EFFECT OF PRIOR HEAT TREATMENT OF BASE METAL ON THE DEFORMATION BEHAVIOR OF HEAT AFFECTED ZONES

C.R.Das[1], A.K.Bhaduri[1], S.K.Albert[1] and B.S.Murty[2]
[1]Materials Joining Section, Materials Technology Division,
Indira Gandhi Centre for Atomic Research, Kalpakkam 603102, India
[2] Department of Metallurgical and Materials Engineering,
Indian Institute of Technology – Madras, Chennai 600036, India

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Abstract:
Instrumented hardness tests on the different heat-affected zones (HAZs) present in weldments of modified 9Cr-1Mo steel, exhibit lower curvature of the loading line for the inter-critical HAZ (ICHAZ) compared to that for the other HAZs irrespective of the initial heat treatment given to the base metal. The curvature of the loading line for the ICHAZ for the weldment made from this material subjected to higher solutionising treatment temperature (1150°C/1h and 760°C/3h) is higher than that for the ICHAZ for the weldment made from material subjected to the conventional higher solutionising treatment temperature (1050-1070°C). The increase in the curvature of the loading line could be correlated to the increase in resistance against indentation of the material with increase in solutionising treatment temperature.

1. INTRODUCTION

Modified 9Cr-1Mo steel is used extensively in fossil power plant, petrochemical industry, steam generator and many other heat transport system due to its good physical and mechanical properties [1-2]. However, weld joints of this steel are susceptible to Type IV cracking during long term service. Cracking of weld joints is classified according to the position of the crack present in the weldment. When cracking occur within the weldmetal, it is designated as Types I and II, with the former being confined within the weldmetal and the later growing into the base metal. Type III cracking occurs in the coarse grain heat-affected zone (CGHAZ), while cracking in the fine grain HAZ (FGHAZ) and inter-critical HAZ (ICHAZ) is designated as Type IV. The reason for Type-IV cracking is the presence of metallurgical notch in the ICHAZ due to the presence of a soft metal zone in the graded HAZ microstructure (which develops during welding because of thermal cycling effects) that has different mechanical properties [3-4]. The enhanced rate of creep void formation in the FGHAZ and ICHAZ of the weldment, as compared to the base metal, leads to premature failure. Similar weldments fail in the base metal during short term tests at high stresses with the failure location shifting to the ICHAZ/FGHAZ at lower stress during long term creep tests [5]. During creep, particle occupancy increases in the ICHAZ/FGHAZ due to the fine grain size and low dislocation density compared to other material zones of the weldment [6]. For increasing the life of ferritic steel weldments in order to increase the thermal efficiency of power plants, the resistance of the material against creep nees to be improved [7]. Improvement of creep resistance of ferritic steels can be done by stabilizing the microstructure near the grain boundaries [5]. However, there is very little and scattered work [5] on improvement of Type IV cracking resistance of modified 9Cr-1Mo steel by changing the heat treatment temperature without changing the basic composition.

Therefore, attempt has been made in this work to increase the prior austenite grain size of the steel by changing the heat treatment temperature for improving of creep resistance property of the weldment. It is known that austenite formation at the transformation temperature during heating depends on the grain size of the material, since austenite formation is a nucleation based process. Therefore, austenite formation in the ICHAZ, during welding thermal cycle is a function of the lath size/grain size. In addition to the grain-size effect, dissolution of precipitates is incomplete in the ICHAZ [5-7] due to the limited time available for dissolution of precipitates ($M_{23}C_6$) during the weld thermal cycle. Therefore, the martensite formed in the ICHAZ will have a lower strength than that formed in the FGHAZ and CGHAZ. Also, the formation of martensite in the ICHAZ is incomplete. Hence, the formation of austenite during heating and formation of martensite during cooling in the ICHAZ of the weldment made from material with larger grain size will be low. Consequently, the mechanical properties of the weldment would be better as. A clear understanding of this interdependent variation is evolving. In this preliminary work it is attempted to correlate the prior austenite grain size to its hardness.

Though, weld simulators can simulate the microstructure of the HAZ of weldments in larger dimensions than in the HAZ formed in actual weldments during welding, the dimensions of the simulated HAZ are still quite small for carrying out meaningful full-scale creep tests. It is in this context that the instrumented indentation method, which provides continuous record of the indentation load (p) as a function of the depth of penetration (h) into the specimen have been used in the preset study. This test method has advantage over other mechanical test methods with respect to the requirement of adequate specimen dimensions. Mechanical properties, such as Young's modulus yield strength and strain hardening exponent as well as fracture toughness of the material, can be obtained from the continuous record of the indentation [8]. In the present work, room temperature deformation behavior of different HAZ is discussed.

2. EXPERIMENTAL

The chemical composition of the as-received normalised and tempered material used in is given in Table 1. The as-received material was subjected to solution annealing heat treatment at 1150 and 1200°C for 1 h and then tempered at 760°C for 3 h. Weld joints were prepared with the different heat treated plates by using shielded metal arc welding (SMAW) process using

E9016 B9 electrodes. After post weld heat treatment (PWHT) at 760°C for 3h, the weldments were subjected to X-radiography and found to be sound. The different weldments are designated as WM1 (as-received), WM2 (1150°C/1h) and WM3 (1200°C/1h) based on the heat treatment condition used for the material.

Table 1: Chemical composition of modified 9Cr-1Mo steel plate

C	Cr	Mo	V	Nb	N	Mn	Si	S	P
0.1	9.5	1	0.25	0.1	0.65	0.39	0.5	0.009	0.021

Specimens of size 10 mm × 12 mm × 30 mm were obtained from the weldments WM1, WM2 and WM3, and each specimen included the weld metal, HAZ and base metal. These specimens were used for instrumented microhardness measurements of different zones of the weldments. Cross-weld tensile tests were carried out using round tensile specimens (as per ASTM E8) of weldments WM1 and WM2 using a strain rate of 6.2×10^{-4} s^{-1}. The microstructure of the weldments was observed using an optical microscope. The microhardness tests were carried out using a loading rate of 100, 125 and 200 $\mu m.s^{-1}$ and an unloading rate of 100, 150 and 200 $\mu m.s^{-1}$ at 5N load with a hold time of 5 s.

3. RESULTS AND DISCUSSION

The hardness of the base metal in the solution-annealed condition increases with increase in solutionising heat treatment temperature, with the hardness increasing from 3.2 GPa (for 1075°C/1h heat treated material) to 3.7 GPa (for the 1150°C/1h heat treated material). After 760°C/3h tempering heat treatment, the hardness decreases to 2.2 GPa for the 1075°C/1h heat treated material and to 2.4 GPa for the 1150°C/1h heat treated material.

The hardness profiles across the weld interface of the weldments after 760°C/3h PWHT (Fig. 1) show that the weldmetal has high hardness of 2.60–2.65 GPa, with these hardness values being equivalent to 260–270 VHN obtained by conventional Vicker's microhardness testing [9]. The hardness of the ICHAZ in WM3 of 2.1 GPa (210 VHN) and in WM2 of 1.91 GPa (191 VHN) is higher than that in WM1 of 1.7 GPa (170 VHN).

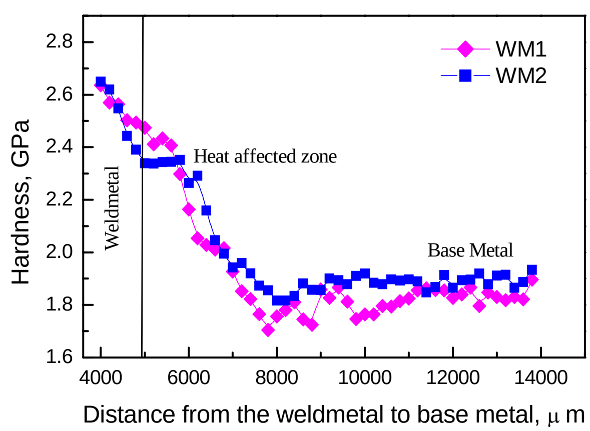


Fig. 1: Hardness profiles across the weld interface of WM1 and WM2 weldments

The load–depth profile for sharp indentation in the ICHAZ of WM1 and WM2 weldments (Fig. 2) show that the loading curve generally follows the relationship $p = Ch^2$, where indentation curvature C is a measure of the resistance of the material to indentation. The value of C for the ICHAZ in WM1, WM2 and WM3 weldments (obtained by fitting a second-order polynomial to the loading line) are 3.58×10^{-5}, 4.9×10^{-5} and 5.15×10^{-5}, respectively. These results show that the curvature of the loading line for the ICHAZ in WM3 weldment is higher than that for the ICHAZ in WM1 weldment, indicating thereby that the ICHAZ of WM3 weldment is harder than that of WM1 weldment. The increase in curvature for the ICHAZ of WM2 and WM3 weldments is about 26.9% and 30%, respectively, compared to that of WM1 weldment. However, the change in curvature of the loading line for the ICHAZ in WM2 and WM3 weldments is marginal (Fig. 2). The strength of the weldment, comprising different material zones, determines the weakest material zone present in the weldment. Increase in hardness of the ICHAZ leads to an over all increase in strength of the weldment. This is in agreement with the results of tensile tests carried out on WM1, WM2 and WM3 weldments [9], which showed 25% increase in yield strength for WM2 and WM3 weldments compared to WM1 weldment.

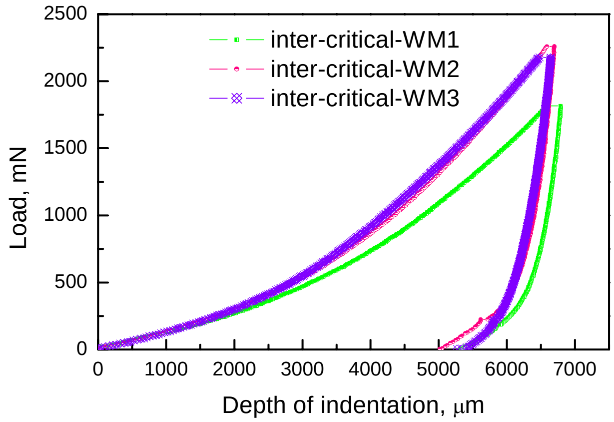
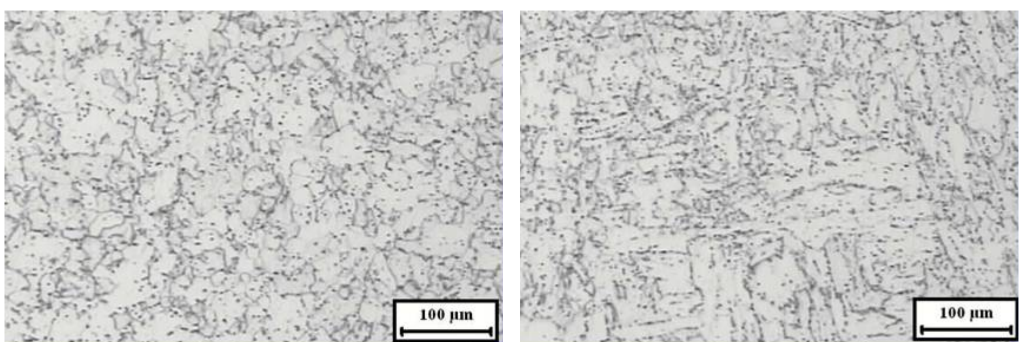


Fig. 2: Load–depth profile for the ICHAZ of WM1, WM2 and WM3 weldments

The microstructure of the ICHAZ shows absence of tetragonality of the lath martensite in the ICHAZ of WM1 weldment (Fig. 3a). Interestingly, although tetragonality has been lost in the ICHAZ of WM1 weldment, it is still present in the ICHAZ of WM2 (Fig. 3b) and WM3 weldment [9]. Thus, increase in curvature of the loading line is clearly indicative of presence of hard microstructure in the weldment.



(a) **(b)**

Fig. 3: Microstructure of ICHAZ in (a) W1 and (b) W2 weldments

The presence of hard microstructure in the ICHAZ of WM2 and WM3 weldments modifies the deformation behaviour in cross-weld tensile test specimen [9]. Double necking (in the ICHAZ and base metal junctions) was observed in the cross-weld tensile tested specimens of WM1 weldment [9]. However, the cross-weld tensile tested specimen of WM2 weldment showed sinle necking in one of the ICHAZ of the cross-weld tensile specimen. Fig. 4 shows the necking behavior in tensile tested specimens of WM1 and WM2 weldments. The hardness profile on both the tensile tested specimens (Fig. 5) clearly shows that the deformation behaviour in the cross-weld tensile test specimens of WM1 weldment is quite different from that of WM2 weldment. This also explains why the curvature of the loading line for the ICHAZ of WM2 weldment is higher than that of WM1 weldment, and can be attributed to the harder martensite formed in the WM2 weldment [9]. Hence, for the same load, higher depth of indentation can be achieved in the ICHAZ of WM1 weldment than in the ICHAZ of WM2 and WM3 weldments.

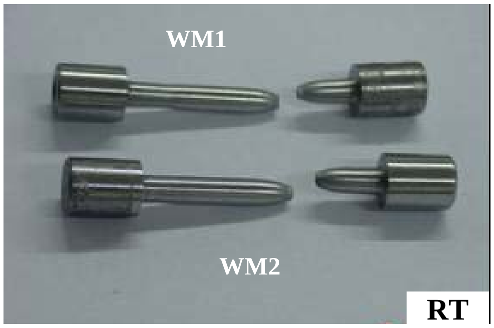


Fig. 4: Tensile tested cross-weld specimens showing presence of double necking in WM1 weldment and single necking in WM2 weldment

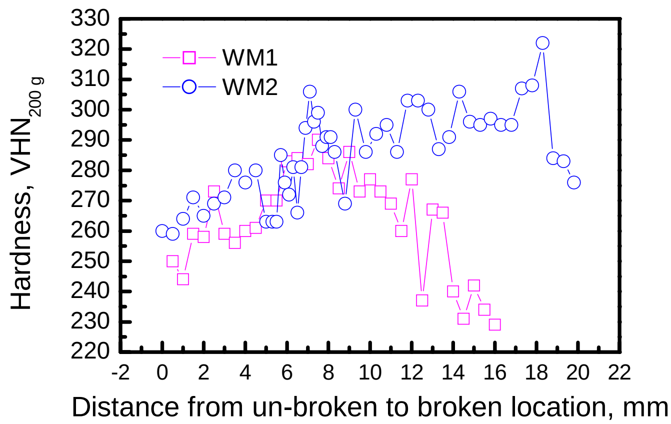


Fig. 5: Hardness distribution on cross-weld tensile tested specimens of WM1 and WM2 weldments

The load–depth profile for different material zones in WM1 weldment (Fig. 6) shows that the curvature of the loading line is higher in the CGHAZ and weldmetal than in the ICHAZ. This indicates that the ICHAZ is softer than the other material zones present in this weldment.

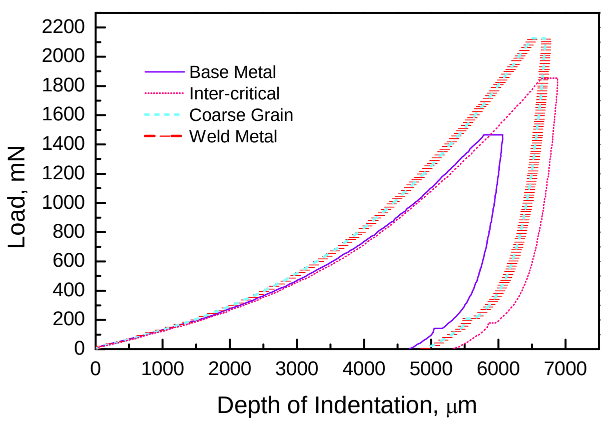


Fig. 6: Load–depth profile for different material zones in WM1 weldment

4. CONCLUSIONS

The present results show that the ICHAZ in WM1 weldment is softer than that in WM2 and WM3 weldments. This can be attributed to the loss of tetragonality of the martensite lath in the ICHAZ of WM1 weldment compared to that in the ICHAZ of WM2 weldment in which partial tetragonality is still present. This is in agreement with the higher curvature of the loading line for the ICHAZ of WM2 and WM3 weldments compared to that of the WM1 weldment.

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