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Effect of initial elevated metal temperature on mechanical properties of an ARC-welded mild steel plate

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Abstract

The effect of metal initial elevated temperature on the microstructures and mechanical properties of a single pass arc welded steel plate were investigated. Hardness properties around the heat-affected zone (HAZ) were found to increase with metal preheat at 200^{o}C while toughness and tensile strength of metal are found to decrease with an initial elevated temperature of welded specimens. The effects of initial elevated temperature on the mechanical properties are more pronounced around the fusion zone as compared with the base metal, as evidenced by the welded steel microstructures.

Keywords: Microstructures, arc-weld, heat-affected zone, preheat, fusion zone.

Introduction

A welded plate of mild steel consists of three regions, the fusion zone, heat-affected zone (HAZ) and unaffected base metal (Weisman, 1976). The fusion zone and heat affected zone normally undergo metallurgical transformations due to the weld heat thus consequently affecting the mechanical properties of the material. Depending on the material composition, an uncontrolled welding heat could result into metal cracks and reduce metal toughness around the heat affected zone (Ibhole & Billingham, 1983). The conventional post weld heat treatment such as stress-relief annealing often causes a reduction in hardness and residual stresses of the welded plates (Alexander & Brewer, 1963). In practice, regular rapid heating and cooling of metal is a major cause of brittleness, hardness and crack of the work-piece. Therefore it is better to preheat the welded plate in order to prevent failure of materials mechanical properties. Effect of metal preheat of welded aluminium plate shows that measured and simulated temperatures increase as preheating increases (Yeh *et al.,* 2003). They observed however that the increase is not pronounced for small amount of preheating. In this investigation, prepared weld plate specimen of size 110 mm x 90 mm x 9 mm were welded at preheat temperatures 100^{o}C and 200^{o}C respectively. The effects of initial preheat on the mechanical properties and microstructures of the welded steel plate taken at different distances from the weld centre line were experimentally investigated and presented.

Materials and methods

Welding rig

The welding rig consisted of a support structure, rolling frame with a track, a pulling wire and track guides (Adedayo, 1998). The support structure comprised mainly of welded 25.4 mm x 25.4 mm angle iron, serving as support for all components of the rig to which is also welded a rolling frame track comprising of two parallel protruding 25.4 mm x 25.4 mm angle iron at a height 225 mm. This track guided the horizontal movement of the rolling frame during welding. In order to ensure a constant welding speed, a milling machine of horizontal sliding carriage was used. To the rolling frame of the welding rig, a guided wire was attached that was pulled by the milling machine sliding carriage during welding operation relative to a stationary electrode at a speed controlled on the milling machine (Adedayo 1998). A calibrated welding speed of 2 mm/sec was used throughout for this investigation.

Work materials

Composition: The test piece material is mild steel of composition 0.25% C, 0.05% S, 0.08% Si, 0.75% Mn and 0.06% P and the rest Fe.

Fig. 1. Butt-Welded specimen (All units in mm).

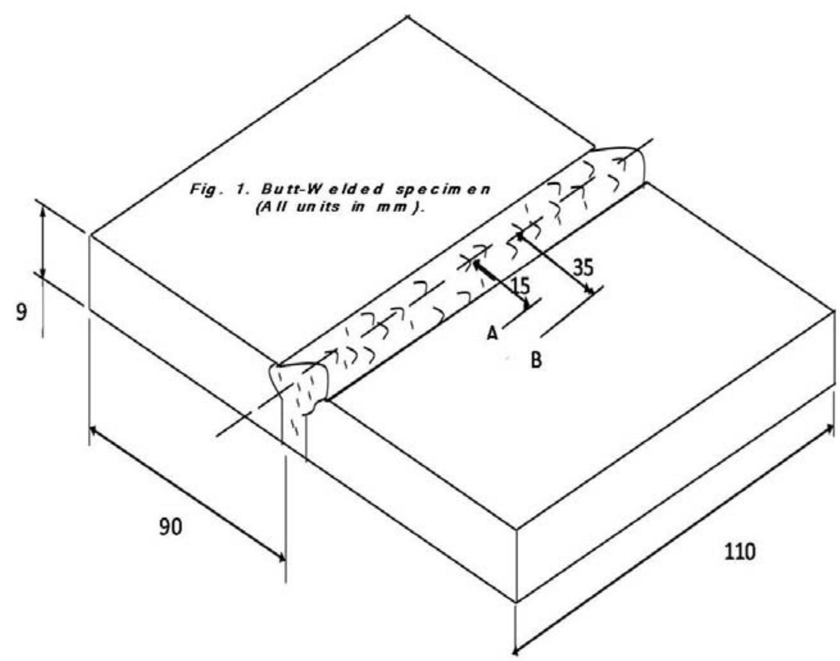

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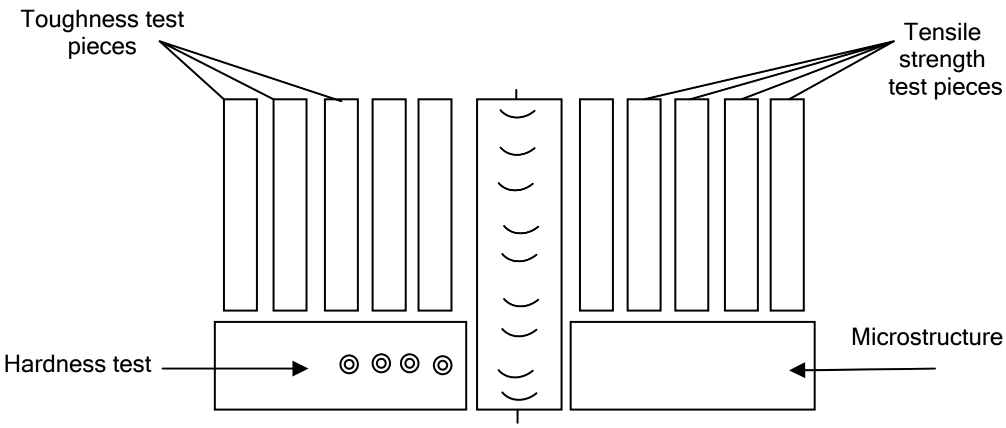
Fig. 2. Layout of test-pieces within the butt-welded



Preparation of work material: Each unwelded mild steel work plate material was machined to specifications of 110 mm x 90 mm x 9 mm as shown in Fig.1. The welded edge of length 110 mm was further milled to a bevel angle of 30^o. Two thermocouple probe holes of diameter 3 mm are located at 15 mm and 35 mm respectively from the weld centre. All test specimens were tack-welded in pairs at the edges and annealed at a temperature of 900^{o}C for 8 h before welding under initial preheat conditions.

Welding operation parameters: Welding current = 120 A, Welding voltage = 80 V, Electrode specification = 2.5 mm (Gauge 10), Welding speed = 2 mm/sec.

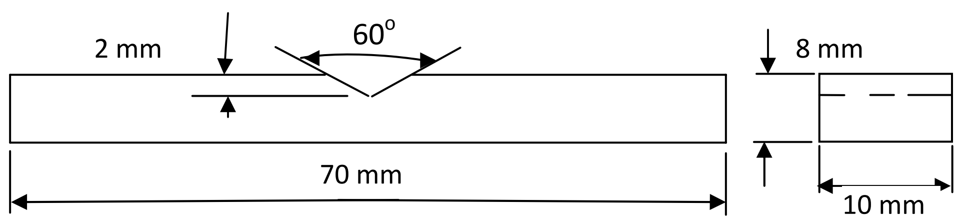
Experimentation

Welding procedures: The prepared test specimens in pairs were arc-welded under the conditions such as: no initial metal preheat, 100^{o}C initial metal preheat and 200^{o}C initial metal preheat.

The pairs of test pieces (as tack-welded) were preheated inside an electric furnace to about 250^{o}C, which is a temperature slightly higher than the required weld preheat temperature. After attaining the required temperature inside the furnace, the work pieces was quickly clamped together to prevent angular distortion during welding, then subsequently supported on the rig. Thermocouples were connected at locations 15 mm and 35 mm from the weld centerline and welding commenced as soon as temperature dropped to 100^{o}C or 200^{o}C as required. At completion of welding, temperature-time curves were monitored by chart plotters. The welded test piece was then removed and prepared for subsequent mechanical tests and micro-structural examinations.

Mechanical tests: (a). Hardness tests: Hardness tests were done on each zone of the welded plate at equidistance spacings of 10 mm along a line perpendicular to the weld centre line. The Brinell hardness number (BHN) with a 60 Kg F ball indentor was used for the hardness measurement (Fig. 2). *(b). Toughness tests:* Test pieces of sizes 70 mm x 10 mm x 8 mm were cut and machined at intervals within each zone of the welded piece (Fig. 2). Sharp V-notches 2 mm deep average root radius of 0.167 mm were then milled into the specimens with a 60^o angle cutter as in Fig. 3 in order to determine Izod impact values, using Izod testing machine.The energy absorbed as indicated by the Izod testing machine was divided by the fracture area to give the crack extension force, G_c. *(c).Tensile strength tests:* Cylindrical rods of diameter 4.8 mm and 45 mm length with additional provision for tensile machine grip were prepared at similar locations as was done for toughness test (Fig. 2). Tensile tests were carried out using Monsanto Tensometer to obtain the yield stress and ultimate tensile stress (UTS).

Fig. 3. Toughness test specimen showing notch details.



Microstructure

The microstructure at a distance 5 mm from weld centre line were examined by cutting through the metal thickness and the exposed cross-sections prepared for micro-structural examination involving specimens prepared from each welded preheat condition and a reference specimen that was not subjected to any welding process. Prepared surfaces were ground, polished and etched with 5% Nital (Momoh, 1998).

Results and discussion

Effect of preheat on temperature history:

Fig. 4, 5 and 6 show the effects of initial preheat temperature on thermal history and temperature gradient at 15 mm and 35 mm from the centre line in the heat affected zone (HAZ) of the welded steel plate respectively. At a distance 15 mm from the weld centerline, peak temperatures of 238^{o}C, 308.4^{o}C and 343.6^{o}C under no preheat (i.e. 25^{o}C), 100^{o}C and 200^{o}C welding preheat conditions respectively are attained as shown in Fig. 4, while Fig. 5 shows that at a distance 35 mm from the weld centre-line peak temperatures attained are 160^{o}C, 232^{o}C and 282^{o}C under no preheat, 100^{o}C and 200^{o}C welding preheat conditions respectively.

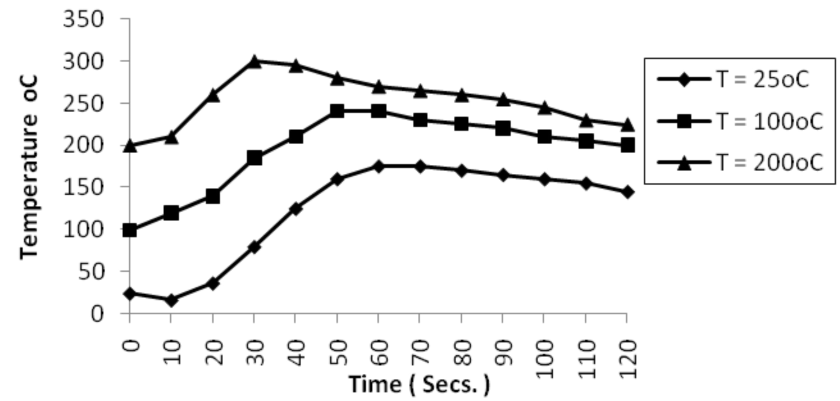


Fig.4 Effect of preheat temperature on thermal history at 15mm from weld line.

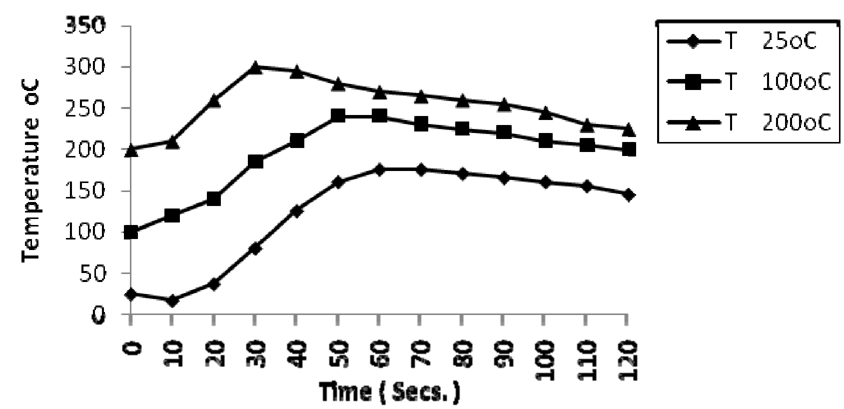


Fig.5 Effect of preheat temperature on thermal history at 35mm from weld line.

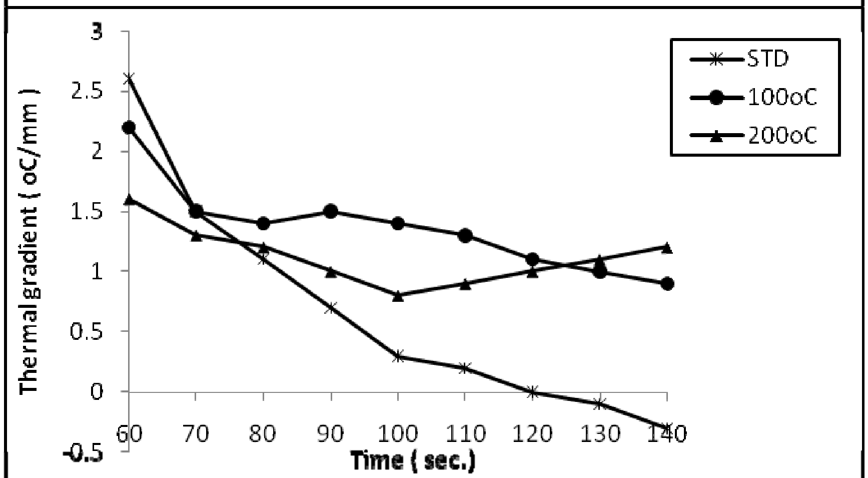


Fig. 6 Post - weld thermal gradients between points A (15mm) and B (35mm)

This shows increases of peak temperatures of 72°C and 122°C under 100°C and 200°C initial metal preheat respectively. Increases in peak temperatures due to weld plate preheat are not proportionate to the preheat temperatures. The higher the weld preheat temperature, the lower the peak temperature incremental rate (Adedayo, 1998). The observed lower incremental rate of attainable peak temperatures at distances 15 mm and 35 mm from the centre-line is attributable to a reduction in thermal conductivity of plate with temperature (Rohsenow & Hartnett, 1973). Fig. 6 shows thermal gradients between points A and B in the HAZ, as recorded immediately after welding. Thermal gradients of 2.75°C/mm and 1.62°C/mm were observed under no preheat and 200°C initial weld preheat conditions immediately after welding. These values dropped and assumed a uniform value with commencement of cooling. Table 1 shows the maximum cooling rates with and without initial weld plate preheat.

Metal hardness: Fig. 7 shows the effect of preheat temperature on metal hardness between the weld centre line and base metal boundary. A 200°C metal preheat resulted in an increase in metal hardness while lower preheat temperature of 100°C and the no preheat plate showed identical hardness values except at a distance 30 mm from the weld centre-line. Maximum hardness values of 126 BHN and 121 BHN observed for 200°C preheat and no preheat weld plate respectively occur around the fusion zone and gradually decrease across the heat affected zone until it attains a constant value in the parent metal. High hardness values close to the fusion zones are attributable to microstructural transformations such as bainite formation resulting from high weld temperature development and instantaneous heat dissipation in the fusion and heat affected zone.

Tensile strength: Fig. 8 shows the variation of yield strength between the fusion zone and the unaffected parent metal boundary under conditions of plate preheat and no preheat. The yield strength is found to decrease with increasing values of initial preheat temperatures. High values of yield strength exist for all conditions of welding in the fusion and heat-affected zone and gradually reduce to the unaffected base metal value at further distances from the weld line. This variation of yield strength

Table 1 Maximum cooling rates with and without initial weld plate preheat

Welding Condition	Point A Max.Cooling rates (°C / Sec)	Point B Max. Cooling rates (°C / Sec.)
No initial metal preheat	1.55	0.7
100°C metal preheat	1.60	1.3
200°C metal preheat	1.45	1.25

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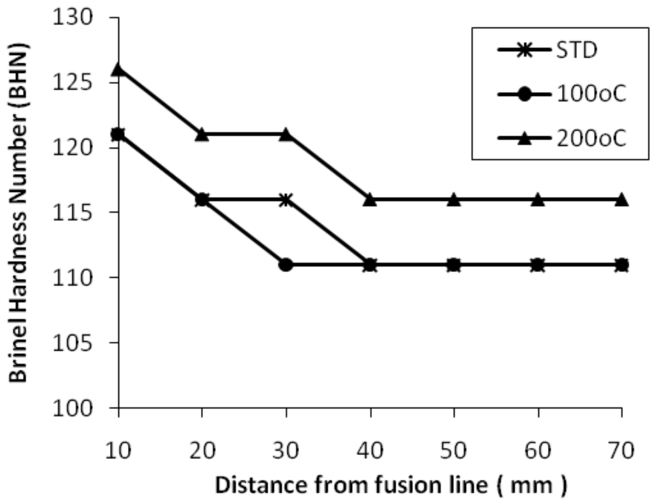

Fig.7 Effect of preheat temperature on metal Hardness

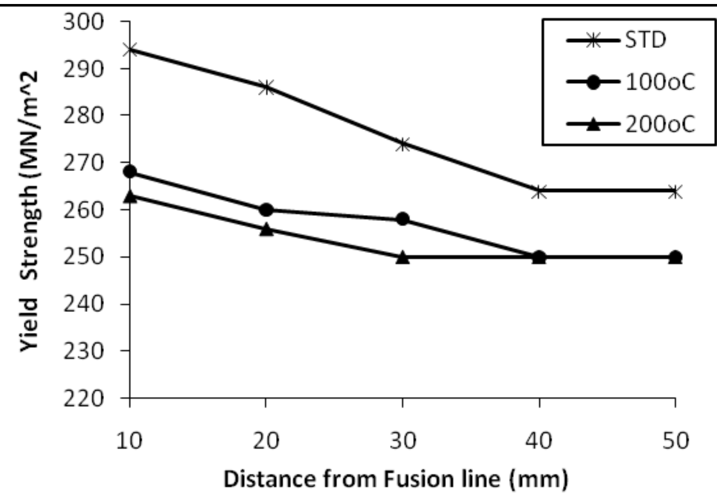

Fig.8 Effect of preheat temperature on yield strength

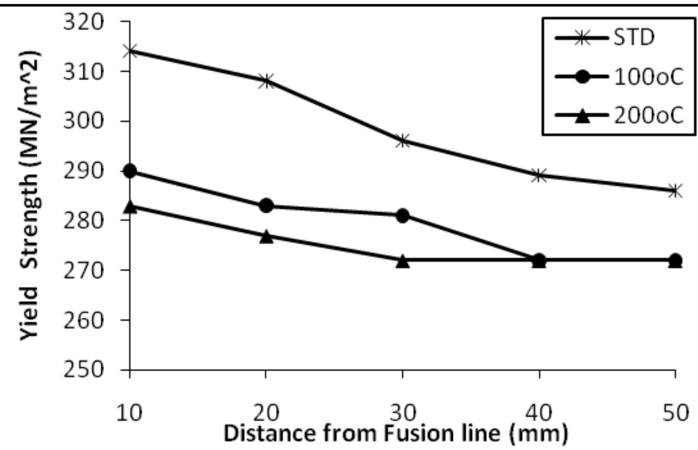

Fig.9 Effect of preheat temperature on ultimate tensile strength

can be explained in terms of the differences in cooling rate values at different positions within the weld zones. The reduced yield strength values with initial metal preheat is attributable to the annealing effect resulting from a slower cooling rate between the weld line and other weld zones during welding operations. Fig. 9 shows the effect of initial metal preheat on ultimate tensile strength across the zones of the weld plate. The ultimate tensile strength (UTS) reduces with increasing initial metal preheat. This follows the same trend as the yield strength values. This trend can also be explained in terms of the annealing effect of a preheat on final metal properties.

Toughness: Fig. 10 shows that initial metal preheat of mild steel before welding reduces its toughness. With no initial metal preheat, a maximum toughness value of 865 KN/M is observed while at 200°C initial metal preheat toughness value is 690 KN/M.

Specimen microstructure

Fig.11a-d shows the microstructure of the heat-affected zone under all welding conditions as stated and in as received base metal states. The as received base metal, Fig. 11d consist of ferrite and pearlite because of low carbon content and the initial annealing carried out on all work pieces. Comparing Fig.11a, 11b and 11c with Fig. 11d, the microstructures of welded plate has finer grains often associated with rapid cooling. Weld preheat work pieces show signs of existence of a lamellae structure often associated with precipitation of bainite (Fig. 11a & 11b).

Conclusion

Mechanical properties of hardness, tensile strength and toughness in arc-welded mild steel plates are found to be higher in the heat affected zone and reduce to the base metal value under all the welding conditions. Impact of initial metal preheat on mechanical properties diminishes with increasing temperature in the heat affected zone. Microstructures of preheated specimens differ from the no preheat specimen, showing traces of precipitation of bainite.

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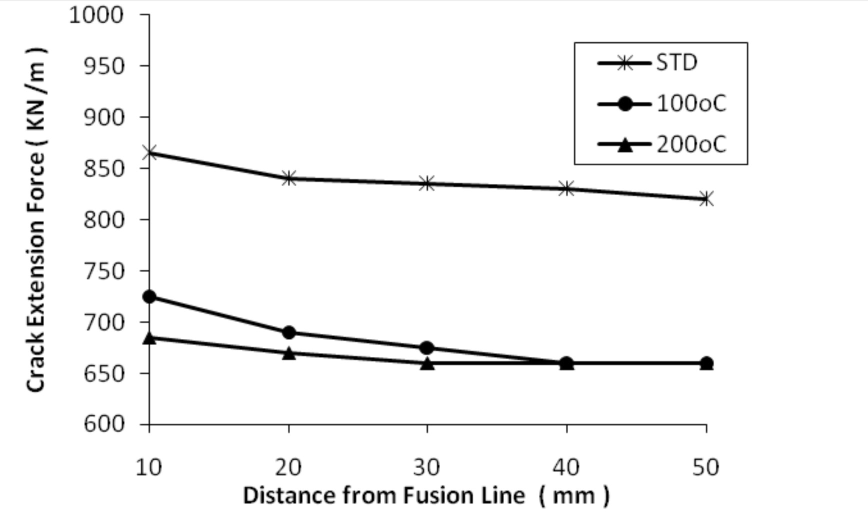
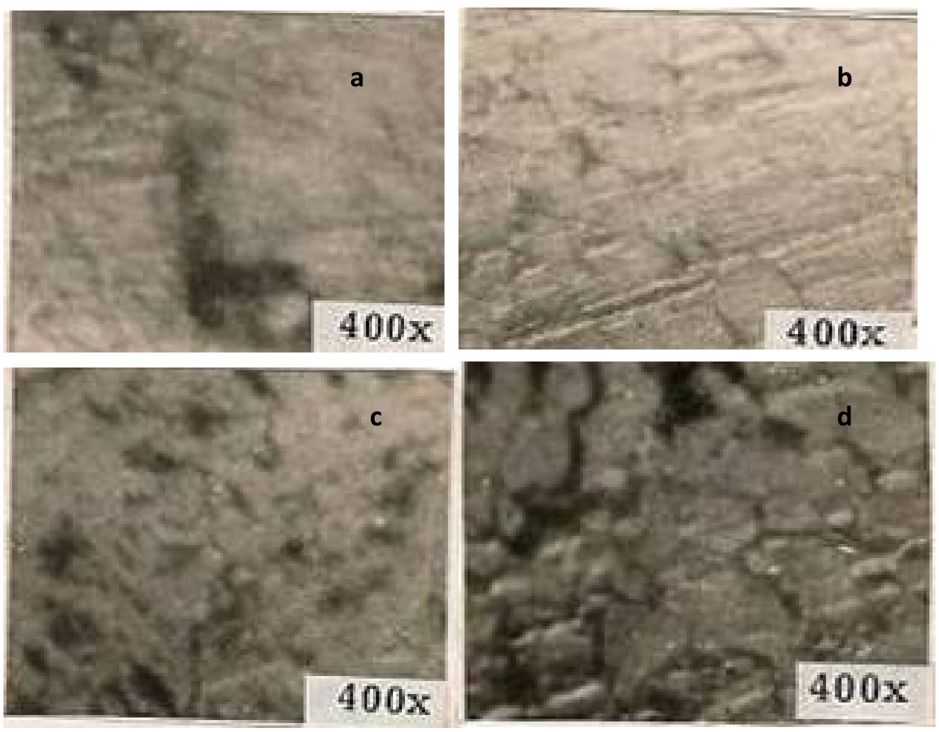


Fig.10 Effect of Initial Metal Preheat on Metal Toughness

Fig.11.a. 200 ^{0}C preheat; b. 100 ^{0}C preheat; c. No preheat; d. As-received base metal



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