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EXPERIMENTAL INVESTIGATION ON MICROHARDNESS PROPERTIES OF AL 7075 (TO2/SIC/GRAPHENE 100 NANO) NMMC'S BY STIR CASTING METHOD

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ABSTRACT

To develop a novel metal matrix composite (NMMC) via stir casting, this work investigates the microhardness characteristics of Al 7075 reinforced with titanium dioxide (TiO2), silicon carbide (SiC), and graphene nanoplatelets. The impact of different process parameters on the microhardness of the composite is thoroughly investigated using the Taguchi experimental methodology. To optimize the experimental settings, a robust L9 orthogonal array is used, and Minitab software simplifies statistical analysis and optimization easier. The results show that the Al 7075 matrix's microhardness significantly improved with the addition of TiO2, SiC, and graphene reinforcements of 100 nano. Maximum microhardness is achieved by determining the most suitable combination of temperature, stirring speed, and reinforcing percentage. The mechanical properties of the composite are improved by the stir casting method, which is successful in evenly spreading the reinforcements within the aluminum matrix. The statistical significance of the chosen parameters on the microhardness results is validated by the analysis of variance (ANOVA). This investigation presents important new information about producing high-performance composites based on Al 7075 for use in aerospace and automotive applications where excellent mechanical qualities are essential. The effectiveness of the Taguchi technique and Minitab software in optimizing the characteristics of composite materials is demonstrated by the effectiveness of their implementation..

Keywords: Analysis of Variance (ANOVA),Silicon carbide(SiC),Graphene, Taguchi

1. Introduction

The continuous demand for advanced materials with superior mechanical properties has driven significant research into metal matrix composites (MMCs). Among various MMCs, aluminum-based composites have gained considerable attention due to their exceptional strength-to-weight ratio, excellent corrosion resistance, and good thermal and electrical conductivity. Al 7075, a high-strength aluminum alloy, is particularly noted for its widespread application in aerospace, automotive, and structural components. However, the inherent limitations of Al 7075, such as its relatively low wear resistance and hardness, necessitate the development of reinforced composites to meet the stringent requirements of advanced engineering applications [1]. Al 7075 is an aluminum alloy predominantly known for its high strength, comparable to many steels, making it a preferred material in high-stress environments. The alloy is composed primarily of aluminum, with zinc as the principal alloying element, followed by magnesium, copper, and other elements. This composition imparts Al 7075 with excellent mechanical properties, including high tensile strength, good fatigue resistance, and toughness [2]. The aerospace industry extensively utilizes Al 7075 in the manufacture of aircraft structures, including wings and fuselage components, due to its light weight and high strength. Additionally, the automotive industry employs this alloy in performance-
critical parts such as chassis and suspension systems [3].Despite its advantageous properties, Al 7075 exhibits limitations in hardness and wear resistance, which can compromise its performance in demanding applications.

Consequently, reinforcing Al 7075 with various ceramic and carbon-based materials has emerged as a promising approach to enhance its mechanical properties. MMCs consist of a metal matrix combined with one or more reinforcing phases, which can be in the form of particles, whiskers, or fibers [4]. The

reinforcement materials are typically ceramics or carbon-based substances, chosen for their high hardness, strength, and thermal stability. The primary aim of developing MMCs is to capitalize on the beneficial properties of both the metal matrix and the reinforcements, resulting in a composite material with superior performance characteristics. In the context of Al 7075-based MMCs, various reinforcements such as silicon carbide (SiC), titanium dioxide (TiO2), and graphene have shown significant potential in enhancing mechanical properties, particularly hardness. SiC is renowned for its high hardness, thermal conductivity, and stability, making it an excellent candidate for reinforcing aluminum alloys [5]. TiO2, with its high hardness and wear resistance, further contributes to the mechanical robustness of the composite. Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, is celebrated for its extraordinary mechanical strength, high surface area, and excellent electrical and thermal conductivity. Among various fabrication techniques for MMCs, the stir casting method stands out for its simplicity, cost-effectiveness, and suitability for large-scale production. Stir casting involves the mechanical stirring of the molten metal matrix with the reinforcement materials to achieve uniform dispersion. The process typically includes the following steps: melting the base metal, adding the reinforcement materials, stirring the mixture to ensure uniform distribution, and then casting the composite into the desired shape [6].
The success of the stir casting method largely depends on the process parameters, including stirring speed, temperature, and the volume fraction of reinforcements. Optimizing these parameters is crucial to achieving a homogeneous composite with enhanced mechanical properties. The Taguchi method is a statistical approach designed to optimize process parameters and improve the quality of manufactured products. By employing an orthogonal array, the Taguchi method systematically examines the effects of multiple parameters on performance characteristics with a minimal number of experiments. This approach not only saves time and resources but also provides robust results that can withstand variations in process conditions. In the context of MMC fabrication, the Taguchi method can be utilized to optimize the stir casting parameters to achieve the desired mechanical properties, such as microhardness. By systematically varying the stirring speed, temperature, and reinforcement volume fraction, and analyzing the resulting microhardness, an optimal set of parameters can be identified[7-10].

MATERIALS AND METHODS :

Al 7075 alloy, Titanium Dioxide (TiO2), Silicon Carbide (SiC), and Graphene nanoplatelets were used to fabricate the metal matrix composites (NMMCs). The Al 7075 was obtained in its cast form, while TiO2, SiC, and Graphene were procured in powder form. The stir casting method was employed to produce Al 7075/TiO2/SiC/Graphene NMMCs. Al 7075 was melted in an electric furnace at 750°C. The reinforcement powders were mixed into the molten metal using mechanical stirring Table 1. The mixture was poured into a preheated mold and allowed to solidify. A Taguchi L9 orthogonal array was used to design experiments. Factors including stirring speed, temperature, and reinforcement percentage were varied Table 2. Microhardness testing was conducted using a Vickers hardness tester. Minitab software was used to analyze the results, perform ANOVA, and optimize the process parameters [21-23].

Table 1: *Base material*

Materials	Properties	Values
Aluminium 7075	Density	2.7 g/cm^3
	Tensile strength	115 MPa
	Elastic modulus	70-80 GPa
	Elongation	25%

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Table 2: *Reinforcement materials*

Materials	Properties	Values
Titanium dioxide (TiO2)	Density	4.23 g/cm^3
	Melting Point	1,843° C
Silicon carbide (SiC)	Density	3.21 g/cm ^{3}
	Melting Point	2,830 °C
Graphene	Density	2270 g/mm ^{3}
	Melting Point	3697° C

EXPERIMENTATION

The experimental procedure for fabricating Al 7075-based metal matrix composites (NMMCs) with Titanium Dioxide (TiO2), Silicon Carbide (SiC), and Graphene nanoplatelets involves several key steps. Initially, the Al 7075 alloy was obtained in its cast form, and the TiO2, SiC, and Graphene were procured as powders. The process began with melting the Al 7075 alloy in an electric furnace, where the temperature was maintained at approximately 750°C. Once the alloy was fully molten, the furnace temperature was adjusted to the desired casting temperature based on preliminary experiments. To incorporate the reinforcements, the TiO2, SiC, and Graphene powders were pre-weighed according to the designed experimental conditions. A mechanical stirrer was then used to introduce the powders into the molten aluminum. The stirring was conducted at a specific speed to ensure uniform dispersion of the reinforcements throughout the molten metal. The stirring process was maintained for a predetermined duration to achieve optimal distribution. After the reinforcements were thoroughly mixed, the molten composite was poured into a preheated metal mold to facilitate solidification and reduce the risk of thermal shock. The mold was kept at a controlled temperature to ensure the composite cooled uniformly. Upon solidification, the composite samples were removed from the mold and subjected to heat treatment, if necessary, to enhance their mechanical properties. The samples were then machined into standardized test specimens for microhardness evaluation Table 3. Microhardness tests were conducted using a Vickers hardness tester to assess the hardness of the composite materials. The data obtained were analyzed using Minitab software to optimize the stir casting parameters and evaluate the effects of different reinforcement combinations on the microhardness of the Al 7075-based NMMCs. Microhardness testing, also known as micro indentation hardness testing, is a technique used to measure the hardness of materials at a microscopic scale. It involves creating a small indentation on the surface of a material and then measuring the size of the indentation. This test is especially useful for evaluating small or thin samples, as well as for assessing variations in hardness within a material's microstructure. Three reading of microhardness were taken at different locations and the mean value of it was considered as final microhardness [24-26].

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Table 3: Hardness experimental values of Al7075 with 100Nano

Exp.No	Matel Matrix Composite (MMC)	Trail 1	Trial 2	Trial 3	Avg HV
1	Al7075 TiO2 (0.5 %) nanocomposites	260.1	229.1	139.5	209.566
2	Al7075 TiO2 (5 %) nanocomposites	109.7	123.9	105.6	113.066
3	Al7075 TiO2 (10 %) nano composites	107.9	159.9	130.5	132.766
4	Al7075 SiC (0.5 %) nano composites	104.3	149.6	134.8	129.566
5	Al7075 SiC (5 %) nanocomposites	181.8	148.2	134.8	129.566
6	Al7075 SiC (10 %) nano composites	145.4	123.0	187.8	151.066
7	Al7075 Graphene (0.5 %)	98.7	84.6	154.6	112.633
8	Al7075 Graphene (5 %) nanocomposites	162.1	112.6	105.0	126.566
9	Al7075 Graphene (10 %) nano composites	112.7	132.1	111.6	118.8

The preparation of samples for microhardness testing begins with polishing and cleaning the surface to ensure accurate and reliable measurements. Once the surface is properly prepared, the sample is carefully placed on the stage of the microhardness testing machine.The appropriate load and indenter type are selected based on the material and its intended application. The indenter is then lowered onto the sample surface under the chosen load for a specified dwell time, allowing the indenter to create an indentation in the material. After the dwell time, the load is removed, leaving a precise indentation on the sample. Using a microscope, the dimensions of the indentation are measured; for Vickers hardness, both diagonals are measured, whereas for Knoop hardness, the long diagonal is measured. Finally, the microhardness value is calculated using the appropriate formula for the chosen method, either Vickers or Knoop, providing an accurate assessment of the material's hardness. It's important to note that microhardness testing requires careful sample preparation, accurate load application, precise measurement techniques, and proper data analysis to ensure reliable and meaningful results.

RESULTS AND DISCUSSION

Al7075 is a high-strength aluminum alloy widely used in aerospace and other high-performance applications due to its excellent mechanical properties. Reinforcing this alloy with materials such as titanium dioxide (TiO_2), silicon carbide (SiC), and graphene can significantly enhance its microhardness, thereby improving its wear resistance and structural integrity. Titanium dioxide (TiO_2) is known for its high hardness and stability. When incorporated into Al7075, TiO_2 particles distribute uniformly throughout the matrix, hindering dislocation movement and increasing hardness machine Fig.1.Silicon carbide (SiC) is another hard ceramic material that, when used as a reinforcement, provides excellent load-bearing capabilities. SiC particles also contribute to grain refinement in the alloy matrix, leading to improved hardness and strength as shown table 4.

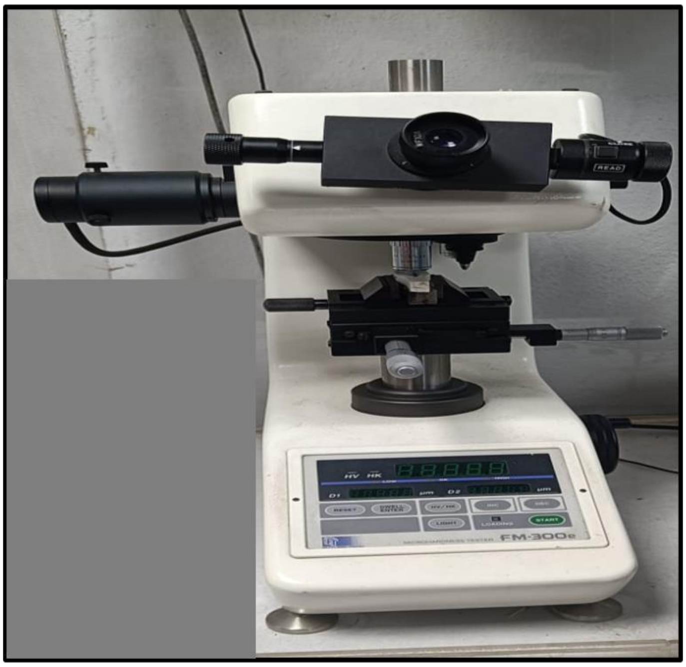

Fig. 1: *Microhardness.*

Table 4: *Micro Hardness test experimental values Mean and S/N Ratio of Al7075 with 100Nano.*

EXP.No	Reinforcements	composite (%)	AvgHV	SNRA1	MEAN1
1	Tio2	0.5	209.566	46.4264	209.566
2	Tio2	2.5	113.066	41.0666	113.066
3	Tio2	5	132.766	42.4617	132.766
4	SiC	0.5	129.566	42.2498	129.566
5	SiC	2.5	129.566	42.2498	129.566
6	SiC	5	151.066	43.5833	151.066
7	Graphene	0.5	112.633	41.0333	112.633
8	Graphene	2.5	126.566	42.0463	126.566
9	Graphene	5	118.8	41.4963	118.8

Table 5: *Response for mean at Larger is better (Micro Hardness 100 Nano).*

Level	Reinforcements	composite (%)
1	43.32	43.24
2	42.69	41.79
3	41.53	42.51
Delta	1.79	1.45
Rank	1	2

The given means provides the relative contribution of machining parameters in controlling the response of machining performance criteria i.e. stir casting during Al7075 with different metal matrix. Table 5 shows that the reinforcements and material composition percentage, control are responsible and have influence on tensile strength while reinforcements with different combinations as shown Table 4. The influence of reinforcements with different combinations is the most significant. And the influence of metal matrix composite percentage is significant influencing factor as compare to other on the tensile accuracy during metal matrix of Al7075 composite

Table 6: *Response for S/N Ratio at Larger is better (Micro Hardness 100 Nano).*

Level	Reinforcements	composite (%)
1	151.8	150.6
2	136.7	123.1
3	119.3	134.2
Delta	32.5	27.5
Rank	1	2

A greater value of S/N ratio is always considered for better performance irrespective of the category of performance characteristics. The difference of maximum and minimum mean S/N ratio Fig 2. indicates the significance of the process parameters, greater the difference, greater will be the significance. Table 6. shows that the reinforcements different combinations most significantly towards microhardness as the difference value is highest, followed by metal matrix percentage.

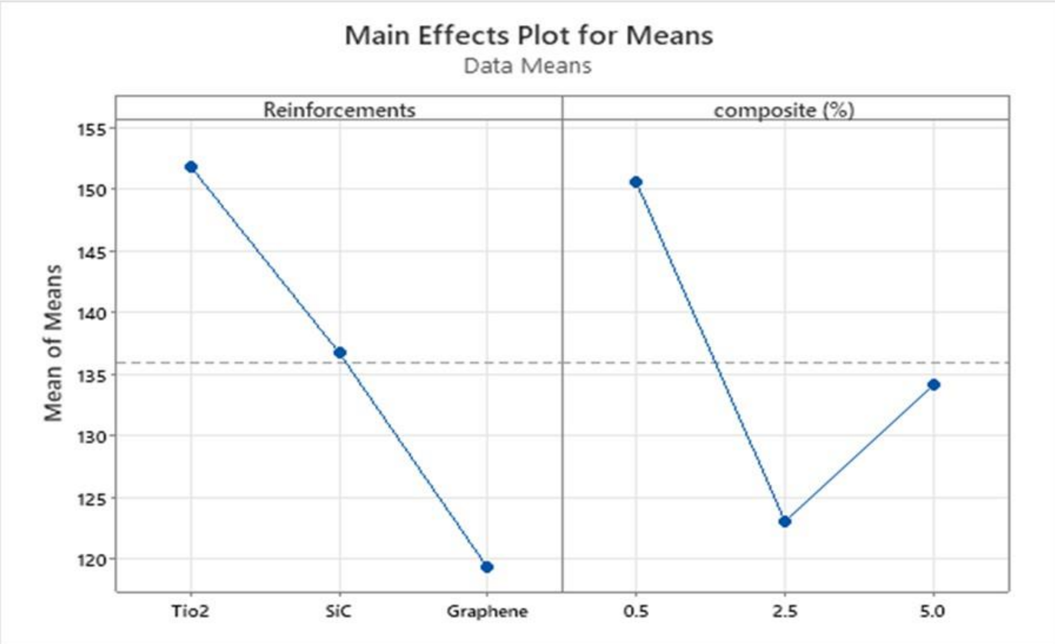

Table 7: *ANOVA for Micro hardness (100 Nano).*

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)
Reinforcements	2	1584	1584	791.9	0.7	0.54	22.03366254
composite (%)	2	1150	1150	575	0.5	0.63	15.99666157
Residual Error	4	4455	4455	1113.8			61.96967589
Total	8	7189					100

Table 7. shown the most significant factor is reinforcements different combinations; the percentage contribution of that parameter to residual errors was 61.9696%. The next significant factor is reinforcements metal matrix which contributed 22.033%, and the third significant factor is the composition % with percentage contribution of 15.99%.

CONCLUSIONS

Effectiveness of stir casting technique and the Mechanical and Tribological characterization of stir casted nano TiO2, Sic and Graphene reinforced aluminium 7075 composites MMC and normal Rolling Al7075.

1. In summary, the incorporation of 100 nano-graphene, TiO2, and SiC particles into metal

matrices significantly enhances the microhardness of MMCs. Each reinforcing material contributes through mechanisms such as dislocation obstruction, grain refinement, and effective load transfer. The choice of reinforcing material and the quality of its dispersion within the matrix are crucial factors determining the extent of hardness improvement.

2. Mechanical Properties: Increased hardness are achieved through the stir-casting process of Al 7075, metal matrix TiO2, SiC, and Graphene (100 Nano). Al7075 and TiO2 (05%) 100 Nano metal matrix achieved a microhardness of 209.56 HV, while graphene (0.5%) produced a microhardness of 112.635 HV.

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