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**Research Article**

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# Comparative Study of Al-$TiB_2$ Composite Fabricated by Different Powder Metallurgical Methods

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***Abstract—***

***Aluminium Metal Matrix Composites (AMMCs) are the new class of materials substituting many industrial materials. It is due to its superior qualities compared to conventional materials. AMMCs has found a versatile application because it has aluminium in matrix phase hence light in weight and also it can acquire different properties as per reinforcements used. Sintering is one of the prominent methods used to manufacture AMMCs. Sintering process is used in Powder Metallurgy in which small powdered particles are heated to bond together. The process enhances the strength as well as other mechanical and tribological properties. The technology enables us to shape materials difficult to machine, parts with complex geometries, materials having high melting point, parts with close dimensional tolerances, or to combine different materials which is not possible with any other process. The most important part is that the density of the product can be controlled according to the requirements and thus self-lubricating and wear-resistant parts are possible. The present study has attempted to see if $TiB_2$ can be used as reinforcement in AMMCs produced through powder metallurgy route and the changes in the properties of AMMCs by the different sintering methods adopted. The compacted preforms of varying compositions of reinforcement were prepared and sintered through three different methods i.e. Microwave sintering, Conventional sintering and Hot-pressing to study the changes in the properties. A comparative study has been done between the three sintering methods to see the limitations and scope for improvement.***

***Keywords: AMMCs, Powder Metallurgy, Conventional Sintering, Microwave Sintering, Hot-pressing, Mechanical & Tribological properties.***

## I. INTRODUCTION

Powder metallurgy technology deals with powders and its behaviours while it is being used for various manufacturing processes. Use of powder material could be of any material such as metals, non-metals, ceramics, or any known combinations. Previously, this method had lot of limitations in achieving low cost process for selected materials, good compact and high strength end product. However, starts of human civilizations, numerous developments have been done on power metallurgy process to get the desired products for various applications. Powder metallurgy intended to develop high strength materials in desired shape with good compactness using single or combination of metals, polymers, or ceramics by various techniques. This methodology includes different stages such as the product formation, blending or mixing, compaction and finally sintering. Compaction of the mixed powders is to make the required end-product shape. Heat treatment and machining of the final product is also needed in certain cases. First and the foremost important step towards powder metallurgy is the Powder Formation. It is due to that the whole product properties like density, mechanical strength, etc depend upon the properties of the powder. There are many factors that influence the properties of powders: (a) particle shape, (b) size, (c) its distribution, (d) flow rate, (e) compressibility, (f) apparent density, and (g) purity. After preparing the powder with required properties, the next step in the process is Blending and Mixing of Powders. Powders are generally categorized as elemental powder (powders of single element) and pre-alloyed powder (containing more than one element). Blending of powders is necessary as to obtain uniform distribution of particle sizes and it also helps in reducing porosity and better intermingling of lubricant with powder to facilitate their interaction during compaction. After blending the powders to near uniform sizes, they are mixed either in dry or wet condition depending on the material. Alcohol, Acetone, Benzene or distilled water can be used as a liquid medium in wet milling, while for mixing the hard metals (like carbides), ball mills or rod mills is employed. Over-mixing of powders can affect the flow characteristics of the mix; thus, mixing should be stopped when the random mixture seems to be achieved. The blended and mixed powder is now ready to take pressure which is called as Compaction Process. Objective of compaction process is to make the specimen ready for sintering and for this powder needs to withstand the heat and pressure without damaging its shape and structure. In this process pressure is applied to the powder in mould die so that a bonding between powder particles can be established and the required end-product shape can be given to the powder. The strength acquired in this stage is termed as green strength or green density. The compaction helps in reducing voids between powder particles and also facilitates plastic deformation of the powder particles to conform to the final desired shape of the part. There are different methods available for compacting which can be chosen according to the requirement, they are: (a) pressing, (b) centrifugal compacting, (c) slip casting, (d) extrusion, (e) rolling, (f) iso-static moulding, and (g) explosive moulding. The final and most important stage in powder metallurgy is Sintering which is heating the compacted powder preform to about 70 per cent of its melting temperature while well above the temperature that would allow diffusion between the neighbouring powder particles and also under controlled atmospheric conditions and time to prevent oxidation of powders. In case of sintering of mixed powders of different melting temperatures, the sintering temperature usually remains above the melting temperature of one of the minor constituents and others remaining in the solid state which also facilitates the bonding between the powders particles as the melted element holds the other particles together. So basically, there are three important variables or factors that govern sintering, atmosphere, temperature and time. The sintering temperature and time varies from material to material but atmosphere taken is generally inert or reducing atmosphere and sometimes vacuum to avoid oxidation. The nature and strength of the bond between the particles largely depends on the mechanism of diffusion and plastic flow of the powder particles, and evaporation of volatile materials from the compacted preform. The three ways in which bonding between the powder particles takes place are: (a) melting of minor constituents in the powder particles, (b) diffusion between the powder particles, and (c) mechanical bonding. Sintering process enhances the density of the final part by filling up the voids formed during compaction and increasing the area of contact among the powder particles in the compact perform. The powder metallurgy technique is known to have many benefits over other manufacturing processes. The whole methodology depends upon the sintering or heating of the compacted preforms as the strength that the final part acquires is through this stage only. Earlier, it is thought that as the rise in temperature increases density of the preform and thus strength. But it is noticed that the conventional way of heating through burning fuel or electrical resistance furnace, is not able to densify the part after a certain point. Thus, microwaves which are electromagnetic waves having frequency range from 300MHz to 300GHz have been attempted to use as a heating source. It has been found that the microwaves have proved to be a better alternative to conventional sintering. However, some limitation in using microwave sintering is that it can only be used for the materials that are able to absorb microwaves so that heat can be generated inside the body. In addition, the leakage of radio waves can hamper the communication system of an area under its influence. Although microwave sintering has some limitations, due to its considerable advantages over conventional sintering, many investigations have been carried out on minimizing its limitations and utilizing the technology. One of the most important limitations in using microwave sintering is that bulk metals could not be able to absorb microwaves restricting its use in many industries. Metals being one of the most used materials in almost every industry are very important in manufacturing and thus many attempts have been made to solve this problem. It is reported that if the metal powders size is reduced to 100µm or less, it can absorb microwaves or, if the bulk metals are preheated to temperature of about 400ºC that can be used in micro wave sintering. Hence, AMMCs are manufactured by the powder metallurgy route.

Metal matrix composites (MMC) are the materials in which any metal is reinforced with different reinforcements as ceramics, metals or organic compounds to improve its physical and mechanical properties. Aluminium is one of the lightest metals and readily available have always been centre of interest for manufacturers and thus researchers. The natural corrosion-resistant property of aluminium makes it suitable for manufacturing long lasting products but its low strength restricts its applications. Thus, aluminium metal matrix composites (AMMC) are emerging materials that have properties of aluminium with improved strength. Addition of reinforcements in any metal has some effects in their properties and thus the selection of reinforcement is done according to the need of product. The important factors while the selection of reinforcements are; its volume fraction (vary from few % to ~70 %), form of reinforcement (may be in particulate form or whisker or continuous/discontinuous fibres), and method of addition i.e. by powder metallurgy/ casting / doping. The use of AMMC has increased to great extent in past few years as it has been implemented successfully in many areas like automotive parts, defence parts, structural parts, research instruments, sports and recreational equipment, etc.

The growing market and increasing scarcity of resources is pushing the world towards the use of energy-saving and more efficient parts. The continuous efforts are being made in the direction of tailoring materials that can use minimum input and also last longer. Iron is said to be the most important material in the history of the material world as it is utilized in every field of manufacturing whether in raw form or its alloy form. However, one of the limitations in its use is its weight (high density, ~7.87 g/cm3). In view, aluminium has potential to replace it due to its light weight (low density, ~2.70 g/cm3), natural corrosion-resistant and abundant availability. The only factor that has restricted its applications is its low strength, thus many different combinations of materials and manufacturing methods are attempted to improve the strength of Al based materials. Several reinforcement materials are available such as SiC, $Si_3N_4$, alumina, $B_4C$, TiC, $TiB_2$ etc. However, in comparison to others, the selection of $TiB_2$ as a reinforcement materials are of great interest due to its unique properties like excellent heat conductivity of 25 W/mK, oxidation stability, high melting point of 2970˚C, and high hardness value 1800 Knoop (azom.com). Due to high hardness of $TiB_2$, it shows superior resistance to mechanical erosion/wear compared to other hard materials. As we know the powder metallurgy route reduces the material wastage to minimum and gives liberty of controlling density of the material, thus, best way to produce self-lubricating parts. Hence, in the present work, literature has been done in search of developing superior wear-resistance material with minimum material wastage so to increase the life of quick wearing parts as cutting tools, brake pads of automobiles, gears, etc.

## II. LITERATURE REVIEW

[1] Conducted several experiments to analyse the mechanical and tribological properties of unreinforced and reinforced Aluminium composites. They found out that poor wear-resistance of unreinforced aluminium got improved with incorporation of ceramic reinforcements. Also, due to increased hardness these composites caused wearing of other parts in contact. They suggested that the use of fly-ash as reinforcement can solve the purpose but it also showed

decrease in tensile strength of the composite. [2] have studied the AMC systems to find out their properties, processing methods and scope of applications. They brought out that the addition of reinforcements to the aluminium improves its various properties based on the material reinforcement. When pure aluminium is reinforced with continuous aluminium fibres, its elastic modulus enhanced from 70 to 240GPa and its coefficient of expansion decreases from 24 to 7 ppm/ºC. Also, the addition of Si 20 vol.% into pure aluminium could increase its wear-resistance to equal that of grey cast iron. The study concluded that though addition of reinforcements improves properties of base metal with the observation of undesirable changes in their properties: it need to be eliminated or controlled. [3] focused on the different combinations of reinforcing materials with aluminium metal and their major fabrication techniques. It is observed that the role of reinforcing materials is very significant in development of any MMC and there are primarily three approaches that can be adopted in the development of cheap and better usable material. Finding and using cheaper reinforcing materials as industrial wastes and agro derivatives is the first approach. Second approach is the reduction of particles size from micron scale to Nano scale which has capability to improve the performance of the product. The use of two or more reinforcing materials is the third approach. They also found out that the stir casting and powder metallurgy method are the most useful methods in fabricating AMMC which can be commercialized. Another work done by [4] to prepare AMMC reinforced with 4 vol.% Cu and varying SiC % through powder metallurgy route and to evaluate their mechanical and tribological properties. The study results are concluded that PM method results in uniform distribution of reinforcements in aluminium matrix and addition of SiC improves the hardness of the composite with the cost of reduced ductility and compressive strength. Up to 7 vol.% of SiC in the composite increases its wear-resistance but after that bonding between reinforcement and matrix gets affected resulting in lower wear-resistance. Further, noticeable decrease in thermal conductivity is also noticed with addition of ceramic reinforcements. [5] deals with the variation of SiC reinforced AMMC strength by a study conducted by micro-indentation. Upon the test results, it found that the indentation hardness value has been decreased with the increase in indentation depth due to the variation of material content. It is concluded that addition of SiC increase the hardness of the developed composite. [6] have fabricated Al-$B_4C$ MMC through powder metallurgy route and investigated the effect of reinforcement in the composite. The study has brought out the reinforced material with decrease in density, increase in hardness value and with increase in volume fraction. It also suggested that the powder metallurgy route results in uniform distribution of $B_4C$ with bonding with matrix phase. [7] attempted an investigation to prepare AMMC with SiC and graphite as reinforcing materials through stir casting method. The study results observed that the addition of SiC has increased the hardness value of the developed composite, whereas the introducing of graphite improves the interfacial bounding between the particles. The best result is obtained for 4 vol.% graphite and 25 vol.% SiC additions. [8] investigated the Aluminium based composites reinforced with micro SiC, $Al_2O_3$, $B_4C$, $TiB_2$, $ZrO_2$, $SiO_2$ and graphite particles. The report concluded that the change in the micro-structural characteristics which could produce the material with superior mechanical and physical properties appropriate for automotive/aerospace applications. [9] suggested that the presence of SiC makes the composites hard. Addition of metal oxides shifts the brittleness of SiC and widens its engineering applications. Oxide phases extensively improve the fracture toughness of the materials. Rutile, a common natural form of $TiO_2$, is readily available, inexpensive and holds substantial wear resistance, mechanical and thermal properties and can be used as a reinforcement to improve the properties of AMMCs. [10] conducted a study by varying the mass fraction of SiC (5%, 10%, 15%, and 20%) with Aluminium. The investigation results found that the weight to strength ratio for Aluminium-SiC is about three times that of mild steel during tensile test. While, the Aluminium-SiC composite material is found to be two times less in weight than the Aluminium of the same dimensions. The maximum tensile strength has been obtained at 15% SiC ratio. It is indicated that the Aluminium-SiC composite is having less weight and more strength.

[11] fabricated the Al–Si/SiC composites in different compositions 7, 14 and 21 wt. % of SiC. Upon increase of reinforcement content, it is found that the developed composite has improved in mechanical properties (such as ultimate tensile strength, yield strength and hardness) with the expense of their impact energy. The authors also found that Mg addition to matrix alloy before SiC addition improved wettability and facilitated homogeneous distribution. While, the increase of SiC particles ratio in composites caused the impact energy to decrease. Investigation of the compressive formability of porous Al/SiC composites is carried out by mechanical alloying [12]. Aluminium matrix composites consisting of pure Al reinforced with different amounts of 5, 10, 20 wt.% SiC with mean particle size of 12 or 16 µm and are produced by powder metallurgy route. The effect of milling time on microstructure and mechanical properties of the composites was studied. The phased compression tests coupled with density measurement and continuous compression of the samples were indicative of increases in strength and decreases in ductility of the composites with increasing milling time, increasing amount of reinforcement particles and decreasing their size. It was also revealed that instantaneous work hardening exponent increase with increasing milling time, increasing weight percentage of the reinforcement and decreasing its particle size. The samples having higher initial densities, containing lower amounts of larger SiC particles show better workability. [13] found out optimal composite fabrication parameters using AHP method. Analytic Hierarchy Process (AHP) was used as the multi-criteria decision-making method. Eight composites with different manufacturing conditions were fabricated via powder metallurgy processing. Both compression test and cold upset test were conducted at room temperature to evaluate the strength and workability of composites. The instantaneous density coefficient, instantaneous strain-hardening exponent and formability stress index under triaxial stress state condition was measured. Findings from AHP method showed that the choice of Al–10 wt.%-SiC with relative density of 95% milled for 12 h, is the preferred alternative. It was concluded that the relative density of the composite is the most significant property which can affect the mechanical property of the composites. The higher relative density and milling time led to optimum condition. The other parameters affected on both strength and workability of composites was

reinforcement's size and weight fraction. [14] reviewed fabrication and characterization of AMMC and concluded that aluminium alloy with reinforcement is clearly better to base alloy. It improves the mechanical properties with their excellent quality of tensile strength, impact strength, wear resistance, hardness and corrosion resistance etc. Fatigue properties of aluminium cast alloy is also presents a better result as compared to other materials but sometimes presence of porosity may cause not so much desirable results. It is also concluded that after adding of reinforcement to the base metal properties like electrical and thermal are also improve compared to base metal.

[15] did the comparative study on mechanical properties for microwave heat treatment and conventional heat treatment of Al (6061) -$B_4C$ composite. Fabricated composites before fabrication were subjected to microwave and conventional heat treatment for enhancing the mechanical properties. Boron Carbide is one of hardest known elements. It has high elastic modulus and fracture toughness. The addition of Boron Carbide ($B_4C$) in Al matrix increases the hardness, but does not improve the wear resistance significantly. Boron carbide is an attractive reinforcement for aluminium and its alloys. It shows many of the mechanical and physical properties required of an effective reinforcement, in particular high stiffness 445 GPa, and hardness 3700 HV. These factors, combined with a density, 2.51 g cm−3, less than that of solid aluminium, 2.7 g cm−3, indicate that large specific property improvements are possible and specific properties will improve with increasing particle addition. The small density difference between B4C and molten Al means that particle sedimentation rates are low, minimizing settling problems observed during solidification processing. They concluded that comparable mechanical properties were obtained in both conventional & microwave heat treatment processes. Time consumption is very less in microwave heat treatment and it is a cleaner energy process. The non-heat treated composite material of Al-B4C is less hard than the heat treated one. The hardness of the composite is increased while adding the B4C reinforcement to the Aluminium matrix. Microwave heat treated composites exhibited finer microstructure in machining compared with non-heat treated composite material. [16] investigated Metal matrix composite (MMC's) using Aluminium Alloy 2900 and 2024 as matrix material with silicon carbide and alumina as reinforcement and then the samples were microwave sintered. They found that 10 μ m sized reinforcements have successfully performed as an excellent microwave suspecter material enhancing the microwave processing of the powder compacts. Among two different reinforcements considered Al2O3 was performing very well in improving the strength-microstructure relationship of the composites compared to SiC Microwave processing, a novel method by which the enhanced ceramic particulate diffusion and good interface bonding achieved resulting in improved strength-microstructure relationship the composites which are the challenging considering industrial aspect of manufacturing. Over all aspects of strength-microstructure performance was analysed and found that by using both matrix and reinforcement of size 10 μ m a critical percentage of 6 wt. % is found to be threshold value for reinforcement addition beyond which the degradation of the strength-microstructure relationship of the composites is observed. [17] studied the variation in mechanical properties due to the different sintering processes both conventional and microwave processes metal matrix composites with Aluminium as the base metal and with varying weight percentage of Silicon Carbide (SiC) as the reinforcement. They observed that density increases with increasing compaction pressures and decreases with increase in weight% of SiC Hardness increases with increase in weight % of SiC. Microwave sintered samples exhibited higher hardness than conventional sintered samples. Porosity distribution is uniform in microwave sintered samples whereas porosities are concentrated more at the core in conventional sintered samples. The microstructure of microwave sintered samples is hardly altered by the microwave sintering process. [18] developed aluminium alloy matrix $Al_2O_3$ particulate composite using microwave energy as a heating source and found that Aluminium 5083 alloy and composite give good response to microwave. Powder morphology and size become uniform i.e. all powder particles were regular shaped with narrow size distribution. Microwave sintering of mechanically alloyed Al5083 alloy and composites resulted in good density, i.e. 97% of theoretical density. The effect of alumina in 5083 alloys was studied with respect to hardness value and found that there was a trend that hardness value increased with increase alumina content. The wear rate was low with increasing alumina content.

[19] studied the effects of $TiB_2$ coating on wearing properties of aluminium-silicon alloy MMC. They concluded that the tool life increased at higher cutting speeds. [20] investigated to find out important factors influencing sintering of Al-Si MMC. They concluded that addition of ceramic particles improves the sintering behaviour of composites and also, increase in temperature and decreasing rate of heating improves the properties of the composites. [21] analysed wear behaviour of AMMC and factors influencing it. They modelled a mathematical relation that can predict amount of reinforcement in the composite based on contact wear. They found out that reinforcement volume fraction, applied Load, rotational speed and counter-face hardness are the factors that influence wear properties of a composite.

## III. PROBLEM IDENTIFICATION & OBJECTIVE

### *A. Problem Identification;*

Based on the thorough analysis of literatures, it has drawn out that aluminium due to its light weight, natural corrosion-resistance, good conductivity, and availability, is the best potential metal that can replace heavy metals that are currently being used in industries and powder metallurgy is the most economical method in volume production in terms of material wastage and energy saving. Also, there are many reinforcements have been tried and being utilized to improve the properties of AMMC but still there are many areas like lower ductility, poor conductivity and counter-face wearing, self-lubrication, etc. where improvement is required.

### *B. Objective of the work;*

Based on the problem that is identified the following research objective has been framed and experimental investigation is conducted to meet these objectives. The goals are: -

1. To make specimens with varying compositions of $TiB_2$ and Aluminium through powder metallurgy route.
2. To sinter the specimens through conventional sintering, microwave sintering and hot-pressing methods.
3. To test the mechanical and tribological properties of specimens prepared through different methods.
4. To find out the best composition and best method that can give superior properties to the AMMC.

## IV. EXPERIMENTAL SETUP

The powders of aluminium (Al) and titanium diboride ($TiB_2$) were procured to prepare the $TiB_2$-Al composite specimens of varying compositions. The powders of Al and $TiB_2$ were weighed according to the required composition and each powder mixer with the separate composition was cup-milled using vibrating cup mill at 1000 RPM for 6-8 minutes to achieve uniform mixtures. To know thermal decomposition and weight change if any, a selected powder Al-$TiB_2$ mixture was characterized using thermo-gravimetry (TG)/Differential thermal analysis (DTA) on Thermo-gravimetric Analyser (model no. STA-PT 1600) in argon atmosphere. This test was carried out by taking 22.5 mg powder mixture in an alumina crucible heated up to 700-degree C at 10-degree C/minute. Upon heating up to 700˚C TG data suggested that slight weight increase has been noticed possibly due to oxidation of Al in air atmosphere. While, the DTA data has indicated the observation of exothermic peak at 660-degree C due to the melting of Al. In addition to this information, no other significant result has been noticed. After that to prepare the compact specimens, the Al-$TiB_2$ mixture was packed in the die-mould set up with hand-tight and then taken for compaction under the load of 3-4 tons using the hydraulic compacting machine, as shown in Fig.1. This compaction process is carried out to increase the green density of the specimens to facilitate the diffusion process between the atoms upon sintering. Besides, the compaction also gives the required end-product shape to the powders. Any required shape can be prepared by using the suitable mould or die.

Fig.1. Hydraulic compacting machine

Fig.2. Specimen prepared after compaction

The prepared specimens as shown in Fig.2. were then utilized for sintering by different metallurgical methods.

Fig.3. Microwave furnace Set-up

Three sets of specimens were taken to microwave heating namely A, B, and C. Each set was heated at different temperatures; viz. 625˚C, 600˚C, and 650˚C respectively placed over the ceramic plate into the vacuum chamber of the set-up shown in Fig.3. The conditions set for heating were:

(a) For set B: Heating temperature - 600˚C; Soaking time (Holding time/Heating time) – 15 minutes; Rate of heating - 20˚C/min.
(b) For set A: Heating temperature - 625˚C; Soaking time – 15 minutes; Rate of heating - 20˚C/min.
(c) For set C: Heating temperature - 650˚; Soaking time – 15 minutes; Rate of heating - 20˚C/min.

 

All specimens were furnace cooled for 5 – 6 hours and then taken outside for further testing.

Fig.4. Electrical furnace set-up for conventional sintering

Three sets of the specimens were conventionally sintered on the conventional furnace at different temperatures: -
(a) For set G: Heating temperature - 650˚C; Soaking time (Holding time/Heating time) – 30 minutes; Rate of heating - 10˚C/min.
(b) For set H: Heating temperature - 600˚C; Soaking time (Holding time/Heating time) – 30 minutes; Rate of heating - 10˚C/min.
For set I: Heating temperature - 560˚C; Soaking time (Holding time/Heating time) – 30 minutes; Rate of heating - 10˚C/min. A portable furnace was used to produce heat during pressing. It was placed under the hydraulic pressing machine so that sintering and compaction could be done simultaneously. Only one composition of Al-$TiB^2$ powder mixture; i.e. 90 vol.% Al – 10 vol.% $TiB^2$ could be sintered and named as 1P.

## V. RESULTS & DISCUSSION

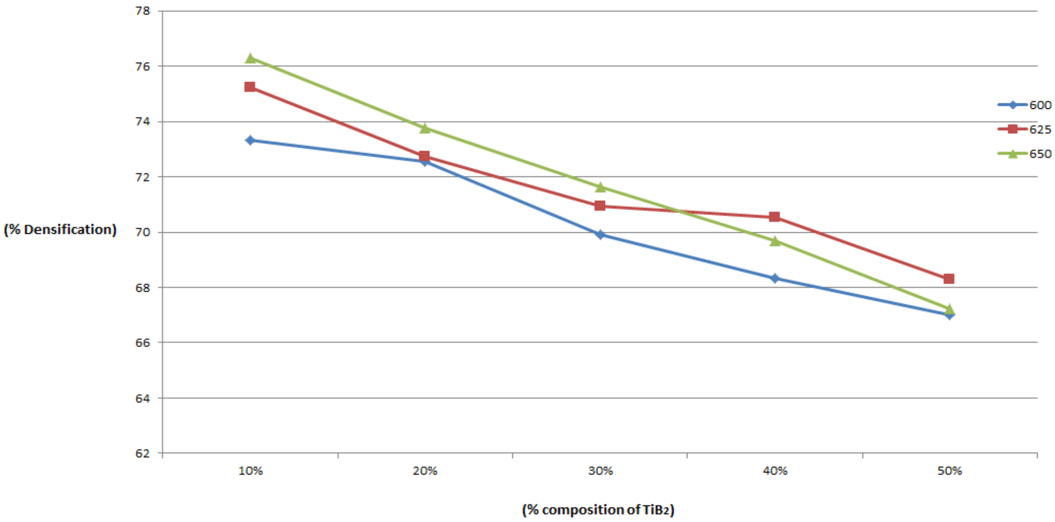


Fig.5. Graph between % densification vs. % composition of $TiB_2$ through microwave sintering

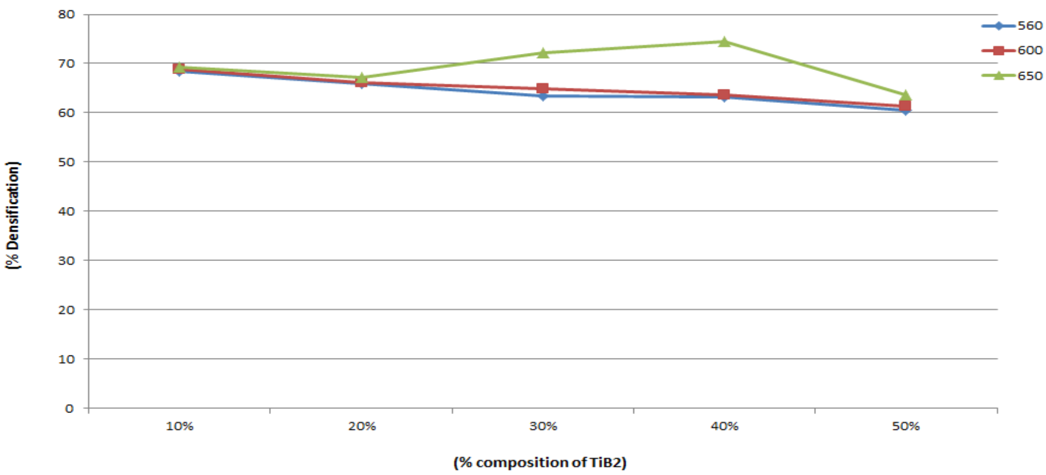


Fig.6. Graph between % densification vs. % composition of $TiB_2$ through conventional sintering

From Fig.5. and Fig.6., it can be seen that in microwave sintering, with increase in sintering temperature the per cent densification of specimens of same composition increased but also with increase in amount of titanium diboride ($TiB_2$) in the specimen the per cent densification at same sintering temperature started decreasing and in conventional sintering, when the specimens were heated at 560˚C the per cent densification of the specimens decreased with increase in amount of $TiB_2$ but when the sintering temperature increased to 600˚C and 650˚C, per cent densification started increasing with increase in amount of $TiB_2$ until it is 40 vol.% and suddenly decreased to minimum at 50 vol.%. The % porosity followed the opposite trend of % densification in both cases. Through hot-pressing method, the specimen achieved the maximum densification of 97.57%. The probable reason of decrease in densification with increasing composition of $TiB_2$ could be the high melting point of $TiB_2$ and its particle sizes which prohibits the diffusion between atoms of Al and $TiB_2$. It can also be concluded that for achieving maximum densification, hot-pressing method is the best among microwave sintering, conventional sintering and hot-pressing. The five specimens that had the maximum % densification was selected, namely 1C, 1G, 3C, 3G, and 1P for the microhardness-testing on VMHT series microhardness tester that gives Vickers hardness values for the tested samples. The test was performed for four different loads 50gf, 100gf, 200gf, and 300gf for each of the selected specimens and the results are tabled below in Table I.

Table I Hardness values for different samples

| **LOADS →** | 50gf | 100gf | 200gf | 300gf |
|---|---|---|---|---|
| **SAMPLES ↓** | | | | |
| 1C | 33.6 HV | 34.9 HV | 67.4 HV | 84.0 HV |
| 3C | 29.9 HV | 40.0 HV | 53.0 HV | 68.8 HV |
| 1G | 24.5 HV | 30.5 HV | 48.9 HV | 103.0 HV |
| 3G | 33.0 HV | 69.3 HV | 75.3 HV | 99.0 HV |
| 1P | 118.0 HV | 86.2 HV | 69.5 HV | 84.4 HV |

From the Table I, it can be seen that for 50gf load the maximum hardness value is for the hot-pressed specimen (1P), which proves that better densification results in better hardness value. With increase in load, the hardness values of all the specimens but 1P increased and this could be due to the indentation point selected as reinforcement particles get randomly distributed, at some places it is densely present and at some places very few particles are present. The decrease in hardness value of 1P with increase in load could be explained as, sometimes with more load applied the reinforcement particles get shifted and load is resisted only by matrix phase thus lower hardness value is achieved. Thus, it can be concluded that for getting more hardness better densification is required and also uniform distribution of reinforcements could give better results. The Wear-testing was done on the micro-tribometer CM-9065 with rotation speed set at 100 RPM and test time as 900 seconds.

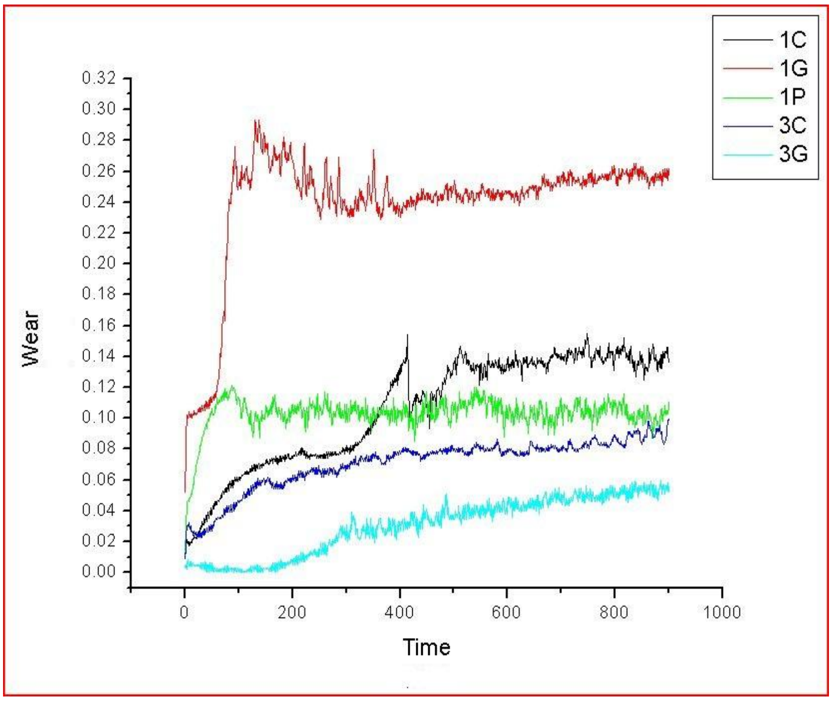


Fig.7. Graph between wear vs. time for 100gm load

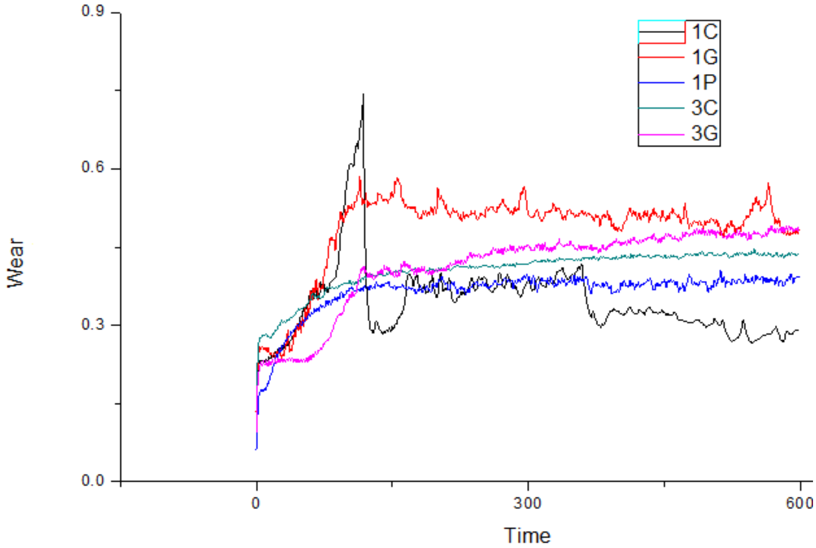


Fig.8. Graph between wear vs. time for 250gm load

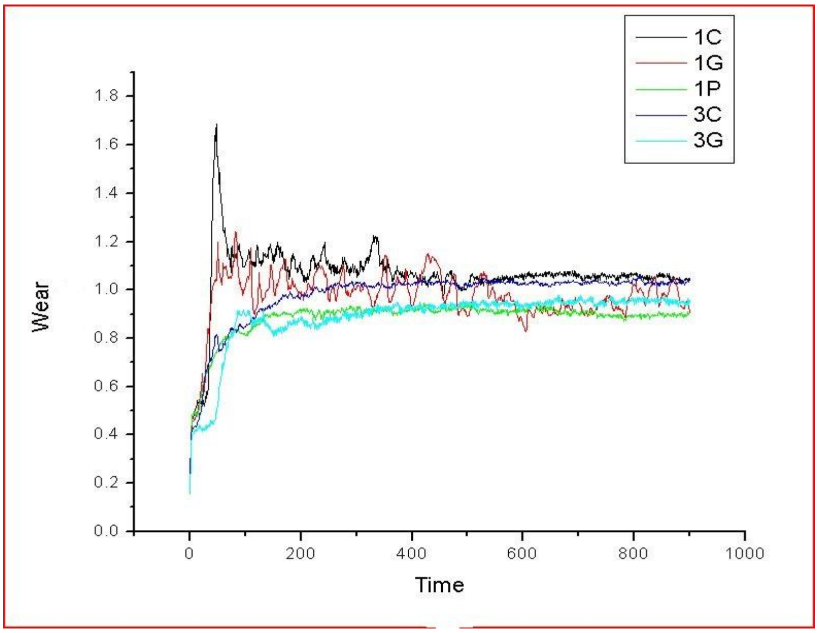


Fig.9. Graph between wear vs. time for 500gm load

From the Fig.7, 8 and 9 it can be seen that the wearing increases with the increase in applied load and which is obvious. In lower load (100g) it is seen that the specimens having greater composition of reinforcements have better wearing resistance compared to that having lower compositions and the specimen hot-pressed fall in between. As the load increased to 250g and 500g, the hot-pressed specimen showed the best wear-resistance compared to both conventionally sintered and microwave sintered specimens and specimens having greater composition of reinforcements still showing better wear-resistance than having lower composition. Co-efficient of friction is also showing the same trends.

## VI. CONCLUSION

Experiments are done for the fabrication of Aluminium Metal Matrix Composites through Powder Metallurgy route and by varying compositions of $TiB_2$ in the composites through three different methods; *viz.* Microwave sintering, Conventional sintering, and Hot-pressing and experimental analysis are done to conclude:

- $TiB_2$ can be used as reinforcement in Aluminium composites and Powder Metallurgy route can be taken for the successful fabrication of Al-$TiB_2$ composites.
- Percentage densification is a function of both sintering temperature and amount of reinforcement added in the composite and microwave sintering gives better densification compared to conventional sintering process. But Hot-pressing method gives the best densification compared to other processes and near-theoretical density can be achieved through powder metallurgy route.
- In microwave sintering better diffusion between atoms occur and increase in amount of reinforcement can decrease the activation energy required but would require more sintering temperature to get better densification.

 

- Hardness of the composite depends upon the reinforcement used and its distribution over the surface of the composite. $TiB_2$ can give better hardness value to Aluminium composites. For getting more hardness better densification is required and also uniform distribution of reinforcements could give better results.
- Hot-pressing method can give maximum wear-resistance compared to both microwave sintering and conventional sintering methods and increase in amount of reinforcements also increase wear-resistance properties of composites.
- In Microwave sintering uniform heating of the powder materials happens and results in uniform distribution of reinforcements over the surface of composites whereas in Conventional sintering agglomeration of reinforcements is seen that gives lesser hardness and wear-resistance. Hot-pressing method also results in uniform distribution of reinforcements.

## VII. FUTURE SCOPE

In order to get better analysis of properties of Al-$TiB_2$ composites following scope of future scope can be summarised:

- The Al-$TiB_2$ composites through powder metallurgy route can be prepared of some specific shape to test on some practical applications as gears, brake pads, machine tools, etc.
- As the powder metallurgy method can produce porous materials, self-lubricating parts made of Al-$TiB_2$ composite can be prepared and tested.
- Due to lack of time hot-pressing could not be done for different compositions of reinforcement, it can be done to see the changes in results.
- As the results showed improvement in properties of composites with increase in reinforcement, it can be sintered in increased sintering temperatures.

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