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Effect of Mild Steel Coated with Locally Formulated Flux as Electrode on the Microstructure and Tensile Properties of Arc Welded Joint

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Abstract

The microstructure and tensile properties of arc welded joint of medium carbon steel using locally formulated low hydrogen flux coated on mild steel as electrode(s) was investigated. The electrodes were formulated using commercial low hydrogen flux (E7018) partially replaced with titanium dioxide, potassium fluoride (KF) and potash extracted from locust bean seed pod (KLBSP) which was enriched with sodium silicate in varying compositions. The electrodes produced were coded as E1, E2, and E3. The welding was carried out at 75A rooting and 115A capping current using direct current electrode positive (DCEP) and direct current electrode negative (DCEN) polarities. The electrode core diameter size of 4mm was employed for the welding. The analogue Avery universal testing machine with maximum load 250 kN was used to determine the tensile properties while microstructure examination was carried out at 400X magnification using optical microscope N 400 POL. The results from tensile properties using electrode coded E1 and E2 using DCEN had yield strength (YS) of 510.33 N/mm2 and 471.67 N/mm2, while ultimate tensile strength (UTS) were 548.67 N/mm2 and 501.33 N/mm2 respectively. These values compare closely with UTS of welded joints made of E7018 electrode which has an average value of 480 N/mm2 and 570 N/mm2 for YS and UTS respectively. Whereas welded joints made from electrodes coded E1, E2 and E3 using DCEP had values of 262.50 N/mm2, 230.33 N/mm2 and 404.00 N/mm2 respectively for YS and 288.67 N/mm2, 262.33 N/mm2 and 431.00 N/mm2 respectively for UTS. Based on this study, the recommended polarity to be employed for welding using the formulated electrode is the DCEN using electrode coded E1 and E2.

Keywords: Locally formulated flux, electrode, welding polarity, rooting, capping, microstructure.

1. Introduction

Steel is regarded as an important engineering material. It has applications in many areas which includes 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 (Ikumapayi *et al.,* 2007. It is capable of presenting economically a very wide range of mechanical and other properties (Talabi *et al.,* 2014). 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 (Rassizadehghani *et al.*, 2006, Momoh *et al.*, 2013. Today, joining technology accounts for a greater part of the whole manufacturing process of investment goods to the required shape and size. Industrial production of technical goods particularly of investment goods today using steel or other materials is hardly carried out without joining technology, Von (2015). Some of these joining processes are done by welding, brazing, and the use of adhesive bonds. These processes are used for the manufacture of household appliances, vehicles of all kinds, electrical as electronic devices as well as building structures in private and industrial sectors. Among these joining processes, shield metal arc welding (SMAW) is commonly used due to its better resistance to wear, versatility in joining and remote welding repair (Messler, 2014). The low cost of the process is attributed to the fact that equipment and electrodes translate to lower cost of project and would ultimately encourage funding of projects (Fadeyi *et al.*, 2021). Welding according to (Hendesen, 2004) is a process of joining two or more similar or dissimilar metals to achieve total coalescence. While the American Welding Society defines welding as a material joining process which produces coalescence of materials by heating them to a suitable temperature with or without the application of pressure or with the application of pressure alone and with or without the use of a filler material.

Metal structures in service life are prone to failure and most of these failures of metal structure occur at the welded joints (Singh, 2008). These failures are due to different stresses imposed on the joints (Igbax *et al.*, 2016; Sunday *et al.*, 2019) One of the greatest challenges in SMAW which causes this weld failure is the introduction of hydrogen atoms in welds called hydrogen induced cracks (HIC) or hydrogen assisted cracks (HAC). The upper threshold weld metal diffusible hydrogen for high steel welding was set at 5 ml/100g of deposited metal, Matsushita and Liu (2000). However, in recent times high performance steels with improved mechanical properties have been developed which requires diffusible hydrogen levels to be lower than 5 ml/100g. Further efforts have been put in place by researchers to reduce the hydrogen content diffusion in welded joints by formulating low hydrogen electrode coating from rutile, potash and potassium fluoride. In the world today, there is an increasing emphasis on the need for quality weldments. Weld quality is seen as an important part of the total quality control. The need for product quality is due to several factors which include economics, safety, government regulations, global competition and the use of less conservative designs.

The quality of welding material according to Makarov, (2014) are attributed to; raw materials, technology of welding electrode preparation, availability of necessary technological equipment, availability of research base and corresponding scientific and technical personnel, availability of welding equipment and welding materials. Messler (2004) and Chandel *et al.*, (1997) stated that the quality of welded joints is influenced by electrode type, metal deposition rate, arc travel and weld polarity. Furthermore, Pagare *et al.*, (2020) investigated the effects of welding parameters on mild steel by shield metal arc welding technique. The authors established that deposition rate increases with increasing electrode diameter and hence increases the HAZ which decreases the weld strength, they also concluded that electrode coating affects the quality of weldments.

Furthermore, Igbax *et al.*, (2016); Mohammed *et al.*, (2019) highlighted the importance of it weld-ability linked with electrodes and should be selected properly. Raj *et al.*, (2002) identified wrong weld current and polarity as factors affecting the quality of welded joints**.** It is therefore important to investigate the effect of polarity on the tensile properties on the welded joint. Hence, this paper presents results from a study carried out on using locally formulated low hydrogen flux coated on mild steel as electrode core to investigate the effect of polarity on microstructure and tensile properties of joints made from SMAW.

2. Method

2.1 Material Preparations and Welding

The electrode was produced with a 4mm mild steel core diameter wire and length 304.8 mm. The flux was formulated from low hydrogen flux (E7018), titanium dioxide, potassium fluoride and potash enriched with sodium silicate in varying compositions coded as E_1, E_2 and E_3 as presented in Table 1. The chemical composition of the formulated flux is presented in Table 2. The mild steel was coated manually using spiral method and compacted. The compacted green electrode was dried in an oven to a temperature of 250ºC and held for two hours.

Medium carbon steel was analyzed to determine its chemical composition. Table 3 presents the spectrometer analysis of the medium carbon steel. The medium carbon steel samples were prepared in the following dimensions 210 X 77 X 9 mm. The specimens were welded using Direct Current Electrode Positive (DCEP) and Direct Current Electrode Negative (DCEN) in the flat position with a root gap of 3.2 mm and 60º VEE single butt joint. Test specimens were cut at the welded joints from the welded coupons. The tensile test specimens were cut having dimensions of 20 mm weld width, 240 mm length, 120 mm gauge length, 25 mm gauge and 9 mm thickness with dog bone shape marked out with a scriber. Standard hand held angle grinder was used for cutting and grinding off the weld deposits flush to dimensions. Sharp edges were also removed before the testing. While rectangular bar of 9 mm X 9 mm X 70 mm. was cut for microstructure examination.

Table 1. Formulation of the Experimental Flux

Experimental runs	**Electrode coatings**	**$KL_{BS}P$ Wt%**	**TiO_2 Wt%**	**KF Wt%**
1	E_1	8	45	7.4
2	E_2	10	35	7.4
3	E_3	12	25	7.4

Table 2. Chemical Composition of the Developed Flux

Element	E_1	E_2	E_3
AlO_2	0.41	0.38	0.42
Bal	41.02	40.81	41.86
SiO_2	6.62	6.52	6.78
SO_2	0.14	0.16	0.17
Cl.	0.37	0.36	0.46
K_2O	5.68	7.58	6.57
CaO	25.49	24.39	24.29
TiO_2	10.06	9.73	8.53
V_2O	0.32	0.32	0.32
Cr_2O_7	0.02	0.02	0.02
MnO	2.48	2.48	2.48
Fe_2O_3	6.89	7.89	7.99
Co	0.02	0.02	0.02
CuO	0.03	0.03	0.03
Rb	0.03	0.03	0.03
Sr	0.04	0.04	0.04
Zr	0.01	0.01	0.01
Nb	0.03	0.03	0.03
Mo	0.03	0.03	0.03
Sn	0.02	0.02	0.02
Ba	0.05	0.05	0.05
W	0.01		
Total	100.00	100.00	100.00

Table 3. Spectrometer Analysis of Medium Carbon Steel

Element	C	Si	Mn	P	Ni	Cr	S	Cu
%	0.34	0.18	0.80	0.045	0.085	0.059	0.049	0.302

2.2 Material Testing

2.2.1 Tensile Properties Testing

Tensile testing on the welded joint is carried out to measure the mechanical property which is considered important to the satisfactory performance of a welded joint in service. The test was carried out to determine the ultimate tensile strength (UTS) and the yield point under static loading of the welded joint. Percentage elongation to determine the ductility of the joint was also determined. The procedure for specimen preparation was followed according to the American Welding Society (AWS) specifications.

The prepared test specimen (for tensile test) of gauge length 40mm was fixed between the upper and lower jaws of the Universal testing machine (analogue Avery universal testing machine with maximum load 250 kN) in accordance with ASTM D638. The graph paper was inserted in the recording drum, and then load was applied on the specimen until failure occurred. The yield strength, UTS and percentage elongation were determined from the data collected from the test. The final gauge length and cross-sectional area was recorded and then the stress, strain and percentage elongation were determined using equations 2.1, 2.2 and 2.3 respectively.

$$stress = \frac{load}{original\ area} \tag{2.1}$$

$$strain = \frac{extension}{original\ length} \tag{2.2}$$

$$\%\ Elongation = \frac{extension}{original\ guage\ length}\ X\ 100 \tag{2.3}$$

$$Young\ Modulus = \frac{stress}{strain} \tag{2.4}$$

$$Yield\ Stress = \frac{load\ at\ upper\ yeild\ point}{original\ area} \tag{2.5}$$

$$Ultimate\ Tensile\ Strength = \frac{maximum\ load}{original\ area} \tag{2.6}$$

The percentage elongation was determined by measuring the length before fracture (l_1) and length after failure (l_2) using a pair of vernier caliper. The percentage elongation was calculated for welded joints using the formulated (experimental) electrodes using equation 2.3

2.2.2 Microstructure Examination

The metallographic studies provide information regarding the presence of defects, mechanical properties and the response from the intended service before components are put into use. Hence, the metallographic study is important in establishing the causes of failure and service condition of a component. The scope of this work was limited to examining the microstructure and tensile properties.

The microscope specification used for this work was PL200W and has a 400X magnification. The welded samples were prepared for the microstructural studies by cutting into rectangular bar of 9mm X 9mm X 70mm. The samples were ground using silicon carbide paper from rough to fine grade. The samples were etched using 2% Nital (2% HNO_3 in 98% ethanol) solution. The specimen was dried. The microstructure of each specimen was revealed on the monitor screen connected to the microscope and shown in a tabular form, in Table 6.

3. Results

3.1 Tensile Properties Testing

To determine the appropriate polarity and most effective flux formulation, tensile strength test was carried out on the specimens.

Table 4 presents the average yield/ ultimate tensile strength and percentage elongation for the welded joints using the electrodes with formulated flux employing DCEN.

Table 4. Average Tensile Test Results (YS and UTS) for Medium carbon Steel Welds Made Using the Formulated Flux Coatings Employing DCEN

Exp. Runs	**Electrode**	**Yield load (kN)**	**Maximum load (kN)**	**Yield Strength (N/mm^2)**	**Ultimate tensile strength (N/mm^2)**	**% Elongation**
1	E_1	57.67	62.00	510.33	548.67	18.8
2	E_2	53.33	56.67	471.67	501.33	18.8
3	E_3	39.00	42.33	344.67	374.67	18.8

Table 5 presents the average yield/ ultimate tensile strength and percentage elongation of welds carried out adopting DCEP using commercial and formulated flux coatings.

Table 5. Average Tensile Test Results (YS and UTS) for Medium carbon Steel Welds Made Using the Formulated Flux Coatings Employing DCEP

Exp. Runs	**Electrode Code**	**Yield load (kN)**	**Maximum load (kN)**	**Yield strength (N/mm^2)**	**Ultimate tensile strength (N/mm^2)**	**% Elongation**
1	E_1	30.33	32.67	262.50	288.67	18.8
2	E_2	26.00	29.67	230.33	262.33	18.8
3	E_3	45.67	48.67	404.00	431.00	18.8

Figure 1 and 2 shows the graphical representation of yield strength and ultimate tensile strengths respectively of the welded joints of the formulated electrodes when employing both polarities.

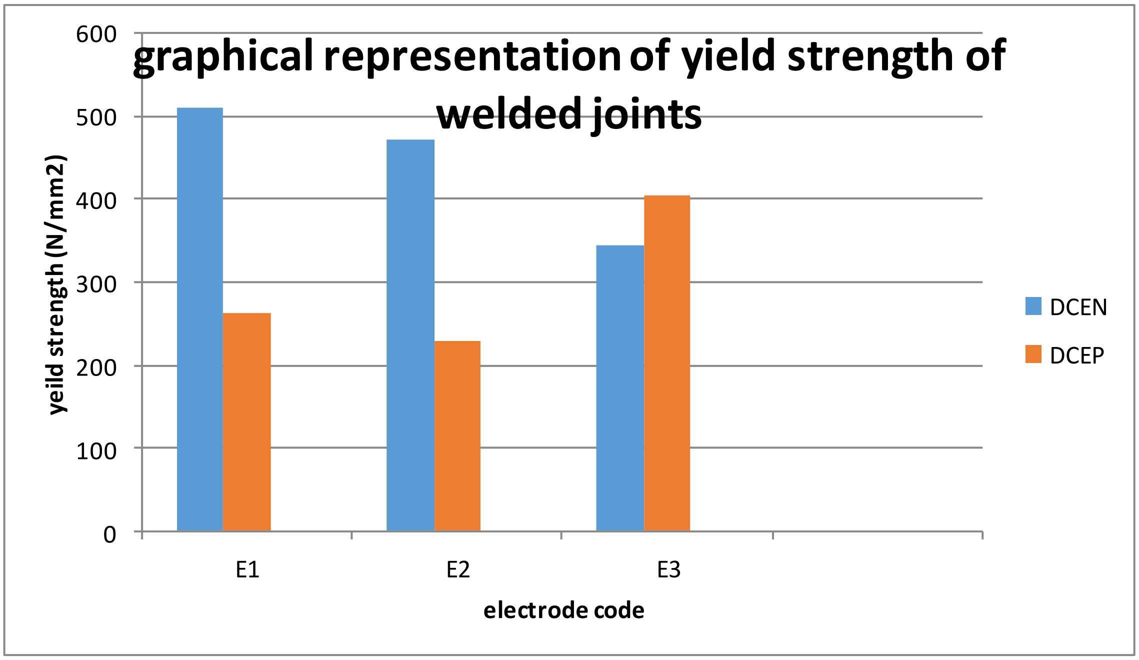

Figure 1: Graph of yeild strength of formulated electrode welded joint for different polarities

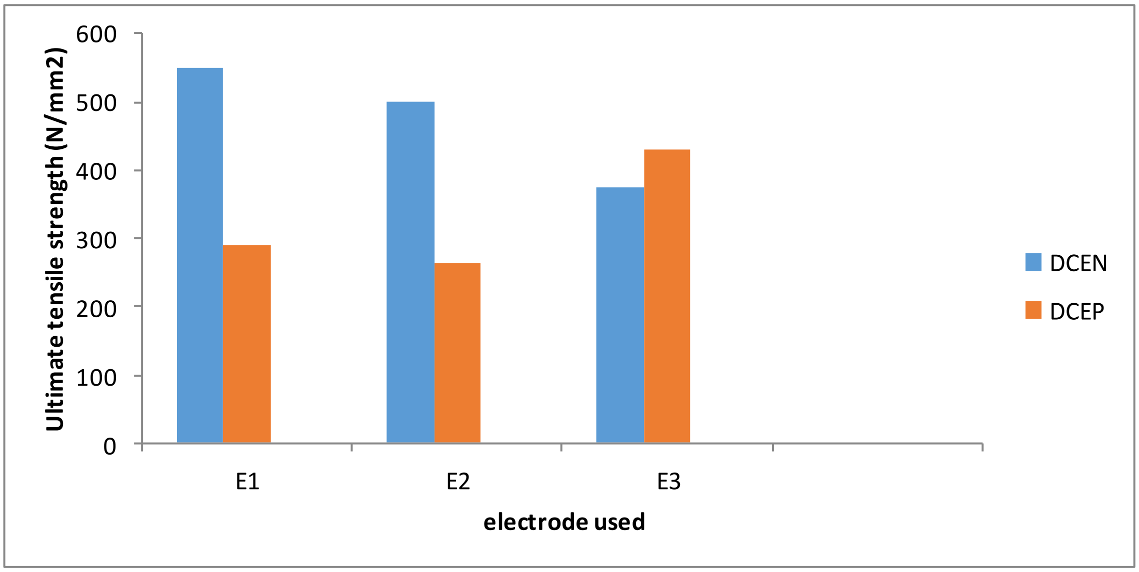

Figure 2: Graph of ultimate tensile strength of formulated electrode welded joint for different polarities

3.2 Microstructure Examination

Microstructural analysis gives information on the types of defects present in a material. It gives information on the grain size and structure which can be used to determine the mechanical properties and response in the intended service life.

Microstructure examination of a welded specimen presented in plates I to XII reveal that the microstructure of the HAZ, the weld and the base metal are different from one another as aserted by Sharma *et al.,* (2020). Plates I to XII presents the microstructure of HAZ and weld join respectively at 400X magnification of weld made by formulated electrodes employing DCEN and DCEP. The white spots in the plates I to XII represents ferrite while the dark spots is a combination of martensite and cementite. The microstructure was viewed with a microscope at 400X magnification. Table 6 presents the nature of the microstructure from each of the plates.

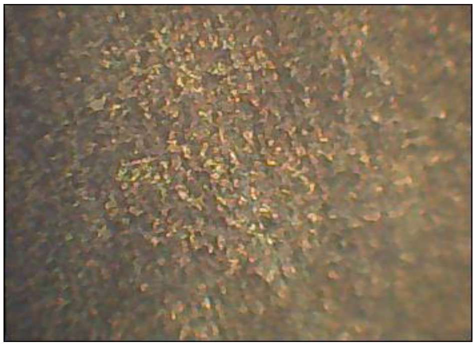

Plate I: DCEN E_1 HAZ at X 400

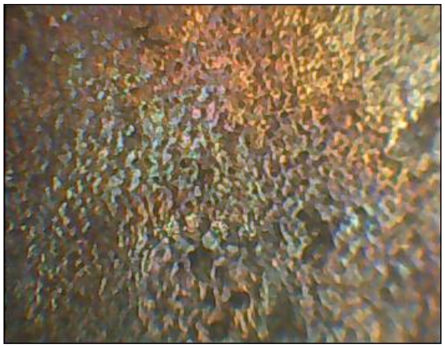

Plate II: DCEN E_1 Welded zone at X 400

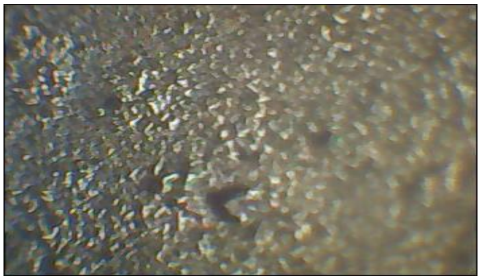

Plate III: DCEP E_1 HAZ at X 400

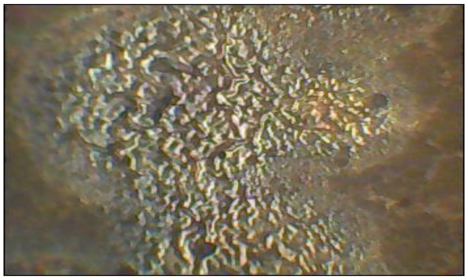

Plate IV: DCEP E_1 weld zone at X 400

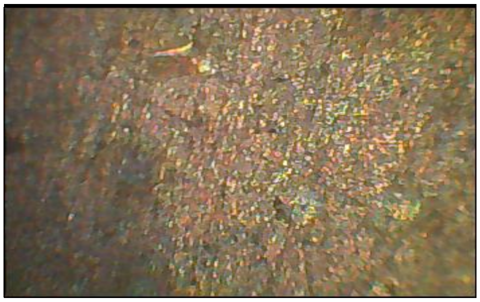

Plate V: DCEN E_2 HAZ at X 400

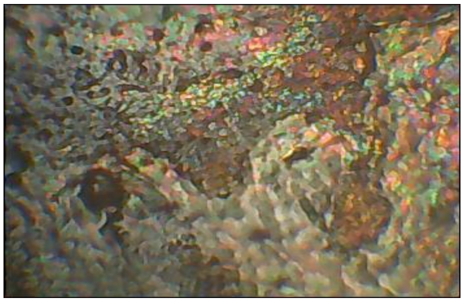

Plate VI: DCEN E_2 weld zone at X 400

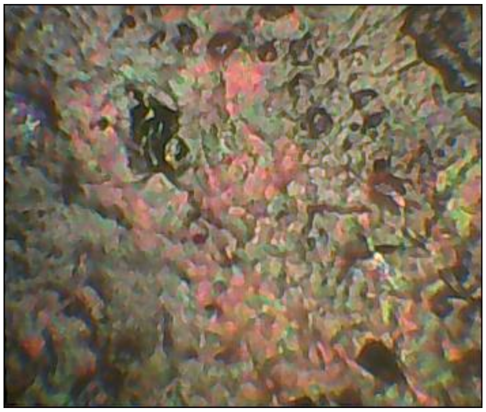

Plate VII: DCEP E_2 HAZ at X 400

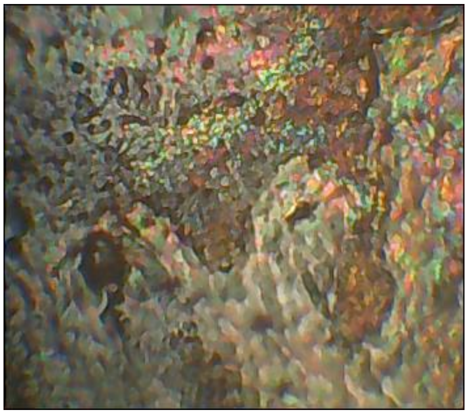

Plate VIII: DCEP E_2 weld zone at X 400

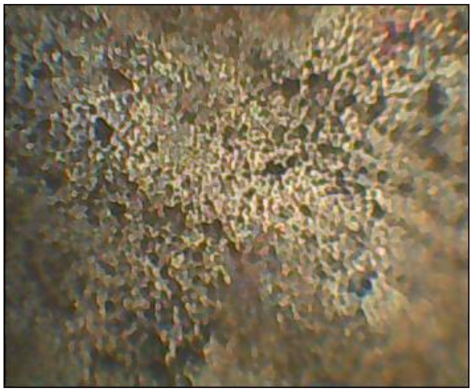

Plate IX: DCEN E_3 HAZ at X 400

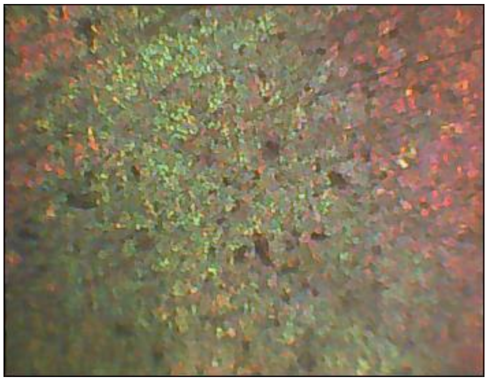

Plate X: DCEN E_3 Weld zone at X 400

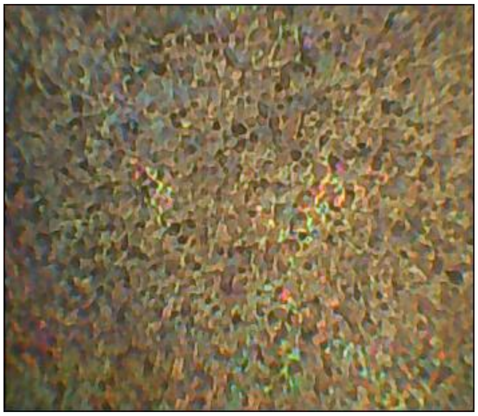

Plate XI: DCEP E_3 HAZ at X 400

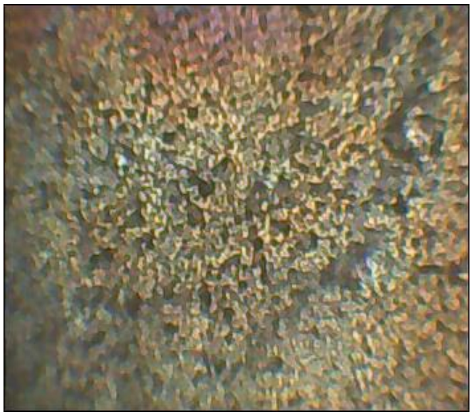

Plate XII: DCEP E_3 weld zone at X 400

Table 5. Presentation from Microstructure

Electrode code	Heat Affected Zones	Fusion Zones
E_1 DCEN	Fine grain structure containing ferrite, Pearlite and cementitte in matrix of pearlite	Fine grain structure containing ferrite, cementitte and pearlite in matrix of pearlite
E_1 DCEP	Slightly coarse grain containing ferrite in matrix of pearlite	More coarse grain than the heat affected Zone. Microstructure contains ferrite, pearlite and cementitie.
E_2 DCEN	Fine grain structure with more of ferrite than pearlite and cementite	Fine grain structure containing ferrite, pearlite and a little cememtite.
E_2 DCEP	Coarse grain size containing pearlite ferrite and cementite	coarse grain structure containing ferrite, pearlite and a little cememtite.
E_3 DCEN	Fine grain structure containing pearlite ferrite and cementite	Fine grain structure containing ferrite, pearlite and cementite structures
E_3 DCEP	Fine grain structure containing pearlite ferrite and cementite	Fine grain structure containing ferrite, pearlite and cementite structures

4. Discussion

Table 4 and 5 shows tensile properties of the welded joints made from the formulated electrodes. Welded joints made by using DCEN showed better tensile properties due to stable current from the negetive electrode to the positive work and more heat concentration on the workpiece resulting in greater penetration with the DCEN (straight polarity). Whereas with the DCEP as reflected in Table 5, electrons move from the work piece to the electrode which gives greater concentration of heat on the electrode and lesser heat which results in lesser penetration and hence lower tensile properties. E_1 had the highest value of 510.33N/mm^2 and 548.67 N/mm^2 for yeild strength and ultimate tensile strength respectively using DCEN. It was also observed that the tensile properties increased with decreasing composition of $KL_{BS}P$. The tensile properties was also observed to increase with increasing TiO_2 contents. The percentage elongations were the same for all formulations and polarities employed. The results revealed that there is an effect of polarity on the microstructure and tensile properties of welded joints.

5. Conclusion

The following conclusions were drawn from the study on the effect of polarity on the tensile properties and microstructure on the welded joints. Yeild strength and ultimate strength was higher using DCEN than DCEP. The tensile properties obtained when employing DCEN compares closely with tensile properties of welded joints made by E7018 electrode. The percentage elongations were the same for all the formulations. Hence, when using the formulated electrode the suitable polarity to be employed is the DCEN of the electrode coded E_1 and E_2

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