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EXPERIMENTALINVESTIGATIONANALYSISOFWEARPARAMETERSONALSICGRMETALMATRIXHYBRIDCOMPOSITEBYTAGUCHIMETHOD

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Experimental Investigation & Analysis of Wear Parameters on Al/Sic/Gr - Metal Matrix Hybrid Composite by Taguchi Method

Rachit Marwaha [α], Mr. Rahul Dev Gupta [σ], Dr. Vivek Jain [ρ] & Er. Krishan Kant Sharma [ω]

Abstract- Metal matrix hybrid composites (MMHCs) are now gaining their usage in aerospace, automotive and other industries because of their inherent properties like high strength to weight ratio, hardness and wear resistance, good creep behaviour, light weight, design flexibility and low wear rate etc. Al alloy base matrix reinforced with silicon carbide (10%) and graphite (5%) particles was fabricated by stir casting process. The wear and frictional properties of metal matrix hybrid composites were studied by performing dry sliding wear test using pin on disc wear test apparatus. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. A L9 Orthogonal array was selected for analysis of data. Investigation to find the influence of applied load, sliding speed and track diameter on wear rate as well as coefficient of friction during wearing process was carried out using ANOVA. Objective of the model was chosen as smaller the better characteristics to analyse the dry sliding wear resistance. Results show that track diameter has highest influence followed by load and sliding speed.

Keywords: taguchi method, orthogonal array, ANOVA, metal matrix hybrid composites.

I. INTRODUCTION

Composite materials to meet the global demand for light weight, high performance, environmental friendly, wear and corrosion resistant materials. Metallurgists from aerospace, defence and nuclear industries have developed a large range of super alloys and heat resistant materials like ceramics and composite materials. Metal matrix composites (MMC) are suitable for applications requiring combined strength, thermal conductivity, damping properties. These properties of MMC enhance their usage in automotive and tribological applications. MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. The matrix is the monolithic material into which the reinforcement is embedded and is completely continuous e.g. metallic, ceramic and polymer. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications the matrix is usually a lighter metal such as aluminium, magnesium or titanium and provides a compliant support for the reinforcement example of metallic matrix. Aluminium alloys are widely used in the automotive industry because of their high strength to weight ratio as well as high thermal conductivity. It is used particularly in automobile engines as cylinder liners as well as other rotating and reciprocating parts such as the piston, drive shafts and brake rotors and in other applications in automotive and aerospace industries.

Aluminium matrix composites (AMCs) refer to the class of light weight high performance aluminium centric material systems. The reinforcement in AMCs could be in the form of continuous/discontinuous fibres, whisker or particulates, in volume fractions ranging from a few percent to 70%. Properties of AMCs can be tailored to the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing route.

When at least three materials are present, it is called a hybrid composite. Al/SiC/Gr-MMHC is one of the important hybrids composite among MMC, which have SiC & Gr particles with Aluminum matrix. The SiC is harder than Tungsten carbide (WC) and Graphite particles provide high resistance to wear in the hybrid composite.

Ceramic particles such as SiC are commonly added as a second reinforcement material in MMC hybrid composite to an increase in wear resistance, elastic modulus; and decrease in the thermal expansion coefficient for contact sliding application, i.e. brake disk rotors.

The hybrid metal matrix composite like Al/SiC/Gr MMC is one of the composites which have many unique properties over Al/SiC-MMC or Al/Gr-MMC. The wear resistance of Al/SiC/Gr composites increases with the increase of the graphite particle size. The improvement of wear resistance id due to the enhancement of lubrication tribo-layer composed of a chemical mixture of graphite as well as SiC particles and some fine particles containing aluminium.

A pin on disc wear test apparatus consists of a stationary pin under an applied load in contact with a

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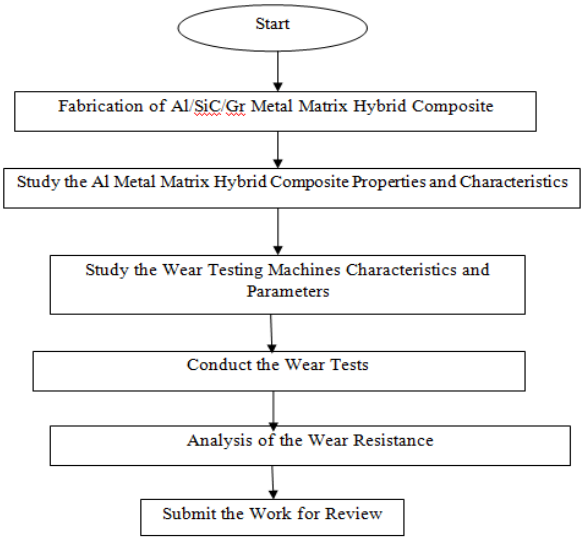
rotating disc. The pin can have any shape to simulate a specific contact, but in this set up square pins are used for experimentation. The pin on disc measures the friction and sliding wear properties of dry surfaces of a variety of bulk materials and coatings. The pin on disc tester consists of a rotating disc of the material to be tested against a stationary pin, usually made of the specimen to be tested, referred to as the pin. The rotational speed, normal load and the duration of time interval are the parameters set for test.

II. EXPERIMENTAL PROCEDURE

Stir casting technique has been used to prepare the work-piece samples. These work-piece samples Al/SiC/Gr- Metal Matrix Hybrid Composite have been utilized for testing on wear and corrosion testing machine.

The two muffle furnaces were used for preparing Al/SiC/Gr Hybrid MMC for experimentations by stir casting.

Experiments conducted on the basis of the initial chosen parameters and at random parameters setting for both the tests. The phasing of research work is represented by following flow chart:-



The melting of matrix material aluminium was carried in a muffle furnace in a range of 760 ± 100C. The crucible material was graphite. A view of the furnaces has been shown in Figure 2.1 below:

Figure 2.1 : Muffle Furnace used for Fabrication of Hybrid Composite

Scraps of aluminium were preheated up to a temperature of 4500C in muffle furnace before melting and mixing Silicon Carbide (SiC) and Graphite (Gr). Particles of Silicon Carbide (SiC) and Graphite (Gr) were also preheated up to a temperature of 11000C in second muffle furnace for 2-3 hours. Crucible used for pouring of composite slurry in the mould was also heated up to 760 0C to make their surfaces oxidized.

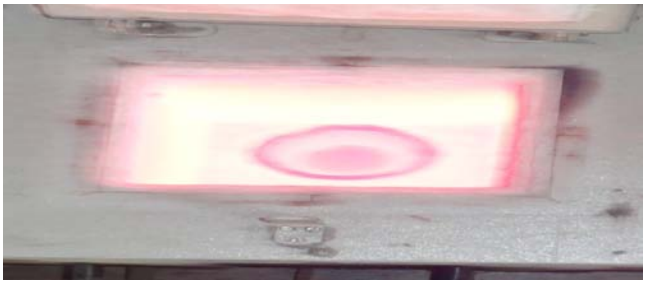


Figure 2.2 : Preheating of Aluminium Scrap

Figure 2.3 : Preheted Mixer of SiC and Graphite Powder

The furnace temperature was first raised above the liquidus to melt the alloy scraps completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated Silicon Carbide (SiC) and Graphite (Gr) particles were added and mixed manually.

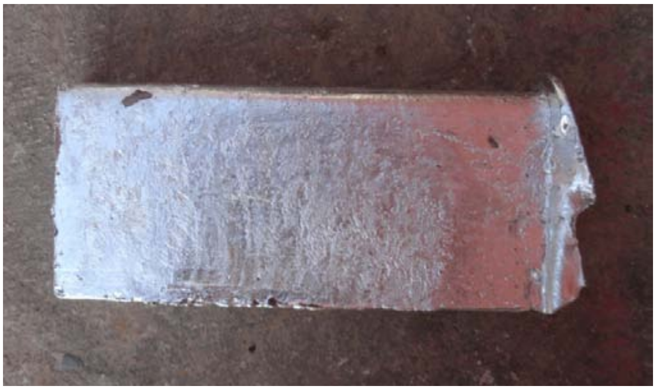


Figure 2.4 : Prepared Al/SiC/Gr MMHC

III. WEAR TEST

A pin on disc wear test apparatus consists of a stationary "pin" under an applied load in contact with a rotating disc. The pin can have any shape to simulate a specific contact, but spherical tips are often used to simplify the contact geometry. The pin on disc tester measures the friction and sliding wear properties of dry or lubricated surfaces of a variety of bulk materials and coatings. The pin on disc tester consists of a rotating disc of the material to be tested against a stationary sphere, usually made of cemented carbide, referred to as the pin. Although the pin surface can also be wear and friction tested. The normal load, rotational speed, and the wear track diameter are all to be set by the user prior to the pin on disc test.

Figure 3.1 : Pin on Disc Machine for Wear Test Al/SiC/Gr MMHC

In the experimentation, the specimens to be tested are taken in the form of a pin and are allowed to slide against a heat treated steel disc. For dry sliding wear test the disc is rotated in varying speed and applied the different load on pin based, and varying sliding distance on Taguchi design of experiments showing in Table 3.1 below. The wear rate is calculated from weight loss measurements taken by weight balance machine (with accuracy 0.01mg) after sliding. Specimens are cleaned by acetone.

Table 3.1 : Parameters and Their Levels for Wear Test of Al/SiC/Gr MMHC

Sr. No	Input Parameters	Levels		
1	Load	50	100	150
2	Sliding Speed (rpm)	500	1000	1500
3	Track Diameter (mm)	50	75	100

The analysis was done on the basis of L^9 (3^3) orthogonal array for wear rate which is shown in Table 3.2. Here, different parameters of load, sliding speed and track diameter are taken into consideration.

Finally, the weight loss due to wearing of the pin i.e. the difference between the final and the initial weight was measured on the Digital Analytical Weight measuring machine.

Table 3.2 : L^9 (3^3) Orthogonal Array for Wear Test

Experiment No.	Parameters and their Levels		
	Load (N)	Speed (rpm)	Track diameter (mm)
1	50	500	50
2	50	1000	75
3	50	1500	100
4	100	500	75
5	100	1000	100
6	100	1500	50
7	150	500	100
8	150	1000	50
9	150	1500	75

And wear rate was calculated and analysis was done with the help of Taguchi method.

IV. RESULTS AND DISCUSSIONS

The aim of the experimental plan is to find the important factors and combination of factors influencing the wear process to achieve the minimum wear rate. The experiments were developed based on an orthogonal array, with the aim of relating the influence sliding speed (rpm), load (N) and track diameter (mm) for the wear test. Taguchi recommends analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

Table 4.1 : Weight loss observation during Wear Test

Sr. No.	Weight of the material before testing (gms)	Weight of the material after testing (gms)	Weight loss(gms)
1.	17.05	16.86	0.19
2.	17.93	17.70	0.23

3.	17.68	17.45	0.23
4.	17.65	17.43	0.22
5.	17.98	17.74	0.24
6.	17.36	17.09	0.27
7.	17.82	17.51	0.31
8.	17.87	17.62	0.25
9.	17.98	17.71	0.27
10.	17.10	16.92	0.18
11.	18.02	17.76	0.26
12.	17.92	17.63	0.29
13.	17.85	17.54	0.31
14.	17.74	17.39	0.35
15.	17.56	19.38	0.18
16.	18.12	17.66	0.46
17.	17.72	17.45	0.27
18.	17.58	17.24	0.34
19.	17.25	17.06	0.19
20.	18.33	18.05	0.28
21.	17.78	17.45	0.33
22.	17.55	17.20	0.35
23.	18.18	17.79	0.39
24.	17.66	17.43	0.23
25.	17.52	17.03	0.49
26.	18.07	17.79	0.28
27.	17.80	17.39	0.41

The Table 4.1 shows the Experimental results for coefficient of friction. In this table the μ_1, μ_2, μ_3 shows the value of coefficient of friction. These values of coefficient of friction come from pin on disc apparatus.

Table 4.2 : Mean value and S/N Ratio for Coefficient of Friction

Exp. No.	Load (N)	Speed (rpm)	Track diameter (mm)	Coefficient of friction μ_1	Coefficient of friction μ_2	Coefficient of friction μ_3	S/N ratio	MEAN
1.	50	500	50	0.52	0.65	0.88	3.106023	0.683333
2.	50	1000	75	0.37	0.6	0.51	5.980254	0.493333
3.	50	1500	100	0.81	0.31	0.46	4.931343	0.526667
4.	100	500	75	0.71	0.31	0.24	6.590274	0.42
5.	100	1000	100	0.71	0.4	0.24	6.187645	0.45
6.	100	1500	50	0.76	0.76	0.64	2.826624	0.72
7.	150	500	100	0.65	0.19	0.21	7.758124	0.35
8.	150	1000	50	0.74	0.56	0.48	4.390577	0.593333
9.	150	1500	75	0.75	0.27	0.22	6.421922	0.413333

The Table 4.2 shows the analysis of variance (ANOVA) results for the coefficient of friction for three factors varied at three levels.This analysis is carried out for a confidence level of 95%.Sources with a P-value less than 0.05 were condsidered to have a statitstically significant contribution to the performance measures.In table 4.3 and 4.4 the last column shows the percentage contribution (Pr) of each parameter.

It can be observed from the Table 4.3, that the track diameter has the highest influence (74.62%) on coefficient of friction. Hence track diameter is an important factor to be taken into consideration

Table 4.3 : Analysis of variance for S/N Ratio

Source	DF	Seq SS	Adj SS	Adj MS	F ratio	P	Pr (%) Contribution
Load	2	3.5606	3.5606	1.78032	27.01	0.036	16.12
Speed	2	1.9092	1.9092	0.95461	14.48	0.065	8.64
Track Diameter	2	16.4820	16.4820	8.24099	125.04	0.008	74.62
Error	2	0.1318	0.1318	0.06591			0.62
Total	8	22.0836					100

during wear process followed by applied load(16.12%) and sliding speed (8.64%).

The Table 4.4 shows the analysis of variance (ANOVA) results for the coefficient of friction for three factors varied at three levels. This analysis is carried out for a confidence level of 95%.Sources with a P-value less than 0.05 were condsidered to have a statitstically significant contribution to the performance measures. In table 4.4 the last column shows the percentage contribution (Pr) of each parameter.

It can be observed from the table 4.4, that the track diameter has the highest influence (78.00%) on coefficient of friction.

Table 4.4 : Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F ratio	P	Pr (%) Contribution
Load	2	0.020830	0.020830	0.010415	216.31	0.005	16.28
Speed	2	0.007207	0.007207	0.003604	74.85	0.013	5.63
Track Diameter	2	0.099756	0.099756	0.049878	1035.92	0.001	78.00
Error	2	0.000096	0.000096	0.000048			0.090

Hence track diameter is an important factor to be taken into consideration during wear process followed by applied load (16.28%) and sliding speed (5.63%).From the analysis of variance and S/N ratio, it is inferred that the track diameter has highest contribution on cofficient of friction followed by load and sliding speed.

The coefficient of friction is decreases with increase in load & the coefficient of friction is increases with increase in sliding speed & for track diameter first the coefficient of friction is decreases by increasing the track diameter from 50 to 75 mm and after that when the track diameter further increases from 75 to 100 mm the coefficient of friction remains constant.

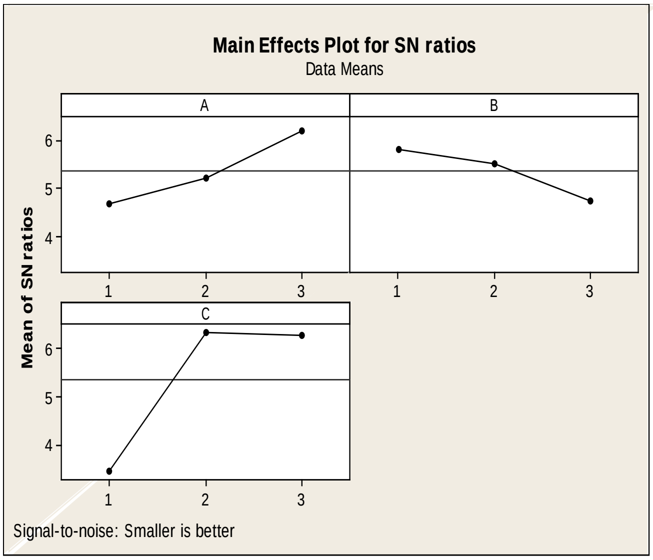


Figure 4.1 : Main Effects Plot for S/N ratios – Coefficient of friction

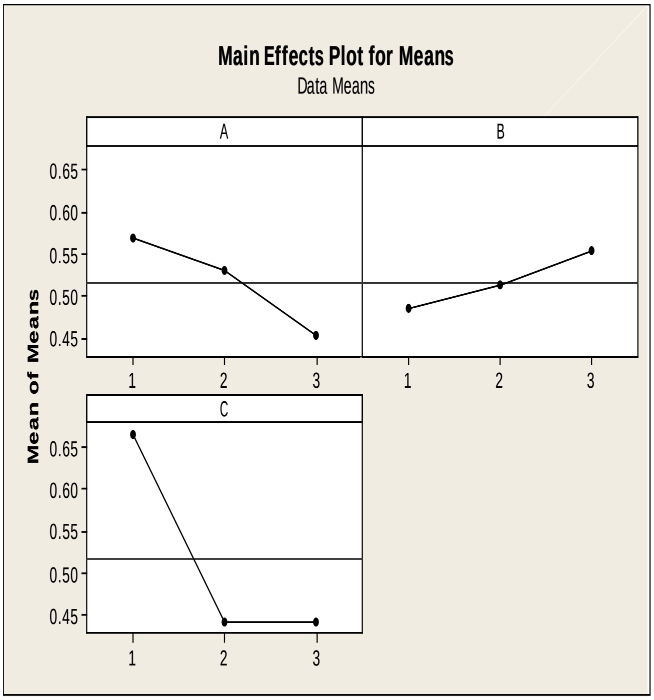


Figure 4.2 : Main Effects Plot for Means– Coefficient of friction

Table 4.5 shows the ranking of wear parameters for optimizing the coefficient of friction. It can be observed that track diameter has the largest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC.

Table 4.5 : Response Table for Signal to Noise Ratios-Smaller is better (coefficient of friction)

Level	Load	Speed	Track Diameter
1	4.673	5.818	3.441
2	5.202	5.519	6.331
3	6.190	4.727	6.292
Delta	1.518	1.092	2.890
Rank	2	3	1

The speed has the smallest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC.

Table 4.6 : Response Table for Means- Smaller is better (Coefficient of friction)

Level	Load	Speed	Track Diameter
1	0.5678	0.4844	0.6656
2	0.5300	0.5122	0.4422
3	0.4522	0.5533	0.4422
Delta	0.1156	0.0689	0.2233
Rank	2	3	1

Table 4.6 shows the ranking of wear parameters for optimizing the coefficient of friction. It can be observed that track diameter has the largest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC. The speed has the smallest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC.

V. CONFIRMATION EXPERIMENT

The optimal values of the response characteristics (coefficient of friction & weight loss) along with their respective confidence intervals have been predicted. The results of confirmation experiments are also presented to validate the optimal results. The optimal levels of the process parameters for the selected response characteristics have already been identified. The optimal value of each response characteristic is predicted considering the effect of the significant parameters only. The average values of the response characteristics obtained through the confirmation experiments must lie within the 95% confidence interval.

a) Coefficient of Friction

The optimum value of CF is predicted at the optimal levels of significant variables which have already been selected as load (A3), speed (B1) and track diameter (C2)

The estimated mean of the response characteristic (CF) can be determined as

$$\mu_{CF} = A_3 + B_1 + C_2 - 2T$$

T = overall mean of coefficient of friction= $(\mu_1+\mu_2+\mu_3)/27$ = 0.516

Where μ_1, μ_2 and μ_3 values of A_3, B_1 and C_2 are taken from Table 4.1 & 4.2:

A_3 = average value of surface roughness at the third level = 0.4522

B_1= average value of surface roughness at the first level = 0.4844

C_2= average value of surface roughness at the second level = 0.4422

Substituting the values of various terms in the above equation,

$$\mu_{CF} = 0.4522 + 0.4844 + 0.4422 - 2\,(0.516) = 0.3468$$

The 95 % confidence intervals of confirmation experiments (CICF) are calculated by using the Equations:

$$CI_{CE} = \sqrt{F_{\alpha}(1,\, f_e) V_e \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

Where, Fa (1, fe) = The F ratio at the confidence level of (1-a) against DOF 1 and error degree of freedom

$$n_{eff} = \frac{N}{1 + [\text{DOF associated in the estimate of mean response}]} = 27 / (1+6) = 3.857$$

N = Total number of results = 9 x 3 = 27
R = Sample size for confirmation experiments = 3
V_e = Error variance = 0.000048 (Table 4.4)
fe = error DOF = 2 (Table 4.4)

$F_{0.05}$ (1,2) = 18.5 (Tabulated F value;)
So, CI_{CF} = ± 0.0229, and

Therefore, the predicted 95 % confidence interval for confirmation experiments is:

$$\text{Mean } \mu_{CF} - CICF < \mu\, CF < \text{Mean } \mu\, CF + CICF \quad 0.3239 < \mu\, CF < 0.3697$$

The optimal values of process variables at their So, CI_{CF} = ± 0.0613, and selected levels are as follows:

Third level of load (A_3): 150 N
First level of Speed (B_1): 500 r.p.m
Second level of track diameter (C_2): 75 mm

Therefore, the predicted 95 % confidence interval for confirmation experiments is:

$$\text{Mean } \mu_{WL} - CIWL < \mu\, WL < \text{Mean } \mu\, WL + CIWL \quad 0.1132 < \mu\, WL < 0.2358$$

The optimal values of process variables at their selected levels are as follows:

Third level of load (A_1): 50 N

First level of Speed (B_2): 1000 r.p.m

Second level of track diameter (C_1): 50 mm

Table 5.1 : Predicted and Confirmation Experiments Results of Single Response Optimization at Optimal Setting

Performance Measures/ Responses	Optimal Set of Parameters	Predicted Optimal Value	Predicted Confidence Interval at 95% Confidence Level	Experimental Value	Percentage (%) Error
Coefficient of friction	A3 , B_1 and C_2	0.3468	$0.3239 < \mu$ CF < 0.3697	0.3386	2.36

Table 5.1 shows the Predicted and Confirmation Experiments Results of Single Response Optimization at Optimal Setting. The table shows the predicted optimal value, experimental value.

The experimental value shows that the value lies within the range of predicted confidence interval at 95% confidence level. The table also shows the percentage (%) error. The percentage (%) error should be less than 10%. The result shows that the (%) error is less than 10%.

VI. CONCLUSIONS AND FUTURE SCOPE

In present work, experimental investigation of Wear Rate of Al/SiC/Gr Hybrid MMC components was carried out. A total of twenty seven (27) experiments were carried out to identify the Wear Rate and to suggest optimized parametric value for minimize Wear Rate. Following are the conclusions drawn from the study on wear test using Taguchi's technique.

a) Conclusions of Wear Test

The lowest coefficient of friction observed at applied load 150N, 500 rpm sliding speed and 75 mm track diameter. The highest wear rate is observed at applied load 50 N, 1500 rpm sliding speed and 50 mm track diameter.

It can be observed that track diameter (78%) has highest influence on coefficient of friction followed by sliding speed (5.63%) & applied load (16.28%) and for weight loss also the contribution of track diameter is (59.50%) and applied load is (38.55%) for Al/Sic/Gr MMHC.

It is concluded that combinations for minimum coefficient of friction is $L_3S_1TD_2$ i.e. 150N load, 500 rpm sliding speed, and 75 mm track diameters.

b) Future Scope

The present investigation was done on Al/SiC/Gr hybrid MMC with 10% SiC and 5% Gr, for further investigations, variation in the percentage of SiC and Gr can be used for experimentation.

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