Lecture Notes in Mechanical Engineering

Bhupendra Prakash Sharma
G. Srinivasa Rao
Sumit Gupta
Pallav Gupta
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Advances in Engineering Materials

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Editors
Bhupendra Prakash Sharma
Department of Mechanical Engineering
Amity School of Engineering
and Technology
Noida, Uttar Pradesh, India

G. Srinivasa Rao
Department of Mechanical Engineering
Amity School of Engineering
and Technology
Noida, Uttar Pradesh, India

Sumit Gupta
Department of Mechanical Engineering
Amity School of Engineering
and Technology
Noida, Uttar Pradesh, India

Pallav Gupta
Department of Mechanical Engineering
Amity School of Engineering
and Technology
Noida, Uttar Pradesh, India

Anamika Prasad
Department of Mechanical Engineering
South Dakota State University
Brookings, SD, USA

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Preface

This book gets together the pool of cutting-edge research articles on different aspects of engineering materials from the Second International Conference on Future Learning Aspects for Mechanical Engineering (FLAME 2020), which was organized by the Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Uttar Pradesh, Noida, India, from August 5 to 7, 2020. The key role of this conference was to lay a platform that brings academicians, industrialists, scientists, and researchers across the globe together to share their innovative ideas and vision in the areas of thermal, design, industrial, production, materials, and interdisciplinary areas of mechanical engineering. FLAME 2020 played a vital role to set up a bridge between academics and industries. The conference hosted almost 600 participants to interchange scientific ideas. During the 3 days of the conference, researchers from academica and industry offered the most recent cutting-edge findings and went through several technical brainstorm sessions and panel discussions, where they exchanged ideas on practical socioeconomic topics and on the theme "How to Frame the Industry Academia collaboration for "ATMANIRBHAR BHARAT." This conference also provided an opportunity to establish a network for joint collaboration between academicians and industries. Major emphasis was on the recent developments and innovations in various fields of mechanical engineering through plenary and keynote lectures. The book gives an overview of recent developments in the field of engineering materials and covers theoretical and experimental processing and development of noble or composite materials, chemical and mechanical characterizations, and microstructural studies. The book is primarily intended for researchers and professionals working in the field of engineering materials. Experts working in the field of materials will be able to evaluate and differentiate all materials or material combinations currently in use whether they are metals, ceramics, polymers, semiconductors, or composites. The success story of this event from begining to outcome in the form of book can not be completed without acknowledgements. Therefore, we would like to acknowledge all the participants who have contributed to this volume. We also deeply express our gratitude for the generous support provided by Amity University, Noida. We also thank the publishers and every staff of the department and institute who have directly or indirectly assisted to accomplish this goal. Finally, we would also like to express gratitude to the respected

Founder President, Amity University, Uttar Pradesh, Dr. Ashok K. Chauhan, for providing all kinds of support and blessings.

In spite of sincere care, there might be typos and always a space for improvement. We would appreciate any suggestions from the reader for further improvements in this book.

Noida, India	Dr. Bhupendra Prakash Sharma
Brookings, USA	Dr. Anamika Prasad
Noida, India	Dr. Pallav Gupta
Noida, India	Dr. Sumit Gupta
Noida, India	Dr. G. Srinivasa Rao
2020	

About This Book

This book comprises select proceedings of the International Conference on Future Learning Aspects of Mechanical Engineering (FLAME 2020). The book gives an overview of recent developments in the field of engineering materials and covers theoretical and experimental processing and development of noble or composite materials, chemical and mechanical characterizations, and microstructural studies. The book is primarily intended for researchers and professionals working in the field of engineering materials. The researchers, working in the area of material science and engineering will be able to evaluate and differentiate all materials or material combinations currently in use such as smart materials, bio-materials, non-metals, metals, ceramics, polymers, semiconductors, or composites. Also, this book will help the working professionals to comprehend the structure of a material for determining its characteristics and how it subsequently works in technological applications. Materials characterization techniques, which emphasize practical applications and real-world case studies, introduce the principles of commonly used, sophisticated surface, and structural characterization methods for quality assurance, contamination control, and process improvement are the key content of this volume. This volume of the book:

- Explores science procedures for characterizing materials using contemporary techniques
- Analyzes the performance of materials under circumstances of use
- Focuses on interrelationships and interdependence between processing, structure, characteristic, and performance
- Details of the advanced tools engaged in an interdisciplinary approach to understanding the broad variety of interrelationships with processes, mechanisms, and materials
- Covers electron, X-ray photoelectron, and UV spectroscopy; scanning electron, atomic power, transmission electron, and laser confocal scanning fluorescent microscopy; and gel electrophoresis chromatography
- Presents the basics of vacuum as well as the principles of X-ray diffraction.

The writers omit long and often intimidating derivations and formulations to explain suitable uses and associated technical specifications for characterization methods. Rather, they highlight helpful fundamental concepts and applications of contemporary techniques used to characterize engineering materials, helping readers to understand micro- and nanoscale characteristics.

Contents

About the Editors

Dr. Bhupendra Prakash Sharma Associate Professor, Department of Mechanical Engineering, Amity School of Engineering and Technology Noida, Amity University Uttar Pradesh. He has completed his Ph.D. from Motilal Nehru National Institute of Technology Allahabad, Prayagraj, Uttar Pradesh India in 2013 and passed Master of Engineering in Automated Manufacturing Systems from Birla Institute of Technology Mesra, Ranchi in 2007. He has more than twelve years of teaching and research experience at private and government institutes and universities. He has contributed more than 50 papers at the national/international levels with two best paper awards and filed four patents as well. His current areas of interest include manufacturing systems, analysis and processing of composite materials, recyclability, circular economy and knowledge management.

Dr. G. Srinivasa Rao is working as an Assistant Professor III in the Department of Mechanical Engineering, Amity School of Engineering and Technology Noida, Amity University Uttar Pradesh. He has completed his Ph.D. from Jawaharlal Nehru Technological University, Kakinada, Andhra Pradesh India in 2016 and passed Master of Technology in Production Engineering from Acharya Nagarjuna University in 2006. He has more than thirteen years of teaching and research experience at private colleges and universities. He has published more than 20 papers in international conferences and journals. His current areas of interest include the welding of aluminium alloys, corrosion and composite materials.

Dr. Sumit Gupta is an Assistant Professor in the Department of Mechanical Engineering, Amity School of Engineering and Technology (ASET), Noida. He is graduated in Mechanical Engineering from University of Rajasthan in 2008 and earned Master's and Doctorate degree from Malaviya National Institute of Technology Jaipur in 2010 and 2016 respectively. He has 10 years of teaching, research and Industry experience. He has published more than 30 research papers in various national and international journals & conferences and delivered invited lectures at various forums. He is Reviewer of various national and International Journals. His areas of research are sustainable manufacturing, lean manufacturing, Industry 4.0, sustainable product design, sustainable supply chain management and sustainable composite materials. He is a member of various International & National professional Societies.

Dr. Pallav Gupta completed his M.Tech. and Ph.D. from Indian Institute of Technology (Banaras Hindu University), Varanasi (INDIA) in year 2011 and 2015 respectively. Since then he is working as an Assistant Professor in Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University Uttar Pradesh, Noida (INDIA). He has published more than 75 research papers in reputed journals and conferences. He has also published 06 chapters in books published by Springer. His area of research includes Material Processing; Composite Materials; Metal Matrix Nanocomposites; Coatings/Nanocoatings; Wear; Deformation and Corrosion.

Dr. Anamika Prasad is working as an Assistant Professor with Department of Mechanical Engineering at South Dakota State University, USA. Before this position, she worked Visiting Asst. Prof, Institute of Technology, University of Washington Tacoma. She, also, worked as an Assistant Professor in the department of applied mechanics, Indian Institute of Technology Delhi, Applied Mechanics. She completed her Ph.D. from Massachusetts Institute of Technology in 2007. Her research areas are Materials Science, Biomaterials, Biomedical devices, Solid Mechanics, Mechanical

Testing. She got Gandhian Young Technological Innovation -Technical Edge Appreciation award in 2015. She received Indian patent for A Novel Device for Measuring Pressure Pulses based on Applanation Tonometry.

Challenges and Opportunities in Synthesis of Hybrid Cu-Al_2O_3-C and Cu-ZrO_2-C Composites Through Stir Casting Route

Prateek Mittal, Shailesh Singh Sengar, Sorabh, Mani Kant Paswan, Jimmy Mehta, Dinesh Chawla, and Pallav Gupta

Abstract Composites have been used by mankind from ages in producing different tools and equipment. Metal matrix composites became popular due to their better mechanical and thermo-physical properties as compared to pure metals and alloys. The aim of the present study is to highlight the key challenges in the synthesis of copper matrix-based hybrid Cu-Al2O3-C and Cu-ZrO2-C composites through stir casting route. The reinforcement varied in composition from 1 wt to 4 wt%. Stir casting as a process for synthesis of metal matrix composites (MMCs) has gained popularity due to its cost effectiveness and simplicity. Stir casting involves the mixing of reinforcement with the molten metal matrix through stirring in a furnace and then pouring it in a die for solidification. This liquid metal process requires careful execution and control over the parameters in order to produce the high quality MMCs. Stir

P. Mittal (✉) · S. S. Sengar · Sorabh · J. Mehta · D. Chawla
Department of Mechanical Engineering, Manav Rachna International Institute of Research and Studies, Faridabad, India
e-mail: prateekmittal.fet@mriu.edu.in

S. S. Sengar
e-mail: shaileshsengar@yahoo.com

Sorabh
e-mail: sorabh012@gmail.com

J. Mehta
e-mail: jimmy.fet@mriu.edu.in

D. Chawla
e-mail: dineshchawla.fet@mriu.edu.in

P. Mittal · P. Gupta
Department of Mechanical Engineering, A.S.E.T., Amity University Uttar Pradesh, Noida, India
e-mail: pgupta7@amity.edu

M. K. Paswan
Department of Mechanical Engineering, National Institute of Technology Jamshedpur, Jamshedpur, India
e-mail: mkpaswan.me@nitjsr.ac.in

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casting process has some limitations associated with it such as nonuniform dispersion, agglomeration of reinforcement particles, formation of oxides and intermediate phases, porosity and cracks. This paper brings to the fore these limitations and suggests the ways to improve the process so that desired properties can be obtained in the composite. This work also generates the opportunities for the development of new and innovative alternatives to overcome the challenges associated with stir casting in synthesis of MMCs.

Keywords Stir casting · Copper matrix composites · Hybrid MMCs · Composite materials · Metal matrix composites

1 Introduction

Metal matrix composites (MMCs) have gained a definite edge over pure metals and alloys because of their better mechanical and thermo-physical properties like high strength-to-weight ratio, low coefficient of thermal expansion and good fatigue resistance [1, 2]. The low weight advantage makes them suitable for the structural applications in aerospace industry. Good thermal conductivity with low coefficient of thermal expansion makes the MMCs deployable in various thermal management applications. Stir casting is the technique wherein reinforcement is added to the molten metal while stirring the mix with a stirrer to create a vortex so that the particles are sucked into the metal matrix and distribute uniformly inside it. Once the mix is stirred for the required time, the molten mixture is poured in a mould to obtain the required composite specimen [2]. Stir casting has been rigorously used in the mass production of MMCs due to its cost advantage over other popular methods [2]. Addition of a ceramic reinforcement in the copper (Cu) metal matrix reduces the coefficient of thermal expansion which enables these materials to effectively work as heat sink or thermal reservoir [3]. MMCs having ceramics as reinforcements tend to become very hard due to hard nature of ceramic particles which is why, in recent times, softer reinforcements are also added to strike a balance between the mechanical and other properties of the so formed composite [4]. The MMCs having two or more reinforcement within the metal matrix are called hybrid composites. The ceramic particles when added as reinforcement tend to enhance the tribological behaviour of the composites, but the thermal properties are somehow compromised, moreover the mixing ability of copper with the ceramic particles is very poor [5, 6]. Due to improper mixing of ceramic particles, the properties of the composites tend to be nonuniform [7]. Even after the existing limitations, stir casting is used as a popular method of producing metal matrix composites due to its cost effectiveness and simplicity [8]. The mechanical and wear properties of the composite materials depend to a great extent on the nature of the reinforcement, quantity of the reinforcement, production process and matrix material [9–15]. There are several challenges associated with stir casting process such as intermediate phase formation, crack development, oxidation and agglomeration of reinforcement phase. [16–21].

Challenges such as agglomeration and sedimentation are common in stir casting due to poor wetting capability of metal matrix with ceramic particles and larger contact angles. The uniform distribution of particles can be attained at higher stirring speeds as suggested by research works reported in the past [22, 23]. In this work, alumina and zirconia were chosen as reinforcement for development of materials suitable for heat sink and dental implants, respectively.

2 Methods and Materials

Method used for the fabrication of the composites in this work is stir casting. Stir casting method was chosen as it is economical and simple as compared to other methods like powder metallurgy, liquid infiltration and chemical vapour deposition. The composition of the composites consisted of copper as the base material. In the first system of composites, Al_2O_3 and graphite were used as reinforcements. In the second system, ZrO_2 and graphite were used as reinforcements. The reinforcements varied in composition from 1 wt to 4 wt%. Firstly, the copper ingots with 99% purity level were taken in the crucible and put to melt in the furnace. The reinforcement particles were preheated to 200 °C to remove any moisture content before adding them to the molten copper. Once the copper was melted, then the stirring was started using a mild steel stirrer with four blades. The stirring speed was kept at 300 rpm. After the staring of stirring process, the reinforcement particles were added, and the stirring was continued for about 90 min to create a strong vortex to suck the ceramic particles inside the matrix so that homogenous distribution of reinforcement is obtained in the composite. After stirring the melt, the mixture was poured in a mould of cylindrical shape to obtain the required composite specimen. For preparation of samples, the cast specimens were ground and rubbed with emery paper followed by polishing and etching using a mixture of HCl and water. Table 1 shows the composition of prepared samples.

Table 1 Composition of prepared samples

System of samples	Matrix wt%	Reinforcement wt%
System-1 (4 samples)	Cu (98–92 wt%)	Al_2O_3 (1–4 wt%), Graphite (1–4 wt%)
System-2 (4 samples)	Cu (98–92 wt%)	ZrO_2 (1–4 wt%), Graphite (1–4 wt%)

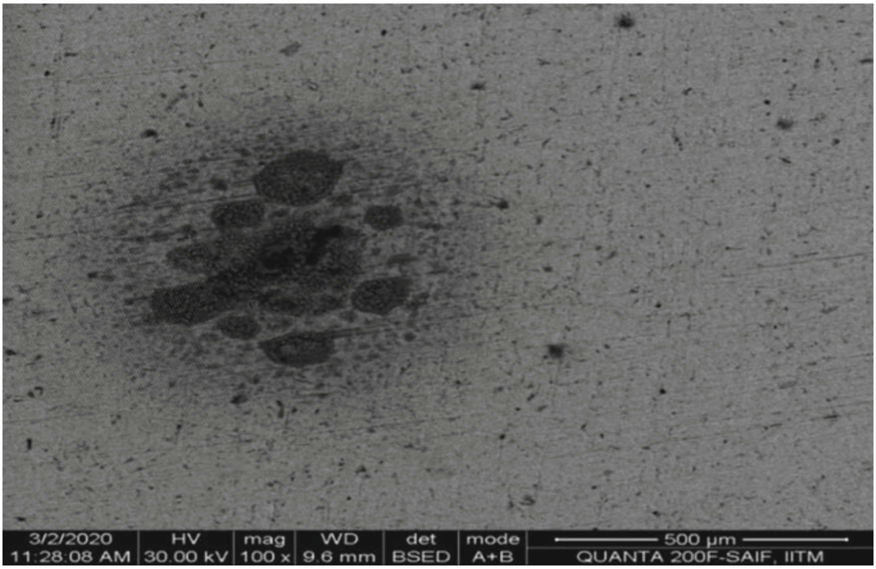

Fig. 1 Agglomeration of reinforcement phase in the metal matrix (Cu-ZrO_2-C)

3 Challenges

3.1 Agglomeration of Reinforcement Phase

Due to poor mixing between copper matrix and the reinforcement (ceramic particles and graphite), the dispersion of the reinforcement is not uniform, and this promotes the occurrence of agglomeration or formation of clusters of reinforcement phase. Figure 1 shows the image of Cu-ZrO_2-C composite wherein agglomeration of ceramic particles is evident with traces of graphite. This agglomeration not only disturbs the homogeneity of the composite but also affects the mechanical and thermo-physical properties [24–27]. This defect in the MMCs prepared by stir casting process can be reduced by the preheating the moulds, dies and reinforcements. Also, addition of some suitable wetting agent like magnesium may yield the desired results.

3.2 Porosity

Porosity is another defect which arises in the stir casting process especially with manual pouring. Porosity deteriorates the quality of the metal matrix composites. The small holes according inside the structure of the composites are indicative of the porosity. Porosity leads to weakening of the composites and reduces its endurance

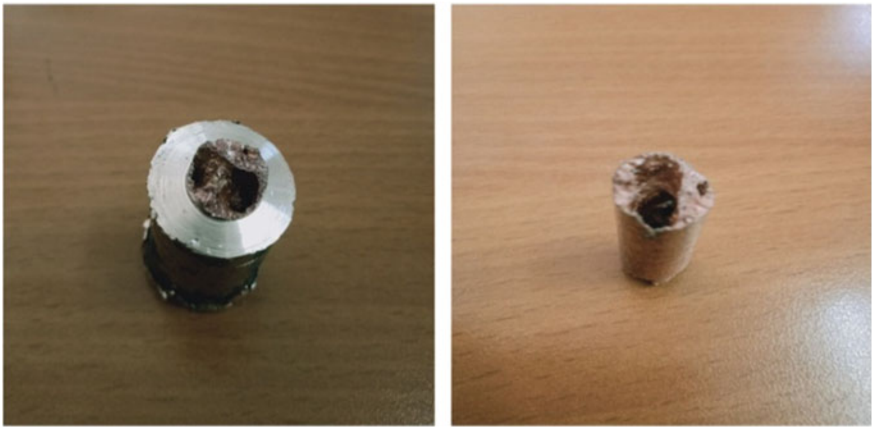

Fig. 2 Porous Cu-ZrO_2-C composite formed by stir casting

limit. Figure 2 shows fractured composites indicating the porosity present inside the material. The primary reason for this porosity is intermittent pouring and entrapment of environmental gases. When the material is poured in the mould or die and the pouring is discontinued even for a short span, then porosity may occur due to differential solidification of the poured material. This defect can be avoided by using shielding gas like argon or carbon dioxide and automatic pouring or automation of the complete stir casting process.

3.3 Oxidation

Molten metal has high tendency to get oxidized. In the fabrication of MMCs through stir casting, the chances of the melt being oxidized are high during pouring as reported by Jamwal et al. [2]. This oxidation of the molten mix can be avoided by using an inert environment by any shielding gas like argon or carbon dioxide. The oxide phase is undesirable and can be detected in patterns obtained after X-ray diffraction (XRD) of the composite samples. Jamwal et al. [2] reported the presence of oxide phase in the hybrid copper composite samples containing SiC and graphite as the reinforcement phase in the peaks of the XRD pattern. Figure 4 shows the SEM micrograph of the defect-free specimens produced through stir casting route in the presence of argon gas as shielding agent.

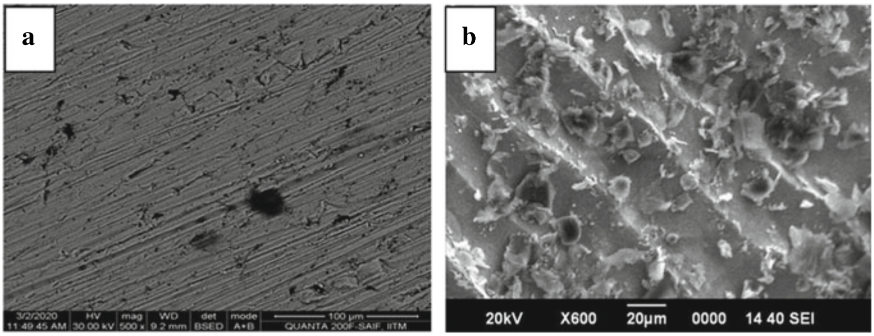

Fig. 3 SEM micrographs of **a** Cu-ZrO_2-C & **b** Cu-Al_2O_3-C composites fabricated through stir casting

3.4 Cracks

Cracks occur in the fabrication of MMCs through stir casting due to variable heat transfer rate during cooling and solidification. This could take place as a result of large difference between mould temperatures and melt temperatures. Also, the improper dispersion of the reinforcement phase in the metal matrix is another reason for crack formation. It has been observed that due to high temperature interaction between reinforcement and matrix material sometimes a new unwanted phase is formed and deters the formation of a strong interfacial bond between reinforcement and matrix. These aforementioned possible reasons of the cracks occurring in the MMCs may be addressed by stirring for longer periods, thereby creating a strong vortex to suck the reinforcements inside the molten matrix. Also, preheating the moulds and reinforcement is one of the ways to avoid cracks. Figure 3 shows a SEM micrograph showing crack in Cu-Al_2O_3-C hybrid MMC.

4 Opportunities

The limitations of the stir casting process create new opportunities in the development of novel techniques and processes to enhance the quality of composites produced through stir casting. The processes may be modified, or a combination of two or more processes may be used in order to obtain the right quality of hybrid metal matrix composites. The opportunities lie in the following areas:

- Simple shielding environments during fabrication of MMCs to avoid oxidation;
- Stirrer geometries, speeds and materials for different MMCs;
- Pouring techniques to avoid differential solidification;
- Development of new materials which may be added as wetting agents so as to increase the interfacial bonding between metal matrix and reinforcement particles;

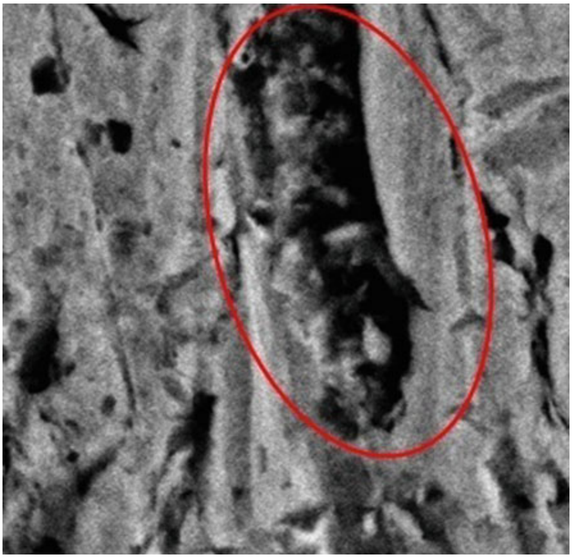

Fig. 4 SEM image of crack in Cu-Al_2O_3-C hybrid MMC

- Quantification of effect of various process parameters on the uniform dispersion of reinforcement particles within the metal matrix.

5 Results and Discussion

After careful examination of the micrographs and other images of composite samples with varied compositions of reinforcement, it has been found that agglomeration of ceramic particles occurs at lower stirring speeds and tends to reduce with the increase in speed. Figure 2 indicates the agglomeration of reinforcement in Cu-ZrO_2-C composite samples. The cracks and porosity in the samples may occur due to entrapment of atmospheric gases or differential solidification or impurities being mixed due to forced vortex created at the time of stirring. Figure 3a, b indicate the porosity and cracks in the composite samples of Cu-ZrO_2-C and Cu-Al_2O_3-C specimens, respectively. The use of shielding gas was found to eliminate the formation of oxides and intermediate phases as indicated in the SEM micrographs in Fig. 4.

6 Conclusions

Based on the study of the hybrid copper composites fabricated through stir casting, the following conclusions can be drawn regarding the challenges that may affect the quality of the composites and the opportunities that lie underneath:

- Although stir casting is an economically superior method as compared to other popular methods of fabricating MMCs, it poses some challenges pertaining to the quality of the composites.
- Density difference, wettability factors and stirring parameters affect the distribution of ceramic particles in the metal matrix and interfacial bonding. This can be improved by preheating the reinforcement and using some suitable wetting agent.
- Use of shielding gas like argon reduces the formation of oxides, gas entrapment and impurities in the MMC which contributes to the improvement in properties of the formed composites.
- Cracks and porosity can be eliminated by preheating the mould, continuous pouring and eliminating differential solidification.
- Development of more suitable and precise alternatives apart from the ones mentioned in this paper to address the challenges in stir casting paves the way towards new opportunities in this area for future researchers.

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Mechanical Characterization of a Fly Ash and Glass Fibers Reinforced Hybrid Epoxy Composite

Sandeep Kumar and Monika Singh

Abstract Epoxy has versatile industrial applications due to its brilliant characteristics, but on the other hand due to the delamination, brittleness, low toughness of epoxy limited its usage. These constraints of epoxy can get over by inclusion with the help of reinforcement before their industrial and aerospace application. In recent days, glass fiber reinforced composites are in demand as structural materials as well as aerospace parts due to low density. Authors have presented the last ten years review articles on different glass fiber composites. The interest of the present study is the focus on the mechanical properties of epoxy hybrid composite, made up of glass fibers, and reinforced with fly ash. Experimental data has been shown by picking various ratios of glass fiber (E-300, MAT form) with epoxy resins and with different composition of fly ash reinforced that fly ash significantly increases hardness as well as compressive strength in epoxy composite.

Keywords Epoxy · Glass fibers (GFRP- glass fibers reinforced polymer) · E-300 MAT form · Fly ash

1 Introduction

Composite materials are constituted of two phases: one is that continuously holds the second phase, i.e., reinforcement. Both phases are not soluble in each other but club together at the macroscopic level [1]. Matrix of epoxy resins are mostly used in fiber-reinforced composites due to their unique balance of chemical and mechanical properties versatile nature in material processing [2]. Due to specific strength, glass fibers reinforced material is most widely applicable in complex structural assemblies [3].

Epoxy resins are one of the best members of plastic group [4]. Epoxy composites have numerous applications in structural industry as well as automobiles and aircraft.

S. Kumar · M. Singh (✉)
Department of Mechanical Engineering, MIT Moradabad, Moradabad 244001, India
e-mail: m_singh@me.iitr.ac.in

S. Kumar
e-mail: sandeep.sun.varshney@gmail.com

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Epoxy resins, depends on the microstructure, can be liquids as well as solids with low and high viscosities [5]. Epoxy resins have excellent electrical properties, high toughness, and good adhesion to many meals with high resistance to moisture. These qualities of epoxy resins are the main reason for their wide applications in composite materials [6]. High pressure and high temperature are required to impregnate the fibers with highly viscous resins, although fibers with low viscosity resins do not require high pressure and temperature to impregnate [7].

Nowadays, hybrid epoxy-based composites are getting attraction of researchers because of brilliant mechanical, chemical qualities as well as these are good as environmental concerns and as well as their wide structural applications [8]. The use of natural fibers is increasing day by day as government regulations are also focusing on environmental issues. The center of the study is the mechanical properties of hybrid fiber consisting of glass fibers and fly ash as a filler material [9].

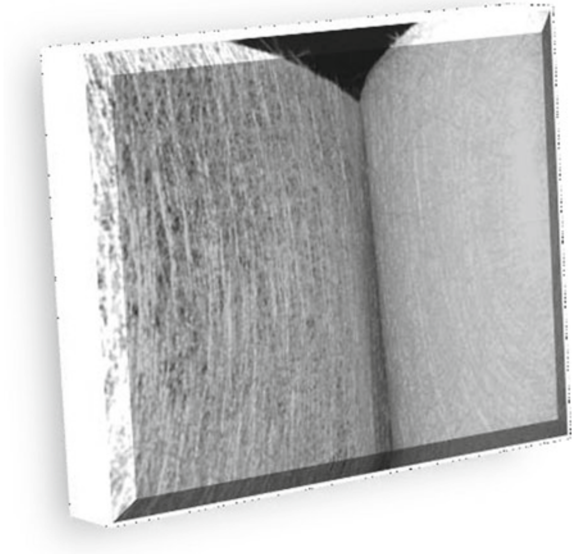
Glass fiber reinforced polymer, i.e., GFRP, has high corrosion resistance, high strength, and low value of modular elasticity. While, glass and other synthetic fibers have high stiffness and specific strength but due to the high cost of producing its use is still limited [10]. Glass fibers have wide application in mechanical joints due to their special physical and mechanical properties [11]. In recent era, natural fibers such as jute, vegetable waste, and cotton are using at the place of glass and carbon fibers [12]. Glass fiber provides the basic structures to the composite material, and fly ash enhances the mechanical and physical properties of the composite [13]. Nowadays, the use of glass fibers is very common in the production of composite [14]. However, the addition of fly ash as filler material gives more environmental friendliness to this hybrid composite. From different researches, it has been shown that the fly ash as the particulate filler can make the composite more compact as well as more compressive because of filling more voids in composite and glass fiber as fiber reinforcement gives directional properties to the composite [7].

The aim of this work is to fabricate a hybrid reinforced composite and testing out its mechanical and physical properties. All the mechanical tests and fabrication of composite have been done in the laboratory of material science in mechanical engineering at MIT Moradabad.

2 Material Used and Fabrication of Hybrid Composite Specimen

Fabricated reinforced composite constituent's fiberglass (matt form) as reinforced and fly ash as filler material. An industrial purposed epoxy resin named "ARALDITE LY556" is used to create acoustic bonding between fly ash and glass fibers. Epoxies are typically cured with stoichiometric or near-stoichiometric quantities of curative to achieve maximum physical properties. To solidify the epoxy resins and matt structure of glass fiber curing agent, "HY951" was used which is manufactured by Araldite. Curing is a process of hardening and toughening of polymers by cross-linking of

Fig. 1 Fiber glass matt form



chemical chains and creating an acoustic bond between them. It is very important to select the proper content of hardener to cure the matrix. Quality of curing is based on the position on which hardener is spread out, time for which specimens leave for curing, and the ratio in which hardener is taking. Uniform distribution of resins and temperature and pressure inside are very important parameters to be maintained [15]. In the present study, epoxy resins and hardener are taken in the ratio of 10:1 (Fig. 1).

Matt form glass fibers reinforced polymers consist of glass fibers that haphazardly arranged with the help of binders. The hand layup method is being used for processing, where material sheets are placed and spread with resins. The material easily conforms to various shapes when wetted out due to dissolved binder in resin. After curing of resins, the hardened product is taken out from the mold (Fig. 2).

Chopped strand matt allows a fiber glass with uniform material properties in all direction. Glass fibers are weak in shear loading, and due to its long aspect ratio, fiberglass are also weak in compression, and it buckles easily [14].

GFRP laminates were made by hand layup technique. Curing was performed at a temperature of about 25 °C for about 48 h.

Fly ash is a coal combustion product also called as pulverized fuel ash. It is mainly comprised of the finer particles of fuel that are driven out with the flue gases from coal-fired boilers.

Fly ash contains an amount of SiO2, Al2O3, and CaO as the main compounds depending upon the makeup of the coal being burned [12]. In coal power plants at the boiler outer periphery, some rest part of waste is collected which contained fly ash and bottom ashes [15]. The demand for materials such as fly ash is arising due