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Review of Advanced Joining Technique for Aluminium Alloys and Its Properties

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Abstract- Emerging techniques to join Al alloys and other metals were studied and compared based on different parameters. More strength to weight ratio of Al attracted many applications in automobile and manufacturing industries. The welded joints of Al and its alloys with other metals show great variation in the joint properties and the base metal. The difference in properties of the joint also depends on the type of method used in the process. This review paper involves the study of Magnetic Pulse Welding (MPW), Hybrid Laser Arc Welding (HLAW), Ultrasonic Resistance Spot Welding (URSW) of Al and its alloys with other metals. There processes are faster than other conventional processes, are useful in mass production. Micro hardness, microstructure, porosity, tensile and shear strength, fracture and failure of the joints welded using these processes were studied and compared. The welded joints obtained showed more strength than base metal. The hybrid joints formed by HLAW & URSW are more efficient than normal processes' joint strength is 300% stronger than RSW.

Keywords: Joining of Aluminium, Advanced joining techniques, Magnetic pulse welding, Hybrid laser arc welding, And Ultrasonic Spot Welding.

I. INTRODUCTION

Metamorphosis is utilized in the aerospace and automotive industries due to its high specific strength, low density, and corrosion resistance, which has caused in an increase in the use of Al alloys.

In the last few years, climate emergencies have made lots of improvisations that embrace features like light weighting of vehicles so as to achieve less fuel consumption which captured interest on joining of dissimilar materials.

Diverse methods are used to join Al alloys which incorporate Resistance, Fusion welding, adhesive bonding, brazing, mechanical joining processes like bolting and riveting [1]. Mechanical joining process despite being easy has its own drawbacks; the gaps between the joints and the holes drilled for it may lead to lessen the strength.

RSW is often used for joining methods in the automotive industry; the downsides of this process are short electrode life and high energy consumption [2].

Considering all the disadvantages of conventional processes it is to be focused on emerging joining technologies for Al alloys to yield greater outcomes of the products. There are plenty of joining processes which are still under research stage where some of them are already being in use. The purpose of this article is to investigate the most recent joining methods for Al alloys, with an emphasis on three divergent welding processes.

Magnetic pulse welding, Hybrid Laser Arc Welding, and Ultrasonic Spot Welding are three types of welding.

MPW is a state-of-the-art jointing technology that blends high-speed collisions with plastic deformation at high strain rates. It's a solid-state welding method that creates a connection using magnetic forces rather than melting the weld contact, preserving the material's characteristics.

High standard welds in similar and dissimilar metals can be made in minimum amount of time with MPW and the requirement of shielding gases and electrodes is eliminated. The joint generally has greater strength than parent metal.

HLAW integrates the use of laser light and an electric welding arc. The arc is generally generated using a gas metal arc welding power source. The laser-focused beam and high energy density contribute to the arc's balance. It takes advantage of both technologies' dominance.

Because filler wire is utilized, the laser's penetrating capabilities, fast speed, and arc allow for mild cooling of welds and adaptation of metallurgical properties. A extremely small heat-affected region is generated as a result of the laser's deep penetration. This enables high-speed welding with reduced heat input, as well as the prevention of shrinkage fractures during weld metal solidification.

USW is a solid-state joining technology in which a junction between metal sheets is created by the function of an ultrasonic frequency shearing vibration of the so not rode with a specified clamping pressure. Friction between two sheets causes plastic deformation, resulting in rapid contact between the two cleaned surfaces, which generates heat at the weld area. The electrical and thermal conductivity of the joints created is exceptional.

II. LITERATURE REVIEW

Yuceet al (2015) Discussed about the different joining techniques of aluminium alloys and other heterogeneous joining processes where the metals can be joined without melting. As the tool rotates so fast on the surface of the metals to be joined there was stress heat produced which changed the grain structure at the joint [3].

Mechanical clinching is a process similar to punching but the difference here was the part that punched made a dent on the sheet. Due to different plastic deformations the sheets are bulged and compressed making an interlock at the punched area. This process is not appreciated for HSS because they have the poor ductility due to which a fracture may occur while clinching.[3]

Cui et al (2019). An experiment is performed to join CFRP and 5A02 aluminium tubes using MPW process. 3 holes are drilled along the circumferential direction on CFRP tubes and the tubes are supported by core tube (6061T5 Al alloy) at the lap. Resistance against load was emerged and a locking was produced between outer tube and core tube.

The samples were made using 30kJ discharge energy, a discharge voltage of 12.1kV, and a frequency of 11.5kHz.To test the tensile strength Instron 5985 tension testing system is used under the load rate of 2mm/min. The joint strength was more than the strength of aluminium. When torsion test was performed with the torsion speed of 10 0/min at 8 0, failure was observed in aluminium [4].

Pereira et al (2019) AA7075-T651 and carbon fibre reinforced polymer were welded under different stand-off distance and discharge energies. Failure in CFRP tubes was found at discharge energy of 1kJ and a stand-off distance of 1mm. higher discharge energy resulted in larger contact areas if no fractures were formed owing to impact. But at 3kJ larger contact ant the axial joint was observed. Cracks can be avoided using sufficient stand-off distance, discharge energy. In order to achieve the losses due to damage, ductile metallic coating was used to absorb the deformations that were created during welding. This improves the efficiency of the joint [6].

Mehdi pourabbas et al (2019). Two alloys of aluminium AA4041 and AA7075 were welded together using MPW under collision angles of 6 0 and 8 0. Since alloys of same metal were welded local bonding was formed at local temperature. As the impact angle and discharge energy rose, so did the likelihood of micro structural defects. Because of the low collision angle and discharge energy, the interface strength at the welded connection was reduced [8].

Huihui Geng et al (2018) The MPW method was used to weld high strength low alloy steel HC340LA and AA5182 at varied discharge energies. The wave was observed sinusoidal at low discharge energies while at high discharge energies it was shear wave.

Joints with larger discharge energies were noticed to have greater joint strength which was obtained due to high impact velocity and pressure. [9]

Huihui Genget al (2019) AA5052 and HC420LA were welded using magnetic pulse welding. Joints showed high fatigue strength when low stress was applied. Brittle fractures were seen in transition zone while the ductile fractures were formed in regions adjacent to transition zone. [11]

R.N. Raoelison et al (2015) Al/Al and Al/Cu were welded using magnetic pulse welding. Al/Al joint showed larger shear deformation. The grain structures were equiaxed without any bond breaking at the interface. In Al/Cu combination, the weld efficiency was less due to formation of micro cracks. A separate melted zone was observed at the interface. [12]

C N D Peters (2006) discussed about various joining techniques used for Aluminium alloys and their limitations & advantages were discussed. Here the processes Self Piercing Riveting (SPR) and Clinching were discussed. Both the processes use a punch and a die, in SPR rivets are forced inside the sheets therefore creating a joint. When the peel & shear strengths of both joining processes were compared, press joints strengths were less than half that achieved with SPR. Using appropriate filler material may avoid hot cracking and loss of strength. [13]

L Han et al (2009) the process's appropriateness Self Piercing Riveting, Resistance Spot Welding, and Remote Laser Welding were investigated, and the mechanical behaviour of the joints was evaluated using the SPR method as a reference value to compare the other two [14].

After testing, the results revealed that RSW samples were stronger than SPR samples, and for RLW specimens, the strength of the work piece increased with stitch length. The result reached was that these three methods are suitable for connecting Al alloys by providing appropriate parameters, and that the strength and failure of the joint are dependent on different parameters and testing circumstances [14].

K. Shibataet al (2006). Examined the effect of weld parameters of Nd: YAG laser and MIG welder in HLAW process. When Laser parameters were changed there was no difference observed in width but appreciable welding length was acquired using high power density laser beam focusing on short focal length. It can be concluded that there was no effect on increasing penetration with MIG energy and the weld depth was based on concentration of laser energy. The welding speed was faster using this hybrid welding process it was more than 60% faster than conventional welding processes. It was concluded that Hybrid welding was more suitable for fillet joint welding [16].

S Katayama et al (2007). Scrutinized the effects of individual welding conditions while using the porosities formed was similar in both conditions. The torch angle was set indifferent angles and it was observed that maintaining torch angle at 30° was suitable for performing welding without any problems. As speed increased the penetration depth and bead width were decreased and the porosities increase with decrease in welding speed. The welding current was changed and observed at low current uneven surface was observed so by using high current smooth surface can be attained [17].

Shaohua Yan et al (2018) explained the effect of filler materials on micro structures and properties of AA6061-T6 joint which were welded using Hybrid laser arc welding using ER5356 and ER4043 filler materials of 1.6mm diameter. It was observed that ER4043 joint was having higher chances to get exposed to corrosion this was observed when it was tested using 3.5% Nacl solution [18].

Umair Shah et al (2019) have stated that using ultrasonic vibration with resistance spot welding has increased the strength by 300% when compared to the normal resistance spot welding. Ultrasonic has minimum energy consumption and heat affected zone. This process improves the bonded area of Al-Fe. The inner cracks that were formed in resistance spot welding were overcome in this hybrid process. [21]

Pravatranjanpati (2020) said that Ultrasonic spot welding is a cost-effective and ecologically beneficial method. The vibrating tip's amplitude has a major impact on the weld quality. Throughout the process, the frequency should remain constant. Up to a certain point, strength increases with increasing weld time and weld energy, then decreases. With increasing weld duration, the plastic deformation area grows [22]

S.M.A.K. Mohammed (2020) used the ultrasonic spot welding for coating a clad layer to the AA7075 aluminium alloy which helps in the prevention of corrosion. The fatigue strength increases with the decrease in the maximum cyclic load. These fractured surfaces in the fatigue failure show elongated shear dimples. [23]

Z.L. Ni (2018) aluminium alloys have high conductivity, low strength at high temperatures. As of now ultrasonic spot welding can be used for the sheet thickness less than 3mm. The vibration amplitude may vary from 10 to 100 micrometers. According to the author the weld involves three types of zones [24]

S.M.A.K. Mohammed (2019) has studied the AA5182 alloy joined using ultrasonic spot welding. He found out that the temperature increased rapidly with the process. The low energy level failed at the weld while the high energy failed at the nugget. [26]

U.H. Shah (2019) has joined TRIP-780 steel using a URW said ultrasonic resistance weld showed nugged pullout failure. In the lap shear tensile test, ultrasonic resistance welds showed improved joint properties but the resistance spot weld failed with interfacial deboning. Marten site is found in the fusion zone of the weld; this might be due to the absorption of the weld energy to transform into marten site. [27]

D.loveborn (2017) said that fossil fuels can be saved with the use of light materials like aluminium in the parts of a vehicle. That this can also be used in rockets because we know that if we can decrease the weight or load of a rocket can reduce the fuel consumption. They are namely 1) oscillation optics and 2) triple-spot optics. In the oscillation optics the laser beam moves in the sinus wave.

The power is oscillated linearly and when it comes to triple spot optics, the power is divided into 3 spots while 2 of them are smaller and the 3rd one is the main spot of them. The penetration in the base sheet is deeper for the oscillation weld than the triple spot weld. But the use of a high-power laser source can improve the penetration profile for triple spot welding. [28]

Tinku Kumar (2020) says that the strength to weight ratio can be increased with the joining of aluminium and steel sheets. A perfect joint can be produced with a low heat input wire GTAW process. Here this low heat and arc stability make this process suitable for joining aluminium. Due to high thermal expansion coefficient of aluminium the distortions in the Al sheets are high. [29]

Ying Lu (2019) discussed a method of joining aluminium sheets to steel sheets using both ultrasonic spot welding and resistance spot welding. An intermediate joint is formed using the ultrasonic spot and then the primary joint is formed using resistance spot welding.

The paper concludes that the failure of the joints made using ultrasonic resistance spot welding process is affected by welding current. This hybrid method takes the good out of both the methods.[30]

III. DISCUSSION

1. Magnetic-Pulse Welding:

1.1 Microstructure: The Al/Al magnetic pulse welded joint had a wavy interface as the alloys of same metal are joined [34]. The Al/Mg joint was also observed to have wavy morphology but the interfacial layer had intermetallic compounds. Different intermetallic compounds were formed with increase in the temperature at which the welded joint was preserved [5].

The Al/Stainless steel joints for different overlap lengths and were divided into three zones where the transition layer was formed at zone I and zone III. Overlap lengths of 10mm, 9mm and 6mm were studied.

The effective binding was observed in overlap length of 6mm as in the transition layer was thick in zone III which always supports effectiveness on the bond. The formation of transition layer is due to joining two different materials. [7, 35]

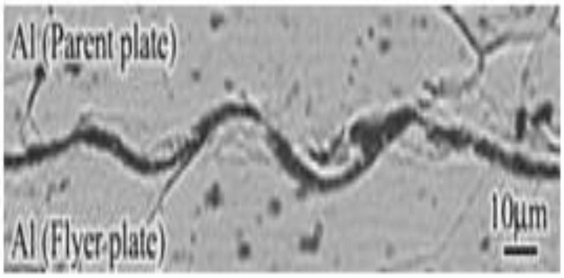

Fig 1. Microstructure of Al/Al joint. [34]

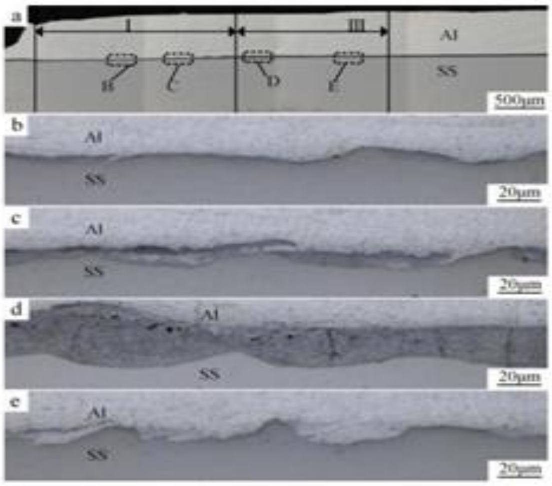

Fig 2. (a) overall look of microscopic morphology (b) Zones B (c), C (d), and D. [7]

1.2 Strength: At the dynamic loading conditions the strength gradually decreased. The inner wall thickness of the Al-Fe tube joints depends on impact speed. The joint showed higher strengths. The strength of the welded zone is affected by the thickness of the wall [31, 32]. The welded joint of Al and high strength joint formed at different discharge energies, when shear strength was tested, the joint with thick transition zone showed maximum shear strength. The thick transition layer was obtained with high discharge energies. [9]

1.3 Failure and Fracture: During the quasi-static loading conditions the strain rate at the joint is minimum. The joint has the higher strength than base metal so the failure was noticed in Al (Base Metal) at quasi static loading condition. The fractures were both brittle and ductile. Only Brittle fractures were observed at high strain loading conditions. [31]

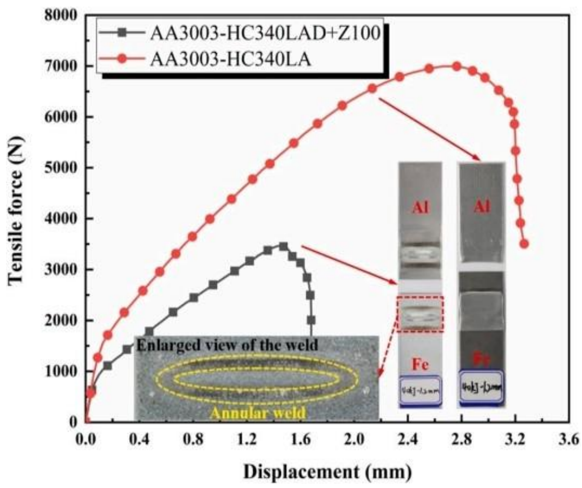

Fig 3. Force-displacement curves and failure modes of the two MPW joints. [33]

1.4 Micro-hardness: The micro-hardness of Al/galvanized steel was less 4.1GPa whereas AL/Non-galvanized steel was 4.7GPa [33]. In Al/Mg joints the micro hardness of the heat treated joint changed on Mg alloy side whereas on the surroundings of Al alloy, the micro hardness did not change specifically. [5]

The welded joint of Aluminium alloy and stainless-steel tubes showed the maximum micro hardness due to fine grain reinforcement in base metal neat transition zone and in the transition zone. So the micro hardness was increased after welding process at the grain reinforced areas. [35] Welded Al/Cu using magnetic pulse welding process, there were intermediate compounds formed in the transition zone due to which the failure was found to be brittle. [36]

2. Hybrid Laser Arc Welding:

2.1 Porosity: From investigating the pore defects and its formation it was observed that the percent porosity was lowered as welding speed or the laser power was improved and when the weld current was raised the percent porosity decreased drastically [37,38]. It was also concluded that the larger size of bottom part of the weld pool decreased the porosity letting the gas bubble to escape easily [37].

During Laser-Arc Hybrid welding the keyhole formation influences formation of macro porosity. A study made on age hardening AA2024-T3 alloy stated that extreme porosity as shown in Figure 1 was observed, due to the fast solidification of weld metal without letting the bubbles escape which formed as the keyhole sagged [39].

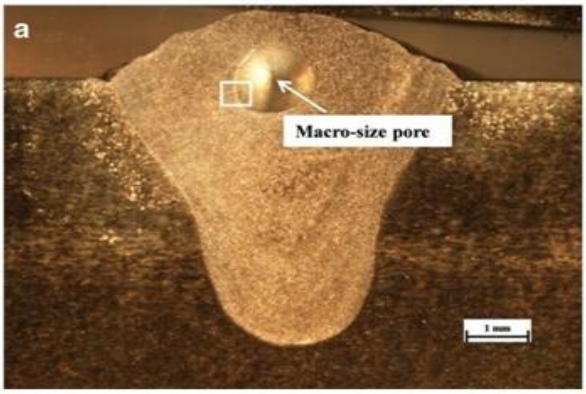

Fig 4. Macro size Pore in weld metal. [39]

Porosity is classified into two kinds depending on their size, appearance, and other characteristics. The pores created by hydrogen were small and uniform, while those formed by flow-induced porosity were large and irregular. Pores influenced mechanical characteristics; as the porosity rate rose, tensile strength and fatigue strength dropped [40].

2.2 Tensile Strength: When a 5A06 aluminium alloy joined using HLAW was tensile tested it was observed that the base metal was having greater tensile strength than the joints [41]. And when the heat input was significant the tensile strength was justifiable, it was exceptional when the filling rate of wire was increased [42]. Using an intermediate layer increased the tensile strength of the specimen [44].

2.3 Micro Hardness: Hardness plays major role in the performance of the specimen; it was observed that at the bonding area the hardness was lower than base metal due to solid solution strengthening but slightly greater than the weld area [45, 46].

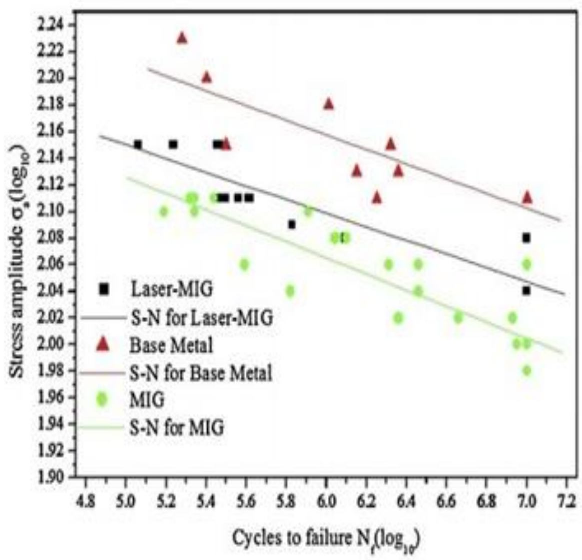

Fig 5. Micro hardness of different zones in weld joint. [45]

The micro hardness is mostly impacted by the welding speed, as it is increased, hardness increased and when welding speed was decreased, pore formation was observed and due to this the average micro hardness decreased [47].

Hardness of the specimens can be improved by using appropriate filler wires using Mg and Si, the study of different filler materials using Si, Mg indicated that the hardness was increased [48]. It was concluded that Aluminium and Si composition was more suitable for increasing of hardness [48, 49].

When the grain sizes of lower and upper part of welds were differentiated the lower part was having small grain size, which indicates hardness is greater due to large number of grain boundaries [49].

2.4 Fatigue & Failure: Fatigue life is salient in manufacturing industries where high speed is required. The usage of different welding process gives different outcomes, while MIG welding and HLAW were compared it was discovered that Hybrid welding specimen was having higher fatigue life [50, 51]. The fatigue life depends on crack formation, it relies on the strength, porosity, even grain structure etc. [52].

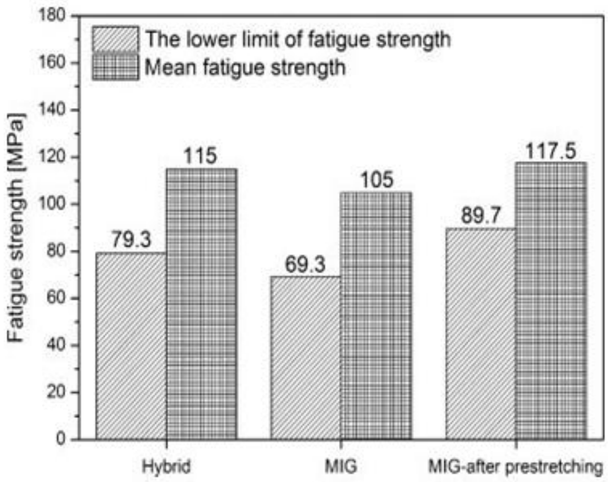

Fig 6. Lower limit and mean fatigue strengths of specimens. [50]

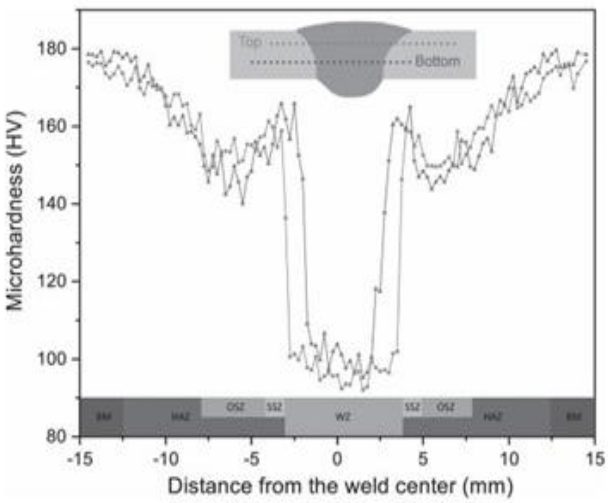

Fig 7. Fatigue results of Hybrid and MIG welding. [51]

3. Ultrasonic Spot Welding:

3.1 Microstructure: Weld zone, weld impacted zone, and compression zone are the three zones. In the compression zone, elongated grains can be seen far from the weld zone. During the USW process, shear forces deform the grains in the weld affected zone. In the weld zone, the grains are not elongated. In the weld zone, re-crystallization does not occur [24, 27]. As the weld energy increases, it can be observed that there will be misalignment in the macrostructure. The weld is formed like a wavy pattern. This wavy bond enhances the joint [22].

The thickness is inversely proportional to the welding pressure. The temperature will increase as the welding pressure increases which may affect the strength of the weld [25]. As the weld energy increases the failure load capacity will increase. Failure energy can be calculated with the Zhang's equation Kc=0.694 Ft/dt the test pieces fail in the shear tests in the weld interface [23].

3.2 Tensile Shear Strength: There are 3 failure modes: all this depends on the depth of the sonotrode tip, interfacial failure mode happens when the depth is less than 0.32mm. Partial interfacial failure happens when the depth is between 0.32mm and 0.36mm. Button pullout failure may happen when the depth is more than 0.36mm.

The weld time should be increased if the vibration amplitude is decreased for the formation of the effective weld [25]. Samples can't be welded correctly if the weld time is less than 0.35s. Tensile failure increases while Impedance value is decreased. Work pieces will fail from the interface when given lower welding energy but will fail from the edge of the weld nugget when given high welding energy [26]

3.3 Fatigue: Fatigue tests were conducted to work pieces which were welded at 500J and 4000J. Fatigue life is more for the work piece welded at 4000J than that welded at 500J at higher loads but a 500J welded joint has more fatigue life for lower loads.

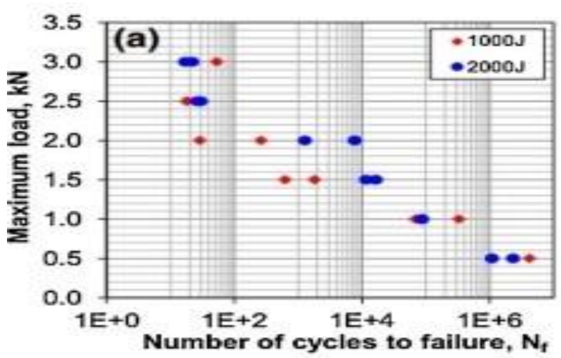

Fig 8. US Wed Al5754 alloy joints S-N curves. [24]

The weld failed in the TTT fracture. This may be due to the decrease in the thickness at high welding energies.[23] With the decrease in the cyclic loads the failure mode changes from nugget-pullout to TTT[24].

IV. CONCLUSION

In this study of joining Al with other metals using magnetic pulse welding, hybrid laser arc welding, ultrasonic resistance spot welding, it is concluded that the processes are faster than other processes and very supportive for mass production.

The joint strength of magnetic pulse welded joint is more and the process is very much suitable to produce lap joints. When compared to base metal the out-processes maximum micro hardness, tensile and shear strengths.

Hybrid Laser arc welding is suitable for fillet joining methods and is 60% faster than conventional processes. The joint strength is more when fillet materials are used but this may risk in formation of oxide layers.

Ultrasonic resistance spot welding is very useful in producing joints of more strength. To obtain a quality weld, the frequency of vibrator must be constant. The process can only be used to join sheets of thickness less than3mm.

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