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OPTIMIZATION OF PROCESS PARAMETERS OF FRICTION STIR WELDING/PROCESSING FOR DISSIMILAR ALLOY-A REVIEW

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Abstract -- Friction stir welding (FSW) is a process of joining of two similar or dissimilar material which uses non-consumable rotating tool. Friction Stir Welding (FSW) was developed for microstructural modification of material and the effect of the welding parameters such as tool rotation speed, welding speed, tool pin diameter, shoulder diameter and tool pin profile have a significant effect on tensile strength, micro hardness, yield strength and strain rate of friction stir welding.

This review provides an overview of the effects of the Friction stir welding on microstructure refinement, tensile strength of welded joint, and tribological properties. This review conclude with recommendations for future research work.

Keywords— *Friction stir welding, Microstructure, Strength, Aluminium alloy*

I. INTRODUCTION

Friction Stir welding (FSW) is a solid state welding process, which means that during the welding process, the base material were joint without melting. FSW is a method of changing the mechanical properties of welded joint through penetrating localized plastic deformation. This distortion is caused by forcing a non-consumable tool in the workpiece and moving the tool in stirring motion, from this technique, friction stir welding is used to join multiple workpiece without creating the heat affected zone (HAZ) such as fusion welding. In the case of strength of aluminum matrix composite material, efficient joints cannot be obtained by fusion-based welding method because the brittle secondary phase is formed in the weld pool due to the reinforcement on molten metal [1-2]. In friction stir welding, cylindrical tool consisting of cylindrical shouldered is used and profiles pin that rotates into the interface between two plates those are need to join. When tool pin and work-piece comes in contact friction takes which generates heat for the welding that causes softening of work-piece without melting and allows traversing of the tool along the weld line under pressure. Due to rotation of tool intermixing of work-piece material takes place and work-piece plates joined together. Friction stir processing is a local thermo-mechanical metal working process used to modify microstructure of metallic materials based on the principle of friction stir welding and it also used to increase ductility, improve corrosion resistance properties and helps to produce super-plastic materials by microstructure refinement. As a versatile material, aluminium matrix composites may be selected as an alternative to high strength aluminium alloys in aero engines and aerospace structures like fins, wing and fuselage. In 2001 NASA used composite aluminium AL-Li 2195 rather than aluminium alloy Al2219 for the external fuel tank of space shuttles leading to a reduction of weight by 3400 kg. The saving in weight increases the cargo capacity of space shuttles and enables it to transport more than one components in a single flight to the international space station [3]. Titanium alloy are used extensively in the aerospace industry due to their excellent structure efficiency and good high temperature strength. Welding is an effective way to produce a structure with complex geometry and multiple components. Titanium alloys are readily fusion weld able. However, some problems associates with fusion welding of titanium alloys include porosity, distortion and formation of coarse cast grain structure [4, 5].

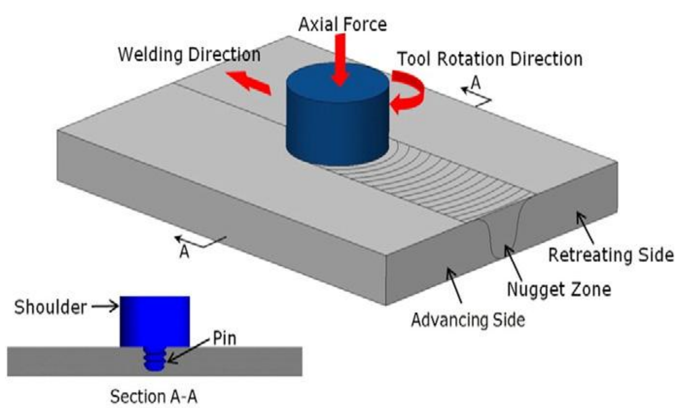

Figure 1: Friction Stir welding

II. LITERATURE REVIEW

Various material which is used in nuclear , aerospace, automobile industries have been joined by various conventional welding technologies, such as gas tungsten arc welding, electron beam welding, plasma arc welding and laser beam welding. Recently, FSW technique, which could avoid the problems associated with the melting and solidification in fusion welding methods such as brittle cast structure, large distortion and residual stress. A comprehensive review of various research data which shows the effect of different process parameters on friction stir welded / processed of dis-similar metals has been discussed.

The literature consisting of the various works which is done by a various researchers for joining aluminium alloys by friction stir welding. Now a day's aluminium alloys are most widely used in the field of automobile, aerospace industries and marine industries because of their light weight and high strength. So welding of aluminium alloys by friction stir welding is a topic of interest for the researchers. This literature describes the effect of the various parameters on the weld quality and strength of joint of different aluminum alloys by friction stir welding.

This review consist of published papers of dissimilar metals has been presented in tabular form. The review table given below explains the details of parameters considered by earlier authors.

S.N	Author	Title of Paper	Material	Input Parameter	Conclusion
1	Ji.Y., et al [6]	Microstructure and Mechanical Properties of Friction Welding Joints with Dissimilar Titanium Alloys	LFW joint with Ti-6Al-4V (Ti64) and Ti-5Al-2Sn-2Zr-4Mo-4Cr (Ti17)	➢ Tool of a cylindrical pin with an increased pin tip diameter 6.3 mm. ➢ Tool rotating speed (rpm) 900, 1000, and 1100. ➢ Welding Feeds 25, 50 mm/min	➢ The microstructure across the linear friction welding dissimilar joints with titanium alloys displayed marked change, mainly consisting of a re-crystallized grain zone in the weld center, deformed grains and partial re-crystallization in the thermo-mechanical affected zones. ➢ The maximum hardness is located in the weld metal, which may result from the fine grains arising from the rapid cooling during the welding process. ➢ The linear friction welding dissimilar joints obtained higher tensile strength than base metal Ti64 with lower strength. The failure located in the Ti64 side approximately 1.2 mm away from the welding interface.
2	Sohn.w., et al [7]	Microstructure and bonding mechanism of Al/Ti bonded joint using Al /10Si /1Mg filler metal	1050 Al alloy and Ti alloy using filler metal(Al /10Si /1Mg) with a thickness of 100 mm Thickness 3 mm	➢ Tool shoulder diameter 18 mm. ➢ Pin diameter 5 mm. ➢ Tool pin length 3.3mm ➢ Tool rotating speed 300-450 rpm ➢ Welding Feeds 1-1.4 mm/sec. ➢ Tilt angle 3 ^{0}	➢ The results show that the bonding at the interface between Al and filler metal proceeds by wetting the Al with molten filler metal, and followed by removal of oxide layer on surface of Al. ➢ The interface between Al and filler metal moved during the isothermal solidification of filler metal by the diffusion of Si from filler metal into Al layer. ➢ The interface between Al and filler metal became curved in shape with increasing bonding time due to capillary force at grain boundaries.
3	Aonuma.M ., et al [8]	Dissimilar metal joining of ZK60 magnesium alloy and titanium by friction stir welding	Titanium and MgZnZr alloy Thickness - 2.0 mm	➢ Tool shoulder diameter 15mm. ➢ Pin diameter 6 mm. ➢ Tool pin length 1.9mm ➢ Tool rotational speed 850 rpm ➢ Tool traverse speed 50, 100 mm/min ➢ Tilt angle 3^{0} ➢ Probe offsets of 1.0 and 1.5 mm	➢ Alloying elements of ZK60 Mg–Zn–Zr alloy on the microstructure of the dissimilar joint interface with titanium and the joint strength in comparison with pure magnesium and titanium has been investigated. ➢ The fracture of the joint by tensile test occurred mainly in the stir zone of Mg–Zn–Zr alloy and partly at the joint interface. The tensile strength of the Mg–Zn–Zr alloy and titanium joint was higher than that of the pure magnesium and titanium.

4	Chen.Y.C., et al [9]	Microstructural characterization and mechanical properties in friction stir welding of aluminum and titanium dissimilar alloys	ADC12 cast aluminum alloy sheet& Pure titanium sheet	➢ Tool shoulder and pin diameter are 15 & 5 mm. ➢ Tool pin length 3.9 ➢ Tool rotational speed 850 rpm. ➢ Tool traverse speed 50 and 100 mm/min. ➢ Tilt angle 3 ^{0}	➢ ADC12 Al alloy and pure Ti can be successfully lap welded using friction stir welding technology. ➢ The maximum failure load of lap joints can reach 62% that of ADC12 Al alloy base metal. The transient phase $TiAl_3$ forms at the joining interface by Al–Ti diffusion reaction. ➢ The formation of $TiAl_3$ is strongly dependent on welding speeds (heat inputs) during FSW and thus affects the mechanical properties of joints.
5	Liu.H.J.,et al [10]	Microstructural characteristics and mechanical properties of friction stir welded joints of Ti–6Al–4V titanium alloy	Ti6Al 4V plates Thickness - 2 mm	➢ Tool rotational speed 400 rpm. ➢ Tool traverse speed 25, 50 and 100 mm/min. ➢ Tilt angle 2.5. ➢ Plunge depth 0.2 mm	➢ Defect-free welds were successfully obtained with welding speeds ranging from 25 to 100 mm/min. ➢ A bimodal microstructure was developed in the stir zone during friction stir welding, while microstructure in the heat affected zone was almost not changed compared with the base material.
6	Bang.H., et al [11]	Joint properties of dissimilar Al6061-T6 aluminum alloy/Ti–6%Al–4%V titanium alloy by gas tungsten arc welding assisted hybrid friction stir welding	Al6061-T6 aluminum alloy and Ti6%Al4%V titanium alloy Thickness - 3.5 mm	➢ Tool shoulder and pin diameter 18 & 5 mm. ➢ Tool pin length 3.3 mm ➢ Tool rotational speed 850 rpm. ➢ Tool traverse speed 50, 100 mm/min. ➢ Tilt angle 3^0 ➢ Probe off sets of 2 mm	➢ The ultimate tensile strength was approximately 91% in HFSW welds by that of the Al alloy base metal, which was 24% higher than that of FSW welds without GTAW under same welding condition. ➢ It was found that elongation in FSW welds increased significantly compared with that of FSW welds, which resulted in improved joint strength. The ductile fracture was the main fracture mode in tensile test of HFSW welds.
7	Scialpi,A et al [12]	Influence of shoulder geometry on microstructure and mechanical properties of friction stir welded 6082 aluminium alloy	AA6082	➢ Shoulder geometries	➢ The investigation results showed that, for thin sheets, the best joint has been welded by a shoulder with fillet and cavity.
8	Padmanaban,G. et al [13]	An experimental investigation on friction stir welding of AZ31B magnesium alloy	AZ31B magnesium alloy	➢ Tool rotational speed, welding speed, and axial force	➢ Joints fabricated using a tool rotational speed of 1,600 rpm, a welding speed of 0.67 mm/s, and an axial force of 3 kN yielded superior tensile properties compared to other joints. Fatigue properties less than base metal.
9	Zhang, H.W., et al [14]	3D modeling of material flow in friction stir welding under different process parameters.	AA 6061 -T6	➢ Tool rotation speed, welding speed and axial force	➢ It seems that there is a quasi-linear relation between the change of the axial load on the shoulder and the variation of the equivalent plastic strain. The material flow can be accelerated with the increase of the translational and angular velocity.
10	Zhang, H., Lin,S.B., [15]	Defects formation procedure and mathematic model for defect free friction stir welding of magnesium alloy	AZ31 Magnesium alloy	➢ Welding speed and welding rate	➢ The pore firstly occurred near the welding line at relatively low welding speed, but move into advancing side and up part of the weld when continues to increase the welding speed. Faster the welding speed is, larger the pore is.

11	Raghu Babu,G.,et al [16]	An Experimental Study On The Effect Of Welding Parameters On Mechanical And Microstructural Properties Of Aa 6082-T6 Friction Stir Welded Butt Joints.	AA6082-T6	➢ Tool rotational speed, welding speed, and axial force	➢ The tensile strength of the joint is lower than that of the parent metal. And it is directly proportional to the travel / welding speed.
12	Heurtier,H., Jones, M.J., [17]	Mechanical and thermal modelling of Friction Stir Welding	AA2024-T351	➢Tool traverse speed 25, 50 and 100 mm/min. ➢Tilt angle 2.5.	➢ The semi-analytical model can be used to obtain the strains, strain rates, and estimations of the temperatures and micro-hardness in the various weld zones
13	Aval,H.J., et al [18]	Theoretical and experimental investigation into friction stir welding of AA 5086.	5086 aluminum alloy	➢Tool rotation speed, welding speed	➢ Work-hardened and annealed conditions, can significantly affect the final microstructures and mechanical properties of welded alloy.
14	Dressler.U., et al [19]	Friction stir welding of titanium alloy TiAl6V4 to aluminium alloy AA2024-T3	TiAl6V4 and Al-alloy 2024-T3 Thickness 2 mm	➢Tool concave shoulder diameter 18 mm. ➢Pin threaded and tapered diameter 6 mm ➢Tool pin length 5.7mm. ➢Tool rotational speed 800 rpm. ➢Tool traverse speed 100 mm/min ➢Tilt angle 2.5 ^{0}	➢ Titanium alloy TiAl6V4 and aluminium alloy 2024-T3 were successfully joined by friction stir welding. ➢ Hardness and tensile strength of the butt joint were investigated. ➢ The weld nugget exhibits a mixture of fine recrystallized grains of aluminium alloy and titanium particles. ➢ Hardness profile reveals a sharp decrease at titanium/aluminium interface and evidence of microstructural changes due to welding on the aluminium side. The ultimate tensile strength of the joint reached 73% of A2024-T3 base material strength.
15	Zhang.Yu , et al [20]	Microstructural characteristics and mechanical properties of Ti–6Al–4V friction stir welds	Ti–6Al–4V plate thickness-3 mm.	➢Tool convex shoulder diameter 15 mm. ➢Pin threaded and tapered diameter 5.1 mm. ➢Tool tapered pin length 3 mm. ➢Tool rotational speed 300 and 600 rpm. ➢Tool traverse speed 2mm and 1 mm/s	➢ The microstructural evolution of these regions during FSW can be reasonably explained by taking into account solid-state transformation and the annealing effect of the microstructure. ➢ Mechanical properties were heterogeneously distributed in the weld, which were directly related with the heterogeneous distribution of microstructure. ➢ The SZ exhibited much higher mechanical properties than the base material, while the HAZ was the weakest in the weld, and its properties were representative of the transverse tensile properties of the weld.
16	Aonuma.M., et al [21]	Effect of alloying elements on interface micro structure of Mg–Al–Zn magnesium alloys and titanium joint by friction stir welding	Mg–Al–Zn alloy plates of AZ31B, AZ61A and AZ91D, and a Ti plate Thickness-2.0 mm	➢Tool shoulder diameter 15 mm. ➢Tool screw-type Pin diameter 5.0 mm. ➢Tool screw-type pin length 1.9 mm. ➢Tool rotational speed 850 rpm ➢Tool traverse speed 50 mm/min ➢Tilt angle 3 ^{0}	➢ An Al-rich layer was formed at the joint interface. Increasing the aluminum content of the Mg–Al–Zn alloy, Ti–Al intermetallic compound layer was observed clearly on the joint interface. ➢ The joint fractured in the intermetallic compound layer in the tensile test. The intermetallic compound plays an important role in making a Ti/Mg joint, but the increased thickness of this

					compound tends to reduce the tensile strength.
17	Ragu Nathan.S.., et al [22]	Failure analysis of tungsten based tool materials used in friction stir welding of high strength low alloy steels	High strength low alloy (HSLA) steel Thickness- 5 mm thick	➢Tool rotational speed 600 rpm. ➢Tool traverse speed 30 mm/min	➢ Three tungsten base tool materials used in this investigation, W99 (W–1%La2O3) tool exhibited better microstructural stability without undergoing physical (dimensional) changes in tool configuration. ➢ It was found that the tool made of 99% W and 1% La_2O_3 withstood high strain rate, temperature and flow stresses generated during FSW of HSLA steel.
18	Husain Mehdi et al [23]	Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy – a review	7050-T651, Al-4Mg-1Zr, Al- Alloy F357	➢350 rpm and 15 mm/min ➢2236 rpm to 1500 rpm	➢ Welding parameter such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints. Microstructure evaluation of FSW joints clearly shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with different amount of heat input by controlling the welding parameter
19	Husain Mehdi et al [24]	Influences of Process Parameter and Microstructural Studies in Friction Stir Welding of Different Alloys: A Review	7475 Al 7050-T65 cast A356 aluminum Al-4Mg-1Zr	➢2236 rpm and travel speed of 2.33 mm/s ➢700 rpm and a traverse speed of 203 mm/min ➢Tool rotation rate of 300,700, 900 and 1100 rpm.	➢ The mechanical properties of welded joint by friction stir welding are largely dependent on the combined effect of both the composition of alloying element and processing parameter.
20	Mironov.S. , et al [25]	Development of grain structure during friction stir welding of pure titanium	Purity a-titanium (ASTM Grade, Thickness- 3 mm thick Butt-welded Joint	➢Tool convex shoulder diameter 15 mm. ➢Pin threaded and tapered diameter 5.1 mm. ➢Tool tapered pin length 3 mm. ➢Tool rotational speed 200 rpm	➢ The global straining state during the process was deduced to be close to the simple shear with the shear surface being nearly along the truncated cone having a diameter close to that of the tool shoulder in the top part of the SZ. ➢ The grain structure evolution was shown to be a complex process driven mainly by the texture-induced grain convergence, but also involving the geometrical effects of strain and limited discontinuous recrystallization.
21	Husain Mehdi et al [26]	Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy- A Review	AA5083 and AA7022 Aluminium, CY16, WC Tool,	➢2100 rpm and travel speed of 2.33 mm/s ➢650 rpm and a traverse speed of 203 mm/min ➢Tool rotation rate of 300,700, 900 and 1100 rpm.	➢ Grain structures had equiaxed and fine grains due to the recrystallization in the SZ while Nano-sized alumina particles distributed differently because of different stirring action. An average grain size as low as 1.46 μm was obtained for a particular process parameters setting.
22	Krishna.G. G., et al [27]	Effect of Tool Tilt Angle on Aluminum 2014 Friction Stir Welds	aluminium AA2014-T4 alloy of 5mm thick	➢Tool shoulder diameter 15mm, Pin dia 4.5mm, Spindle speed 800 rpm, Traverse speed 100 mm/min, Tilt angle 0.5^0 , 1^0 , 1.5^0 , 2^0 , 2.5^0 and 3^0	➢ High tool tilt angle of around 3^0 is recommended for welding AA 2014 aluminium alloy for the given value of feed 100 mm/min and speed 1000 rpm to get defect free welds. Defects are formed on the surface and inside the weld due to lack of filling at lower tilt angles.
23	Arora.A.,et al [28]	Toward optimum friction stir welding tool shoulder diameter	AA6061 alloy	➢Shoulder diameter 15, 18, 21 mm, Pin diameter 6 mm., Pin length 5.5 mm., Pin	➢ The optimum tool shoulder diameter computed from this principle using a numerical heat transfer and material flow model resulted in best weld metal

29				profile Cylindrical, no thread, Tool Rotational velocity 900-1500 rpm	strength in independent tests and peak temperatures that are well within the commonly encountered range.
24	Baillie.P. [29]	Friction Stir Welding of 6mm thick carbon steel underwater and in air	S275 hot rolled structural steel	➢ Travel speed 100 (mm/min), Speed of rotation 200 revs/min). ➢ FSW Travel speed 100 (mm/min) Speed of rotation 240 (revs/min)	➢ Between the processes the longitudinal tensile results are the same, the micro hardness does not vary. It was also shown that underwater FSW has benefits compared to SAW and FSW in air. Charpy impact toughness was however shown to decrease for the underwater weld. Within the available data it is difficult to fully explain the toughness difference as the relative grain sizes do not vary significantly.
25	Panneerselvam.K., et al [30]	Study on friction stir welding of nylon 6 plates	Nylon 6 Thickness - 10mm	➢ Tool shoulder dia 24 mm, Pin dia 6 mm, Tool pin length 9.5 mm, Tool rotating speed (rpm) 750 to 4000, Welding Feeds 10- 100 mm/min.	➢ By using secondary heat sources with 0.5 or 0.6mm gap provision in between shoulder and top of the workpiece is the optimal gap to weld the nylon 6 material without any visible defects. When fixed welding speed in between 600 and 1200 rpm and feed rate also in between 10 and 40mm/min, got good weld region compared with the other.
26	De.A., et al [31]	Friction stir welding of mild steel: tool durability and steel microstructure	C–Mn 1018 steel	➢ Tool rotational speed 300, 450, 600, 750, 900 rev/min, ➢ Welding speed 0.42, 1.05, 2.10 mm/s, Tool shoulder diameter (mm) 15, 18, 21, 24 Pin diameter 7.9, 9.0 mm. ➢ Tool pin length 9.5 mm	➢ For the FSW of mild steel, an increase in either the tool shoulder diameter or the tool rotational speed increases workpiece temperature and hence, enhances tool durability. A faster welding speed reduces peak temperature, increases stresses on the tool and thus, reduces tool durability. In contrast, thicker tool pins increase tool durability because of enhanced structural stiffness.
27	Sato.Y.S., et al [32]	Evaluation of microstructure and properties in friction stir welded superaustenitic stainless steel	NSSC 270 superausteniti c stainless steel Thickness - 6 mm	➢ Rotational speed 400 and 800 rev per min, ➢ Traverse speed 1 and 0.5 mm /s	➢ Findings of the present study suggest that low heat input friction stir welding is an effective method to produce a weld with relatively good properties in superaustenitic stainless steels. ➢ The high rotational speed drastically reduced mechanical and corrosion properties of the weld due to the high density of intermetallic phases, while the reduction of the properties was not significant at low rotational speed.
28	Ramesh.R. , et al [33]	Microstructure and mechanical characterization of friction stir welded high strength low alloy steels	High strength lowalloy HSLA plates Thickness - 3 mm	➢ Tool shoulder diameter 18 mm. Tool pin length 2.7 mm. Pin profile was tapered cylindrical with a dia 8 mm) Traverse speed 57, 67, 77, 87 mm/min	➢ The joint strength was 540 MPa at 57 mm/min and 407 MPa at 97 mm/min. The higher strength below 78 mm/min traverse speed was due to hard weld nugget. The lower joint strength with further increase in traverse speed was due to poor consolidation and macroscopic defects. The tendency to form macroscopic defects increased with increase in traverse speed. Root flaw and groove defect were observed at a traverse speed of 97 mm/min.
29	Gan.W., et al [34]	Tool materials selection for friction stir welding of L80 steel	High strength pipe steel L80	➢ Tool Travel speed 1.7 mm/s. Tool Rotational speed 170 rev/min, Pin length 1.5 mm	➢ The results indicate that the physical wear amounts to a material loss of 7% of the original volume. Mushrooming of the tool was successfully predicted. The calculations also indicated that the pin tool material should have a yield

					strength larger than 400 MPa at 1000uC to avoid mushrooming.
30	Bahrami.M ., et al [35]	On the role of pin geometry in microstructure and mechanical properties of AA7075/SiC nano-composite fabricated by friction stir welding technique	7075-O Aluminum Alloy Thickness - 6 mm	➢ Tool rotational speed 1250 rpm, Tool traverse speed 40 mm/min, Pin profile Threaded tapered (TT) diameter 6 & 4 mm, Triangular (T) dia 6 mm, Square 6 mm.	➢ The most uniform particle distribution was found in the case of using threaded tapered pin tool. Reinforcements had severely accumulated in the SZ of specimen friction stir welded (FSWed) with four-flute cylindrical pin tool. Moreover, threaded tapered and four-flute cylindrical specimens showed the highest and the lowest micro hardness, respectively. Highest ultimate tensile strength (UTS) was recorded for the specimen FSWed with triangular pin tool.
31	Bahrami.M ., et al [36]	A novel approach to develop aluminum matrix nano-composite employing friction stir welding technique	7075-O Aluminum plate Thickness - 6 mm	➢ Tool shoulder diameter 16 mm, Threaded taper pin profile height 5.7 mm, Tool Rotational speed 800, 1000,and 1250 rpm, Traverse speed 30.5, 40, and 50 mm/min.	➢ 7075 Aluminum matrix Nano-composite reinforced with SiC particles was developed in the stir zone. At high rotational speed (1250 rpm) powder dispersion improved due to effective stirring action of the pin. UTS of specimen FSWed with powder at 1250 rpm and 40 mm/min was 31% superior to that of the specimen FSWed without powder. The addition of SiC particles led to 76.1% enhancement of elongation.

III. CONCLUSIONS

The following conclusions are made from the above literature review.

1. Increasing the tool rotational speed results greater heat input and increases grain size of the metal alloy and simultaneously more shattering effect of rotation, results a better distribution of Nano particles.
2. The Welding parameter such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints.
3. Microstructure of Friction stir welding joints shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with different amount of heat input by controlling the welding parameter.
4. Friction stir welding have a potential benefits in cost reduction, joint efficiency improvement and high production accuracy make it more attractive for non-weldable.
5. The wear of FSW tools is a main issue when joining different material with the help of friction stir welding, the life of welding tool could be more, when we use correct processing parameter for different material and working conditions.

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