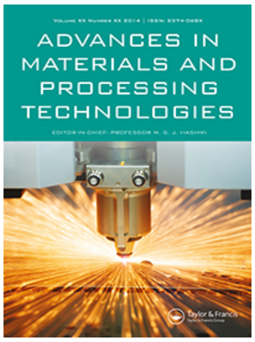

Taylor & Francis
Taylor & Francis Group

Advances in Materials and Processing Technologies

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tmpt20

Tribological behaviour of AA7168 hybrid composite sheets for aerospace structures fabricated through COMPO casting

Venkatesan S, Giridharan P. K., Sivakumar N S, Sharavanan S, Ram Subbiah & Senthamilselvi A

ADVANCES IN MATERIALS AND PROCESSING TECHNOLOGIES
https://doi.org/10.1080/2374068X.2021.1959088

Tribological behaviour of AA7168 hybrid composite sheets for aerospace structures fabricated through COMPO casting

Venkatesan S[a], Giridharan P. K.[b], Sivakumar N S[c], Sharavanan S[d], Ram Subbiah[e] and Senthamilselvi A[f]

[a]School of Mechanical Engineering, College of Engineering and Technology, Wachemo University, Hosaena, Ethiopia; [b]Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidhyapeetham, Chennai; [c]Department of Mechatronics, Tishk International University, Erbil, KRG, Iraq; [d]Mechanical Engineering, Vels Institute of Science, Technology and Advanced Studies (Vistas), Deemed to Be University, Chennai, India; [e]Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad; [f]Department of Aeronautical Engineering, Nehru Institute of Engineering and Technology, Coimbatore, India

ABSTRACT
In this research work, an attempt was made to reinforce AA7168 aluminium alloy with Boron Carbide (B_4C) and Silicon Carbide (SiC) through compos casting technique. Tribological test were performed by varying weight percentage (3, 6, 9, 12%), Load (10, 20, 30, 40 N), Sliding velocity (10, 20, 30, 40 m/s) and sliding distance (1000, 2000, 3000, 4000 m). The results revealed that the wear resistance increases with addition of reinforcing particles until a saddle point of 9 wt.% owing to the formation of mechanical mixed layer. At 12%, the wear resistance reduces because of the clustering of particles. Because of the hardness of the particles, the coefficient of friction increases with increasing weight percentage. From Taguchi approach, it was revealed that percentage reinforcement was most influential factor followed by load, sliding velocity and sliding distance. The addition of particles increases the hardness and tensile strength due to the hall petch effect and orowan strengthening. WASPAS technique was utilised to optimise the input variables.

ARTICLE HISTORY
Accepted 14 July 2021

KEYWORDS
Compo casting; WASPAS; sheet metal; tribology; hybrid composites

1. Introduction

Aluminium Metal Matrix Composite (AMMC) gaining its importance in aerospace sector owing to its enhanced material properties and strength to weight ratio [1]. Power sintering, in-situ fabrication and liquid metallurgy are the various techniques utilised for the production of composites [2–4]. Among these methods manufacturing by liquid stir casting was cost effective and suitable for mass production [5]. The particles size, volume fraction, particle shape and surface treatment are the various factors influences the homogeneous distribution of composites [6–8]. Boron Carbide (B_4C), Silicon Carbide (SiC), Aluminium oxide (Al_2O_3), Graphite (Gr), Carbon Nano Tubes (CNT) were predominantly used reinforcing materials [9–11]. The key problem in the

CONTACT Giridharan P. K. kpranandkumar@gmail.com Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidhyapeetham, Chennai

AMMCs is wettability with a molten matrix state when particles were processed [12]. Addition of flux improves the wettability of the composites [13]. Heat-treated particles mixes uniformly as compared with untreated particles [14].

Owing to the presence of mechanical mixed layer the wear resistance of composites increases due to prevention of direct metal to metal contact [15,16]. The weight percentage and counterface stiffness contribute negatively while the load and speed applied contribute positively to the wear rate [17]. Owing to the presence of tribo substrate, the duct surface has little effect on wear rate [18]. Composite materials display abrasion and delamination wear at lower loads and extreme wear at higher loads [19]. The deceleration of the subsurface raises in the moderate wear area with the increasing rush although reduces as reinforcing particles are added [20,21]. The inclusion of graphite triggers the self-lubrication property that is necessary for the components that often have lubrication [22].

Tribological properties of silicon carbide and graphite strengthened hybrid composites have been studied by Basavarajappa et al. The AA2219 hybrid composites were fabricated through stir casting by varying volume fraction. The wear test were conducted by varying sliding speed and load. The results revealed that the composites exhibit better wear resistance as compared with unreinforced composites [23]. With full factor design surappa et al studied the impact of the strengthening proportion, sliding velocity, loading and sliding distance on wear. They proposed a regression equation demonstrating wear reinforcing dependency, sliding velocity, load and sliding distances as well as wear dependence [24].

In the manufactures sector choices are always faced with the dilemma of deciding and choosing the right solution based on contradictory parameters in a wide variety of alternatives. Weighted Aggregated Sum–Product Assessment (WASPAS) is a Multi Criteria Decision Making techniques (MCDM) used for selecting the best alternative from the available resources [25,26]. Each problems of classification comprises mostly of four key components, i.e. (a) equivalents, (b) abilities, (c) relatively large weight of each attribute and (d) alternative output measurements in relation to various attributes [27]. From the above survey it was evident that lot of works have been done to improve the material properties by adding reinforcing particles. But very limited work were reported to enhance the property of AA7168 aluminium alloy. In the current research, AA7168 aluminium alloy was reinforced with Silicon Carbide (SiC) and Boron Carbide (B4C) particles through compo-casting route. The obtained results were optimised using the WASPAS technique.

2. Experimental work

AA7168 aluminium alloy of chemical composition as depicted in Table 1 was used as matrix material was procured from perfect metal alloys, Bangalore. The SiC and B_4 C particles of average particle size 5 μm was selected as reinforcement as obtained from

Table 1. Chemical composition of AA7168 aluminium alloy.

Al	Zn	Mg	Cu	Fe	Zr	Si	Ti
85.34	8.1	2.9	3.1	0.21	0.14	0.11	0.1

Table 2. Casting process parameters.

Casting temperature	860 C
SiC preheating temperature	250 C
B_4C preheating temperature	250 C
Die preheating temperature	400 C
Stirring speed (RPM)	1100
Stirring time (s)	420
Flux	Magnesium powder

Table 3. Wear process parameters and its levels.

Process parameters	Levels
Weight percentage of B_4C and SiC	3, 6, 9, 12
Load (N)	10, 20, 30, 40
Speed (m/s)	10, 20, 30, 40
Distance (m)	1000, 2000, 3000, 4000

Table 4. Equipment's utilised for research work.

Equipment Name	Make/Model	Used for
Stir Casting Furnace	VB ceramics consultants	Casting
Computerised Universal Testing Machine	FIE Machines	Tensile strength
Rockwell hardness tester	Fine testing instruments	Hardness
Pin on Disc testing machine	Ducom Instruments	Wear & Friction

bhukhanwala sectors. The selected reinforcing particles was preheated to a temperature of 250°C to remove the moisture content in it. The graphite crucible has been fitted with around 1 kg of AA7168 in electric furnace and heated to 860°C. Magnesium powder was applied as a flux to increase the wettability of reinforcement particles. The preheated reinforcement has been added to the charge and stirred at the speed of 1100rpm. After stirring for 180 seconds, the charge was cooled to 500°C and stirred for another 120 seconds. Once again, the charge was heated to 860°C, stirred for 120 seconds and poured in the preheated die made of high carbon steel. The casting input variables were shown in Table 2. The same procedure was repeated for making composite of various weight percentage (3%, 6%, 9% and 12%). The composite surface was turned for the depth of 2 mm to remove the surface defects. The pin on disc experiments were performed on the composites as per ASTM G99 standards by varying Load (N), sliding speed (m/s) and sliding distance (m) as shown in Table 3. The tensile strength and hardness of the composites were determined as per ASTM E8 and ASTM E18 standards respectively. The equipment's utilised for research work was depicted in Table 4. The observed results were optimised utilising the WASPAS optimisation technique.

3. Result and discussion

From the experimental result it was evident that the hardness of the composites increases with the addition of reinforcing particles as shown in Figure 1. The increase in hardness was attributed to the two facts (i) the presence ceramic particles increases the hardness of the composites as reported by numerous researchers (ii) the addition of magnesium as the flux induces the grain refinement which upsurge hardness because of hall petch effect. The increase in weight percentage of reinforcement improves the tensile strength of

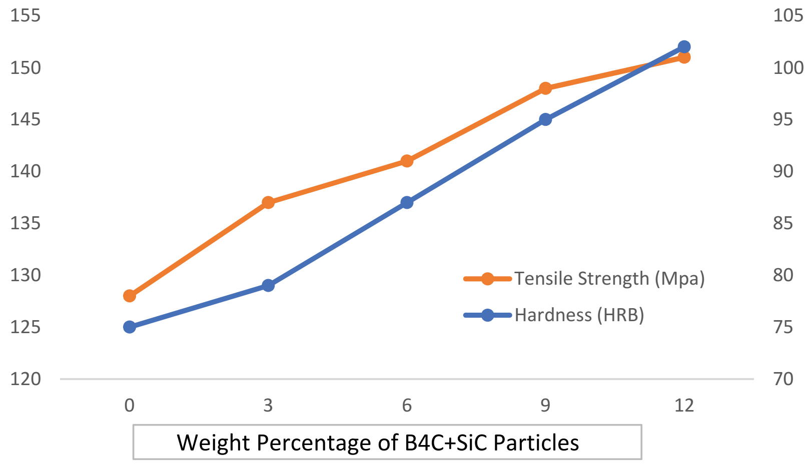

Figure 1. Impact of reinforcing particles on tensile and mechanical properties of AA7168 hybrid composites.

composites owing to orowan strengthening. This reinforcement prevents the propagation of cracks which result in improvement in tensile strength.

The wear rate of the composites decreases with increase in the weight percentage of the composites. As wear rate inversely proportional to the hardness of the composites, it decreases as hardness increases. When the surface contacts, the particles present in the composites abrades the counter-disc which forms Mechanically Mixed Layer (MML). This MML prevents direct metal to metal contact, hence wear rate reduces. Wear resistance reduces when reinforced with 12% reinforcing particles due to particle agglomeration. The wear rate increases with rising load until a saddle point of 30 N is reached. When the load is raised, the contact surface exerts more strain, which increases the wear rate. After the saddle point the metal liquified owing to intense pressure and re-deposited over the surface, hence wear rate decreases. The wear rate increases with increase in sliding velocity. This is because improvements in strain intensity and friction heating are to be anticipated as sliding speeds rise. The wear rate was mild until the sliding distance of 2000 m, there after steep increase in wear rate was observed. While sliding at longer distance, the material plastically deformed which increases the wear rate.

The wear rate increases with increasing load, regardless of the reinforcing content of the composites as shown in Figure 2. With the extra pressure created with the additional load the wear rate goes up. However, as composites are manufactured with nine weight percentage of reinforcement particles, the wear resistance increases as the load increases. Owing to the uniform dispersion of particles while sliding the reinforcement particles present in the composites erodes the counter face which creates MML. This MML prevents avoids direct metal-to-metal interaction, lowering wear rate. The wear rate increases as the load and velocity of the series increases simultaneously. When slides at lower load of 10 N and at the speed of 10 m/s the composite exhibit minimal wear rate.

The Coefficient of Friction (COF) increases with the addition of reinforcing particles owing to the presence of hard ceramic particles as shown in Figure 3. The particles while sliding detached from the surface and abrades the counter disc which ultimately increases

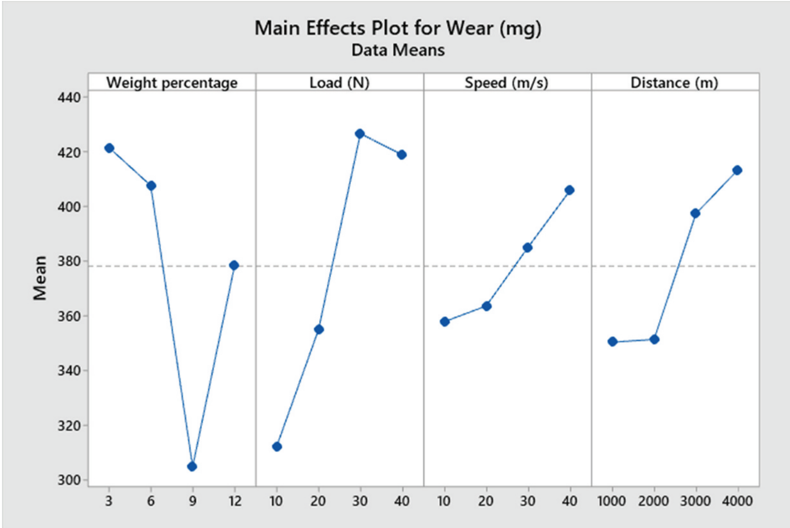

Figure 2. Wear rate of AA7168/SiC/B_4C particulate reinforced hybrid composite.

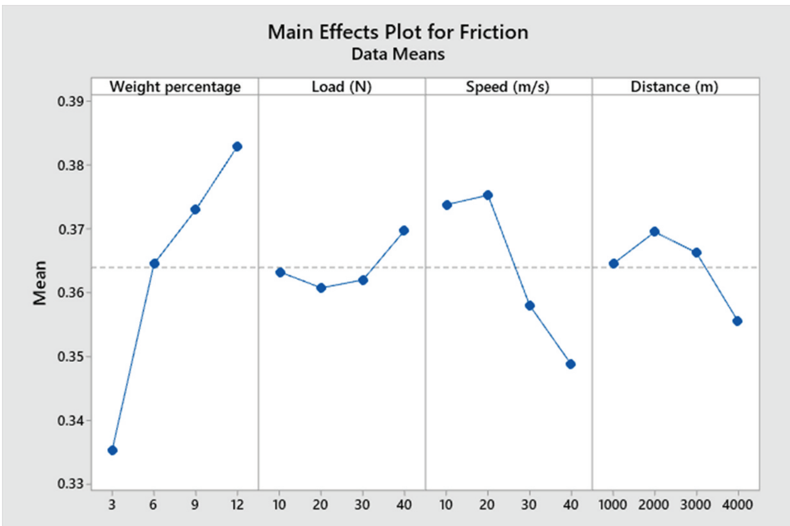

Figure 3. Friction co-efficient of AA7168/SiC/B_4C particulate reinforced hybrid composite.

the COF. The COF increase with the increase in the applied load. At higher load because of the extent pressure exerted on the contacting surface COF increases. COF increases with increase in velocity until a saddle point of 20 m/s thereafter it starts to decline. With increase in velocity the materials attained the deformation state which reduces the value of COF. The MML formed between the surface prevents the direct surface contact which reduces friction. The COF decreases when sliding beyond the distance of 2000 m owing to the presence of MML. At higher sliding distance the surface exerts higher temperature which ultimately reduces the COF.

4. Weighted Aggregated Sum-Product Assessment (WASPAS)

The optimal weight percentage of reinforcing particles were find out utilising WASPAS optimisation technique. The first step was the construction of decision matrix; in this current scenario, 16 experiments were carried out by 4 input variables. Wear and friction were recorded as response hence a decisive matrix of 16 × 4 was formed as shown in Table 5.

$$N_{ij} = W_{ij}\left(\sum_{j=1}^{n}\frac{X_{ij}}{Max(X_{ij})}\right) \tag{1}$$

$$T1_{ij} = \sum_{i=1}^{n} N_{ij} \tag{2}$$

The decisive matrix was then normalised in the following steps. The maximum and minimum values were calculated from the reported responses. This normalisation value was the ratio of the maximum value of the decision matrix column to the individual variable present in that column for beneficiary attributes, and individual element to the minimum value for non-beneficiary attributes. The normalised value was multiplied with weight of the each criteria to form weighted normalised matrix as depicted in equation 1.

$$M_{ij} = \left(\sum_{j=1}^{n}\frac{X_{ij}}{Max(X_{ij})}\right)^{W_{ij}} \tag{3}$$

$$T2_{ij} = \prod_{i=1}^{n} M_{ij} \tag{4}$$

The taxation value one was the sum of the weighted normalised matrix value as portrayed in Table 5. To compute the taxation value two, the normalised value was squared with the weight of the corresponding response, and the acquired value was multiplied by each

Table 5. Decision matrix formed from experimental results.

S.no.	Weight percentage	Load (N)	Speed (m/s)	Distance (m)	Wear (mg)	Friction
1	3	10	10	1000	328	0.346
2	3	20	20	2000	388	0.347
3	3	30	30	3000	434	0.329
4	3	40	40	4000	537	0.319
5	6	10	20	3000	358	0.379
6	6	20	10	4000	337	0.362
7	6	30	40	1000	487	0.346
8	6	40	30	2000	449	0.371
9	9	10	30	4000	312	0.356
10	9	20	40	3000	349	0.358
11	9	30	10	2000	318	0.388
12	9	40	20	1000	241	0.39
13	12	10	40	2000	251	0.372
14	12	20	30	1000	346	0.376
15	12	30	20	4000	468	0.385
16	12	40	10	3000	449	0.399
λ = 0.5				W_{ij}	537	0.399

other, as seen in equations 3 and 4. The assessment value was the sum of the taxation value one to the lamida and the taxation value two of the discrepancy between unit value and lamida as shown in equation 5. The parameters with highest assessment value were taken as optimum. From the Table 6, it was observed that the AA7168/9B_4C/9SiC hybrid composites exhibits better tribological properties.

$$A_{ij} = \sum_{i=1}^{n} \left(\lambda\left(T1_{ij}\right) + (1-\lambda)\left(T2_{ij}\right)\right) \tag{5}$$

5. Conclusion

The AA7168 hybrid composites sheets were successfully fabricated through compo casting technique for aerospace structural application. The wear, hardness and tensile test were performed on the composites and following results were observed.

(1) The hardness and tensile strength of the composites increases with increase in weight percentage owing to hall petch effect and Orowan strengthening.
(2) The wear resistance of the composites were optimum when reinforced with 9 weight percentage of SiC and B_4C particles due to the formation of mechanical mixed layer and beyond that limit particle agglomeration occurs.
(3) The minimal coefficient of friction of 0.319 was observed which favoured the hybrid composites for the fabrication of aircraft structural components.
(4) The WASPAS technique was utilised to find out the optimal process parameters. From the results it was found that AA7168/9B_4C/9SiC hybrid composites slided at the velocity of 20 m/s for 1000 m distance with applied load of 9 N offers better wear resistance.

Table 6. Calculation of assessment value.

S. no.	Normalised Decision Matrix		Weighted Normalised Decision Matrix (Nij)		Taxation Value 1	Normalised Decision Matrix		Taxation Value 2	Assessment Value	Rank
1	0.734756	0.921965	0.440854	0.368786	0.80964	0.831162	0.968023	0.804585	0.80711	4
2	0.621134	0.919308	0.37268	0.367723	0.740404	0.751469	0.966907	0.7266	0.7335	10
3	0.5553	0.969605	0.33318	0.387842	0.721022	0.702613	0.987729	0.693992	0.70751	11
4	0.44879	1	0.269274	0.4	0.669274	0.618338	1	0.618338	0.64381	14
5	0.673184	0.841689	0.403911	0.336675	0.740586	0.788643	0.933385	0.736107	0.73835	9
6	0.715134	0.881215	0.42908	0.352486	0.781566	0.817772	0.950677	0.777437	0.7795	6
7	0.494867	0.921965	0.29692	0.368786	0.665706	0.655681	0.968023	0.634715	0.65021	13
8	0.536748	0.859838	0.322049	0.343935	0.665984	0.688434	0.941384	0.648081	0.65703	12
9	0.772436	0.896067	0.463462	0.358427	0.821889	0.85648	0.957054	0.819698	0.82079	3
10	0.690544	0.891061	0.414327	0.356425	0.770,751	0.800783	0.954911	0.764677	0.76771	7
11	0.757862	0.822165	0.454717	0.328866	0.783583	0.846748	0.924663	0.782956	0.78327	5
12	1	0.817949	0.6	0.327179	0.927179	1	0.922764	0.922764	0.92497	1
13	0.960159	0.857527	0.576096	0.343011	0.919106	0.975902	0.940371	0.917709	0.91841	2
14	0.696532	0.848404	0.417919	0.339362	0.757281	0.804942	0.936356	0.753712	0.7555	8
15	0.514957	0.828571	0.308974	0.331429	0.640403	0.671526	0.927539	0.622866	0.63163	16
16	0.536748	0.799499	0.322049	0.319799	0.641848	0.688434	0.914381	0.629491	0.63567	15

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

[1] Safri SNA, Sultan MTH, Jawaid M, et al. Impact behaviour of hybrid composites for structural applications: a review. Compos Part B Eng. 2018;133:112–121.
[2] Stalin B, Ravichandran M, Mohanavel V, et al. InveStIgatIonS into MIcroStructure and mechanical propertIeS of Mg-5wt.% cu-tiB2 coMpoSIteS produced vIa powder metallurgy route. J Mini Metall B. 2020;56(1):99–108.
[3] Purohit R, Qureshi MMU, Jain A. Forming behaviour of aluminium matrix nano Al2O3 composites for automotive applications. Adv Mater Process Technol. 2020;6(2):272–283.
[4] Banoriya D, Purohit R, Dwivedi RK. Wear performance of titanium reinforced biocompatible TPU. Adv Mater Process Technol. 2020;6(2):284–291.
[5] Boppana SB, Dayanand S. Impact of heat treatment on mechanical, wear and corrosion behaviour of in situ AlB 2 reinforced metal matrix composites produced by liquid metallurgy route. J Bio Tribocorros. 2020;6(2):1–18.
[6] Mallikarjuna HM, Ramesh CS, Koppad PG, et al. Nanoindentation and wear behaviour of copper based hybrid composites reinforced with SiC and MWCNTs synthesized by spark plasma sintering. Vacuum. 2017;145:320–333.
[7] Halil K, İsmail O, Sibel D, et al. Wear and mechanical properties of Al6061/SiC/B4C hybrid composites produced with powder metallurgy. J Mater Res Technol. 2019;8(6):5348–5361.
[8] Zheng Z, Zhang X, Li J, et al. Achieving homogeneous distribution of high-content graphene in aluminum alloys via high-temperature cumulative shear deformation. Mater Des. 2020;193:108796.
[9] Kumar A, Rana RS, Purohit R. Effect of stirrer design on microstructure of MWCNT and Al alloy by stir casting process. Adv Mater Process Technol. 2020;6(2):320–327.
[10] Kumar S, Singh R, Hashmi MSJ. Metal matrix composite: a methodological review. Adv Mater Process Technol. 2020;6(1):13–24.
[11] Tan A, Teng J, Zeng X, et al. Fabrication of aluminium matrix hybrid composites reinforced with SiC microparticles and TiB2 nanoparticles by powder metallurgy. Powder Metall. 2017;60(1):66–72.
[12] Arif S, Alam MT, Ansari AH, et al. Analysis of tribological behaviour of zirconia reinforced Al-SiC hybrid composites using statistical and artificial neural network technique. Mater Res Express. 2018;5(5):056506.
[13] Ranjith R, Giridharan PK, Devaraj J, et al. Influence of titanium-coated (B 4 C p+ SiC p) particles on sulphide stress corrosion and wear behaviour of AA7050 hybrid composites (for MLG link). J Aust Ceram Soc. 2017;53(2):1017–1025.
[14] Polat S, Sun Y, Çevik E, et al. Investigation of wear and corrosion behavior of graphene nanoplatelet-coated B4C reinforced Al–Si matrix semi-ceramic hybrid composites. J Compos Mater. 2019;53(25):3549–3565.
[15] Ranjith R, Giridharan PK. Experimental investigation of surface hardness and dry sliding wear behavior of AA7050/B 4 C p. High Temp Mater Process. 2015;19(291–305).
[16] Virinchy CS, Jayakumar V, Asif AH, et al. Experimental investigation of Al-Mg-SiC-Fly ash composites for automotive alloy wheel rims. Int J Vehicle Struct Syst (IJVSS). 2019;11(121–124).
[17] Singhal C, Murtaza Q, Alam P, et al. Structural and mechanical properties of microwave hybrid sintered aluminium silicon carbide composite. Adv Mater Process Technol. 2019;5(4):559–567.
[18] Alam MT, Ansari AH, Arif S, et al. Mechanical properties and morphology of aluminium metal matrix nanocomposites-stir cast products. Adv Mater Process Technol. 2017;3(4):600–615.

[19] Senthil Kumar M, Managalaraja RV, Senthil Kumar K, et al. Processing and characterization of AA2024/Al2O3/SiC reinforces hybrid composites using squeeze casting technique. Iran J Mater Sci Eng. 2019;16(2):55–67.

[20] Puttegowda M, Rangappa SM, Jawaid M, et al. Potential of natural/synthetic hybrid composites for aerospace applications. In: Sustainable composites for aerospace applications. Woodhead Publishing Series in Composites Science and Engineering; 2018. p. 315–351. https://doi.org/10.1016/B978-0-08-102131-6.00021-9

[21] Bhanuprakash L, Parasuram S, Varghese S. Experimental investigation on graphene oxides coated carbon fibre/epoxy hybrid composites: mechanical and electrical properties. Compos Sci Technol. 2019;179:134–144.

[22] Mahesh K, Bharathiraja G, Jayakumar V. Wear analysis of rice husk shell powder reinforced epoxy composite. International Journal of Mechanical and Production Engineering Research and Development; 2019;9(5):997–1004.

[23] Basavarajappa S, Chandramohan G, Davim JP. Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites. Mater Des. 2007;28(4):1393–1398.

[24] Surappa MK, Prasad SV, Rohatgi PK. Wear and abrasion of cast Al-alumina particle composites. Wear. 1982;77(3):295–302.

[25] Chakraborty S, Zavadskas EK. Applications of WASPAS method in manufacturing decision making. Informatica. 2014;25(1):1–20.

[26] Chakraborty S, Zavadskas EK, Antucheviciene J. Applications of WASPAS method as a multi-criteria decision-making tool. Econ Comput Econ Cyber Stud Res. 2015;49(1):5–22.

[27] Baušys R, Juodagalvienė B. Garage location selection for residential house by WASPAS-SVNS method. J Civil Eng Manage. 2017;23(3):421–429.