INFLUENCE OF MICROSTRUCTURE ON WELDMETAL TOUGHNESS PROPERTY OF LINE PIPE STEEL

S.K.Chaudhuri & V. Ramaswamy

Research & Development Centre for Iron & Steel
Steel Authority of India Limited
Ranchi 834002: INDIA

ABSTRACT

The severity and the extent of non-polygonal/acicular ferrite structure has been varied by altering the Molybdenum content in the weldmetal. The degree of acicularity was estimated by measuring the grain size and also by comparison of dislocation densities which in turn influenced the residual stresses. Behaviour of toughness and strength properties of parentmetal, heat affected zone (H.A.Z) and weldmetal were studied at room temperature and sub-zero temperatures and these were co-related with their microstructures. Besides, the critical crack lengths were estimated for the parentmetal and weldmetal of a pipe samples at various temperatures. Furthermore, the minimum requirement of Charpy V-notch energy to produce crack arrest by the parentmetal was also estimated.

Higher toughness properties of the weld zone were ensured even at lower temperatures when the crack propagated by forming very fine dimples. In comparison, H.A.Z. toughness was severely affected by lowering the temperature when the crack appeared to be nucleated at different planes in a brittle manner.

KEYWORDS

Weldmetal; Microstructure; Acicular Ferrite; Molybdenum; Electrode; Residual Stress; Dislocation; Toughness; Critical crack length;

INTRODUCTION

One of the important considerations for the line pipe welding is that the welded joint should have adequate toughness and strength and it is also desirable that these properties are retained even at sub-zero temperatures. In the case of low carbon steel such unique properties can be derived by having an acicular/fine grained ferritic structure. The degree of acicularity is controlled by the extent of micro alloying elements that are added to low carbon steel and subsequent processing history as observed by Smith and co-workers (1971).

It has often been noted that even after achieving a most favourable microstructure in the welded joints, the material fails in service condition. The reason being no welded joints are free from defects. Moreover, these areas are generally associated with higher amount of residual stresses. Under such circumstances, any physical discontinuities located in this critical zone will cause stress concentration which leads to a catastrophic failure. In order to guarantee the performance of such welded joints in service, it is therefore necessary to establish certain guide lines for preventing crack initiation leading to an unstable fracture. For example, the critical crack opening displacement values measured at different test temperatures can be used for estimating the allowable defect size that can be present either in the state of through thickness or in buried form. In addition, Maxey's (1974) empirical relation was used to estimate minimum Charpy V-notch energy required by the parentmetal, if a crack emanating from the weld zone has to be arrested by parentmetal.

In this paper it is intended to show that by varying the Molybdenum content in the weld wire the acicular ferrite structure can be varied in the weldmetal and this in turn affects the mechanical properties. The various mechanical properties were evaluated for the parentmetal, weldmetal and heat affected zone at different test temperatures and correlated with their microstructures. This will enable to establish a suitable microstructure which will provide adequate toughness and strength properties in the weldmetal.

EXPERIMENTAL PROCEDURE

7.2mm thick API X-52 grade Hot rolled coil having a chemical analysis as given in Table I was used in the present investigation. The edges of the cut out plates from the coil were prepared in such a way that the included angle between the faces was 45°. The plates were clamped together in a cross seam welding head of the spiral weld machine. For each assembly, a different electrode wire was used with a Lincoln 761 flux and maintaining a heat input of 0.8 KJ/mm. Altogether three electrode wires were used having 0.60%, 0.41% and 0.38% molybdenum content. The chemical analysis of the wires used are given in Table 2; and Table 3 gives the details of submerged arc welding conditions.

TABLE 1 Chemical Analysis of API X-52 Grade Hot Rolled Coil.

%C	%Mn	%Si	%P	%S	%V
0.22	1.19	0.20	0.03	0.03	0.04

TABLE 2 Chemical Analysis of Electrode wires

	%C	%Mn	%Si	%P	%S	%Mo
Type 1	0.1	1.2	0.12	0.02	0.02	0.60
Type 2	0.09	1.0	0.04	0.21	0.02	0.41
Type 3	0.07	1.15	0.05	0.02	0.02	0.38

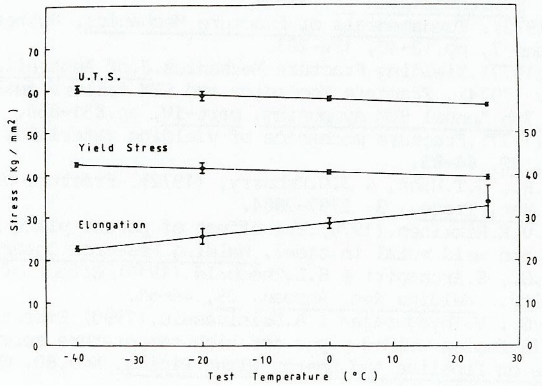
TABLE 3 Welding Parameters

Type of Welding	Current (Amp)	Voltage (Volt)	Welding Speed (m/min)	Av. Heat input (KJ/mm)
Spirally Welded Pipe	560	30	1.0	1.2
Hot rolled flat plates	400	30	0.9	0.8

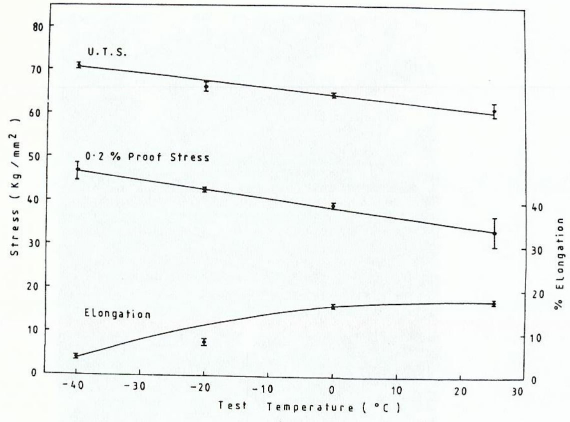
After depositing the first layer the plate was reversed and a second bead was deposited. Before collecting the test samples from each plate, the entire length of the weld bead was examined by radiography. After this examination, test samples were collected from each zone and tested at room temperature and various sub-zero temperatures. For comparison of mechanical properties the electrode wire having 0.38% Molybdenum was used for making a 608.8 mm diameter spiral welded pipe. Residual stresses were measured by single exposure X-ray technique with CoK_{α} radiation using back reflection photographs.

RESULTS AND DISCUSSION

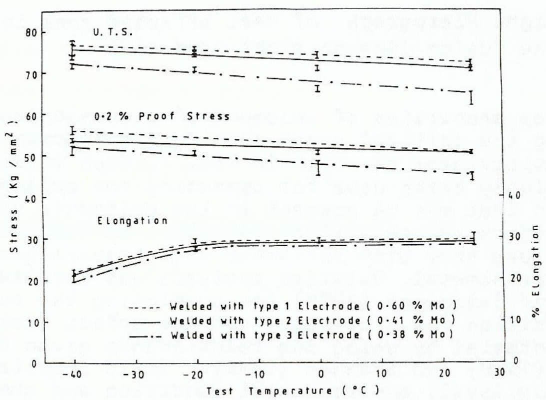
Figures 1. a,b and c give the tensile properties of parentmetal as well as heat affected zone and weldmetal respectively tested at various temperatures. It is evident from the figures that unlike parentmetal and weldmetal, the ductility of H.A.Z. was severely affected when tested at lower temperature while the strength did not vary much. Interestingly, such properties of weld zone for all three cases showed reasonably higher value at all test temperatures and this was further confirmed from Charpy V-notch toughness measurements as shown in Fig. 2. Besides this, the highest toughness was achieved when higher Molybdenum bearing electrode was used.



a



b



c

Fig. 1. a,b & c. Tensile properties of Parentmetal (a) Heat affected zone (b) and Weldmetal (c) at different test temps.

An increase in Molybdenum content also increases both the severity and the extent of acicularity in ferrite structure as shown in Fig. 3. a,b & c. Similar observations were made by Bernard and co-workers (1976). The average length and width of grain size were found to be (3.5x0.87µm),(5.5x1.25 µm) and (9.0x1.5µm) with increasing order of severity in acicular structure when the prior Austenite grain size in the weld zone was approximately 50 µm.

It has further been observed that with the increasing acicularity caused by different levels of Molybdenum content the extent of dislocation density within the ferrite grain increases to a considerable extent and this has been shown in Fig. 4. a,b & c. This is in agreement with earlier findings of Tither and co-worker (1975). In addition, very fine precipitates of $\simeq$ 100 Å size were also observed and these were identified as Mo_2C by electron diffraction analysis.

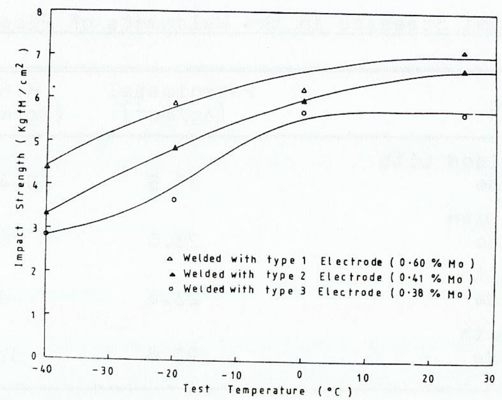
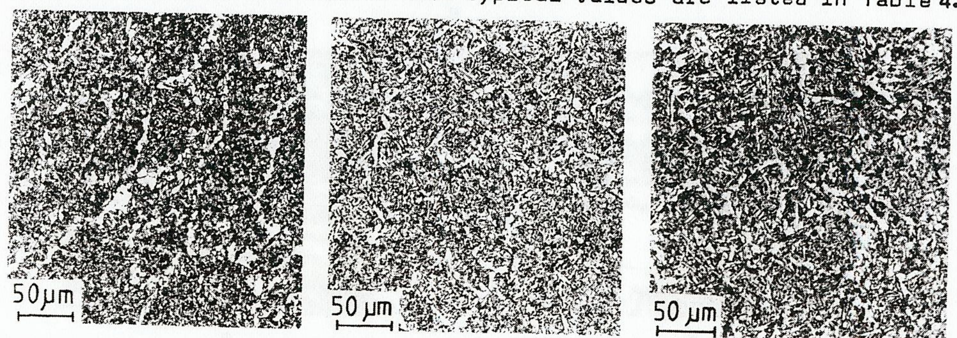


Fig. 2. Charpy V-notch values of different Weldmetals.

From these observations it is concluded that the appearance of higher amount of dislocation density is mainly due to the presence of stresses arising from the phase transformation, fine precipitates and due to the contractional effect during cooling.

Table 4 gives the residual stresses measured in the weldments of all the welded plates and pipe sample. Higher values of stresses in the weldmetal are found to be associated with the acicular ferrite structures.

Fractography studies were carried out on broken samples and these showed that even at $-40^{\circ}C$ the fracture surface of weld zone was essentially a dimple rupture and the size of each dimples were very small. On the other hand, the H.A.Z. consists of very coarse bainitic structure (Fig. 5) resulting in very poor toughness. In this zone the average grain size was of the order of 110 µm whereas the parentmetal grain size was 11µm only. The lower toughness value in this critical zone also reflected in the hardness value surveyed across the weld zone as shown in Fig. 6. Furthermore, these areas are associated with higher degree of residual stresses caused by thermal stresses and some of the typical values are listed in Table 4.



a b c

Fig. 3. a,b&c. Influence of increasing Mo content in Ferrite Structure.

TABLE 4 Residual Stresses in the Weldments of Pipe and Plate Samples

Type of Welding	Parentmetal (Kg/mm^2)	H.A.Z. (Kg/mm^2)	Weldmetal (Kg/mm^2)
Spiral Pipe Welded with Type 3 Electrode	27.5	40.4-48.1	23.15
Plates Welded with Type 3 Electrode	23.6	26.5	4.13
Plate welded with Type 2 Electrode	23.6	41.3	8.26
Plate welded with Type 1 Electrode	23.6	37.23	33.09

In case of welded pipe samples the residual stresses of all three zones were found to be little higher compared to plate sample. The severity of stress at the weld zone was found to be much greater and was primarily due to faster cooling rate and use of higher heat input of 1.2 KJ/mm.

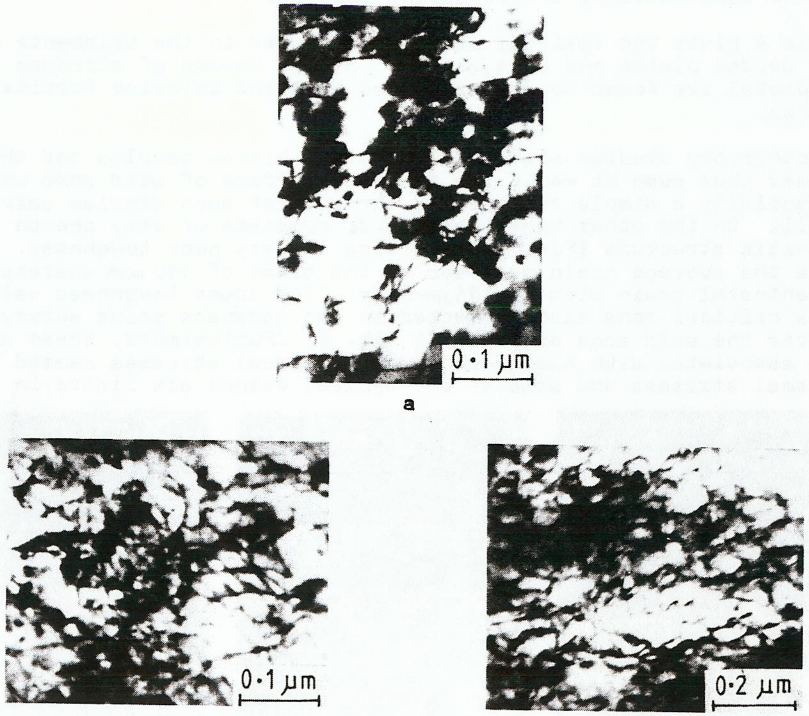


Fig. 4. a,b & c. Electron micrographs showing dislocation structure.

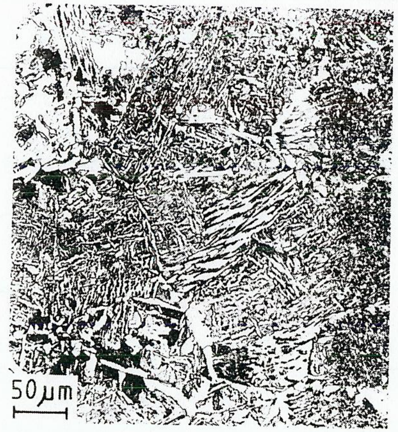


Fig. 5. Light Micrograph of Heat affected zone indicating the fusion line on right hand side .

The toughness properties of weldments of pipe samples were estimated by measuring the critical crack opening displacement values at various test temperatures as shown in Fig. 7. Such material information is progressively being used for computing the critical dimension of crack length that may be present in the weldments either in the form of through thickness or surface defects. In Table 5 it is shown how such values vary with different test temperatures for the weldmetal and parentmetal. Detailed analysis was carried out by Chaudhuri and Ramaswamy (1979) for predicting the rupture and no rupture condition for a critical surface defect that may be present in the parentmetal by using the relationship given by Hahn and co-workers (1969) and Shannon (1974). It is important to note that if the stress level, environmental condition and the dimension of defect are controlled to a sufficient extent it is less likely that the crack will initiate from the existing defects. If any one of these factors go out of control, it may still be possible to check a disastrous failure by arresting the crack emanating from the weldmetal at the weld - parentmetal interface. This is true only when the toughness of the parentmetal is sufficiently high. Maxey (1974) has proposed an empirical relationship by which it was possible to predict the minimum Charpy V-notch toughness property required for the X-52 grade pipe material in arresting the propagating crack.

TABLE 5 Calculated Critical Crack Length Values (mm)

	25^{0}C	0^{0}C	-20^{0}C	-40^{0}C
For Parentmetal	26.3	21.5	7.2	5.1
For Weldmetal	36.9	35.1	26.8	20.9

At room temperature the calculated Charpy value from the Maxey's formula was about 15J when the operating stress level was 62% of the minimum yield stress. The experimental Charpy V-notch value obtained was 18J which means that such X-52 pipe material should not be operated beyond 65% of the minimum specified yield stress if crack has to be arrested successfully. Considering all the aspects of various mechanical properties and microstructure obtained the following conclusions can be drawn.

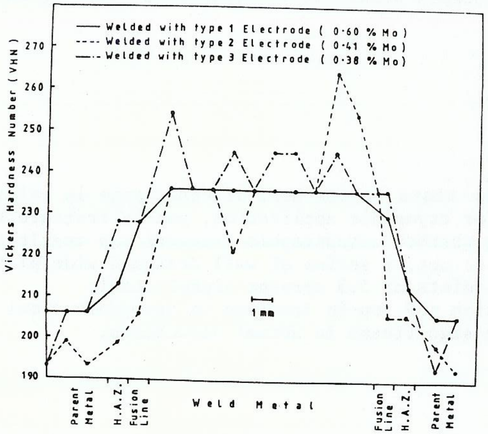


Fig. 6. Hardness variation across the weld for three different electrodes.

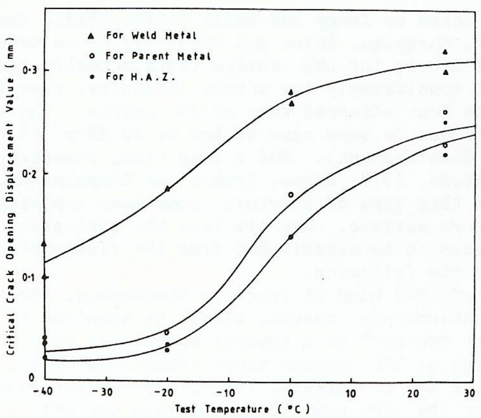


Fig. 7. C.O.D. values at different test temperatures.

CONCLUSIONS

1. With the increasing percentage of Molybdenum in the electrode wire the degree of acicular ferritic structure is increased. This in turn increases the dislocation densities which give rise to higher degree of residual stresses.

2. Acicular ferrite structure is found to be superior both in strength and toughness property even at sub-zero temperature as compared to a mixed structure of acicular and irregular ferrite. Higher strength is ensured due to the appearance of very fine scale precipitation of Mo_2C.

3. The toughness property of H.A.Z. is extremely poor and this is associated with higher residual stress and very coarse bainitic structure.

4. An unstable crack emanating out of the welded zone could be arrested in the parentmetal provided its toughness is high enough. For X-52 grade pipe steel at room temperature such crack may be successfully arrested when the maximum operating stress does not exceed 65% of the yield stress.

ACKNOWLEDGEMENTS

The authors are very grateful to Dr.G.Mukherjee, Director, Research & Development Centre, Ranchi, for his permission to publish this paper. They are grateful to Dr.S.K.Gupta, General Manager, Research and Development Centre, for his support and help.They are thankful to Dr.N.S.Datar, Managing Director and Mr.M.M.Aeron, Superintendent, Pipe Plant, Rourkela Steel Plant, for giving the facilities for carrying out the trials at the spirally welded pipe plant, Rourkela. Besides, the help rendered by the Welding Research Institute, BHEL, Tiruchi, Indian Institute of Technology, Madras and National Metallurgical Laboratory, Jamshedpur, are gratefully acknowledged.

REFERENCES

Bernard,G., F. Faure and Ph.Maitrepierre (Nov.1976). Proceedings of an International Conference on Welding of HSLA(Microalloyed) Structural Steels, American Soc. for Metals, Ohio. pp. 187-211.

Chaudhuri, S.K. and V. Ramaswamy (1979). Steel India, Vol.2, No.1,1-6

Hahn,G.T., M.Sarate and A.R.Rosenfield (1969). Int. J. of Fracture Mechanics Vol.5, 187-210.

Maxey, W.A.(Nov.1974). 5th Symposium on Line Pipe Research, American Gas Association.

Shannon, R.W.E. (1974). Int. J. of Pressure Vessels and Piping, Vol.2, 242-253.

Smith,A.E., A.P. Coldren and R.L.Gyderman (Oct 1971). Proceedings of Symposium on towards improved Ductility and Toughness, Climax Molybdenum Development Company, Japan. pp. 119-142.

Tither, G. and M. Lavite (1975). J.of Metal, Vol.27, 15-23.