MANUAL METAL ARC WELDING OF MODIFIED 9Cr-1Mo STEEL PIPE

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ABSTRACT

Welding of modified 9Cr-1Mo Steel Pipe has been carried out by two filling passes using Manual Metal Arc Welding (MMAW) process at different energy inputs and post weld heat treatment at different temperatures. Microstructure of the weld and HAZ has been studied and correlated with the post weld heat treatment and energy input of the second pass, where the energy input of the first pass was practically kept constant. At a given energy input of first filling pass the influence of post weld heat treatment and energy input of the second pass on hardness of the weld and HAZ has been studied. At a given preheating the correlation among hardness (weld and HAZ), energy input of first pass and energy input of second pass, observed at different post weld heat treatments has been investigated. The tensile properties of weld joint, prepared at different energy inputs of the second filling pass and post weld heat treated at different temperatures, are also studied. It is observed that the variation in energy input of the first and second filling passes, to control proper filling of the weld groove, affects the microstructure and hardness of the weld and HAZ. The post weld heat treatment at temperatures upto about 1123K(850°C) has been found to retain sufficient strength of the weldment, when the energy inputs of the first and second filling passes of SMAW are kept as about 2.7 and 4.1kJ/cm respectively.

INTRODUCTION

The modified 9Cr-1Mo steel containing small amounts of vanadium and niobium has gathered considerable attention as a power plant material like turbine parts etc. due to its superior creep-rupture properties (1,2) in applications upto about 923-973K (650-700°C). The improvement of this material is primarily attributed to solid solution hardening imparted by the presence of Mo up to 1% [2], precipitation hardening caused by fine precipitation of $M_{23}C_6$ carbides and addition of vanadium to $M_{23}C_6$ precipitate retarding its growth at elevated service temperature. Thus, they give rise to a complex microstructure, which may adversely affect the properties of this steel under an unfavourable thermal environment. The selection of structural steels for fabrication of steam piping and tubing in thermal and nuclear power plants is largely governed by weldability of the material. Due to its high sensitivity to the phase transformations the weldability of 9Cr-1Mo steel significantly depends upon weld thermal cycle under a given welding process along with the pre- and post-weld heating. In fabrication of a power plant, the manual metal arc welding (MMAW) process is commonly used in joining of various components.

Keeping in view the above aspects, an effort has been made in this investigation to study the weldability of a modified 9Cr-1Mo steel pipe under MMAW process. At a given preheating, the effect of energy input in first and second filling passes and the influence of post weld heat treatment at different temperatures on microstructure and hardness of the weld and HAZ and tensile properties of the weldment have been studied.

EXPERIMENTAL PROCEDURE

Welding of hot 1423K(1150°C) extruded modified 9Cr-1Mo steel pipe, having outer diameter and wall thickness of 50 and 5.6 mm respectively, was carried out by employing autogenous TIG welding root pass followed by two filling passes using MMAW process. Chemical composition of

Table - I
Chemical Composition of the Steel Pipe

	Chemical Composition								
	C	Mn	Si	Cr	Mo	V	Nb	S	P
Wt.%	0.108	0.35	0.155	8.44	0.91	0.21	0.14	0.018	0.02

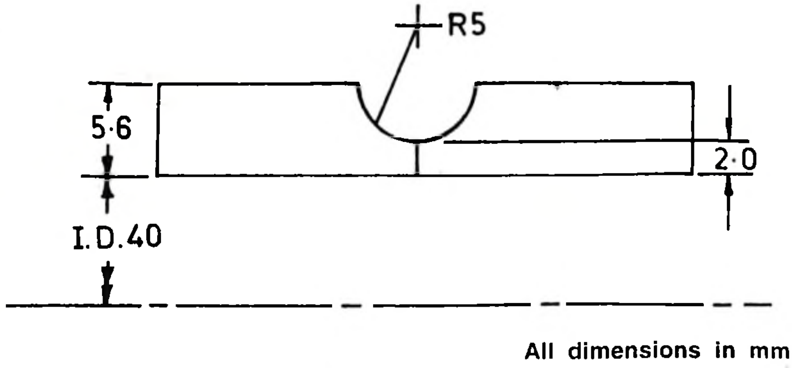


Fig. 1 : Schematic diagram of the weld groove

the steel pipe has been shown in Table-I. For welding, the pipe was cut into pieces of length of 90 mm using band saw, and a U-groove joint preparation was made as schematically shown in Fig. 1. Welding of the pipe was carried out on a three-jaw self centering chuck capable to rotate upto 10 rpm through a stepless motor. A fixture was also arranged to hold the TIG welding torch vertically above the groove so as to facilitate automatic welding of the root pass by rotation of pipes. The welding of pipe was carried out according to the practices recommended by the American Welding Society (3) as follows.

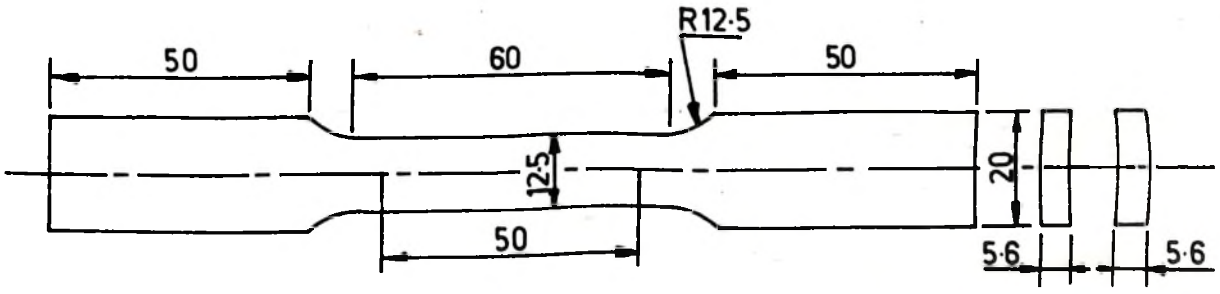
Prior to welding, the weld groove was thoroughly cleaned by wire brushing to remove any unwanted surface contamination followed by preheating at a temperature of 523K(250°C) for 10-15 minutes allowing sufficient hydrogen to diffuse out of the matrix. The preheating was performed using neutral oxyacetylene flame. The preheating temperature was measured with the help of a surface sensing probe connected to a digital thermometer. The root pass was carried out by arranging the pieces so that there is no root gap and by employing autogeneous TIG welding process. The TIG welding was carried out under argon shielding at a flow rate of 10 l/mm and using a 2.14 mm diameter thoriated tungsten electrode having a tip angle of 35°. The root pass was performed by DCEP at a welding current, arc voltage and rotating speed of 70A, 14V and 1rpm respectively.

After carrying out the root pass, rest of the weld groove was filled by two manual metal arc welding (MMAW) passes. The MMAW was performed by using 350 mm long and 3.15 mm diameter basic coated (Philips KV7, AWS A5.4 E505-15) electrode, capable to produce weld deposit containing 9Cr-0.5Mo. The interpass temperature was maintained as the preheat temperature. Prior to welding the electrodes were baked for 1 hr at 523K (250°C) in an electric oven. The MMAW was carried out at different welding parameters of desired energy input as shown in Table-II. The weld joints were given a post weld heat treatment (PWHT) immediately after welding without allowing them to cool down to room temperature. The PWHT was carried out by keeping the weld joints inside an electric muffle furnace for one hour at temperatures of 923K(650°C), 1023K(750°C) and 1123K(850°C), as given in Table II, followed by cooling in normal atmosphere.

Transverse section of the weld joint was prepared by standard metallographic procedure and etched by Vilella's etchant containing picric acid 1gm, Hcl 5ml and alcohol 100 ml, to reveal

Table - II
Scheme of Welding parameters used in MMAW process

Welding Current (A)		Arc Voltage(V)		Energy Input (kJ/cm)		PWHT [K(°C)]
Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	
80	80	24	24	2.72	4.07	923(650)
80	100	24	22	2.72	4.28	923(650)
80	120	24	24	2.72	5.09	923(650)
90	80	25	23.5	3.19	4.20	923(650)
90	100	25	23	3.19	5.24	923(650)
80	80	24	24	2.72	4.07	1023(750)
80	100	24	24	2.72	5.17	1023(750)
80	120	24	23	2.72	6.93	1023(750)
90	80	25	22.5	3.19	4.26	1023(750)
90	100	25	23	3.19	5.28	1023(750)
80	80	24	24	2.72	4.53	1123(850)
80	100	24	24	2.72	5.45	1123(850)
80	120	24	22	2.72	5.97	1123(850)
90	80	24	23	3.06	4.53	1123(850)
90	100	24	23	3.19	4.96	1123(850)



All dimensions in mm

Fig. 2 : Schematic diagram of the tensile specimen

microstructure of the weldment. The microstructures of weld centre and heat affected zone (HAZ) were studied under optical microscope. The hardness of base metal, weld centre and HAZ was studied at a load of 981mN. The hardness of HAZ was studied at a distance of 1mm from the fusion line. Tensile properties of the weld joint were also studied using standard tensile specimen as schematically shown in Fig. 2. The tensile testing was carried out on a universal testing machine operated at a cross head speed of 1mm/min. Elongation of the specimens at fracture was measured at a gauge length of 50mm having weld at its centre.

RESULTS AND DISCUSSIONS

Microstructure

The microstructure of the hot extruded base material, showing the presence of fibrous extruded morphology along with formation of fine tempered martensite in the matrix, has been presented in Fig. 3. The typical appearances of the TIG root pass and MMA weld have been shown in Fig. 4(a) and (b) respectively. The photographs show that the weld quality is practically good and acceptable.

At different energy inputs of first pass of about 2.7 and 3.2kJ/cm. the effect of energy input of second pass and temperature of post weld heat treatment (PWHT) on the microstructure of weld deposit have been shown in Figs. 5 and 6 respectively. The micrographs reveal that the increase in energy input of the second pass comparatively reduces the ferrite content of the matrix and relatively refines/tempers the dark second phase containing martensite, bainite and pearlite. It is also interesting to note that the increase in energy input of the first pass results in a relatively finer microstructure of the weld deposit and the increase in PWHT temperature refines the same significantly. The presence of martensite, bainite and pearlite in the matrix has been identified by their microhardness as (425-440VHN). (340-380VHN) and (225-275VHN) respectively.

The variation in energy input of the first pass has not been found to affect the microstucture of HAZ significantly. However, at a given energy input of the first pass the increase in energy input of the second pass has been found to relatively refine/temper the microstructure of HAZ and the increase in PWHT temperature has been found to refine the same significantly as they are depicted in the micrographs presented in Fig. 7, where the energy input of first pass was kept as 2.7kJ/cm.

Hardness

Hardness of the untreated base material and the effect of heat treatment, at the same schedule as PWHT, on hardness of the base material are shown in Table III. The table shows that the increase in heat treatment temperature enhances the hardness of the base material.

At a given energy input (2.72kJ/cm) of the first pass, the effects of variation in energy input of the second pass and post weld heat treatment temperature on hardness of the weld deposit and HAZ are shown in Figs. 8 and 9 respectively. The figures show that the hardness of both the weld and HAZ reduces relatively with the increase in energy input of second pass, but considerably with the increase of temperature of PWHT upto 1123K(850°C). These behaviours are in agreement to the microstructural features of the weld deposit (Figs. 5 and 6) and HAZ (Fig. 7) as discussed above, showing the refinement of microstructure with the enhancement of energy input of second pass and temperature of the PWHT. At a given energy input of the second pass, the effects of energy input of the first pass and post weld heat treatment temperature on hardness of the weld deposit and HAZ are shown in Figs. 10 and 11 respectively. The figures show that the increase in energy input of the first pass also relatively reduces hardness of the weld, but practically does not affect the hardness of HAZ. The

Table - III
Effect of post weld heat treatment on properties of the base material

PWHT[K(°C)]	UTS[N/mm²]	Hardness [VHN]
0	750	230
923(650)	722	235
1023(750)	721	247
1123(850)	718	259

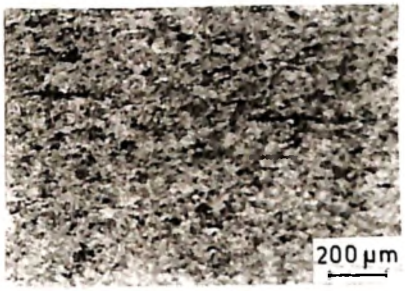


Fig. 3 : Microstructure of the base metal

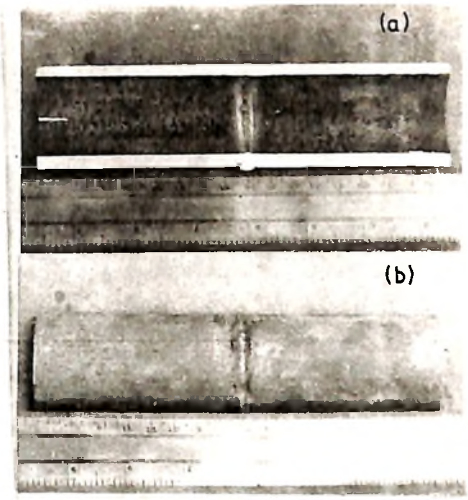


Fig. 4 : Typical appearance of the (a) TIG root pass and (b) MMA weld.

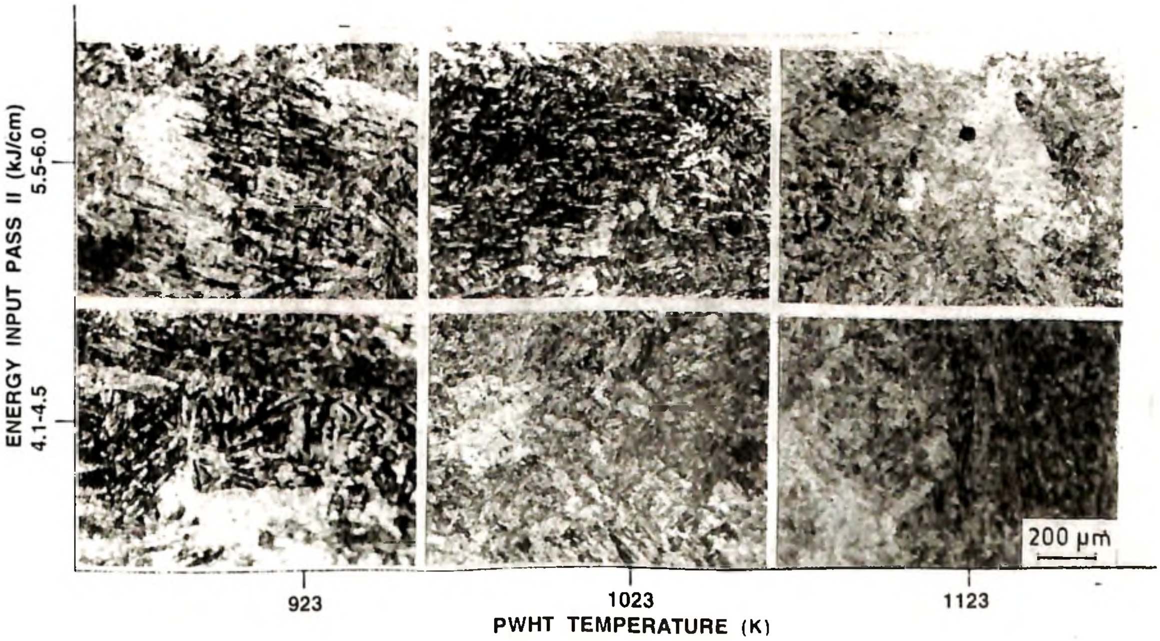


Fig. 5 : At a given first pass energy input of 2.72kJ/cm the effects of energy input of the second pass and temperature of the post weld heat treatment on microstructure of the weld

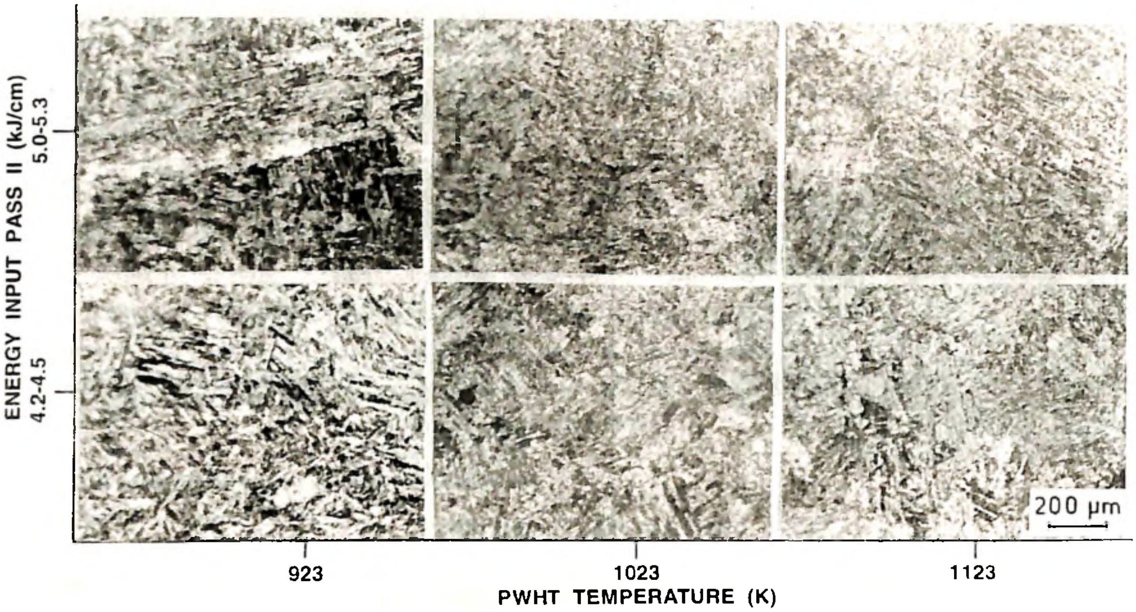


Fig. 6 : At a given first pass energy input of 3.2kJ/cm the effects of energy input of the second pass and temperature of the post weld heat treatment on microstructure of the weld

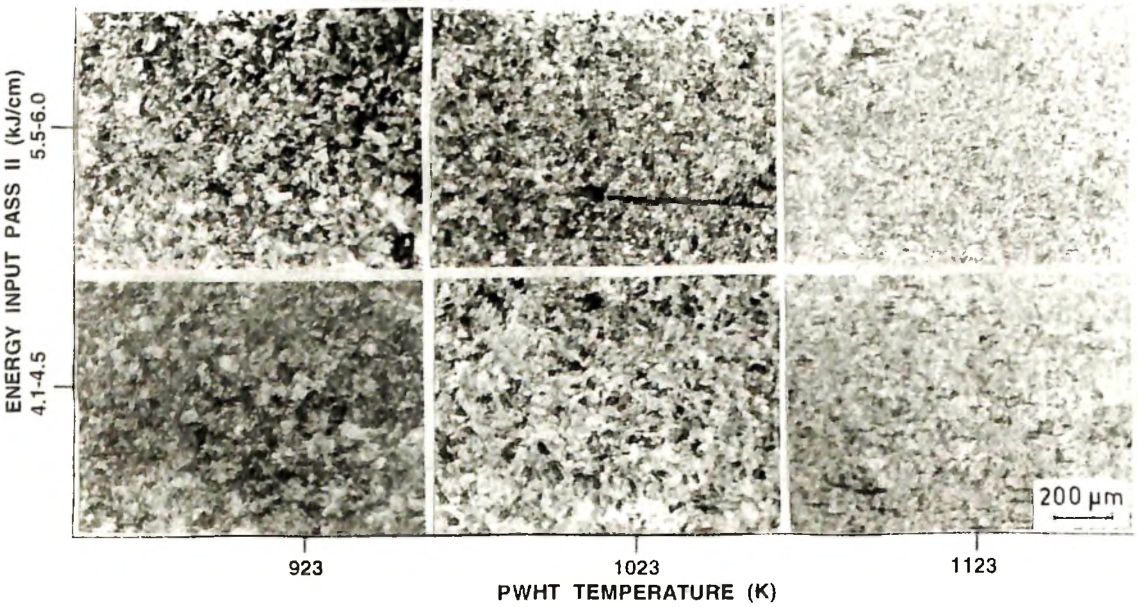


Fig. 7 : At a given first pass energy input of 2.72kJ/cm the effects of energy input of the second pass and temperature of the post weld heat treatment on the microstructure of HAZ.

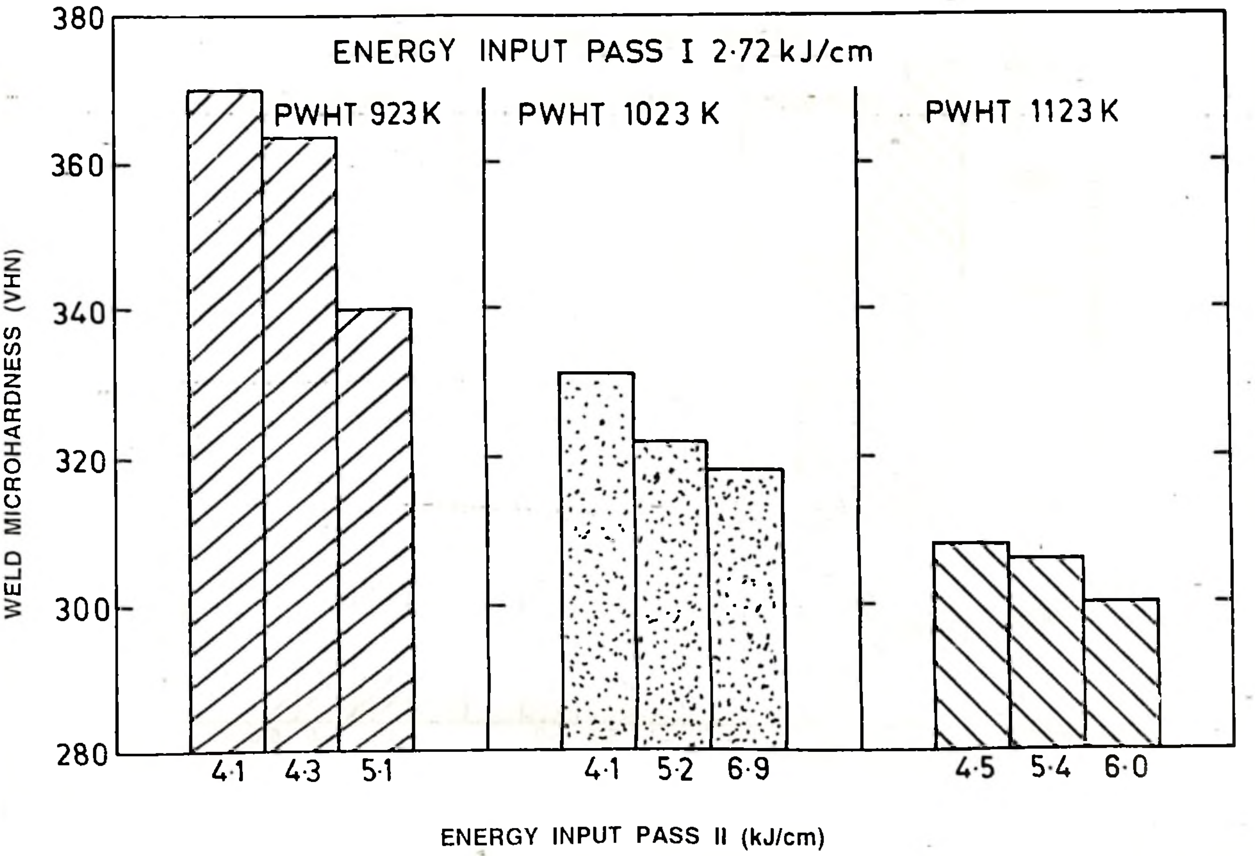


Fig. 8 : At a given first pass energy input of 2.72kJ/cm the effects of energy input of the second pass and temperature of the post weld heat treatment on the microhardness of the weld.

observations are also in agreement to the effect of energy input of the first pass on microstructure of the weld deposit (Figs. 5 and 6) and HAZ as discussed above. Here also, the increase in temperature of PWHT has been found to reduce hardness of the weld and HAZ significantly.

Tensile Properties

The ultimate tensile strength of the base material and its variation with heat treatment at different temperatures, same as PWHT, has been shown in Table - III. The table shows that the strength of the base material reduces significantly during heat treatment at 923K(650°C) followed by no markable change in it with a further increase in heat treatment temperature up to 1123K(850°C). The elongation at tensile fracture of the base material is measured as being of the order of 19%,and it is found to be comparatively reduced to the range of 15-17% with the heat treatment at different temperatures as mentioned above.

During tensile testing of the weld joint the specimens are always found to be fractured from the base material away from the HAZ. Thus, the results obtained from tensile testing of the weld joint do not reflect the effect of variation in welding process parameters (energy input of the first and second pass) on tensile properties of the weld joint, rather they depict influence of PWHT on tensile properties of the base material. The ultimate tensile strength (UTS) and elongation of the weldments post weld heat treated at 923K(650°C) is found to be of the order of 720-727N/mm^2. But, after PWHT at the further higher temperatures of 1023K(750°C) and 1123K(850°C)

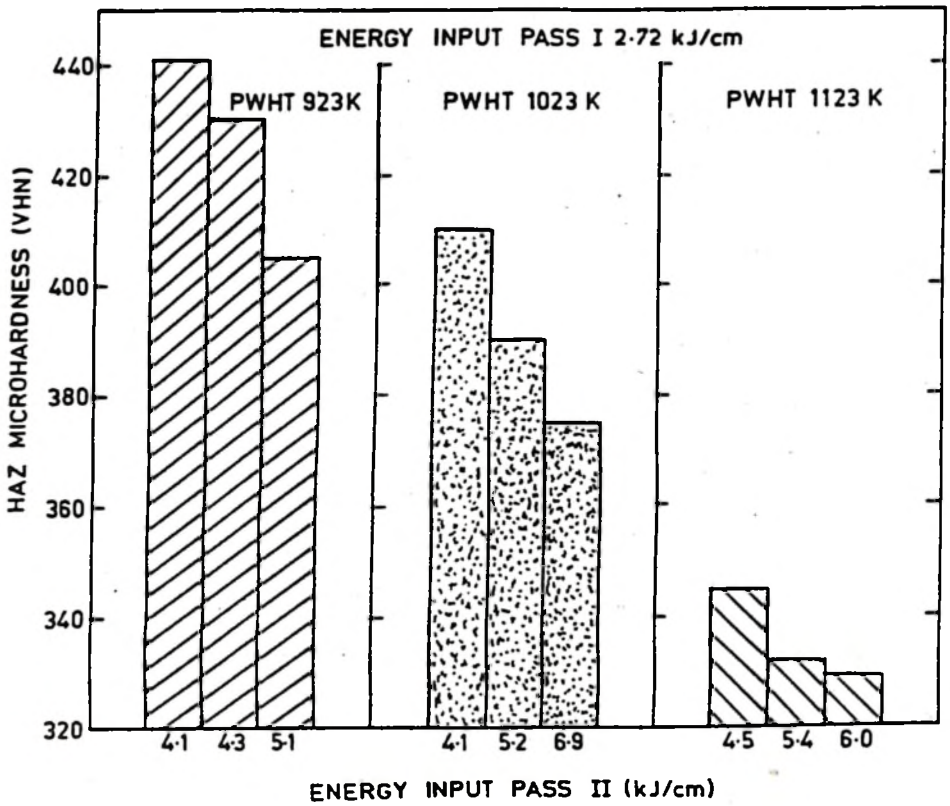


Fig. 9 : At a given first pass energy input of 2.72kJ/cm the effects of energy input of the second pass and temperature of the post weld heat treatment on the microhardness of HAZ.

the UTS of the weldments has not been found to be reduced more significantly, maintaining its level in the range of 715-727N/mm². The elongation of the weldments is always found to lie in the range of 15-17%. The UTS of the weldments is found to be lowered with the PWHT at 923K(650°C) without having any further significant change with an increase in temperature of the PWHT. The variation in UTS is largely marked to be covered by scattering in result, primarily due to presence of inclusions in the matrix. without giving any significant indication as the effect of PWHT. The observations depict that to obtain optimum properties of the weldments of the modified 9Cr-1Mo steel the PWHT is enough to carry out at temperatuere below 1023K (750°C),which is in agreement to the temperature of 950K (677°C) recommended for the similar steel, when the energy input of the first and second filling passes of SMAW are kept as about 2.7 and 4.1kJ/cm respectively.

CONCLUSIONS

The present investigation may be concluded as follows:

1. A variation in energy input of the first pass is having minor influence on microstructure of the weld deposit. However, at a given energy input of first pass the increase in energy input of the second pass comparatively reduces ferrite content and coarsens morphology of the second phase of the weld deposit as well as relatively coarsens the morphology of second phase of HAZ adjacent to the fusion line.
2. The increase in PWHT temperature upto 1123K

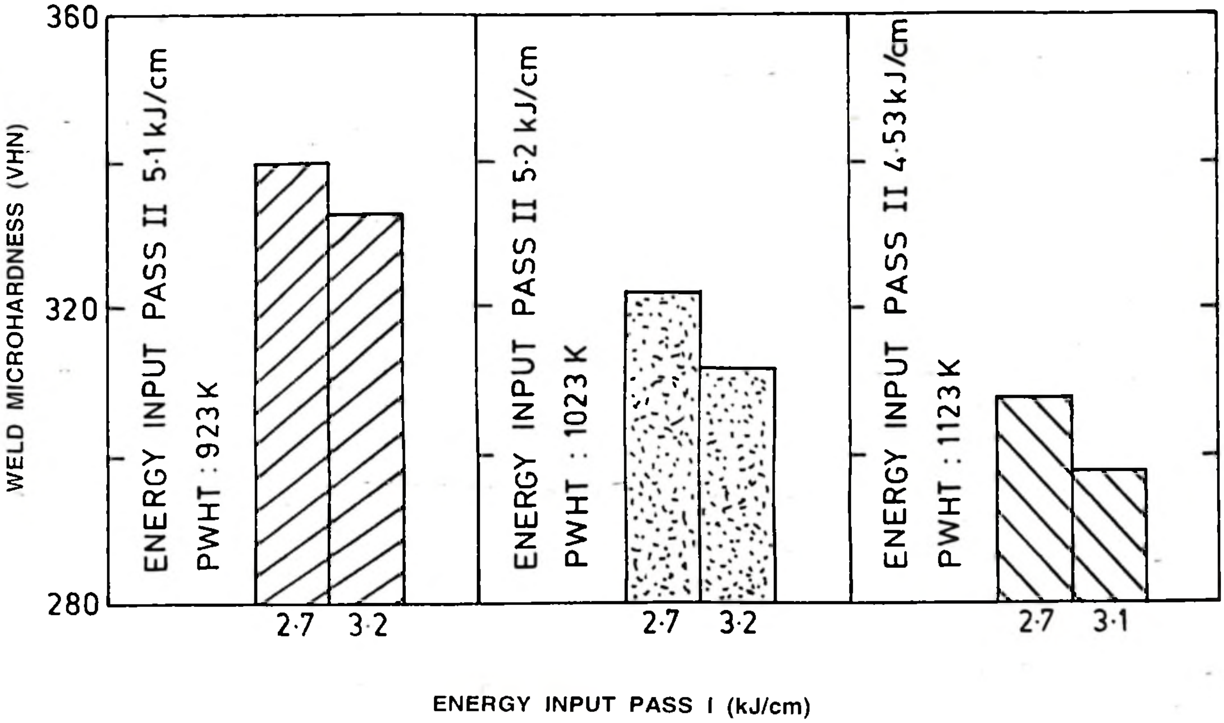


Fig. 10 : At a given energy input of the second pass the effects of energy input of the first pass and post weld heat treatment temperatures on microhardness of the weld.

(850°C) dissolves certain amount of second phase resulting in enhancement of ferrite content of weld deposit.

3. The increase in energy input of the first pass marginally reduces hardness of the weld and HAZ, whereas the increase in energy input of the second pass reduces the hardness of weld and HAZ significantly especially at lower PWHT temperature of 923K(650°C).

4. The increase in PWHT temperature upto 1123K (850°C) considerably reduces the hardness of both the weld and the HAZ.

5. Weld joints are always found to fracture from the base material and thus reflects the effect of PWHT on tensile properties of base material, being weaker than the weld joint, without indicating the influence of energy input of the first and second passes of SMAW. The PWHT at 923K(650°C) is found to reduce the UTS and elongation of the base material significantly without being more affected significantly with a further increase of PWHT temperature upto 1123K(850°C).

6. Post weld heat treatment at temperature upto about 1123K(850°C) has been found to retain sufficient strength of the weldment produced by using energy input of the order of 2.7 and 4.1kJ/cm in the first and second filling passes of MMAW respectively.

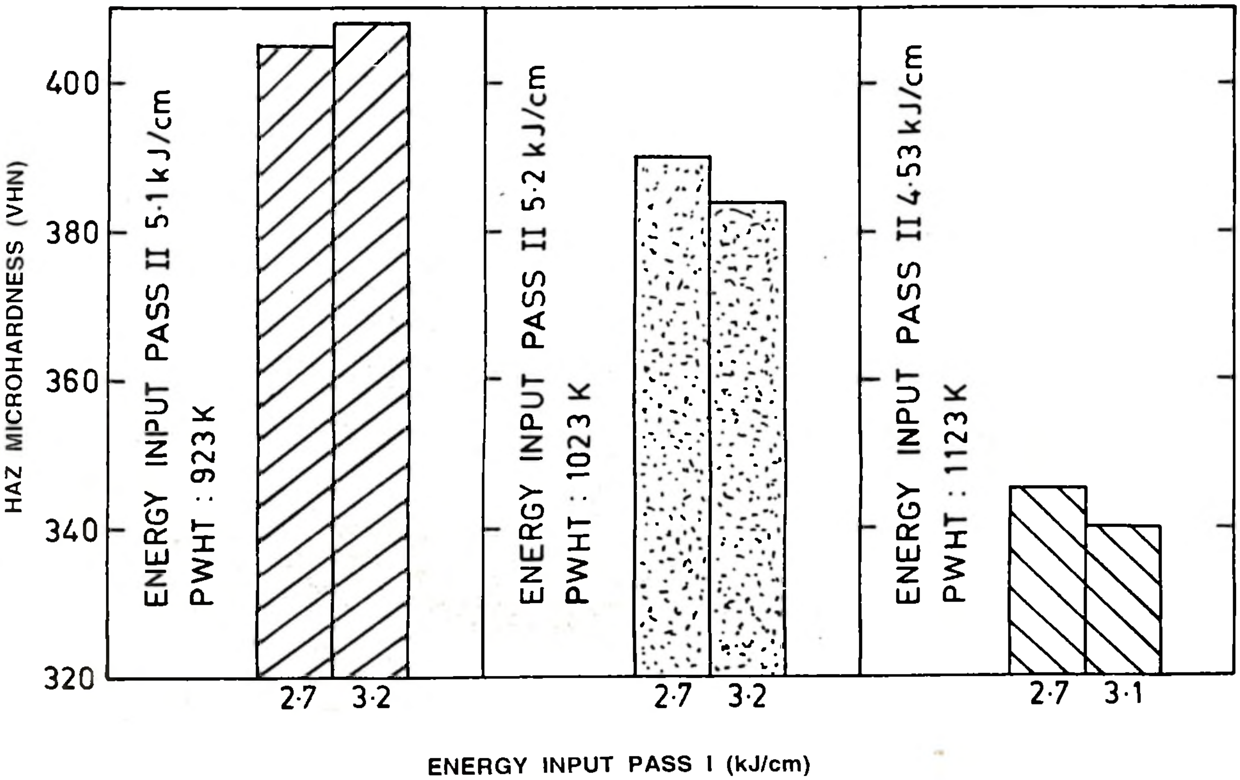


Fig. 11 : At a given energy input of the second pass the effects of energy input of the first pass and post weld heat treatment temperatures on the microhardness of HAZ.

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