RESEARCH ARTICLE OPEN ACCESS

Studying the Microhardness Characteristics of Stir-cast Al 7075 (To2/SiC/Graphene 200 nano) NMMCs Experimentally

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ABSTRACT
This study investigates the microhardness characteristics of Al 7075 reinforced with Titanium Dioxide (TiO_2), Silicon Carbide (SiC), and 200-nanometer Graphene nanoplatelets to form novel metal matrix composites (NMMCs) using the stir casting method. The Taguchi experimental design is employed to systematically analyze and optimize the influence of various process parameters on the composite's microhardness. An L9 orthogonal array is utilized to optimize experimental conditions, while Minitab software facilitates the statistical analysis. The stir casting process involved melting Al 7075 alloy at 750°C, incorporating pre-weighed TiO_2, SiC, and Graphene nanopowders, and mechanically stirring the molten mixture for uniform dispersion. The composites were then cast into preheated molds and solidified. Microhardness testing was performed using a Vickers hardness tester, and the indentation dimensions were measured to calculate the microhardness values. The results show significant improvements in the microhardness of the Al 7075 matrix with the addition of TiO_2, SiC, and Graphene reinforcements. The Taguchi method and ANOVA identified the optimal combination of parameters, including stirring speed, temperature, and reinforcement percentage, to achieve maximum microhardness. This research highlights the potential of Al 7075/TiO_2/SiC/Graphene NMMCs for advanced engineering applications requiring superior mechanical properties.

Keywords – Aluminum, Microhardness, Nano powders, Stir casting, Taguchi.

Date of Submission: 12-08-2024 Date of acceptance: 27-08-2024

I. INTRODUCTION

The extraordinary mechanical features of aluminum-based metal matrix composites (AMMCs), such as their high strength-to-weight ratios, increased wear resistance, and improved thermal stability, have attracted a lot of attention in the engineering and materials scientific fields. Al 7075 is one of the most popular aluminum alloys for usage in structural, automotive, and aerospace applications among the other varieties. Because of its remarkable strength and resilience, this alloy is a great choice for reinforcement when combined with other hard particles, such as ceramic, to build cutting-edge composite materials[1]. The goal of this work is to examine the microhardness properties of stir-cast Al 7075-based nanocomposites that have been reinforced with nanoparticles of graphene, silicon carbide (SiC), and titanium dioxide (TiO2). The purpose of enhancing particular qualities that are essential for different industrial applications is what motivates the addition of reinforcements such as graphene, SiC, and TiO2 to aluminum alloys. Excellent hardness and wear resistance are attributes of TiO2, whereas SiC offers notable gains in strength and strong thermal conductivity[2-3]. With its remarkable mechanical and electrical characteristics, graphene has become a ground-breaking material in the realm of composite materials, with the potential to greatly improve metal matrix composites' (MMCs') mechanical performance[4]. When these reinforcements work in concert, it should result in a hybrid nanocomposite that is stronger than the original Al 7075 alloy in terms of mechanical properties and microhardness. The current investigation utilizes the stir-casting technique, which is a commonly used method for creating metal matrix composites because of its ease of use, affordability, and capacity to generate consistent distributions of reinforcement particles inside the metal matrix[5]. The molten aluminum alloy is mixed with reinforcement particles during the stir-casting process, and the mixture is vigorously stirred to guarantee that the particles are distributed evenly. Since uniform dispersion of nanoparticles is essential to achieve the desired improvements in material characteristics, this approach is especially beneficial for the manufacture of MMCs including nano-sized reinforcements. This investigation aims to provide insights into the effectiveness of TiO2, SiC, and graphene reinforcements in improving the mechanical performance of the base alloy[6]. Furthermore, understanding the microhardness behavior of these composites can offer valuable information for optimizing their use in various industrial applications, particularly where high strength and wear resistance are required. Microhardness is a critical mechanical property that reflects the resistance of a material to localized plastic deformation and is frequently used as an indicator of wear resistance and durability in engineering applications. This study is motivated by the growing demand for advanced materials that can meet the stringent requirements of modern engineering applications. By exploring the microhardness characteristics of stir-cast Al 7075-based nanocomposites, the research seeks to contribute to the development of high-performance materials that combine lightweight properties with exceptional mechanical strength and durability as shown figure1.

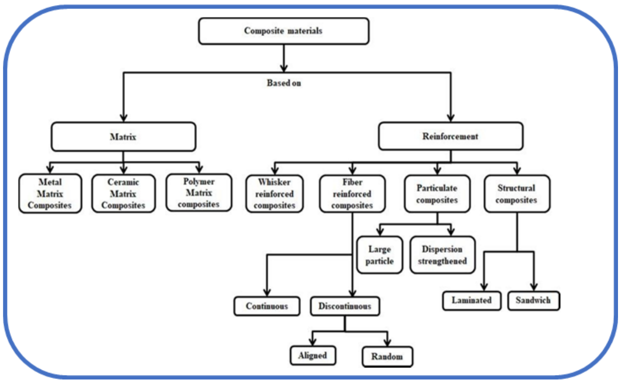

Figure 1:Classification of composites.

The findings of this study are expected to provide a foundation for future research and development efforts aimed at optimizing the composition and processing techniques of aluminum matrix composites, thereby broadening their applicability in critical sectors such as aerospace, automotive, and defense industries. 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].

II. LITERATURE

A comprehensive review of the literature has been done in order to assess the state of the field. This chapter presents the specifics of the literature that was reviewed for this investigation. The capacity of composite materials to withstand compressive pressures, their longevity, superior strength-to-weight ratio, reduced density, resistance to corrosion and impact, and exceptional fatigue strength properties are widely recognized. Metal matrix composites have developed quickly as a result of the aerospace and automotive sectors' need for novel technical materials. Rajan Rajan T.P.D. *et.al.*[11] MMCs can be fabricated using a wide range of matrix and reinforcements making it an attractive choice in a wide variety of products ranging from aerospace applications such as jet engines, turbine blades, turbine shafts, compressor blades, aerofoil surfaces, wing box structures, fan blades, flywheels, engine bay doors, rotor shafts in helicopters, helicopter transmission structures, etc. Pulkit Garg *et. al.*[12] automobile applications such as engines, bodies, piston, cylinder, connecting rod, crankshafts, leaf springs, bearing materials, etc. Phuong Ngoc Pham *et.al.*[13].Aluminium matrix composites are appropriate to the class of light weight high enactment reinforced aluminium metal. The reinforcements in AMCs could be in the form of continuous/discontinuous fibres, whisker or particulates, in varying volume fractions. Their properties can be altered with ease to suit the hassles of innumerable industrial applications by proper combinations of matrix, reinforcement and processing routes. Surappa M. K. *et.al.* [14] have stated that though aluminium alloys possess a number of mechanical and physical properties which make them highly attractive for automotive applications, they exhibit extremely poor resistance to seizure and galling. This can be reduced by reinforcing aluminium alloys with solid lubricants, hard ceramic particles, short fibres and whiskers. Schobel M. *et.al.*[15] Silicon Carbide reinforced aluminium (Al-SiC) metal matrix composites has the advantages of both, high thermal conductivity of a metal and the low coefficient of thermal expansion of a ceramic. The silicon content present within the matrix contributes to the long term stability by providing an interpenetrating composite architecture. Roussos G. *et al.*[16] Titanium dioxide reinforced aluminium (Al-TiO2) metal matrix composites were found to possess better fatigue resistance, improved hardness, lower wear coefficient, superior corrosion and wear resistance. M. Dhanashekar *et al.*[17] This paper reports the mechanical properties and wear behaviour of AA6061/Silicon Carbide (SiC) composites fabricated through powder metallurgy routine. Green uni-axially pressed compacts in the range of 350 MPa was sintered at temperatures in the range of 610–640 °C. The microstructures of AA6061/SiC composites interfaces were characterized by Optical Microscope and mechanical properties were evaluated by Vickers hardness tester and compression test. The test results revealed that increase in hardness and compressive strength of the composite was evidenced with increasing reinforcement level. The fabricated composites showed a good sintering response and the density achieved was maximum. Optimal microstructure showed homogeneous distribution of reinforcement particles in the composites. The wear rate of composites gets decreased with increased wt% of SiC due to formation of mechanical mixed layer (MML) and resist the direct contact of mating parts. Tiejun Ma *et al.*[18] Dry sliding block-on-ring wear tests were performed on a squeeze cast A390 Al alloy, a high pressure die cast 20%SiC–Al MMC, and a newly developed as-cast 50%SiC–Al MMC. The testing conditions spanned the transition that control the mild to severe wear for all materials. Bharath Va *et al.*[19] Aluminum MMCs are preferred to other conventional materials in the fields of aerospace, automotive and marine applications owing to their improved properties like high strength to weight ratio, good wear resistance etc. In the present work an attempt has been made to synthesize metal matrix composite using 6061Al as matrix material reinforced with ceramic Al2O3 particulates using liquid metallurgy route in particular stir casting technique. P Mandloi *et al.*[20] Metal matrix composites (MMCs) are gaining importance as a promising material in various engineering applications like marine, defense, automobile, aerospace etc. due to better mechanical and tribological properties such as high specific strength, corrosion resistance, stiffness, thermal properties, wear resistance etc. By establishing a sophisticated Al 7075-based NMMC with improved microhardness qualities, our work advances the fields of materials science and engineering[21-24]. The effectiveness of these tools in enhancing the characteristics of composite materials is demonstrated by the successful optimization of stir casting parameters using Minitab software and the Taguchi method. The results of this study may lead to an expansion in the use of Al 7075 composites in high-performance engineering fields including automotive, aerospace, and others where outstanding mechanical qualities are essential. In summary, the goal of this work is to lay the groundwork for future research and development in advanced composite materials by offering a thorough understanding of the creation and optimization of Al 7075/TiO2/SiC/Graphene NMMCs. A significant breakthrough in composite material technology is the incorporation of carbon- and ceramic-based reinforcements into the Al 7075 matrix, which presents encouraging opportunities for improved performance in a range of technical applications[25].

III. MATERIALS AND METHODS

The metal matrix composites (NMMCs) were created using graphene nanoplatelets, silicon carbide (SiC), titanium dioxide (TiO2), and Al 7075 alloy. Al 7075 was acquired as a cast, and powdered forms of TiO2, SiC, and graphene were obtained.

Using the stir casting technique, Al 7075/TiO2/SiC/Graphene NMMCs were created [26-27]. At 750°C, Al 7075 was melted in an electric furnace. Using mechanical stirring, the reinforcing powders were combined with the molten metal. After filling a heated mold, the mixture was left to solidify. To plan the tests, a Taguchi L9 orthogonal array was utilized. Stirring speed, temperature, and percentage of reinforcement were among the variables that were changed. A Vickers hardness tester was used to assess microhardness. Minitab software was utilized for data analysis, ANOVA, and optimize the process parameters[28-29].

IV. EXPERIMENTATION AND RESULTS

A number of crucial phases are involved in the experimental process for creating metal matrix composites (NMMCs) based on Al 7075 that contain titanium dioxide (TiO2), silicon carbide (SiC), and graphene nanoplatelets. First, the Al 7075 alloy was acquired as a cast, and the powdered forms of TiO2, SiC, and graphene were acquired[30].

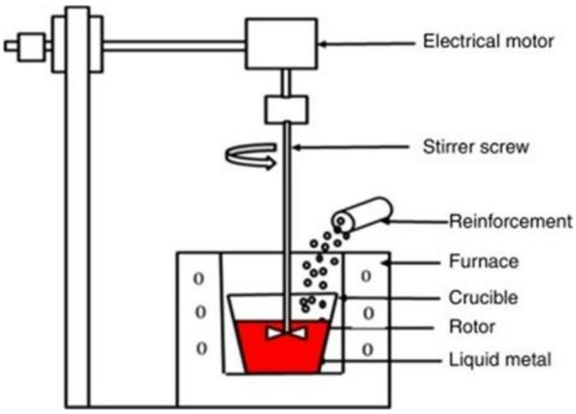

Figure 2: Stir casting

The Al 7075 alloy was first melted in an electric furnace that was kept at a temperature of roughly 750°C throughout the procedure as shown in figure 2. Based on early trials, the furnace temperature was adjusted to the desired casting temperature once the alloy was totally molten. The powders of TiO2, SiC, and graphene were pre-weighed in accordance with the intended experimental conditions in order to incorporate the reinforcements. The granules were then added to the molten aluminum using a mechanical stirrer. 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[31-32]. When incorporated into Al7075, TiO_2 particles distribute uniformly throughout the matrix, hindering dislocation movement and increasing hardness as table1.

Table 1: Hardness experimental values of Al7075

Exp.No	MMC	Trail 1	Trial 2	Trial 3	Avg HV
1	Al7075 TiO2 (0.5 %) nanocomposites	113.8	111.2	119.9	114.96
2	Al7075 TiO2 (5 %) nanocomposites	118.3	100.9	64.1	94.43
3	Al7075 TiO2 (10 %) nano composites	115.6	138.4	126.5	126.833
4	Al7075 SiC (0.5 %) nanocomposites	113	159.7	137.8	136.833
5	Al7075 SiC (5 %) nanocomposites	135.2	145.6	138	139.6
6	Al7075 SiC (10 %) nano composites	115	97.4	131.9	114.766
7	Al7075 Graphene (0.5 %) nanocomposites	129.1	132.2	149.6	136.966
8	Al7075 Graphene (5 %) nanocomposites	121.8	185.7	113.7	140.4
9	Al7075 Graphene (10 %) nano composites	144.2	157	173.7	158.3

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 3 mean and S/N ratio.

Table 2: Micro Hardness test experimental values Mean and S/N Ratio.

EXP.No	Reinforcements	composite (%)	AvgHV	SNRA	MEAN
1	Tio2	0.5	172.45	44.7333	172.45
2	Tio2	2.5	94.43	39.5022	94.43
3	Tio2	5	126.833	42.0646	126.833
4	SiC	0.5	136.833	42.7238	136.833
5	SiC	2.5	209.4	46.4195	209.4
6	SiC	5	114.766	41.1963	114.766
7	Graphene	0.5	136.966	42.7323	136.966
8	Graphene	2.5	140.4	42.9473	140.4
9	Graphene	5	158.3	43.9896	158.3

Table 3: Response for mean at Larger is better

Level	Reinforcements	composite (%)
1	42.1	43.4
2	43.45	42.96
3	43.22	42.42
Delta	1.35	0.98
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 3 shows that the reinforcements and material composition percentage, control are responsible and have influence on microhardness while reinforcements with different combinations as shown Figure 3. 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 microhardness accuracy during metal matrix of Al7075 composite.

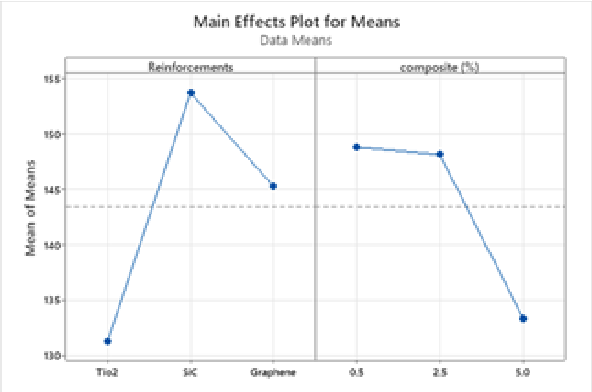

Figure 3: Mean plot for Micro Hardness (200Nano)

Table 4: S/N Ratio Response for mean at Larger is better

Level	Reinforcements	composite (%)
1	131.2	148.7
2	153.7	148.1
3	145.2	133.3
Delta	22.4	15.5
Rank	1	2

A greater value of S/N ratio is always considered for better performance irrespective of the category of performance characteristics as shown table 4. The difference of maximum and minimum mean S/N ratio figure 4 indicates the significance of the process parameters, greater the difference, greater will be the significance. Table 5. shows that the reinforcements different combinations most significantly towards microhardness strength as the difference value is highest, followed by metal matrix percentage.

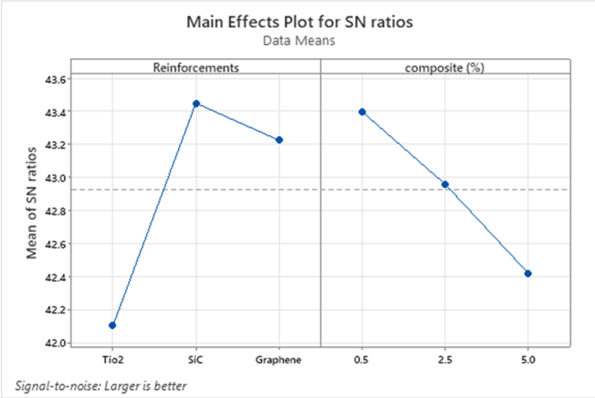

Figure 4: S/N Ratio Mean plot for Micro Hardness

The Microhardness S/N mean plot is shown in Figure 4. This layout is useful to determine whether the model meets the assumptions of the analysis[3]. The residual plots in the graph and the ANOVA analyse as response parameter, microhardness of the samples is given in 9. The relative contribution percentages (%) of each machining parameters of each factor obtained by the ANOVA method are given in Table 2 It can be concluded from Tables 3. and 4., based on microhardness the following order of importance (1) ANOVA for Reinforcements (2) Material composition.

Table IV: ANOVA for Micro hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)
Reinforcements	2	769.9	769.9	385	0.2	0.83	8.546942129
composite (%)	2	457.5	457.5	228.8	0.1	0.89	5.07887521
Residual Error	4	7780.4	7780.4	1945.1			86.37307253
Total	8	9007.9					100

Table 5. shown the most significant factor is reinforcements different combinations; the percentage contribution of that parameter to residual errors was 86.37%. The next significant factor is

reinforcements metal matrix which contributed 8.54%, and the third significant factor is the composition % with percentage contribution of 5.07%.

V. CONCLUSION

The mechanical and tribological assessment of stir-casted nano TiO2, Sic, and graphene reinforced aluminum 7075 composites MMC and conventional Rolling Al7075, as well as the effectiveness of the stir casting approach. In result, the microhardness of metal matrix composites (MMCs) is greatly increased by the addition of nano-graphene, TiO2, and SiC particles. Through processes including dislocation blockage, grain refining, and efficient load transfer, each reinforcing material makes a contribution. The type of reinforcement material used and how well it disperses throughout the matrix have a critical role in deciding how much the hardness improves. Mechanical Properties: Stir-casting Al 7075, metal matrix TiO2, SiC, and graphene (200 Nano) results in increased hardness. The 200 Nano Al7075 Metal matrix composite SiC(10%) is stronger. The microhardness of the Al7075 and graphene (10%) 200 Nano metal matrix was 158.3 HV, whereas the microhardness of the TiO2 (0.5%) was 112.635 HV.

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