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EFFECTS OF POST WELD HEAT-TREATMENT ON MICROSTRUCTURE AND MECHANICAL BEHAVIOR OF DIS-SIMILAR MATERIALS PRODUCED BY GTAW PROCESS

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Abstract— **Welding is a well-known economic fabrication process in that GTAW is one of the reliable and easy weld techniques compared with other fabrication techniques. The present research focused on the dissimilar metal welds, a weldment between ferrous and non-ferrous alloys taken into consideration. A part of experimental work, AA6061 with Ferrous alloys like EN8, SS302, SS316 welded with TIG welding process known as GTAW. Aluma steel filler rods are used for the weldment in a two-step process; the primary rod is used to fill the ferrous side, and the second filler is used to join them both. The structures for different samples of post welded joints to check the structural variation between all 3-zones, base-metal, Heat affected zone (HAZ), and weld zone using optical microscopy and scanning electron microscopy (SEM). The investigation further continued to check the mechanical properties of weld structures tensile and hardness. Hardness testing has been carried out like structures in 3- zones to check the hardness variation in HAZ and weldment. The results obtained are satisfactory based on weld strength and structures obtained in the sample analysis.**

Keywords— **TIG Welding, Dissimilar materials, Microstructural analysis.**

I. INTRODUCTION

Welding is a procedure that involves putting two crystal-to-crystal-bonded chunks of metal or other crystalline materials into close contact and fusing them. Depending on the welding technique, the heat necessary for welding can be derived from burning natural gas or an electric arc or generated by electric resistance. [1] Alternatively, a filler rod may melt between the fit surfaces to produce a bridge. In addition to buildings, bridges, ships, pressure vessels, and nuclear reactors, industrial applications can be found in many other areas [2]. To its numerous advantages, including design freedom, cost savings, lower total weight, and improved structural performance [3-4], welding is becoming increasingly popular in these sectors. Depending on the heat source, fusion welding can be classified as gas, arc, or high-energy beam welding. An electric arc is used to transport energy from the welding electrode to the base metal. When the angle is started, a suitable quantity of power (energy transferred per unit time) and energy density is delivered to the electrode. The weld is formed by melting the base metal and the filler metal together. [5-6]. Gas Welding with a non-consumable tungsten electrode is referred to as inert tungsten gas (TIG) and is used in GTAW. No melting occurs when using the correct welding procedures and equipment. To perform the operation, the tungsten electrode and the work piece are connected by an electrical source; the arc can approach 19400 C. [7]. Filler metal can be used in GTAW welding. It is possible to add filler metal directly into the molten pool, but it is more challenging when the metal is already molten. When filler metal is not used, it is heated, melted, and flowed together as the metal cools. The weld requires minimal finishing. Weld quality has been connected to GTAW's widespread adoption as an assembly process because of the precision with which heat input and filler additives can be controlled. Among the industries where GTAW has been widely used include atomic energy, aircraft, chemical and instrument industries, nuclear, food and maintenance and repair, and some manufacturing sectors [8]. Stainless steel, aluminum, and magnesium alloys are among the metals and alloys that can be joined with GTA welding [9-10]. Additionally, copper, brass, titanium, nickel alloys, stainless steel, Inconel, high temperature and hard surface alloys like zirconium titanium have been successfully welded with the GTA welding procedures [11].

II. METHODOLOGY

The materials AA6061aluminium alloy with EN8, SS302, and SS316L are taken as welding components for dissimilar weld amendment where the materials are machined for proper sampling for tests. In TIG welding, there is a distinction between the two types. This type of welding uses direct current, the most common method. The negative pole is where the tungsten electrode sits in the electrode holder. Alloy steels and non-ferrous metals like copper and brass can be joined using this type of welding. In contrast, alternating current welding is utilized. Lightweight metals like aluminium and magnesium can be joined with this welding method since the oxide layer is broken up. When welding lightweight metals with direct current, the electrode is joined to a pole on the positive side of the welder. TIG welding may be used to weld any metal that can be fused using the fusion welding procedure.

A. Method of TIG welding process for AA6061and EN8, SS302, SS316L

In TIG welding, stick welding and arc welding are the two most common methods. It uses the most popular way of welding, direct current. It is at the negative pole of the electrode holder that the tungsten electrode is located. Non-ferrous metals like copper and brass, as well as alloy steel, can be connected using this form of weld. In contrast, the metal parts are fused using alternating current. When welding lightweight metals with direct current, the electrode is attached to a pole on the positive side of the welding. As a general guideline, however, TIG may be used to weld any metal that can be fused using fusion.

Table- 1 Chemical compositions of materials used in present study

Materials	**Young's Modulus (E)**		**Tensile Strength MPa**	**Yield Strength MPa**	**Elongation (%)**
	Psi	**Gpa**			
AA6061 with EN8	**297000ksi**	**215**	**440**	**370**	**15.0**

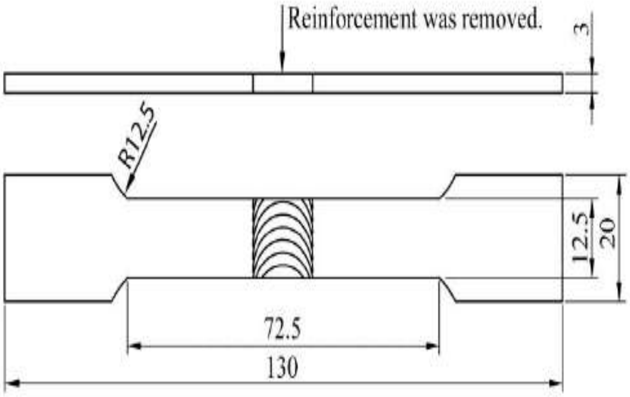

Fig. 1. Shows the preparation drawing for tensile test

Fig. 2. Shows welding rod- filler rod

Fig. 3. Tensile and hardness testing samples

The TIG welding process is carried out in two steps; in the first stage, the ferrous metals samples are chamfer in weld side to fill-up with filling rod 1 and then they joined with copper-based aluma- steel weld rod 2. The filler electrodes with Ø3mm used in both steps with copper composition is more.

Fig. 4. Sample after etching for micro hardness

Fig. 5. Samples for SEM and XRD

The materials Al6061 with EN8, SS302, SS316L, are taken and as welding components for dissimilar weld amendment where the materials are machined for proper sampling for tests

III. RESULTS AND DISCUSSION

The plates of AA6061 with EN8, SS302 and SS316L are welded by using the TIG welding process. The quality of the weld depends upon various factors likewise welding speed, voltage and ccurrents.

A. Metallographic analysis of the bonding interface

In this work, photomicrograph of the structures between Al6061 with EN8 taken in the central region of the sample with an increase of 200X, during the TIG welding process, the interface region has a straight line with occasional irregularities. There are no micro structural changes around the interface for any of the materials, as there are in fusion welding.

B. OM results for Al 6061 with EN8 weld

In case of 20μm the weld bead strength is medium as the probability of crack propagation is influenced on Al6061 side. The graphical representation clearly shows the variation in weld strengths for all dissimilar welds at different distances of 2mm, 4mm, 6mm, 8mm and 10mm. It is clearly observed the Al6061 with EN8, SS302, and SS316 L weld is having high weld strength when compared with other two welds.

Table- 2 Observed Crack propagation rate (m/cycle) for welded samples

Distance	Al 6061 With EN8	Al 6061 With SS302	Al 6061 With SS316L
2	0.000076	0.000072	0.000075
4	0.000138	0.000139	0.000138
6	0.000148	0.000147	0.000150
8	0.000154	0.000153	0.000152
10	0.000168	0.000169	0.000169

C. Microstructural Results

(i)Sample-1 (AA6061&EN8) 60 Amp

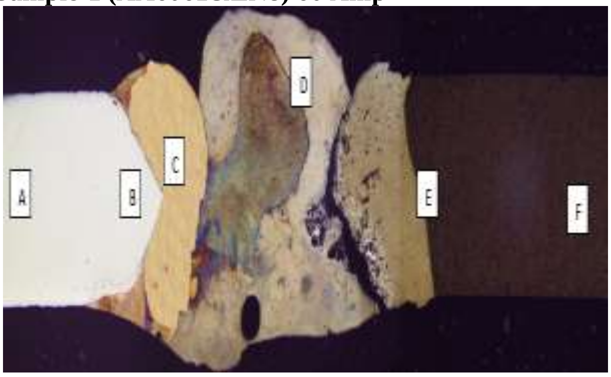

Fig. 6. Welded Sample

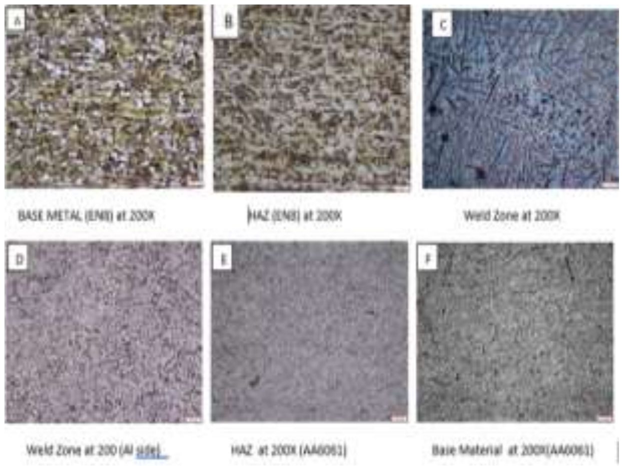

Fig. 7. Sample-1 micro structure with different specimens in 60 Amps

There is a clear difference in structures found in HAZ to base metal on both sides, while the bond structure in EN8 at HAZ shows much difference compared with base EN8.

(ii) Sample-1(B) (AA6061&EN8) 70 Amps

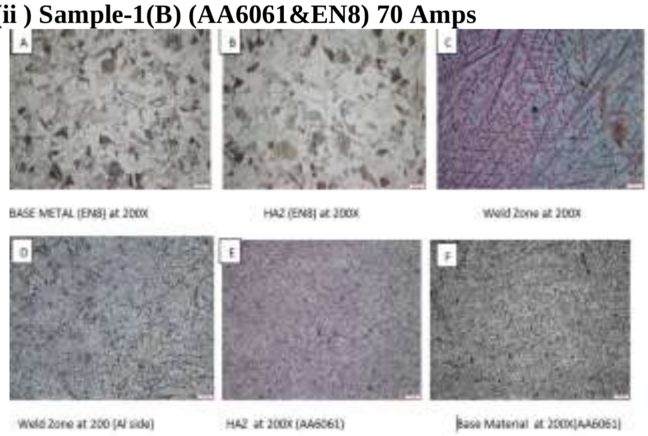

Fig. 8. Sample-1 micro structure with different specimens in 70 Amps

No such variation was found in the structure at 70 amps current used for welding, copper particles found in the weld zone and less transmission of heat found in AL side micro-structure with morphology changes between the base metal and HAZ.

(iii) Sample-1(C) (AA6061&EN8) 80 Amps

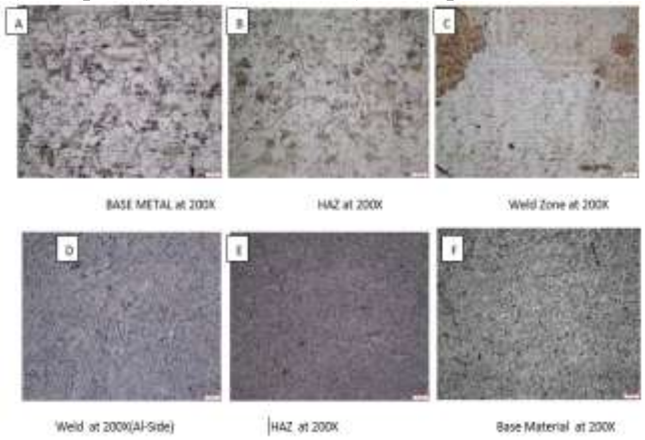

Fig. 9. Sample-1 micro structure with different specimens in 80 Amps

Clear changes found in all structures at 80 amps between all the zones base metal, HAZ and weld zone, a clear structure with copper elements found in weld zone whereas HAZ and weld contact zone also have some copper elements.

The microstructure from EN8 base material consists of an equi-axed ferrite structure within the matrix of pearlite structure as shown in structures Fig 9. Weld zone from EN8 side showing the sharp dendritic structure, weld zone from the aluminium side showing equiaxed grain structure, base material and HAZ of AA6061 shows the Mg_2Si precipitates within the matrix of Aluminum, whereas in HAZ, the microstructure shows the fine grain structure within the matrix of Aluminum.

(iv) Sample-2 (a) (AA 6061&SS302) 60 Amps

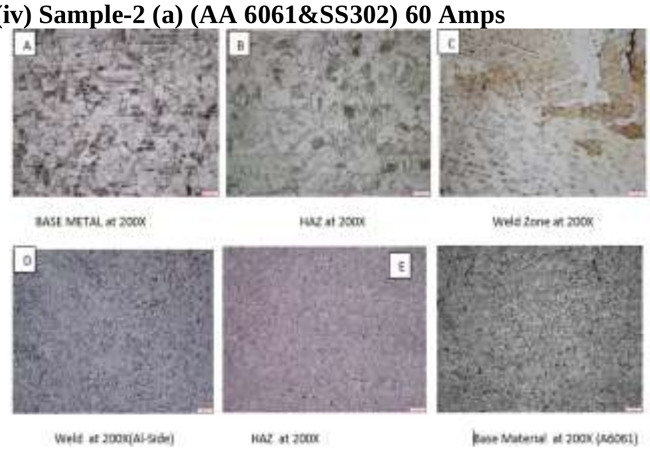

Fig. 10. Sample-2 micro structure with different specimens in 60 Amps

Copper, ferrous and aluminium mixed particles found in the weld zone of 302 sample. Higher rate of copper as well as aluminium melted particles with small cracks found at 60 amps.

(v)Sample-2(b) (AA6061&SS302)70 Amps

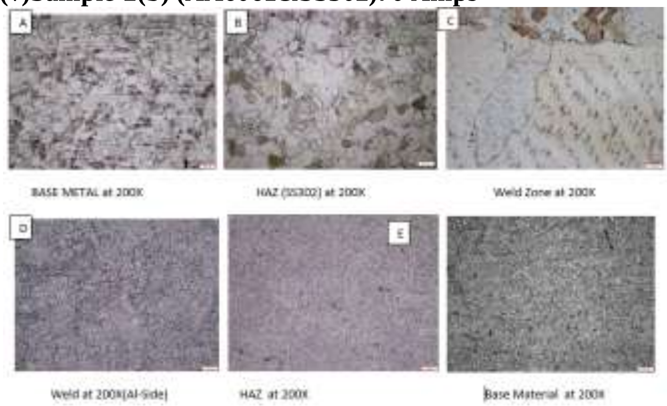

Fig. 11. Sample-2 micro structure with different specimens in 70 Amps

Clear particle distribution found in weld zone at 70 amps, particle distribution in HAZ also good, bonding between copper filler particle and aluminium with fine pores also observed.

(vi) Sample-2 (c) (AA 6061&SS302) 80 Amps

Fig. 12. Sample-2 micro structure with different specimens in 80 Amps

Welding at higher power with the fillers copper particles distribution in the weld zone is more, clear cracks found in weld zone, more melting of filler affected the HAZ on SS202 side. Bonding between aluminium and copper found in weld zone and a defective bonding on SS side structure.

The microstructure from SS302 base material consisting of twin austenitic grain structure having a grain size of ASTM G =6,7,8 respectively from above 3 samples, where as in HAZ is reporting average grain size no is 6, weld zone from SS302

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side showing the coarse grain structure with in the copper grain and alpha aluminium grain, weld zone from aluminium side showing fine equiaxed grain structure, base material and HAZ of AA6061 showing the Mg2Si precipitates within the matrix of Aluminium, where as in HAZ the microstructure showing the fine grain structure with in the matrix of aluminum.

(vii) Sample-3 (a) (AA 6061&SS316L) 60 Amps

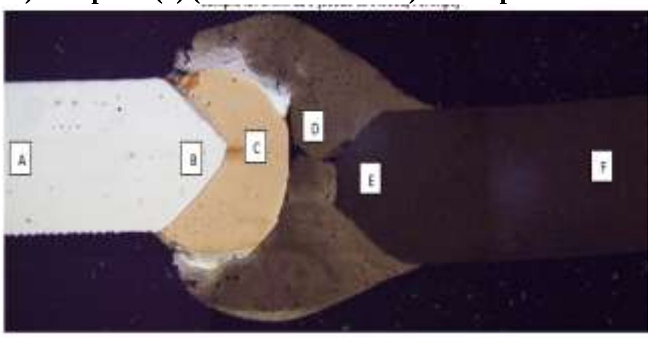

Fig. 13. Sample-3 micro structure with different specimens in 60 Amps

Cracks are observed at low power weldment, a distributed continuous lean crack observed in weld zone, ferrous copper and copper aluminium bonding observed in the above structures. There is no such affect in HAZ with 60 amps power.

(viii) Sample-3(b) (AA 6061&SS316L) 70 Amps

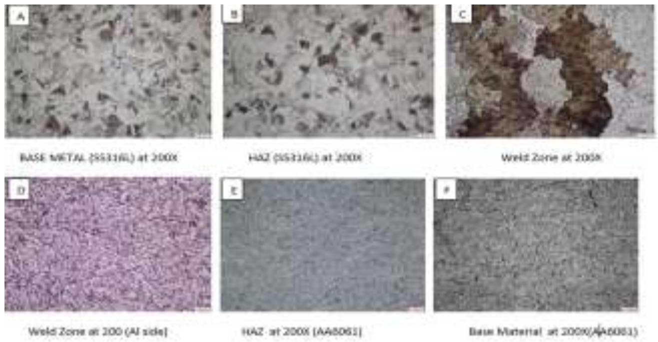

Fig. 14.Sample-3 micro structure with different specimens in 70 Amps

At 70 amps, the weld zone was observed far better when compared with the other samples, the particles of copper, ferrous and aluminium distribution found without cracks.

(ix) Sample-3 (c) (AA 6061&SS316L) 80 Amps

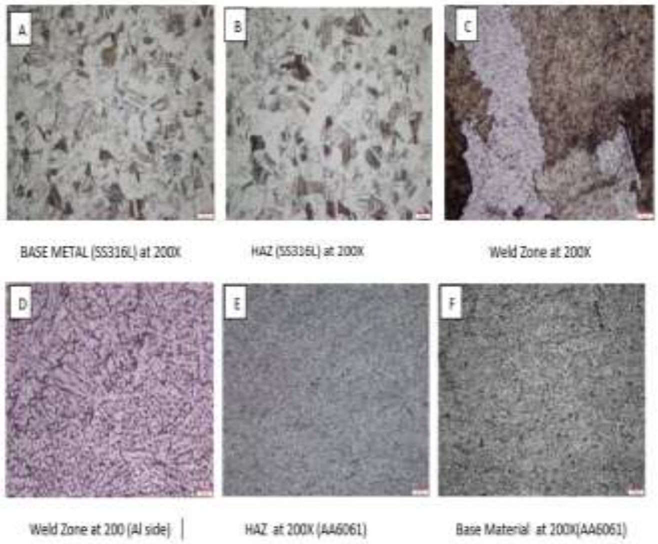

Fig. 15. Sample-3 micro structure with different specimens in 80 Amps

Better weld zone formed for SS316 at 80 amps, fine pores and good bonding structure observed in the weld zone, change observed in heat-affected zones with morphology change compared with the base metal.

The microstructure from SS316L base material consisting of twin austenitic grain structure having a grain size of ASTM G =6,7,8 respectivelywhereas in HAZ is reporting average grain size no is 7, weld zone from SS316L side showing the coarse grain structure, weld zone from the aluminum side showing coarse equiaxed grain structure, base material and HAZ of AA6061 showing the Mg2Si precipitates within the matrix of Aluminium, whereas in HAZ the microstructure showing the fine grain structure with in the matrix of aluminum.

D. Tensile Properties

To determine the metal's tensile strength, yield strength, elasticity, and other properties tensile testing must be carried out. When a composite or plastic specimen break, this analysis evaluates how far it extends or elongates before it breaks. It is common practice to conduct fundamental tension or flat-bread tensile tests on composite materials by standards.

Table -3 AA6061& EN8 Materials tensile test results

S.NO	Sample Specimens ID	UTS (Ultimate tensile strength) Mpa	% Elongation
1	AA6061& EN8 (60Amps)	28.44	0.24
2	AA6061& EN8 (70Amps)	69.21	16.04
3	AA6061& EN8 (80Amps)	54.95	10.24

Tensile properties of the transition joints are accumulating in table 4.2 (AA6061 & EN8). Highest bond strength has been achieved for AA6061&EN8 (70Amps) and the AA6061&EN8 (60Amps) shows the weakest joining. The reduced strength at the joint can be accrediting to the presence of both the brittle and soft phases at the joint.

Table -4. AA6061& SS302 Materials tensile test results

S.NO	Sample Specimens ID	UTS (Ultimate tensile strength) Mpa	% Elongation
1	AA6061& SS302 (60Amps)	22.70	1.08
2	AA6061& SS302 (70Amps)	62.83	3.75
3	AA6061& SS302 (80Amps)	39.01	3.32

Table 4.3 lists the mechanical properties of the AA6061 & SS302 material. Highest bond strength has been achieved for AA6061& SS302 (70Amps) and the AA6061&SS302 (80Amps) shows the weakest joining. The reduced strength at the joint can be accrediting to the presence of both the brittle and soft phases at the joint.

Table -5.AA6061& SS316L Materials tensile test results

S.NO	Sample Specimens ID	UTS (Ultimate tensile strength) Mpa	% Elongation
1	AA6061& SS316L (60Amps)	42.80	4.82
2	AA6061& SS316L (70Amps)	60.15	6.42
3	AA6061& SS316L (80Amps)	90.32	10.36

Table 4.4 lists the mechanical properties of the AA6061 & SS316L weld joint. Highest bond strength has been achieved for AA6061& SS316L (80Amps) and the AA6061&SS316L (60Amps) shows the weak joining. The reduced strength at the joint can be accrediting to the presence of both the brittle and soft phases at the joint.

E. Hardness Properties

To determine the value of treatments and coatings, metal hardness testing is frequently conducted. Its resistance to penetration measures a material's tensile strength during a material hardness test. The reported hardness value of a material indicates how readily it can be machined and how well it will wear, making hardness test findings particularly valuable when selecting materials.

Table- 6-Hardness test results in AA6061& EN8 Samples

S.ID	Sample ID	Observed Values in HV					
		BM EN8	HAZ EN8	WELD 1	WELD 2	HAZ AA 6061	BM AA 6061
1	AA6061& EN8 (60Amps)	180	218	131	101	33	39
2	AA6061& EN8 (70Amps)	181	209	141	107	31	36
3	AA6061& EN8 (80Amps)	164	203	146	108	35	38

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Tables 5, 6, and 7 demonstrate the distribution of micro hardness values over the joint. Stir zone hardness discrepancy is reduced in this study. According to micro structural studies, the amount of secondary phase in the stir zone was shown to be reduced significantly. As a result, the hardness discrepancy was reduced and the overall hardness was raised because of the grain reinforcing in the stir zone. There is a significant drop in hardness at the AA6061parent material's nuggets zone, as evidenced by an abrasive interface.

Table- 7 Hardness test results in AA6061& SS302 Samples.

S.ID	Sample ID	Observed Values in HV					
		BM SS302	HAZ SS302	WELD 1	WELD 2	HAZ AA6061	BM AA6061
1	AA6061 & SS302 (60Amps)	279	268	131	101	33	37
2	AA6061 & SS302 (70Amps)	276	270	130	98	36	39
3	AA6061 & SS302 (80Amps)	280	268	128	108	29	37

Table- 8. Hardness test results in AA6061& SS316L Samples

S.ID	Sample ID	Observed Values in HV					
		BM SS316L	HAZ SS316L	WELD 1	WELD 2	HAZ AA6061	BM AA6061
1	AA6061& SS316L (60Amps)	264	186	165	106	36	39
2	AA6061& SS316L (70Amps)	261	179	160	103	36	39
3	AA6061& SS316L (80Amps)	260	183	162	101	36	37

F. Discussions

As per the specimens observed from the experiment's a flow has been taken from the initiation that dissimilar metal weld possibilities and its strengthening properties observed in a proper manner with the researched filler rods. For the final Al 6061 with EN8, SS302, SS316L weldment, filler electrodes with different welds were detected. Many of the advantages of these methods, such as high efficiency and stability of the process, or better conditions of worker safety and health, than in the case of traditional welding technologies, make them very appealing to manufacturers. However, the ability to combine materials with disparate properties has surfaced as the most critical in recent times. Although intermetallic compounds occur in the zone of fusion between two different materials, joining two dissimilar materials is frequently a difficult process. An understanding of the phase diagrams of the two welded materials is essential for a high-quality junction." Microstructure and various properties of intermetallic phases, such as crack sensitivity, flexibility, and corrosion resistance, are also highly important considerations.

IV. CONCLUSION

Experimental investigation on ferrous and non-ferrous (AL6061-T6) samples is welded in the GTAW method with special filler rods in a two-step procedure. Micro-structures are analyzed for 200X magnification, relying on the structural observation of 9 samples at 70 Amps power the reliability if weldment good in all three varied materials. Observing all micro-structure results makes the fillers more useful in joining hardened alloys like SS316L. Easily machinable materials of EN series like En-8 melted at high current and weak fastened at 60 amps. As the tensile test result, the ultimate tensile strength is more for SS316 fastened to Al alloy. 70 Amps of current give stable results in UTS for all ferrous alloys, not much variation found in any series fastened to AL6061-T6. Hardness results showed a remarkable difference in three materials of the ferrous family as the weld zone strength is more in SS316L. Successful experimentation between aluminium and Ferrous alloys can be elaborated for high strength alloys like Titanium nickel-based alloys (ex; Inconel) as a future enhancement.

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