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Fabrication and characterization of hybrid composite of Al6082/SiC/rice husk powder using friction stir processing

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Abstract
Friction Stir Processing (FSP) is a technology in which the microstructure of a material, as well as the mechanical properties of this material, is enhanced by the action of friction with a special tool. There are many applications for FSP materials which are in high demand in various industries, including aerospace, shipbuilding, instrumentation, and many others. The paper presents a study of a hybrid composite made from silicon carbide powder and rice husk (RHP) as reinforcement, included in the Al6082 aluminum alloy. The study of the characteristics of the fabricated composite was performed using an optical microscope, field emission scanning electron microscope (FESEM), X-ray diffraction (XRD) method. Tensile strength (UTS) and hardness were determined. It was revealed by microscopy that a modification of the microstructure occurs on the surface of the composite. X-ray diffraction analysis showed the presence in the spectrum of elements similar to the Al/SiC/RHP hybrid composition. It is shown that UTS tensile strength and Brinell hardness is being increased by factors of 1.36 and 1.75, respectively, compared to base aluminum material.

Keywords
friction stir processing, hybrid composite, SiC, rice husk powder, tensile strength, hardness

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УДК 66.011

Изготовление и характеристика гибридного композита Al6082/SiC/порошок рисовой шелухи, получаемого методом фрикционного перемешивания

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Аннотация
Обработка трением с перемешиванием (Friction Stir Processing, FSP) — технология, в которой микроструктура материала и его механические свойства усиливаются за счет воздействия трения специальным инструментом. Существует множество применений материалов, получаемых методом FSP, которые используются в различных отраслях промышленности, в том числе аэрокосмической, судостроении, приборостроении и многих других. В работе представлено исследование гибридного композита, изготавливаемого из порошков карбида кремния (SiC) и Rice Husk Powder (RHP) в качестве армирующего элемента, включаемого в алюминиевый сплав Al6082. Исследование характеристик изготовленного композита выполнено с применением оптического микроскопа, автоэмиссионного сканирующего электронного микроскопа рентгеновским дифракционным методом. Определены прочность на растяжение и твердость. Методом микроскопии выявлено, что на поверхности композита происходит модификация микроструктуры. Рентгеноструктурный анализ показал наличие в спектре

элементов, аналогичных гибридной композиции Al/SiC/RHP. Показано увеличение прочности на растяжение и твердости по Бриннелю в 1,36 и 1,75 раза соответственно по сравнению с основным алюминиевым материалом.

Ключевые слова
обработка трением с перемешиванием, гибридный композит, карбид кремния, порошок рисовой шелухи, предел прочности на растяжение, твердость

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Introduction

In the current scenario of the industry, every industrialist wants to use good material getting some superior quality mechanical properties on that material. There are various processes from which composite material is fabricated. For example, that processes are used in powder metallurgy, casting, diffusion bonding and much more. After fabrication, there is lot of waste as well as defects have also been produced, but out of these, Friction Stir Processing (FSP) has lower drawbacks while fabrication as compared to other processes. For this reason, FSP has been used to improve or modify their microstructure by solid-state plastic deformation which will help utilize them in different structural domains as well as in metallurgical industries. FSP came in 1991 after a few years of friction stir welding [1] which formed the basis of the manufacturing process. In FSP, pin of tool is inserted on the groove by applying axial force at a particular rpm. Plastic deformation has taken place when sufficient heat is generated and there is micro structural modification occurred by using different reinforcements on it. The schematic diagram of the FSP is shown in Fig. 1.

FSP can be done on various materials like magnesium, aluminum, copper, zinc, etc. At the same time, aluminum has a low weight, as well as good strength, that is why it is preferable for various applications due to having these properties [2]. For this research aluminum 6082 was chosen. To enhance the microstructure of the material by using FSP, some additive (called reinforcement) is added. Silicon Carbide (SiC) and Rice Husk Powder (RHP) are used as reinforcement.

SiC is ceramic nature type material which is a quite common material used in industry. There are various useful properties of SiC material. For example, it has high thermal shock resistance. It has also high strength as well as high hardness and high wear resistance properties. For this reason, SiC was chosen as reinforcement for our research. Hybrid composites use many types of reinforcement in a single matrix intending to achieve a synergistic impact between the qualities of the reinforcements and the overall properties of the composite [3]. RHP is an agricultural waste material that is produced from rice mills. It is also burned after the crop grows and mixed in the air due to having tiny particles and forms various unwanted gases. These gases produce unwanted containment which is very dangerous for the lungs. This waste has created many health-related issues while mixing these particles in the air. But due to showing its mechanical properties, it can be the best while using a hybrid composite. It has enormous potential to increase strength as well as hardness [4]. It has also a wear resistance nature. So, by using these reinforcements, it will not only reduce the waste but also make an eco-friendly environment.

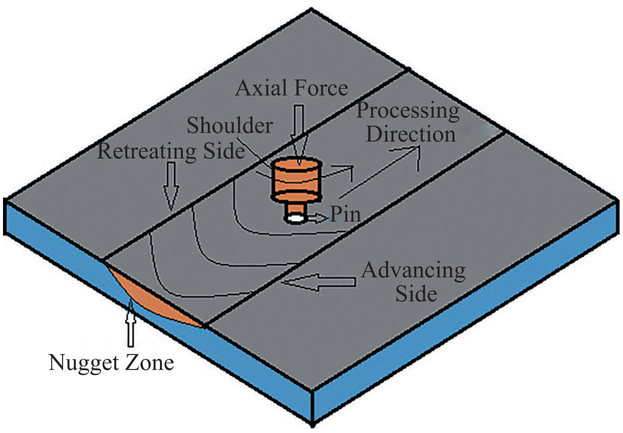

Fig. 1. Schematic diagram of friction stir processing

Literature Review

Fuse et al., [5], examined the effect of process parameters, i.e., number of passes, bobbin tool and rotational speed on Al 6064 when using FSP. The result revealed that with the use of bobbin tool at the third passes of FSP maximum hardness is achieved, i.e., 95.11 HV which is 28 times more than in the base material.

Maji et al., [6], examined the tool traverse speed, no. of passes, rotational speed, and plunge depth on Al 7075-T6 when using FSP. Results revealed that grain size is reduced to 5.69 from 32.34 μm at a lower traverse speed in the 2nd pass of processing.

Saravanakumar et al., [7], analyzed the effect of process parameters, i.e., rotational speed, transverse speed and axial force on Cu when using FSP. They revealed that 18 % volume reinforced rice husk ash has maximum wear resistance of $5.3 \cdot 10^{-5}$ mm^3/Nm due to having an increase in hardness.

Parbhu et al., [8], reported the effect of the process parameters, i.e., tool material, tool rotation direction, tool rotation speed and feed rate on Al 6082 when using FSP. Results show that a composite abrasion resistance is increased twice compared to the base material while incorporating $CaCo_3$.

Patil et al., [9], investigated the effect of the process parameters, i.e., downward axial force, rotational speed, tool traverse speed, and tilt angle on Al 7075 when using FSP. Authors concluded that higher micro hardness of 604 HV was achieved in linear lined holes pattern which means it has superior hardness than the zigzag lined holes pattern and grooves pattern.

Liu et al., [10], examined the effect of process parameters, i.e., tool rotation speed, traverse speed, and tilt angle on Al 7075 when using FSP. Results revealed that with the addition of scandium its strength drops in comparison to the T6 original sample whereas the damping force increases with the addition of the scandium.

Luo et al., [11], investigated the effect of the process parameters, i.e., tool rotating direction, transverse direction, and multi-pass on AZ61 when using FSP. Results concluded that, when using a multipass FSP, grain size is refined to 7.8 μm due to having dynamic recrystallization.

Nadammal et al., [12], reported the effect of process parameters, i.e., tool plunge depth, tool rotation rate, and traverse speed on Al 5086 when using FSP. Results revealed that because of the comparatively reduced heat input received and the resistance supplied by some of the shear texture components, the creation of such a weak texture can occur towards the bottom of the nugget zone.

By analysing these research papers, we can say that FSP finds application in various domains. These authors are generally used aluminum as a base material due to having a lower weight with good strength. So, in this research, we also use aluminum as a base material. But as a hybrid reinforcement, SiC (2 wt.%) and RHP (2, 4 and 6 wt.%) were used. This mixed hybrid composite will not only reduce the cost of material by the utilization of waste material RHP but also reduce environmental pollution. After fabrication, their different characterisation, like optical microscopic, X-ray Diffraction (XRD), tensile and hardness, were also examined. So, it will be beneficial for industrialists as well as for researchers to utilize the process in the best way.

Materials and Methods

For this fabrication, rectangular plate of Al 6082 with dimensions (80 × 95 × 10 mm) is taken as a base material which has the following chemical composition: Aluminum (Al) — 95.2 wt.%; Silicon (Si) — 1.3 wt.%; Magnesium (Mg) — 1.2 wt.%; Manganese (Mn) — 1.0 wt.%; Iron (Fe) — 0.5 wt.%; Chromium (Cr) — 0.25 wt.%; Zinc (Zn) — 0.2 wt.%; Titanium (Ti) — 0.1 wt.%; Copper (Cu) — 0.1 wt.%.

For this reinforcement, SiC is taken which has extremely high thermal shock resistance. Used SiC reinforcement is shown in Fig. 2.

For the hybrid composite, another reinforcement is used, i.e., RHP. The Scanning Electron Microscope (SEM) image of RHP is illustrated in Fig. 3. **The average size of RHP is 58 μm.** From SEM image, the structure of the RHP is observed.

The chemical composition with their wt.% of RHP is identified with the help of the Energy dispersive X-ray (EDX) spectrometer. Its spectrum is illustrated in the Fig. 4. From EDX spectrum, maximum amount of elements observed in RHP are C and Ni followed by Cu, Mg, Ca and Zn.

Groove is prepared on the plate with the shaper machine, which is shown in Fig. 5. Dimension of the groove is (6 × 6 mm). Reinforcements (SiC and RHP) are inserted into the groove of the plate.

For FSP, threaded tool is taken. It is made up of high carbon and high chromium steel which was analyzed in the study of various literature reviews; there the information was found that tools made of these materials are suitable for the fabrication of aluminum alloys [13]. The diameter

Fig. 2. SiC reinforcement. The average size of the SiC particles is 150 μm

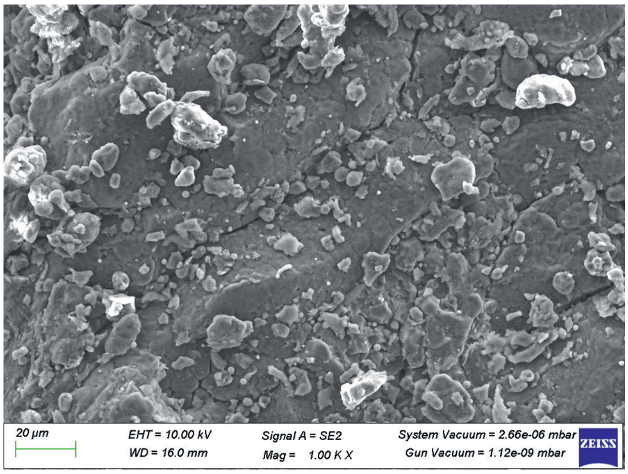

Fig. 3. SEM image of RHP. The average size of RHP is 58 μm

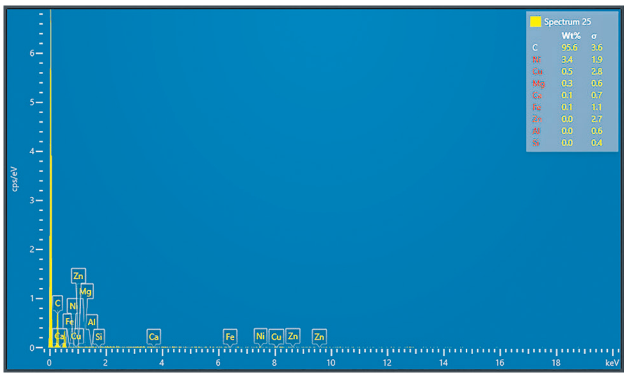

Fig. 4. EDX spectrum of the RHP

Fig. 5. Grooving on the sample

of the shoulder is 16 mm whereas the length of the pin is 8 mm and the diameter of the pin is 6 mm (it is shown in Fig. 6).

Process parameters have a vital role in the FSP. There are various process parameters like rotation speed, rotation direction, traverse speed, tilt angle, pin profile, shoulder diameter, and much more. Out of these, some process parameters have been adopted, for example, the rotation speed is taken equal to 1500 rpm, the traverse speed is taken equal to 50 mm/min and the tilt angle is taken equal to 3° to show the effect on the material.

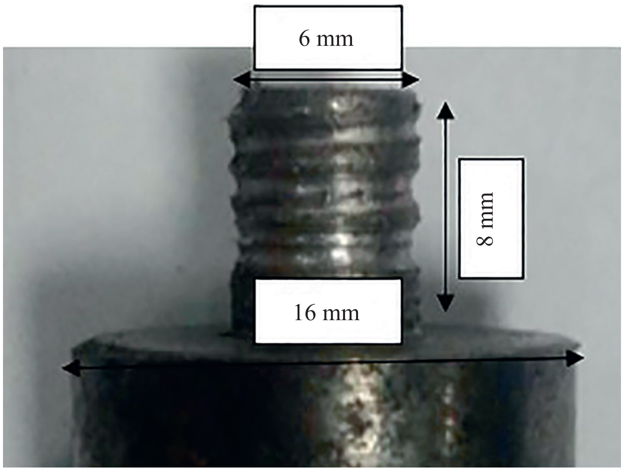

Fig. 6. Threaded tool pin profile

Experimentation

FSP was implemented on the vertical milling machine. The set-up of the FSP for fabrication of hybrid composite AA6082/SiC/RHP is illustrated in Fig. 7. Using a threaded tool, the fabrication was completed. The tool has been inserted into the collet. The tool shoulder contacts the workpiece when axial downward force is applied, while the pin is put into the sample groove **on which reinforcements are inserted on it**. While the shoulder comes into contact, workpiece with revolving at 1500 rpm speed creates friction, and then plastic deformation takes

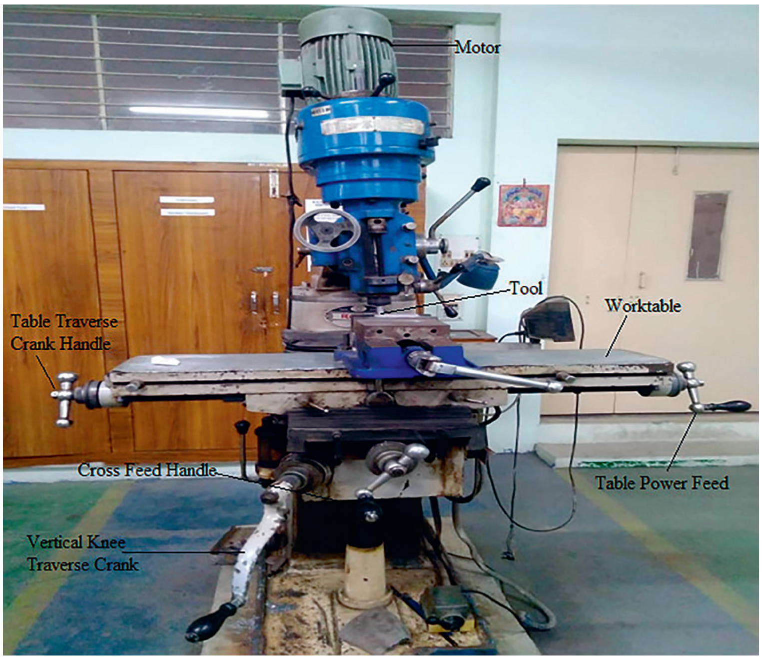

Fig. 7. FSP set-up machine

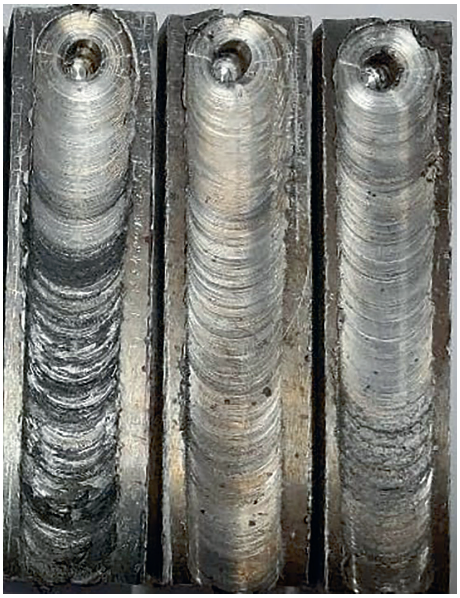

Fig. 8. Fabricated hybrid composite AA6082/SiC/RHP

place on **FSP Zone**. The traverse speed, on the other hand, aids in the movement of the workpiece in the processing direction as well as the deposition of material from back to forth. This process is continuously taking place after the processing tool is removed by the removal of axial force, and the power supply is off.

A fabricated sample of hybrid composite AA6082/SiC/RHP is shown in Fig. 8.

Results and Discussions

Microstructural Analysis

An optical microscope is used to show the macrostructural change in the material. All the fabricated hybrid composite of AA6082/SiC/RHP is examined under the microscope on the composite sample with the size 10 × 10 mm (Fig. 9). Before examining, the sample is rubbed on the emery paper of the grit no. 400, 600, 800, 1200 and 1500. Then the rubbed sample is polished with the chemical powder Al_2O_3. This chemical powder is used to better surface finish as well as to clear structure. The polished sample is also etched with HNO_3 solution to enhance the contrast on the surface so that the microstructure can be seen easily.

Fig. 9, *a* shows the microscopic view of base material without fabrication in which no defect on the material found. This is confirmed by the examining different sides under an optical microscope and it was found that there is not any porosity as well as available cracks on unprocessed workplace. Fig. 9, *b* shows the fabricated composite microscopic image in which 2 wt.% of SiC as well as 2 wt.% of powder of rice husk reinforcement is mixed. Fig. 9, *c* shows the microscopic image of fabricated composite on which 2 % SiC and 4 % powder of rice husk is mixed as a wt. percentage of the base material. Similarly, Fig. 9, *d* shows the fabricated composite microscopic image on which reinforcement 2 % SiC and 6 % RHP are incorporated with wt. percentage of the base material. It can be seen from these analyzed microscopic images that a superior microstructure is achieved in the sample on which 2 % SiC and 4 % powder of rice husk are mixed. There takes place a proper mixture between the reinforcement and the base material. Due to plastic deformation, good dynamic recrystallization takes place with threaded tools creating a better microstructure than in the base material. Due to medium rpm, i.e., 1500 rpm, there is sufficient heat generated which helps microns reinforcements to mix properly. Similarly, tilt angle of 3° also helps to get sufficient friction produced between shoulder of tool and surface of workpiece. As a result, process parameters are also affected the microstructure of the composite.

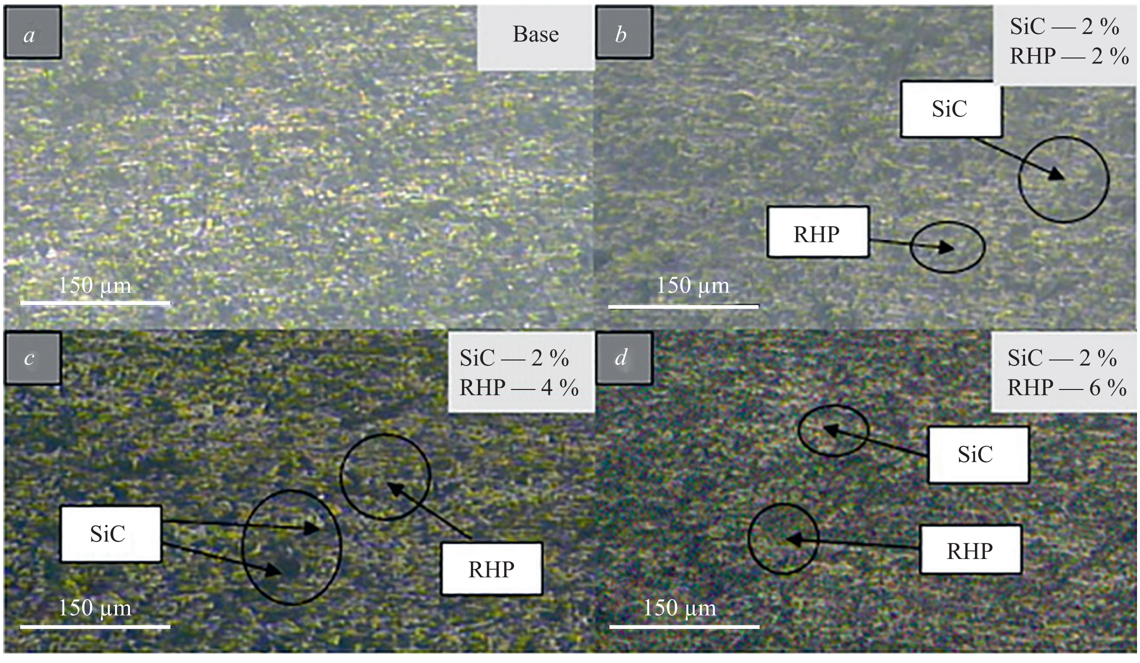

Fig. 9. Microstructure of: base material AA6082 (*a*); AA6082/SiC/2 % RHP (*b*); AA6082/SiC/4 % RHP (*c*); AA6082/SiC/6 % RHP (*d*)

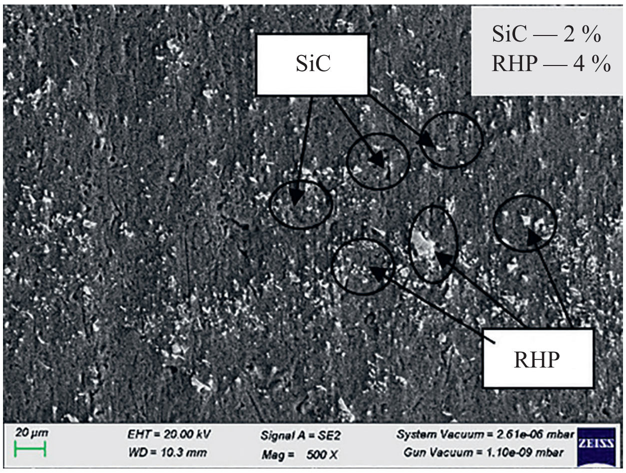

Fig. 10. FESEM of fabricated AA6082/SiC/RHP hybrid composite

To get further analysis, Field Emission Scanning Electron Microscope (FESEM) is also used for that fabricated composite to get more information on the microstructure (Fig. 10).

From FESEM analysis, it was observed that the correct distribution of the reinforcement, i.e., SiC, as well as the RHP on the fabricated composite, was received. These microns reinforcements are identified by the showing brighter particles of reinforcements distributed over the aluminium metal matrix. Sufficient plastic deformation occurred at a proper tilt angle which helps the better distribution of particles due to sufficient heat generated between the tool shoulder and workpiece. As a result, a fabricated hybrid composite with modified microstructure is obtained. To get elemental analysis information an EDX spectrum is also used which is illustrated in Fig. 11.

EDX spectrum of the fabricated AA6082/SiC/RHP hybrid composite gives the detailed information about elements used with their wt. percentage on that composite. Maximum amount of C, Si, and Mg is found followed by the Fe, Zn, and Ni on the aluminum matrix. So, the EDX spectrum can confirm that there is a presence of elements on the aluminum matrix which are also observed on the EDX spectrum of RHP. These elements are very useful for strengthening the material as well as to increase the hardness of a material. Also EDX spectrum confirms that there is proper utilization of reinforcement elements on the metal matrix.

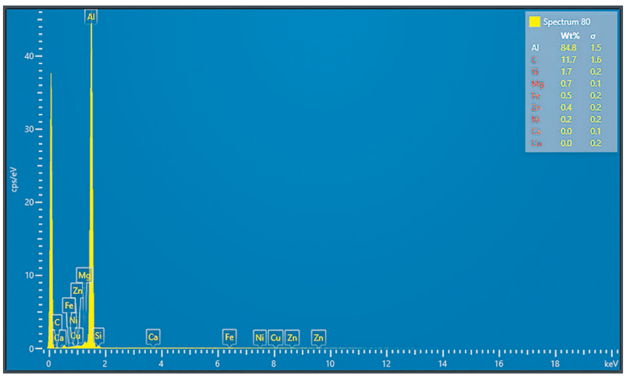

Fig. 11. EDX spectrum of fabricated AA6082/SiC/RHP hybrid composite

XRD analysis

XRD is used to detect the phase of crystalline structure and also detect the various compound formations from the presence of elements. XRD characterization is done from the IIT Roorkee Lab, India. XRD is done by using Bruker D-8 advanced diffractometer with CuK radiation. The samples were scanned at 2 kcps with a scanning speed of 12 °/min while rotating the MiniFlex (300/600) goniometer in the 2θ range of 5–90°.

The XRD result in Fig. 12 shows that the compound formation has taken place from the same element as the elemental composition of base material AA6082. There also got information that no harmful effects present for machining compound formation.

Fig. 13 shows the XRD result of the fabricated hybrid composite of AA6082/SiC/RHP. The result of the XRD revealed that different compounds and elements are observed on the different peaks. A compound like SiO_2 is hard in nature as well as it has also beneficial to improve the hardness of the composite. Similarly, there is also observed MgO which is physically and chemically stable at high temperatures. The compound, as well as elements which are observed on the peak of the fabricated hybrid composite AA6082/SiC/RHP, were very useful in enhancing the mechanical properties.

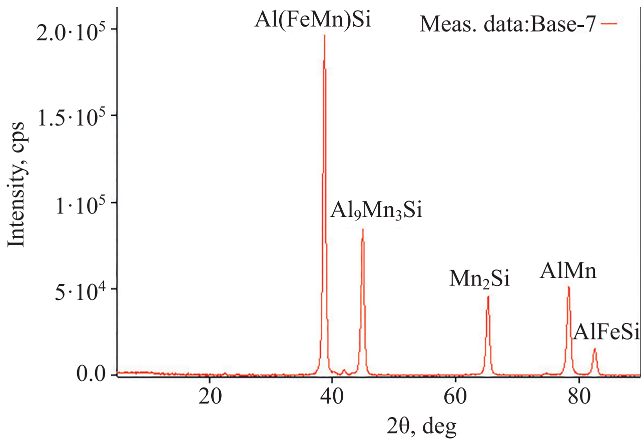

Fig. 12. XRD of base material AA6082

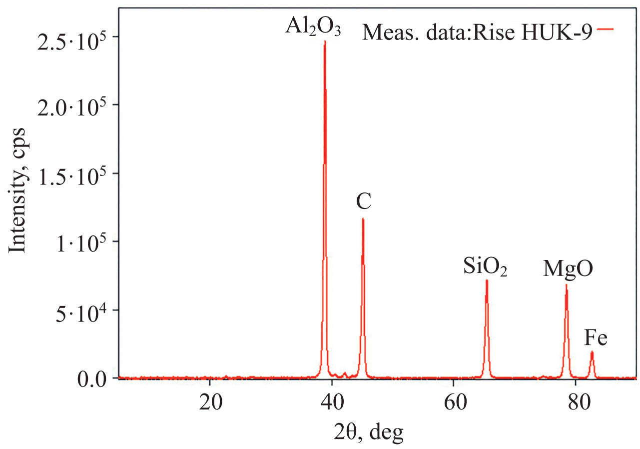

Fig. 13. XRD of AA6082/SiC/RHP

Ultimate Tensile Strength

After fabrication, ultimate tensile strength is also measured with the help of a tensometer at NIET Greater Noida, India material science lab. From the tensometer it was found that the fabricated composite has the following ultimate tensile strength which is shown in Fig. 14.

The ultimate tensile strength of the fabricated composite shows different data as the varying reinforcement wt. %. The maximum ultimate tensile strength is achieved in the sample on which reinforced 2 % SiC whereas the 4 % powder of rice husk. The used reinforcement increases the material strength up to a point of 4 wt. % of RHP, but beyond that, it decreases its value when utilising 6 wt. % of RHP.

Due to the agglomeration of **reinforcement**, the tensile strength has decreased at 6 wt. % but, while increasing reinforcement up to 4 %, the proper mixing happens and sufficient plastic deformation has occurred as a resulting tensile strength is increased. The tensile strength is found to be higher than the base material, also due to the used suitable process parameter. This contributes to the flow of the material, and mixing with reinforcement particles at 1500 rpm is very appropriate. Dinaharan et al., [14], showed a similar result, the tensile strength is increased, while mixing the rice husk as reinforcement in the Al 6061 alloy, because the composite has more grain refinement than the aluminium matrix, so the tensile strength is increased according to the Hall-Petch equation.

Hardness

Hardness is also measured on the Brinell Hardness testing machine at the material science lab NIET Greater Noida, India. Hardness is measured at five points on the fabricated composite and we take an average of them to achieve good accuracy. The hardness of that fabricated composite is shown in Fig. 15.

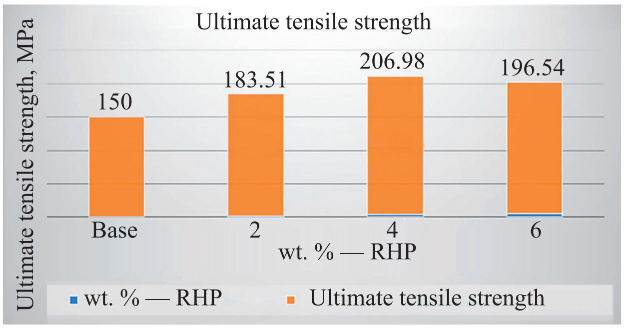

Fig. 14. Ultimate tensile strength of fabricated hybrid composite AA6082/SiC/RHP

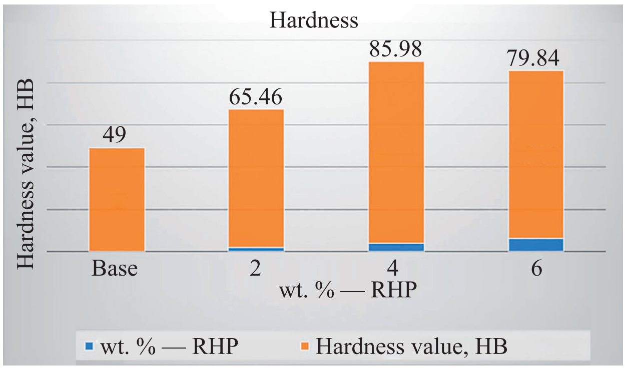

Fig. 15. Hardness of fabricated hybrid composite AA6082/SiC/RHP

The hardness of the fabricated composite shows increasing order up to a certain limit; after that it is decreased which is shown in Fig. 15. The maximum hardness achieved is 85.98 HB on which reinforcement of 2 % SiC as well as 4 % RHP is mixed as a wt. % on Al 6082 alloy. The hardness is drastically increased due to the threaded tool creating proper mixing with of powder of rice husk and SiC, both have good bond formation while mixing with aluminum. Fatchurrohman et al., [15], also showed similar result due to the inclusion of tiny eutectics particles by the mixing of RHP in the main aluminium matrix which also has resulted in increased hardness.

Conclusions

A hybrid composite of AA6082/SiC/RHP is successfully fabricated with help of FSP. Fabricated composite has also been tested by different characterization to show their bonding as well as their mechanical properties. The optical microscope and FESEM show that a modified microstructure is obtained compared to the base material, whereas the EDX spectrum shows the presence of elements that are similar to those found in EDX spectrum of RHP on the aluminium matrix. Similarly, from the XRD result it was found that the observed compounds as well as elements on the peak are helpful in nature and also improve the nature of composites. There is also ultimate tensile strength as well as the hardness are increased 1.36 times and 1.75 times, respectively, compared to the base material. So the fabricated hybrid composite has superior microstructure as well as improved mechanical strength and is also useful for various applications.

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