Pertanika J. Sci. & Technol. 26 (4): 1837 - 1848 (2018)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

An Exploratory Study to Evaluate the Thermal Conductivity of LM25-Borosilicate Glass (P) Composites under the Influence of Different End Chills

Anupama Hiremath[1]* and Joel Hemanth[2]

[1]*Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal-576104, Karnataka, India.*
[2]*School of Engineering, Presidency University, Bengaluru-560064, India*

ABSTRACT

The present paper encompasses the fabrication, experimentation, testing and thermal property evaluation of LM25-Borosilicate glass (p) composites obtained through stir casting route with judicious selection and placement of different end chills within the sand molds. The composites required for the present study were cast by melting LM25 aluminum alloy into which varied weight percent of Borosilicate glass powder was introduced under the application of a mechanical stirrer. The melt with required content of reinforcement was introduced in a sand mold containing one end chill. Metallic end chills (copper and mild steel) and non- metallic end chills (silicon carbide and graphite) were employed in the current research. Various thermal tests were conducted on the specimens drawn from near the chill end to evaluate thermal diffusivity and thermal conductivity of the fabricated composite. The analysis of the obtained results illustrate the fact that end chill materials have a pronounced effect on the evaluated thermal properties of the composite as employment of metallic end chills resulted in the reduction of the thermal conductivity of the specimens as opposed with the thermal conductivity values for specimens fabricated with the aid of non-metallic end chills.

Keywords: End chills, stir casting, thermal conductivity

ARTICLE INFO

Article history:
Received: 04 December 2017
Accepted: 25 April 2018
Published: 24 October 2018

E-mail addresses:
anupama.hiremath@manipal.edu (Anupama Hiremath)
joelhemanth@hotmail.com (Joel Hemanth)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

Recent years have witnessed the development of advanced aluminum alloys that possess excellent strength. But, the introduction of the required quantity and quality of alloying components and secondary processes to bring about the required modification in the final microstructure of the alloy is proven to be a costlier effect yielding a very slight improvement in the strength of the new alloy as compared to the base metal. The ever increasing demand for materials that exhibit immaculate strength to weight ratio coupled with superior mechanical and thermal properties has led to greater innovation in the field of aluminum metal matrix composites reinforced with nano-to- micro meter scale particulate reinforcements (Mousavian et al., 2016, pp. 58-70; Ma et al., 2014, pp. 366-373). Particle reinforced aluminum matrix composites (PAMCs) (Bodunrin et al., 2015), are known to demonstrate considerable advancement in tensile strength, resistance to wear and also exhibit excellent tailorability of the physical and thermal properties such as coefficient of thermal expansion, density and many more. Due to these derived advantages particle reinforced aluminum matrix composites are preferred over un-reinforced composites for practical applications (Kumar et al., 2016). PAMCs are composed of aluminum and its alloy as matrix reinforced with oxide, boride and carbide ceramic particles. The soft aluminum matrix (Ramnath et al., 2014; Nestler et al., 2014, pp. 125-130) imparts the required ductility, formability, conductivity of heat and electricity. On the other hand, the hard ceramic particles infuse the composite with excellent hardness, strength, resistance to wear and heat (Ma et al., 2017). PAMCs are fast replacing conventional monolithic metals in automotive applications which constantly demand for an extremely low strength- to-weight ratio to gain an excellent fuel economy (Saito et al., 2000). This calls for a thorough study of composite properties at elevated temperatures (200°C-550°C) to validate its use in automotive applications (Ravi Kumar et al., 1999, Garb et al., 2017). Thermal property evaluation is imperative for successful implementation of PAMCs in various automotive, aerospace, electronic packaging and various other heat management applications (Krishna et al., 2016). An effort has been made in the present paper to investigate thermal diffusivity and thermal conductivity of the fabricated PAMC to analyze its behavior at higher operating temperatures. Researchers are experimenting with glass, a most widely used ceramic material, for incorporation as reinforcement within aluminum and other metal matrices. Glass is easily available in all commercial grades at a very low cost and is known for its hardness and excellent resistance to very high operating temperatures. Review of the available literature also proves the fact that glass reinforced aluminum matrix composites possess appreciable mechanical and thermal properties over their matrix metal (Khoramkhorshid et al., 2016; Gopal et al., 2017). But, less work has been done to study the effect of borosilicate glass particulate reinforcement on the properties of aluminum and its alloys. An effort is made in the current research work to analyze the effect of borosilicate glass addition into LM25 matrix on the thermal conductivity of the PAMCs. Aluminum alloys pose a difficulty in feeding them into the mold cavity as they tend to cool over a varied range of temperature through the entire course of solidification. Thus it becomes imperative to strictly control various process parameters of casting. Researchers have found that judicious inclusion of end chills in the mold cavity results in drastic improvement in the quality of the PAMC castings (Hiremath et al., 2017).

MATERIALS AND METHODS

LM25 as matrix material

LM25 aluminum alloy is a cast alloy which finds its extensive application in the field of automobile industries where it is used to fabricate components such as cylinder heads and cylinder blocks that call for a material with excellent resistance offered against wear, corrosion and can retain its structural stability even at high operating temperatures (Bhatija et al., 2017). In the current research work, LM25 was selected as the matrix material due to its ability to be casted easily into any intricate shape with excellent accuracy. The elemental composition on weight percent basis of LM25 is illustrated in Table 1.

Table 1
Elemental composition of LM25

Elements	Zinc	Magnesium	Silicon	Copper	Manganese	Iron	Aluminum
Composition (Wt. %)	0.10	0.37	7.00	0.20	0.10	0.20	Balance

Borosilicate Glass Particles as Reinforcements

The work investigates the employability of the cast composites in severe operating temperatures which calls for the incorporation of thermally stable reinforcements. Hence, borosilicate glass, which is thermally very stable, was used as reinforcement. The available literature illustrates the fact that glass can be effectively used as reinforcement in PAMCs to obtain a newer composite exhibiting superior strength and structural stability (Zhang et al., 2017). In the current work borosilicate glass particles of 100 µm size was incorporated within the LM25 matrix as reinforcement. Borosilicate glass is a particular type of glass in which silica and boron trioxide elements are the main glass-forming constituents. Borosilicate glass possesses superior mechanical and thermal properties coupled with excellent resistance to wear and corrosion and possessing a very low coefficient of thermal expansion and hence, making it suitable to be employed in severe operating conditions (Hiremath et al., 2017). The elemental composition of borosilicate glass on weight percent basis, is approximately 80% silica, 13% boric oxide, 4% sodium oxide and 2–3% aluminum oxide. Table 2 depicts the mechanical and thermal properties of borosilicate glass.

Table 2
Mechanical and thermal properties of Borosilicate Glass

Mechanical Properties	
Compressive strength	2000 MPa
Young's Modulus	68 GPa
Ultimate Tensile Strength	280 MPa
Knoop Hardness	510
Thermal Properties	
Specific Heat Capacity	830 J/kgK
Coefficient of Thermal expansion	3.3 µm/m-K
Thermal Conductivity	1.2 W/mK

Materials for End Chills

The employment of end chills together with stir casting is made to obtain superior quality castings with minimum to zero defects through the promotion of controlled directional solidification. This is achieved by the ability of the chill to extract heat at a faster rate from the melt at the chill-composite interface, thus promoting directional solidification of the entire casting (Hemanth, 2017). External end chills possessing different volumetric heat capacities (VHC) were utilized in the current research to obtain sound castings with superior mechanical and thermal properties such as tensile strength, hardness and thermal conductivity. Table 3 depicts the thermal properties of the end chills employed in the current research.

Table 3
Thermal properties of the end chills

End chill material	Density (g/cm^3)	Specific heat (J/kg K)	Coefficient of Thermal Expansion ($\alpha \times 10^{-6}$/°C)	Thermal conductivity (W/m K)
Silicon carbide	3.21	650	4.0	120
Graphite	1.95	710	7.1	150
Copper	8.96	385	16.2	385
Mild Steel	7.85	502	12	66

Chill Casting

End chills of the required dimensions were carefully placed in the thoroughly air-dried sand mold cavity before the introduction of the melt (molten alloy mixed with required quantity of reinforcement) into the cavity. Two metallic chills made of copper and mild steel and two non-metallic chills made of silicon carbide and graphite were selected for the present research. The molds for the rectangular castings were prepared using silica sand with 5% bentonite and 5% moisture. The mold dimensions and arrangement of end chills in the mold cavity is as shown in Figure 1.

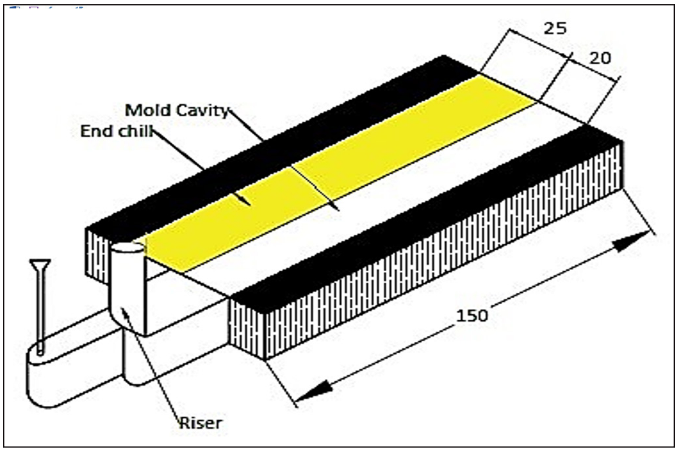


Figure 1. Placement of the End Chills in the Mold Cavity

Vortex Technique for Casting Particle Reinforced Composites

Vortex technique which is also called as stir casting is the most viable commercial technique for fabricating particle reinforced composites due to its numerous advantages that include low-cost, tailorability, simplicity and ease of adaptation in mass production scenarios. The vortex technique involves the addition of particulate reinforcements into molten metal matrix while the melt is simultaneously stirred with the help of a mechanical stirrer and thus producing a vortex that promotes uniform distribution of the particles within the melt (Singh et al., 2017). The LM25 alloy was melted in an electric furnace at approximately 750˚C; preheated borosilicate glass particulates (100 micrometers) were introduced in varied weight percent starting from 3 weight percent and going up till 12 weight percent with an increment of 3 weight percent in consecutive steps. The molten melt was stirred with the help of a mechanical stirrer rotated at 800 rpm for about 5 minutes. The melt was then introduced in properly air-dried green sand molds containing end chills. Figure 2 illustrates the solidified castings in the mold cavity.

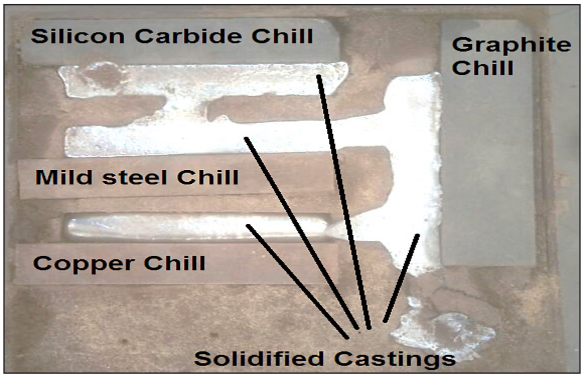


Figure 2. Solidified castings in the mold cavity

Density Measurement

The theoretical density (ρ) of the fabricated composite is obtained from the rule of mixtures as follows:

$$\rho_C = (V_M \times \rho_M) + (V_R \times \rho_R) \quad (1)$$

Where ρ is the density, V is the volume and suffixes C, M and R represent the cast LM25-borosilicate glass composite, LM25 matrix and borosilicate glass reinforcement respectively. The density of LM25 alloy used in the present work was 2.68 g/cc and the density of borosilicate glass particulate reinforcement was 2.23 g/cc. Experimental density was calculated by using the Archimedean water displacement method at ambient conditions.

Thermal Conductivity Test

The determination of thermal conductivity is achieved by the laser flash technique. The NETZCH LFA 447 Nano Flash ® equipment was used in the present work to evaluate the thermal conductivity of the specimens. Thermal conductivity of the sample can be calculated by measuring its thermal diffusivity provided its specific heat and density are known. The specific heat capacity of the composites was determined with the help of NETZCH DSC 200 f3 Maia differential scanning calorimeter equipment. If the density of the sample is known then thermal conductivity of that sample is obtained through:

$$\lambda_T = a_T \times C_{p_T} \times \rho_T \quad (2)$$

Where $\lambda_T$the thermal conductivity of the test sample, a_T the thermal diffusivity of the test sample, C_{p_T} the specific heat capacity and ρ_T the density of the test sample. The square samples of dimensions 10 × 10 × 3 mm were machined near the chill end of the Metal Matrix Composites (MMCs). The specimens were coded for recognition and were tested from room temperature to 300ºC. The specimens were coated with graphite spray on their front and rear side to improve the absorptivity of the flash on the front side and emissivity from the rear side.

RESULTS AND DISCUSSION

Density of the Composites

Table 4 illustrates the theoretical and experimental density of all the specimens with varied reinforcement content calculated using the above stated methods. Figure 3 illustrates the percentage difference in density for the cast MMCs.

Figure 4 depicts the microstructure of the composites reinforced with 6 wt.% reinforcement cast with the aid of metallic and non-metallic end chills. It is clear from the

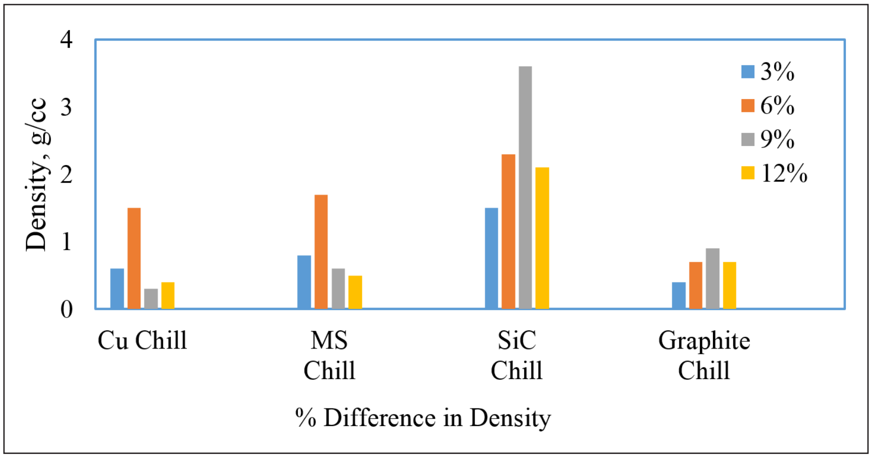
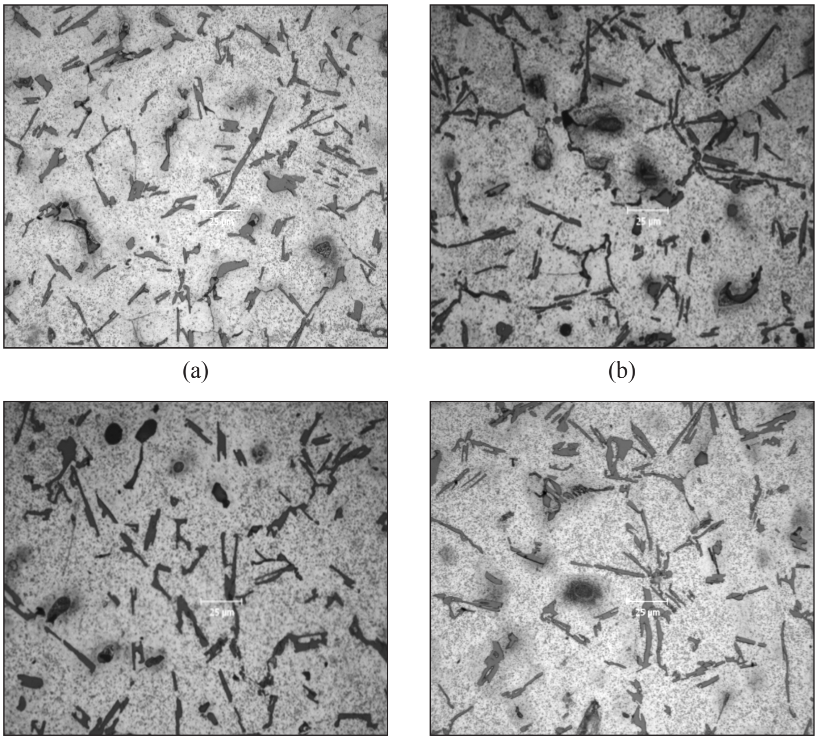


Figure 3. Percentage difference in density

Table 4
Specific heat capacity, experimental and theoretical densities of cast composites

End chills	LM25-Borosilicate glass Composites	Density in g/cc		Error	Specific heat capacity, Cp of cast MMCs (J/kgK)
	Wt.% Reinforcement	Theoretical	Experimental		
Copper	3%	2.665	2.671	0.006	950
	6%	2.653	2.668	0.015	947
	9%	2.639	2.642	0.003	940
	12%	2.626	2.630	0.004	938
Mild steel	3%	2.665	2.673	0.008	951
	6%	2.653	2.670	0.017	946
	9%	2.639	2.645	0.006	940
	12%	2.626	2.631	0.005	939
Silicon carbide	3%	2.665	2.680	0.015	950
	6%	2.653	2.676	0.023	945
	9%	2.639	2.675	0.036	941
	12%	2.626	2.647	0.021	940
Graphite	3%	2.665	2.669	0.004	952
	6%	2.653	2.660	0.007	944
	9%	2.639	2.648	0.009	940
	12%	2.626	2.633	0.007	939

microstructural examinations that the composites cast with the help of metallic end chills possess a refined grain structure. This is due to the fact that metallic end chills possess higher volumetric heat capacities and hence promote directional solidification of the melt (Hiremath et al., 2017; Hemanth, 2009; Anantha Prasad et al., 2015). Thus, composites cast with silicon carbide end chill possess a greater difference in their experimental and theoretical density values.



(a) (b) (c) (d)

Figure 4. Microstructure of Composites (6 wt.% reinforcement) Cast using Metallic and Non-metallic end chills. (a) Copper chill (b) Mild steel chill (c) Silicon carbide chill (d) Graphite chill

Specific Heat Capacities of the Composites

The specific heat capacities of the specimens are measured with the aid of NETZCH DSC 200 f3 Maia differential scanning calorimeter equipment and the results are tabulated. Table 4 illustrates the specific heat capacity values for the cast MMC samples.

Thermal Conductivity of the Composites

Figures 5, 6, 7 and 8 illustrate the variation of thermal conductivity of the fabricated composites with respect to temperature.

Analysis of the above mentioned result indicates that the thermal conductivity of the fabricated composites reduce with temperature and also with an increase in the borosilicate glass particulate content within the matrix. This is because borosilicate glass particulate reinforcement has an excellent resistance to temperature and a very low thermal conductivity of 1.2 W/m K at 90°C. This acts as a thermal insulator and thus lowers the thermal conductivity of the fabricated composite material. As the percent content of borosilicate glass particulate increases within the matrix, the thermal conductivity of the

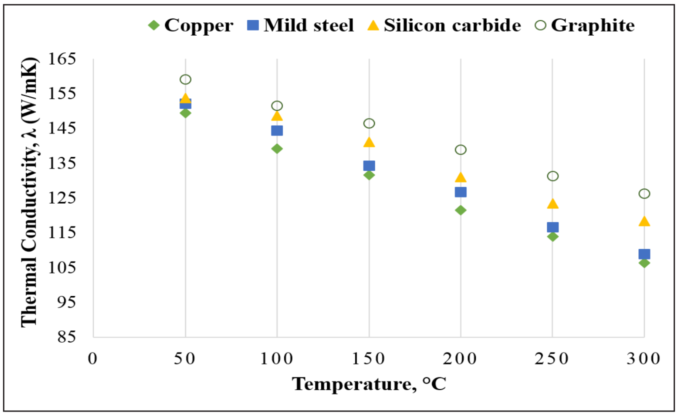


Figure 5. Thermal conductivity vs temperature for LM25-3 wt. % borosilicate glass particulate composite fabricated with different end chill

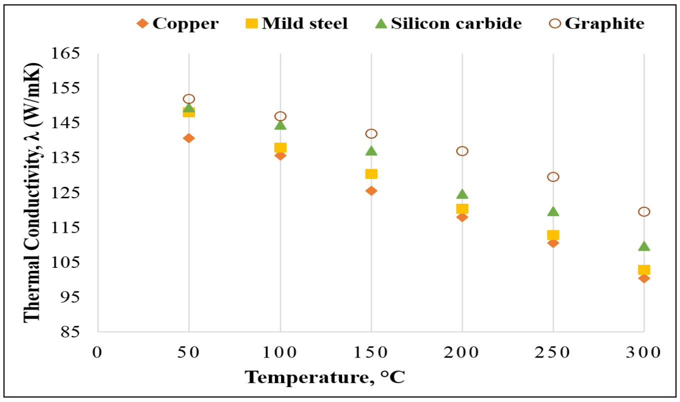


Figure 6. Thermal conductivity vs temperature for LM25-6 wt. % borosilicate glass particulate composite fabricated with different end chill

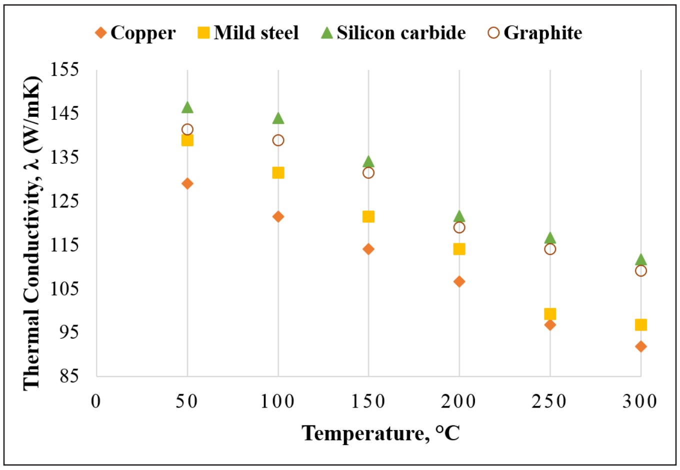


Figure 7. Thermal conductivity vs temperature for LM25-9 wt. % borosilicate glass particulate composite fabricated with different end chill

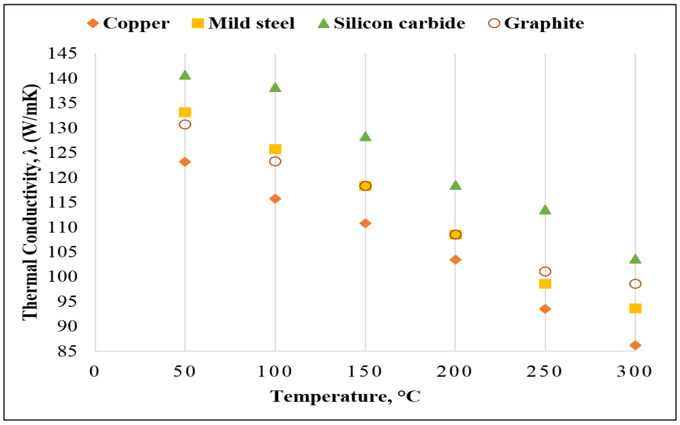


Figure 8. Thermal conductivity vs temperature for LM25-12 wt. % borosilicate glass particulate composite fabricated with different end chill

MMC also reduces. The thermal conductivity values for MMCs are less than the thermal conductivity value of LM25 (170 W/m K at 300°C). Analyzing the above mentioned thermal conductivity values we can conclude that the composite fabricated with the help of copper chill has the least value in comparison to the composite samples fabricated with the help of mild steel, silicon carbide and graphite end chills. Because copper chill with its higher VHC ensures a uniform distribution of borosilicate glass particles within the matrix compared to other end chills. The uniform distribution of the thermally resistant reinforcement results in the overall reduction of the thermal conductivity of the MMC.

CONCLUSIONS

The following conclusions can be drawn from the aforesaid statements:

- Increasing the borosilicate glass particulate content within the matrix is not beneficial for the thermal conductivity of the composite material.
- Chilling has a pronounced effect on the quality of the castings obtained and thus MMCs produced by the employment of metallic end chills have experimental densities almost equal to theoretical densities.
- The thermal conductivity values are least for composites fabricated with copper end chill followed by mild steel, silicon carbide and graphite end chills respectively.

REFERENCES

Bhatija, K. A., & Radhika, N. (2017). Studies on sliding wear characteristics of aluminium LM25/silicon dioxide functionally graded composite and optimisation of parameters using response surface methodology. *Materialwissenschaft und Werkstofftechnik, 48*(6), 600-610.

Bodunrin, M. O., Alaneme, K. K., & Chown, L. H. (2015). Aluminium matrix hybrid composites: A review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. *Journal of Materials Research and Technology, 4*(4), 434-445.

Garb, C., Leitner, M., & Grün, F. (2017). Effect of elevated temperature on the fatigue strength of casted AlSi8Cu3 aluminium alloys. *Procedia Structural Integrity, 7*, 497-504.

Gopal, P. M., Prakash, K. S., Nagaraja, S., & Aravinth, K. (2017). Effect of weight fraction and particle size of CRT glass on the tribological behaviour of Mg-CRT-BN hybrid composites. *Tribology International, 116*, 338-350.

Hemanth, J. (2009). Quartz (SiO_2p) reinforced chilled metal matrix composite (CMMC) for automotive applications. *Materials & Design, 30*(2), 323-329.

Hemanth, J. (2017). Effect of Metallic, Nonmetallic, Water Cooled and Cryogenic Chills on Pearlite Content (PC), Eutectic Cell Count (ECC) and Grain Size (GS) of Hypo Eutectic Nickel Alloyed Cast Iron. *Modeling and Numerical Simulation of Material Science, 7*(1), 1.

Hiremath, A., & Hemanth, J. (2017). Experimental Evaluation of the Chill Casting Method for the Fabrication of LM-25 Aluminum Alloy-Borosilicate Glass (p) Composites. In *6th International Conference of Advanced Materials and Engineering Materials, ICAMEM* (Vol. 748, pp. 69-73). Singapore.

Hiremath, A., & Hemanth, J. (2017). Experimental Evaluation of the Coefficient of Thermal Expansion of Chilled Aluminum Alloy-Borosilicate Glass (p) Composite. *Journal of Materials and Environmental Sciences, 8*(12), 4246-4252.

Khoramkhorshid, S., Alizadeh, M., Taghvaei, A. H., & Scudino, S. (2016). Microstructure and mechanical properties of Al-based metal matrix composites reinforced with Al 84 Gd 6 Ni 7 Co 3 glassy particles produced by accumulative roll bonding. *Materials & Design, 90*, 137-144.

Krishna S. A. M., Shridhar T. N., & Krishnamurthy L. (2015). Microstructural Characterization and Thermal Conductivity Behaviour of Al-6061-SiC-Gr Hybrid Metal Matrix Composites. *Indian Journal of Engineering & Materials Sciences, 23*(4), 207-222.

Kumar, A., Kumar, M., & Goyal, R. (2016). Mechanical behavior of Particle Reinforced Aluminium Matrix Composites. *International Journal for Innovative Research in Science & Technology, 2*(12), 436-439.

Ma, K., Lavernia, E. J., & Schoenung, J. M. (2017). Particulate Reinforced Aluminum Alloy Matrix Composites–A Review on the Effect of Microconstituents. *Reviews on Advanced Materials Science, 48*(2), 91-104.

Ma, Z., Samuel, A. M., Doty, H. W., Valtierra, S., & Samuel, F. H. (2014). Effect of Fe content on the fracture behaviour of Al–Si–Cu cast alloys. *Materials & Design, 57*, 366-373.

Mousavian, R. T., Khosroshahi, R. A., Yazdani, S., Brabazon, D., & Boostani, A. F. (2016). Fabrication of aluminum matrix composites reinforced with nano-to micrometer-sized SiC particles. *Materials & Design, 89*, 58-70.

Nestler, A., & Schubert, A. (2014). Surface properties in ultrasonic vibration assisted turning of particle reinforced aluminium matrix composites. *Procedia CIRP, 13*, 125-130.

Prasad, M. A., & Bandekar, N. (2015). Study of microstructure and mechanical behavior of aluminum/garnet/carbon hybrid metal matrix composites (HMMCs) fabricated by chill casting method. *Journal of Materials Science and Chemical Engineering, 3*(03), 1-8.

Ramnath, B. V., Elanchezhian, C., Jaivignesh, M., Rajesh, S., Parswajinan, C., & Ghias, A. S. A. (2014). Evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites. *Materials & Design, 58*, 332-338.

Ravi Kumar, D., & Swaminathan, K. (1999). Tensile deformation behaviour of two aluminium alloys at elevated temperatures. *Materials at high temperatures, 16*(4), 161-172.

Saito, M., Iwatsuki, S., Yasunaga, K., & Andoh, K. (2000). Development of aluminum body for the most fuel efficient vehicle. *JSAE Review, 21*(4), 511-516.

Singh, R., Singh, R., Dureja, J. S., Farina, I., & Fabbrocino, F. (2017). Investigations for dimensional accuracy of Al alloy/Al-MMC developed by combining stir casting and ABS replica based investment casting. *Composites Part B: Engineering, 115*, 203-208.

Zhang, L., Yang, L., Leng, J., Wang, T., & Wang, Y. (2017). Alloying Behavior and Properties of Al-Based Composites Reinforced with Al85Fe15 Metallic Glass Particles Fabricated by Mechanical Alloying and Hot Pressing Consolidation. *JOM, 69*(4), 748-755.