RESEARCH PAPER

Improvement Mechanical Properties of (Al-Cu-Mg) Alloy by Reinforced Nanoparticles with TiB_2 Using Powder Metallurgy Technique

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ABSTRACT

Al-Cu-Mg alloy is a superior corrosion and resistant alloys within the aluminum alloys family. Notwithstanding its commendable corrosion resistance, it has inadequate mechanical qualities, resulting in suboptimal expansion across diverse applications. In this work, samples of (Al-Cu-Mg) alloy reinforced with titanium boride (TiB_2) nanoparticles with a length of (90 mm) and a diameter of (10 mm) were synthesis using powder metallurgy technique and powder pressing method. TiB_2 nanoparticles were selected with a weight percentage of (1, 3, 5%). The X-ray diffraction, surface morphology, and mechanical properties investigated. The base and composite materials were prepared by powder pressing method using a 10-ton press. Tensile strength, ductility, hardness, and microscopic examinations were performed on the composite, revealing that an increase in the particle size ratio of TiB_2 correlates with enhanced tensile strength, reduced ductility, increased hardness, and a uniform distribution of particles relative to the base matrix (Al-Cu-Mg).

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INTRODUCTION

Due to the resistance of non-high alloys (change in mechanical properties) to high load conditions or applications requiring high mechanical properties, aluminum and its alloys have faced many problems when used. Since these alloys have aluminum as the matrix, which is a non-hard metal at the level of iron and the second most widely used metal in the world after steel. The aluminum alloy in our study is Al-4.5% Cu-1.5% M [1-3]. Since aluminum can be hardened by precipitation or powder heat treatment, Al-Cu-Mg alloy is an important alloy that acquires strong mechanical properties after heat treatment. The possibility of using aluminum alloys in the production of aluminum-based composite materials reinforced with ceramic particles to enhance mechanical properties such as age hardening has recently motivated many researchers in this field to intensify their research efforts [4]. In addition to the use of ceramic or metal materials to strengthen or reinforce composite materials that can withstand operating conditions at high temperatures and friction, powder technology and the filtration (leakage) method underwent many modifications in the last quarter of the twentieth century and continue to this day [5]. A multitude of researchers have investigated the use of several earthen materials, inclusive (TiB_2, B_4C, Al_2O_3, SiC, TiC, and TiO_2) among others [6-8]. TiB_2 possess distinctly protrude

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as a significant reinforcing additive owing to its attributes, including elevated hardness, rise Young's modulus, low particular gravity, satisfactory electrical accessibility, and exceptional corrosion impedance [9-13]. The materials (TiB_2) is known as one of the hard materials used as additions to enhance the mechanical capabilities of the aluminum matrix [14]. Furthermore, TiB2 particles remain inert in molten aluminum, so averting the formation of brittle reaction byproducts upon interaction with the reinforcing matrix. This original sin results in the synthesis and advancement of (Al-Cu-Mg): TiB_2 compounds with superior characteristics for diverse applications [15-17]. In this research, a varying percentage of TiB_2 is add in (Al-4.5% Cu-1.5% M) to observed the change in the mechanical and tribological properties. The ratios of TiB_2 adding were 1, 3 and 5 wt.%. Also, the X-ray diffraction (XRD) and surface morphology by scan electron microscopy (SEM) were investigated.

MATERIALS AND METHODS

Matrix Material

Using powder metrology method to preparation (Al-Cu-Mg) alloy, where the raw materials used to synthesis alloy include pure aluminum (99.99%), copper powder purity (99.9) and magnesium nano powder with purity (99.9) purchased from Merck. The ratios of alloy were (Al-4.5%Cu-1.5%Mg).

Synthesis alloy

After mixing and grinding with an agate ball mill for 4 hours, the mixed powder at ratios (Al-4.5%Cu-1.5%Mg) were pressed into molds with a diameter of 2 cm using a press weighing 5 tons. After that, the centrifugation processes the sintering was executed using an electric oven at a temperature of 600 ^{o}C at two hours under vacuum to ensure that the materials do not oxidize. The chemical composition of the alloy showed in Table1. To find the ideal ratio of TiB_2 addition to the base alloy, granules of the reinforcing material TiB_2 with granule sizes smaller than 100 nm and varying weight percentages (1, 3, and 5wt%) were used.

The addition ratios of TiB_2 granules used were varied at 1%, 3%, and 5%, using granule sizes smaller than 100 nm to ascertain the optimal TiB_2 addition ratio for the fundamental aluminum alloy. The composite material was fabricated using powder technology via the direct mixing

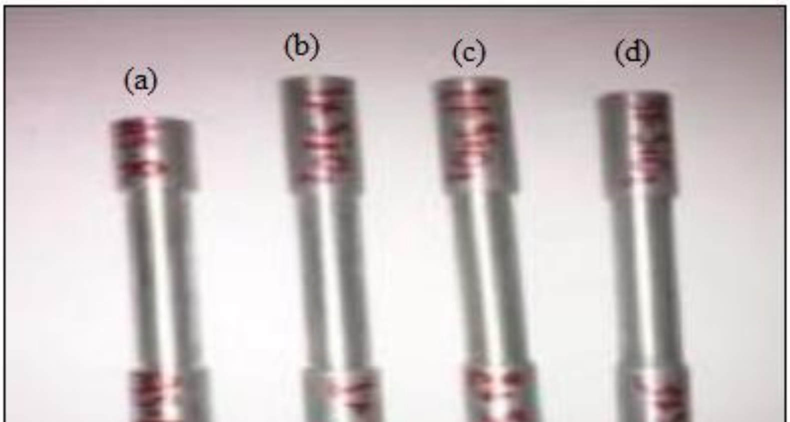

Fig. 1. Saples prepared for testing, (a) pure Al-Cu-Mg, (b) Al alloy:1wt%TiB_2, (c) Al alloy:3wt%TiB_2, (d) Al alloy:5wt%TiB_2

Table 1. Chemical composites of prepared alloys.

Elements	Fe	Cu	Mn	Cr	Zn	pb	Ni	Sn	Mg	Sb	Al
Present.%	0.7	4.38	0.009	0.006	0.016	0.0012	0.01	0.004	1.41	0.012	Rest%

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process in accordance with the specified ratios. Subsequent to amalgamation in an agate ball mill, the resultant powder was positioned in specialized molds and subjected to a 10-ton press, where it remained under pressure for 5 minutes to guarantee material homogeneity and the integrity of the cast form. Subsequently, heat treatment was conducted in an electric oven with a heat of 600 °C for a period of 2 hours. Upon completing the preparation of the reinforced alloy, the samples were molded into cylindrical forms. To guarantee uniformity in composite materials, the initial and terminal sections of the constructed cylindrical models were disregarded by excising 0.5 cm from both the top and bottom of each sample to mitigate concerns over the uneven distribution of the reinforcing components. The residual portion of the composite material was sectioned into samples measuring 1 to 1.5 cm in length for hardness testing models. The remaining samples were used to fabricate tensile test specimens. Fig. 1 showed the prepared samples for testing.

Characterization

Tensile tests were performed on the fabricated samples in accordance with normal requirements tensile test conducted using a mechanical testing machine (model TINIUS OISEN H50KT). The compression test on the samples was conducted using a universal mechanical testing equipment (model RH1 5DZ, Tiniusoisen Ltd), manufactured in England, with the samples prepared in accordance with the ASTM D 695 standard at room temperature. The hardness test is conducted at ambient temperature using a Digital Micro Shore D Durometer (QUALITEST HPE) in accordance with ASTM D2240, manufactured in the USA. An X-ray diffraction apparatus equipped with CuKα1, U.S. Monogr, is also used to study the crystal structure of the prepared alloy with measure situation X-ray tube base Cu, voltage 40.0 kV, and current 30.0 mA. The electron microscope used was manufactured by Thermo Fisher Scientific, USA.

RESULTS AND DISCUSSION

Fig. 2 showed the typical XRD patterns of nano powder TiB_2-doped alloy (Al-Cu-Mg) that were formed at room temperature. (Al-Cu-Mg) alloy and (Al-Cu-Mg): 5wt%TiB_2 alloy were detected by XRD analysis; however, because of the small percentage of other alloying metals, peaks for additional phases were not readily discernible. The identification method was made more difficult by the overlap of diffraction peaks with the peaks of the main aluminum matrix. We notice from the graphical figure that only the aluminum phase appears in the pure Al-Cu-Mg alloy, while for the doping samples (Al-Cu-Mg): 5wt%TiB_2 only appears the phase ($Al_{3.21}Ti_{0.47}$), while the copper or magnesium phase does not show. This indicates that an active substance has occurred between the silicon oxide and the alloy. These outcomes

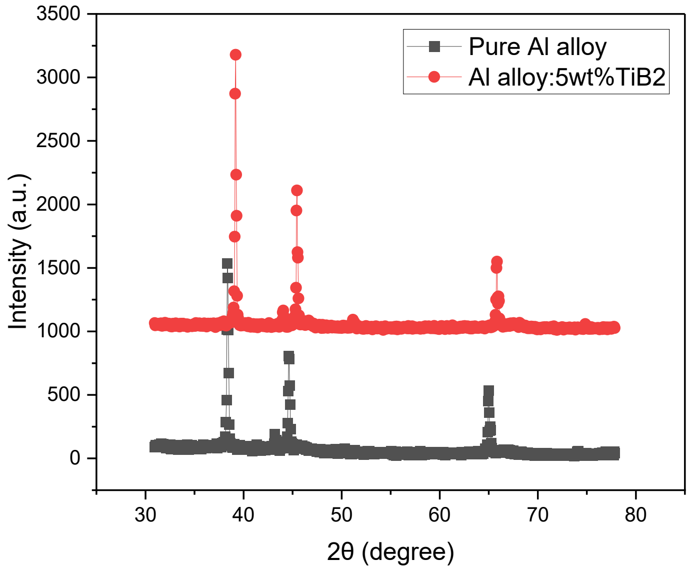

Fig. 2. XRD patterns of Al alloy and Al alloy:5wt%TiB_2.

are consistent together with the outcome of the researcher [18]. Fig. 2, it can be observed that there is a deviation of 0.1 for the phases of the reinforced alloy from the phases of the non-reinforced alloy, and this is due to the difference amidst the TiB_2 diameter and the Al ion diameter [19].

Fig. 3 showed the SEM images of (Al-Cu-Mg) alloy after sintering at 600 °C for two samples pure alloy and 5wt%TiB_2 adding. It's clear the (Al-Cu-Mg) alloy made from Al as matrix and Cu, also, Mg, then press defects and grain enlargements

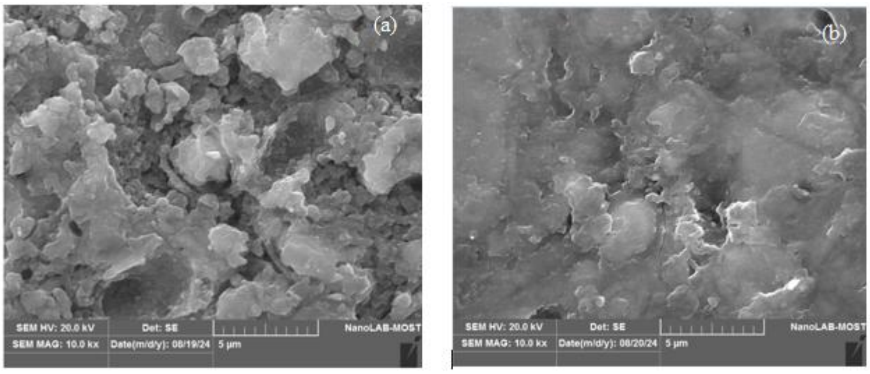

Fig. 3. the SEM of (a) pure (Al-Cu-Mg) alloy and (b) (Al-Cu-Mg) : 5wt%SiO_2

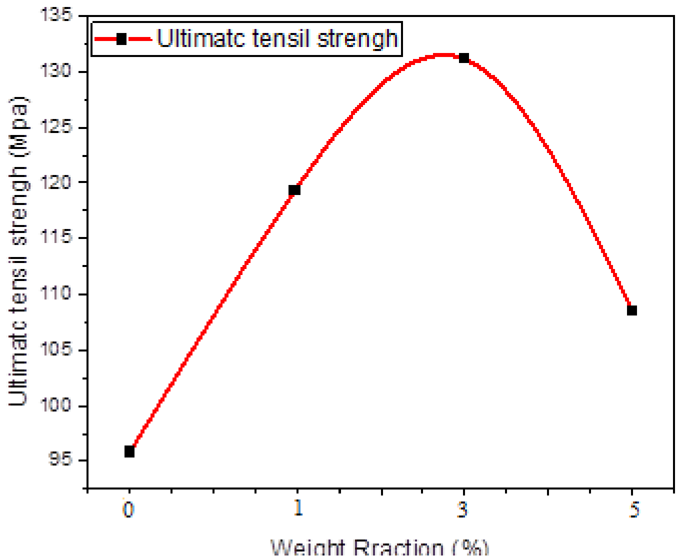

Fig. 4. Tensile strength with W.F % of the (A-Cu-Mg): TiB_2 alloy.

Table 2. data of (Al-Cu-Mg) alloy and (Al-Cu-Mg): TiB_2 as Tensile strength, yield stress, and ductility.

Name Samp.	σ (u.t.s.) (Mpa)	σy (Mpa)	El%
(Al-Cu-Mg) alloy	95.34	51	7.234
(Al-Cu-Mg):1wt%TiB_2	118.32	58	9.224
(Al-Cu-Mg):3wt%TiB_2	129.54	63	11.89
(Al-Cu-Mg):5wt%TiB_2	107.2	47	11.46

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that resemble voids. While we notice from the figure 3, b after mixing the TiB_2 with the alloy that the porosity has decreased with the presence of agglomerations on the surface. These results converge with the researcher's results [20].

In addition to the above, the presence of TiB_2 nanoparticles at a proportion higher than (5%) for the current research may increase the possibility of many groups dispersed within the base alloy coming out in an inhomogeneous manner, which lowers the hardness values slightly from their higher values. The experiments were performed on the (Al-Cu-Mg) alloy augmented with TiB_2 that was fabricated using nano powder metallurgical techniques. The findings were analyzed as follows: tensile test results, plasticity test results, hardness test results, and overall structural test results [21]. Table 2 presents the tensile strength of (Al-Cu-

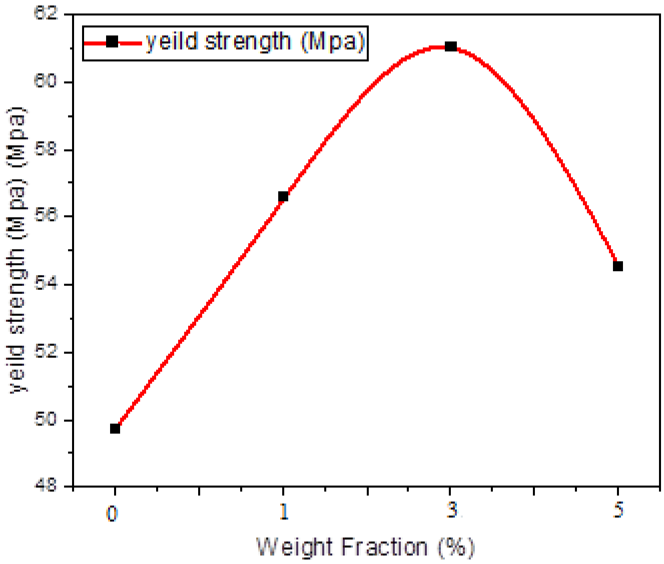

Fig. 5. Yield stress with W.F. % of the (A-Cu-Mg): TiB_2 alloy.

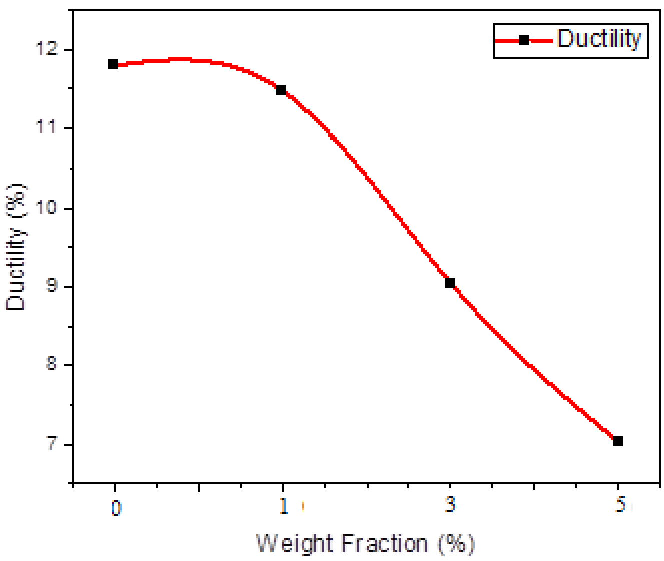

Fig. 6. Ductility with W.F% of the (A-Cu-Mg): TiB_2 alloy.

Mg) alloy and reinforced alloy, including ultimate tensile strength, yield stress, and tensile stress for the weighted percentages of 1%, 3%, and 5% for both the base alloy and the reinforced TiB_2 nanoparticle alloys.

Figs. 4 and 5 illustrate how the percentages of TiB_2 nanoparticles added to the base alloys and the reinforced alloys change the values of final tensile strength with yield stress. It is evident that both the final tensile strength with yield stress values rise as the weighted percentages of the added TiB_2 nanoparticles increase, and that the values continue to rise as the weighted percentages increase to extent the highest amount at the weighted proportion (3%) and thereafter the material conduct differently as the values of yield stress and final tensile strength decrease as the proportion of adding TiB_2 nanoparticles raise, while maintaining higher values than in the base alloys. The nature of these hardened particles, which are distributed in the basic alloy with varying molecular sizes and contribute to the alloy's strength through the mechanism of hopeless hardening, is what causes the increase in the final tensile strength and yield stress values of TiB_2-reinforced aluminum alloys. The presence of large particles with granular sizes greater than 100 nm, which act as partition to deformation of the (Al-Cu-Mg) alloy due to their rise hardness, and little particles with granular sizes less than 100 nm, which work to block the movement of dislocations and thereby increase the material's strength. The distribution of these hardened particles in the basic alloy in varying proportions contributes to a reduction in the distance between particles (Dp) based on the following relationship: [22]

Consequently, it will require additional stress to man oeuvre the dislocations around each particle, as the yield value of the alloy-reinforced TiB_2 nanoparticles is inversely related to the square root of the interparticle distance, which diminishes with an increase in the proportion of added particles, up to a certain limit (3%), as illustrated in the subsequent relationship [11]

The altered behavior of the mixture at this rate is attributable to pores and casting flaws, which arise from higher levels of additional particles and the increased density of mixture, leading to some aggregation of the added particles.

Fig. 6 illustrates the correlation between plasticity values and the weighted concentration of the included TiB_2 nanoparticles. The (Al-Cu-Mg) alloy exhibited a reduction in flexibility amount with the addition of these particles, which further diminished with the increasing weighted ratios of the additional particles. Plasticity exhibits behavior contrary to tensile and hardness parameters. This occurs because the brittle characteristics of the ceramic particles diminish the interparticle distance, resulting in less flexibility.

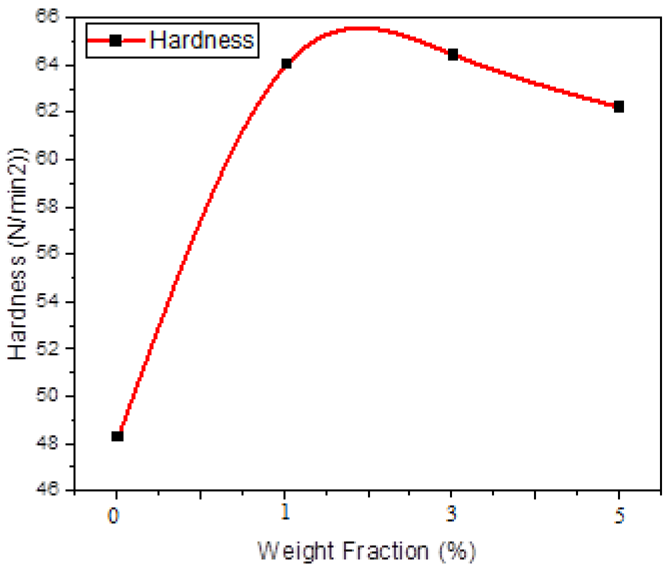

Fig. 7. Hardness with W.F. % of the (A-Cu-Mg): TiB_2 alloy.

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Fig. 7 illustrates the impact of varying maximum hardness values with the inclusion proportions of nano powder TiB_2 (1, 3, 5%). It is observed that hardness values increase with higher addition ratios, as particles exceeding one micron in size serve as barriers to alloy distortion due to their elevated hardness. Conversely, particles smaller than 0.1 µm, dispersed within the base alloy structure, hinder the propagation of dislocations in the base material. Furthermore, the addition of TiB_2 particles at ratios exceeding 5% in this study may result in an increased likelihood of numerous groups within the base alloy exiting in an inhomogeneous way, thereby slightly diminishing the hardness values from their peak levels.

CONCLUSION

An alloy of (Al-Cu-Mg) reinforced with nanoparticles of TiB_2 at ratios (1, 3, and 5)wt% was successfully prepared using the powder metrology technique and the powder mixing method. Characterization and mechanical properties of the prepared alloys were examined, and conclusions can be drawn from the results obtained as follows:

1- The final tensile strength test and hardness test of the fabricated composite material (Al-Cu-Mg): TiB_2 exceed those of the base alloy, with these values rising as the proportion of TiB_2 nanoparticles raise. Conversely, the ductility of the composite material diminishes, and this reduction intensifies at higher ratio of TiB_2 nanoparticles added to the base alloy.

2- An augmentation in the size of the nanoparticles of TiB_2 will lead to a reduction in final tensile strength and hardness, however an increase in grain size would enhance the ductility of the composite materials.

3- The incorporation of TiB_2 grains and their dispersion within the alloy matrix results in enhanced hardness values.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

1. Md Aliahsan B, Ahmed M, Rauf MA. Exploring the Integration of Informed Machine Learning in Engineering Applications: A Comprehensive Review. SSRN Electronic Journal. 2024.
2. Chithra NV, Karuppasamy R, Manickaraj K, Ramakrishnan T. Effect of Reinforcement Addition on Mechanical Behavior of Al MMC - A Critical Review. Journal of Environmental Nanotechnology. 2024;13(2):65-79.
3. Furrer DU, Dimiduk DM, Ward CH. Evolution of Model-Based Materials Definitions. Integrating Materials and Manufacturing Innovation. 2024;13(2):474-487.
4. Li X, Du S, Ma C, Shi T, Qi W, Yang H. Nano-SiO2 based anti-corrosion superhydrophobic coating on Al alloy with mechanical stability, anti-pollution and self-cleaning properties. Ceram Int. 2024;50(6):9469-9478.
5. Saini S, Gupta A, Mehta AJ, Pramanik S. Effect of graphite and rice husk-derived SiO_2 on mechanical and thermal properties of re-sintered aluminium-based metal matrix hybrid nanocomposites. J Therm Anal Calorim. 2023;148(6):2335-2344.
6. Bhaskar S, Kumar M, Patnaik A. Mechanical and Tribological overview of ceramic particulates reinforced aluminium alloy composites. Reviews on Advanced Materials Science. 2019;58(1):280-294.
7. Sharath BN, Madhu P, Verma A. Enhancing tribological performance: A review of ceramic reinforced aluminium hybrid composites for high-temperature engineering applications. Hybrid Advances. 2023;4:100094.
8. Oyewo AT, Oluwole OO, Ajide OO, Omoniyi TE, Hussain M. A summary of current advancements in hybrid composites based on aluminium matrix in aerospace applications. Hybrid Advances. 2024;5:100117.
9. Tang S, Chen X, Zhang D, Xie W, Ran Q, Luo B, et al. Effects of nano-SiO_2 particle addition on the structure and properties of micro-arc oxidation ceramic coatings on 7075 aluminum alloy. Anti-Corrosion Methods and Materials. 2024;71(5):482-490.
10. Sulima I, Hyjek P, Jaworska L, Perek-Nowak M. Influence of ZrB_2 on Microstructure and Properties of Steel Matrix Composites Prepared by Spark Plasma Sintering. Materials (Basel, Switzerland). 2020;13(11):2459.
11. Wang C, Wang M, Yu B, Chen D, Qin P, Feng M, et al. The grain refinement behavior of TiB2 particles prepared with in situ technology. Materials Science and Engineering: A. 2007;459(1-2):238-243.
12. Mallikarjuna C, Shashidhara SM, Mallik US, Parashivamurthy KI. Grain refinement and wear properties evaluation of aluminum alloy 2014 matrix-TiB_2 in-situ composites. Materials & Design. 2011;32(6):3554-3559.
13. Balcı Ö, Ağaoğulları D, Gökçe H, Duman İ, Öveçoğlu ML. Influence of TiB_2 particle size on the microstructure and properties of Al matrix composites prepared via mechanical alloying and pressureless sintering. J Alloys Compd. 2014;586:S78-S84.
14. Dong B-X, Li Q-Y, Shu S-L, Duan X-Z, Zou Q, Han X, et al. Investigation on the elevated-temperature tribological behaviors and mechanism of Al-Cu-Mg composites reinforced by in-situ size-tunable TiB_2-TiC particles. Tribology International. 2023;177:107943.
15. Liu Y-X, Zhang C-C, Wang R-Z, Zhang K-M, Wang J, Yao S-L, et al. Quantitative evaluations of improved surface integrity in ultrasonic rolling process for selective laser melted in-situ TiB2/Al composite. Journal of Manufacturing Processes. 2022;77:412-425.
16. Singh H, Raina A, Irfan Ul Haq M. Effect of TiB2 on Mechanical and Tribological Properties of Aluminium Alloys – A Review. Materials Today: Proceedings. 2018;5(9):17982-17988.
17. Farooq SA, Mukhtar SH, Raina A, Ul Haq MI, Siddiqui MIH, Naveed N, et al. Effect of TiB_2 on the mechanical and

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tribological properties of marine grade Aluminum Alloy 5052: An experimental investigation. Journal of Materials Research and Technology. 2024;29:3749-3758.
18. Ouyang Z, Mo W, Deng P, pan y, Bai HZ, Luo BH. Effect of in Addition on the Microstructure and Mechanical Properties of an Al-Cu-Mg-Ag Alloy. Elsevier BV; 2024.
19. Duan X-Z, Xin B-D, Miao T-J, Xie J-F, Yang H-Y, Han X, et al. Microstructural and performance characterization of in-situ biphasic micro-nano scale (TiB_2-TiC_x)/Al-Cu-Mg composites with different ceramic and metal ratios designed for compact integration. Journal of Materials Research and Technology. 2020;9(3):3418-3429.
20. Mair P, Kaserer L, Braun J, Weinberger N, Letofsky-Papst I, Leichtfried G. Microstructure and mechanical properties of a TiB2-modified Al–Cu alloy processed by laser powder-bed fusion. Materials Science and Engineering: A. 2021;799:140209.
21. Padmavathi KR, Ramakrishnan R. Tribological Behaviour of Aluminium Hybrid Metal Matrix Composite. Procedia Engineering. 2014;97:660-667.
22. Zhao J, Wu X, Ning L, Zhang J, Han C, Li Y. Wetting of aluminium and carbon interface during preparation of Al-Ti-C grain refiner under ultrasonic field. Ultrason Sonochem. 2021;76:105633-105633.

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