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Effect of Heat Input on the Weld Metal Toughness of Chromium-Molybdenum Steel

M. S. Kaiser

***Abstract*—**An attempt has been made to determine the strength and impact properties of Cr-Mo steel weld and base materials by varying the current during manual metal arc welding. Toughness over a temperature range from -32 to 100°C of base, heat affected zone (HAZ) and weld zones at three current settings are made. It is observed that the deterioration in notch toughness at any zone with the temperature decreases. The values of notch toughness for all zones at -32°C are almost same for any current settings. The values of notch toughness at HAZ area are higher than that of weld area due to the coarsening of ferrite grain of HAZ occurs with higher heat input. From microhardness and microstructure result, it can be concluded that large inclusion content in weld deposit is the cause of lower notch toughness value.

***Keywords*—**Chromium-Molybdenum steel, post-weld heat treatment, heat affected zone, microstructure**.**

I. INTRODUCTION

CHROMIUM-MOLYBDENUM steels used mainly in power plants, fertiliser plants and oil refineries at service temperatures up to 600°C and high pressure up to 30 MPa. They are distinguished from other low- alloy steels by their remarkable oxidation resistance, resistance to sulphide corrosion and high temperature strength or creep resistance. These properties are derived from chromium and molybdenum and they improve with the increase of these alloying elements [1, 2]. Cr-Mo steels are readily weldable with the conventional arc welding and electroslag processes. Alloy content of the base and weld metal and associated thermal cycle during welding demand that correct welding procedures including preheat, postweld heat treatment, low-hydrogen consumables and proper filler metal chemistry are required to prevent heat affected zone (HAZ) and weld-metal cracking [3]. Effects of welding parameters (i.e. heat-input, filler metal composition, number of passes) on the mechanical properties and influence on the microstructure were studied to control the cold cracking and provide adequate weld zone toughness for resistance to fatigue cracking [4-5]. Improve mechanical properties associated with alteration of weld zone microstructure is a great concern and various attempts are being made to optimise weld productivity with adequate toughness by controlling welding heat [6].

In the present work, an attempt has been made to determine the impact properties of Cr-Mo steel weld and base materials by varying the current during manual metal arc welding. Microhardness profiles along the weld centre line to base materials and metallographs of these areas are also studied to find out the notch toughness in the weld area as compared to heat affected zone (HAZ).

II. EXPERIMENTAL

The material used in the present investigation was obtained in the form of a Cr-Mo steel pipe having 132 mm outer diameter and 20 mm thick. A single-vee butt joint with an angle of 60° and a root face of 1.5 mm was prepared along the circumference of the pipe. Oxy-acetelene flame was used before the weld deposit was made to preheat the pipe and the preheat temperature was maintained to about 300°C. Shielded metal arc welding process was used for welding joint. Weld deposit was made with a covered electrode of 4mm consisting of a core wire of matching alloy contents of base metal associated with an alternating current (AC) power source. Variation in welding current 100 A, 150 A, and 250 A with a constant voltage of 50 V was considered as the welding process variables. The chemical composition of the Cr-Mo alloy steel pipe and the weld metal used in the present investigation were determined using wet chemical and spectrochemical methods simultaneously and are given in Table I.

Postweld heat treatment of the welds was conducted at the holding temperature of 650°C for two hours followed by furnace cooling to room temperature at a maximum rate of 70°C per hour. Microstructure was examined using conventional metallographic techniques. The transverse specimens were ground and polished using standard metallographic technique and afterwards etched in a 5% nital. Microhardness profiles from weld centre line to base metal at mid-thickness of stress relived samples were made using a Shimadzu micro-hardness tester applying 50 g loads for 15 seconds by a pyramidal diamond indentor. The Charpy-V impact toughness was determined at four temperatures using five test pieces at each test temperature. Cryogenic test temperatures were attained by quenching the samples in liquid nitrogen for 60 minutes. Immediately after soaking time samples were placed at working table of the Charpy impact tester. Fire blower was used for the temperature 75°C and 100°C. The surface temperature of samples was continuously monitored using the digital thermometer capable of measuring the temperature ranging from -38°C to 356°C. As soon as the specimen reached the desired surface temperature the impact test was conducted just releasing the pendulum already set at standard lift angle. Standard sized 10x10 mm specimens were

Md. Salim Kaiser, Dr., Deputy Director, Directorate of Advisory, Extension and Research Services, Bangladesh University of Engineering and Technology, Dhaka- 1000, Bangladesh (Fax: 0088-02-9665622, phone: 0088-02-9663129, Cell No. 0088-01712280843, E-mail: mskaiser@iat.buet.ac.bd).

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used. Testing was performed in accordance with ASTM E23. Specimens were made from weld produced at three different current levels and the notches were placed at weld deposit area, base metal and HAZ regions of each weld.

TABLE I
CHEMICAL COMPOSITION (WT %) OF BASE METAL AND WELD METAL

Material	C	Mn	P	S	Si	Cr	Mo	Fe
Base	0.14	0.44	0.01	0.01	0.36	1.02	0.55	bal
Weld	0.08	0.45	0.01	0.01	0.28	0.78	0.65	bal

III. RESULTS AND DISCUSSION

A. Microstructure

Fig. 1a shows the microstructures of base metals after obtaining PWHT at a temperature of 650°C for 2 hours. It consists of ferrite and constituents similar to grain-shaped pearlite, in condition after normalization annealing and tempering. Carbides of different dispersion can be seen within the boundaries of ferrite grains and in the grains. After this annealing the pearlite is spheroidized, making the microstructure more stable [7].

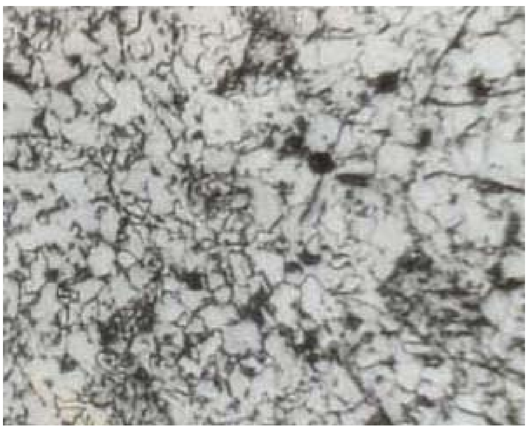

Fig. 1 Optical micrographs (a) base metal (b) heat affected zone and (c) weld metal deposited at a current value of 150A

These postweld heat treated HAZ microstructures are much fine than those of postweld heat treated base metals. Ferrite grains were found in these postweld heat treated HAZ. Carbide precipitation was found along grain boundaries. Fig. 1c shows the microstructure of weld metal after PWHT was done at 650°C for 2 hours. These obtained microstructures are different from those of HAZ and base metal zones. In general, the microstructures consist of more coarsening grain structures occurring due to a sufficient level of welding heat to transform the structure to coarsen austenite grain structure and cooled down later to be coarsening bainite grain structure instead. However, after applying PWHT, all microstructures would transform again to ferrite structure with carbide precipitation. HAZ microstructure after 6-hours PWHT consists of most coarsening ferrite grain structure [8].

B. Microhardness

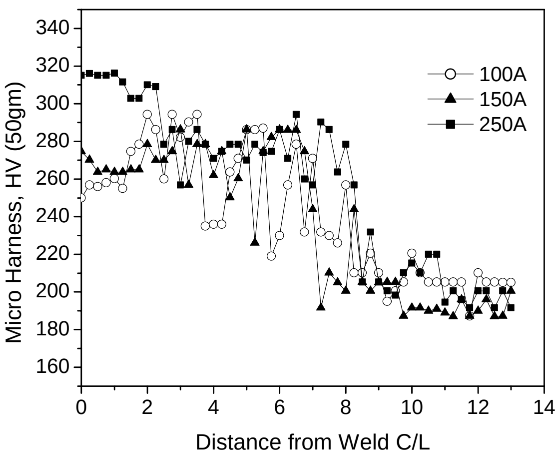

Fig. 2 Variation in microhardness of different area measured at room temperature for Cr-Mo steel welded at various curent settings

Microhardness measurement from weld centre line towards base metal after stress relieving clearly demonstrates the lowering of values as shown in Fig. 2. This descending trend associated with large inclusion content in weld deposit is attributed to lower notch ductility in weld deposit and this is also supported by metallographs where the finer grains are observed in weld deposit compared to HAZ area. The hardness weld metal Increases due to the gamma prime precipitates in the matrix [9]. This precipitation obstructs the dislocation movement resulting in increase of hardness.

C. Impact Energy

The results for impact energy of weld deposit and HAZ area of stress relieved samples at different current settings are plotted as a function of temperature and are shown in Fig. 3 and Fig. 4 respectively.

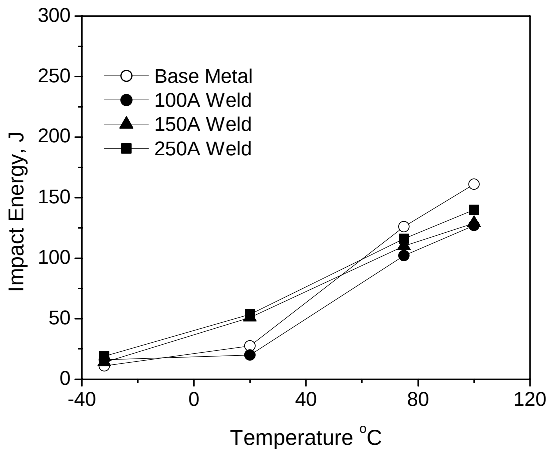

Fig. 3 Impact energy-temperature relationships for Cr-Mo weld, depositing weld metal at various current settings

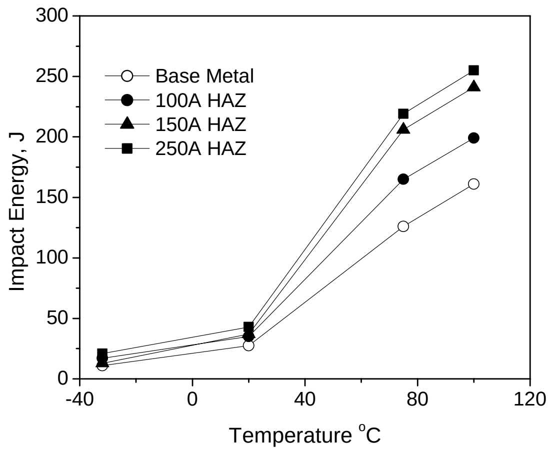

Fig. 4 Impact energy-temperature relationships for Cr-Mo HAZ, depositing weld metal at various current settings

It is seen from those figures that cryogenic test temperature (-32°C) the impact energy absoluted in the lowest and no significant change occur with the current for both the weld deposit and HAZ. This is due to the brittle fracture of the metals on the fracture mode changes to the brittle from ductile mode at the cryogenic test temperature. With increasing test temperature the impact energy absorbed in increased in both the weld deposit and HAZ as the metal fracture mode change to brittle to ductile at higher temperature [4]. It is also observed from Fig. 3 and Fig. 4 that at higher temperature impact energy increases with increasing welding current as well as higher heat input for both zones. It is thought that with increasing heat input, the grain size becomes finer which are pinned with molybdenum and chromium carbide particles. Impact energy absorbed by HAZ at higher temperature is found to higher as compared to weld deposit because the coarsening of ferrite grain of HAZ occurs with higher heat input.

IV. Conclusion

The microstructure formed from carbon rich austenite in the specimen containing molybdenum changed from bainite and martensite to polygonal ferrite and fine grain pearlite. Variation in microstructure gives the varying hardness values in the base, HAZ and weld regions at any current settings and the weld area has the maximum hardness. Toughness increases as the test temperature is increased and at sub-zero temperature insensitive to all test area and heat input. Impact values of weld are less than that of HAZ area at any current settings and test temperature.

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