International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 12 | Dec 2025 www.irjet.net p-ISSN: 2395-0072

Optimization and Microstructural Analysis of AZ31-Based Surface Composite Using Friction Stir Processing (FSP)

Mohammad Faiz Khan[1], Ajay Kumar Singh[2]

[1]M.*Tech (ME) Scholar, Department of Mechanical Engineering, B.N. College of Engineering & Technology, Lucknow, Uttar Pradesh, India*

[2] *Assistant Professor, Department of Mechanical Engineering, B.N. College of Engineering & Technology, Lucknow, Uttar Pradesh, India*

Abstract- *Friction Stir Processing (FSP) is a sophisticated surface modification method that uses a stirrer's motion against the surface that has to be improved to increase the mechanical characteristics of materials. The effects of several FSP factors, such as tool angle, stirring speed, and reinforcement type, have been examined in this study. During FSP, heat generation is essential to plastic deformation and has a direct effect on the effectiveness and results of the process.*

Derived from Friction Stir Welding (FSW), FSP is a unique, energy-efficient, and environmentally friendly method that is especially useful for creating surface composite. AZ31 was chosen as the matrix phase in this study, and MgO and B4C were used as reinforcements. The creation of surface composite, such as AZ31+B4C, AZ31+B4C+MgO, and AZ31+MgO, was thoroughly examined. The impact of tool type, tool angle, and rotational speed on the composite' characteristics was the main focus of the investigation.

The main conclusions emphasise how the composite formed uniform, fine-grained microstructures. Grain size was shown to be inversely related to rotational speed, with finer grains produced at greater speeds. This study highlights the significance of parameter optimisation for reaching desired material properties and offers insightful information about the creation and improvement of AZ31-based surface composite using FSP.

Keywords: Friction Stir Welding (FSW), AZ31-based surface composite, MgO and B4C as reinforcements, Microstructural analysis etc.

1. INTRODUCTION

Nowadays, the manufacturing industry is seeing a continuous increase in demand for new kinds of engineering materials. Such materials need to have extraordinary properties, such high strength to weight ratio and outstanding electrical and thermal conductivity. Combining these types of characteristics in a particular unique material promotes materials like composite and speeds up manufacture. [1] Metal Matrix Composite (MMC) rate well among all composite kinds for technological applications. When two distinct materials combine, a homogeneous phase known as Metal Matrix Composite (MMC) is produced. The metallic phase of the matrix and the non-metallic phase of the reinforcement disperse across the metallic phase [2]. The techniques employed were either melting the matrix material or hot pressing it into the fibre. In another case, the production of these uncommon composite depends on high temperatures. Reinforcement phases including oxides, nitrides, and carbides have high strength and evenly distributed modules in metallic materials.

Crude MMC have been demonstrate make better physical and mechanical properties, ability of structure, reliability. Crude MMC make certain towards enhances the engineering performances compare to non-reinforcement matrix [3]. In form of matrix material, some common materials are used mainly like aluminium, magnesium, titanium, copper etc. Whereas reinforcement material like AL_2O_3 Aluminium oxide, Boron, Carbide [B4C] , Silicon Carbide [SIC] and Magnesium Oxide [MgO] are used[4]. Magnesium-based MMCs are widely employed in the automotive sector because of their admirable qualities, which include their light weight and ability to promote mechanical and thermal properties. When compared to other manufacturing materials, these qualities make them better for engineering applications. [5] For better execution, mmcs are a healthier substitute for large construction materials like steel or casting in the present day.[6] MMC can be elaborate by some technique which varies gradually according to type of reinforcement are used. [7] The selection of development techniques depends on the homogeneous scattering of the reinforcement into the matrix alloy and precision of the MMC.

1.1. Friction Stir Processing (FSP)

Currently, MMCs are widely used in the transportation, maritime, automotive, structural, and aerospace sectors. They are extremely valuable and appropriate for a variety of applications due to their exceptional qualities, which include their high strength-to-weight ratio, high specific stiffness-to-weight ratio, and lightweight nature. Usually, MMCs are created by adding liquid or particle reinforcement to the base metal (matrix material).

1.2. Process Parameters of FSP

The acceptability of the produced MMCs is significantly influenced by the friction stir processing process parameters, including plunging speed, traverse speed, tool tilt angle (pin and shoulder), and percentage of reinforcement. Figure 1.1 displays the specific parameters along with their underlying reasons.

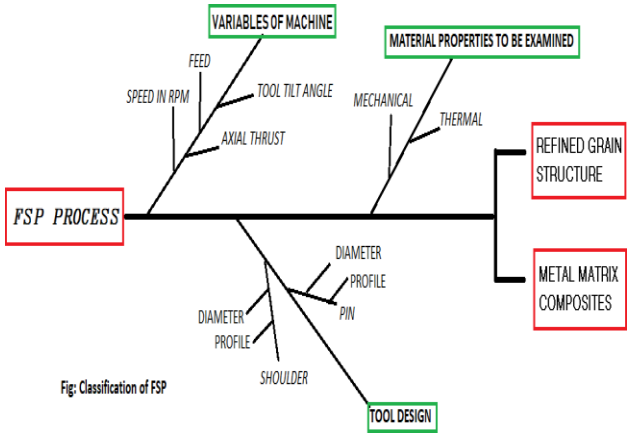


Figure 1.1 Fish bone diagrams of Process parameters of FSP

2. LITERATURE REVIEW

In their study, R.S. Mishra et al. [8] examined (a) how friction stir processing refines the microscopic structure of alloys of metals and (b) how process variables impact the final metal's mechanical characteristics. Aluminium alloys were the subject of the majority of their studies. FSP is now acknowledged as a useful instrument.

The reinforcement of SiC with Al356 was investigated by Ma et al. [9]. A 6.35 mm thick plate, variable traverse speeds, single-pass FSP, and various tool rotating speeds were all used in their investigation.

The microstructure of aluminium alloy 7065 under FSP was examined by Su et al. [10], who discovered that friction stir processing did not result in a consistent grain distribution in the structure.

In their analysis of the FSP approach, Thomas et al. [11] discovered that qualities like tensile strength & fatigue strength are enhanced when the tool is rotated on the lateral surface of an element. The produced sample showed improved microstructure and fine-grained aluminium MMC (Metal Matrix Composite).

The impact of feed rate and tool rotation speed on AZ31 magnesium alloy was examined by Gupta et al. [12]. They discovered that an ideal SiC content is necessary to boost the strength of magnesium-based composites.
For alloys made of magnesium and aluminium, friction stir processing has been used extensively. But since FSP tool materials have advanced so much, new studies have looked into applying technique to high-melting-point materials including titanium, nickel-based alloys, and iron-magnesium-based alloys [13-14].

In their study of the magnesium AE42 alloy, Arora H.S. et al. [15] discovered that FSP improves microstructure and hardness while lowering wear rates.

The mechanical characteristics of aluminium alloy 2024 were investigated by Mahendra Boopathi [16]. They treated the MMC under FSP and reinforced Al2024 with fly ash and SiC in various compositions. They came to the conclusion that the MMC became harder. Multi-pass FSP on zircon-reinforced Al MMCs and its corrosion behaviour were investigated by Sucitharan et al. [17]. They proposed that zircon reinforcement enhances the wear resistance characteristics of aluminium alloy composites.

Mishra et al. [18] examined the casting of Al356 and proposed that friction stir processing on temperatures ranging from 470°C to 570°C improves superplastic properties in aluminium alloy. Fadhel A. et al. [19] examined the effects of FSP on aluminium alloy and discovered that yield strength increased by 9% and tensile strength increased by 15% following friction stir processing.
In order to produce finer aluminium grains, Darras et al. [20] investigated the friction stir processing of AZ31 by regulating heat input and persistent deformation in the material.

2.1. Objective of the Present Work

The objectives of the present work are as follows:

1. **Development of MMCs using Friction Stir Processing (FSP)**

(a) Selection of material
(b) Selection of process parameters for FSP

2. **Characterization of Developed MMCs**

(a) Microstructural Observations
(i) macroscopic observations through optical macrography
(ii) Microscopic observations (morphology) using SEM images
(iii) SEM images for fracture analysis after tensile testing

(b) Elemental and Chemical Composition Analysis
(i) Through energy-dispersive spectroscopy (EDS)
(ii) Through X-ray diffraction (XRD)

3. EXPERIMENTAL METHODOLOGY

3.1. Selection of Material

At present, various materials are available that can undergo different machining processes. Among them, aluminum (Al) and magnesium (Mg) have unique and attractive properties. Many researchers have extensively studied Al metal alloys and their properties. Therefore, for innovation, it is essential to explore alternative materials.Magnesium has a hexagonal lattice structure, which contributes to the fundamental property enhancements of Mg alloys. The lightweight nature of Mg alloys helps reduce fuel consumption, lower emissions, and improve environmental sustainability.

Table 3.1: MG alloy (%) composition [AZ31B]

ELEMENT	Mg	Al	Zn	Mn	Si	Cu	Ca	Fe	Ni
%	97	2.5 3.5	-0.6-1.40	0.2	0.1	0.05	0.04	0.005	0.005

Figure 3.1: AZ31 Mg Alloy Sheet

3.2. Selection of Process

A method that does not change the material's phase while processing is necessary for the assessment of microstructure and the creation of metal matrix composite (MMC). The objective is to produce a refined microstructure with a fine, equiaxed grain structure. To achieve these qualities, friction stir processing (FSP) is a good fit.

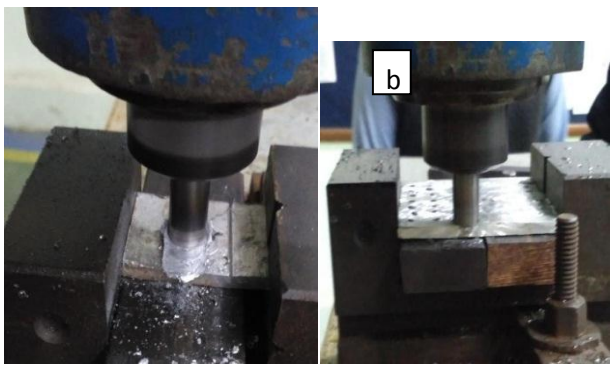


Figure3.3: Friction stirs processing of AZ31surface composite

3.3. Machine Used

In this work, a Vertical Milling Machine (VMM) is utilised for Friction Stir Processing (FSP). A vertical milling machine is a high-precision instrument used to shape and fabricate metal objects. It can also be applied to plastics, depending on the kind of material and the equipment.

A VMM can be operated manually or by use of Computer Numerical Control (CNC) techniques. Because the tool is secured within the spindle, it can travel both up and down. Milling, which uses rotary cutters to remove undesirable material from the workpiece, is one of the main processes carried out on a vertical milling machine. The specifications of the Vertical Milling Machines (VMC) used in this work are provided in Table 3.2, and Figure 3.4 shows the actual machine used.

Table 3.2: Specification of FSP.

MODEL	X6323
TRAVEL x , y , z	610 , 350 , 380
Table dimension width and length	230 , 1070
HEAD STRUCTURE	PHASED GEAR HEAD (VERTICALSTEELHEAD(VSH) NONPHASEDHEAD (NPH)
SPINDLESPEED	PGH80 5400 VSH 80 8400 NPH 60 4200
MOTOROUTPUT	3 HP
RAM TRAVEL	305 mm
MACHINESIZE	250 kg

Figure3.4: Machine used for FSP (Vertical Milling Machine)

3.4. Tool

The tool is essential to the creation of the final result in FSP. It carries out two primary tasks: material movement and localised heating. This instrument consists of a 50mm cylinder, a pin, a shoulder, and a tiny cylinder lock drill. In addition to these components, two new pins have emerged: Flared Tri flute: the pin has vertical engravings; A skew is when a pin's axis is angled towards a spindle's axis.

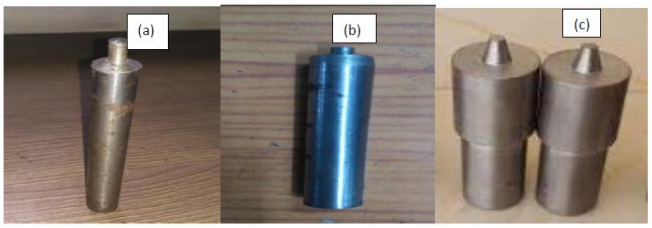


Figure 3.5: Tool used in the study (a) Thread cylindrical pin (b)Plain Cylindrical pin; (c) Tapered cylindrical pin

3.5. Muffle Furnace

Muffle furnace is box type furnace which has a heating chamber it is used in all lab work up to 3000 degree Celsius. It is used for high temperature application such as milling glass, creating enamel coating soldering and brazing.

Figure 3.6: (a) Muffle Furnace Figure 3.6 (b).Heating Chamber

3.6 Experimental Procedure

The magnesium alloy sheets are used in this study. The magnesium alloy AZ31B's composition is listed in table 3.1. A vertical milling machine is used to friction stir process magnesium alloy sheet. The FSP magnesium alloy sheet is treated using a stirrer as the tool under various tool angles, variable speeds, and varying reinforcement material compositions. Because of the heat inside, the rotating tool is able to penetrate the seat while turning. The magnesium alloy sheet becomes entangled with the reinforcement material. It is a heated working procedure because of the plastic deformation caused by the mixing of the reinforcement material and magnesium. First, the sheet is drilled, and then the VMM is processed using a stirrer under FSP.

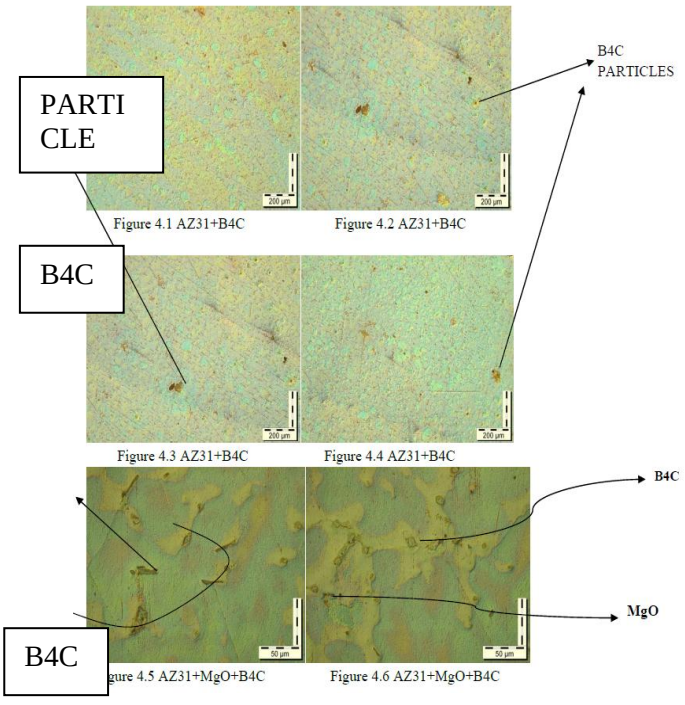
3.7 Micro structural analysis procedure

After the FSP of Mg alloy the samples from the sheet are cut down and the samples are cleaned by the use of proper use of abrasive paper. The size of samples has been chosen wisely according to the sizes provided by the microscopy machine. Now these samples are prepared by use of appropriate grit papers of different size. After this sample are to be moulded with use of mounting press machine with Bakelite powder. Afterwards these samples undergo testing in the electron microscopy machine. Through this we get the Grain refined region and the size of grain and grain boundary.

4. RESULT AND DISCUSSIONS

4.1 Micro structural analysis

The figure displays the microstructure of the magnesium alloy's FSP at various rotational speeds and with varying reinforcement materials. The uniform mixing of reinforced particles in the magnesium alloy's base metal is shown in Fig 4.1-4.10.
After a while, less heat is produced and the boron particles continue to be larger. This is because mixing is useless. By generating turbulence and speeding up the stirrer's spin, this can be decreased. The microstructure pictures of various samples are shown below.



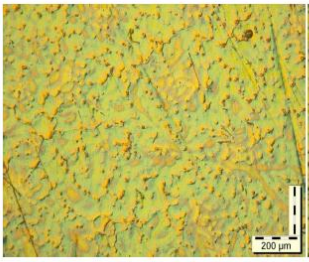


Figure 4.7 AZ31+MgO

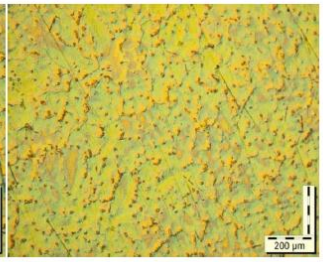


Figure 4.8 AZ31+MgO

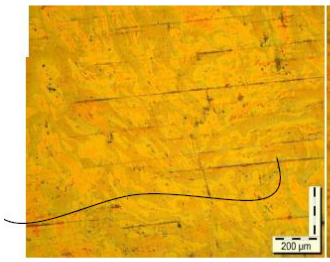


Figure 4.9 Flow of material in MgO+B4C+AZ31

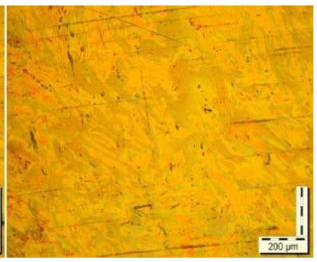


Figure 4.10 Flow of material in B4C+AZ31

4.2 Scanned Electron Microscopy (SEM)

SEM image of FS processed samples at different magnification of samples

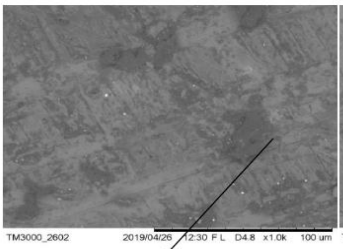


Figure 4.11 B4C particles

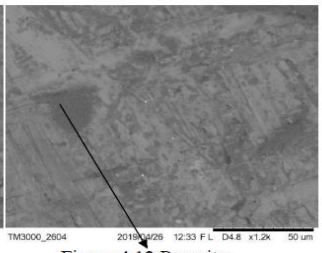


Figure 4.12 Porosity

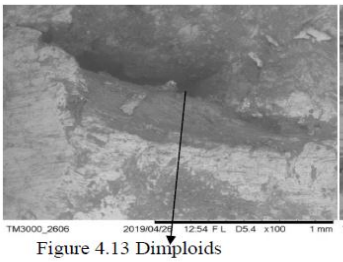


Figure 4.13 Dimploids

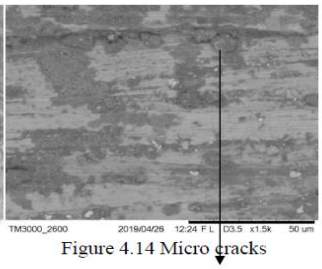


Figure 4.14 Micro cracks

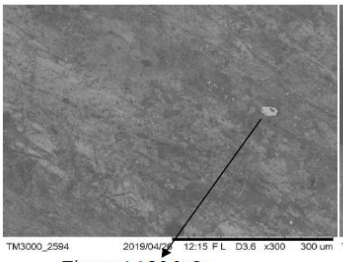


Figure 4.15 MgO

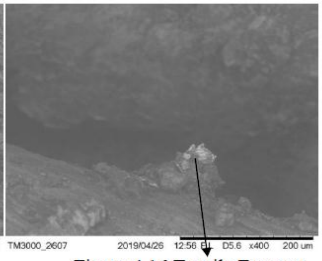


Figure 4.16 Tensile Fracture

4.3 EDX

Energy dispersive x-ray analysis or EDAX test is performed for determining the different elements present in MMC . By EDX calculation of their chemical composition atomic weight % is calculated. Test of material reinforced with B4C +MgO is done here.

4.3.1 (AZ31+B4C+ MgO)

Test of material reinforced with B4C +MgO is done here. Composition of Boron and Mg can be seen from graph. There is also the presence of Mn and Fe is there due to the composition present in the base metal.

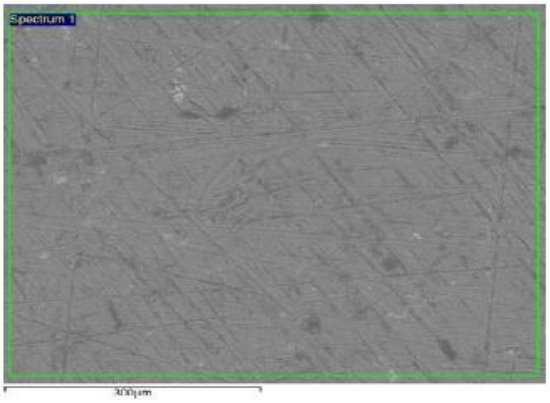


Figure 4.17 EDX images of AZ31+B4C+ MgO

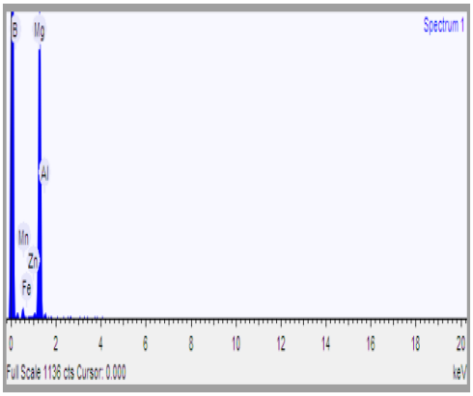


Figure 4.18 EDS spectra of AZ31+B4C+ MgO

4.4. Summary results

Table 4.1: Table of composition of AZ31+B4C+ MgO

Element	Weight %	Weight % σ	Atomic %
Boron	30.6%	0.346	10.256
Mg	63.445	1.144	95.731
Aluminium	3.688	0.702	3.383
Manganese	0.398	0.698	0.179
Iron	0.000	0.000	0.000
Zinc	1.869	0.661	0.708

5. CONCLUSION AND FUTURE WORK

5.1 Conclusion

The project's outcome indicates that the process has been impacted by a number of FSP process parameters, including tool angle, speed, and reinforcement. According to the microstructure of magnesium alloy and its reinforcement, the grain of that portion processed at low speed is less refined than the grain of that part processed at high speed. Grain growth and plastic deformation are significantly influenced by heat generation during processing. Therefore, the effect of process parameters can be used to analyse and evaluate the entire process as well as demonstrate how to optimise it for better future purposes.

5.2. Future Work

- By adjusting additional process parameters, more experimental research may be conducted to gain a deeper knowledge of the process.
- Preheating, or heating the specimen, may assist us improve the sample's grain growth cause.
- The literature review indicates that fine grain has superior strength and ductility; therefore, this might be another topic of focus for future research.

.

REFRENECES

[1] Kumar G. B. Veeresh, RaoC. S. P., Selvaraj N., Mechanical and tribo logical behavior of particulate reinforced aluminium metal matrix composite -a review, Journal of Minerals & Materials Characterization & Engineering, 2011, 10(1), 59-91.

[2] Hull D., Cline T. W., An introduction to composite materials, Cambridge, UK: Cambridge Univ. Press, 1996.

[3] Rohatgi P.K., Low-cost fly-ash-containing aluminium-matrix composite- overview, JOM-1994, (46), 55-59.

[4] Rohatgi P.K., Guo R.Q., Huang P., Ray S., Friction and abrasion resistance of cast aluminium alloy-fly ash composite,Metallurgical and Materials Transactions- A,1997, (28), 245-250.

[5] Miller W.S., Zhuang L., Bottema J., Wittebrood A.J., Smet P. De, Haszler A., Vieregge A., Recent development in aluminium alloys for the automotive industry, Materials Science and Engineering, 2000, A(280), 37-49.

[6] Naher S., Brabazon D., and Looney L., Simulation of the stir casting process, Journal of Material Processing and Technology, 2003,(143-144), 567–571.

[7] Srinivasan,A.,ArunachalamR.M.,RameshS.andSenthilkumaarJ.S., Machiningperformancestudyon metal matrix composite-a response surface methodology approach, American Journal of Applied Sciences ,2012, 9 (4), 478-483.

[8] BergesonA.,Non-ferrousMaterials, Nucleus,1996,8(5),5-11.

[9] KellyA.,Thenatureofcompositematerials,Science American,1967,217(3),161-176.

[10] SuchetclanVan,PhilipsRes.Reports,1972,(27), 28.

[11] Behera R, Das S, Chatterjee, D. and Sutradhar, G, 2011. Forgeability and machinability of stir cast aluminum alloymetal matrixcomposite. Journal of Minerals & Materials Characterization &Engineering, (10), 923-939.

[12] SurappaM.K.,Rohatgi,P.K.,Preparationandpropertiesofaluminiumalloyceramicparticlecomposite, Journal of material sciences,1981, (16), 983–993.

[13] Gupta M and Surappa MK, Processing-Microstructure-Mechanical properties of al based metal matrix composite synthesized using casting route, Key to Engineering Materials, 2003, (104-107), 259-274.

[14] Das S., Development of Aluminum Alloy Composite for Engineering Applications, Indian Institute of Materials, 2004, 27(4), 325-334.

[15] Trostyanskaya E.B., Polymeric materials in fibre-reinforced composite material, Polymer Matrix Composite, 1995, R.E. Shalin (Eds.), 1-4.

[16] Upadhya K., Ceramics and composite for rocket engines and space structures, Journal of the

Minerals, Metals and Materials Society, 1992, 44(5), 15-18.

[17] ChawlaK.K.,Ceramicmatrixcomposite,secondeds. ,KluwerAcademicPublishers,Massachusetts, 2003, 1-10.

[18] ClyneT.W.,AnintroductoryoverviewofMMCsyste m,typesanddevelopments,T.W.Clyne(Eds.), Comprehensive Composite Materials, 2000, (3), 1-26.

[19] Rohatgi, P.K., Gupta, N., Daoud, A., Synthesis and processing of cast metal matrix composite and their applications, ASM Handbook Casting, 2008, (15). ASM International, 1149-1164.

[20] IbrahimA.,MohamedF.A.,LaverniaE.J.,Particulate reinforcedmetalmatrixcomposite-areview, Journal of Material Sciences, 1991, 26 (5), 1137-1156.