A Literature Review paper on friction stirs welding (F.S.W) of aluminum alloy

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Abstract: In many industrial applications steel is readily replaced by non ferrous alloys, in most cases aluminium alloys. Some of these materials merge good mechanical strength which is analogous with structural steel and low weight that allows a significant reduction in weight. But the joining of aluminium alloys by unadventurous welding processes can occasionally cause severe problems. The difficulties are often credited to the solidification process and structure including loss of alloying elements and presence of segregation and porosities in the weld joint. Friction stir welding (FSW) offers an alternative through solid-state bonding, which eliminates all these problems of solidification associated with the conventional fusion welding processes. In this research work an attempt has been made to develop an empirical relationship between FSW variables and the mechanical properties (tensile strength, yield strength, percentage elongation, micro hardness and impact toughness) of friction stir welded aluminium alloy joints. Response surface methodology was adopted for analyzing the problem in which several independent variables influence the response. Central composite rotatable design matrix was used to prescribe the required number of experimental conditions. A four-factors-five-level central composite design was used to determine the optimal factors of friction stir welding process for aluminium alloy. The central composite design (CCD) with a quadratic model was employed

The welding of aluminium and its alloys has always represented a great challenge for researchers and technologists. Friction stir welding (FSW) is a new welding process that has produced low cost and high quality joints of aluminium alloys.In order to formulate the present research problem along with the methodology that could be adopted for accomplishing this research work, the selective review of the relevant literature surveyed is presented briefly.

Key Wards:-FSW of aluminium alloys, Post weld heat treatment, FSW with conventional welding processes ,Design and formulation.

1. FSW of aluminum alloys:-

Thomas (1997) focuses on this study the relatively new joining technology, friction stir welding (FSW). Friction stir welding can be used to join most aluminium alloys and surface oxide presents no difficulty to the process. On the basis of this study it was recommend that number of light weight materials suitable for the automotive, rail, marine and aerospace transportation industries can be fabricated by FSW. **Ying et al., (1999)** used FSW to join the plates of 2024 Al and 6060 Al having thickness of 0.6 cm each. The tool rotation speed was varied between 400 to 1200 rpm. Dislocation spirals and loops are observed in the 2024 Al intercalation regions within the weld zones at higher speeds (>800 rpm). Micro hardness profiles follow microstructural variations which result in a 40% reduction in the 6061 Al workpiece micro hardness and a 50% reduction in the 2024 Al workpiece micro hardness just outside the FSW zone. **Sutton et al., (2002)** prepared the weld joints of 7 mm thickness using 2024-T351 aluminium rolled sheet material by Friction stir welding. Metallurgical, hardness and quantitative energy dispersive X-ray measurements were performed. The tests demonstrated a segregated, banded, microstructure consisting of alternating hard particles. Since the band spacing is directly correlated with the welding tool advance per revolution, the results indicated that the opportunity exists to manipulate the friction stir weld process parameters in order to modify the weld microstructure and improve a range of material properties, including fracture resistance. **Lee et al., (2003)** welded A356 alloys sheets using friction-stir-welding to observe the effect of mechanical properties at the weld zone by varying the welding speeds. The microstructures of the weld zone are composed of SZ (stir zone), TMAZ (thermo-mechanical affected zone) and BM (base metal). The microstructure of the SZ is very different from that of the BM. But the microstructure of TMAZ, where the original grains were greatly deformed, is characterized by dispersed eutectic Si particles aligned along the rotational direction of the welding tool. The mechanical properties of the weld zone are greatly improved in comparison to that of the BM.

Peel et al., (2003) used AA 5083 aluminium alloy for friction stir welding by varying the welding conditions like tool design, rotation speed and translation speed. The effect of different welding speeds on the weld properties remains an area of uncertainty. The results of microstructural, mechanical property and residual stress investigations of four aluminium AA5083 friction stir welds produced under varying conditions were reported. It was found that the weld properties were dominated by the thermal input rather than the mechanical deformation by the tool. **Mustafa and Adem (2004)** prepared the weld joints of Al 1080 alloy using five different stirrers, one of them square cross-sectioned and the rest were cylindrical with 0.85, 1.10, 1.40 and 2.1 mm screw pitch. The stirrers pitched 1.40 and 2.0 mm acted like a drill rather than a stirrer and compelled the weld metal outward in the form of chips. Bonding could be affected with square cross section stirrer but poor mechanical and metallographic properties were observed. The specimen welded with cross-section stirrer has 60 N/mm2 Tensile Strength and the fracture took place within the weld metal. This type of stir sweeps a large amount of metal from the plasticized zone and results in an inhomogeneous structure. But the specimen welded using 0.85 and 1.10 mm pitched stirrers, have 110 N/mm2 UTS. The higher strength of the weld metal can be attributed to heat generation during stirring.

Cavalierea and Squillace (2005) used 7 mm thick sheet of 7075 aluminium alloy to analyze the mechanical and microstructural properties by Friction Stir Processing (FSP). The sheets were processed perpendicularly to the rolling direction and the mechanical properties were evaluated at room temperature in the transverse and longitudinal directions. **Cavalierea (2006)** welded the 2014 aluminium alloy using friction stir processing (FSP). The sheets were processed parallel to the extrusion direction; and the tensile properties were evaluated at room temperature in the longitudinal direction. The fatigue endurance (S–N) curve of the FSP material was obtained by using a resonant electro-mechanical testing machine under constant loading control up to 250 Hz with sine wave loading. The microstructure resulting from the FSW process was studied. **Elangovan and Balasubramanian (2007)** used five different tool pin profiles (straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square) to FSP at three different tool rotational speeds. The formation of FSP zone has been analyzed and tensile properties of the joints have been evaluated and correlated with the FSP zone formation. From this investigation it is found that the square tool pin profile produces mechanically sound and metallurgically defect free welds compared to other tool pin profiles.

2. <u>Post weld heat treatment</u>:-

Krishnan (2002) carried out Post weld heat treatment (PWHT) of Friction Stir Welds (FSW) at solutioninsing temperatures of 520, 540, and 560ºC followed by ageing at 175ºC or 200ºC. It was found that the weld (stir) region exhibited very coarse grains after the PWHT. The hardness was found to be uniform across the weldment after the PWHT. **Elangovana and Balasubramanian (2008)** reported that the influences of various post-weld heat treatment procedures on tensile properties of friction stir-welded AA6061 aluminium alloy joints. Solution treatment, an artificial aging treatment and a combination of both were given to the welded joints. Mechanical properties such as yield strength, tensile strength, elongation and joint efficiency were evaluated. A simple artificial aging treatment was found to be more beneficial than other post weld treatment methods. **Malarvizhia and Balasubramanian (2011)** welded AA2219 aluminium alloy square butt joints without filler metal addition using gas tungsten arc welding (GTAW), electron beam welding (EBW), and friction stir welding (FSW) processes. The fabricated joints were post-weld aged at 175 ºC for 12 h. The effect of three welding processes and post weld aging (PWA) treatment on the fatigue properties is reported. Transverse tensile properties of the welded joints were evaluated. It was found that the post-weld aged FSW joints showed superior fatigue performance compared to EBW and GTAW joints. This was mainly due to the formation of very fine, dynamically recrystallized grains and uniform distribution of fine precipitates in the weld region.

Singh et al., (2011) reported the effect of post weld heat treatment (T6) on the microstructure and mechanical properties of friction stir welded 7039 aluminium alloy joints. FSW parameters were optimized by making welds at constant rotary speed of 635 rpm and welding speed of 8 and 12 mm/min. It was observed that the thermo-mechanically affected zone (TMAZ) showed coarser grains than that of nugget zone. As welded joint has highest joint efficiency (92.1%). Post weld heat treatment lowers yield strength, ultimate tensile strength but improves percentage elongation.

3. Comparisons of friction stir welding with conventional welding processes:-

Squillace et al., (2004) compared two different welding processes one is conventional tungsten inert gas (TIG) process and second is friction stir welding (FSW). A micro-hardness measurement allows pointing out a general decay of mechanical properties of TIG joints, mainly due to high temperatures experienced by material. In FSW joint, instead, lower temperatures involved in process and severe plastic deformations induced by tool motion allow rising of a complex situation: by a general point of view a slight decay of mechanical properties is recorded in nugget zone, flow arm and thermo-mechanically altered zone (TMAZ), while in heat-affected zone (HAZ), due to starting heat treatment of alloy under investigation, a light improvement of such properties is appreciated. In flow arm and in nugget zone, however, a light recovery of hardness, w.r.t. TMAZ zone, is recorded, due to the re-crystallisation of a very fine grain structure.

Maggiolino and schmid (2008) made a comparison between the corrosion resistance of AA6060-T5 and AA6082-T6 jointed surfaces via Friction Stir Welding (FSW) and Metal Inert Gas (MIG). The test was conducted putting the welded and polished samples in an acid salt solution. The corrosion resistance was detected via morphological analysis of the surface. The attack was localized (pitting), an index referred to the pit density was used for the comparison. The result indicated that the joint welded via Friction Stir is more resistant than that welded via Metal Inert Gas technique. **Wang et al., (2008)** reported the effect of welding processes (FSW and TIG) on the fatigue properties of 5052 aluminium-welded joints was analyzed based on fatigue testing. The results show that the fatigue properties of FSW welded joints are better than those of TIG welded joints.

4. Design of experiments:-

Hasan et al., (2007) developed an artificial neural network (ANN) model for the analysis and simulation of the correlation between the friction stir welding (FSW) parameters of aluminium (Al) plates and mechanical properties. The input parameters of the model consist of weld speed and tool rotation speed (TRS). The outputs of the ANN model include property parameters namely: tensile strength, yield strength, elongation, hardness of weld metal and hardness of heat effected zone (HAZ). Good performance of the ANN model was achieved. The model can be used to calculate mechanical properties of welded Al plates as functions of weld speed and TRS. The combined influence of weld speed and TRS on the mechanical properties of welded Al plates was simulated. A comparison was made between measured and calculated data. The calculated results were in good agreement with measured data. **Lakshminarayanan and Balasubramanian (2008)** applied Taguchi approach to determine the most influential control factors which will yield better tensile strength of the joints of friction stir welded RDE-40 aluminium alloy. Through the Taguchi parametric design approach, the optimum levels of process parameters (tool rotational speed, traverse speed and axial force) were determined. The results indicate that the rotational speed, welding speed and axial force are the significant parameters in deciding the tensile strength of the joint. **Sarsilmaz and Çaydaş (2008)** applied the full factorial experimental design to study the effect of friction-stir welding (FSW) parameters such as spindle rotational speed, traverse speed, and stirrer geometry on mechanical properties of AA 1050/AA 5083 alloy. Ultimate tensile strength (UTS) and hardness of welded joints were determined for this purpose. Analysis of variance (ANOVA) and main effect plot were used to determine the significant parameters and set the optimal level for each parameter. A linear regression equation was derived to predict each output characteristic.

Sharma et al., (2009) offers statistical modeling of deposition rate in twin-wire submerged arc welding. 'Best subset selection method' and 'Mallows criterion' have been used for model development. The developed models of deposition rate in twin-wire submerged arc welding can be used for practical purposes with admissible error in prediction and better predictability compared with conventional models.

5. Problem formulation and Objectives of research:-

Gurmeet Singh et al, (2012) After a comprehensive study of the existing literature, a number of gaps have been observed in friction stir welding of aluminium alloy. Most of the researchers have investigated influence of a limited number of process parameters on the friction stir welding of aluminium alloy. Literature review reveals that the researchers have carried out most of the work on varying one parameter at a time and no consideration has been given to interaction effect of two or more parameters. No literature is available to study the effect of post weld heat treatment on the properties of FS welded aluminium alloy joints. The comparison of friction stir welded joint and TIG welded joints of aluminium alloys joints. Thus, keeping in view of the above research gaps, it was planned to investigate the effect of FSW process parameters on mechanical and metallurgical properties of friction stir weldment of aluminium alloys using design of experiment technique. The main objectives of the present research work are explained as follows:Development of parametric window for friction stir welding of aluminium alloy. To study the affect of process parameters on the mechanical and metallurgical properties of friction stir welded aluminium alloy joints using design of experimental technique.

6. Conclusion:-

Thus, keeping in view of the above research gaps, it was planned to investigate the effect of FSW process parameters on mechanical and metallurgical properties of friction stir weldment of aluminium alloys using design of experiment technique. The main objectives of the present research work are explained as follows:Development of parametric window for friction stir welding of aluminium alloy. To study the affect of process parameters on the mechanical and metallurgical properties of friction stir welded aluminium alloy joints using design of experimental technique.

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Papers published/accepted related to present research work are given as follow:

(a) International Journals

1. Gurmeet Singh, Kulwant Singh, Jagtar Singh, "Modelling of the effect of process parameters on tensile strength in friction stir welding of aluminum alloy joints", In press, ***Journal of Experimental Techniques***, doi:10.1111/j.1747-1567.2012.00808.x, Wiley publication.

2. Gurmeet Singh, Kulwant Singh, Jagtar Singh, "Effect of process parameters on microstructure and mechanical properties in friction stir welding of aluminum alloy", ***Journal of Transaction of Indian Institute of Metals***, 64 (4-5) (2011), pp 325-330, Springer publications.