

STUDIES ON MECHANICAL PROPERTIES AND FRACTURE TOUGHNESS OF WELDED HIGH MARTENSITE DUAL PHASE STEELS FOR STRUCTURAL APPLICATIONS

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Abstract Composite microstructures of ferrite and 30 to 76% martensite have been obtained by intermediate Quenching (IQ) heat treatment of a boron-vanadium micro-alloyed steel. Welding parameters were established for shielded metal arc welding (SMAW) using bead on plate experiments. Test coupons were prepared as per AWS D1.1 (Structural welding code). The microstructural studies were correlated with microhardness, tensile, bend, impact and fracture toughness values. A Scanning Electron Microscope analysis of the broken welded tensile specimens and ½ CT specimens were carried out. The results indicate that as the percentage of martensite content increases in the welded specimens, there has been increase in the ultimate tensile strength, yield strength, percentage of elongation, impact and fracture toughness values. The fractographic observation of welded tensile specimens indicates predominantly cleavage to predominantly dimpled fracture surface. Where as, ½ CT welded specimens indicate a cleavage type of fracture in the fatigue pre- cracked regions and a dimpled type of fracture in the fast crack growth region due to tensile loading. Further it has been found that the microstructure of the base material has a bearing on the mechanical behaviour exhibited by the weldments. The mechanical properties of the welded joints were found to be comparable with mechanical properties of the base metal.

Keywords: Dual phase steel, welding, thicker section, structural applications

INTRODUCTION

The global crisis has thrown open perpetual challenges to the technologists working in the area of material development to evaluate newer materials with improved combinations of high strength, ductility and toughness. This has led to the emergence of a series of composite microstructures in which dual – phase (DP) steels represent a distinguished class. The DP steels usually exhibit microstructures consisting of about 80 percent ferrite and 20 percent martensite with small amounts of retained austenite and/or bainite, depending on their composition and processing.

Literature survey indicates that, the DP steels exhibit high strength to weight ratios and high crushing strength, due to which their usage could be envisaged in the fabrication of offshore structures, space applications and in heavy structural assemblies like earth moving equipments, heavy machineries etc.

The understanding gained on various aspects of dual-phase steels over the last three decades is limited to

microstructures containing volume fraction of martensite (V_f) within about 25%. The major cause for this limitation is the apprehension that, though strength gradually increases, ductility and impact toughness of DP steels may decrease beyond 25% of martensite content. It appears from the literature survey that much research work has not been reported covering the entire range of the composite microstructure of soft ferrite and hard martensite in DP steels. Specifically the DP steels containing higher [$>25\%$] [1,3,]. martensite have not been well studied. In this context, it is felt that any research work pursued in the area of secondary operation of thicker section DP steels, such as welding of DP steels may be useful for any structural applications where improved combinations of high strength, ductility and toughness are desirable. Therefore in the present investigation, it has been planned to carryout systematic studies in the area of mechanical properties of welded joints of dual-phase steels of thicker sections using Shielded Metal Arc Welding (SMAW) process.

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MATERIALS AND METHODS

Material

Micro alloyed steel in the form of 14mm thick hot rolled stock was selected for this study. The composition of the material was determined using a Baird optical emission spectrometer, together with a Leco Carbon Sulphur and Oxygen –Nitrogen determinator and is found to be 0.11% C, 1.32% Mn, 0.002% S, 0.13% P, 0.44% Si, 0.03% Cr, 0.09% Mo, 0.056% V, 0.0019% B and 0.004% N by weight percent of the steel.

Development of Dual –phase steel as a base material by heat treatment

The dual-phase microstructure were developed by IQ treatments. The IQ treatment consists [4] of Soaking the specimens at 920 °C for 30 min, Quenching in Iced brine, re soaking at different inter-critical annealing temperature (ICT) for 60minutes and then Quenching in oil. Fig 1 shows the schematic representation of heat treatment schedule for the intermediate Quench treatment.

Microstructural Characterization

Several stereological measurements were carried out to estimate (a) The volume fraction of ferrite (V_f) and martensite (V_m) in developed microstructure using a manual point counting technique. (b) The amount of retained austenite was estimated by X-ray diffraction meter [2,5]. The Table 1 shows the approximate volume fractions of Dominant Phases and Fig 2 shows the microstructure obtained through intermediate quench treatment.

Welding Parameters and procedure for shielded Metal Arc Welding (SMAW) process

The welding parameters for welding dual phase steels plates of 14mm thick using Shielded Metal Arc Welding (SMAW) process were optimised using bead on plate experiments[6]. The optimum parameters were found to be as follows. The suitable electrode specification was found to be E11018M with 3.15mm diameter, current was found to vary from 110Amps – 120Amps, voltage was found to vary from 22volts – 27volts, heat in put was found to be 0.4KW to 0.7KW with an inter pass temperature varying from 100°C to 150°C and the maximum preheat temperature was found to be 150°C.

Using above welding procedure welding was carried out on edge prepared plates. After welding, weldments were subjected to radiographic examinations to ensure the soundness of the joints. During radiographic examination of weldment specimens subjected to ICT heat treatment at 840°C and 860°C exhibited cracks in the fusion line of the weldment. This was attributed to higher percentage of martensite present in the base metal. Therefore, in the present investigation, the ICT

heat treatment was restricted up to 820°C, in other words, volume percentage of martensite was restricted upto 59.37.

In order to know the mechanical properties of the weld joint of DP steels containing different volume percentages of martensite, the specimens were cut in the transverse direction of the weld seam, using electric discharge saw (model – DC 501).

Specimen preparation and Experimental details

The tensile test were carried out on reduced tensile specimens of rectangular cross section as per AWS D1.1 (E8-86) specifications. The specimens were tested using a universal testing machine (Type RH-30 TV MO. 51212).

The side bend test was carried out using universal testing machine. The size of the specimen used for this test was 12mm x 10mm x 200mm. The specimen was simply supported over a span length of 76mm having mandrel diameter of 40mm. The testing was carried out as per AWS D1.1 standard.

The impact toughness of welded DP steels were assessed using Charpy Impact testing machine. The Charpy impact specimens were prepared as per AWS D1.1 (ASTM E23-86) standard. The specimen size was 55mm x 10mm x 10mm with 2mm deep groove, 45° angle and 0.25mm root radius. The testing was carried out at room temperature using pendulum type impact machine (model IT-30, 0-300 Joules capacity).

Fracture toughness studies were made using ½ CT specimens as described in ASTM standard E647-93 to estimate average values of K_{Ic} under plain strain condition. Determining fracture toughness of welded DP steels on the prepared specimen involves tensioning of notched specimens which have been pre-cracked by fatigue. The test was carried out in a Instron 8032 make servo hydraulic machine as per ASTM standards, at room temperature using as sine – wave cyclic frequency of 20 Hz and a load ratio (R) of 0.1. The crack extension in the test specimens was monitored using a traveling microscope.

Fractured surfaces of broken welded tensile specimens and ½CT specimens were preserved in desiccator for fractographic examination under the SEM. The fractured surfaces were scanned using a JEOL JSM – 840 make Scanning Electron Microscope. Standard methods of grinding, polishing and etching were used to examine the microstructural features in the base material portion, HAZ portion and weldmetal portion of the entire weldment.

RESULTS AND DISCUSSION

Development of dual phase steels

The composition of the base material chosen in this research work was found to be suitable to develop dual-phase steels. It is possible to obtain composite microstructure of ferrite and 31% to 76% martensite from this micro alloyed base steel by Intermediate Quench treatment method. The dual phase microstructure obtained by IQ treatment contain 2% to 3% retained austenite and contain some untransformed fine carbides. Blocky ferrite regions mixed with the martensite domains having globular or plate morphology were observed in the dual – phase microstructure. The variation of average microhardness values with the variation of volume fraction of martensite, were found to be similar when examined at different loads.

Microstructural and hardness profile on weld gradient

All the welded specimens made up of different martensite contents show three distinct zones viz, weldmetal zone, heat affected zone (HAZ) and basemetal zone which are shown in Fig 3. In the weldmetal zone microstructure, dendritic structure of ferrite, pearlite and martensite along with precipitates of carbides were observed. In the heat affected zone microstructure, martensite, tempered martensite, ferrite and few amounts of carbides (with variation in grain size) were observed. As already mentioned earlier in the basemetal zone microstructure, blocky ferrite regions mixed with the martensite domains having globular or plate morphology were observed. The weldmetal zone exhibited higher hardness value than the basemetal. This may be due to presence of considerable amount alloying elements like Nickel, Chromium and Molybdenum in the filler metal. The heat affected zone is having higher hardness value than both the weldmetal and basemetal. This may be due to exposure of heat affected zone over a range of temperature during welding and precipitation of some alloying element like Boron, Molybdenum and Vanadium which are present in the base metal.

Mechanical properties

All the welded tensile specimens of different volume percentage of martensite had failed in the HAZ region with significant variation in strength. As the percentage of martensite content increases in the weld specimen, there has been increase in ultimate tensile strength, yield strength and percentage of elongation which are shown in Table 2.

The fracture toughness (K_{Ic}) increases with an increase in the volume percentage of martensite in different welded specimen .

There has been an increase in impact strength obtained as the percentage of martensite increases in the welded specimen, even though the filler metal and the welding condition used for all the specimens has been almost same.

Fractography

Fractographic observation on broken welded tensile specimen indicates predominantly cleavage to predominantly dimpled fracture surface. The amount of transgranular cleaved regions and those of dimpled regions were found to be quantitatively varying with the volume percentage of martensite present in the welded specimen.

Fractographic observation of fractured ½ CT welded specimen indicates a cleavage type of fracture in the fatigue pre-cracked regions and a dimpled type of fracture in the fast crack growth region due to tensile loading Which are shown in Fig 4.

CONCLUSIONS

It has been found that the microstructure of the base material has a bearing on the mechanical behaviour exhibited by the weldments. The mechanical properties of welded joints were found to be comparable with mechanical properties of base metal.

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Table –1 Volume Fractions of different phases obtained from microstructural analysis of different ICT specimens.

Specimen Code	V _a	V _m	V _f
A 73	-----	31.0	69.9
A 76	2.17	43.05	54.78
A 80	1.26	51.04	47.7
A 82	1.34	59.37	39.29

Table –2 Range of mechanical properties obtained from welded specimens containing different volume percentage of martensite content

V _m %	UTS (M Pa)	YS (M Pa)	% elong	Impact Strength	K _q (MPa√m)
30 to 60	570 to 700	432 to 620	8.15 to 17.8	60 to 90	50 to 94

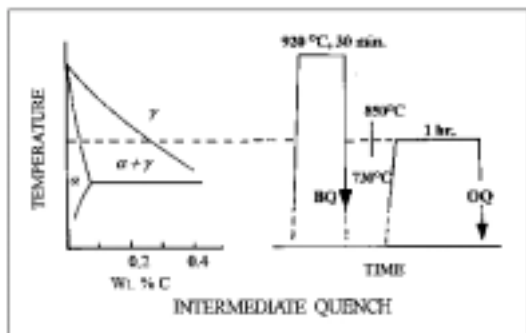


Fig. 1 Schematic representation of heat treatment schedule for the intermediate quench (IQ) treatment

Fig. 2 Typical optical micro graphs of IQ treated specimens corresponding to ICT at (a) 730°C b) 760°C c) 800°C d) 820°C

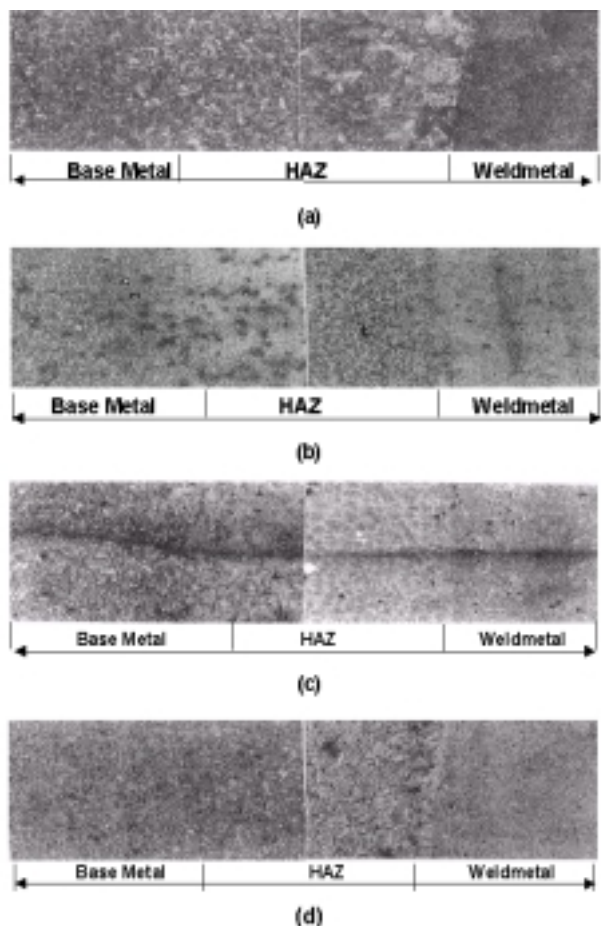


Fig. 3 A typical micro structure gradient of weld metal –HAZ –Base metal corresponding to weldment (a) A73 (b) A76 (c) A80 and (d) A82

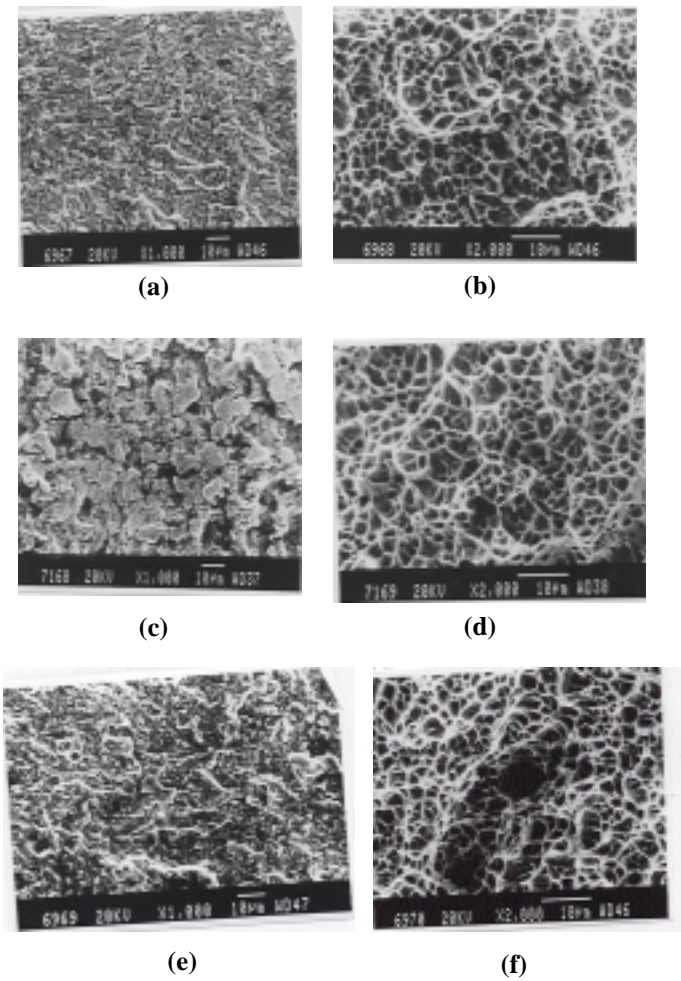


Fig. 4 Typical fractograph of broken $\frac{1}{2}$ CT welded specimen in weld metal region when observed under SEM. Photograph (a), (c) and (e) represent slow crack growth region corresponding to A76, A80, and A82 at 1000X. Photograph (b), (d) and (f) represent fast crack growth region corresponding to A76, A80 and A82 at 2000X