

# Analyzing the Surface Roughness of WC Particulate Hardened MMCs with Al-Mg-Cr alloys

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## Abstract

**Aim:** This study compares the surface roughness of Al-Mg-Cr alloys with novel nano WC (Tungsten carbide) reinforced Al-Mg-Cr alloys composites.

**Materials and Methods:** A rectangular plate with a thickness of 10mm and a length of 120mm of reinforced Al-Mg-Cr alloy nanocomposites and unreinforced aluminum alloy synthesized using stir casting method was used in this research. The drilling was performed with HSS drills of diameter 8mm, and the surface roughness test was conducted according to ASTM standards. In both experimental and control groups, there are 20 test samples each, with g-power 80% used for calculating sample sizes. A significant difference between the synthesized composites and the as-cast alloys was revealed to be  $P=0.001$  ( $p<0.05$ ).

**Results:** The surface roughness values are calculated for 20 samples of both as cast Al-Mg-Cr alloys and inclusion of 2wt% WC ceramic strengthening particulates nano composites. The minimum surface roughness values obtained for both samples are 3.89 $\mu$ m and 8.06 $\mu$ m respectively.

**Conclusion:** Within the limitations of present study, it was observed that the inclusion of hard novel nano WC ceramic particulates slightly increases the surface roughness 3.89% in comparison with as cast Al-Mg-Cr alloys.

**Keywords:** Nano composites, Al-Mg-Cr alloys, Novel Nano WC, Stir casting method, CNC drilling, Surface roughness.

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## INTRODUCTION

Aluminum alloys are commercially used in industries such as automobiles and aerospace to take advantage of their enhanced properties like corrosion resistance, strength and stiffness (“Website,” n.d.). Metal matrix nanocomposites are often used to develop high strength materials for various structural and functional applications because these composites are virtually used in all core industries due to its high strength-to-weight ratio (“Website,” n.d.). Owing to enhanced stiffness and hardness of aluminum alloy nano composites it finds tedious for machining of such composites for functional applications. This exhibits challenges for researcher to perform machining characteristics for such applications (Belov, Eskin, and Aksenov 2005). For particle reinforced nano metal matrix composites the mechanism for removing material is different from that for monolithic metals. A complex deformation mechanism is caused by the reinforcements present in metal matrix composites which results in high tool wear during traditional machining. This can be overcome by adding nano sized ceramic strengthening particulates in the base aluminium alloy (Bauri and Yadav 2017). Composites made of aluminium nano matrix can reduce the weight, fuel consumption, and emissions of automobiles and aircraft industries (Raja et al. 2020).

There are around 2,430 and 526 research articles about tungsten carbide reinforced aluminium alloys nano composites indexed in Google Scholar and ScienceDirect respectively. Stir casting is the most cost-effective method for preparation of aluminium alloy nanocomposites owing to its low cost and in order to enhance uniform distribution and enhance the wettability between the intermixtures (Anbuechhiyan et al. 2021). The drilling characteristics of SiC reinforced aluminium composites was analyzed by varying different process parameters such as coated and uncoated high-speed steel, carbide and PCD-tipped drills and solid-carbide drills. It was observed that the presence of coated high speed drill does not show significant improvement compared with convention tool

(Monaghan and O'Reilly 1992)The influence of cutting parameters on cutting force and surface roughness in drilling of Al/20%SiC/5%Gr and Al/20%SiC/10%Gr hybrid composites was analysed.It was observed that surface roughness is proportional to feed rate and inversely proportional to cutting speed (K. Kumar et al. 2019).The effect of machining parameters on composites during drilling in a dry environment using a radial drilling machine with HSS by considering constant speed, feed and analyzing their surface roughness, and comparing them with as-cast aluminum alloy. It was observed that the surface roughness improved in composites compared with monolithic materials (G. B. V. Kumar et al. 2017).The tool wear on Al-Si/10% AlN composites was analyzed and it was observed that the uncoated tool has poor surface finish compared with coated drill (Ravikumar, Kiran, and Sreebalaji 2017) and it is considered to be best study closely related to the current research.. Our team has extensive knowledge and research experience that has translate into high quality publications(Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar, Ravel, and Perumal 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al. 2021; Arun Prakash et al. 2020; Kamath et al. 2020; Shanmugam et al. 2021; Rajasekaran et al. 2020; Adhinarayanan et al. 2020; Rajesh et al. 2020; Aurtherson et al. 2021)

It was found that from the published research, no comparison was made on surface roughness between monolithic Al-Mg-Cr alloy with 2 wt.% novel nano WC reinforced Al-Mg-Cr alloy. Considering this as a major research gap an effort was made to synthesize such composites using Stir casting method and analyzing its surface roughness by utilizing CNC Drilling machine for functional applications. The expertise in this research is theoretical and experimental knowledge on fabricating metal matrix composites.

## MATERIALS AND METHODS

The research was conducted at the Saveetha Institute of Medical and Technical Sciences' Saveetha School of Engineering. Since this project involves the manufacturing of metal matrix composites, no ethical approval was necessary. Each group had a sample size of 20 subjects, with an 80 % pre-test power, a beta of 0.05 %, and a CL of 95 %. The significance value  $p=0.001$  was achieved (G. B. V. Kumar et al. 2017).

To make Al-Mg-Cr alloy nanocomposites, sufficient amounts of aluminium alloy were employed as matrix materials, and a novel WC particle size of 50 nm was used as reinforcement. Table 1. shows the chemical composition of Al-Mg-Cr alloys.Stir casting with bottom pouring was used to create aluminium nanocomposites. After a resistance heating furnace was preheated to 450<sup>0</sup>C, the required alloy components were added. The alloy was melted after being heated to 750<sup>0</sup> C.

To ensure that the molten metal was completely melted, the stirrer was spun at 400 rpm. An external sprue was used to insert 2wt percent nano-WC particles with a diameter of 50 nm into the molten metal, which was melted at 785<sup>0</sup>C. The stirring speed was increased to 500rpm and the stirring duration was retained at 10 minutes to ensure uniform reinforcement dispersion in the matrix alloy. The molten slurry was heated to 800<sup>0</sup>C before being poured into the mold to increase its viscosity. To reduce porosity in the matrix material, the die (120 x 120 x 25 mm) was heated to 250<sup>0</sup>C. When the stirring speed was increased to 550 rpm, the molten slurry was poured into the dia and left to cool at room temperature.

Test data for real-time testing was given by the SCM-3000 software. The initial setting knob was set to zero to align the load pointer. The diameter of the test piece was measured many times with vernier calipers, and the average value was computed.

A VMC (YCM-EV1020A) with the following specifications was used to drill the holes: 8 mm maximum tool diameter, 1000 rpm maximum spindle speed, 500 kg load capacity, and 30 kVA maximum power consumption. A suitable jig was utilized to hold the workpiece in the VMC, and through holes were drilled in line with the face-centered central composite design using a coated tungsten carbide drill bit. With a portable surface roughness tester, the surface roughness of the drilled hole side walls was measured along the feed route with a conventional detector, whose stylus is 6 mm high, 3.5 mm broad, with a tip radius of 2 mm and a tip angle of 60<sup>0</sup>.The ASTM standard E1082-90 was used to determine the surface roughness of the drilled holes.The surface roughness of the aluminium composites is determined.

## STATISTICAL ANALYSIS

The analysis was carried out using SPSS 26 software. The multiple comparison table, and G graph were generated by integrating nano WC reinforced Al-Mg-Cr alloy composites as independent variables. In both experimental and control groups, there are 20 test samples each, with g-power 80% used for calculating sample sizes. A significant difference between the synthesized composites and the as-cast alloys was revealed to be  $P=0.007$  (Anbuezhayan et al. 2021)

## RESULTS

To make aluminium composites using the stirring casting process, the researchers used a novel WC reinforcement and Al-Mg-Cr alloys as foundation materials. The surface roughness strength of aluminium nanocomposites is shown in Fig. 1. Fig. 2 shows the SPSS bar graphs of the created aluminium nanocomposites. Table 2 compares surface roughness. The average of the results is shown in Table 3 and 4 gives the mean and standard deviation. Table 5 shows independent Sample Test for Surface Roughness of Al-Mg-Si alloy and 2 wt% of  $TiO_2$  reinforced Aluminium nanocomposites, respectively.

## DISCUSSION

In the current study, a stir casting technique was utilized to manufacture 2wt % WC reinforcing particles. The surface roughness of synthesized aluminium alloy composites improved considerably when compared to as-cast Al-Mg-Cr alloys, as seen in Fig 2. Because the WC strengthening particles are evenly distributed throughout the matrix alloy, there are no remaining holes. The parameters investigated were injection speed in the first and second phases, cooling time, and melt temperature. The temperatures of the Fix and Moving side dies were changed, with the Fix side being kept hotter followed by machinability studies (Jarfors 2012).

The feasibility and possibilities of lowering the cost of manufactured aluminium hybrid composites for automotive and aerospace applications are investigated in this study. In addition, the tribological performance of aluminium hybrid composites (AHC) made by stir casting has been assessed. The purpose of this research is to examine the tribological and machining performance of composites made up of various reinforcing elements (C. P. Kumar 2020). The mechanical and machinability behavior of ZL111 aluminium expanded glass (EG) syntactic foam is investigated in this work using two alternative production processes. Stir casting produced a closed-cell morphology and overall stronger syntactic foam samples. The metallic matrix of the infiltration casting samples had an open-cell shape, which resulted in weaker and denser foams and a poor surface finish was observed (Broxtermann et al. 2020). In this experiment, the impact strength, hardness, tensile strength, and yield strength of various weight percentages of materials like Copper and Silicon were used as the fundamental material of Al6070 aluminium alloy composites. Each specimen was put through its paces according to the terms and circumstances of each testing procedure. To establish the proper percentage of weight-based components to include in the composite, the results of all individual specimens and their drilling characteristics were analyzed (Rajkumar, Monish, and Keerthika 2021). The goal of this paper is to explain the manufacture and characterization of aluminium syntactic foam created by the stir casting method. The microstructure of the generated foam was also looked at to see whether there was any cenosphere dispersion in the aluminium matrix. The microstructure results indicate that cenosphere particles are evenly dispersed (Sahu, Ansari, and Mondal 2020). In comparison to the findings of the previous study, the physical features of the aluminium alloy reinforced with novel molybdenum trioxide by stir casting technology have substantially improved. The production process is the same in all of the trials, demonstrating that the stir casting method produces substantially superior outcomes and its machinability studies were analyzed.

The limitation of the research is found to be that using the stir casting method a few percentages of nano reinforcement were added with aluminium matrix alloy and its surface roughness was analyzed. It was noted that the addition of a small amount of compound to the matrix alloy greatly improved those properties in comparison with the parent alloy. Increasing the wt.% of compound strengthening particles significantly improved the surface roughness, according to the literature. On the other hand, increasing the percentage of reinforcement exhibits agglomeration, which reduces the physical and machinability properties of aluminium alloy composites. The problem is rectified in the present study by adding a few percentages of titanium dioxide particle in the matrix alloy significantly increased its physical properties and its surface roughness also improved which significantly used for functional applications. The future scope of the present study is still an attempt to be carried out by increasing the proportion of nano reinforcement and its surface roughness needs to be analyzed further for such applications.

## CONCLUSION

Within the limitation of this study, the surface roughness behavior of the novel nano WC-assisted Al-Mg-Cr mix was compared to the basic alloy material in this experiment. They observed that the novel WC-reinforced Al-Mg-Cr composite has higher surface roughness than Al-Mg-Cr alloy. There is about a 20.81% increment in the surfaceness of the experimental group than the control group. This concept has a lot of potential for future upgrades and enhancements to vehicle bodies and other aluminium-based materials.

## DECLARATION

### Conflict of interest

The authors declare that there is no conflict of interest in this manuscript.

### Authors Contribution

Author AJ was involved in data collection, data analysis, Manuscript writing. Author.GA was involved in conceptualization, data validation, and critical review of the manuscript.

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**TABLES AND FIGURES**

**Table 1.** Chemical composition of Al-Mg-Cr alloys

Concentration of wt%								
Cr	Cu	Fe	Mg	Mn	Si	Cr	Zn	Al
0.28	0.1	0.4	2.6	0.1	0.25	0.35	0.1	Balance

**Table 2.** Comparison of surface roughness of Al-Mg-Cr alloys with Al-Mg-Cr Alloy + 2Wt% of nanoWC

Exp No	Al-Mg-Cr Alloy	Al-Mg-Cr Alloy + 2Wt% of nanoWC

1	8.060	7.085
2	8.299	7.012
3	8.543	6.987
4	8.824	6.432
5	9.035	6.087
6	9.435	5.923
7	9.923	5.789
8	9.178	5.234
9	9.456	5.012
10	9.967	4.912
11	10.097	4.709
12	10.379	4.589
13	10.83	4.456
14	11.023	4.248
15	12.129	4.134
16	12.398	4.043
17	12.267	3.970
18	12.358	3.893

19	12.580	3.356
20	12.673	3.178

**Table 3.** Average surface roughness of as cast Al-Mg-Cr alloy and 2 wt% of WC reinforced Aluminum nanocomposites.

S.NO	TYPES OF MATERIAL	AVERAGE SURFACE ROUGHNESS (MPa)
1.	Al-Mg-Cr alloy	10.35235
2.	Al-Mg-Cr alloy + 2wt% of nanoWC	5.079944

**Table 4.** Descriptive tabular column of Surface roughness (Mean value, Standard deviation and standard error) of Al- Mg-Cr alloy nano composite laminates.

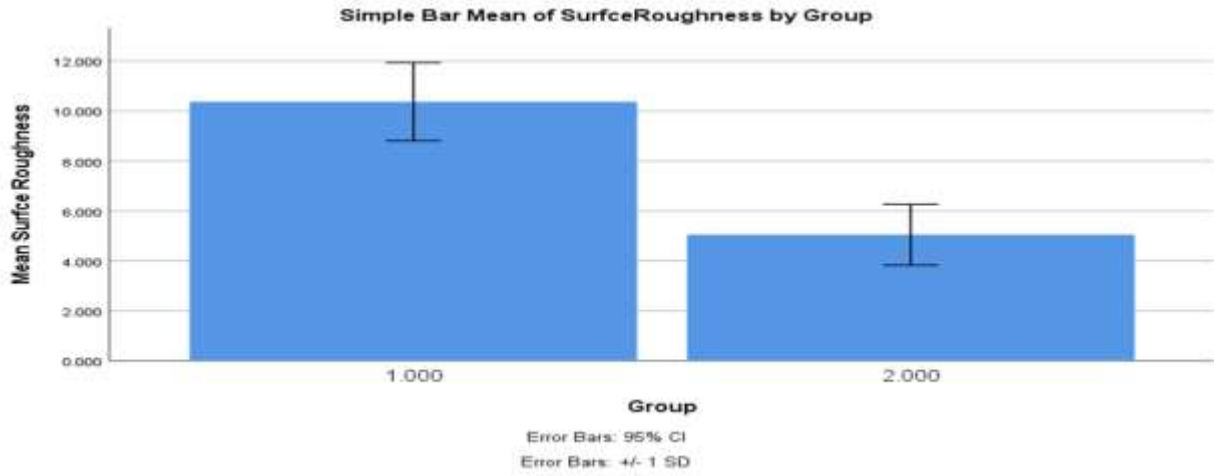
DESCRIPTIVES								
SURFACE ROUGHNESS								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Al-Mg-Cr Alloy	20	10.372	1.560805	0.34900	4.424292	6.21620	8.062	12.673
Al-Mg-Cr Alloy + 2Wt% of nanoWC	20	5.0524	1.217146	0.27216	4.422542	6.21795	3.178	7.085
Total	40	7.7122	1.38897	0.31058	4.42341	6.21707	5.62	9.879

**Table 5.** Independent Sample Test for Surface Roughness of Al-Mg-Si alloy and 2 wt% of TiO<sub>2</sub> reinforced Aluminium nanocomposites.

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Surface Roughness	Equal variances assumed	17.26	0.001	-15.75	38	0.001	-6.71725	.324552	-7.658	-7.776
	Equal variances not assumed			-15.75	25.43	0.001	-6.71725	.324552	-7.673	-7.760



Fig. 1. Surface roughness composites samples of Al-Mg-Cr alloy reinforced nano WC ceramic particulates



**Fig. 2.** Bar graph shows the comparison between the surface roughness of Al-Mg-Cr alloys with 2wt% of nano WC reinforced aluminium alloy. The error bars  $\pm 1$  SD was attained.