FUOYE Journal of Engineering and Technology, Volume 2, Issue 2, September 2017 ISSN: 2579-0625 (Online), 2579-0617 (Paper)

Determination of Hardness and Tensile Properties of Dissimilar Phase Structured Steel Weld

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Abstract- This work involves the use of submerged arc welding (SAW) technique in joining heat treated steel in alternate arrangement. The selected as-received steel was initially cut, machined and heat treated to develop a conventional microstructure prior to joining operation. All samples were subsequently characterized to investigate the effect of the process on the mechanical behaviors. 3360 Instron Universal Tensile testing machine was used for the tensile properties evaluation; Vickers' microhardness testing machine was also used for the hardness evaluation at various zones. From the result, it was found that interchanging arrangement of the microstructures during welding yield better combined properties of the ultimate tensile strength, yield strength and with improvement in the strain-to-fracture of some of the samples. The adopted mechanism was also observed to yield better hardness property on the sample. This led to the recommendation of this technique to the oil and gas industry that need to transport their products via the giant water bodies to clients.

Keywords - Submerged Arc Welding, Characterization, Fusion Zone, Heat Affected Zone, Interface.

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1 INTRODUCTION

The general interest of manufacturers and researchers in the use of steel has been attributed to its amenability to alloying and heat-treatment which makes it possible to modify its microstructure to improve desired properties to suite specific service requirements (Bag et al, 1991; Gracar, 2007). Plain carbon steels are utilized for a number of structural applications where high strength, toughness, hardness and ductility are some of the crucial properties required for excellence service performance. Plain carbon steel is essentially known to contain ferrites and pearlites which account for the inherent properties (Higgins, 2004). Ferrites are soft and ductile while pearlites are hard as it contain free existing carbon which exists in the form of cementite (Fe3C). This combination enhances the excellent weldability of steel. During heat treatment, these structures and properties can be changed and makes welding relatively difficult (Zakari et al, 2010).

The weldability of engineering material is usually considered to be the production of a fusion welds in a manner such that the weldment does not contain injurious imperfections (more commonly described as defects when they detrimentally affect the metallurgical structure, properties and subsequent manufacturing operations). The advantages of welding, as a joining process include high joint efficiency, simple set up, flexibility and low fabrication costs (Armentani et al, 2007); This account for the reason of joining large diameter pipes designed for long distance laying (surface or underground) for fluid transportation. Also, because of its high reliability, deep penetration, smooth finish and high productivity, submerged arc welding (SAW) has become a natural choice in industries for fabrication.

As it is well known, the residual stresses have a strong influence on weld deformation, fatigue strength, fracture toughness and buckling strength (Yongyutph et al, 1992; Wen et al, 2001; Armentani et al, 2007). As such, SAW has been considered a very productive welding process over the years (Bipin et al, 2010). Some of the factors that determine the quality of weld are voltage, current, stick out, wire feed rate, welding speed or travel, etc. To this end while describing the Microstructure and Tensile Properties of Submerged Arc Welding in engineering materials, Keshav and Dwivedi (2008) and Momoh et al (2012) concluded that the increase in the heat input affects the proportions of different micro constituents both in the weld fusion and heat affected zone (HAZ). They also observed that the tensile strength (UTS, YS) decreases with increase in heat input.

The efforts to curtail the failure of the laid pipes, welding at a regular interval have been a generally accepted option. However, the knowledge of varying the joining mechanism with respect to alternating the microstructure as an alternative to the predominantly single phase has not been explored to determine its response to fusion welding; and the corresponding effects in the mechanical properties of the selected steel. This thus serves as an impetus to this study.

2 MATERIALS AND METHOD

2.1 MATERIALS AND EQUIPMENT

With the aim of determining the response of alternating conventional microstructure steel to Submerged Arc Welding (SAW), a commercially available plain carbon steel of chemical composition shown in Table 1 was procured. The equipment used to carry out the experiment includes: muffle furnace, electric arc welding machine, hack saw, bench vice, spectrometer, tensile testing machine and microhardness machine, some of which is as shown in Fig 1.

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Fig. 1: Post heat treated welded samples

2.2 METHOD

The chemical composition of the as-received 10mm thickness sheet was initially determined at The Universal Steel Ltd, Lagos using spectrometric analyzer for the spectrometric analysis, and the result was adopted as the working chemistry of the selected steel for the experiment. The as-received steel was machined using lathe machine to tensile configuration of average gauge length 42mm and diameter 5mm. The machined tensile pieces were subsequently cut into two half and the inner cut-ends was chamfered to 60o bevel, this is to allow for thorough weld pool during welding operation.

Muffle furnace was used for the heat treatment operation; all the machined samples were initially normalized in order to annul the mechanical history of the steel that must have been inherited as a result of the induced stress from the machining operation (Momoh, 2012). Conventional steel microstructures were then developed by heat treating the normalized samples to austenitic temperature of 900oC and then allowed the soaked in the furnace for 60 minutes before cooling the samples in various environments. While some sample were allowed to cool in air (normalizing), some others were allowed to cool in the furnace, and still some other sets were allowed to undergo rapid cooling in warm water. Warm water at 40oC was prepared to serve as the quenchant; this is to avoid crack initiation and propagation during cooling; the later sets were segmented into two and a set was further heat treated in the same muffle furnace (which has been allowed to cool for 24 hours) at 300oC and held for 30 minutes. The samples were allowed to cool in air to allow for re-orientation of the atomic structure within the sample piece. This later process in termed tempering operation (Khanna, 2009).

The resulting structures were then joined together in alternating forms using S.A.W. technique and designated as shown in Table 2. Five (5) heat treated half tensile piece is selected and joined each with another annealed, normalized, quenched and tempered half treated piece; such was also done for normalized, quenched and tempered half tensile pieces; this is done in order to determine the combinations with the best combined hardness property. The operations were carried out prior to tensile and hardness characterization most of which was carried out at the Engineering Materials Development Institute (EMDI), Akure, Nigeria. The microstructural view of the selected geometry was conducted and analyzed to compliment the hardness results.

3 RESULTS AND DISCUSSION

3.1 CHEMISTRY AND WELD CONFIGURATION

Table 1 shows the spectrometric analysis of the selected steel for this experiment. A relatively low sulphur and phosphorus content is observed thus indicating the purity of the specimen. This will improve the adhesive property of the selected steel when joined together.

Table 1: Chemical composition of the selected steel

Element	C	Si	Mn	S	P	Cr	Ni	Cu	Ti	Fe
%wt	0.308	0.489	0.546	0.048	0.013	0.166	0.071	0.194	0.009	96.401

Table 2: Sample's treatment and designation

S/N	Designation	Interpretation	Targeted Application
1	AA	Annealed-to-Annealed	Steel pipes for fluid transportation
2	AN	Annealed-to-Normalized	
3	AQ	Annealed-to-Quenched	
4	AT	Annealed-to-Tempered	
5	NN	Normalized-to-Normalized	
6	NQ	Normalized-to-Quenched	
7	NT	Normalized-to-Tempered	
8	QQ	Quenched-to-Quenched	
9	QT	Quenched-to-Tempered	
10	TT	Tempered-to-Tempered	
11	A(Control)	Annealed as control	
12	N(Control)	Normalized as control	
13	Q(Control)	Quenched as control	
14	T(Control)	Tempered as control	

3.2 EFFECTS OF POST-HEAT TREATMENT ON TENSILE PROPERTIES OF STEEL WELD

The response of the joined steel to stress under uni-axial loading is shown in Figure 2 and 3; unweld samples were also treated (i.e normalized, annealed, quenched and tempered) respectively and subjected to tensile loading to serve as the control for the experiment. From the result, it was observed that the unweld sample exhibited expected relatively high strength. Literature review has established that this strength would be sacrificed for ductility when subjected to tempering operation (Khanna, 2009). The unweld quenched sample was observed to have negligible yield strength, this is as a result of presence of excess carbon which have transformed into cementite (Fe3C) as shown in Plate 1, thus making the sample brittle; this is in accordance to initial findings in literatures (Armentani et al, 2007; Momoh et al, 2012).

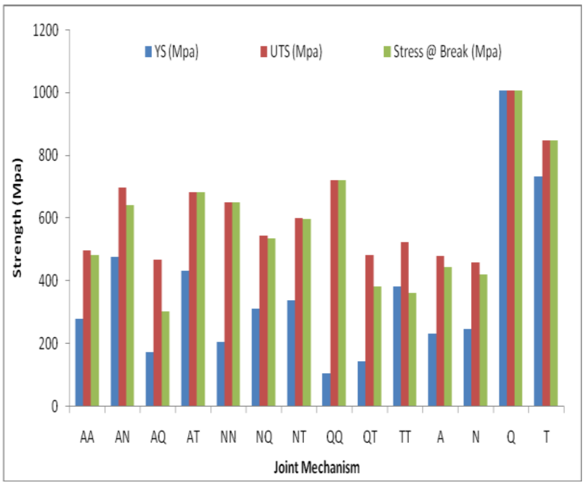

Fig. 2: Response of the joint mechanism to strength of the steels under uniaxial loading

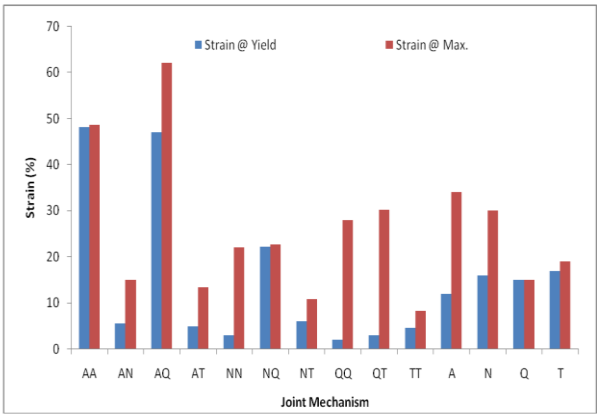

Fig. 3: Response of the joint mechanism to strain of the steels under uniaxial loading

Varied response was observed in the joined tensile pieces, while they were observed to have generally exhibited relatively low yield strength, it was noticed that the samples could not sacrifice their respective ductility even when quenched to improve on the hardness. This could be as a result of the limited holding time (of 30 minutes) during the heat treatment operation. There is a significant improvement in the ductility of weld samples as compared to the unweld with the AA and AQ samples exhibiting a surprising high strain values of 48 and 47% respectively with a difference of about 36% when compared with the just annealed sample and the quenched sample that virtually has no yield strength. The transformed acicular ferrite and martensites could be responsible for this development.

Generally, while some of the joined weld samples were observed to exhibit a diminishing ductility sacrificed for strength, some others were observed to displays high ductility and still others moderate ductility with relatively high strength. The amount of martensite (not estimated in this work) in the samples could be responsible for this. This result generally proves that when steels when joined in alternating structure, reliable tensile properties will ensue favorable for structural applications.

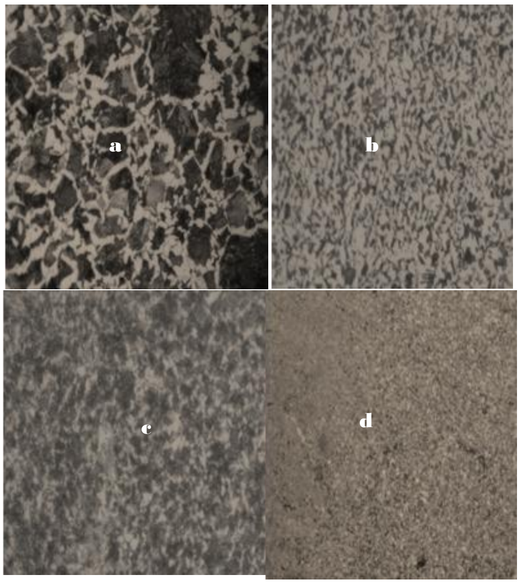

Plate 1: Micrographs of mild steel (at x200 magnifications) after being subjected to: (a) Annealed structure (b) Normalized structure (c) Quenched Structure and (d) Tempered Structure.

Table 3: Summary of tensile properties of welded and unwelded samples

S/N	Joints	UTS (MPa)	Strain @ Max.	Stress-to-Fracture (Mpa)	Yield Stress (Mpa)	Yield Strain
1	AA	496.78	0.48095	480	278.43	0.48616
2	AN	694.93	0.15	640	473.95	0.056
3	AQ	467.17	0.47	300	171.94	0.62
4	AT	680.41	0.135	680	430.74	0.049
5	NN	650.01	0.22	650	204.03	0.03
6	NQ	542.72	0.22143	535	308.76	0.22758
7	NT	599.88	0.1082	596	335.44	0.06
8	QQ	720.46	0.28	720	102.55	0.02
9	QT	480.79	0.30215	380	140.75	0.03
10	TT	520.98	0.0827	360	380.63	0.047
11	A (Control)	476.33	0.34	441.85	230.67	0.12
12	N (Control	455.98	0.3	419.11	245.14	0.16
13	Q (Control)	1005.98	0.15	1005.98	1004.62	0.15
14	T (Control)	846.7	0.19	846.7	730.63	0.17

3.3 EFFECTS OF POST-HEAT TREATMENT ON HARDNESS PROPERTY OF STEEL WELD

The rate at which steel fractures in operation, inspite of its amenability to heat treatment and alloying, in fluid transportation is becoming alarming. One of the possible causes of these failures, among others, is improper weld geometry, and wrong selection of materials for specific application. This served as an impetus in the study of joint variation of developed dissimilar phase structured steel. The developed weld structure was characterized to evaluate the consequence of heat treatment prior to welding in steel pipes. After applying a load of 490MN over a dwell time of 10 seconds in a Vicker's hardness testing machine, the results for the microhardness test was explicit.

Figure 4 shows the hardness values of the steel with respect to the heat treatment operations; this expected result correspond to literature review (Higgins, 2004; Khanna, 2009) with the quenched sample exhibiting the highest hardness value of about 202Hv.

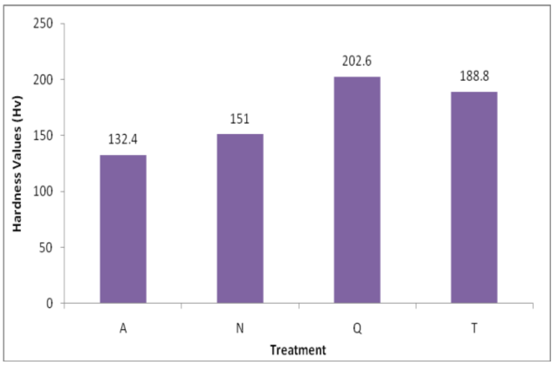

Fig. 4: Variation of microhardness of unweld conventionally treated steel to serves as control and initial value for the experiment

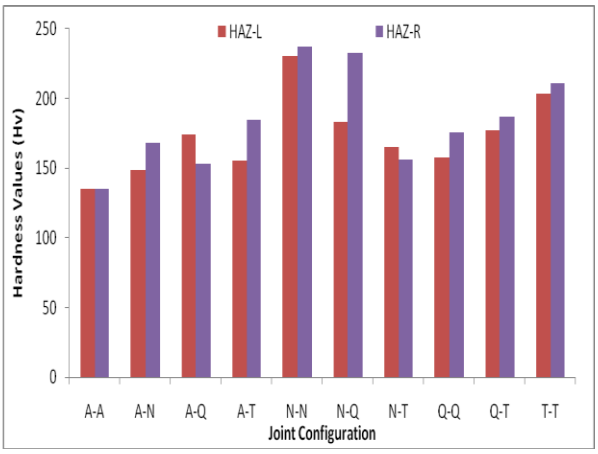

Fig. 5: Hardness variation of the Heat Affected Zone (HAZ) of the welded steel samples

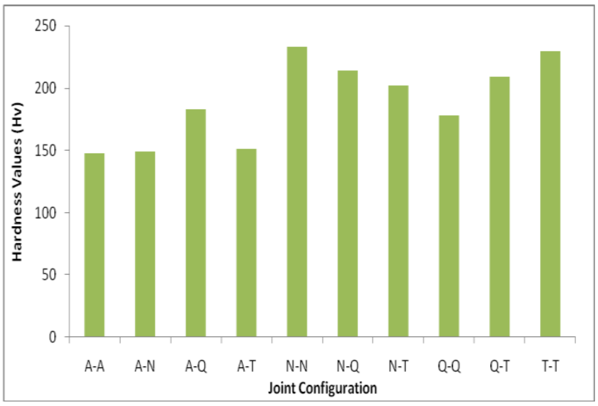

Fig.6: Hardness variation of fusion zone (FZ) of the selected weld steel

a) Heat Affected Zone (HAZ)

In the course of welding, it has been established that certain part of the material undergoing welding experiences heat transferred from the weld or fusion zone; this parts of the material is referred to as the Heat Affected Zone (HAZ). In this context, every sample subjected to SAW has double end HAZs designated as HAZ-L and HAZ-R which implies the HAZ to the left hand side and to the right hand side respectively as shown in Figure 5 below.

When the samples were subjected to annealing operation prior to welding, it was observed that after joining the hardness values at both end of the joint sample were virtually equal. These are however not so when annealed (½) sample (Left side of the weld sample - L) was joined with normalized (½) sample (right side of the weld sample - R); the results as shown in Figure 5 indicates that the displayed hardness value of the HAZ toward the normalized end is higher compared to the other half end. The reason for this disparity could be traced to the initial microstructures (ferrite + pearlite) prior to welding operation (See: Plate 1). The normalized structure with coarse pearlite in ferrite matrix (Momoh et al, 2015) could have undergone atomic re-orientation after re-heat treatment during welding, thus resulting into finer structure with possible precipitates of carbide-forming drops of the used electrode.

Similar differences were observed in all other eight (8) configurations. Critical observation shows that when normalized sample is joined to another normalized sample, a uniquely high hardness values at both ends of the weld sample was recorded. This phenomenon is also observed in other samples like the N-Q and T-T which is believed to have undergone martempering operation in the course of welding, and this have been confirmed to be a plus to the hardness property of steel similar to ductile iron (Oyetunji and Barnabas, 2012) which has their reason for the increment boiled down to the initial and datum microstructures.

b) Fusion or Weldment Zone (FZ)

Figure 6 shows the relationship of the hardness and the joint configuration of pre-weld heat-treated steel at the fusion zones or weldment zones. The corresponding increments in the hardness results were recorded in all the sample, this increments were in comparison to the base which serves as the control (See Figure 4 above) to the assessment of the welds. All FZ hardness values compliment the record of the HAZ (earlier discussed); however, a contrary value was observed in the sample where annealed sample was joined with tempered sample to make a weld piece. The fusion zone in this piece exhibited relatively low hardness value due to inappropriate weld operation.

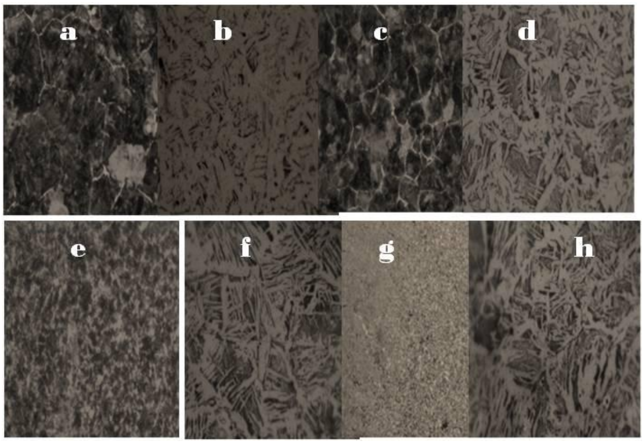

Plate 2: Photomicrograph of mild steel (at x200 magnifications) after: (a) HAZ of A-A weld joint (b) FZ of A-A weld joint (c) HAZ of N-N weld joint (d) FZ of N-N weld joint (e) HAZ of Q-Q weld joint (f) FZ of Q-Q weld joint (g) HAZ of T-T weld joint (h) FZ of T-T weld joint.

4 CONCLUSION

In a view to proffering solution the frequent failure of pipelines that ensues from vandalism, this work was tailored to considering varied joint mechanism by altering the weld geometry. The selected specimen is medium carbon steel and all ½ tensile pieces from this specimen were heat treated prior to welding using sub-merged arc welding (SAW) technique. After tensile and hardness characterization, a general improvement was observed in both the tensile and harness properties of the steel. While varied response were observed in the tensile properties with each exhibiting unique tensile properties, all the samples were observed to have exhibited increment in the hardness property both at the HAZ and FZ.

Summarily, sample A-A and A-Q shows the best combined mechanical properties in consideration and as such could be recommended for application in pipeline laying.

REFERENCES

Armentani .E, Esposito .R, Sepe .R (2007): The Effect of Thermal Properties and Weld Efficiency on Residual stresses in welding. Journal of Achievements in Materials and Manufacturing Engineering, Vol. 20, Pp. 319-322.

Bag .A, Ray .K.K and Dwarakadasa .E.S (1991): Influence of martensite content and morphology on tensile and impact properties of high-martensite dual-phase steels. Metallurgical and Materials Transactions A (Warrendale); Vol. 30, Issue 5, Pp. 1193-1202.

Bipin K.S, Tewari S.P, Jyoti. P (2010): A Review on Effect of arc Welding Parameters on Mechanical Behaviour of Ferrous metals/alloys. International Journal of Engineering Science and Technology. Vol. 2, Issue 5, Pp. 1425-1432.

Grajcar .A (2007): Effect of hot-working in the $\gamma + \alpha$ range on a retained austenite fraction in TRIP-aided steel. Journal of Achievements in Materials and Manufacturing Engineering (Gliwice); Vol. 22, Issue 2, Pp. 79-82.

Higgins A.R, (2004): Engineering Metallurgy - Part 1 - Applied Physical Metallurgy. 7 Edition. Edward Arnold. England.

Keshav P, Dwivedi D.K (2008): Microstructure and Tensile Properties of Submerged Arc Welded 1.25Cr-0.5Mo Steel Joints, Journal of Materials and Manufacturing Processes, Vol. 23, Pp. 463-468.

Khanna O.P (2009): Material Science and Metallurgy. Dhanpat Rai Pub (P) Ltd.

Momoh M.I., Akinribide J.O., Ayanleke J., Olowonubi J., Olorunfemi G.O., Oshodin T. (2013): Investigating the Mechanical Properties of post weld heat treated 0.33%C low alloy steel. International Journal of Science and Technology. Vol. 2, No. 6, Pp 433 – 437.

Momoh M.I. (2012). Microstructures, Corrosion and Mechanical Behavior of Dual Phase Medium Carbon Low Allow Steels. [Thesis]. Nigeria. University of Technology, Akure. 56 - 68.

Momoh M.I., Bamike J.B., Saliu M.A., Adeyemi O.A. (2015): Effects of Polyethylene Glycol on the Mechanical Properties of Medium Carbon Low Alloy Steel. Nigerian Journal of Technological Development, Vol. 12, No.2. Pp. 61-64.

Oyetunji A., Barnabas A.A. (2012): Development of ductile iron by step-quenching method in warm water. Journal of Emerging Trends in Engineering and Applied Sciences. Vol. 3, issue 3. Pp. 470 – 477.

Wen S.W, Hilton .P and Farrugia .D. C. J (2001): Finite Element Modeling of a Submerged Arc Welding Process. Journal of Materials Processing Technology, Vol. 119, Pp. 203-209.

Yongyutph .P, Ghoshp .K, Guptaa .C, Patwardha .K, Satya .P (1992): Influence of Macro/Microstructure on the Toughness of 'All Weld' Multipass Submerged Arc Welded C-Mn Steel Deposits, ISIJ International Vol. 32, Pp. 771-778.

Zakaria B., Chemseddine D., Thierry B. (2010): Effect of Welding on Microstructure and Mechanical Properties of an Industrial Low Carbon Steel. Engineering Vol. 2, Pp. 502 – 506