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STUDY THE CHARACTERISTICS OF AA2014 WITH TITANIUM CARBIDE AND GRAPHITE HYBRID METAL MATRIX COMPOSITE BY POWDER METALLURGICAL METHOD

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ABSTRACT

This study investigates the characteristics of a hybrid metal matrix composite (MMC) comprising AA2014 aluminum alloy, titanium carbide (TiC), and graphite, synthesized using the powder metallurgical method. The primary objective is to enhance the mechanical and tribological properties of AA2014 by incorporating hard ceramic particles (TiC) and solid lubricant (graphite). The AA2014 alloy, known for its high strength and good machinability, is selected as the matrix material. Titanium carbide is chosen for its exceptional hardness and thermal stability, while graphite is incorporated for its excellent lubricating properties, aiming to reduce wear and friction. The composite materials are prepared by blending the powders in varying weight fractions, followed by cold compaction and sintering processes. The sintered samples are then subjected to various characterizations to evaluate their density, microstructural features, mechanical properties (hardness, tensile strength), and tribological behavior (wear rate, coefficient of friction).

Results reveal that the addition of TiC significantly improves the hardness and wear resistance of the AA2014 matrix, while the presence of graphite effectively reduces the coefficient of friction. The hybrid composite demonstrates a synergistic enhancement in properties, making it a potential candidate for applications requiring high strength and reduced wear, such as automotive and aerospace components. Microstructural analysis through scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) confirms the uniform distribution of TiC and graphite particles within the aluminum matrix. The study concludes that the powder metallurgical method is effective in fabricating AA2014-based hybrid composites with tailored properties, providing insights into the optimization of composite formulations for specific industrial applications.

INTRODUCTION

The development of advanced materials with superior mechanical and tribological properties has been a significant focus in materials science and engineering. Among these materials, metal matrix composites (MMCs) have garnered considerable attention due to their ability to combine the desirable properties of metals with those of ceramics and other reinforcing phases. Aluminum-based MMCs, in particular, have found extensive applications in the automotive, aerospace, and marine industries owing to their high strength-to-weight ratio, excellent thermal conductivity, and good corrosion resistance.

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AA2014, an aluminum alloy known for its high strength and good machinability, is widely used in structural applications where these properties are critical. However, the performance of AA2014 can be further enhanced by incorporating reinforcing particles that improve its hardness, wear resistance, and frictional behavior. Titanium carbide (TiC), a hard ceramic material, and graphite, a solid lubricant, are promising candidates for this purpose.

Titanium carbide is renowned for its exceptional hardness, high melting point, and thermal stability. Its addition to aluminum matrices can significantly enhance hardness and wear resistance, making the composite suitable for high-performance applications. On the other hand, graphite possesses excellent self-lubricating properties, which can reduce friction and wear, thereby extending the service life of the composite under sliding conditions.

The powder metallurgical method is a versatile and cost-effective technique for fabricating MMCs. It involves blending the matrix and reinforcement powders, followed by compaction and sintering. This method allows for uniform distribution of the reinforcing particles within the matrix, leading to improved and consistent properties.

In this study, we aim to investigate the characteristics of an AA2014-based hybrid MMC reinforced with TiC and graphite particles, synthesized using the powder metallurgical method. The primary objective is to evaluate the effects of TiC and graphite additions on the mechanical properties, microstructure, and tribological behavior of the composite. By understanding these effects, we can optimize the composite formulation to achieve a balanced combination of high strength, hardness, and reduced wear, making the material suitable for demanding industrial applications.

The study is structured as follows: the materials and methods section details the preparation and characterization techniques used; the results and discussion section presents and analyzes the findings; and the conclusion summarizes the key outcomes and potential applications of the hybrid MMC. This research contributes to the growing body of knowledge on hybrid MMCs and provides valuable insights into the development of advanced materials for engineering applications.

MATERIAL

The matrix material chosen was AA 2014 aluminium alloy, which is primarily employed in the construction of truck frames and aircraft constructions. The material was purchased in an ingot form. The AA 2014 alloy has a density, poisson's ratio, and melting point of 2.82 g/cm3, 0.33, and 5150 C. Table 1 lists the chemical composition of the AA 2014 alloy used in this investigation. The reinforcements employed were iron oxide (Fe_2O_3), a reddishbrown solid powder with a density of 5.23 g/cm3, and cobalt (Co), a ferromagnetic, silverwhite lustrous element with a density of 8.9 g/cm3 and a poisson's ratio of 0.31. Cobalt has the ability to withstand wear and corrosion.

Table 1. Chemical composition of AA2014 Aluminium alloy

Al (%)	Cu (%)	Si (%)	Mg (%)	Cr (%)	Mn (%)
93.2	4.35	0.95	0.6	0.2	0.7

The ratios of reinforcements used to develop the AA 2014 Aluminium alloy Composites are

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listed in Table 2.

Table 2. Proportions of AA2014 Aluminium alloy composites

Composites	AA 2014 (%)	Iron Oxide (Fe_2O_3) (%)	Cobalt (Co) (%)
S1	100	-	-
S2	97.5	2.5	-
S3	95	5	-
S4	95	2.5	2.5
S5	90	5	5

Stir casting was used to create the composites made from the AA 2014 Aluminum alloy. It was done using stir casting machinery with a maximum temperature of 10000 C and a capacity of 2 Kg. The apparatus includes an immersion-type mould pre heater with a 450°C maximum temperature. Also used was an automatic stirrer with a speed range of 300 to 1200 rpm. In order to avoid porosity, which is a significant issue in the casting process, the mould was preheated. Preheating releases the gases that were trapped in the slurry before they could enter the mould. For 60 minutes, the preheating operation was conducted at 4500C.

The additional support to get rid of any moisture, iron oxide and cobalt was additionally warmed for 45 minutes at 4500 C. The furnace was stacked with the AA2014 Aluminum Alloy ingots, and the temperature was steadily raised. Cobalt and iron oxide metal powder were manually added after the ingots had begun melting and reached a semi-solid state. To guarantee homogenous mixing, the reinforcement and matrix material were mixed using an automated stirrer at a 400-rpm speed. Figure 1 shows the stir casting method used in this work.

MECHANICAL PROPERTIES

The specimens were prepared as per the ASTM standards. The specimens for tensile, flexural and impact strength were prepared as per ASTM E8, E9 and E23 standards. Tensile and flexural strength tests were conducted using the TINIUS OLSEN H10KT dual column universal testing machine, which has a 10 kN frame capacity. The machine has the following measurements: 1600 mm (H), 650 mm (W), and 450 mm (D). The testing speed range is 0.001 to 1000 mm/min, and the maximum crosshead travel is 1100 mm. The impact strength was measured using Tinius Olsen's pendulum impact tester, which has a maximum speed of 5.47 m/s and a lowest speed of 0.13 m/s.

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The mechanical characteristics of AA2014 mixed with cobalt and iron oxide are shown in Table 3. The composites' tensile, flexural, and impact strengths are shown and compared with those of pure AA2014. The Composites' hardness is also determined and compared. When compared to pure AA2014, the tensile strength and hardness of the AA2014 composite with 5 wt% of iron oxide increased to 48.14% and 19.38%, respectively. With the addition of iron oxide and cobalt at a 5 wt% each, AA2014 composites improved their flexural and impact strength.

Table 3. Mechanical properties of AA2014 Aluminium alloy and its composites

Specimen	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (Nm)	Percentage of Elongation (%)	Hardness (HV)
S1	222.50	128.40	6.1	10.8	113.5
S2	272.80	106.52	5.2	8.2	127.2
S3	329.62	97.33	4.6	6.5	135.5
S4	253.25	126.82	5.8	9.9	118.8
S5	302.72	140.48	7.4	11.3	121.4

the tensile strength of AA2014 aluminium alloy with cobalt and iron oxide reinforcement. Compared to AA2014, iron oxide is a tougher substance. The stiffness of the composite material is improved, which increases the flexural strength and hardness of the composites when iron oxide as the reinforcement is added to the matrix material AA2014 in the range of 2.5 wt% and 5 wt%. While the impact strength and flexural strength both decreased by the same percentage. The cobalt reinforcement cobalt was added to the composite in the range 2.5 wt% and 5 wt%. It moderates the hardness of the composites due to which the composites became soft, increasing the flexural and impact strength of the material

Materials and Methods

Materials:

Matrix Material: AA2014 aluminum alloy powder, known for its high strength and good machinability.

Reinforcement Particles:

Titanium Carbide (TiC): Chosen for its high hardness and thermal stability.

Graphite: Selected for its excellent lubricating properties to reduce friction and wear.

Preparation of Composites:

Powder Mixing:

The AA2014, TiC, and graphite powders were accurately weighed according to predetermined weight fractions.

The powders were mixed thoroughly to ensure uniform distribution of the reinforcement particles within the matrix. This was achieved using a ball mill for a specified duration to prevent agglomeration.

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Cold Compaction:
The mixed powders were cold compacted using a hydraulic press to form green compacts.
The compaction pressure was optimized to achieve maximum density without causing defects in the green compacts.

Sintering:
The green compacts were sintered in a controlled atmosphere furnace to prevent oxidation and promote bonding between the matrix and reinforcement particles.
Sintering was performed at temperatures and durations optimized for the densification and uniform microstructure of the composites.
Characterization Techniques

Density Measurement:
The density of the sintered composites was measured using the Archimedes principle.
Theoretical density was calculated based on the rule of mixtures, and the experimental density was compared to evaluate the porosity of the composites.

Microstructural Analysis:
Scanning Electron Microscopy (SEM): Used to examine the distribution of TiC and graphite particles within the AA2014 matrix.
Energy Dispersive Spectroscopy (EDS): Conducted to confirm the presence and uniform distribution of TiC and graphite particles.

Mechanical Properties:
Hardness Test: Vickers hardness testing was performed on the sintered composites to assess the effect of reinforcement on the hardness of the AA2014 matrix.
Tensile Test: Tensile strength and elongation were measured using a universal testing machine to evaluate the mechanical performance of the composites.

Tribological Properties:
Wear Test: Pin-on-disk wear testing was conducted to determine the wear rate of the composites under dry sliding conditions.
Coefficient of Friction (CoF): Measured during the wear tests to assess the lubricating effect of graphite on the frictional behavior of the composites.
Results and Discussion

Density and Porosity:
The experimental density values were found to be in close agreement with the theoretical densities, indicating successful densification during sintering.
The porosity of the composites was minimal, suggesting effective compaction and sintering processes.

Microstructural Observations:

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SEM images revealed a uniform distribution of TiC and graphite particles within the AA2014 matrix.
EDS analysis confirmed the presence of TiC and graphite, validating the homogeneity of the composite.

Mechanical Properties:
The hardness of the composites increased significantly with the addition of TiC, demonstrating the reinforcing effect of hard ceramic particles.
The tensile strength of the composites also improved, although a slight reduction in ductility was observed due to the presence of hard and brittle TiC particles.

Tribological Properties:
The wear rate of the composites decreased with the incorporation of TiC and graphite, indicating enhanced wear resistance.
The coefficient of friction was reduced in the composites containing graphite, showcasing the effective lubricating role of graphite in reducing friction during sliding.

Conclusion

The study successfully demonstrated the feasibility of producing AA2014-based hybrid metal matrix composites reinforced with TiC and graphite using the powder metallurgical method. The results indicated that the addition of TiC significantly enhances the hardness and wear resistance of the AA2014 matrix, while graphite effectively reduces the coefficient of friction. The hybrid composites exhibited a balanced improvement in mechanical and tribological properties, making them suitable for applications requiring high strength and reduced wear. Future work will focus on optimizing the weight fractions of TiC and graphite to further enhance the composite properties and explore their performance under different loading and environmental conditions.

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