

A study on the structural characters of nano hybrid sintered aluminium composites

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Abstract. Metal matrix composites play a vital role in automotive and aerospace industries and preparation of such materials with superior strength-to-weight ratio is a challenge for researchers. The present research focuses on the preparation and inquiry of characters on the aluminium matrix reinforced with nano Boron Nitride (BN) and nano Titanium dioxide (TiO₂) powders for aerospace applications. Composites have been prepared through powder metallurgy route with pure aluminium, pure aluminium reinforced with nano boron nitride (Al+BN), pure aluminium with nano titanium dioxide (Al+TiO₂) and pure aluminium with both nano boron nitride and nano titanium dioxide (Al+BN+TiO₂) hybrid forms under various compositions. Physical characterization showed that pure aluminium with 2.5 wt% BN a least density among all the fabricated composites. Also, it is revealed that pure aluminium with 1 wt% BN and 1.5 wt% TiO₂ produced a maximum tensile and flexural strengths. On the other hand, pure aluminium with an equal composition (1.25 wt%) of BN and TiO₂ produced a maximum compressive strength. The overall best composite is identified and concluded that the hybrid form of composite is superior in all aspects.

1 Introduction

Aluminium based composites have got wide applications in automotive, aircraft and other industries due to their improved properties [1, 2]. Aluminium metal matrix composites (Al-MMC) have attained high importance in automotive and other industries due to its all-round properties such as high strength to weight ratio, ductility, recycling ability, corrosion resistance, and thermal conductivity. However, the tensile strength and wear properties of aluminium alloys are not on par with the conventional materials [3]. The characteristics of metal matrix composites are governed by many parameters such as particle size, composition of the reinforcement material, the mixing procedures, the sintering temperature, and the time duration. Research on aluminium-based MMC used powder metallurgy as the fabrication technique with silicon carbide (SiC) as reinforcement and revealed that elevating the SiC composition by 5% enhances the hardness of the composites by 14% and a maximum compressive strength has been achieved at a SiC content of 25% [4].

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In another probe on Al-MMC, it has been identified that, the sintering temperature in the 300 – 6000C would be an optimum range that governs all the characters of the composite materials such as compression strength, wear rate and thermal expansion co-efficient [5]. Al-MMC may also be reinforced with natural reinforcements from plant-based and mineral-based materials. A study on the natural fiber reinforced Al composites used coconut shell fly ash (CSFA) and SiC as reinforcing materials in different combinations. It has been observed that, there is an enhancement in the interfacial bonding between the matrix and reinforcement under a combination of 4 % CSFA and 8 % SiC. This improved bonding capacity is responsible for an elevated tensile strength, compression strength, density with reduced plastic deformation [6]. Palm Kernel Shell Ash (PKSA) is another potential reinforcement that could be used along with BN for wear character enhancement. It has been revealed that, as compared to the reinforcement composition, the speed and applied load has a dominant influence on the wear index and volume loss [7].

The effect of hexagonal boron nitride as a reinforcement in aluminium alloy matrix is studied for mechanical and tribological characteristics and concluded that the fabricated materials have executed a maximum tribological properties and improved ultimate tensile strength and Brinell hardness as compared to that of aluminium alloy [8]. Research works have been carried out by using TiO₂ as additive material in composite. One such a work utilized micro/nano SiC/TiO₂ additive in aluminium and tested for its mechanical strengths. The fabricated materials have shown a superior mechanical property when compared to aluminium alloy, with microscopic analysis indicating a uniform dispersion of reinforcements throughout the matrix [9]. Aluminium based alloy material were used as matrix in several research works with the inclusion of nano particles and no studies have been reported with pure aluminium as the matrix material along with solid lubricants such as BN as nano fillers. Hence, the present work uses nano hybrid BN and TiO₂ as reinforcing agents in pure aluminium matrix to evaluate the mechanical properties.

2. Experimental set-up

The ball milling method has been used for the powder blending process, which uses a cylindrical grinder for grinding and mixing the materials. The ball sizes range from 10 mm to 30 mm, and the process takes place for 2-6 hours under a constant speed of 600 r.p.m. At this point, a mixture of 50 µm sized aluminium and 5 nm sized powder are placed inside the container along with the grinding balls. The powder thus obtained is then subjected to compaction process by using a punch and die setup in a universal testing machine under a pressure of 6.5 MPa. In the next step, the compacted material is placed in a heating furnace for sintering at a temperature of 900 C for about 90 minutes. The sintering process produces bonding between the particles and thus giving a proper shape to the composites [10]. The step-by step procedure used for the specimen preparation and the test specimens are depicted in Figure 1. 16 samples have been fabricated with different compositions of Al, TiO₂ and BN as listed in Table 1.



Fig. 1. Experimental sequences and test specimens

The fabricated specimens have been tested for its density by using ASTM B962-17 standard. Mechanical tests have been carried out by using ASTM standards.

Table 1. Samples and compositions.

Sl.No	Sample Number	Composition
1	S1	Pure Al
2	S2	Al +0.5 wt%BN
3	S3	Al +1.0 wt%BN
4	S4	Al +1.5 wt%BN
5	S5	Al +2.0 wt%BN
6	S6	Al +2.5 wt%BN
7	S7	Al +3.0 wt%BN
8	S8	Al+0.5 wt%TiO ₂
9	S9	Al+1.0 wt%TiO ₂
10	S10	Al+1.5 wt%TiO ₂
11	S11	Al+2.0 wt%TiO ₂
12	S12	Al+2.5 wt%TiO ₂
13	S13	Al+3.0 wt%TiO ₂
14	S14	Al +1.0 wt%BN+1.5wt%TiO ₂
15	S15	Al +1.25 wt% BN+1.25 wt%TiO ₂
16	S16	Al +1.5 wt %BN+1.0wt%TiO ₂

Initially the specimens are prepared in the form of rectangular bars of size 40 mm x 12 mm x 10 mm and then they have been cut in to the required shape using wire cut EDM technique. Tension test has been done based on ASTM E8 standard. Compression and flexural tests have been performed as per ASTM B331 and ASTM E90 standards respectively.

3. Results and discussion

3.1 Density analysis

Density plot of all the samples is presented in Fig 2. Among the Al+BN samples, a hike in the BN proportion reduces the density of samples. A least density of 2.619 g/cm³ is executed by S6 confirming that 2.5 wt% of BN is the optimum proportion for Al+BN composites. Density of pure aluminium is very close to the peak value of 2.693 g/cm³ revealing that there is a notable alleviation in the density due to BN addition. This reduction is due to increased porosity and decline of bonding between the particles. Among the Al+TiO₂ composites, increase in the TiO₂ reduces the density until 2.5 % and then increases for further enhancement. A lowest density of 2.674 g/cm³ was given by sample S12. Comparing pure aluminium and Al+TiO₂ composites, it is observed that, a minimum of 2 wt% of TiO₂ must be retained in order to obtain a density lesser than the pure aluminium. Among the hybrid samples, S15 with equal composition of BN and TiO₂ produced a minimum density of 2.638 g/cm³ which is somewhat greater than S6. This reveals that, the inclusion of TiO₂ gives only a minor decline in the density of composites. Density values are superior for hybrid composites as compared to pure aluminium. Inclusion of both the nanoparticles has an effect on the density of composites wherein BN nano particles create obstacles at grain boundaries and TiO₂ nano particles distribute uniformly and create high surface area, thereby reducing the porosity and thus reducing the density of composites [11, 12].

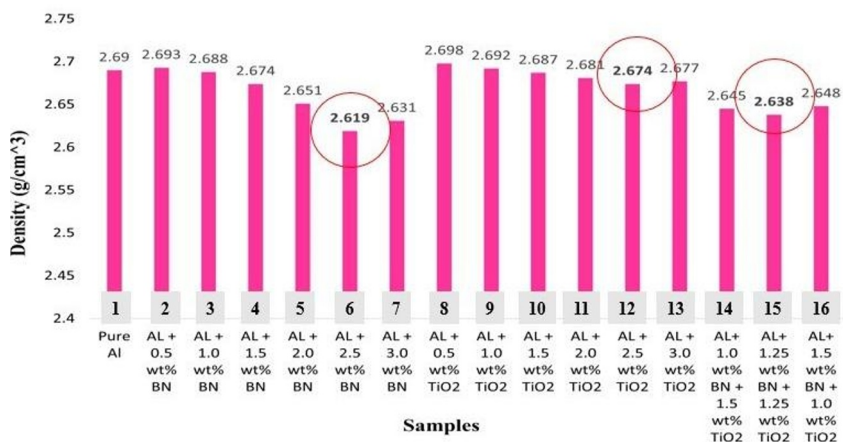


Fig. 2. Density plot

3.2 Tensile test analysis

The Tensile test plot of all the composites is shown in Fig 3. Among the Al+BN composites, a hike in the BN composition enhances the tensile strength of composites. A

maximum tensile strength of 90MPa was shown by sample S6 confirming that 2.5 wt% would be an optimum combination for Al+BN composites. Further increases in BN content beyond 2.5 wt% result in a reduction of tensile strength. Among the Al+TiO₂ composites, a hike in the TiO₂ decreases the tensile strength until a composition of 2.5 % and then increases for further decreases. A maximum tensile strength of 95.81MPa was shown by S12. Comparing pure aluminium and Al+TiO₂ composites, it has been observed that, a minimum of 0.5 wt% of TiO₂ must be maintained to obtain a tensile strength greater than pure aluminium. Among the hybrid composites, S14 with the composition of minimum BN and maximum TiO₂ produced a maximum tensile strength of 97.81 MPa which is some what greater than other samples. This shows that the inclusion of TiO₂ gives an increases in the tensile strength of composites. The uniform distribution of TiO₂ increases the interface between the matrix and reinforcement. The TiO₂ nanoparticles distribute uniformly and create a high surface area, thereby the porosity is reduced and hence the tensile strength of the sample is also increased [13, 14].

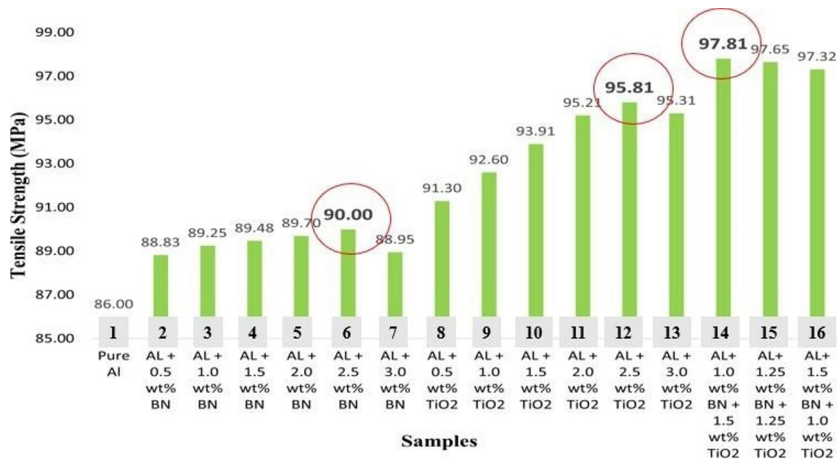


Fig. 3. Tension test plot

3.3 Compressive test analysis

The compressive test plot of all the samples is shown in Fig 4. Among the Al+BN composites, an elevation in the BN % increases the compression strength of composites. A maximum compression strength of 54.16MPa is executed by S5 revealing that 2.0 wt% would be an optimum combination for Al+BN composites. A further increase in the BN % decreases the compression strength. Among the Al+TiO₂ composites, increase in the TiO₂ declines the compression strength until a composition of 2.5 % and then enhances for further decrease. The highest compression strength of 70.27MPa was given by S12. Comparing pure aluminium and Al+TiO₂ composites, it has been observed that, a minimum of 0.5 wt% of TiO₂ must be retained to obtain a compression strength greater than pure aluminium. Among the hybrid composites, S15 with an equal composition of BN and TiO₂ produced a maximum compression strength of 102.33 MPa which is somewhat greater than other samples. This shows that the inclusion of TiO₂ gives an increase in the tensile strength of composites. The BN nanoparticles create obstacles at the grain boundaries. It prevents grain growth during sintering. The TiO₂ nanoparticles reduce the porosity and create a high surface area. Hence the compression strength is improved. [13, 14].

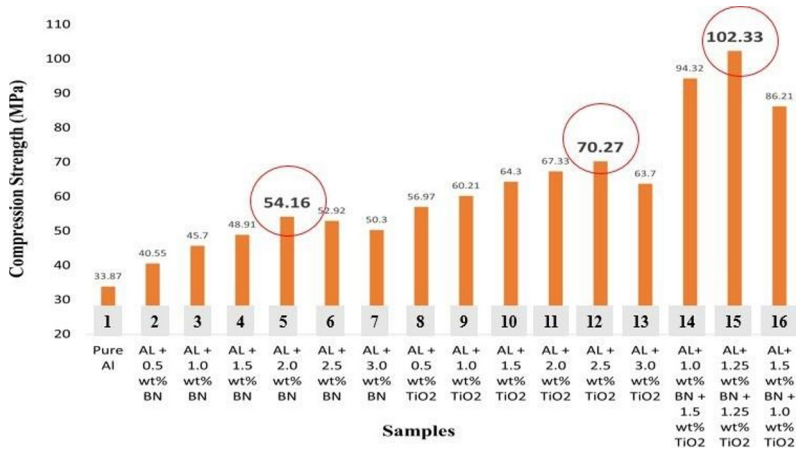


Fig. 4. Compression test plot

3.3 Flexural strength analysis

The flexural strength plot of fabricated samples is presented in Fig 5. Among the Al+BN composites, an increase in the BN composition raises the flexural strength of composites. A maximum flexural strength of 115.2MPa was shown by S6 revealing that 2.5 wt% would be an optimum combination for Al+BN composites. A further increase in BN reduces the flexural strength. Among the Al+TiO₂ composites, increases in TiO₂ content beyond 2.5 wt% result in a reduction of flexural strength. A maximum flexural strength of 177.9MPa is shown by S12. Comparing pure aluminium and Al+TiO₂ composites, it has been observed that, a minimum of 0.5 wt% of TiO₂ must be retained to obtain a flexural strength greater than pure aluminium. Among the hybrid composites, S14 with a composition of minimum BN and maximum TiO₂ produced a maximum compression strength of 221.7 MPa which is somewhat greater than other samples. This shows that the inclusion of TiO₂ gives an increase in the flexural strength of composites. The BN nanoparticles create obstacles at the grain boundaries [14, 15]. It prevents grain growth during sintering. The TiO₂ nanoparticles reduce the porosity and create a high surface area. Hence the flexural strength is improved.



Fig. 5. Flexural test plot

Conclusion

Aluminium metal matrix composites have been fabricated with nano BN and nano TiO₂ as reinforcements by using powder metallurgy method and the structural characters have been analyzed. Tensile strength represents that composite specimens were showing higher tensile strength than the pure aluminium. The optimum composition of this metal matrix composites during the tensile loading is found to be pure aluminium with 1.0 wt% nanoBN and 1.5 wt% nano TiO₂ reinforcement composition. The increase in nano TiO₂ increases the tensile strength of pure aluminium. Compression strength represents that composite specimens were showing higher compression strength than the pure aluminium. The optimum composition of this metal matrix composites during the compression loading is found to be pure aluminium with 1.25 wt% nanoBN and 1.25 wt% nano TiO₂ reinforcement. The equal percentage of nano BN and nano TiO₂ increases the compression strength of pure aluminium. Flexural strength represents that composite specimens were showing higher flexural strength than the pure aluminium. The optimum composition of this metal matrix composites during the flexural loading is found to be pure aluminium with 1.0 wt% nanoBN and 1.5 wt% TiO₂ composition. The increase in nano TiO₂ increases the flexural strength of pure aluminium. Among the fabricated composites, it is revealed that, hybrid composites are superior in all aspects as compared to that of the pure aluminium and composites reinforced with a single reinforcement.

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