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Effects of Quenchants on Impact Strength of Single-Vee Butt Welded Joint of Mild Steel

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Abstract- The effects of quenching medium on the impact behaviour of mild steel welded joints were investigated, single – vee butt welded joint was employed in welding the samples. The welding was carried out at 100A and at a terminal voltage of 140V (14kW), using gauge 8 coated electrode (4mm size) throughout the welding processes. Four (4) quenching media were employed which are Brine solution (0.1 Molar concentration), two (2) Litres of water, two (2) Litres of diesel oil and abundant air. 8mm thick mild steel bars were used for the heat treatment process at variable annealed temperature steps of 200^0C – 400^0C – 600^0C. The Izod impact machine was employed in carrying out the Impact Test. The results obtained from the test carried out show that quenching in brine solution gives least average impact strength while normalized in air gives highest average impact strength and is the mildest of all the quenchants. The overall results show that air was the best medium for quenching welded mild steel followed by diesel oil, then water and lastly brine solution for quenching welded parts or components under influence of impact or sudden loading. The results will enable engineers, welding personnel and roadside welders select the best and most economic quenchant that will be best suitable for quenching welded components or parts made of mild steel subjected to impact or shocking loading.
Keywords: Quenchants, Mild Steel, Single-Vee, Butt welded Joint, Impact strength, annealed

1. Introduction

Many welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and still others by pressure alone, with no external heat supplied. In some welding processes a filler material is added to facilitate coalescence. The assemblage of parts that are joined by welding is called a weldment. Welding is most commonly associated with metal parts, but the process is also used for joining plastics [1].
Although in its present form it has been used since about the beginning of 20^{th} century but it is fast replacing other joining processes like riveting and bolting. At times it may be used as an alternative to casting [2].
Presently welding is used extensively for fabrication of vastly different components including critical structures like boilers and pressure vessels, ships, off-shore structures, bridges, storage tanks and spheres, pipelines, railways coaches, anchor chains, missile and rocket parts, nuclear reactors, fertilizer and chemical plants, structural, earth moving equipment, plate and box girders, automobile bodies, press frames and water turbines. Welding is also used in heavy plate fabrication industries, pipe and tube fabrication, joining drill bits to their shanks, automobile axles to brake drums, lead wire connections to transistors and diodes, sealing of containers of explosives like, nitroglycerine, welding of cluster gears, and the like [2].

Steel is an important engineering material. It has found applications in many areas such as vehicle parts, truck bed floors, automobile doors, domestic appliances, Ship's hull, structural castings, Railway rolling stock, automotive castings, Hot metal ladles, Rolling mill equipment, Rolls and rollers, Machines and tools, Mine and quarry equipment, Oil and petroleum equipment etc. It is capable of presenting economically a very wide range of mechanical and other properties [3]. For instance, the most commonly used material for petroleum pipelines is mild steel, this is because of its strength, ductility, weldability formability and its amenability to heat treatment for varying mechanical properties [4, 5].

Steel is an effective, cheap and commercially available material for structural applications; large tonnages of commercial steels in Nigeria contains very little alloying elements with carbon composition at varied percentage and thus are classified as low carbon, medium carbon and high carbon steel, [6]. Due to its amenability to heat treatment processing and alloying, this segment of steel finds its wide application in both structural and domestic applications [7]. These processes are widely utilized to achieve high mechanical (high yield strength, high proportional limit, and high fatigue strength) properties for their respective applications. The desirable properties of medium carbon steel can be achieved by adding suitable alloying elements and secondly by various conventional heat treatment [8]. The mechanical strength of medium carbon steels can also be improved by quenching in appropriate medium. However, the major influencing factors in the choice of the quenching medium are the kind of heat treatment, composition of the steel, the sizes and shapes of the parts [9, 10]. These properties can further be enhanced by welding.

Susheel and Syed [11] considered welding parameters such as voltage, current and welding speed on depth of penetration. The material was carbon alloy steel(0.14%C) of dimension 75 x 50 x6mm,voltage 18v and current was 250amps.The maximum penetration takes place with minimum speed even by maintain constant voltage and current. Samer [12] studied the influence of Welding Parameters on Mild Steel, this research investigated variation of depth of penetration, welding speed and heat input during the welding process. It was observed that depth of penetration is increases at each case of voltages and current with the increased heat input. Sunar et al. [13] worked on thermal and stress analysis of a sheet metal in welding, the study centered on a cantilever assembly subjected to heating at its fixed end which resembles the welding of a sheet metal, stress fields and temperature are computed during the heating process. The study employed finite element approach to predict stress fields. It is found that the temperature distribution in the transverse direction does not vary considerably but varies significantly in the longitudinal direction. The temporal change of temperature gradient induces stresses in the substrate material. However, the maximum magnitude of the Von Mises stress is less than the yield strength of the substrate material.

Talabi et al. [3] investigated the effect of welding variables on mechanical properties of low carbon steel welded joint. The study concentrated on the effect of welding variables on the mechanical properties of welded 10 mm thick low carbon steel plate, welded using the Shielded Metal Arc Welding (SMAW) method. Welding current, arc voltage, welding speed and electrode diameter were the investigated welding parameters. The welded samples were cut and machined to standard configurations for tensile, impact toughness, and hardness tests. The results showed that the selected welding parameters had significant effects on the mechanical properties of the welded samples. Increases in the arc voltage and welding current resulted in increased hardness and decrease in yield strength, tensile strength and impact toughness. Increasing the welding speed from 40-66.67 mm/min caused an increase in the hardness characteristic of the welded samples.

Singh et al. [14] worked on the effects of joint geometries on welding of mild steel by Shielded Metal Arc Welding (SMAW). This research compared the effects of variations in geometry of butt-joint welding on the mechanical properties of mild steel plate. The welding was carried out on different butt-joint designs, such as, square butt-joint, single V-joint, double V-joint and single J-joint, keeping all other process parameters like current, voltage, welding speed etc. as constant. The mechanical test and the microstructural investigation were carried out to analyse the change in mechanical and microstructural behaviour of the weld metal. The results of tests peformed revealed that the Double-V joint was the superior of all other joints, having better mechanical properties than other joints. Single-V was also up to the mark but the more width of HAZ was recorded in this case as compared to others.

Bodunde and Momohjimoh [15] studied effects of welding parameters on the mechanical properties of welded Low-Carbon Steel using two welding processes of Oxy-Acetylene Welding (OAW) and Shielded Metal Arc Welding (SMAW). Two different edge preparations on a specific size, 10-mm thick low-carbon steel, with the following welding parameters: dual welding voltage of 100 V and 220 V, various welding currents at 100, 120, and 150 Amperes and different mild steel electrode gauges of 10 and 12 were used. The tensile strength, hardness and impact strength of the welded joint were carried out and it was discovered that the tensile strength and hardness reduce with the increase in heat input into the weld. However, the impact strength of the weldment increases with the increase in heat input.

2. Materials and Methods

2.1 Materials

Mild steel samples were used in this work. The steels were obtained as 20mm by 12mm from commercially available mild steel plain bars at Ibadan gate Iron and Steel Market, Oyo State, Nigeria. Coated gauge 8 (Size 4mm) AWS E6013 (150 – 190Amp) Mild steel electrodes were used for the welding, this was chosen based on the thickness of mild steels plain bars used.
Four different quenchants were employed in this study namely, Brine solution (0.1 Molar concentration), two (2) Litres of water, two (2) Litres of diesel oil and abundant air.
The migatronic LTC 140 arc welding machine was used. The machine has a voltage terminal of 140V with a variable of 0 to 140A. Honnsfield balance impact machine was used for impact testing. The impact energy absorbed can be varied from between 0 and 50 ft.pd. Izod impact test was carried out on the specimen.

2.1.1 Material Compositions

A spark test analysis was carried out on the Mild Steel sample to know its composition. Table 1 shows the chemical analysis of as-received mild steel (medium carbon steel) containing 0.33% carbon content as carried out at the universal steel (U-Steel) Ltd, Ikeja, Lagos

Table 1: Spectrometer analysis result of as-received medium carbon steel (MCS) - Mild Steel

Element	C	Si	S	P	Mn	Ni	Cr	Mo	V	Cu	W	As	Sn	Co	Al	Ca	Zn	Fe
Percentage	0.3300	0.1740	0.0499	0.0341	0.8225	0.0911	0.0585	0.0018	0.0029	0.3031	0.0003	0.0060	0.0230	0.0094	0.0019	0.0002	0.0037	Bal

2.2 Methods

2.3 Welding Procedure

5cm long pieces were cut from the mild steel sample and one end of each piece was milled at 30^0 one side and joined to form single – vee butt joints and to ensure proper weld penetration as shown in figure 1 and Figure 2 represents model of a welded sample under investigation.

Gauge 8 Electrode (4mm size) , 140V and 100A (14kW) were used in this work, the same voltage and current setting were used for all the specimens to have a base of assessing the effect of quenching on the impact behaviour of mild steel welded joints. The samples were welded together in pairs to give a single – Vee butt joint.

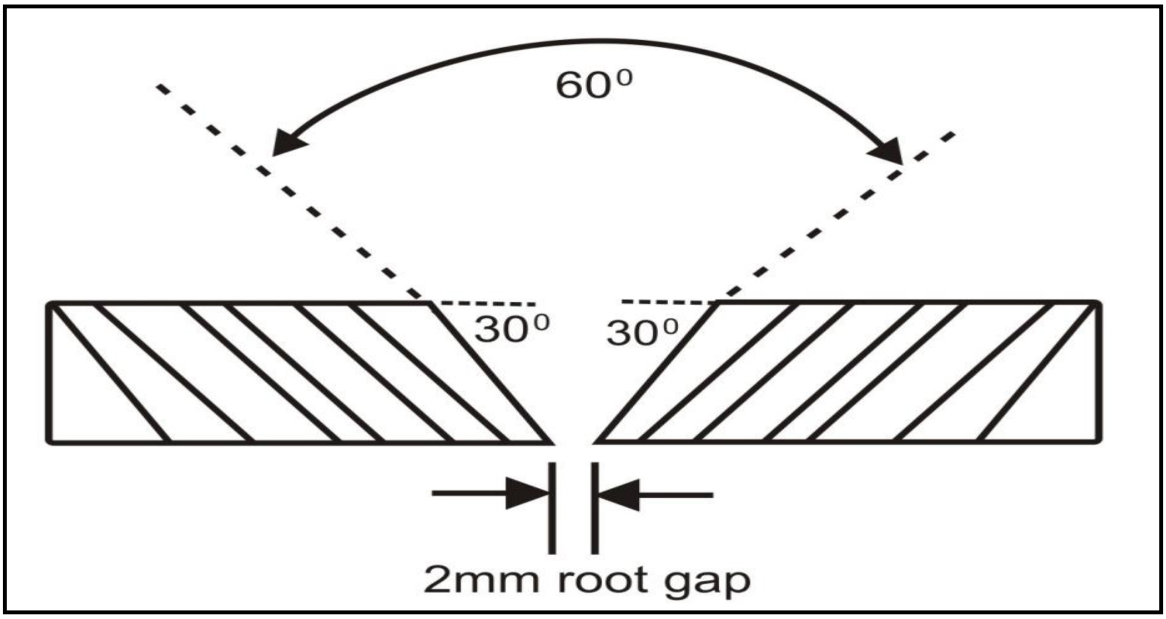

Figure 1: A pair of the milled piece ready for welding

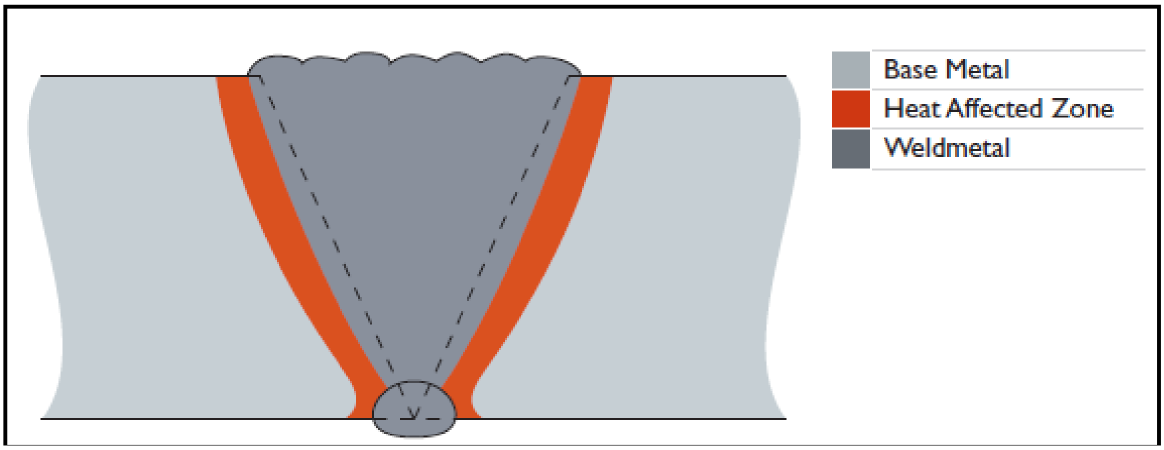

Figure 2: A model of a welded sample

2.4 Heat Treatment
2.4.1 Heat Treatment Process

A minimum of two pairs of welded samples were selected per treatment. Some of the conventional heat treatments procedure chosen include: annealing, normalizing, quenching (in diesel oil, Brine Solution and water)

2.4.2 Annealing process

After the machining to impact test specimens as shown in figure 3 and 4 then the impact test specimens were annealed in the electric furnace at different temperature range of $200^{o}C$, $400^{o}C$ and $600^{o}C$ respectively for each quenching medium before the impact test was conducted.
It is held at these temperatures for sufficient time (about 1 hour) to ensure thorough homogeneity and for all the material to transform into austenite. It is then cooled slowly inside the furnace to room temperature after the furnace has been turned off. The specimen was taken out of the furnace after reasonable hours of gradual loss of heat when the furnace temperature would have attained the nominal room temperature. The grain structure has coarse pearlite with ferrite or cementite.

2.4.3 Normalizing process

Immediately after set of machined samples, each samples of the medium carbon steel to be normalized were placed in the furnace and heated to temperature range of $200^{o}C$, $400^{o}C$ and $600^{o}C$ respectively. Two (2) pairs of 60^{0} single – vee butt welded joints were normalized in air. The samples were retained at this temperature for the period of 1 hour for full transformation to austenite. They were later removed from the furnace and left in air for cooling.

2.4.4 Quenching Procedure

The selected samples for quenching were heated at different temperature range of $200^{o}C$, $400^{o}C$ and $600^{o}C$ respectively. At these temperatures the samples were held for 1 hour to ensure uniform homogeneity. In order to enhance the hardness, the red hot steel is directly and rapidly cooled

i. 2 pairs of 60^{0} single – vee butt welded joints were quenched in diesel oil
ii. 2 pairs of 60^{0} single – vee butt welded joints were quenched in water
iii. 2 pairs of 60^{0} single – vee butt welded joints were quenched in brine solution (10 percent solution)

2.5 Material Testing

After the successful heat treatment operation, the various heat treated samples were taken for the Impact test. The test was performed on Izod Impact Testing Machine. Impact Test was conducted at various quenching medium.

2.5.1 The Impact Testing Procedure

Test specimens with a V notch in the fusion zone for impact test fracture were performed according to ASTM E23 standard. The impact test used in this research work was Izod test. The test was carried out on specially prepared specimens in the form of a notched bar (see figure 3 and figure 4).
For the purpose of this research, 8mm thick mild steel bars were used for the heat treatment process at variable annealed temperature of $200^{0}C$, $400^{0}C$ and $600^{0}C$ respectively, and the Izod impact test was carried out on the sample pieces. The bar of the material was 55mm long, and a V-notch 2mm deep of 60^{0} included angle was made at the centre of the specimens as shown in figure 3

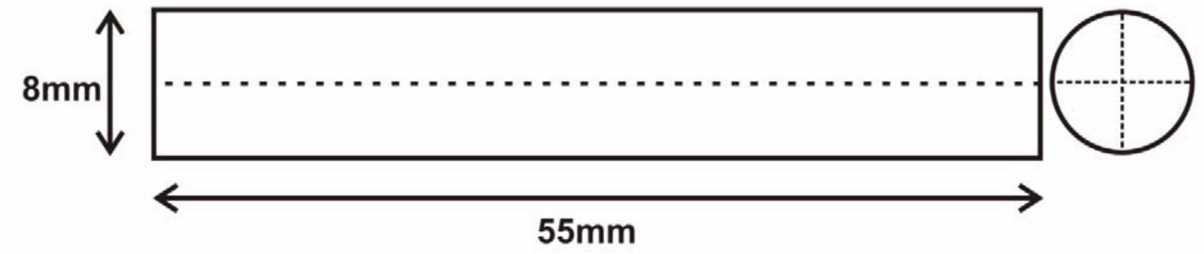

Figure 3: Unnotched impact specimen

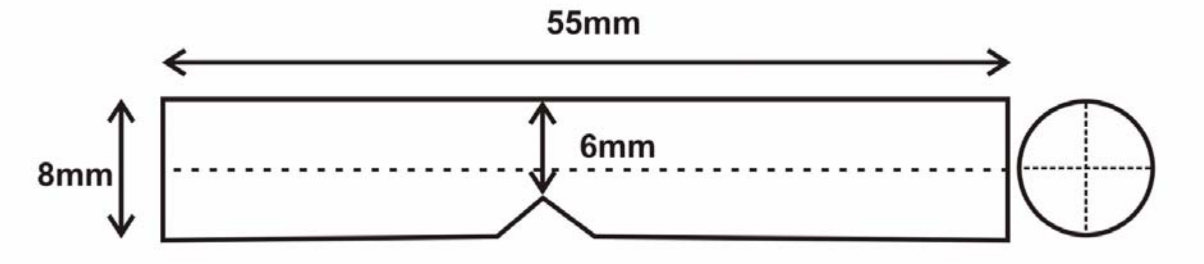

Figure 4: 60^0 V-notched

The prepared specimen was placed on the Anvil with V-notch gauge. The testing machine consists essentially of a weighted pendulum hammer which was then raised to a predetermined operating position in which it stores up 162.725J of potential energy at a velocity of 3.8m/s its weight and height above the point where it strikes the specimens and it was then released from a cooked position at a fixed height. Upon released, a knife edge mounted on the pendulum strikes and bends or fractures the specimen at the notch, which act as a point of stress concentration for this high velocity impact blow. The V-notch was located facing the striker and with the base of the V exactly in line with the top edge of the vice and was lined up with a small hang jig. The striker hits the specimens at the striking height 6mm above the V notch.

The height to which it swings over depends upon how much energy has been absorbed in fracturing or bending the specimen. If no energy were taken it would swing to its original height, while if all its energy were taken it would be arrested at the bottom of its swing. The amount of energy absorbed was shown by a pointer on the indicating dial and was recorded. The notches in the specimen are milled with a special form cutter or angle files. The Izod value was expressed in Joules (Nm) and represents the energy necessary to fracture or bend the test piece.

3. Results and Discussion

3.1 Results

Table 2, 3, 4 and 5 show the results obtained from the impact test for different quenching media i.e Brine Solution, water, diesel oil and air respectively, after annealed at different desired temperature steps of 200^0C – 400^0C – 600^0C. The impact strengths were calculated for each medium at different temperature using the equation (1),

$$Impact\ Strength = \frac{E}{A} \quad (1)$$

E = Energy required to bend or fracture specimen

A = Cross-sectional area of the specimen as shown in equation (2)

Note: The diameter of each impact specimen used in this work is 8mm

$$A = \pi\left(\frac{d}{2}\right)^2 = \left(\frac{8}{2}\right)^2 \pi = 50.27mm^2 = 50.27\ x\ 10^{-3}m^2 \quad (2)$$

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Table 2: Impact value for annealed specimen quenched in Brine Solution

S/N	TEMPERATURE $(°C)$	IMPACT ENERGY ABSORBED (E) Ft - Ib_f	Joules	IMPACT STRENGTH =$\left(\frac{E}{A}\right)\left({}^{J}/_{m^2}\right)$
1	200	30.50	41.358	822.72
2	400	32.30	43.800	871.30
3	600	41.00	55.600	1106.03
		AVERAGE IMPACT STRENGTH		**933.35**

Table 3: Impact value for annealed specimen quenched in Water

S/N	TEMPERATURE $(°C)$	IMPACT ENERGY ABSORBED (E) Ft - Ib_f	Joules	IMPACT STRENGTH =$\left(\frac{E}{A}\right)\left({}^{J}/_{m^2}\right)$
1	200	31.80	43.121	857.79
2	400	32.50	44.070	876.67
3	600	42.10	57.088	1135.63
		AVERAGE IMPACT STRENGTH		**956.70**

Table 4: Impact value for annealed specimen quenched in diesel Oil

S/N	TEMPERATURE $(°C)$	IMPACT ENERGY ABSORBED (E) Ft - Ib_f	Joule	IMPACT STRENGTH =$\left(\frac{E}{A}\right)\left({}^{J}/_{m^2}\right)$
1	200	38.3	51.935	1033.12
2	400	42.0	56.952	1132.92
3	600	45.6	61.834	1230.04
		AVERAGE IMPACT STRENGTH		**1132.03**

Table 5: Impact value for annealed specimen normalized in air

S/N	TEMPERATURE $(°C)$	IMPACT ENERGY ABSORBED (E) Ft - Ib_f	Joules	IMPACT STRENGTH =$\left(\frac{E}{A}\right)\left({}^{J}/_{m^2}\right)$
1	200	44.3	60.071	1194.97
2	400	45.1	61.156	1216.55
3	600	46.8	63.461	1262.40
		AVERAGE IMPACT STRENGTH		**1224.64**

Graphical representation of the impact test (that is impact energy versus temperature) for the different quenching medium are as shown in Figure 5

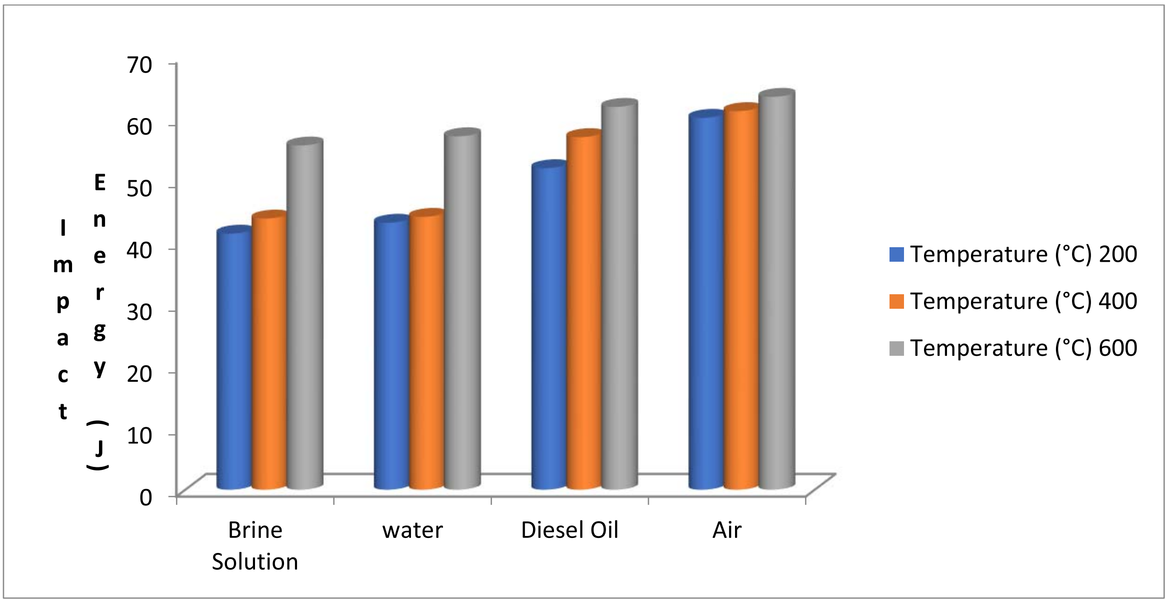

Figure 5a: Graph of Izod Impact energy versus Annealed Specimen temperature of different quenching Media

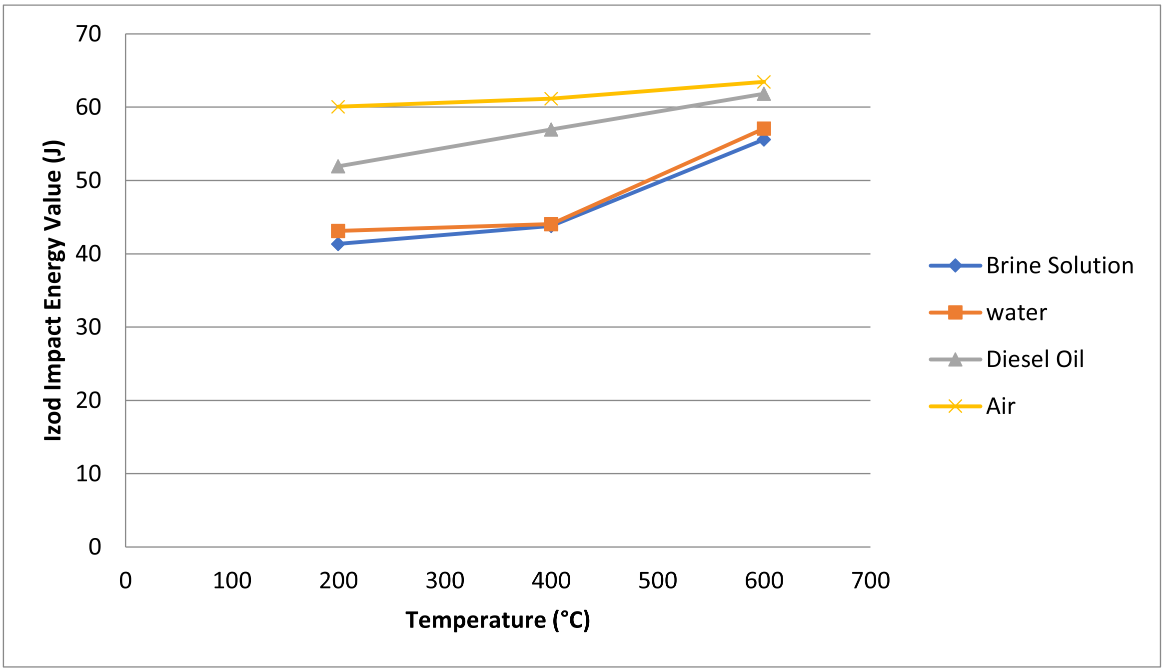

Figure 5b: Graph of Izod Impact energy versus Annealed Specimen temperature of different quenching Media

3.2 Discussion of Results

From Table 2 to 5 showing the effects of quenching on impact strength, it was observed that the impact strength increases as the temperature increases in each quenching medium; this was in line with the work of [15]. The average impact strength was higher in Air medium than diesel oil medium, diesel oil medium is higher than water medium and lastly water medium is higher than brine solution. Results show that welded mild steel normalized in air produces greatest impact strength followed by the one quenched in diesel oil and from the result the one quenched in brine solution produces less impact strength. Also impact strength of specimens quenched in diesel oil is greater than that quenched in water this was in agreement with the report made by [5, 9]; this is because the cooling rate of diesel oil is slower than water. The net result shows that the vapour transport stage is shortened, thus showing the cooling rate which of course, reduces the risk of distortion and cracking in diesel oil than water quenched.
This was also evidence in the graphical representation of the comparison of different quenching medium as shown in figure 5, Air cooled specimens at all annealed temperature had highest impact energy absorbed and were more ductile than other specimens quenched in other media, this was also supported by the work. It was observed that brine quenched specimens had the least impact energy absorbed at all annealed temperatures leading to least impact strength in all and consequently had highest brittleness.
In the same figure 5, it was observed that quenching in brine solution was brittle at lower temperature than all other quenching media. It was revealed that normalized in air had the highest ductility at all temperature range followed by diesel oil quenchant.
Figure 5 shows clearly that at annealed temperature, 200^0C, air cooled had higher impact energy absorbed followed by oil cooled, followed by water cooled and lastly brine solution. At annealed temperature 400^0C and 600^0C, the same trend applicable.
It was further revealed that at 400^0C, quenching in water and brine solution had equivalent impact energy absorbed but that of water quenched was a little bit higher impact strength than that quenched in brine solution. The Implication of this was that air cooled had the highest impact strength and more ductile than any other cooling medium and can be less prone to distortion and crack. Whereas water cooled and brine solution cooled were relatives, they had almost equivalent impact energy absorbed at each annealed temperature while oil cooled had better cooling after air cooled.

4. Conclusion

From the results obtained and their discussions, the following conclusions were drawn from the research carried out on the effects of quenching on impact strength of mild steel welded joints. Impact strength increases as the annealed temperature increases. Impact strength is higher in air cooled welded joints than oil cooled, while oil cooled was higher than water cooled and lastly water cooled was higher than brine solution cooled. That air is the best and the most economic quenching medium for welded components or parts made of mild steel subjected to impact or sudden or shocking loading.

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