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EFFECT OF POSTWELD HEAT TREATMENT ON THE MECHANICAL BEHAVIOUR OF AUSTINITIC STAINLESS STEEL

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KEYWORDS: Weldment, Quenching Media, Mechanical properties, Micrograph.

ABSTRACT
The mechanical behaviour of type 304 austenitic stainless steel (ASS) welded joints were investigated in the post weld heat treated (PWHT) condition. 3mm thick as-received ASS was cut into cuboid pieces of 50mm x 20mm x 3mm and butt welded with the aid of shielded metal arc welding (SMAW) technique, stress relieved at 6000C which were later prepared into standard specifications of tests samples before heating them to 9100C. These heated samples were quenched into some selected vegetable (Jatropha and Neem) seed oils, and finally tempered to 3000C. The physiochemical characteristics and suitability of the vegetable oils as alternative quenchants to SAE 40 engine oil for industrial heat treatment were compared. Vickers hardness, izod impact, tensile tests and surface morphology examinations were carried out to characterize the mechanical properties of the welded treated and welded untreated (control) ASS samples. From the results obtained, it was observed that PWHT has slightly depreciated the mechanical properties of the substrates due to the presence of welding defects including microcracks and inclusions on the weldments and HAZ.

INTRODUCTION
Austenitic stainless steel (ASS) is an alloy steel that consists of chromium and nickel as the major alloying elements [1]. The importance of ASS in industrial applications and development cannot be over-emphasized as its excellent properties which range from high tensile strength, good impact resistance, corrosion and wear resistances have found various applications in many engineering industries such as chemical, petrochemical, nuclear industries, food processing, dairy equipment, low and high pressure boilers and vessels, fossil-fired power plants, flue gas desulphurization equipment, evaporator tubing, super heater, reheating tubing, steam headers and pipes and structural applications [2]. Conventionally ASSs are fabricated by casting and forging processes [1]. The microstructure of austenitic stainless steel consists of a mixture of austenite (γ) and delta ferrite (δ) phases [3]. Austenite, which is paramagnetic, has a face centred cubic (FCC) crystal structure, and is the predominant phase in these alloys. The remainder is ferrite, which is ferromagnetic and has a body centred cubic (BCC) crystal structure [3].

They are the most easily machinable, weldable and heat treatable of the stainless steel family, and can be welded by all welding processes. Welding is one of the most employed methods of fabricating ASS components. It is basically a fusion of two or more pieces of metals by the application of heat and sometimes pressure [4]. During the welding process, the fusion and heat affected zone (HAZ) normally undergo metallurgical transformation due to the weld heat, subsequently affecting the mechanical properties of the materials as a result of varying microstructural properties of the material [5]. Although, fully hardened steel is not suitable for use directly [6]. The modification of microstructures to effect changes in the weldment is done chiefly by alloying and heat treatment [7].

Heat treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. It is a process utilized to change certain characteristics of metal and alloy in order to make them more suitable for a particular kind of application [8]. It enhances the properties of stainless steel such as corrosion resistance, microstructure and mechanical strength [9]. Post-weld heat treatment (PWHT) is a term that refers to any heat treatment that is applied to a material after welding. The process is often used to

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improve the properties of the weldment. In most cases, the goal of PWHT is to increase the resistance of the material to brittle fracture by relaxing residual stresses which can occur in weldment due to restrains by the parent metal during weld solidification [6]. Depending on the chemistry of the metals in these areas, hardening occurs to various degrees, dependent mainly upon carbon content. Oil quenchants are used when lower cooling rates and more uniform cooling is desired for better distortion control and crack prevention of alloy steels [10]. One of the major concerns regarding mineral oil quenchants such as SAE 40 engine oil is that it will form steam, resulting in enormous volume expansion. As the steam bubbles out of the quench, the sample surface is coated with oil, and as it exit from the furnace, usually under extremely high pressure, it is readily ignited which may constitute environmental hazard [11].

Neem seeds and Jatropha seeds are some of the species which grow abundantly in Northern Nigeria, but have not been properly exploited economically. There are very few researchers that used Neem seed and Jatropha seed oils as quenching fluids, even though they are cheaper, non-edible, readily available, eco-friendly and less pollutant than mineral oil [12]. However, because of environmental concerns and growing regulations over contamination and pollution, associated with petroleum based oils, it is of continuing interest to identify safer, renewable and biodegradable alternative quenchants to petroleum based oils, such as SAE40 engine oil [11]. The unpredictable degradation of these engineering materials has recently been a cause for worldwide concern. Its consequence is huge financial loses (about 4-24% metals produced annually are destroyed by corrosion) and many mechanical failures result from it [13]. It has been discovered that poor quenching processes give birth to microstructural deficiency which will in turn affect the mechanical properties of steels [11]. Some quenchants such as water, though abundant and low cost have the drawback of inducing cracks or dimensional changes on the quenched component due to its fast cooling rate. Brine produces more quenching severity than water; but it also has the problem of corrosive attack on the components and the equipment used for the quenching [14]. Therefore, there is a need to exploit the suitability of some vegetable oils that are readily available and cost effective to minimise stresses and distortions that are developed within welded metals. Therefore, the objective of the present research is to investigate the effects of Jatropha seed oil, Neem seed oil and compare with the SAE 40 engine oil as quenching media on the mechanical properties of ASS joints.

MATERIALS AND METHODS

Materials

The ASS and welding electrodes used for this work was sourced locally from Kakuri market, Kaduna-Nigeria whose chemical composition (0.06 wt% C, 8.34 wt% Ni, 20.12 wt% Cr, 0.188 wt% Mo, 68.70 wt% Fe, 2.59 wt% others), was determined with the aid of *XRF* AT National Metallurgical Development Centre (NMDC) Jos-Nigeria. Jatropha, Neem seed oils and SAE 40 engine oil were sourced from Zango Area of Sabon Gari LGA whose physiochemical properties (Table 2.1) were determined at National Research Institute for Chemical and Technology (NARICT) Zaria-Nigeria.

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Figure 2.1: Seeds used to extract oil as quenching media for ASS (A) – (C) Jatropha curcas L plant with riped fruits, Fresh seeds and dried seed (D) – (F) Neem plant with fruit, fresh and dried neem seed

Physiochemical properties of quenchants

Physiochemical experiment of quenchants (Table 2) was carried out at NARICT, Zaria-Nigeria with the aid of the following:

- The viscosities of the oils were measured according to ASTM D445-06 using NDJ-S 8S Viscometer.
- Flash point of oil was measured using the Pensky-Martens closed Tester (PMC) procedure.
- Hydrometer was used to measure the specific gravity of the oils according to the Society of Tribologists and Lubrication Engineers (STLE).

Table 2.1: Physiochemical Properties of the Quenchants

Quenching media	Physiochemical properties		
	Viscosity (cSt) at 27.6^{0}C and 60rpm	Flash point Temperature (^{0}C)	Specific gravity
Neem oil	45.8	244	0.907
Jatropha oil	44.5	225	0.980
SAE40 Engine oil	46.3	260	0.868

Extensive characterization of the vegetable oils was carried out and the correlation between physiochemical properties and quenching characteristics were established. Table 2 contains the flash point, viscosity and specific gravity of the quenchants used for the research, which was carried out at NARICT Zaria-Nigeria. SAE 40 engine oil and Neem seed oil recorded higher viscosities which caused them to exhibit substantially fast cooling rates during the quenching period, as reflected by their higher hardness values of 450.3HV and 489HV respectively, which is in good agreement with the findings of [11].

Welding Procedure

ASS was butt-welded with the aid of shielded metal arc welding (SMAW) process. The substrates were prepared for subsequent mechanical examination according to American Standard for Testing and Materials (ASTM). The surfaces of the samples were made smooth and uniform by polishing process [6].

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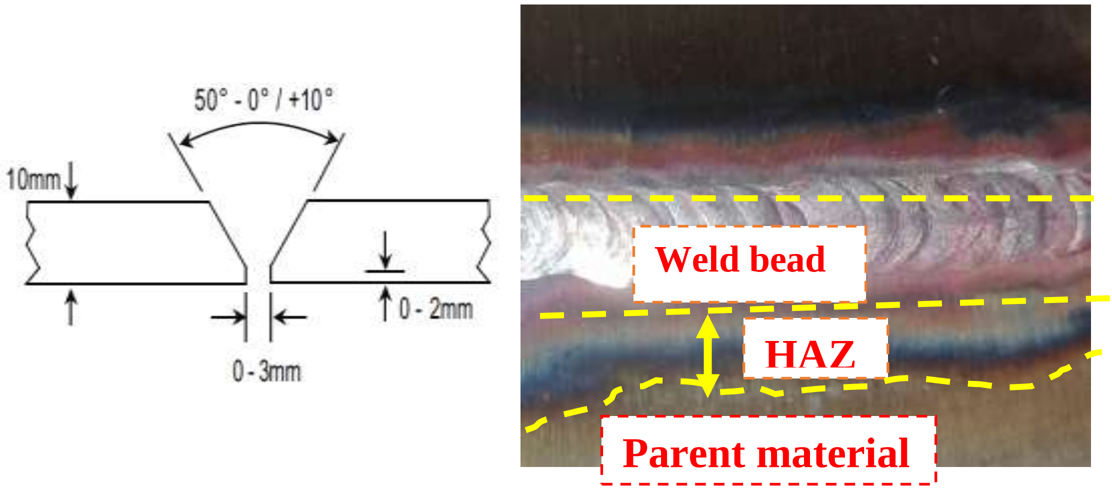

Figure Error! No text of specified style in document.***2: But weld design and welded joint of ASS sample***

Table 2.2: Welding Parametres

Electrode type	Electrode diameter	Polarity	Current	Voltage
E308-16	3.2mm	DCEP	500A	80V

Post Welding Thermal Treatment Methods

Two methods of post thermal heat treatment were adopted in the research, namely:

- Stress relieve annealing
- Hardening by quenching

a. Stress Relieve Annealing Process

This treatment was carried out by heating the welded samples from ambient temperature up to 600^{0}C, and then soaked or held it at this temperature for 30 minutes to ensure homogeneity of the microstructure throughout the samples. They were removed from the furnace and allowed to cool in air.

b. Quenching and Tempering Process

Welded samples that were previously stress relieved were heated to the austenite temperature (910^{0}C), and then soaked at that temperature for sufficient time (30 minutes). The samples were quickly removed and plunged into the tanks containing the quenching media (Jatropha, Neem and Engine oils) at room temperature. The quenched samples were tempered slowly by reheating them to 300^{0}C, and allowed to soak for some time, after which they were removed from the furnace and allowed to cool down to ambient temperature in air.

Mechanical Test Procedure

i. Hardness Test

Hardness test was carried out on the treated and untreated samples according to ASTM E18-79 using standard computerized Vickers Hardness Testing Machine, Model MV1-PC with a load of 0.3kgf, Max/Min limit of 500/300HV, by placing the samples on the anvil and the indentor pressed upon the polished weldment. The results were displayed on the computer system, and average hardness values were taken after three readings were obtained on each sample. These tests were carried out in the Shell Laboratory, Ahmadu Bello University, Zaria-Nigeria.

ii. Impact Test

Fig. 2.3a shows the sample dimensions used for the impact tests. The tests were conducted in accordance with ASTM A370 Standard Method and Definitions for Mechanical Testing of Steel Products. V-notches of 0.5mm depth were made on the samples each and the impact strength was determined with the aid of Izod impact testing machine (Joules). The samples were gripped or held in the chucks of the impact testing machine and impact load was applied to the samples at the joints (notch) until the samples fractured thereby obtaining the results by deflection of a pointer on the graduated scale. This was carried out in the Strength of Materials Laboratory, Department of Mechanical Engineering, Ahmadu Bello University, Zaria-Nigeria.

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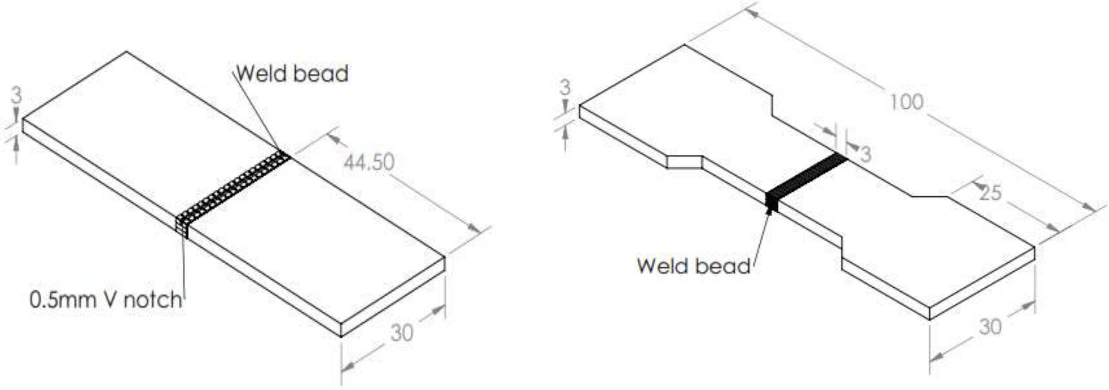

Figure 2.3: Substrates prepared for (a) Impact test (b) Tensile tests

iii. Tensile Strength Test

Fig. 2.3b shows the sample dimensions prepared for tensile tests. The tensile strength tests were conducted in accordance with ASTM E8 Standard Method using the Monsanto Tensometer, type W Serial No. 9875. The samples were gripped or held in the chucks of the tensometer and load was applied with the aid of load handle, until the samples fractured. The load was measured by the deflection of a pointer around a graduated scale. This was carried out in the Strength of Materials Laboratory, Department of Mechanical Engineering, Ahmadu Bello University, Zaria-Nigeria.

Surface Morphology Analysis

i. Mechanical polishing

Prior to the surface morphology examinations, the surfaces of coupons were ground successively, using grit papers of different grades 120, 180, 320, 400, 600, and 800 with the application of coolant intermittently, to prevent overheating and provide a rinsing action that flushed away the particles being removed from the surface. They were subsequently polished with the aid of a polishing machine, using alumina to remove scratches left during grinding, thereby obtaining a mirror-like polished surface.

ii. Etching process

Etching was carried out to expose and make visible the grains of the samples, using the mixture of 5g of Ferric Chloride, 20ml of Hydrochloric acid and 100ml of distilled water, by swabbing with the aid of a tong, thereby making the polished mirror-like surface dull, thus, exposing the grains of the coupons.

iii. Scanning Electron Microscopic Analysis

A Phenol proX scanning electron microscope (SEM) EVO MA-10 manufactured by Carl, was used for the analysis of surface morphology in the Department of Chemical Engineering Laboratory, Ahmadu Bello University, Zaria. The etched samples were loaded into a column, which is connected to the monitor in a closed loop, for which control and feedback are actualized. A finely focused electron beam with voltage energy of 15Kv was scanned across the surface of the weldment, and then generated secondary electrons. The magnification was computed by the ratio of the image width of the output medium divided by the field width of the scanned area. The micrographs of the samples were taken at the weldments.

RESULTS AND DISCUSSION

Results

3.1.1 Effects of quenching media on the mechanical behaviour of welded ASS test samples

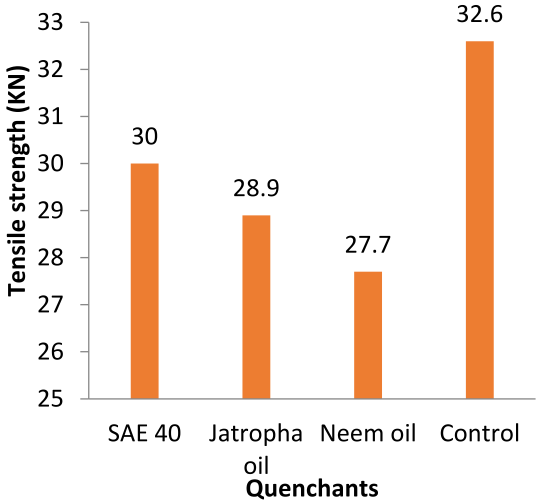

Fig 3.1: Tensile strength of samples

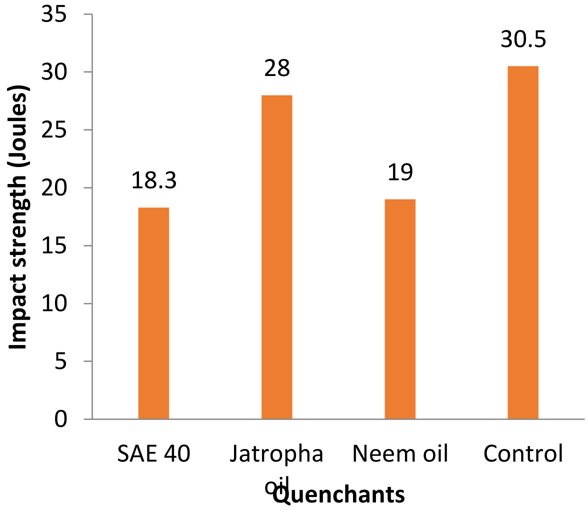

Fig 3.2: Impact strength of samples

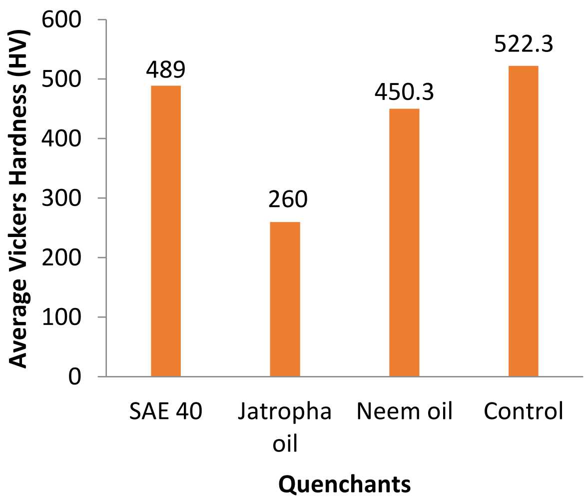

Fig 3.3: Vickers Hardness of samples

Mechanical Properties of Samples

All mechanical tests carried out in the research were in accordance with American Standard for Testing and Materials (ASTM). In each test, average values were taken as the representative results after three consecutive trials.

3.2.1 Tensile properties of the Test Samples

Tensile tests were carried out on three each of treated and untreated samples, with the aid of the Denison tensile test machine with 5000KN capacity, at 40mm gauge length. Average tensile strength was taken as the representative of the samples. All fractures occurred in the weldment, which signified that welding has affected the tensile strength of the material.

Fig. 3.1 shows the tensile strength of both treated and untreated samples. There was no significant effect of the heat treatment on the samples as the strength of control samples (32.6KN) was close to that of the sample quenched in SAE 40 engine oil (30.0KN), followed by sample quenched in Jatropha seed oil (28.9KN) and finally Neem seed oil (27.7KN). This agreed with the findings of [16] which states heat treatment of martensitic stainless steel at 650oC for at least 30 minutes decreased the mechanical properties of the alloy at both HAZ and weld.

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3.2.2 Impact properties of the test samples

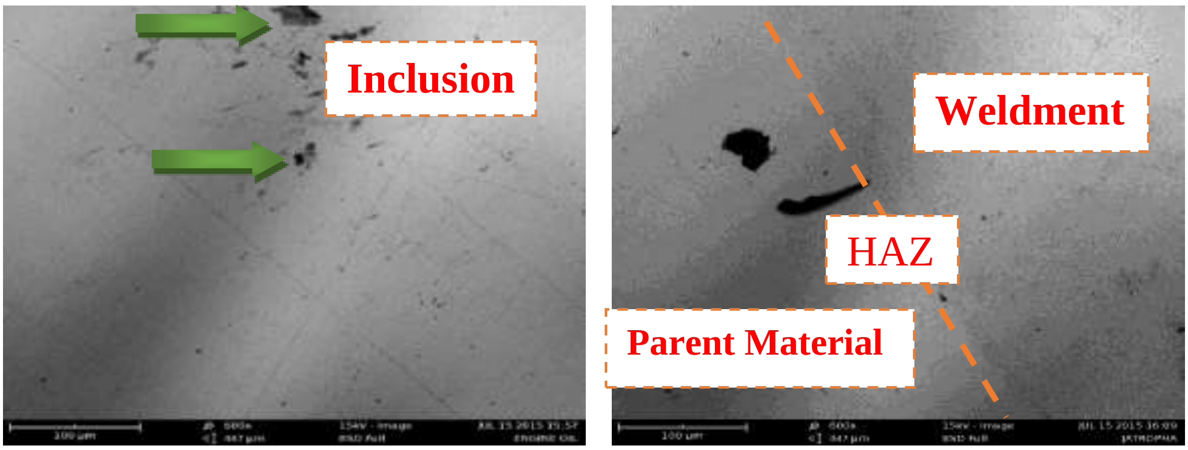
Fig. 3.2 shows the variation of impact energy of the representative samples. The impact toughness of the untreated sample appeared to be higher than those of the treated (30.5J). The decrease in impact toughness of the treated could be attributed to the more coarse grains in the microstructure indicating comparatively lower strength [16]. The sample treated in Jatropha oil appeared to have high impact energy (28.0J), when compared to the other quenched samples; this indicates that the medium (Jatropha oil) is comparatively suitable for industrial heat treatment as observed by [11].

3.2.3 Hardness Properties of the Test Samples

Hardness value of the untreated sample appeared to be comparatively higher (522.3HV) than those of the treated ones (**Fig. 3.3**). This could be attributed to the high residual stresses induced during welding [2]. It has been reported that one of the objectives of post weld heat treatment (PWHT) is to decrease the peak hardness in the weldment (HAZ). Therefore, it has been observed that the PWHT has reduced the hardness value of the weldment; this agreed with the recent research of [16]. The sample treated in Neem seed oil, shows high hardness value (450.3HV), when compared with the Jatropha seed oil and it is also very close to the value of sample treated in SAE 40 engine oil (489HV); this indicates the suitability of the medium (Neem seed oil) for industrial heat treatment as observed by [11].

3.3 Surface morphological characteristics of substrate

It has been reported that the chemical composition of the filler metal for welding ASS produces small quantities of 3 – 5 % d-ferrite in the weld metal of austenitic stainless steels. This is done because; fully austenitic stainless steel welds have a high tendency towards hot cracking. The d-ferrite has beneficial effects in dissolving harmful elements, influencing the susceptibility for cracking, such as sulphur, phosphorus and boron in austenite [17]. **Fig. 3.4** have shown that heat treatment has refined the surface morphology of the samples, but the presence of cracks and inclusions on the vicinity of the weldment could have been the reason for the decrease in the mechanical properties of the samples [6]. During welding, hydrogen, Nitrogen and Oxygen might have dissolved in the weld. This has led to porosity in the weld metal, or the dissolved elements might have combined with elements in the alloy to form the inclusions. The elements have different effects in the weld metal; Hydrogen induces cracking, nitrogen increases the yield and tensile strength but reduces the ductility, and oxygen promotes the formation of inclusions. A Nitrogen adsorption/desorption phenomena might have led to porosity in the weld metal [17]. Micro-segregation which had occurred in the weld metal when d-ferrite was formed during cooling could have been responsible for the formation of Cr-depleted zones. The microsegragation was reduced with faster cooling rates as established by [17].



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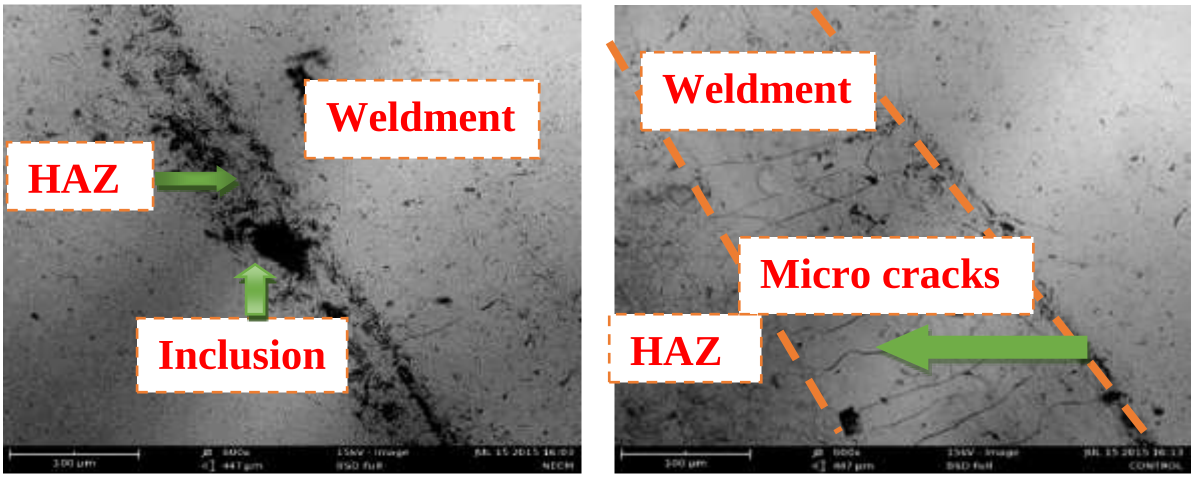

Figure 3.4: Micrographs of ASS welded joints showing some defects in HAZ and weldment

CONCLUSION

From the results and discussions of the study, the following conclusions were drawn:

i. The results of physiochemical properties of the quenchants (**Table 2.1**) showed different values of viscosities, flash points and specific gravity. This could have been the reason for different cooling rates, which affected the mechanical and corrosion behaviour of the weldments.

ii. The austenitic stainless steel (ASS) samples were welded successfully, using shielded metal arc welding (SMAW) process. The choice of welding process depends on the application or service life which the material will be subjected to. Tensile, impact and hardness tests revealed that welding reduced or depreciated the mechanical properties of such material.

iii. Quenching at high temperature in vegetable oils resulted in micro cracks which significantly affected the mechanical properties of the alloy when compared to the welded untreated samples. Jatropha and neem oils showed inferior mechanical properties when compared to the conventional engine oil. Therefore, their suitability as quenching liquid could be investigated on other materials.

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