Comparative Analysis of Mechanical Properties of Mild Steel Plates Welded with the Developed Welding Robot and Manual Electric Arc Welding

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***Abstract* - Mild 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm and 1.0 mm thick steel plates were prepared into 66 test samples. After welding with the Developed Welding Robot and Electric Arc Welding Machine these test samples were subjected to Tensile Strength and Hardness tests. All data obtained including hardness, tensile stress, tensile strain, break point and elasticity modulus were analyzed and the data produced from Electric Arc welding operations were also compared with those obtained from the Robot welding operations created. The findings showed the difference in hardness values of welded and unwelded mild steel plates (specimens) of different sizes where the highest hardness of the produced robot welding samples is located. The 1.0 mm soft, non-welding steel plate (CONTROL Sample) had the highest effect on load. 0.8 mm Sample gave the highest amount for developed robot welding. Sample 1.0 mm gave the highest for the electric arc welding. The results revealed that the 1.0 mm sample without welding had the highest overall impact on load. The robot welding sample produced gave the lowest tensile stress while the unwelded samples (CONTROL) gave the highest. The unwelded (CONTROL) samples gave the highest tensile strain values while the lowest was provided by developed robot welding samples. The robot welding samples developed gave a trend of comparatively lower elasticity modulus values than both the unwelded and the electric arc welding samples. This pattern was anticipated given the higher hardness values, lower extension values, tensile stress and tensile strain of the robot welding samples formed over those of the electric arc welding and unwelded (CONTROL) samples.**

***keywords* - Mechanical properties, mild steel, welding mini-robot, manual electric arc welding**

I. Introduction

Mild steel is the most common type of steel because its price is relatively small while it provides material properties suitable to many applications. Low carbon steel contains around 0.16–0.29 per cent carbon and mild steel contains 0.05–0.15 per cent carbon, and it is neither brittle nor ductile. Mild steel is inexpensive and malevolent but has fairly poor tensile resistance. Surface hardness can be improved by combustion requiring heating of the alloys in a carbon-rich setting [1]. Since the 1920s, steel has been the primary material used in automotive parts manufacturing [2-4]. The use of steel and welded joints was extensively explained in the works of [5]. Welding usually involves a heat source to create a high temperature zone to melt the steel, this type of common process is known as fusion welding which is essentially a fusion of two or more pieces of metal by applying heat and sometimes pressure. Welding therefore requires a broad variety of scientific variables such as time, temperature, electrode, input power and welding speed [6-9]. The benefits of welding include high joint performance, easy deployment, versatility and low manufacturing costs as a joining process [10]. Any weld design shall aim at ensuring weld integrity and effectively reducing weld defects. Yongyutph, Ghoshp, Guptaa, Patwardha and Prakash [11] while researching the impact of macro / microstructure on the durability of all submerged multipass welded arc C-Mn steel deposits concluded that welding parameters have no effect on chemical composition, overall hardness and microstructure in the as-welded state. Tughness of effect decreased as the welding current increased. Pandey, Bharti and Gupta [12] while researching the effect of submerged arc welding parameters and fluxes on the transfer behavior of elements and weld-metal chemistry, it was concluded that the welding current and voltage had a major impact on the movement of elements and on the welding composition. Welding properties including strength, durability, and the cracking behavior of solidification are influenced by chemical composition. Owolabi. Adeosun, Aduloju, Metu and Onyedum [13] explored the novel use of slag fluxes and salts in the metallurgical industry. Authors of Ana, Paniagua, Victor, López and Maribel [14] conducted a study on the impact of the chemical composition of flux on the microstructure and tensile properties of submerged-arc welds shows the importance of flux composition selection to improve the mechanical properties of steel welds while Kanjilal, Pal and Majumdar [15] studying the combined effect of flux and welding parameters on chemical composition. Amongst welding parameters, polarity is found to be important for all responses under study.

Mohammed, Abdulwahab and Dauda [16] used shielded metal arc welding method (SMAW) to examine the mechanical and metallurgical properties of medium carbon steel with respect to weld metal, heat affected area and parent metal. From the results, shielded metal arc welding (SMAW) of medium carbon steel increased the strength of the welded joint in particular the heat affected zone (HAZ), as revealed by lower impact strength, higher tensile strength an d hardness values as compared with the parent and weld metal which is attributed to the fine ferrite matrix and fine pearlite distribution as compared to the weld and parent metal. There was, however, a loss of ductility in the welded joint which resulted in the material being brittle. Talabi, Owolabi, Adebisi and Yahaya [17] addressed the effect of welding variables on the mechanical properties of a 10 mm thick low carbon steel plate welded using the Shielded Metal Arc Welding (SMAW) process. The examined welding parameters were soldering current, arc voltage, welding speed and electrode diameter. The welded samples were cut and machined to standard tensile, impact toughness and hardness test specifications. The findings showed that the parameters chosen for welding had important effects on the mechanical properties of the welded samples. Increases in arc voltage and welding current increased hardness and decreased yield strength, tensile strength and durability of effect. Increasing the welding speed from 40-66.67mm / min caused the welded samples to increase their hardness characteristics. Initial decrease in tensile and yield strength was observed which subsequently increased as the welding velocity increased. A 2.5 mm diameter of the electrode offered the best combination of mechanical properties compared to the samples collected as. This behavior was due to the fact that increased current and voltage meant increased heat input that could create space for the creation of defects, thereby reducing the mechanical properties observed. This research work is concerned with the comparative analysis of the mechanical properties of welded mild steel plates of different thickness using the developed welding robot and manual electric arc welding.

II. Instruments Deployed for the Experiments

The following instruments were deployed for carrying out experiments of mechanical properties on the welded and unwelded mild steel plates of different thickness as shown in Plates 1 and 2.

Plate 1: Universal Instron Machine, Model 3369, Maker (Instron)

Plate 2: Brinell Hardness Testing Machine

III. Tensile Strength Test of Welded Mild Steel Plate with the Developed Welding Robot

The results and analyses of the tensile strength tests of welded mild steel plates of different thickness using the developed welding robot are shown in Tables 1 to 6.

Table 1: Tensile Test on 0.5 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	1377.23871	1.00862	58.78099	0.01681	8695.97473	1.17537
2	2104.77915	0.70862	89.83266	0.01181	14403.78265	1.04181
3	1948.17912	1.26694	83.14892	0.02112	8394.52515	1.68362
4	1933.04736	1.58337	82.50309	0.02639	7966.05911	1.74312
5	2892.69276	2.01669	123.46107	0.03361	10642.78030	2.46700
AVG	**2051.187**	**1.316848**	**87.54535**	**0.021948**	**10020.62**	**1.622184**
SD	**487.8069**	**0.453486**	**20.81976**	**0.007558**	**2375.68**	**0.503704**
SE	**218.1539**	**0.202805**	**9.31088**	**0.00338**	**1062.437**	**0.225263**

Table 2: Tensile Test on 0.6 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)

1	174.97364	1.55862	7.46793	0.02598	-----	3.22531
2	711.03214	0.38362	30.34708	0.00639	9394.64111	0.58300
3	2886.65723	2.10019	123.20347	0.03500	4040.35339	2.36637
4	2280.73299	0.77531	97.34242	0.01292	23115.09552	1.45000
5	811.29335	1.04200	34.62626	0.01737	3094.28253	1.86662
AVG	**1372.938**	**1.171948**	**58.59743**	**0.019532**	**9911.093**	**1.89826**
SD	**1029.963**	**0.601135**	**43.95916**	**0.010019**	**7992.917**	**0.884538**
SE	**460.6135**	**0.268836**	**19.65913**	**0.004481**	**3574.541**	**0.395577**

Table 3: Tensile Test on 0.7 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	335.41701	0.19975	14.31571	0.00333	-----	0.39944
2	2742.91094	0.59181	117.06833	0.00986	19616.97235	1.26687
3	569.26035	0.67475	24.29622	0.01125	4393.96782	0.90512
4	3669.73765	1.07512	156.62559	0.01792	12870.72144	1.26194
5	5548.74055	2.54200	236.82205	0.04237	14355.67932	3.15869
AVG	**2573.213**	**1.016686**	**109.8256**	**0.016946**	**12809.34**	**1.398412**
SD	**1954.916**	**0.811766**	**83.43645**	**0.013531**	**5467.113**	**0.935499**
SE	**874.2651**	**0.363033**	**37.31392**	**0.006051**	**2444.967**	**0.418368**

Table 4: Tensile Test on 0.8 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	3960.70220	1.42519	169.04405	0.02375	15964.16626	2.68337
2	2921.90202	1.05025	124.70773	0.01750	15081.05621	2.37481
3	1662.07906	0.72531	70.93807	0.01209	19467.34924	0.81644
4	3863.44381	1.77519	164.89303	0.02959	7167.07382	2.89981
5	3533.40730	3.44181	150.80697	0.05736	8273.20557	4.41700
AVG	**3188.307**	**1.68355**	**136.078**	**0.028058**	**13190.57**	**2.638286**
SD	**845.2031**	**0.947198**	**36.07354**	**0.015786**	**4714.397**	**1.150895**
SE	**377.9863**	**0.4236**	**16.13258**	**0.00706**	**2108.343**	**0.514696**

Table 5: Tensile Test on 0.9 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	229.24948	0.34981	16.98144	0.007	-----	0.702
2	5025.1681	0.71669	372.2347	0.01433	40828.98254	2.98312
3	1826.5482	0.417	135.2999	0.00834	26622.76306	0.73312
4	3305.0597	0.99162	244.8192	0.01983	25157.26471	1.7665
5	4602.1439	0.87512	340.8996	0.0175	39700.89417	3.22475
AVG	**2997.6339**	**0.670048**	**222.047**	**0.0134**	**33077.47612**	**1.881898**
SD	**1778.4967**	**0.250689**	**131.7405**	**0.005012**	**7217.142577**	**1.071551**
SE	**795.36789**	**0.112111**	**58.91614**	**0.002241**	**3227.604281**	**0.479212**

Table 6: Tensile Test on 1.0 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	4334.66695	2.80856	185.00499	0.04681	7275.82855	4.66681
2	1310.00392	1.03344	55.91139	0.01722	6461.48300	1.99987
3	2401.74290	1.01700	102.50717	0.01695	14411.11908	2.49975
4	4582.03629	3.34181	195.56279	0.05570	22870.30334	6.86662
5	2560.47770	1.05037	109.28202	0.01751	14805.67932	1.56669
AVG	**3037.786**	**1.850236**	**129.6537**	**0.030838**	**13164.88**	**3.519948**
SD	**1239.695**	**1.014337**	**52.91057**	**0.016907**	**5967.529**	**1.984045**
SE	**554.4083**	**0.453625**	**23.66233**	**0.007561**	**2668.76**	**0.887292**

The graphs of the tensile strength test of the welding operation using the developed welding robot for different thicknesses of mild steel plates are shown in Figures 1 to 6.

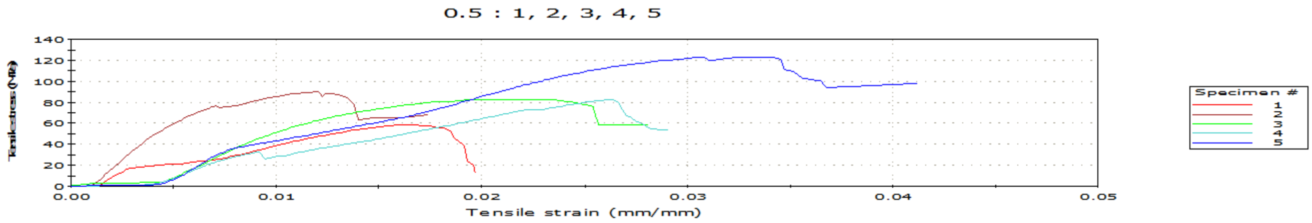


Figure 1: Tensile Test of 0.5 mm Mild Steel Plate Specimens

Figure 1 shows initial increases in tensile stress as tensile strain increases; afterwards tensile stress decreases as the tensile strain increases. Sample 5 gave the longest trend of increases in tensile strain followed by 4, 3, 1 and sample 2 gave the shortest trend.

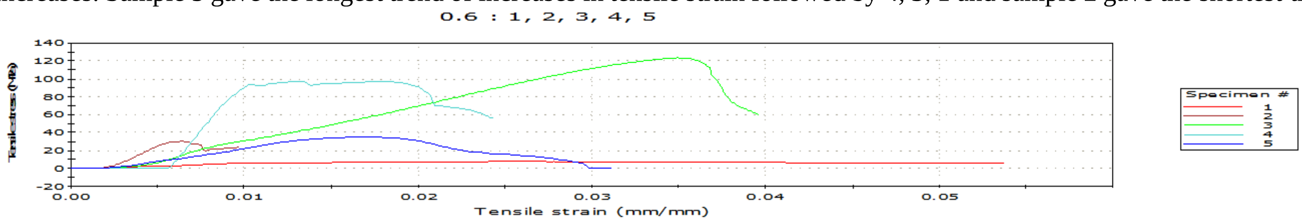


Figure 2: Tensile Test of 0.6 mm Mild Steel Plate Specimens

Figure 2 shows increases in tensile stress and tensile strain; later stress decreases as the strain increases. Sample 1 gave the longest trend of increases in tensile strain with constant tensile stress before decreasing, followed by 3, 5, 4 and sample 2 gives the shortest trend.

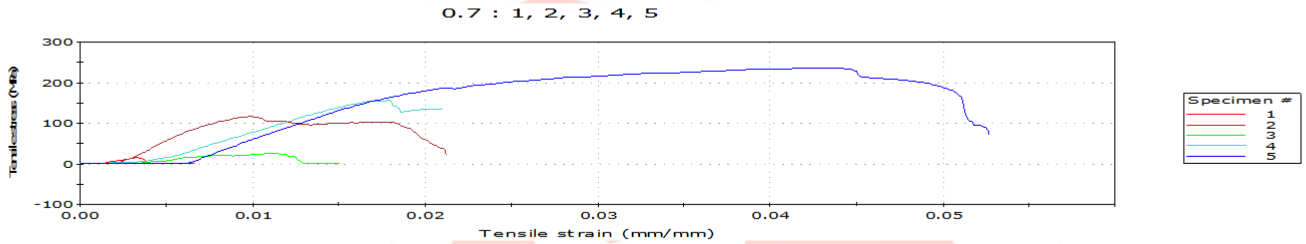


Figure 3: Tensile Test of 0.7 mm Mild Steel Plate Specimens

Figure 3 also shows increases in tensile stress and tensile strain; after some time the stress decreases as the strain increases. Sample 5 gave the longest trend of increases in tensile strain followed by 4, 2, 3 and sample 1 gave the shortest trend.

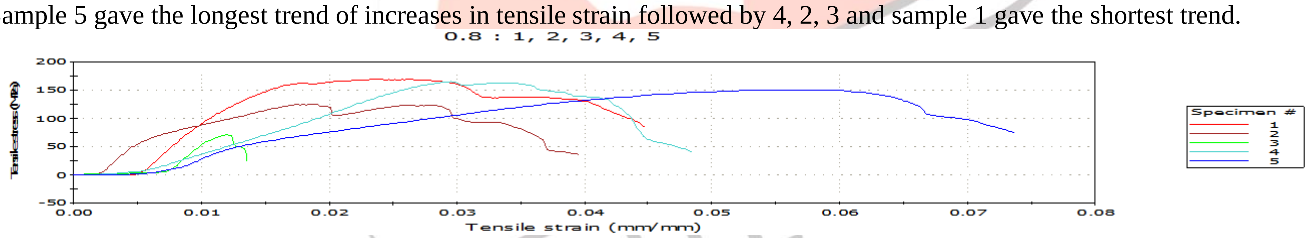


Figure 4: Tensile Test of 0.8 mm Mild Steel Plate Specimens

Figure 4 shows increases in both tensile stress and tensile strain; it got to a point where the stress decreases as the strain increases. Sample 5 gave the longest trend of increases in tensile strain followed by 4, 1, 2 and sample 3 gave the shortest trend.

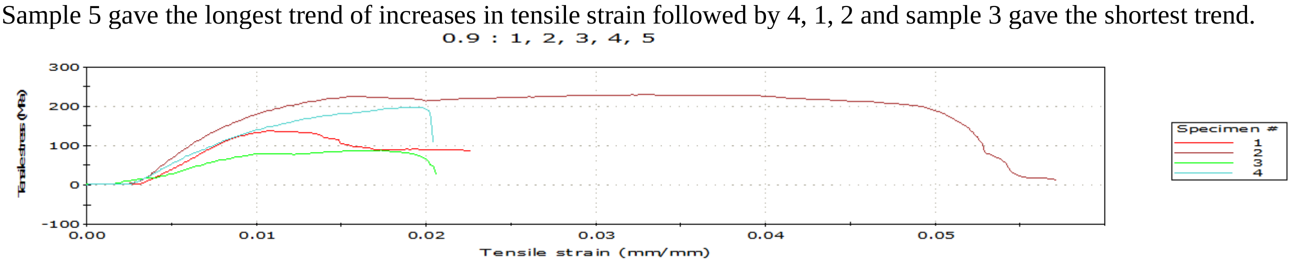


Figure 5: Tensile Test of 0.9 mm Mild Steel Plate Specimens

Figure 5 shows increases in tensile stress and tensile strain; the trend changed when stress decreases as the strain increases. Sample 5 gave the longest trend of increases in tensile strain followed by 2, 4, 3 and sample 1 gave the shortest trend

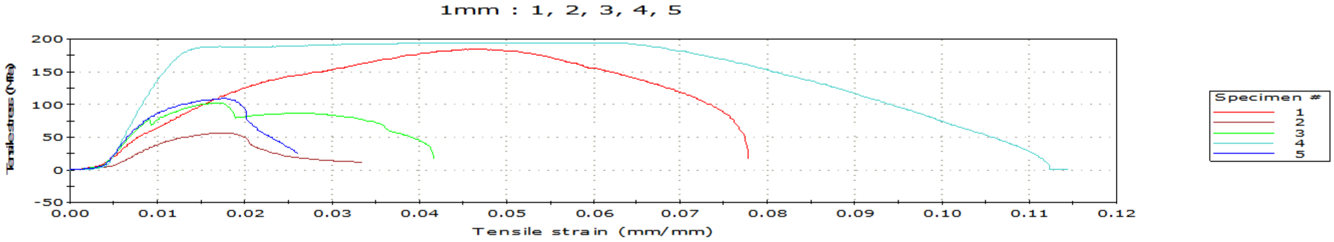


Figure 6: Tensile Test of 1.0 mm Mild Steel Plate Specimens

Figure 6 shows increases in tensile stress and tensile strain at first; later stress decreases as the strain increases. Sample 4 gave the longest trend of increases in tensile strain followed by 1, 3, 2 and sample 5 gave the shortest trend.

IV. Hardness Test of Welded Mild Steel Plate with the Developed Welding Robot

The results and analyses of the hardness tests of welded mild steel plates for different gauges using the developed welding robot are shown in Table 7.

Table 7: Hardness Test on Welded Mild Plates using Developed Welding Robot

Hardness Test on the Developed Welding Robot					
0.5 mm Mild Steel Plate Specimen					
Number of Test	**Samples**				
	A	B	C	D	E
1	147	149	146	158	157
2	143	146	143	156	156
3	143	143	143	143	131
4	131	143	143	143	128
5	121	144	131	131	121
6	118	143	128	143	143
AVG	**133.83**	**144.67**	**139.00**	**145.67**	**139.33**
SD	**11.29**	**2.21**	**6.86**	**9.09**	**13.77**
SE	**4.61**	**0.90**	**2.80**	**3.71**	**5.62**
0.6 mm Mild Steel Plate Specim					
1	111	95.5	147	95.5	111
2	143	111	143	143	121
3	143	121	111	111	95.5
4	111	103	103	103	95.5
5	111	111	103	111	95.5
6	95.5	95.5	95.5	103	94.3
AVG	**119.08**	**106.17**	**117.08**	**111.08**	**102.13**
SD	**17.78**	**9.17**	**20.27**	**15.23**	**10.23**
SE	**7.26**	**3.74**	**8.28**	**6.22**	**4.18**
Hardness Test on the Developed Welding Robot					
0.7 mm Mild Steel Plate Specimen					
1	135	137	120	145	116
2	131	131	111	143	111
3	121	95.5	95.5	95.5	111
4	103	95.5	95.5	95.5	111
5	95.5	95.5	95.5	94.3	103
6	94.2	95.5	103	94.1	102
AVG	**113.28**	**108.33**	**103.42**	**111.23**	**109.00**
SD	**16.49**	**18.23**	**9.32**	**23.18**	**4.93**
SE	**6.73**	**7.44**	**3.80**	**9.46**	**2.01**
0.8 mm Mild Steel Plate Specimen					
1	111	115	95.5	103	95.5
2	121	111	121	103	95.5
3	95.5	111	131	95.5	95.6
4	95.5	103	95.5	111	95.5
5	121	95.5	95.5	121	94.5
6	95.5	95.5	95.5	95.5	94.3
AVG	**106.58**	**105.17**	**105.67**	**104.83**	**95.15**
SD	**11.57**	**7.71**	**14.66**	**8.95**	**0.53**
SE	**4.72**	**3.15**	**5.99**	**3.65**	**0.22**
Hardness Test on the Developed Welding Robot					
0.9 mm Mild Steel Plate Specimen					

1	102	111		137	117
2	96.5	103		131	111
3	95.5	95.5	95.5	111	103
4	95.5	94.7	95.5	103	103
5	95.7	94.8	95.5	103	121
6	95.5	94.5	103	95.5	121
AVG	**96.78**	**98.92**	**97.38**	**113.42**	**112.67**
SD	**2.36**	**6.17**	**3.25**	**15.33**	**7.61**
SE	**0.96**	**2.52**	**1.33**	**6.26**	**3.11**
	1.0 mm Mild Steel Plate Specimen				
1	143	144	111	146	108
2	143	143	143	143	103
3	131	121	121	143	121
4	103	103	121	156	121
5	95.5	121	121	143	131
6	103	111	95.5	95.5	121
AVG	**119.75**	**123.83**	**118.75**	**137.75**	**117.50**
SD	**19.82**	**15.21**	**14.16**	**19.45**	**9.31**
SE	**8.09**	**6.21**	**5.78**	**7.94**	**3.80**

V. Tensile Test of Welded Mild Steel Plate with Electric Arc Welding (Manual)

The results and analyses of the tensile tests of welded mild steel plates for different gauges using manual electric arc welding are shown in Table 8.

Table 8: Tensile Test on 0.5 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	917.42668	1.16669	57.33917	0.02333	6418.73016	2.56656
2	1113.64396	0.96656	69.60275	0.01933	6340.66353	1.90994
3	1124.91408	1.76669	70.30713	0.03533	4954.21104	3.56669
4	1547.52750	2.23337	96.72047	0.04467	7686.98730	4.76669
5	770.65546	1.47512	159.556	0.03688	5870.79811	3.31694
AVG	**1094.833536**	**1.521686**	**90.7051**	**0.031908**	**6254.27803**	**3.225364**
SD	**261.8225024**	**0.447856**	**36.74589**	**0.009285**	**885.933839**	**0.965912879**
SE	**117.0905827**	**0.200287**	**16.43326**	**0.004153**	**396.201658**	**0.431969372**

Table 9: Tensile Test on 0.6 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	1640.60015	1.16669	102.53751	0.02333	8180.17349	1.23344
2	2586.62775	5.69994	161.66423	0.11400	9804.63715	7.90006
3	1711.68745	1.20006	106.98047	0.02400	8415.74402	2.10006
4	2537.16111	3.23337	158.57257	0.06467	15102.11487	4.73337
5	1874.55397	2.13344	117.15962	0.04267	7008.68835	2.86681
AVG	**2070.12609**	**2.6867**	**129.383**	**0.053734**	**9702.272**	**3.766748**
SD	**408.92907**	**1.685532**	**25.5581**	**0.033712**	**2842.397**	**2.367446**
SE	**182.87864**	**0.753793**	**11.4299**	**0.015076**	**1271.159**	**1.058754**

Table 10: Tensile Test on 0.7 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	2118.50442	1.50006	132.40653	0.03000	6989.93683	2.90006
2	2269.80150	2.46669	141.86259	0.04933	12301.72272	3.33337
3	1758.12040	1.43325	109.88252	0.02866	15345.96710	1.86669
4	2096.62318	1.36662	131.03895	0.02733	10479.25491	1.76675
5	1807.10685	2.06669	112.94418	0.04133	11827.61765	2.83356
AVG	**2010.03127**	**1.766662**	**125.627**	**0.03533**	**11388.9**	**2.540086**
SD	**195.643841**	**0.429495**	**12.2277**	**0.00859**	**2715.232**	**0.615876**
SE	**87.4945855**	**0.192076**	**5.46841**	**0.003841**	**1214.289**	**0.275428**

Table 11: Tensile Test on 0.8 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	2694.37172	3.36669	168.39823	0.06733	14241.66412	5.30012
2	3220.08468	5.09994	201.25529	0.10200	19358.72650	8.73325

3	2938.94038	3.53344	183.68377	0.07067	19823.44208	4.73350
4	3208.89950	7.36669	200.55622	0.14733	17286.01074	11.23350
5	2174.27518	2.00006	135.89220	0.04000	11107.85141	3.95737
AVG	**2847.31429**	**4.273364**	**177.957**	**0.085466**	**16363.54**	**6.791548**
SD	**388.45078**	**1.832449**	**24.2782**	**0.036648**	**3283.828**	**2.756579**
SE	**173.72047**	**0.819496**	**10.8575**	**0.01639**	**1468.573**	**1.232779**

Table 12: Tensile Test on 0.9 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	3083.41049	1.86669	192.71316	0.03733	20491.10870	3.63344
2	4431.70294	3.16669	276.98143	0.06333	26590.30457	5.53344
3	3381.82934	1.46669	211.36433	0.02933	20226.51367	3.06669
4	3837.78773	3.66669	239.86173	0.07333	14816.67175	5.96681
5	4015.22927	2.40006	250.95183	0.04800	26680.57556	4.66687
AVG	**3749.99195**	**2.513364**	**234.374**	**0.050264**	**21761.03**	**4.57345**
SD	**473.848786**	**0.810376**	**29.6155**	**0.016207**	**4465.767**	**1.097789**
SE	**211.911619**	**0.362411**	**13.2445**	**0.007248**	**1997.152**	**0.490946**

Table 13: Tensile Test on 1.0 mm Mild Steel Plate Specimens

S/N	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
1	2576.97925	0.78331	171.7986	0.01567	23718.9972	1.04981
2	5005.12719	1.83356	333.6752	0.03667	24184.8816	5.21669
3	4449.04901	2.00019	296.6033	0.04	24800.6882	3.25031
4	4438.64465	5.92519	295.9096	0.1185	29599.2523	8.50869
5	4505.3374	0.8335	300.3558	0.01667	30665.448	2.35837
AVG	**4195.0275**	**2.27515**	**279.6685**	**0.045502**	**26593.8535**	**4.076774**
SD	**836.0036034**	**1.891948**	**55.73357**	**0.037837**	**2928.94828**	**2.59768181**
SE	**373.8721773**	**0.846105**	**24.92481**	**0.016921**	**1309.86549**	**1.16171862**

The graphs of the tensile strength test of the welding operation using Electric Arc Welding (Manual) for different thickness of mild steel plates are shown in Figures 7 to 12.

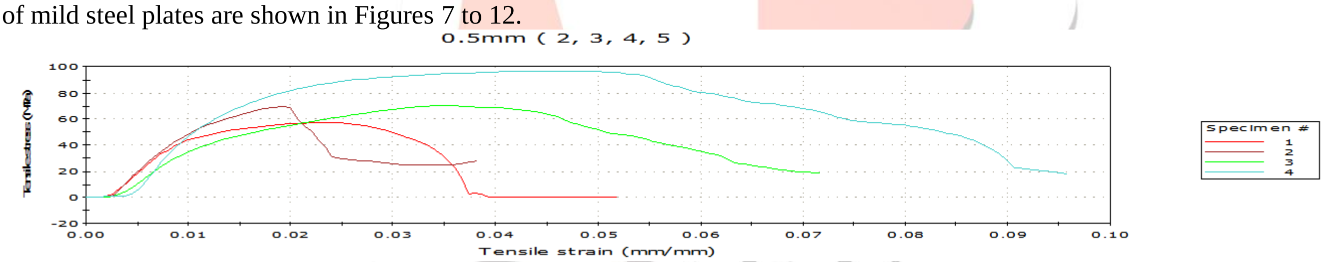


Figure 7: Tensile Test of 0.5 mm Mild Steel Plate Specimens

Figure 7 shows initial increases in tensile stress and tensile strain. Stress later decreases as the strain increases. Sample 4 gave the longest trend of increases in tensile strain followed by 3, 1 and sample 2 gave the shortest trend.

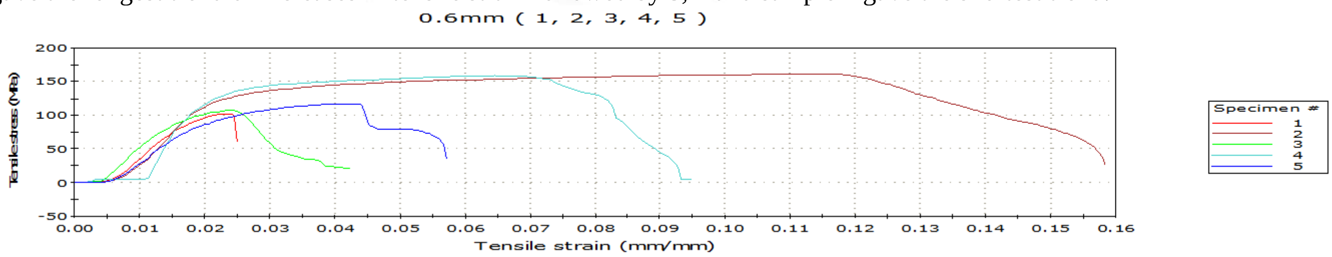


Figure 8: Tensile Test of 0.6 mm Mild Steel Plate Specimens

Figure 8 shows increases in tensile stress and tensile strain. This trend changed as tensile stress began to decrease with an increase in tensile strain. Sample 2 gave the longest trend of increases in tensile strain followed by 4, 5, 3 and sample 1 gave the shortest trend.

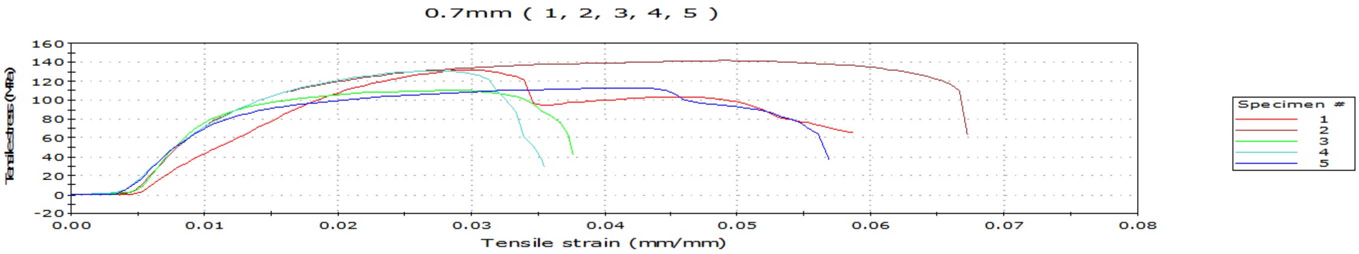


Figure 9: Tensile Test of 0.7 mm Mild Steel Plate Specimens

Figure 9 shows increases in tensile stress and tensile strain but at a point tensile stress began to decreases as tensile strain increased. Sample 2 gave the longest trend of increases in tensile strain followed by 1, 5, 3 and sample 4 gave the shortest trend.

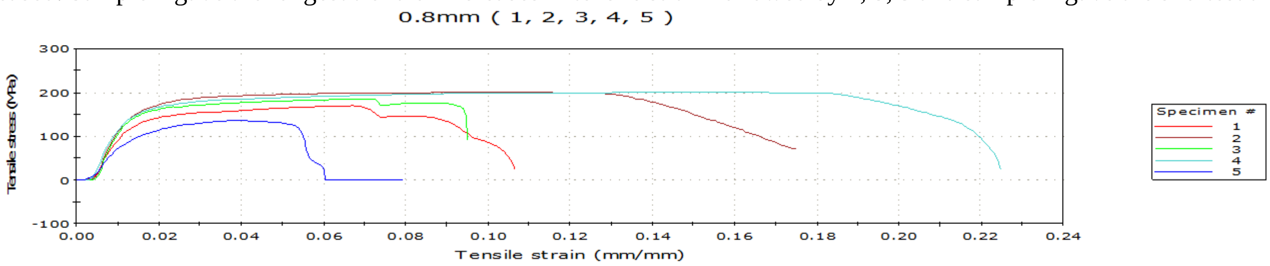


Figure 10: Tensile Test of 0.8 mm Mild Steel Plate Specimens

Figure 10 shows initial increases in tensile stress and tensile strain; tensile stress then decreases as tensile strain increases. Sample 4 gave the longest trend of increases in tensile strain with constant tensile stress before decreasing, followed by 2, 1, 3 and sample 5 gave the shortest trend.

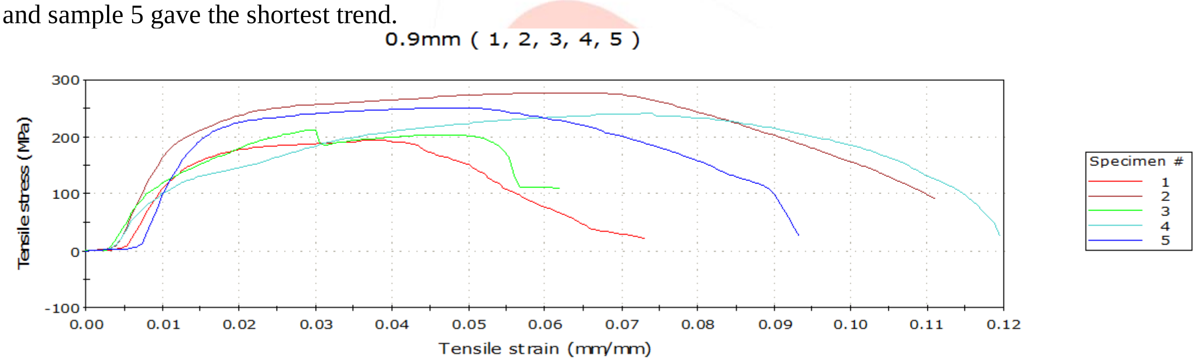


Figure 11: Tensile Test of 0.9 mm Mild Steel Plate Specimens

Figure 11 shows the increases in tensile stress and tensile strain but it got to a point where the stress decreases as the strain increases. Sample 4 gave the longest trend of increases in tensile strain followed by 2, 5, 1 and sample 3 gave the shortest trend. All the samples mostly have constant tensile stress before decreasing.

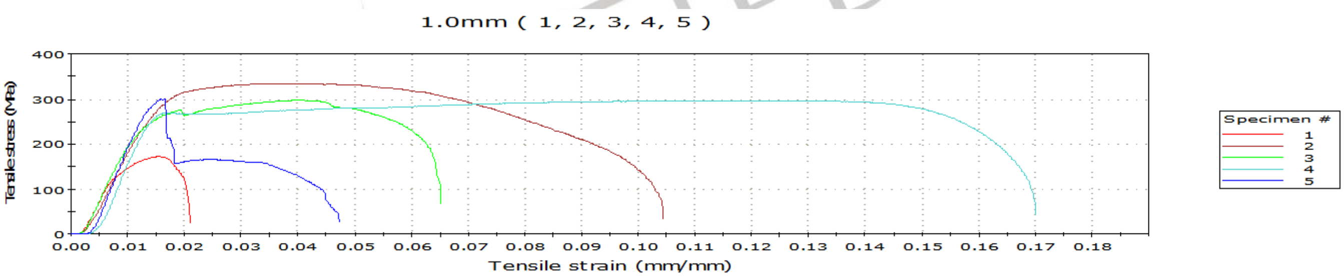


Figure 12: Tensile Test of 1.0 mm Mild Steel Plate Specimens

Figure 12 shows that tensile stress increases with an increase in tensile strain; then stress decreases as tensile strain increases. Sample 4 gave the longest trend of increases in tensile strain followed by 2, 3, 5 and sample 1 gave the shortest trend.

VI. Hardness Test of Welded Mild Steel Plate with Electric Arc Welding (Manual)

The results and analyses of the hardness tests of welded mild steel plates for different thicknesses using electric arc welding are shown in Table 14.

Table 14: Hardness Test on Welded Mild Plates using Electric Arc welding (Manual)

Hardness Test on Manual welding Test					
0.5 mm Mild Steel Plate Specimen					
Number of Test	**Samples**				
	A	B	C	D	E

1	143	121	118	106	95.5
2	121	95.5	95.5	111	121
3	120	95.5	98	131	95.5
4	118	103	103	121	95.5
5	115	100	95.5	121	95.5
6	111	95.5	95.5	121	95.5
AVG	**121.33**	**101.75**	**100.92**	**118.50**	**99.75**
SD	**10.24**	**9.06**	**8.09**	**8.04**	**9.50**
SE	**4.18**	**3.70**	**3.30**	**3.28**	**3.88**
0.6 mm Mild Steel Plate Specimen					
1	143	103	95.5	103	95.5
2	130	95.5	95.5	97.6	95.7
3	95.5	96.1	95.6	95.5	95.9
4	96.2	95.5	95.5	96.2	95.5
5	95.6	95.7	96.9	103	97.2
6	96.3	95.5	103	95.5	96.5
AVG	**109.43**	**96.88**	**97.00**	**98.47**	**96.05**
SD	**19.51**	**2.74**	**2.73**	**3.28**	**0.62**
SE	**7.96**	**1.12**	**1.11**	**1.34**	**0.25**
Hardness Test on Manual welding Test					
0.7 mm Mild Steel Plate Specimen					
1	111	99.1	118	121	96.8
2	121	95.5	111	116	95.5
3	111	95.5	96.8	95.5	95.5
4	131	95.5	95.5	111	95.5
5	95.5	95.5	95.5	121	95.5
6	103	94.2	95.5	111	95.7
AVG	**112.08**	**95.88**	**102.05**	**112.58**	**95.75**
SD	**11.53**	**1.51**	**9.04**	**8.66**	**0.48**
SE	**4.71**	**0.62**	**3.69**	**3.54**	**0.19**
0.8 mm Mild Steel Plate Specimen					
1		95.5	111	111	126
2	131	95.5	111	95.5	121
3	121	121	103	95.5	103
4	95.5	111	111	111	103
5	111	102	103	95.5	103
6	111	105	103	103	121
AVG	**113.90**	**105.00**	**107.00**	**101.92**	**112.83**
SD	**11.82**	**8.96**	**4.00**	**6.95**	**9.97**
SE	**4.82**	**3.66**	**1.63**	**2.84**	**4.07**
Hardness Test on Manual welding Test					
`0.9 mm Mild Steel Plate Specimen					
1	103	131	95.5	121	95.5
2	131	143	95.5	112	111
3	111	103	95.5	103	95.5
4	103	103	103	103	95.5
5	103	95.5	95.5	121	131
6	111	95.5	95.5	103	121
AVG	**110.33**	**111.83**	**96.75**	**110.50**	**108.25**
SD	**9.91**	**18.39**	**2.80**	**8.08**	**14.00**
SE	**4.05**	**7.51**	**1.14**	**3.30**	**5.71**
1.0 mm Mild Steel Plate Specimen					
1	131	156	131	121	111
2	143	131	95.5	103	143
3	143	121	101	131	103
4	95.5	131	111	131	111
5	95.5	111	131	95.5	121
6	111	101	132	143	123
AVG	**119.83**	**125.17**	**116.92**	**120.75**	**118.67**
SD	**20.25**	**17.42**	**15.12**	**16.62**	**12.78**
SE	**8.27**	**7.11**	**6.17**	**6.79**	**5.22**

VII. TENSILE STRENGTH TEST ON DIFFERENT THICKNESSES OF MILD STEEL PLATE SPECIMENS WITHOUT WELDING OPERATION (CONTROL)

The results and analyses of the tensile strength test of unwelded mild steel plates for different thicknesses without welding operation, which serves as control specimens are shown in Table 15.

Table 15: Tensile Test on Different Thicknesses of Mild Steel Plate Specimens without Welding Operation (Control)

Specimen/Gauge (mm)	Load (N)	Extension (mm)	Tensile Stress (MPa)	Tensile Strain (mm/mm)	Modulus of Elasticity (MPa)	Break Point (mm)
0.5	1595.27883	2.86669	99.70493	0.05733	13735.00061	5.82750
0.6	2344.70200	5.36669	146.54387	0.10733	12758.95157	8.30000
0.7	2802.22949	5.60000	175.13934	0.11200	14891.91437	8.43331
0.8	3403.11117	8.53337	212.69445	0.17067	20461.91559	12.70019
0.9	4309.11109	7.16669	269.31944	0.14333	24727.86560	10.60012
1.0	4863.79825	9.86669	303.98739	0.19733	31200.43335	13.90012
AVG	**3219.705**	**6.566688**	**201.2316**	**0.131332**	**19629.35**	**9.960207**
SD	**1118.195**	**2.279705**	**69.8872**	**0.045595**	**6645.387**	**2.757018**
SE	**456.5013**	**0.930686**	**28.53133**	**0.018614**	**2712.968**	**1.125548**

The graph of the tensile strength test of different thicknesses of mild steel plates without welding operation which serves as control for comparison with the welded plates is shown in Figure 13.

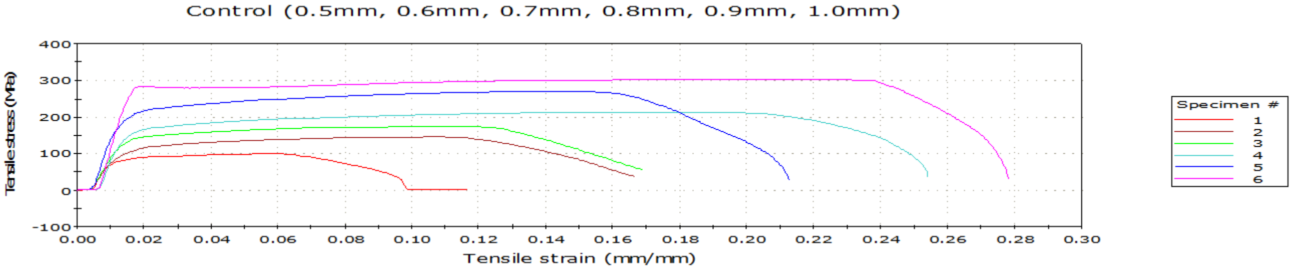


Figure 13: Tensile Test on Plates of different thicknesses without welding operation.

Figure 13 shows increases in tensile stress and tensile strain initially; at a certain period tensile stress decreased as tensile strain increased. Specimen 1.0 mm gave the longest trend of increases in tensile strain with constant tensile stress before decreasing, followed by 0.8 mm, 0.9 mm, 0.7 mm, 0.6 mm and specimen 0.5 mm gave the shortest trend.

VIII. HARDNESS TEST ON DIFFERENT THICKNESSES OF MILD STEEL PLATE SPECIMENS WITHOUT WELDING OPERATION (CONTROL)

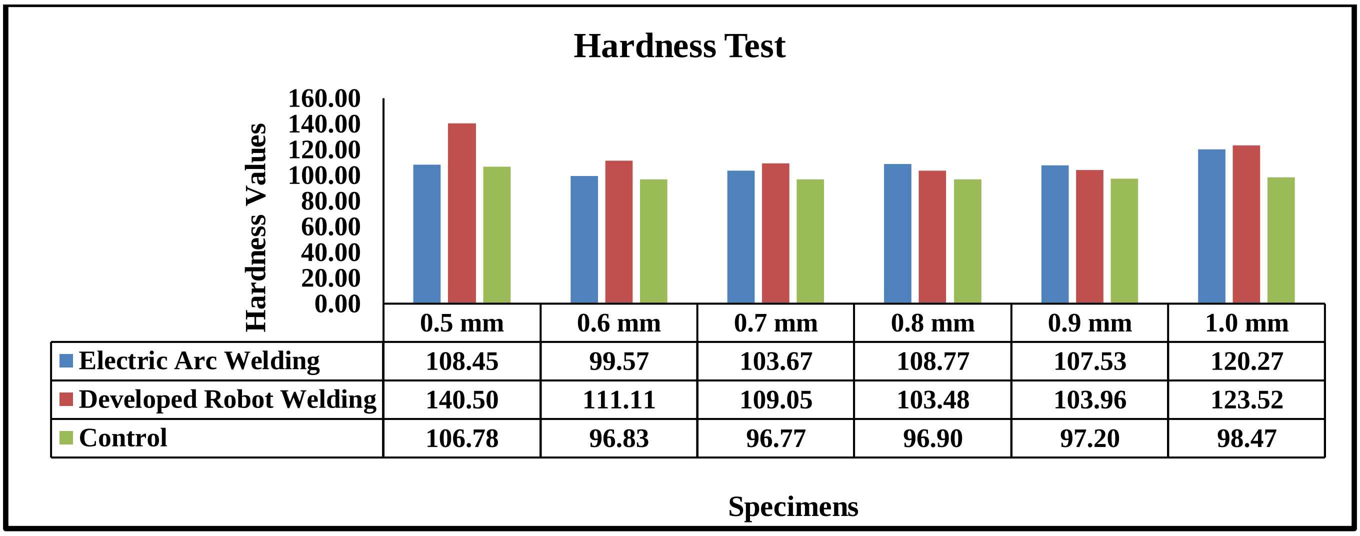
The results and analyses of the hardness test of unwelded mild steel plates for different thickness without welding operation, which serves as control specimens are shown in Table 16.

Table 16: Hardness Test on Different Thicknesses of Mild Steel Plate Specimens without Welding Operation (Control)

S/N	Specimens					
	0.5 mm	**0.6 mm**	**0.7 mm**	**0.8 mm**	**0.9 mm**	**1.0 mm**
1	116	103	103	97.3	95.7	97.5
2	111	96.1	95.5	97.1	95.1	95.5
3	107	95.1	94.8	96.3	95.4	96.2
4	105.4	95.6	96.3	97.3	95.5	103.1
5	101.2	95.7	95.8	97.1	98.5	103
6	100.1	95.5	95.2	96.3	103	95.5
AVG	**106.78**	**96.83**	**96.77**	**96.90**	**97.20**	**98.47**
SD	**5.49**	**2.77**	**2.83**	**0.43**	**2.83**	**3.31**
SE	**2.24**	**1.13**	**1.15**	**0.18**	**1.16**	**1.35**

IX. Summary of the Results

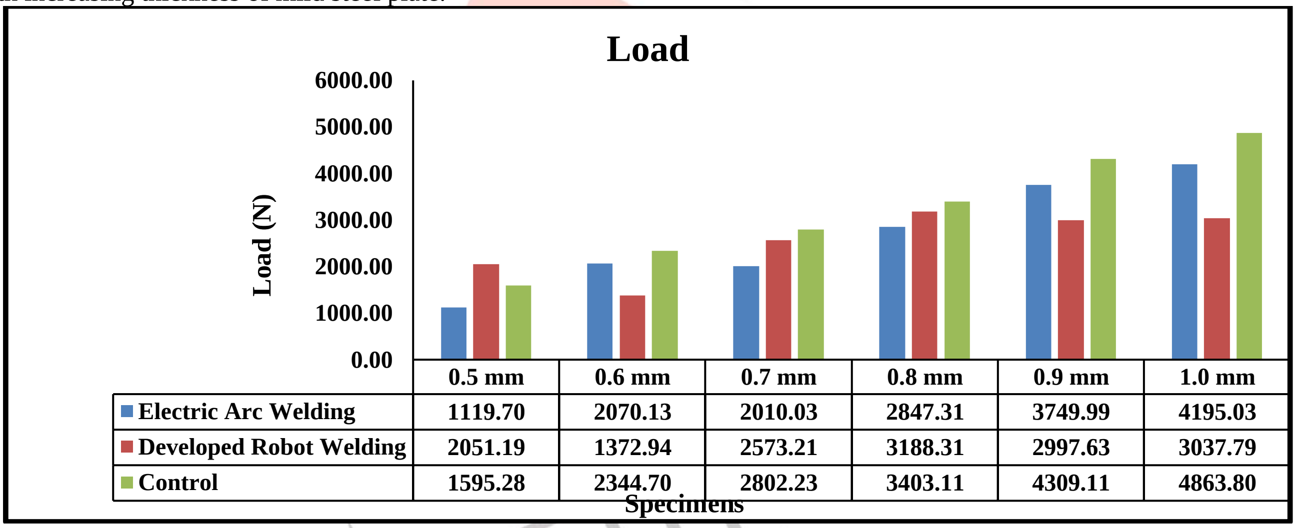
Tables 7, 14 and 16 and figure14 showed the variation in hardness values of welded and unwelded mild steel plates (specimens) of different sizes in which the developed robot welding samples have the highest hardness.



	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
Electric Arc Welding	108.45	99.57	103.67	108.77	107.53	120.27
Developed Robot Welding	140.50	111.11	109.05	103.48	103.96	123.52
Control	106.78	96.83	96.77	96.90	97.20	98.47

Figure 14: Hardness Test of Welded and Unwelded Mild Steel Plate Specimens

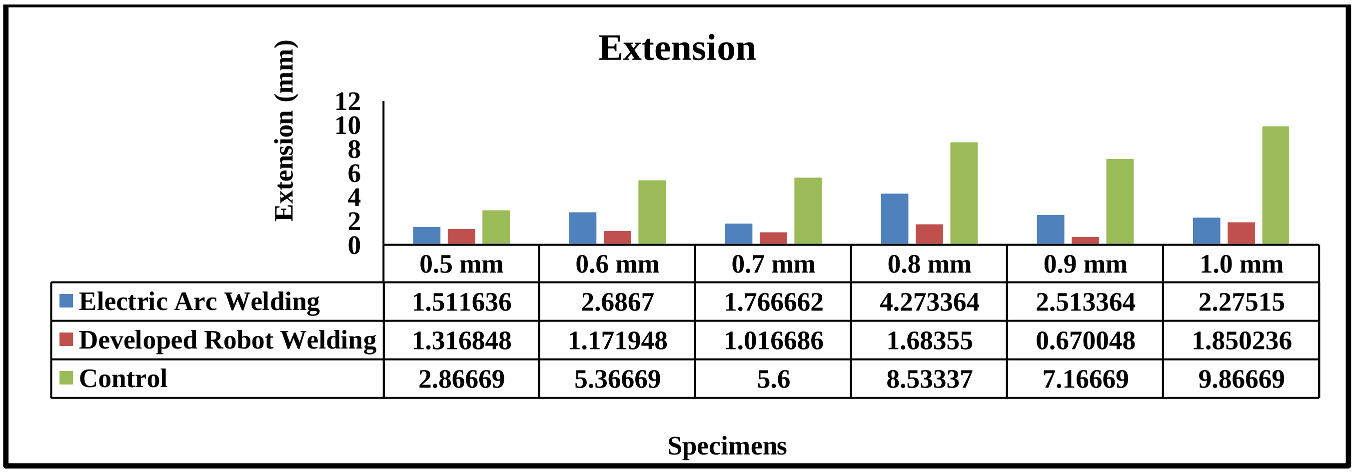
Figure 15 shows variation in load on welded and unwelded mild steel plates (specimens) of different sizes in which 1.0 mm mild steel plate without welding (CONTROL Sample) gave the highest load impact. For developed robot welding 0.8 mm Sample gave the highest. For electric arc welding, Sample 1.0 mm gave the highest. The chart reveals that 1.0 mm sample without welding gave the overall highest load impact. The three sets of Samples showed fair trend of increase in load impact with increasing thickness of mild steel plate.



	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
Electric Arc Welding	1119.70	2070.13	2010.03	2847.31	3749.99	4195.03
Developed Robot Welding	2051.19	1372.94	2573.21	3188.31	2997.63	3037.79
Control	1595.28	2344.70	2802.23	3403.11	4309.11	4863.80

Figure 15: Load on Welded and Unwelded Mild Steel Plate Specimen for the Tensile Strength Test

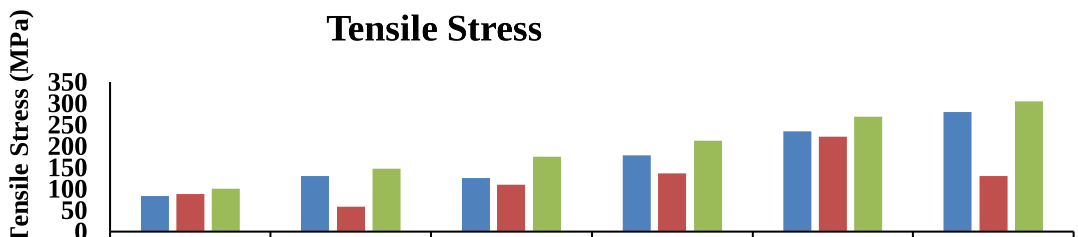
Figure 16 shows variation in extension of welded and unwelded mild steel plates (specimens) of different sizes in which the unwelded (CONTROL) samples gave the highest extension. Developed robot welding samples gave the lowest. This may be attributed to their comparatively higher hardness values over the electric arc welding and CONTROL values as already discussed in Figure 14.



	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
Electric Arc Welding	1.511636	2.6867	1.766662	4.273364	2.513364	2.27515
Developed Robot Welding	1.316848	1.171948	1.016686	1.68355	0.670048	1.850236
Control	2.86669	5.36669	5.6	8.53337	7.16669	9.86669

Figure 16: Extension of Welded and Unwelded Mild Steel Plate Specimen for the Tensile Strength Test

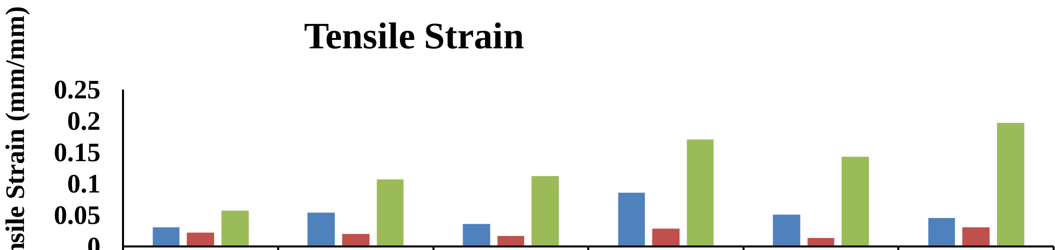
Figure 17 shows variation in tensile stress on weld and unwelded mild steel plates (specimens) of different sizes in which the unwelded (CONTROL) samples gave the highest. Developed robot welding sample gave the lowest. This was expected of the developed robot welding samples given their comparatively higher hardness and lower extension values over both the electric arc welding and unwelded (CONTROL) Samples.



	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
Electric Arc Welding	82.660786	129.383	125.627	177.957	234.374	279.668502
Developed Robot Welding	87.54535	58.59743	109.8256	136.078	222.046954	129.6537
Control	99.70493	146.54387	175.13934	212.69445	269.31944	303.98739

Figure 17: Tensile Stress of Welded and Unwelded Mild Steel Plate Specimen for the Tensile Strength Test

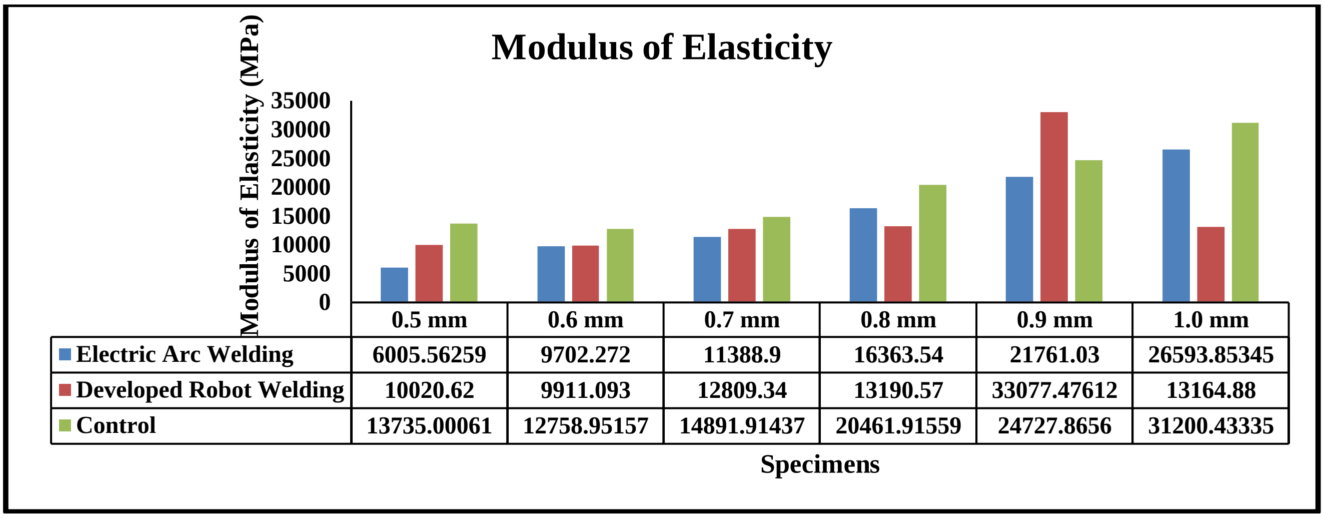
Figure 18 shows the variation in tensile strain on welded and unwelded mild steel plates (specimens) of different sizes in which the unwelded (CONTROL) samples gave the highest values while developed robot welding samples gave the lowest. This was expected since developed robot welding samples had comparatively higher hardness, lower extension and lower tensile stress values over both the electric arc welding and unwelded (CONTROL) values.



	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
Electric Arc Welding	0.030232	0.053734	0.03533	0.085466	0.050264	0.045502
Developed Robot Welding	0.021948	0.019532	0.016946	0.028058	0.0134	0.030838
Control	0.05733	0.10733	0.112	0.17067	0.14333	0.19733

Figure 18: Tensile Strain of Welded and Unwelded Mild Steel Plate Specimen for the Tensile Strength Test

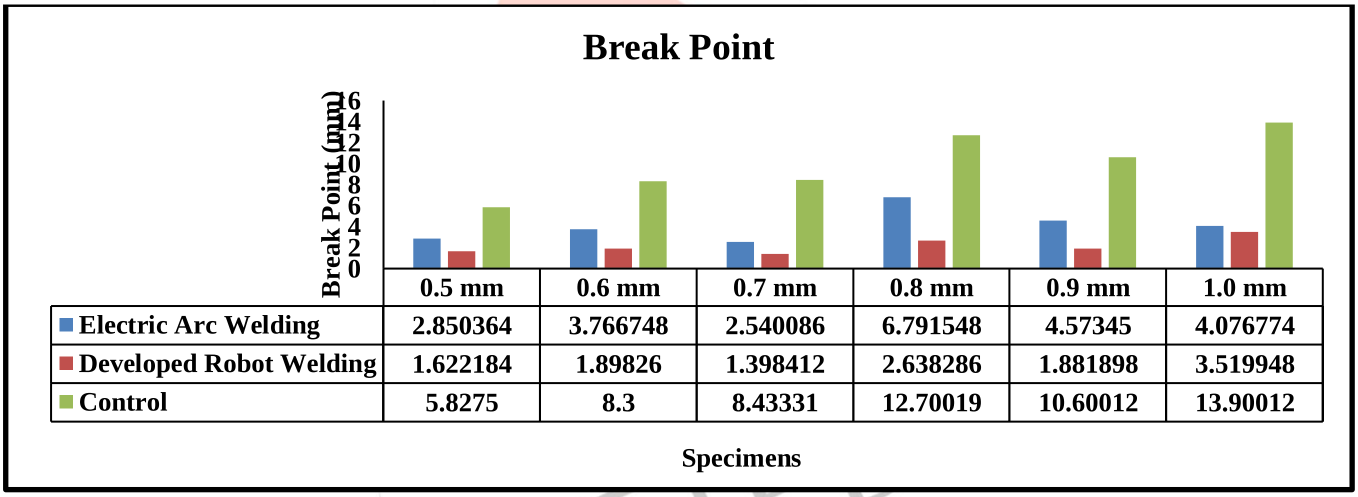
Figure 19 shows that the unwelded mild steel (CONTROL) samples gave a very good trend of high values of modulus of elasticity. The developed robot welding samples gave a trend of comparatively lower values of modulus of elasticity than both the unwelded and electric arc welding samples. This trend was expected given the higher values of hardness, lower values of extension, tensile stress and tensile strain of the developed robot welding samples over those of the electric arc welding and unwelded (CONTROL) samples.



	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
Electric Arc Welding	6005.56259	9702.272	11388.9	16363.54	21761.03	26593.85345
Developed Robot Welding	10020.62	9911.093	12809.34	13190.57	33077.47612	13164.88
Control	13735.00061	12758.95157	14891.91437	20461.91559	24727.8656	31200.43335

Figure 19: Modulus of Elasticity of Welded and Unwelded Mild Steel Plate Specimen for the Tensile Strength Test

Figure 20 shows variation in break point on welded and unwelded mild steel plates (specimens) of different sizes in which the unwelded (CONTROL) samples gave the highest while developed robot welding samples gave the lowest, This result was in trend and agreement with the earlier results of high values of hardness, low values of extension, tensile stress, tensile strain and modulus of elasticity exhibited by the developed robot welding samples in comparison with those of the electric arc welding and unwelded (CONTROL) samples.



	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
Electric Arc Welding	2.850364	3.766748	2.540086	6.791548	4.57345	4.076774
Developed Robot Welding	1.622184	1.89826	1.398412	2.638286	1.881898	3.519948
Control	5.8275	8.3	8.43331	12.70019	10.60012	13.90012

Figure 20: Break Point of Welded and Unwelded Mild Steel Plate Specimen for the Tensile Strength Test

X. Conclusion

In conclusion, the research results showed that the developed robot welding samples have the highest hardness. The results also revealed that 1.0 mm sample without welding gave the overall highest load impact. The three sets of Samples showed fair trend of increase in load impact with increasing thickness of mild steel plate. The unwelded (CONTROL) samples gave the highest extension. Developed robot welding samples gave the lowest. This may be attributed to their comparatively higher hardness values over the electric arc welding and CONTROL values. Developed robot welding sample gave the lowest tensile stress while the unwelded (CONTROL) samples gave the highest. This was expected of the developed robot welding samples given their comparatively higher hardness and lower extension values over both the electric arc welding and unwelded (CONTROL) Samples. The unwelded (CONTROL) samples gave the highest values of tensile strain while developed robot welding samples gave the lowest. This was expected since developed robot welding samples had comparatively higher hardness, lower extension and lower tensile stress values over both the electric arc welding and unwelded (CONTROL) values. The developed robot welding samples gave a trend of comparatively lower values of modulus of elasticity than both the unwelded and electric arc welding samples. This trend was expected given the higher values of hardness, lower values of extension, tensile stress and tensile strain of the developed robot welding samples over those of the electric arc welding and unwelded (CONTROL) samples.

XI. ACKNOWLEDGMENT

The authors are thankful to all doctorates thesis supervisors and technologists at the Federal University of Technology, Akure and the Federal Polytechnic Ado Ekiti who played a vital role in making this research project a success.

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