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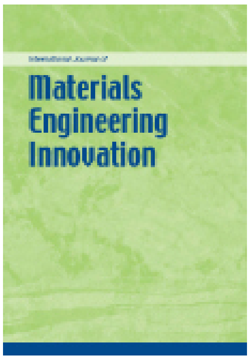

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Analysis optimisation of machining aspects and wear characterisation of Al6061 reinforced with SiC and graphite

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Abstract: Aluminium alloy confirming to Al6061 specifications was reinforced with 3%, 6%, and 9% SiC in powder form along with 1% graphite powder by weight basis. Stir casting route was employed to prepare the specimen. Micro structure examination and mechanical properties such as UTS, hardness measurements were carried out. Wear studies in the dry sliding condition were carried out using standard pin-on-disc apparatus confirming to ASTM G99 specifications. The structural examination revealed a uniform dispersion of the reinforcement. Tensile strength and hardness values increased with concentration of SiC. Wear resistance is improved with higher amounts of reinforcement. Decrease in the wear rate is observed with addition of graphite. Regression analysis was carried out for assessment of wear and the wear rate was obtained. The contribution of input parameters on the wear rate has been determined using ANOVA. Model and experimental data compare well with each other.

Keywords: Al6061; SiC; graphite; metal matrix composites; MMC; wear; hardness; tensile strength; universal testing machine; UTM; regression analysis; analysis of variances; ANOVA.

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1 Introduction

Metal matrix composites (MMC) (Prasad et al., 2014; Auradi et al., 2014) have created lot of interest among the researchers all over the world (Muthukrishnan and Paulo Davim, 2011; Basavarajappa et al., 2006). It is almost three decades since the MMCs have taken right shape and found as potential materials substituting conventional metals and alloys in different applications owing to their improved tensile strengths at elevated temperatures (Karabulut, 2015; Aurich and Zimmermann, 2016). Main constituents of MMCs are the bulk which constitutes the metal or the alloy and the reinforcement. The reinforcement may be in the form of powder or particulate or fibres or whiskers, resulting in high strength, stiffness, improved wear resistance, lower weight and better thermal expansion coefficient.

Wear is a phenomenon of the contacting rubbing surfaces experiencing friction leading to the surface damage of the mating surfaces. The study of wear has gained importance and found itself as an important property to characterise materials especially with respect to the applications involving the surfaces in contact having relative motion, for example, bearing, engine components, agricultural implements, etc.

Aluminium complexes are the most popular matrix for the MMCs. Studies on Al alloys are important owing to their low density, capacity to get stronger by precipitation, corrosion resistance, high thermal and electrical conductivity, and high damping capacity. Aluminium matrix composites (AMCs) have been widely studied for over a century and are widely used in many industrial applications (Surappa, 2003). Also, lightweight, high specific strength and environmental friendly materials are in demand in domestic, automotive and aerospace industries (Wang et. al., 1984). Owing to the layered structure of carbon, carbon is used in a wide range of applications as an additive such as engine bearings, pistons, piston rings, and cylinder liners (Bragg, 1928). In the present investigation, Al6061 alloy was reinforced with SiC additions (3%, 6% and 9%) along with graphite powder by weight basis. Stir casting route was employed (Shahin et al., 2015).

SiC particles improve tensile strength and act as load bearing members. In addition, SiC gives good hardness to the material which is desirable in wear resistant applications. Graphite is used in order to improve strength and stiffness. Graphite also acts as a solid lubricant and it gives an identical property throughout the composite material.

Wear tests (dry sliding conditions – using standard pin on disc machine – for varying speeds, loads and duration) and mechanical property assessments such as tensile strength and hardness assessments were carried out on base alloy and the alloy with the reinforcement. Regression analysis was used to develop mathematical model for wear rate of each composition of specimen for confirmation.

2 Experimental details

We have used Al6061 Alloy for our studies in which it has a very high corrosion resistance in any atmospheric conditions. Composition of the alloy Al6061 used in the present investigation is given in Table 1. The composition was confirmed by EDAX spectroscopy.

Table 1 Composition of Al6061

Composition	*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Zn*	*Ti*	*Al*
Percentage	0.6	0.7	0.28	0.15	0.2	0.2	0.25	0.15	Rem

Reinforcement was in the form of SiC powder added in 3%, 6% and 9% along with 1% graphite.

2.1 Melting and casting

Melting of the alloy and preparation of composite was carried out in a regular production foundry, vis., M/S FenFe Metallurgicals, Bangalore. Alloy in the form of ingots was placed inside a crucible which was kept inside the hearth of an electrical resistance furnace. The unit was switched on and when the metal attained the molten condition (super heating), crucible containing the metal was taken out of the furnace, slag and other impurities were skimmed off. To this alloy, calculated amounts of reinforcement were added and stirred well for uniform dispersion (Shahin et al., 2015). This product was then transferred to a precoated and preheated cylindrical CI moulds to get castings. Specimen for structure examination and mechanical properties assessments and wear specimens were machined from the above castings.

2.2 Density studies

The density of the base metal (Al-6061) is very near to its theoretical value (2.7 g/cc) shown in Figure 1. The density of the composites with different compositions is found to be increased due to addition of SiC and graphite.

2.3 Mechanical properties

Standard procedures were employed to assess the tensile strength using a universal testing machine (UTM) and the hardness using Vickers/Micro hardness tester. Assessments were made for the base alloy and the alloy with reinforcement.

2.3.1 Wear studies

Wear studies in the dry sliding condition were carried out using a pin-on-disc machine. Weight loss method was employed to assess the wear of the specimen. Specimen in the form of pin (8 mm diameter × 30 mm height) was made to slide against a standard EN19 wear disc. Wear parameters such as load, sliding distance, sliding speed were varied. Table 2 summarises the results of wear studies.

Figure 1 Density of the composites with different compositions

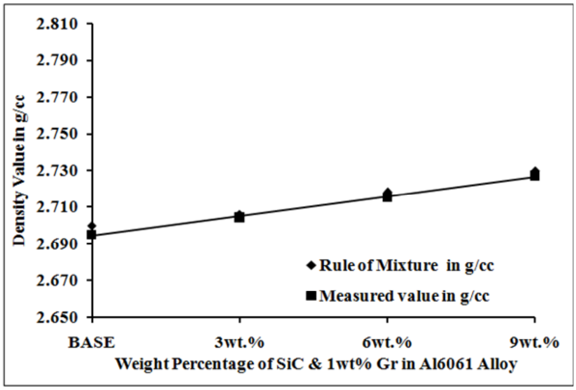


Table 2 Levels of each input parameters

Input parameter	*Levels*			
	1	*2*	*3*	*4*
Normal load (N)	10	20	30	40
Sliding distance (m)	500	1,000	1500	2000
Sliding speed (RPM)	100	200	300	400
Composition	Al6061	Al6061 + 3%SiC + 1%Gr	Al6061 + 6%SiC + 1%Gr	Al6061 + 9%SiC + 1%Gr

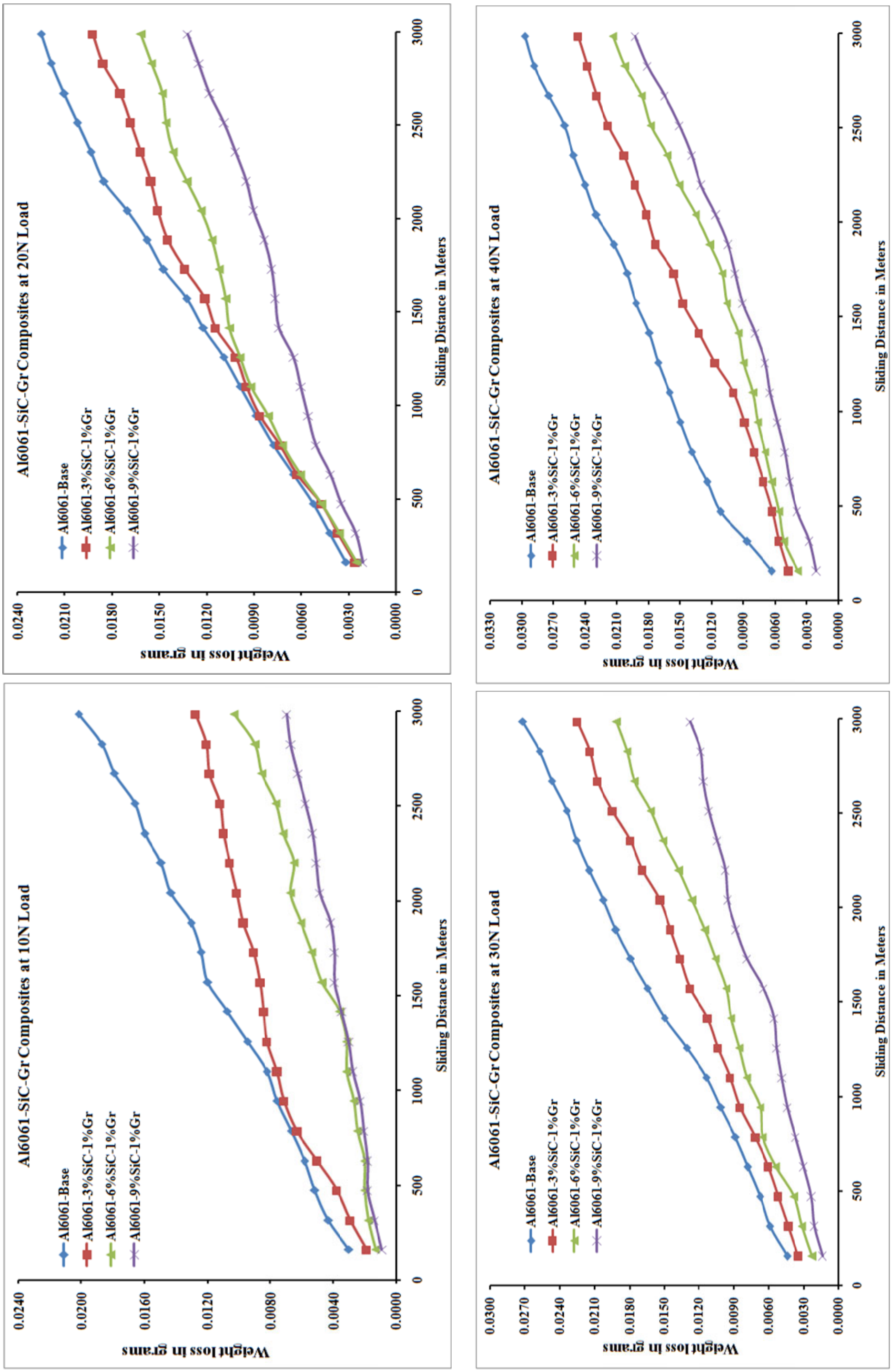
The test was conducted for duration of 20 minutes. At the end of every five minutes the motor was switched off, specimen was removed from the specimen holder; surface of the specimen was thoroughly cleaned, dried and weighed precisely using an electronic balance. Final weight of the specimen was noted down.

The results of the dry sliding wear studies carried out on the base metal and with reinforcement indicate that with increase in duration of testing, weight loss also increases. Severe wear was observed in the as-cast specimen whereas, lesser wear was observed with the specimen reinforced with SiC. Increased wear resistance was observed in the specimen reinforced with 9% SiC, indicating that the reinforcement decreases the wear of the specimen.

Addition of SiC particles reduces the delamination wear. In addition to this, SiC forms a protective oxide layer which also inhibits the wear and hence an increase in wear resistance with an increase in SiC concentration.

Wear rate increased with increase in the applied load that is consistent with earlier reports (Idrisi and Mourad, 2019; Miyajima and Iwai, 2003). Wear rate was determined using the above data. The analysis was carried out using MINITAB 17 software. Analysis of variances (ANOVA) was used to study the effect of each input parameter on the wear behaviour of the composites.

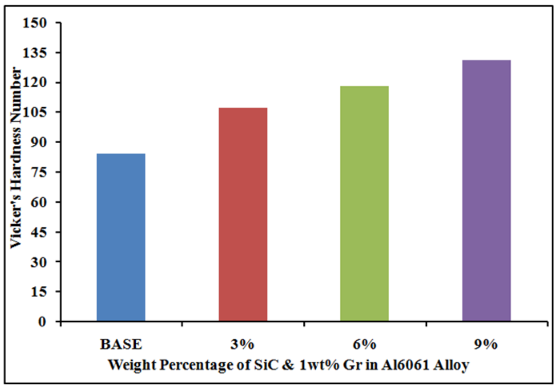
Figure 2 Weight loss of composites at different loads (see online version for colours)



2.3.2 Hardness studies

Hardness studies were carried out using highwood micro Vicker's hardness tester. Figure 3 shows the histogram of the hardness values (base alloy and base alloy with reinforcement). It can be seen from the histogram that the base alloy exhibits the least hardness value of 84. Increased hardness values were observed with the reinforcement. Base alloy with 9% addition of SiC has resulted in the highest hardness value of 134 with an enhancement of close to 60%. We attribute this increase in the hardness to the Silicon particles present in the matrix.

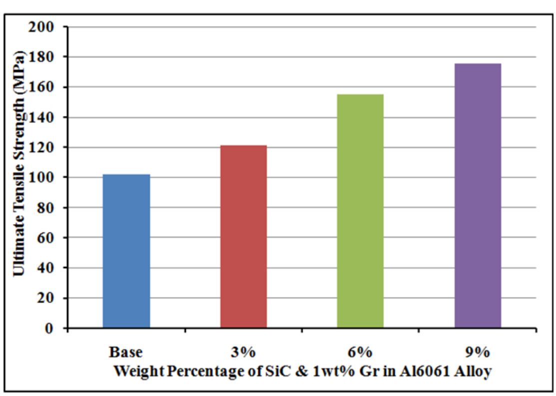
Figure 3 Hardness values for different compositions (see online version for colours)



2.3.3 Tensile strength

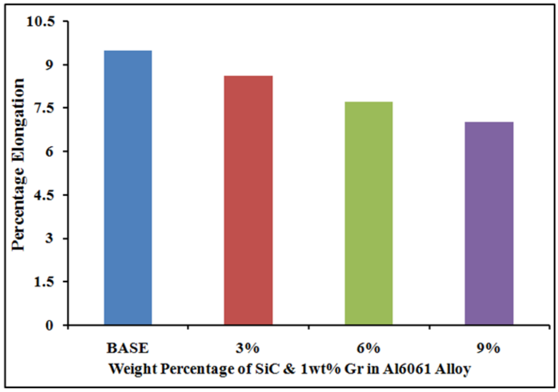
Figure 4(a) shows the variation of ultimate tensile strength, UTS for different conditions. Here also, the base alloy exhibited the least value of UTS equal to 102.07 MPa. Further, with increase in the reinforcement, an increase in the UTS values was observed. Base alloy with 9% addition of SiC has resulted in the highest UTS value of 178 with an enhancement of close to 75%.

Figure 4 (a) UTS values for different compositions and (b) percentage elongation values for different compositions (see online version for colours)



(a)

Figure 4 (a) UTS values for different compositions and (b) percentage elongation values for different compositions (continued) (see online version for colours)



(b)

Figure 4(b) shows the variation of percentage elongation for different conditions. The base alloy exhibited 9.5% elongation. With an increase in the reinforcement, percentage elongation decreased. With an addition of 9% SiC, the percentage elongation dropped by close to 25%.

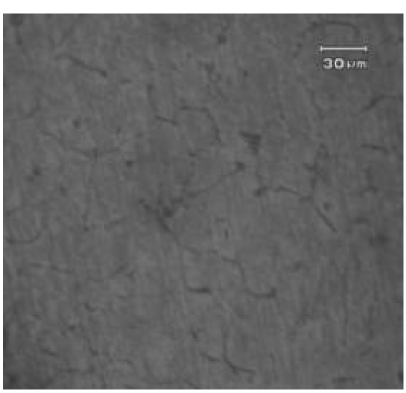
We attribute the enhancement in the tensile strength of the composite to strong bonding between the base material and reinforcements (Sabry et al., 2020; Arunachalam et al., 2019; Mourad et al., 2020).

3 Results and discussion

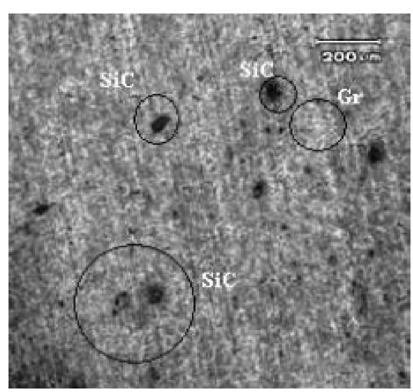
3.1 Microstructure examination

The optical micrograph of the aluminium metal matrix and the one reinforced with 9% wt. of SiC and 1% wt. of graphite are shown in Figures 5(a) and 5(b). The SiC particles are seen to be angular in shape and are dispersed uniformly in the matrix.

Figure 5 (a) Alloy (Al6061) and (b) MMC (Al6061 + 9%SiC + 1%Gr)



(a)



(b)

3.2 Optimisation using S/N ratio and ANOVA

ANOVA was utilised to find the factually huge parameters affecting the execution criteria during wear testing of composites and to evaluate the rate commitment of each control factor on the wear rate. Here the examination was done for the confidence level of 95%. The experiment was conducted for 16 times as highlighted below. Wear rates obtained for L16 trials are shown in Table 3.

Table 3 Wear rate for different testing conditions

Sl. no.	*Applied load, N*	*Sliding speed, RPM*	*Sliding distance, m*	*Composition*	*Wear rate mm^3/m*
1	10	100	500	Al6061	0.0584
2	10	200	1,000	Al6061 + 3%SiC + 1%Gr	0.006178
3	10	300	1,500	Al6061 + 6%SiC + 1%Gr	0.006517
4	10	400	2,000	Al6061 + 9%SiC + 1%Gr	0.007545
5	20	100	1,000	Al6061 + 6%SiC + 1%Gr	0.005217
6	20	200	500	Al6061 + 9%SiC + 1%Gr	0.00578
7	20	300	2,000	Al6061	0.009787
8	20	400	1,500	Al6061 + 3%SiC + 1%Gr	0.008686
9	30	100	1,500	Al6061 + 9%SiC + 1%Gr	0.007068
10	30	200	2,000	Al6061 + 6%SiC + 1%Gr	0.00855
11	30	300	500	Al6061 + 3%SiC + 1%Gr	0.006609
12	30	400	1,000	Al6061	0.00836
13	40	100	2,000	Al6061 + 3%SiC + 1%Gr	0.009703
14	40	200	1,500	Al6061	0.008177
15	40	300	1,000	Al6061 + 9%SiC + 1%Gr	0.007791
16	40	400	500	Al6061 + 6%SiC + 1%Gr	0.00874

Table 4 Regression analysis table

Sources	*DF*	*Adj SS*	*Adj MS*	*F value*	*P value*
Regression	6	0.000026	0.000004	8.94	0.002
Applied load (N)	1	0.000009	0.000009	17.79	0.002
Sliding speed (rpm)	1	0.000004	0.000004	8.96	0.015
Sliding distance (m)	1	0.00001	0.00001	21.57	0.001
Composition	3	0.000003	0.000001	1.78	0.021
Error	9	0.000004	0.0		
Total	15	0.00003			

Table 4 shows the effect of parameters affecting the wear calculated using regression analysis and the variation in the wear rate under the influence of each process parameter. Wear rate increases with increase in load, sliding distance and speed. The composite (Al6061 + 9%SiC + 1%Gr powder) showed higher wear resistance. As the load increases, the delamination wear mechanism intensifies and accelerates the wear rate. The increase in load has resulted in higher local stress of the composite through asperities and accelerates the wear by forming deeper grooves. The wear rate of the alloy increases with an increase in sliding speed. As the sliding speed increases, the friction-induced temperature at the interface rises resulting in the softening of the wear surfaces and sub surfaces. Compared to the Al alloy, the composite showed improved wear resistance. The addition of SIC enhances the matrix strength. Also, it minimises the adhesive wear prone matrix contacts with the counter surface. Thus, the effects of delamination and adhesive wear were reduced. Compared to the base material, the composites showed better wear resistance.

3.3 *Regression analysis*

The mathematical models for response criteria were developed using regression models in Minitab 17. The regression equations obtained for each specimen are highlighted in Table 5.

Table 5 Regression equations

Sl. no.	*Material*	*Regression equation*
1	Al6061	0.003454 + 0.000065 load + 0.000005 sliding speed + 0. 000001 sliding distance
2	Al6061 + 3% SiC + 1% Gr	0.003207 + 0.000065 load + 0.000005 sliding speed + 0. 000001 Sliding distance
3	Al6061 + 6% SiC + 1% Gr	0.002669 + 0.000065 load + 0.000005 sliding speed + 0. 000001 sliding distance
4	Al6061 + 9% SiC + 1% Gr	0.002459 + 0.000065 load + 0.000005 sliding speed + 0. 000001 sliding distance

The predicted values of wear rate for each composition were calculated for a load of 25 N, sliding distance of 750 m and speed of 250 rpm with the help of above expressions obtained from surface regression equations. Comparison of the predicted and the experimental values for regression equations are represented in Table 6.

Table 6 Error table

Sl. no.	*Predicted (mm^3/m)*	*Experimental (mm^3/m)*	*% Error*
1	0.007329	0.006112	17.31
2	0.007082	0.007821	10.43
3	0.006544	0.005664	13.42
4	0.006334	0.005256	17.02

4 Conclusions

Al6061 Composites were prepared with different weight proportions of SiC reinforcements. Microstructure examination revealed uniform distribution of reinforcements in the matrix material. Tensile, hardness, compressive strength and density of the alloy increased with reinforcements. Tribological behaviour of all compositions was studied for the different levels of process parameters selected. Experimental planning for wear performance was done using Taguchi design of experimental method. L16 orthogonal array was selected for the wear analysis. The optimal combination of process parameters and its effect on wear has been found out using main effects plot for S/N ratio. The contribution of input parameters on the wear rate has been determined using ANOVA. From ANOVA results, it was found that sliding distance plays a significant role in wear rate compared to other factors and type of composite being the least significant parameter. Regression analysis of wear rate was verified with the experimental results.

References

Arunachalam, R., Piya, S., Krishnan, P.K. et al. (2019) 'Optimization of stir-squeeze casting parameters for production of metal matrix composites using a hybrid analytical hierarchy process – Taguchi-Grey approach', *Eng. Optim.*, https://doi.org/10.1080/0305215X.2019.16396 93.

Auradi, V., Rajesh, G.L. and Kori, S.A. (2014) 'Processing of B4C particulate reinforced 6061 aluminum matrix composites by melt stirring involving two-step addition', *3rd International Conference on Materials Processing and Characterization (ICMPC 2014)*, *Procedia Materials Science*, Vol. 6, pp.1068–1076.

Aurich, J.C. and Zimmermann, M. (2016) 'Turning of aluminum metal matrix composites: influence of the reinforcement and the cutting condition on the surface layer of the work piece', *Advances in Manufacturing*, Vol. 4, No. 3, pp.225–236.

Basavarajappa, S., Chandramohan, G., Paulo Davim, J., Prabu, M., Mukund, K., Ashwin, M. and Prasanna Kumar, M. (2006) *Drilling of Hybrid Aluminium Matrix Composites*, 11 November, Springer-Verlag London Limited, UK.

Bragg, W.L. (1928) *Introduction to Crystal Analysis*, p.64, Bell and Son, London.

Idrisi, A.H. and Mourad, A-H.I. (2019) 'Wear performance analysis of aluminium matrix composites and optimization of process parameters using statistical techniques', *Metall. Mater. Trans. A*, Vol. 50, No. 11, pp.5395–5409.

Karabulut, Ş. (2015) 'Optimization of surface roughness and cutting force during AA7039/Al2O3 metal matrix composites milling using neural networks and Taguchi method', *Measurement*, Vol. 66, pp.139–149.

Miyajima, T. and Iwai, Y. (2003) 'Effects of reinforcements on sliding wear behavior of aluminum matrix composites', *Wear*, Vol. 255, pp.606–616.

Mourad, A-H.I., Idrisi, A.H., Zaaroura, N. et al. (2020) 'Damage assessment of nanofiller-reinforced woven kevlar KM2 plus/epoxy resinlaminated composites', *Polym. Test.*, https://doi.org/10.1016/j.polymertes ting.2020.106501.

Muthukrishnan, N. and Paulo Davim, J. (2011) 'An investigation of the effect of work piece reinforcing percentage on the machinability of Al-SiC metal matrix composites', *Journal of Mechanical Engineering Research*, Vol. 3, No. 1, pp.15–24.

Prasad, D.S., Shoba, C. and Ramanaiah, N. (2014) 'Investigations on mechanical properties of aluminum hybrid composites', *Journal of Materials Research and Technology*, Vol. 3, No. 1, pp.79–85.

Sabry, I., Mourad, A-H.I. and Thekkuden, D.T. (2020) 'Optimization of metalinert gas-welded aluminium 6061 pipe parameters using analysis of variance and grey relational analysis', *SN Appl. Sci.*, Vol. 2, p.175.

Shahin, S., Rasoul, A.K., Reza, T.M., Jiang, Z-Y., Alireza, F.B. and Dermot, B. (2015) 'Stir casting process for manufacture of Al-SiC composites', *Rare Met.*, DOI: 10.1007/s12598-015-0565-7.

Surappa, M.K. (2003) 'Aluminium matrix composites: challenges and opportunities', *Sadhana*, Vol. 28, pp.319–334.

Wang, A.S.D., Chou, P.C. and Lei, S.C. (1984) 'A stochastic model for the growth of matrix cracks in composite laminates', *J. Compos. Mater.*, Vol. 18, No. 3, pp.239-254.