A Review On Friction Stir Processing of Aluminium Alloy Surface Composite

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Abstract: This paper mainly focuses on the improvement of hardness of aluminium 6061 alloy by using the most common technique ‘Friction Stir Processing (FSP)’. Friction Stir Processing (FSP), a strong state materials handling procedure is essentially used to switch the microstructure and properties of surface which chips away at the standards of Friction Stir Welding (FSW). FSP is one in all the foremost promising techniques that produces surface composites. FSP enhances the mechanical properties like lastingness, hardness, ductility and fatigue and also tribological properties like wear resistance. It also eliminates the defects that are produced within the matrix alloy during casting process and reduces distortion. The vast majority of the Severe Plastic Deformation (SPD) methods changes the greater part properties of the texture yet FSP doesn't change the lion's share properties, rather, grain size refinement might be accomplished in light of information heat that rises up out of erosion. This paper investigates the hardness of aluminium 6061 alloy after the reinforcement of properties after the application of Friction Stir Processing (FSP).

Keywords: Hardness, Ballistic Performance, Aluminium Alloy, Friction Stir Processing.

1. Introduction

Friction stir processing originally depends on the principle of Friction Stir Welding invented in 1991 by Wayne Thomas at the Welding Institute (TWI) of United Kingdom that is used for microstructural modification. FSP is merely same when compared with friction stir welding process, the difference is that in FSW process, two plates are fabricated for joining purpose whereas FSP is employed to change the surface properties of the fabric. In FSP, a solid tool with a shoulder and a pin is used and is rotated at high speed, the pin of the tool plunges within the material and because of friction between the surface of work piece and power shoulder, heat is generated which ends in plastic deformation zone of the material due to recrystallization. When certain reinforcements like Al2O3 or Si carbide powders are used in this process, the properties of work piece are found to be increased when compared with without using composites as reinforcements.

2. Literature review

R. Arun Kumar et al. (2019) investigates the friction stir processing technique which involves in the modification of microstructure of the material. It also explains about the process. The tool and the work piece come into contact, at that time friction is developed between the surfaces which in turn causes the plastic deformation of the material and because of its thermal properties, tensile strength the microstructure gets reinforced.

R. Abrahams, et al. (2019) discuss the improvement study of FSP process parameters and tool design, especially the tool rotational and transverse speeds. It also focuses to show the correlation between the mechanical properties and the resulting microstructure using different FSP parameters. It is awaited that FSP will improve the mechanical properties of aluminium alloy which can lead to many industrial applications.

S. Bharti et al. (2019) talks about the process of FSP done in aluminium 6000 series alloys. In this experiment, microstructural examination is done for aluminium 6000 series alloys. Vickers Micro Hardness test is done for the polished work piece and the tensile test is carried out for the same. It is also confirmed that if the number of passes is increased, the hardness of the material is also increased. FSP has the ability to increase the hardness of the material.

S. Chainarong et al. (2014) said that the surface of the skin is smooth and mixed uniformly after the FSP process. It is also found that the stirred area has uniform pattern and there are no cracks found in the particular zone. The heat generated from Friction Stir Processing is mainly due to rotation speed and travel speed which results in the reduction of internal resistance and surface roughness.

I. Sudhakar et al. (2015) mainly discuss the ballistic resistance for the aluminium alloys. The industrial applications of aluminium and its alloys is limited because of its poor tribological properties. But the surface matrix composites of aluminium shows better ballistic resistance. There are some improvements in wear resistance found in the friction processed areas. The wear resistance is improved with the help of boron carbide powder in friction stir processing.

H.G. Rana et al. (2016) mainly investigates about a green and energy efficient technique called Friction Stir Processing (FSP). In this work, the aluminium 7075 alloy is mainly used and boron carbide powder is used for improvement. It found that there are some defects in the processed area but the hardness is increased 40-70% higher than that of the initial one. The wear...
resistance also increased up to 100%.

M. M. El-Rayes, et al. (2012) mainly investigates the multi-pass friction stir processing technique and inspect the microstructure of aluminium 6082 alloy. In this work, three passes are done for the inspection. One unchanged rotational speed and three changeable traverse speeds. The microstructure, mechanical properties such as hardness and tensile strength which are to be addressed with respect to the number of passes and traverse speeds. The hardness and tensile test done in the processed zone were good when the number of passes increased which causes softening and reduce the ultimate tensile strength. At the same time, increasing the traverse speed increases the strength and hardness.

P. Nelaturu et al. (2018) investigates about the initiation of fatigue crack and growth mechanisms in cast and friction stir processed A356 aluminium alloy. FSP is an emerging technology which is used over a decade. From the work, it is observed that crack initiation mainly occur at macrostructural defect sites and it is the main reason for the low fatigue life. FSP has given great improvement in fatigue life in order of magnitude.

V. V. Patel et al. (2017) discuss the experimental investigation on hybrid friction stir processing using compressed air in aluminium 7075 alloy. It is found that in hybrid FSP with compressed air cooling has produced fine equiaxed grain microstructure. The hybrid sample generated less heat input which resulted in the inhibition of grain growth during the process. The micro hardness gets improved by hybrid FSP process.

V. Sharma et al. (2015) gives a review of surface composites by friction stir processing. He also proposes that FSP is a promising technique for making surface composites. It can improve the wear resistance, hardness, strength, ductility, corrosion resistance, fatigue life and formability. It is mainly used for making the composites of aluminium and magnesium alloys. The paper explains about the FSP technique and the fabrication of surface composites by FSP. It also discusses the merits and demerits of using FSP. One of the most disadvantages is the tool wear which restricts the use of FSP to prepare hard surface composites.

J. Qu et al. (2011) mainly presents about the improvement of tribological characteristics of aluminium 6061 alloy with the help of friction stir processing. It is found that tribological and mechanical properties are enhanced after the Friction Stir Processing (FSP).

K. Surekha et al. (2011) compares the behavior of friction stir processed and laser melted AA 2219 aluminium alloy. Potentiodynamic and polarization and chemical impedance spectroscopy tests were done to compare the corrosion behavior. The corrosion resistance is well achieved by FSP rather than laser melted. The hardness values of Friction Stir Processed material are higher than the laser melted material which shows that the material done with FSP has better mechanical properties than the material done with LM technique.

M. Sharifitabar et al. (2011) investigates the microstructure and mechanical properties of alloy 5052 Al/Al₂O₃ surface composite. Two series of samples are tested with and without powder were done FSP by one to four passes. Tensile test is done to calculate the mechanical properties of the material. It is proved that grain size in the stirred zone gets decreased with the increase in the number of FSP passes. Then, the increase in the FSP passes causes the uniform distribution of Al₂O₃ alloy. The tensile strength and elongation is improved to 118% and 165% in composite by four FSP passes.

N. Netto et al. (2019) proposes a failure analysis study on the tool degradation during Friction Stir Processing (FSP) of 6061-T6 aluminium alloy. It explains about the process of FSP that the tool consists of a pin and a shoulder which is plunged into the material until the shoulder comes in contact with the top layer of the workpiece. The pin of the tool forces the work material to undergo plastic deformation resulted in a homogeneous and recrystallized structure. The tool degradation found in three phases.

Aruri Devaraju et al. (2017) prepared the nano composite surface layer by reinforcing TiB₂ on 6061-T6 aluminium alloy with Friction Stir Processing. The composites are examined by optical microscope and scanning electron microscope for the dispersion of reinforcement particles. It is found that increase in the volume percentage of TiB₂ particle, the micro hardness was increased up to 132 HV and the specified value is higher than the received aluminium alloy’s micro hardness. It also proved that the tensile properties of Al surface nano composites were decreased as compared with the initial one.

A. Devaraju et al. (2013) fabricated the aluminium 6061-T6 alloy incorporated with mixture of (SiC+Gr) and (SiC+Al₂O₃) particles. A technique called Friction Stir Processing is employed to improve the tribological properties and to refine the microstructure and to improve the mechanical properties on aluminium 6061-T6 alloy. As a result, reinforcement particles of (SiC+Gr) and (SiC+Al₂O₃) were uniformly distributed along the nugget zone without any imperfections. Both of the composites’ hardness values are increased when compared with the initial one.

S. Rathee et al. (2016) adopted Taguchi’s experimental design for the optimization of process parameters for enhanced micro hardness of AA 6061/SiC surface composite. Three process parameters such as rotational speed, tool traverse speed and tool tilt angle with three levels to maximize the micro hardness. The paper explains about the importance of FSP and its process parameters. The paper resulted in the improvement of micro hardness values due to combined effect of hard nature of reinforcement of particles, grain refinement and uniform dispersion of reinforcement particles and pinning of grain boundaries.

Abhishek SHARMA et al. (2019) done a comparative study on the surface properties of AL-SiC-multi-walled carbon nanotubes (CNT) and AL-SiC-graphene nano platelets (GNP)
hybrid composites. Carbon nanotubes (CNT), graphite and graphene are extra-ordinary reinforcements because of their high thermal conductivity, low coefficient of expansion and self-lubricating properties. Finally, the comparative study concluded that Al-SiC-GNP hybrid composite to be the best one among the carbonaceous compound family for increasing the surface hardness and wear resistance of aluminium alloys.

R. Keshavamurthy et al. (2018) reports mainly on the mechanical behavior of friction stir processed aluminium 6061-Boron Nitride surface composite. In this paper, the effect of number of passes and the reinforcement in the microstructure of the alloy. The hardness and tensile characteristics are also examined. The microstructure resulted in the homogeneous distribution of boron nitride particles after friction stir processing. SEM analysis confirmed the good relationship existing between aluminium alloy and boron nitride particles. Boron Nitride reinforcement particles show improvement in ultimate tensile strength, yield strength and hardness values when compared with the unreinforced aluminium alloy. It also found that increasing the number of passes increases the hardness, ultimate tensile and yield strength of both alloy and the boron nitride surface composite.

M. AMRA et al. (2018) analyzes the microstructure and wear performance of AL5083/CeO₂/SiC mono and hybrid surface composites done by friction stir processing (FSP). The observations of microstructure in friction stir processed regions and worn out surfaces were done by optical and scanning electron microscope. Among the samples, the hybrid composite (AL5083/CeO₂/SiC) revealed highest wear resistance and lowest friction coefficient. All composite samples showed higher hardness value and wear resistance when compared with the unreinforced alloy.

M. Balakrishnan et al. (2019) analyzes the effect of friction stir processing on microstructure and tensile properties and its behavior of aluminium 6061alloy / Al₃Fe cast aluminium composites. In this paper, he proposed that FSP is an emerging technology for the improvement of microstructure and properties of aluminium matrix composites. He also stated that Al₃Fe aluminium matrix composites are formed by adding pure iron powder to molten aluminium and subjected to the process FSP. Then the study of microstructural changes is done before and after FSP with the help of OM, SEM, EBSD and TEM. FSP process resulted in the total homogenous rearrangement of particles due to the stirring action of the FSP tool. It also eliminated the typical casting defects (pores) due to proper plasticization. It also improved the tensile strength and ductility of the material after Friction Stir Processing (FSP).

Sunil kumar Tiwari et al. (2018) mainly investigates the fabrication of aluminium composites reinforced by carbon nanotubes. There are many issues such as improper distribution of AL-CNT composites, agglomeration of CNTs in Aluminium composites and distortion in the structure on CNTs. In this paper, the author tried to discuss the remedial approaches for AL-CNT composites. To overcome these issues, he proposed some remedial measures. The usage of properly designed stirrer and the parameters. Coating of CNTs with copper to increase their densities. The usage of methanol and ethanol to prevent cold welding of aluminium particles.

A. Tajiri et al. (2015) studied the effect of friction stir processing conditions on the behavior of fatigue and texture development in A356-T6 cast aluminium alloy. FSP allows the alloy to modify its microstructure to eliminate casting defects under two different rotational speeds. To enhance the fatigue strength, plane bending fatigue tests are carried out with low rotational speeds which yield better results. The enhancement of fatigue strength eliminated the casting defects. The work resulted in the improvement of fatigue strength when compared with the cast specimen due to the elimination of casting defects. FSP done in lower speed yield better results rather than higher speed.

J. Tang et al. (2019) presented how the multi-pin tool in Friction Stir Processing influence the parameters on microstructure and mechanical properties of SiC/Al composites. In this work, multi-pin tool and single pin tool to fabricate the aluminium matrix composites reinforced by SiC particles. The multi-pin tool improved the refinement of particles and increased the homogeneous distribution of SiC particles when compared to the traditional single pin tool, mainly due to the increased effect of multi-pin tool on the stir and friction ability of the material. It also increased the micro hardness and decreased the coefficient of friction.

S. Zhang et al. (2019) discuss the effect of energy input during FSP on microstructure and mechanical properties of AL/CNT composites. In this work, Raman Spectroscopy, Scanning Electron Microscope and Transmission Electron Microscope are used to analyze the microstructure and mechanical properties of AL/CNT composites. The author also found that grains of aluminium matrix in the nano composites were coarsened slightly with increased energy input. The carbon nanotubes dispersion and their mechanical characteristics and behavior are different in various energy inputs. But, better carbon nanotubes dispersion and tensile properties were exhibited in higher energy input. With the high energy input, the tensile strength of the composite was to be increased 53.8% when compared with the reinforced aluminium composite and elongation was to be increased 31.2% which has extra-ordinary ductile property. Thus the author came to know that the energy input plays a notable role in the refinement of carbon nanotube dispersion and mechanical characteristics of Al/CNT nanocomposites.

K. J. Hodder et al. (2012) discuss the fabrication of aluminium-alumina metal matrix composites through cold gas dynamic spraying followed by Friction Stir Processing. Cold dynamic spraying is used for surface modification on various structures mainly in aircraft and automobile industries. This method restricts the unnecessary phase transformations and micro structural changes on substrate material. The results obtained reveals that coupling cold spraying with Friction Stir
Processing improves the hardness of Al-Al_{2}O_{3} composites and gives an appropriate method for the fabrication of dense MMC coatings with improved material properties when compared to the initial one.

M. Sivanesh Prabhu et al. (2019) reports the friction and wear measurements of friction stir processed aluminium alloy 6082/CaCO_{3} composite. It is found that there are some improvements in microstructure of FSPed AA6082/CaCO_{3} composite. He also proposed that friction coefficient and wear of the aluminium composites are mainly caused due to the applied load. The micro hardness of friction stir processed AA6082/CaCO_{3} composite has increased to 82 HV from 64 HV by grain refinement. These results are gained by Scanning Electron Microscope and the values are compared with the unreinforced one.

3. Material and its composition

Aluminium 6061 alloy is used in this work. It is a precipitation-hardened aluminium alloy, majorly contains magnesium and silicon. It was developed and started its usage in 1935. It was originally called as “Alloy 61S” and now-a-days it also referred as “Structural Aluminium”. It is used widely because of its better mechanical properties, weldability. It exhibits better fatigue strength, good formability. It is not acceptable for very complex sections. It is one of the most commonly used alloys of aluminium for general purpose. It is mainly used in heavy structures such as rail coaches, truck frames, yacht construction, flashlight, bridge construction, aerospace applications, tower construction, automotive parts, motor boats etc.

Table 1
Chemical composition of aluminium 6061 alloy

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>97.9%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.972%</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.607%</td>
</tr>
<tr>
<td>Copper</td>
<td>0.183%</td>
</tr>
<tr>
<td>Iron</td>
<td>0.120%</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.084%</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.077%</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.029%</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.004%</td>
</tr>
</tbody>
</table>

Table 2
Physical and mechanical properties of aluminium 6061 alloy

<table>
<thead>
<tr>
<th>Physical &amp; Mechanical Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (ρ)</td>
<td>2.70 g/cm³</td>
</tr>
<tr>
<td>Young’s Modulus (E)</td>
<td>68.9 GPa (9.990 ksi)</td>
</tr>
<tr>
<td>Tensile Strength (σ_t)</td>
<td>124-290 MPa (18.0-42.1 ksi)</td>
</tr>
<tr>
<td>Elongation (ε) at break</td>
<td>12-25%</td>
</tr>
<tr>
<td>Poisson’s Ratio (υ)</td>
<td>0.33</td>
</tr>
</tbody>
</table>

The chemical composition of aluminium 6061 alloy is tabulated in table 1.

The physical and mechanical properties of aluminium 6061 alloy is tabulated in table 2.

4. Method

A. Friction Stir Processing

Friction Stir Processing (FSP) is a solid-state emerging technique from the standards and principles of Friction Stir Welding (FSW) which is mainly used to change the properties of metal through plastic deformation. This is achieved by forcibly inserting a non-consumable tool in to the workpiece. In this process, a rotating tool with a pin and a shoulder is used to improve the toughness and flexibility. The friction between the tool and workpiece creates a localized heating which softens and plasticizes the workpiece. This method is used everywhere where the mechanical properties of the material are to be improved. This technique can improve the wear resistance, tensile strength, creep, fatigue etc.

B. Micro hardness (or Micro indentation) test

The term ‘micro hardness’ is often engaged in the literature to define the hardness testing of materials with low loads. A most accurate term for the test is “Micro indentation hardness testing”. In this type of testing, a diamond indenter is impressed on the surface of the material with a known applied force. The hardness number is calculated on the basis of the indent impressed on the surface of the material. Micro hardness testing is used where the minute work pieces are to be tested or the specimen size is very low. Through this method, the hardness of thin samples can also be measured. It can also use where the small regions in a composite sample to be measured. It can provide exact and specified information about the features of the surface material in terms of microstructure, non-homogeneous or inclusive to cracking.

C. Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) is a type of test process which scans a sample with the help of electron beam to produce an enlarged image of the material for analysis purpose. It is also called SEM microscopy. It is used very effectually in microanalysis and failure analysis. It is performed at high enlarged and high resolution images and exactly measures very minute features and defects. It is one of the most versatile technique and it can be used to image the morphology of the given test samples. It is used to examine wet and dry samples while viewing them. It can generate X-rays from samples for the purpose of microanalysis. It is very helpful to gather the information about heterogeneity.

D. Ballistic Test

Ballistic Test is a standard-based process where products are examined to check that they will meet the protection, safety and performance. It is the study of motion, dynamics, angular movement and the effects of projectile motion of the body. Most of this tests helps in commercial research and development areas and military applications. It is used to measure how hard the material is. The term used in ballistic
testing is DOP which means Depth of Penetration. By using this value, the hardness of the material can be calculated under the applied momentum.

E. Carbon Nano Tubes (CNTs)

Carbon nanotubes (CNTs) are round and hollow particles that comprise of moved up sheets of single-layer carbon atoms (graphene). Their length can arrive at a few micrometers or even millimeters. CNTs are used as antennae and it can also be used as an electromagnetic device. The properties of nanotubes have made analysts and organizations think about utilizing them in a few fields. For instance, since carbon nanotubes have the most noteworthy strength to-weight proportion of any known material, analysts at NASA are consolidating carbon nanotubes with different materials into composites that can be utilized to construct lightweight shuttle. CNTs have been in the eyes of researchers because of their extraordinary thermal, electrical, chemical characteristics and stability. It has virtuous elastic modulus of 1 TPa, high aspect ratio of 50-500, strength of 100 GPa (approx.), high stiffness and low density of -1.2g/cm³ to -1.8 g/cm³.

5. Conclusion

By surveying all the papers mentioned above, it is came to know that Friction Stir Processing is mainly done to improve the mechanical properties of aluminum 6061 alloy. It can increase the fatigue strength, ductility, wear resistance, hardness, formability etc. This process resulted in the refinement of microstructure of the material. With the continuous stirring on the material surface, the material plasticizes and the particles are homogeneously distributed. So the micro hardness of the material can be increased and the friction coefficient of the material can be decreased. Thus the main aim of this paper is to analyze the hardness of aluminium 6061 alloy after FSP. From this study, it is concluded that the hardness can be increased after the FSP process which can be ensured by various tests such as micro hardness test, Scanning Electron Microscope (SEM), Ballistic Test.

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