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# Evaluation of Toughness Properties of Aluminium based Metal Matrix Hybrid Composites Joined by Solid-State Welding

**Sadashiva M[1], H K Shivanand[2], Srinivasa M R[3], Sharanraj V[4]**
[1,3]Assistant professor, Dept. of Mechanical Engg., PESCE, Mandya, Karnataka, India
[2] Professor, Dept. of Mechanical Engg., UVCE, Bengaluru, Karnataka, India
[4]Senior grade lecture, Dept. of Mechanical Engg., S.J.P., Bengaluru, Karnataka, India
sadashiva015@gmail.com, shivanand.uvce@gmail.com, srinivasamr77@gmail.com, sharanraj407@gmail.com

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**Abstract:**

Challenges towards the fabrication of composite materials and joining have some issues related to microstructural behavior. During fabrication, the distribution of minor ingredients in the matrix phase and wettability attains great focus to achieve sound cast products, but real challenge arises during joining of composites. Specially aluminum-based metal matrix has low melting temperature pose sevire problems including heat affected zone, thermal and work strain. This paper focused on to develop, sound cast plates with ingredients of aluminum 6061 alloy, E-glass fiber and SiC particles blended with ASTM standard proposition in traditional stir casting process followed by joining of hybrid composite plates by one of versatile solid-state welding technique called friction stir welding. The welded hybrid composite plates were subjected to impact loading using charpy test and evaluate the toughness characteristics of welded plates and tabulated the results.
***Keywords:*** *Impact loading, Toughness, Friction stir welding, Hybrid composites.*

## I. INTRODUCTION

Composite materials especially fiber-reinforced composites are advanced engineering materials. They have superior properties and outperform applications than conventional materials in their field.[1] The development of advanced materials is associated with the generation of new knowledge and intellectual property. The development of advanced materials can even lead to the design of completely new products. And also be remarkably adaptable. The advanced materials industry encompasses a full life cycle from materials extraction, primary production, process development and materials characterization to product fabrication, testing, use and end-of-life waste management and recycling. Supporting activities would include research, design and development, together with skills and standards development.[2]

A more insightful and focused approach to the fabrication of such advanced materials is to consider materials that are early in their product and/or technology lifecycle. In other words, there is significant research for growth in terms of the improvement of the performance characteristics, technology lifecycle and sales volume. Examples of these elites of materials include ceramics, composites, polymers, semiconductors, glass and metals.[3]

Hybrid Composites materials and their associated process technologies, with the potential to be exploited in high value-added products, is both a multidisciplinary area within itself and cross-cutting over technology areas and market sectors.[4] In this regard, the principal focus of the research work is to impart the knowledge of fabrication of hybrid composite plates and joining them with help of plastic state or solid state welding using friction stir welding technique. Also evalute the toughness properties of work in order to enhace their synthesizing, characterization and applications in the present industrial scenario.

## II. LITERATURE REVIEW

From the thorough review of the available literature related to the Aluminium based metal matrix composites are developed by the stir cat method and joined with the Friction stir welding (FSW) process, the following observations have been highlighted.[7] Metal matrix composites were fabricated with traditional casting techniques using reinforcement with different parameters successfully with defect free with varies plenty of input variables like stir speed, stir time, preheating temperature, pouring temperature etc. Limited studies had been focused and considered E-glass fibers as reinforcement due to wettability .

A comprehensive study of mechanical characterstics of hybrid composites subjected impact loading. A composite may be a material created by combining two or more simillar or dissimilar materials in such a way that the resultant material possess high degree of properties superior to the base metal.[5] Particulate-reinforced and chopped fibres are incorporated with matrix phase to produce the composites, Further due to their excellent properties, the composite materials are used in several fields like defence, aerospace, engineering applications etc. The E-glass oriented composites have gained attention and interests among several materials. Recently Scientists and researchers have focussed on composites due to its formidable strength, high hardness, corrosion resistance, stiffness, wear resistance and thermal properties.[6]

## III. MATERIALS SELECTION AND METHODOLOGY

Weight fraction of 7% of fine greenish 25 micron silicon carbidei particulates (SiCp) and 3% of chopped E-glass fibers of 2 to 3 mm length and 10 to14 micron diameter have been used as reinforcing particulates in the present research and also enhance the mechanical characteristics of the composite materials. Silicon carbide is commonly used reinforcement with aluminium because SiCp is economical and has good wettability with aluminium alloys. Further the density of silicon carbide is 3.2 g/cm3 which makes it a potential candidate for its use in aluminium matrix.

Fiber glass is created by spinning or processing liquefied glass into short, thin fibers. The primary stage is to soften the sand/chemical combine to liquid kind in massive furnaces about 1500 C, the temperature of the E-Glass soften is lowered to about 1,260°C (2,300°F).

**Table 1.** Composition of E-glass fibers.

| E-glass | $SiO_2$ | $AlO_2$ | $B_2O_3$ | CaO | MgO | $FeO_2$ |
|---|---|---|---|---|---|---|
| | 52-56% | 12-16% | 5-10% | 16-25% | 0-5% | 0-0.8% |

**Table 2.** Composition of Al 6061 alloy.

| Al 6061 | Si | Fe | Cu | Mn | Mg | Cr |
|---|---|---|---|---|---|---|
| | 0.4-0.8 | 0-0.7 | .15-04 | -0.15 | .8-1.2 | .04-1.2 |

### Casting process

The process of producing cast products involves pouring molten metal to desired shape of mould cavity, followed by subsequent solidification. Casting is the most familiar and useful process to produce complex products of metal matrix composites. Several casting process have their own advantages over others, among those, stir casting is best suitable for production of MMC's, reason for this selection of stir casting method being uniform dispersion of reinforcements; The process of stir casting consists of mechanical stirrer which helps homogeneous distribution of glass and silicon carbide particulate reinforcement in Al606 matrix phase in its liquid state, that eventually enhances the iso-tropic mechanical characteristics in composite structure.

The casted hybrid composites machined according to ASTM standard using machining process.

### Friction stir welding process

The thermal stresses and residual stress were common problem found during non ferrous metal joining due to low melting temperature. Even thickness also define the quality of joint. If thickness was predomiently high its difficult to join plates with use of traditionl joining methods. The alternative technique that compiles and minimize the traditional

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joining methods limitations and join in their solid state condition in orderto achieve good quality , defect free joint. It achieved by one of the advanced , solid state, novel technique well suited for non ferrous metal joing was “Friction stir welding” developed by The welding institute (UK). Friction stir welding is commoly called as FSW. FSW process applications are more familiar for aerospace and marine applicationsdue to its clean and quality nature even burr free.

The friction stir welding process involves a number of defects that has to be addressed appropriately, further the causes of the welding defects have to be noted for critical analysis of the key aspects involved and subsequent remedial measures to be taken for addressing the major defects encountered. Some of the weld defects that are commonly encountered are wormholes, nugget collapse, surface galling, ribbon flashing, scalloping.

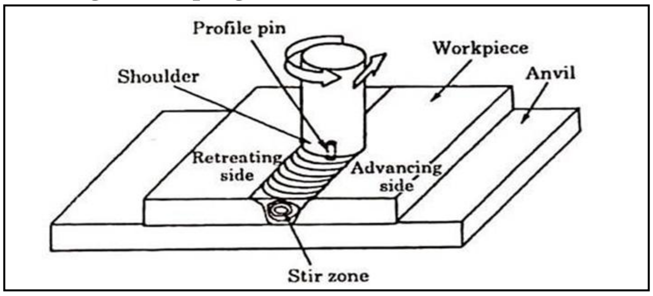


**Figure 1.** Principle of friction stir welding process.

The machined work plates (hybrid composite plates) were clamped against work table with the help of fixture in three axis FSW machine. It has heavy load hydraulic unit hold non consumable tool madeup of high carbon high chromium steel. The tool was plunged against work, the workpiece is rotated to create the friction between plates and tool, so that sufficient amount of heat was generated. The combination of heat and localized turbulence created due to stirring action form diffusion of atoms in adjacent plates to form strong solid joint.


**Figure 2.** Friction stir welding unit. ( IISc. Bengaluru)

The heat generated in the zone of welding wasa enough to soften the work and additional forge action of tool against the work form deep compression leading to localised plasticization of materials that eventually forms strong plastic weld. Optimize the parameters and minimize the weld defects at joint. welded and unwelded AA6061 base and hybrid composites (AA6061+7%SiCp+3%E-Glass) with varying feed rates with constant tool speed rate.

**Figure 3.** Friction stir welded specimen

**Table 3.** Welding parameters.

| Sl. No. | Rotational speed (rpm) | Traverse speed (feed) (mm/min) | Tilt angle (degree) |
|---|---|---|---|
| 1 | 600 | 40 | 0 |
| 2 | 600 | 80 | 0 |
| 3 | 600 | 120 | 0 |

## IV. TESTING

Impact test was a dynamic loading test which evaluates the behaviour of materials for sudden loading condition. The Charpy Impact test sample was machined by wire EDM process with according to

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ASTM E-23 standards. The Charpy test was a methodology of evaluating the fracture toughness or impact strength of specimens. V- Notched sample was placed between two supports of anvil and sudden load was used to strike the sample in the opposite side of notch towards anvil. The impact load fractures the sample and the maximum energy was recorded in the scale in the form of absorbed energy.

**Table 4.** Specifications of charpy impact testing machine.

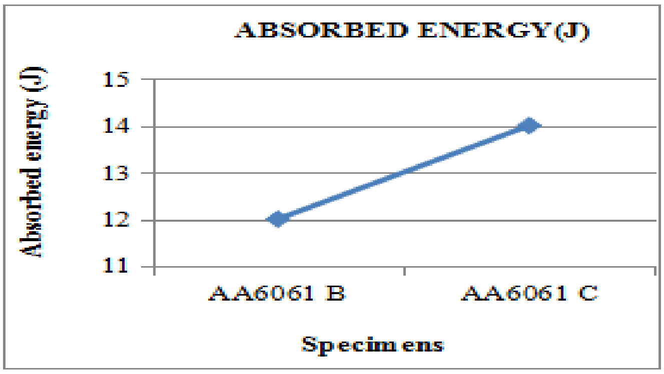
| Sl. No. | Particulars | Values |
|---|---|---|
| 1 | Initial potential energy | 300J |
| 2 | Pendulum drop angle | $140^0$ |
| 3 | Impact velocity | 5.182 m/s |
| 4 | Effective weight of pendulum | 22.35 kg |
| 5 | Angle of strike edge | $30^0$ |
| 6 | Width of strike edge tip | 4mm |
| 7 | Distance between anvil | 40mm |
| 8 | Angle of anvil | $80^0$ |
| 9 | Radius of support | 1mm |
| 10 | Specimen size | 10 mm x 5 mm x55mm |

## V. RESULT AND DISCUSSION

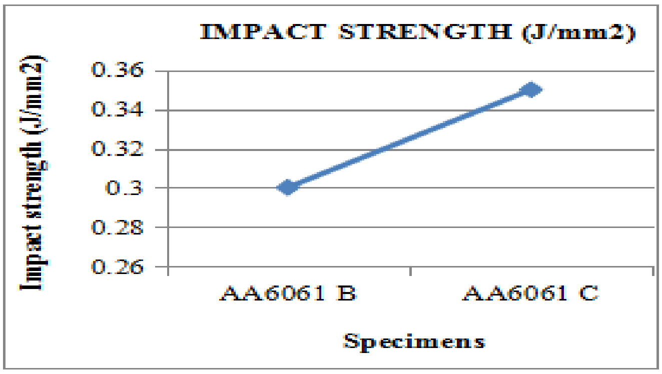
The impact strength of unwelded base metals and composite specimens are given in the table. The result found that the impact strength of unwelded composites increase as compared to the base metal due to the improvement in toughness because of addition of reinforcements that lead to micro-coring or segregation.Further, the impact test results were noted to improve with the uniform dispersion of the reinforcements in the matrix phase of aluminium 6061, that eventually causes better cohesion and intermittent development of a network of framed matrix reinforcement zones.

**Table 5.** Impact strength of unwelded AA6061 base and AA6061+3% E-Glass+7% SiC composite.

| Sample details | Impact Velocity (m/s) | Absorbed Energy(J) | Impact strength ($J/mm^2$) |
|---|---|---|---|
| AA6061 (Base, Unwelded) | 5 | 12 | 0.30 |
| AA6061 (Composite, Unwelded) | 5 | 14 | 0.35 |




**Graph 1.** Variation of absorbed energy (J) of unwelded AA6061 base and AA6061+3% E-glass+7% SiC composite.




**Graph 2.**Variation of impact strength ($J/mm^2$) of unwelded AA6061 base and AA6061+3% E-Glass+7% SiC composite.

The fracture toughness of the composites shows almost same values that of the base materials due to the development of low yield stress and coherent atomic fusion at the interface of the grain boundaries due to stir casting of the composite materials. The fracture toughness values of unwelded Base AA6061is 0.30 $J/mm^2$, composite AA 6061 unwelded FSW sample is 0.35 $J/mm^2$. Further the impact strength of the composites has improved by 16% as compared to base metal.

**Table 6.** Impact strength of welded and unwelded AA6061 base metal .

| Sample | Impact | Absorbed | Impact |
|---|---|---|---|

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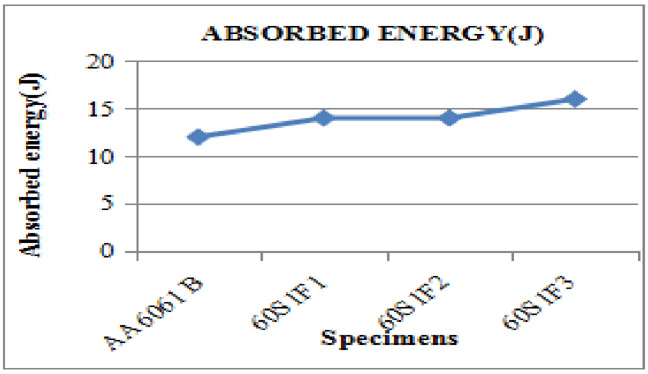
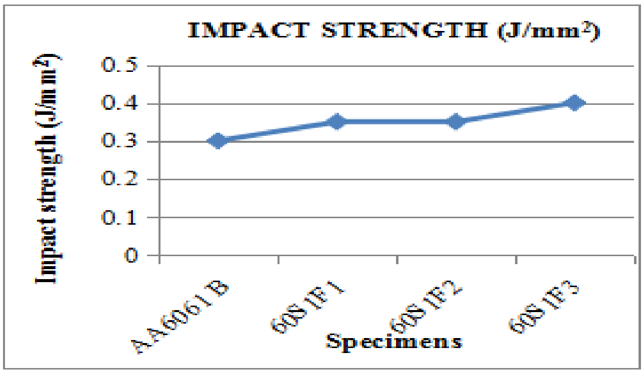
| details | Velocity (m/s) | Energy(J) | strength (J/mm$^2$) |
|---|---|---|---|
| AA6061 (Base, Unwelded) | 5 | 12 | 0.30 |
| 60S1F1 | 5 | 14 | 0.35 |
| 60S1F2 | 5 | 14 | 0.35 |
| 60S1F3 | 5 | 16 | 0.40 |




**Graph 3.** Variation of absorbed energy (J) of welded and unwelded AA6061 base metal.




**Graph 4.** Variation of impact strength (J/mm2) of welded and unwelded AA6061 base metal.

**Table 7.** Specification of AA 6061 test samples.

| Sl. No. | Specimens | | Welding parameters: Tool rotational speed, rpm | Welding parameters: Tool feed, mm/min |
|---|---|---|---|---|
| 1 | 6061 (Base) | | Unwelded | |
| 2 | 60S1F1 | AA6061 Welded samples | 600 | 40 |
| 3 | 60S1F2 | | 600 | 80 |
| 4 | 60S1F3 | | 600 | 120 |
| 5 | 6061 (Composite) | | Unwelded | |

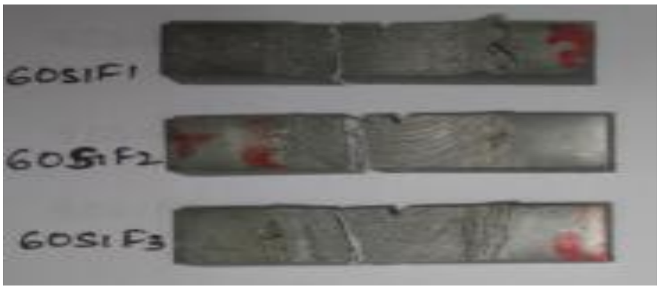



**Figure 4.** Tested impact samples.

The graph is evident that friction stir weld specimens exhibit higher resistance to fracture than that of the welded AA6061. During friction stir welding process, so co-relation has been establish between fracture toughness of weld joint. The Impact strength of welded AA6061 base metal with Tool rotational speed 600 rpm and Tool feed rate of 40mm/min, 80mm/min and 120mm/min are 0.35, 0.35 and 0.4 J/mm$^2$ respectively. The development of grain boundary periphery in the welded zone has resulted in better grain deformation zone which eventually leads to increase in toughness thereby avoiding the fracture and enhancing its characteristic property of impact strength.

The impact strength of the welded and unwelded AA 6061 composite specimens is given in table. The critical analysis of the results shows that the toughness increases with the feed due to inter-atomic nugget zone formation in the welded aluminium 6061 composite specimens, this nugget zone enhances the hardness and reduces the deformation mechanics leading to better characteristics.

## CONCLUSION

[1] Successfully develop hybrid composite plates with AA6061, Sic particulates and E- glass fibers using stircasting process.

[2] The ASTM Standard casted base and composite plates have been join with the help of friction stir welding process.

[3] Impact strength of unwelded AA6061 base is 0.3 J/mm$^2$ and AA6061 composite is 0.35 J/mm$^2$. The impact strength increases due to the addition of reinforcements that eventually increases impact

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strength by 16% and in case of the comparison between welded base and composite samples.

[4] The fracture toughness of the welded composites shows almost same values as that of the base materials due to the development of low yield stress and high angle boundaries of atoms at the nugget zone of weld component.

[5] The Impact strength of welded AA6061 base metal with Tool rotational speed 600 rpm and Tool feed rate of 40mm/min, 80mm/min and 120mm/min are 0.35, 0.35 and 0.4 J/mm$^2$ respectively.

[6] The highest strength achieved are noted to be 0.4 J/mm$^2$ for 6061 base welded at a tool speed of 600rpm and a tool feed rate of 120mm/min.

[7] The welded samples have excellent impact strength because forging action during FSW miniatures the micro cracks which in turn leads to maximum energy absorption.

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## AUTHORS PROFILE

**Dr. SADASHIVA. M**, the corresponding author, received his Ph.d in Mechanical Engineering from JNTU Ananthpuramu, Andrapradesh (2019) and M.E (Manufacturing science and Engg.) from UVCE., Bengaluru Univrsity (2011). He has nine years of teaching experience. Author awarded with "RULA International Award-2018" for his reseach work. He is currently working as Assistant Professor, Department of Mechanical Engineering at PESCE (Govt. Aided Institution), Mandya, Karnataka. In his research activities, he is focusing on hybrid composite materials, Processing and Friction stir welding technique.

**Dr. H. K. SHIVANAND**, the second author, received his Ph.d in Mechanical Engineering from Bangalore university (2002) and he has more than 26 years of teaching experience in various prestigious colleges like UVCE, RVCE. Author has successfully produced more than 20 PhD. Publishing almost 200 rueputed journals in national and internation publications and also wrote several technical books among most famous "Flexible Manufacturing System" published by New Age International Publishers-New Delhi. He visited more than ten countries. Author awarded with "Bharat Jyoti Award (2013)" by India International Friendship Society – New Delhi. He is currently working as Professor, Department of Mechanical Engineering at UVCE (Govt.), Bengaluru, Karnataka. Author field of research are Advanced materials, composites and welding technology.

**Mr. SRINIVASA. M. R**, the third author, purcusing his Ph.d in Mechanical Engineering and M.Tech. (Machine Design) from BMSEC, VTU (2015). He is currently working as Assistant Professor, Department of Mechanical Engineering at PESCE (Govt. Aided Institution), Mandya, Karnataka. He has thirteen years of teaching and ten years of industrial experience. Author publish number of papers on shock wave properties on graphene material. In his research activities, he is focusing on Shock wave technology, Composite materials and welding techniques.

**Dr. SHARANRAJ. V,** the fourth author, received his Doctorate in Materials Science and Engineering from VTU and M. Tech. in Computer Integrated Manufacturing from Ramaiah Institute of Technology,VTU. He has nine years of teaching experience. Author has recognized reviewer for several reputed journal include Spinger. He is currently working as a senior grade lecturer, Department of Mechanical Engineering (W&SM) at Sri Jayachamarajendra polytechnic( Govt.). In his research activities, he is focusing on biomaterials, ceramic materials and composite material processing.