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Wear Analysis of Composite made by Matrix Material Al6061 and Filler Particle TiO_2

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A B S T R A C T

In this study, the goal was to fabricate aluminum 6061 metal matrix composites (MMCs) with varying weight percentages of micro titanium dioxide (TiO2) particles. The MMCs were prepared using stir casting technology, and the effects of wear factors and the varying weight percentages of TiO2 particles on the wear rate were analyzed using the response surface methodology (RSM) and the Taguchi technique. The micro hardness of the material was also assessed. The results showed that the lowest load conditions resulted in the least amount of wear, and optimal solutions were identified through the use of RSM and ANOVA testing of the data generated by the experiments. The wear test analysis was conducted on an in-house testing facility developed by the researchers. The use of MMCs, particularly in engineering applications where sliding wear is a problem, has shown promising features due to the incorporation of hard particles into the metal matrix.

Keywords:Composite material, Al-6061, Nano Particle, TiO_2, drilling operation, hardness, Tensile Strength, Wear Properties etc.

1. Introduction

Metal matrix composites (MMCs) are materials that are composed of metal and reinforced particles, and they have a wide range of applications in engineering due to the unique combination of functional qualities that they offer. The incorporation of hard ceramic particles into the composite matrix is a primary goal of MMC production, and the use of micron and nano particles has helped to broaden the range of applications for MMCs. Magnesium, titanium, and aluminum are the three metals that are most commonly used in MMCs due to their high strength to weight ratio, stiffness, and resistance to temperature.

In this particular study, the goal was to fabricate aluminum 6061 (Al6061) metal matrix composites (MMCs) with varying weight percentages of nanoparticles. Stir casting was the technology that was used to prepare the MMCs, and the effects of various wear factors on the wear rate were analyzed using the response surface methodology (RSM) and the Taguchi technique. The micro hardness of the material was also assessed as part of the experiment.

The RSM and Taguchi technique were used to create experiments for the purpose of analyzing a variety of wear and mechanical characteristics, and the results showed that the lowest load conditions resulted in the least amount of wear. The micro hardness of the material was also found to be an important factor in determining the wear rate of the MMCs.

In addition to analyzing the wear rate, the researchers also used the RSM and ANOVA testing to identify optimal solutions for the MMCs. The wear test analysis was conducted on an in-house testing facility that was developed by the researchers, and the results of the study showed that the use of MMCs can be a promising solution for engineering applications where sliding wear is a problem.

Overall, this study demonstrated the potential of using Al6061 MMCs with nanoparticles for engineering applications where sliding wear is an issue. The incorporation of hard ceramic particles into the composite matrix helps to improve the functional qualities of the MMCs, and the use of the RSM and Taguchi technique allowed the researchers to identify optimal solutions for the MMCs. Further research may be needed to optimize the MMCs for specific applications and to understand the mechanisms behind their improved performance.

2. Literature Review

There have been several studies exploring the use of aluminum alloys and metal matrix composites (MMCs) for various applications in the automotive industry. Kala Mer and colleagues (2014) found that the car industry has been using lightweight aluminum alloys for 20 years due to their damping, stability, and machinability properties. However, aluminum alloys have low peak strength compared to other structural components and are not widely used in cars due to their lack of heat resistance or high cost. In an effort to develop high-performing, lightweight materials, researchers have also explored the use of calcium matrix composites and cost-effective production methods.

One study (V.K Sharma et al., 2018) examined the influence of graphite powder on the wear and friction of molten aluminum, and found that the inclusion of graphite particles in aluminum composite materials reduced wear and friction. Another study (Rana Purohit et al. 2012) explored the use of high-temperature aluminum alloys, including Mg-AlCA, Mg-Re-Zn-Zr, Mg-Sc-Mn, and Mg-Y-Re-Zr, in order to expand the industrial use of aluminum alloys. However, these alloys are not widely used in the automotive industry due to their lack of heat resistance or high cost.

Khoshsima et al (2022) studied the use of hybrid metal matrix composites (HMMCs) reinforced with composite metal boride particles (MMCs) in order to improve the mechanical properties of aluminum-based materials. The researchers found that the inclusion of Co-Ni-B or Co-Ti-B particles in the HMMCs improved the microstructures, physicochemical characteristics, and mechanical properties of the materials. In addition, the HMMCs reinforced with Co-Ni-B particles showed the highest hardness and lowest indentation depths, as well as improved wear resistance and hardness compared to other binary and ternary boride phases.

Other studies have explored the use of various ceramic reinforcements, such as ZrO2 and SiC, in aluminum matrix composites. Researchers (2012) used stir casting to create reinforced and unreinforced hybrid composites containing 2%, 4%, and 6% ZrO2 and 4%, 8%, and 12% SiC, and found that the inclusion of these reinforcements improved the wear resistance of the hybrid composites. Another study (Srinivasan et al, 2022) examined the use of titanium carbide (TiC) and graphite (Gr) as ceramic reinforcements in Al7075-TiC-Gr composites, and found that the addition of TiC increased the hardness of the composites but decreased their impact strength due to the reinforcing brittleness.

3. Material and Methods

The research approach in this study involves the use of a recommended experimental methodology to investigate the foundation of thermosetting aluminum (Al) and metal matrix composite (MMC) composites with a filled matrix in order to improve their mechanical and wear characteristics. The process of preparing the suggested composites involves the use of mechanical stirring and cleaning in order to distribute MMC in Al6061 and nanoparticle titanium dioxide (TiO_2) with or without curing. A specially structured styrene-free MMC with the appropriate level of viscosity was used to distribute the alloy during intense mixing. This new method of combining Al6061 with nanoparticle TiO_2 has resulted in significantly improved qualities compared to their old composites. The mechanical properties, such as wear, mechanical strength, and so on, were characterized through evaluations. Morphological analysis was also conducted on fractured surfaces to determine the factors that reduce stress concentration restrictions, such as Al6061 and Al6061TiO2 interactions and agglomerations, pull outs, and voids. The research flow diagram for this study is shown in figure 1.

The aluminum alloy 6061 used in the construction of the composite was purchased in the form of cylindrical rods from a local source in Jaipur, India. Titanium dioxide (TiO_2) nanoparticles were used as a reinforcing material in the manufacturing of the aluminum matrix composite (AMC). TiO_2 is a refractory material that is both hard and lightweight, and it has excellent resistance to both thermal shock and abrasion. The TiO2 ingredient was purchased in the form of powder from Madras Fluorine Private Ltd in Chennai, India. The raw Al6061 rods used to make the AMC were initially melted in a laboratory to remove impurities before being subjected to the stir casting process.

TABLE 1 CHEMICAL COMPOSITION OF THE AL6061

Si	Fe	Cu	Mn	Pb	Zn	Ti	Sn	Mg	Al
%	%	%	%	%	%	%	%	%	%
0.809	0.155	0.355	0.027	0.023	0.008	0.01	0.01	0.802	balance

TABLE 2 MECHANICAL PROPERTIES OF THE AL6061

Material	Density (kg/m3)	Micro hardness (HB500)	EM (GPa)	TS (MPa)
Al-6061	2700	30	70 to 80	115
TiO2	4230	89	230	680

EM: Elastic Modulus; TS: Tensile Strength

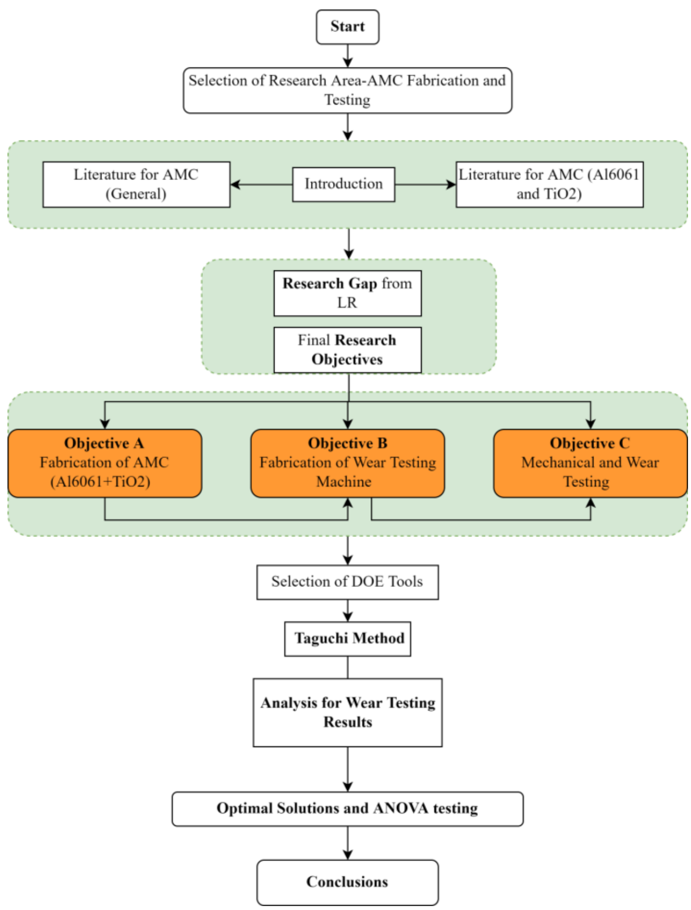
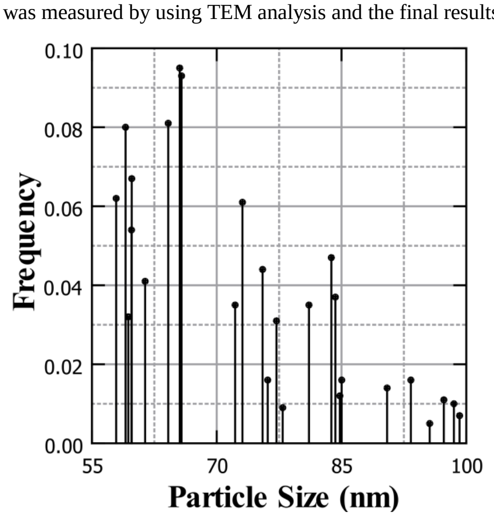
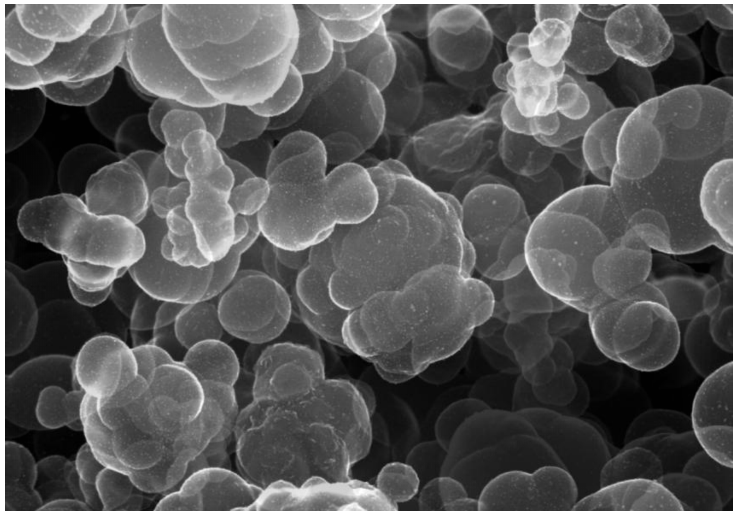


Fig.1. Research Flow Diagram of the present investigation

The particle distribution of the nanoparticle TiO_2 was measured by using TEM analysis and the final results for the distribution was shown in figure 2.



(a.) TiO2 particle distribution using TEM images



(b.) TiO_2 particle distribution using TEM images

Fig.2 Particle distribution of the TiO_2 nanoparticle

4. Fabrication Steps

The stir casting process for the aluminum matrix composite (AMC) began by melting impurity-free AA6061 in a closed graphite crucible inside an electrical resistance furnace at a temperature of 750 degrees Celsius. This was done to prevent oxidation of the aluminum during casting. The necessary amount of titanium dioxide (TiO_2) nanoparticles was weighed precisely and combined with AA6061 in proportions of 1, 3, and 5 weight percent. The TiO_2 nanoparticles were first heated to 500 degrees Celsius to remove moisture and then carefully inserted into the molten aluminum at 750 degrees Celsius. A motor-controlled stirrer was used to thoroughly mix the ingredients for three to five minutes. The composite was then heated to 750 degrees Celsius and subjected to a second stirring with a mechanical stirrer in order to increase the dispersion of the TiO_2 nanoparticles throughout the molten AA6061. The mixture was poured into cast iron molds and allowed to cool and solidify. The AA6061- TiO_2 composites were then removed from the molds and machined into the necessary dimensions and shapes. The production of composites with varying weight percentages of reinforcement was achieved by following the same technique. After proper stir casting, the mixed composite liquid metal was then cast into a final product using the sand casting method. The sand casting process involved preparing samples according to ASTM standards and project requirements.

5. Instrumentation and Factors

In this section all instruments required for the testing of the AMC made by stir casting was discussed. In present study the following experiments are performed to measure the selective testing on the AMC.

Mechanical Strength and Wear Test

Factor and Levels Selection

In accordance with the information presented in the prior chapter, a total of three process parameters will be selected. The final list of variables and their values are displayed in table 3. This list was prepared using the findings of the literature review as well as the AMC results for the nanoparticles made of Al6061 and TiO2.

TABLE 3

FACTOR AND LEVEL SELECTION FOR AMC

	Factor	1	2	3	4
A	Nano Particle (TiO_2) (% by Weight)	0	2	4	6
B	Load (kg)	1.0	1.5	2.0	2.5
C	Sliding Distance (m)	250	500	750	1000

6. Result and Discussion

In present study wear testing was performed for the MMC made with Al6061 and nanoparticel TiO_2 using various composition of the nano particles and normal load applied to the test object made with MMC composite. The variations of the wear rate due to different load conditions and percentage contribution of the nano particels were present in following tbales.

TABLE 4

Wear rate for different sliding distance and load conditions for Alloy Al6061

Sliding Distance	Vol Wear Loss (10 N)	Vol Wear Loss (15 N)	Vol Wear Loss (20 N)
250	8.75	13.30	13.94
500	10.28	14.73	17.73
750	13.15	18.96	20.89
1000	17.28	25.45	31.88

TABLE 5

Wear rate for different sliding distance and load conditions for Alloy Al6061and 2% TiO_2

Sliding Distance	Vol Wear Loss (10 N)	Vol Wear Loss (15 N)	Vol Wear Loss (20 N)
250	7.53	8.46	10.07
500	9.63	11.65	14.77
750	10.25	15.18	17.49
1000	11.81	19.39	27.28

TABLE 6

Wear rate for different sliding distance and load conditions for Alloy Al6061and 4% TiO_2

Sliding Distance	Vol Wear Loss (10 N)	Vol Wear Loss (15 N)	Vol Wear Loss (20 N)
250	3.90	6.39	6.91
500	5.97	9.52	11.15
750	6.06	11.39	13.63
1000	7.52	14.80	21.20

TABLE 7

Wear rate for different sliding distance and load conditions for Alloy Al6061and 6% TiO_2

Sliding Distance	Vol Wear Loss (10 N)	Vol Wear Loss (15 N)	Vol Wear Loss (20 N)
250	1.59	2.78	4.65
500	2.83	5.94	7.86
750	4.72	7.55	9.43
1000	5.11	11.67	15.10

8.Conclusion

In conclusion, the use of nanoparticle titanium dioxide (TiO_2) as a reinforcing material in aluminum matrix composites (AMCs) has several advantages. TiO_2 is a refractory material that is both hard and lightweight, and it has excellent resistance to thermal shock and abrasion. This makes it well-suited for use in applications that require high wear resistance, such as pistons, contactors, and connecting rods. In addition, the incorporation of TiO_2 nanoparticles into AMCs can lead to improved mechanical properties, such as higher strength and stiffness, as well as improved resistance to temperature. Overall, the use of TiO_2 nanoparticles in AMCs made of Al6061 can broaden the range of applications for these materials and improve their functional qualities.

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