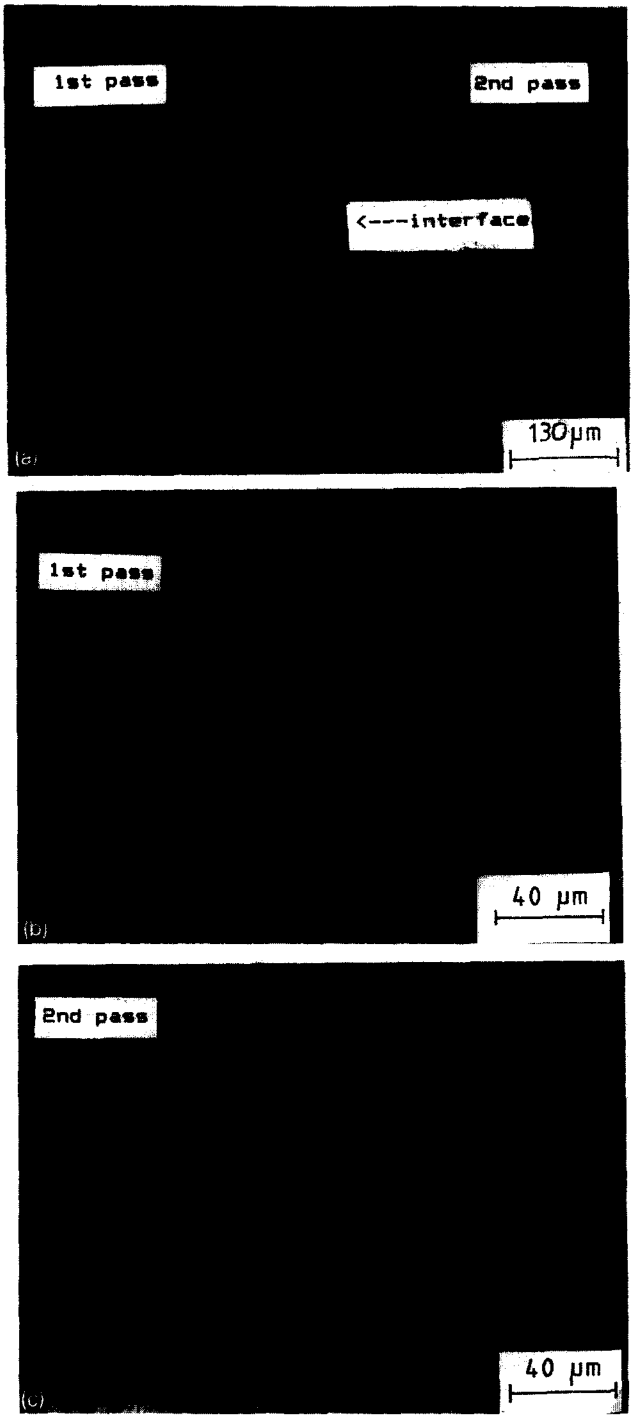


Fig. 13. CVN fracture surface of weld metal deposited with 309L filler metal: (a) weld interface between the 1st and 2nd pass; (b) fracture surface of the 1st pass; (c) fracture surface of the 2nd pass.

Table 3
Tensile properties of the welded joints

Test specimen	YS (MPa)	UTS (MPa)	El (%)
309L Weld deposit	730	1230	8
18–8–6 Weld deposit	860	1260	6
Base metal	1370	1720	13

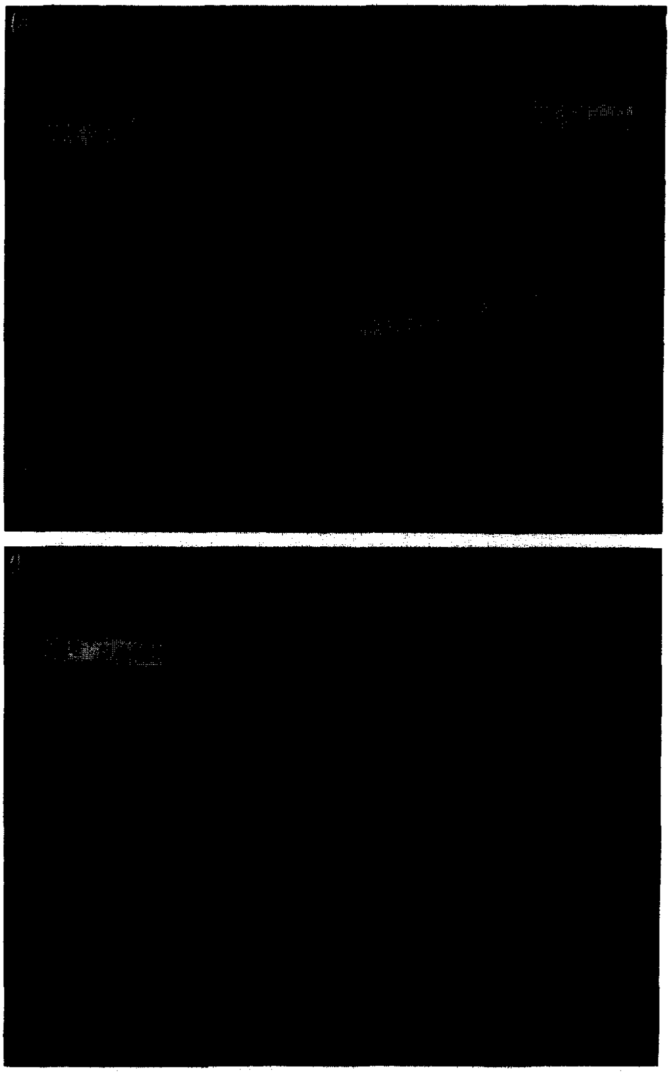


Fig. 14. CVN fracture surface of weld metal deposited with 18–8–6 filler metal: (a) weld interface between the 1st and 2nd pass; (b) transugranular failure in the 1st pass; (c) fracture surface of the 1st pass; (d) fracture surface of the 2nd pass.

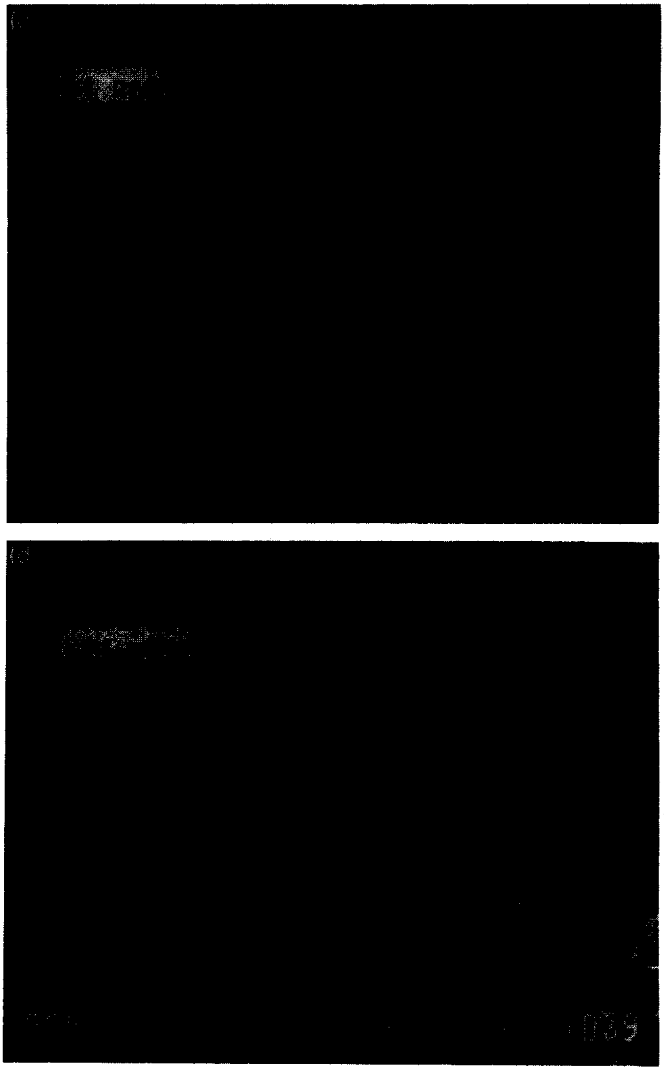


Fig 14. (Continued)

Table 4
Impact toughness test data (in Joules) Test conducted for sub-size samples of dimensions 55 × 10 × 5 mm at room temperature.

Test specimen	1	2	3	Average
Base metal	17.5	18	18.5	18
309L filler:				
Weld metal	26	27.5	26.5	26
HAZ	15.5	17	18	16.75
18–8–6 filler:				
Weld metal	11.5	11	10	10.9
HAZ	17	18	17	17.3

higher dilutions. This difference in the 309L filler and the 18–8–6 filler can be attributed to the greater percentage of nickel in the case of 309L.

Acknowledgement

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