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Research Article

Optimization on Stir Casting Process Parameters of Al7050/Nano-B_4C Metal Matrix Composites

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Aluminum matrix composites are widely employed in aerospace, military, automobile, and transport applications. The high-strength with low-weight materials are required to fulfill the requirement of high-performance applications. The low-weight materials are reinforced with hard reinforcements to obtain high-strength-to-weight properties for using high-performance applications. The process parameters of fabrication technique define the mechanical and tribological properties. Many types of optimization tools are used for optimizing the process parameters of fabrication method. In this research, the aluminum alloy 7050 and boron carbide are selected as matrix material and reinforcement material. The fabrication of Al7050/B_4C composites is produced by the stir casting method. The optimization on stir casting process parameters is done by using the Taguchi approach. The L9 orthogonal array is chosen for this investigation. The chosen input stir casting process parameters are wt% B_4C, stirring time (10, 15, and 20 min), stirring speed (300, 350, and 400 rpm), and melting temperature (700, 750, and 800°C). The microhardness is selected as a valuable response parameter for optimizing the stir casting process parameters. The influencing stir casting process parameter sequence is determined by using mean table. The influencing parameters of stir casting on microhardness are stirring speed, stirring time, wt% B_4C, and melting temperature. The 9 wt% of boron carbide addition increases the microhardness, and it is higher than the other wt%. The optimum combination of input process parameter combination is 9 wt% boron carbide, 750°C melting temperature, 350 rpm stirring speed, and 15 min stirring time (A3B2C2D2). The percentage of microhardness value improvement is 20.3%.

1. Introduction

Metal matrix composites (MMCs) are produced to fulfill the requirement of growing industries by reinforcing the matrix material. The piston rods, braking systems, piston, pins, brake caliper, and brake disc are manufactured by the MMCs. The MMCs have high-strength, better tribological, and mechanical properties [1]. The MMCs application is limited by its manufacturing problems [2]. The optimized properties of the composites are obtained by the optimized process parameters combination. There are many techniques have been invented to produce MMCs, such as powder metallurgy approach, stir casting technique, vapor deposition method, and squeeze casting. The stir casting is the better one while comparing with other fabrication methods in connection with large quantity manufacturing and simplicity [3, 4]. The Taguchi approach is widely employed to optimize the process parameter, and it is better than others because of its characteristics in forming interaction relationships between the process parameters [5, 6]. Analysis of variance is widely employed to determine the significance of process parameters and the contribution of input process parameters on its responses [7, 8]. The various kind of hard and soft reinforcements are used for increasing the properties of matrix material. The SiC, TiB_2, B_4C, TiC, ZrO_2, and TiO_2 are used as hard reinforcement in fabricating composites to enhance the properties of the matrix material [9, 10]. The MoS_2 and Gr are used as soft reinforcements for reducing particularly friction coefficient of the MMCs [11]. The wear resistance of the composites is mainly influenced by the microhardness of the composite. The hard reinforcements highly enhance the microhardness of the composites

Table 1: Elements in Al7050.

Element	Aluminum, Al	Copper, Cu	Magnesium, Mg	Zinc, Zn	Zirconium, Zr
Content %	89	2.3	2.4	6.1	0.12

Table 2: Properties of matrix and ceramic reinforcement.

Properties	Al7050	Boron carbide
Density	2.8 g/cm^3	2.52 g/cm^3
Melting point	494°C	2,673°C
Tensile strength	515 MPa	500 MPa
Thermal conductivity	180 W/mK	42 W/mK

[12–14]. The influence of the stir casting process parameters, such as stirring speed, melting temperature, and stirring time, is determined on its responses. The reinforcement particle is analyzed by the hardness distribution [15]. There is no research has been done to optimize the stir casting process parameters of Al7050/B_4C MMCs. In this research, optimization is done the determination of the influencing sequence of stir casting process parameters on its microhardness.

2. Materials and Methods

The aluminum alloy 7050 is chosen as matrix material for this investigation. The presence of elements in the aluminum alloy 7075 is shown in Table 1. The boron carbide is selected as ceramic reinforcement to enhance the properties of the composites. The particle size of boron carbide is 15 μm, and it is determined by the particle size analyzer [16]. The boron carbide is added with the matrix Al7050 for enhancing the microhardness and wear resistance of the composites. The properties of matrix and ceramic reinforcement material are shown in Table 2.

2.1. Fabrication of Composites. The matrix aluminum alloy 7050 is in the round rod shape and it is cut into a very large number of small pieces. A small number of round rod form pieces are kept into the crucible furnace. The 1 wt% magnesium is used to increase the wettability of the reinforcements with matrix. The deoxidation agent is used to prevent the oxidation during casting. The boron carbide is preheated for 30 min at 400°C. A different combination of parameters is used for fabricating Al7050/B_4C composites. The stir casting different combination process parameters are wt% B_4C, stirring time (10, 15, and 20 min), stirring speed (300, 350, and 400 rpm), and melting temperature (700, 750, and 800°C). The 1 wt% Mg is added to the molten metal for increasing the wettability of B_4C and Al7050 matrix material [17]. The unwanted gas formation is avoided by using degassing tablet [18]. The L9 orthogonal array combination specimens are prepared by using stir casting setup. The small spices are kept into the crucible furnace and heated to the required temperature. The preheating is done on the required wt% of boron carbide for 30 min at 400°C. The preheated reinforcement is fed into the crucible furnace, and stirrer is rotated at required speed for required time. The molten melt is then fed into the mold cavity to form casting. The process is repeated for all combinations of process parameters. The nine specimens are prepared at nine different process parameters. The stir casting arrangement is shown in Figure 1. The L9 combination process parameters are shown in Table 3. The fabricated composite's size is a diameter of 2.5 cm and a length of 25 cm. The composite specimen is shown in Figure 2.

Figure 1: Stir casting arrangement.

2.2. Testing of Composites. The orthogonal array L9-based composites are fabricated using stir casting setup, and it is further subjected to Vickers microhardness testing. The microhardness tester LM 248 AT(LECO serial no XM8 116, Michigan) is employed to determine the microhardness of Al7050-based composites, and it is shown in Figure 3. The L9 specimen process parameter combination with microhardness is shown in Table 4. Each specimen is subjected to the applied load of 350 g for 15 s duration [19]. The microhardness value is noted for each trial. The three trials are done for each combination prepared specimen. The average microhardness value is taken for the investigation. The Taguchi technique is employed for the optimization on microhardness.

3. Results and Discussion

The orthogonal array L9 combination process parameters are used for fabricating AL7050/B_4C composites, and they are subjected to Vickers microhardness test. The composite specimens are fabricated by using L9 orthogonal array combination of input process parameters of stir casting. The influence of each input parameter of stir casting is determined by using an optimization technique. The optimization is done with the help of Minitab 19 software.

The main effect plot for S/N ratio of microhardness is shown in Figure 4 and Table 5. The larger is better criteria is

Table 3: L9 stir casting process parameters.

Ex. no	wt% B_4C	Melting temperature (°C)	Stirring speed (rpm)	Stirring time (min)
1	3	700	300	10
2	3	750	350	15
3	3	800	400	20
4	6	700	350	20
5	6	750	400	10
6	6	800	300	15
7	9	700	400	15
8	9	750	300	20
9	9	800	350	10

Figure 2: Fabricated composite specimen.

Figure 3: Microhardness tester.

selected for optimization on stir casting process parameters on microhardness response [20]. The main effect plot for S/N ratio revealed that increasing boron carbide addition increases the microhardness of the AL7050/B_4C composites. The highest microhardness value is obtained at 9 wt% (A3) of boron carbide addition. The microhardness is increased from 700 to 750°C and falls at 800°C. The intermediate melting temperature (B2) allows the matrix material to surround the reinforcement material effectively. The intermediate temperature is also an important reason for getting better bonding strength. The stirring speed is the important input process parameter in the uniform dispersion of boron carbide in the A7050 matrix material. The stirring speed increases the microhardness from 300 to 350 rpm and decreases at 400 rpm. The highest microhardness is obtained at 350 rpm (C2) stirring speed.

The stirring time is also an important input process parameter in increasing the microhardness of the Al7050-based composites. The microhardness is improved from 10 to 15 min and decreases at 15 min. The highest hardness value is obtained at 15 min (D2) stirring speed. The response table shows the influencing input process parameter sequence on microhardness of AL7050/B_4C composites, and it is wt% B_4C, melting temperature, stirring speed, and stirring time. Based on the main effect plot, the ideal combination of input process parameters is 9 wt% boron carbide, a melting temperature of 750°C, a stirring speed of 350 rpm, and a stirring time of 15 min denoted as A3B2C2D.

The contour plots for microhardness are shown in Figure 5(a)–5(e). The combination of wt% B_4C, melting temperature for microhardness, combination of wt% B_4C, stirring speed, for microhardness, combination of wt% B_4C, stirring time for microhardness, combination of stirring time, melting temperature for microhardness, combination of stirring speed, melting temperature for microhardness and combination of stirring time, stirring speed for microhardness is analyzed. All input process parameters are influenced by microhardness because all input parameters intersect with others.

The confirmation test specimen is fabricated, and it is further subjected to energy-dispersive X-ray analysis test (EDAX) and scanning electron microscope (SEM) test to confirm the presence of AL7050 matrix and boron carbide reinforcement materials, respectively [21, 22].

The EDAX and SEM of AL7050/9 wt% B_4C are shown in Figure 6(a)–6(b). The uniform dispersion of reinforcement material is obtained in the fabrication of AL7050, and it is confirmed by the Figure 6(a) SEM image [23]. The EDAX test result exhibits the presence of elements like aluminum, boron, carbide, and zinc. Figure 6(b) confirms that there is no oxide formation and porosity in the fabricated composite. The confirmation test is conducted on the AL7050/B_4C composites, and the microhardness response is noted at the 350 g for 15 s condition. The obtained microhardness value is 195, and it is higher than the initial setting (162). The percentage of microhardness value improvement is 20.3%. The increase of microhardness of manufactured composite is mainly by increasing the bonding strength of the matrix with reinforcement.

4. Conclusions

The AL7050/B_4C metal matrix composites are manufactured as per L9 orthogonal array-based input process parameters

Table 4: L9 stir casting process parameters with microhardness.

Ex. no	wt% B_4C (A)	Melting temperature (°C) (B)	Stirring speed (rpm) (C)	Stirring time (min) (D)	Microhardness
1	3	700	300	10	162
2	3	750	350	15	171.5
3	3	800	400	20	164
4	6	700	350	20	173
5	6	750	400	10	175.5
6	6	800	300	15	175
7	9	700	400	15	182
8	9	750	300	20	185
9	9	800	350	10	185.5

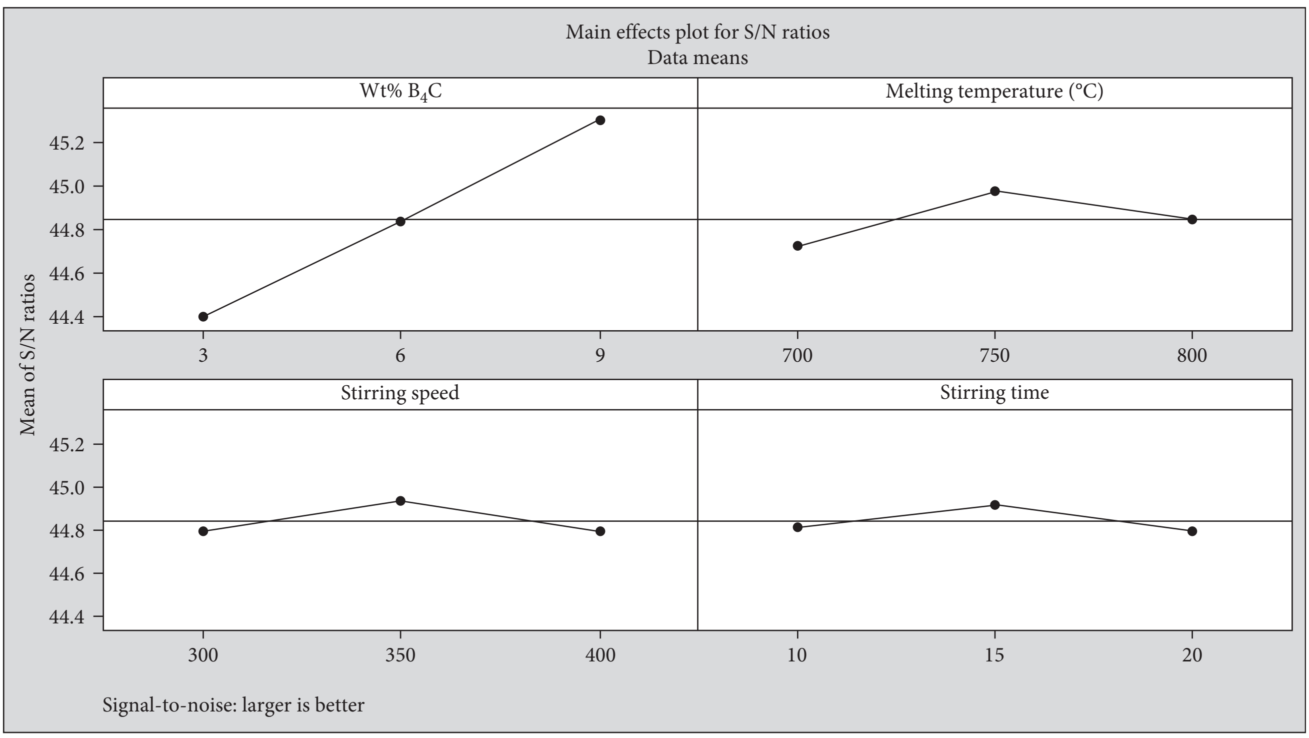


Figure 4: Main effect plot for S/N ratio for microhardness.

Table 5: Response table for signal-to-noise ratios (larger is better).

Level	wt% B_4C	Melting temperature (°C)	Stirring speed (rpm)	Stirring time (min)
1	44.39	44.72	44.80	44.81
2	44.84	44.97	44.94	44.92
3	45.30	44.84	44.79	44.80
Delta	0.91	0.25	0.14	0.12
Rank	1	2	3	4

combination successfully by employing stir casting method. The microhardness test is done on all AL7050-based composites to determine the hardness of the composites. The Minitab 19 is used for this investigation. The larger is better criterion is selected for S/N ratio of microhardness. The 9 wt% of boron carbide addition increases the microhardness and it is higher than the other wt%. The intermediate melting temperature (750°C), intermediate stirring speed (350 rpm), and intermediate stirring time (15 min) input process parameters produce composites with higher microhardness. The optimum combination of input process parameter combination is 9 wt% boron carbide, 750°C

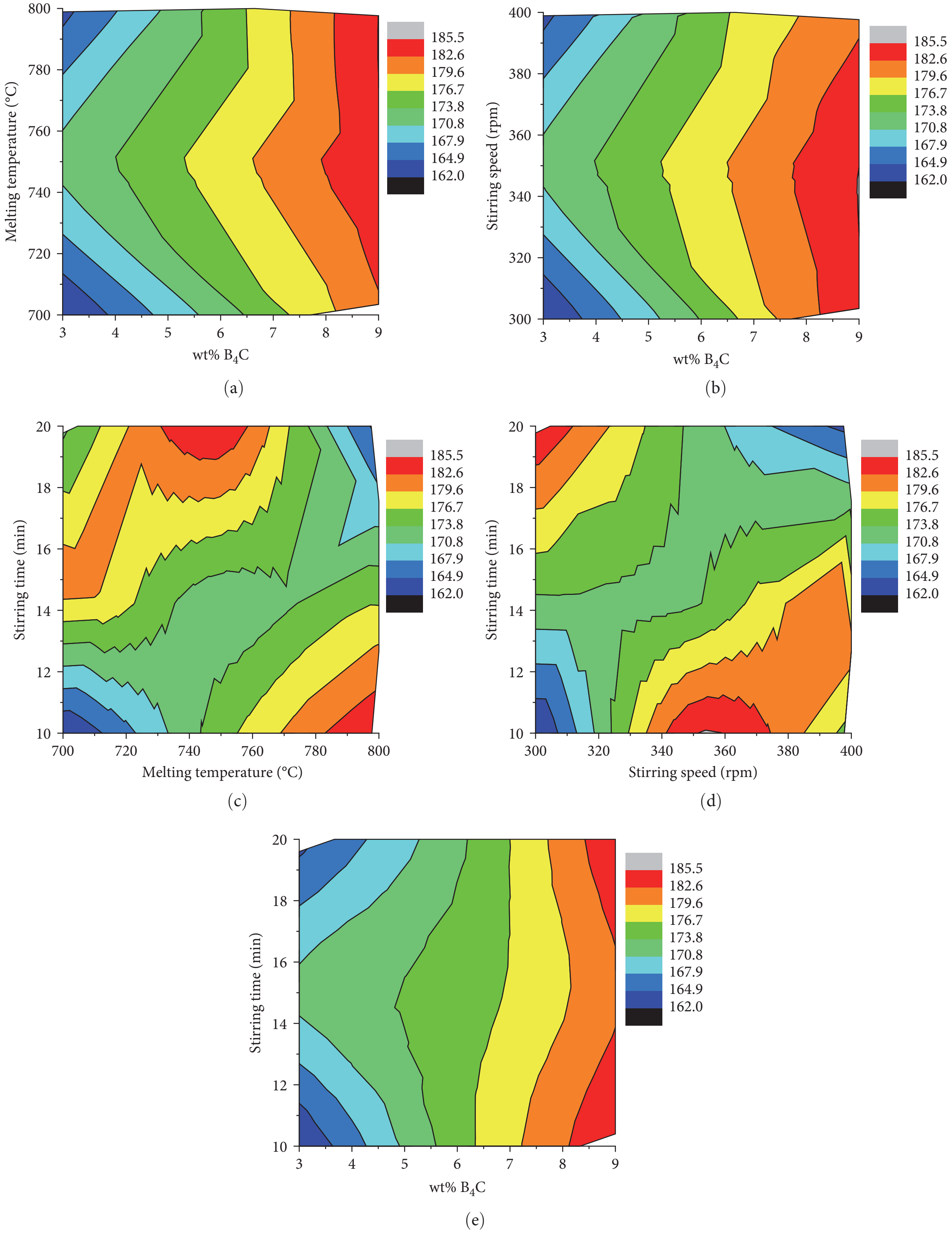
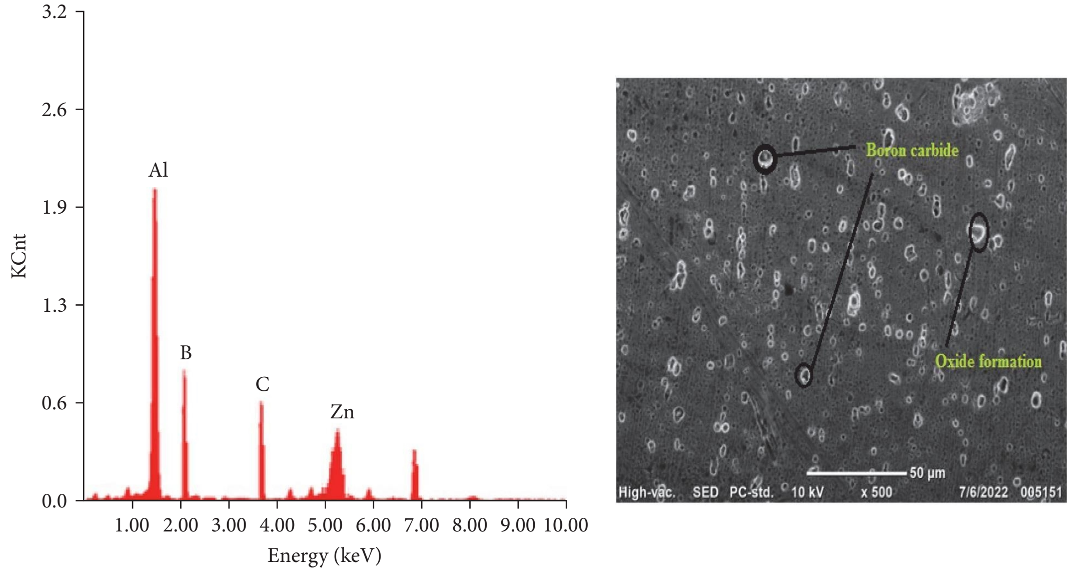


FIGURE 5: (a) Contour plots of microhardness with melting temperature and wt% of B_4C; (b) contour plots of microhardness with stirring speed and wt% of B_4C; (c) contour plots of microhardness with stirring time and melting temperature; (d) contour plots of microhardness with stirring time and stirring speed; (e) contour plots for microhardness with stirring time and wt% of B_4C.



(a) (b)

Figure 6: (a) EDAX of Al7050/9 wt% B_4C; (b). SEM image of Al7050/9 wt% B_4C.

melting temperature, 350 rpm stirring speed, and 15 min stirring time (A3B2C2D2). The percentage of microhardness value improvement is 20.3%.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. K. Sharma, R. Bhandari, A. Aherwar, R. Rimašauskienė, and C. Pinca-Bretotean, "A study of advancement in application opportunities of aluminum metal matrix composites," *Materials Today: Proceedings*, vol. 26, Part 2, pp. 2419–2424, 2020.

[2] J. M. Kunze and C. C. Bampton, "Challenges to developing and producing MMCs for space applications," *JOM*, vol. 53, pp. 22–25, 2001.

[3] G. F. Aynalem, "Processing methods and mechanical properties of aluminium matrix composites," *Advances in Materials Science and Engineering*, vol. 2020, Article ID 3765791, 19 pages, 2020.

[4] P. Garg, A. Jamwal, D. Kumar, K. K. Sadasivuni, C. M. Hussain, and P. Gupta, "Advance research progresses in aluminium matrix composites: manufacturing & applications," *Journal of Materials Research and Technology*, vol. 8, no. 5, pp. 4924–4939, 2019.

[5] J. A. Ghani, I. A. Choudhury, and H. H. Hassan, "Application of Taguchi method in the optimization of end milling parameters," *Journal of Materials Processing Technology*, vol. 145, no. 1, pp. 84–92, 2004.

[6] T. Sathish, K. Palani, L. Natrayan, A. Merneedi, M. V. De Poures, and D. K. Singaravelu, "Synthesis and characterization of polypropylene/ramie fiber with hemp fiber and coir fiber natural biopolymer composite for biomedical application," *International Journal of Polymer Science*, vol. 2021, Article ID 2462873, 8 pages, 2021.

[7] B. M. Gopalsamy, B. Mondal, and S. Ghosh, "Taguchi method and ANOVA: an approach for process parameters optimization of hard machining while machining hardened steel," *Journal of Scientific & Industrial Research*, vol. 68, pp. 686–695, 2009.

[8] L. Natrayan, M. Singh, and M. S. Kumar, "An experimental investigation on mechanical behaviour of SiCp reinforced Al 6061 MMC using squeeze casting process," *International Journal of Mechanical and Production*, vol. 7, no. 6, pp. 663–668, 2017.

[9] K. Shirvanimoghaddam, H. Khayyam, H. Abdizadeh et al., "Effect of B_4C, TiB_2 and $ZrSiO_4$ ceramic particles on mechanical properties of aluminium matrix composites: experimental investigation and predictive modelling," *Ceramics International*, vol. 42, no. 5, pp. 6206–6220, 2016.

[10] V. Rama Koteswara Rao, J. Rangaraya Chowdary, A. Balaji et al., "A review on properties of aluminium based metal matrix composites via stir casting," *International Journal of Scientific & Engineering Research*, vol. 7, no. 2, pp. 742–749, 2016.

[11] A. Saravanakumar, D. Ravikanth, L. Rajeshkumar, D. Balaji, and M. Ramesh, "Tribological behaviour of MoS_2 and graphite reinforced aluminium matrix composites," *IOP Conference Series: Materials Science and Engineering*, vol. 1059, Article ID 012021, 2021.

[12] S. Khoshsima, S. Mertdinç, A. Motallebzadeh, Z. Altıntaş, D. Ağaoğulları, and Ö. Balcı-Çağıran, "Enhanced hardness and wear resistance of Al-based hybrid MMCs by using of composite metal boride reinforcement particles," *Materials Chemistry and Physics*, vol. 288, Article ID 126377, 2022.

[13] A. Simon, D. Lipusz, P. Baumli et al., "Microstructure and mechanical properties of Al-WC composites," *Archives of Metallurgy and Materials*, vol. 60, no. 2, pp. 1517–1521, 2015.

[14] G. Iacob, V. G. Ghica, M. Buzatu, T. Buzatu, and M. I. Petrescu, "Studies on wear rate and micro-hardness of the Al/Al_2O_3/Gr hybrid composites produced via powder metallurgy," *Composites Part B: Engineering*, vol. 69, pp. 603–611, 2015.

[15] M. S. Kumar, S. R. Begum, and M. Vasumathi, "Influence of stir casting parameters on particle distribution in metal matrix composites using stir casting process," *Materials Research Express*, vol. 6, no. 10, Article ID 1065d4, 2019.

[16] P. Barick, D. C. Jana, and N. Thiyagarajan, "Effect of particle size on the mechanical properties of reaction bonded boron carbide ceramics," *Ceramics International*, vol. 39, no. 1, pp. 763–770, 2013.

[17] S. Venkatesan and M. A. Xavior, "Tensile behavior of aluminum alloy (AA7050) metal matrix composite reinforced with graphene fabricated by stir and squeeze cast processes," *Science and Technology of Materials*, vol. 30, no. 2, pp. 74–85, 2018.

[18] D. Dhaneswara, M. R. Firmansyah, Y. Prasetyo, and A. Ashari, "Comparative study of degassing method by using NaF-$NaNO_3$-based tablet degasser, technical argon gas, and pure argon gas in aluminum casting," *AIP Conference Proceedings*, vol. 2232, no. 1, Article ID 070011, 2020.

[19] F. Mazhari, B. Ajami, S. M. Moazzami, B. Baghaee, and B. Hafez, "Microhardness of composite resin cured through different primary tooth thicknesses with different light intensities and curing times: *in vitro* study," *European Journal of Dentistry*, vol. 10, no. 2, pp. 203–209, 2016.

[20] G. Patil and M. H. Patil, "Optimization of stir cast process parameters for better mechanical properties," *International Journal of Engineering Research & Technology*, vol. 9, no. 8, 2020.

[21] M. S. Kumar, L. Natrayan, R. D. Hemanth, K. Annamalai, and E. Karthick, "Experimental investigations on mechanical and microstructural properties of Al_2O_3/SiC reinforced hybrid metal matrix composite," *IOP Conference Series: Materials Science and Engineering*, vol. 402, Article ID 012123, 2018.

[22] T. Anandaraj, P. P. Sethusundaram, C. Chanakyan, S. Sakthivelu, and M. Meignanamoorthy, "Influence of different reinforcements on properties of metal matrix composites: a review," *Materials Today: Proceedings*, vol. 37, Part 2, pp. 3480–3484, 2021.

[23] J. James, A. R. Annamalai, A. Muthuchamy, and C.-P. Jen, "Effect of wettability and uniform distribution of reinforcement particle on mechanical property (tensile) in aluminum metal matrix composite—a review," *Nanomaterials*, vol. 11, no. 9, Article ID 2230, 2021.