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# Characterization of Microstructure and Hardness of Aluminum Alloy Matrix Composites Reinforced with Boron Fiber (Coarse and Fine) Particles Prepared by Powder Metallurgy Technique

**R. Ramanjaneyulu, K.Raja Gopal, B.Durga Prasad**

***Abstract:*** ***Powder metallurgy is one of the best methods to achieve uniform distribution of reinforcement in to the matrix. In this Paper, characterization of microstructure and hardness of aluminum alloy matrix composites reinforced with boron fiber particles prepared by powder metallurgy technique are investigated. The effects of boron fiber (Coarse particles size of 120 µm and Fine particles size of 50 µm) on mechanical properties were studied. Increasing the reinforcement of boron fiber content with 5%, 10% and15% into the matrix improved the mechanical properties. The percentage of boron fiber reinforcement increasing the strength of the hardness number is also increasing simultaneously, the aluminum alloys and boron fiber particles on the microstructure and mechanical properties of the composites were investigated. X-ray diffraction (XRD) and scanning electron microscopy (SEM) with Energy dispersive spectrum (EDS) analyses indicated. Analysis and observing microstructure of the composite is boron fiber particles are uniformly dispersed in the aluminum alloy matrix composites.***

***Key words: Aluminum alloy (2024) with Boron fiber composites, X-ray diffraction (XRD), Microstructure (SEM with EDS), Rockwell hardness and Powder metallurgy***

## I. INTRODUCTION

Particle reinforced Metal matrix composites (MMCs) have been known for quite a few years. Among this Aluminum based metal matrix composites are of extraordinary enthusiasm inferable from their amazing mechanical properties, including low density, high young's modulus, good strength and great wear resistance, which make them attractive applications in the aviation, defense and automotive industries [1-5].

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* Correspondence Author

**R. Ramanjaneyulu*,** Research Scholar, Department of Mechanical Engineering, JNTUA, Ananthapuramu, Andhra Pradesh, India. Email: rrramanjaneyulu@gmail.com

**K. Raja Gopal,** Professors, Department of Mechanical Engineering, Email: rajagopalkurnool@yahoomail.co.in

**B. Durga Prasad,** Professors, Department of Mechanical Engineering, JNTUA, Ananthapuramu, Andhra Pradesh, India. Email: mukdhajntu@gmail.com



In conventional Metal matrix composites (MMCs), the most generally utilized reinforcements are ceramics materials, such as $B_4C$, SIC, $Al_2O_3$ and boron fiber in the form of fibers, flakes or particles [6-9].

Decrease in boron carbide percentages also decreases hardness [10]. Powder metallurgy procedures have points of interest over throwing strategy by disposing of isolation. Mixing the blend to accomplish a homogeneous appropriation of reinforcement into base an alloy is a key step of advance of powder metallurgy [11]. Regardless, the interfaces between the ceramic reinforcements and the metal matrix are ordinarily not extraordinary, which results in exceedingly porous materials with decreased mechanical properties furthermore, expanded corrosion sensitivity [12]. Powder metallurgy is the technique wherein powder of materials which includes metals, alloys, ceramics and many others. Are combined, Blended and compacted into the preferred form and then sintered in a controlled environment to bond the particle and desired properties are obtained [13, 14]. MMCs are used for numerous Programs together with area travel, business airliners, electronic substrates, and so forth. When in comparison to polymer matrix composites, the benefits of MMCs are strength and stiffness at multiplied temperature, true abrasion and creep resistance homes. In conventional sintering, heating takes location because of conduction and subsequently the sintering time depends on thermal conductivity of a material. Though the thermal conductivity of aluminum Silicon carbide composites is high, nonetheless it takes greater time for sintering which ends up in the better energy intake. As a trade, microwave heating can reduce energy consumption and normal processing time with improved mechanical properties [15, 16]. The different reinforcement materials utilized in the aluminium matrix as a result of their quality are connected with their particle size, in this matrix The microstructure and how they are appropriated which thusly enhancing the physical &mechanical properties of the delivering aluminium metal matrix composites [17]. Powder metallurgy method is the least demanding and fitting approach to create MMCs with a few points of interest comprehensive of uniform circulation of reinforcing the matrix necessity of less temperature while in contrast with other melting methods and value effective one [18]. Metal matrix composites have been getting huge consideration as of late, especially in the territory of handling systems.

In numerous occasions, the properties of a reinforced metal have been seemed to give an execution advantage over a strong metal, however the high cost of conveying the composite has blocked no matter how you look at it business use, of the various potential metal network frameworks, aluminum amalgam lattice composites have been the object of much investigate, in a general sense due to the lightweight, ease, and effortlessness of assembling of aluminum [19].
Lattice composites (AMCs) are seen to be potential materials in perspective on their awesome physical, mechanical and tribological properties [20].As of late, consideration has been paid for utilizing AMCs as close to home shield [21]. Where higher stiffness, higher specific strength and greater work hardening rate are important considerations. A large variety of production methods have been developed for the processing of FGMs, such as powder metallurgy [22].Thermal spray [23]. Slip casting [24]. Centrifugal casting [25].Laser cladding [26] and chemical vapor deposition [27]. Powder metallurgy is considered as a good technique in producing metal−matrix composites. A significant favorable position in this strategy is its handling temperature is low. Contrasted and melting methods. Then again, great circulation of the reinforced particles can be accomplished [28]. And also favorable position of powder metallurgical method in the capacity to make close net shape item with ease [29].

## II. MATERIALS AND METHODS

Material Selection: Al 2024 is picked as matrix material inferable from its wide application in many engineering aspects including automobile and aviation fields. Further, this combination shows great strength and formability. Table 1 shows the chemical composition of Al 2024.

## III. EXPERIMENTAL STEPS

This work is, the composite is AL/BC and AL/BF is prepared by the technique used powder metallurgy as following number of stages.

**A.Die Preparation**

By using Die and punch raw material used HS steel which is medium carbon steel, to facilitating the die was easy removal of compacted specimen. Dimension of the die is 180mm height, 25mm thickness and 25mm diameter. For overall length of 200mm in punch. The die has been designed in such a way to withstand 450 MPa.

**Table 1.shows chemical composition ratio of AL 2024**

| Aluminium | Chromium | Copper | Iron | Magnesium | Manganese | Silicon | Tin | Zinc |
|---|---|---|---|---|---|---|---|---|
| 90.85 % | 0.05 % | 3.96 % | 3.04 % | 1.20 % | 0.40 % | 0.23% | 0.10 % | 0.17 % |

**Fig.1: 3D view of the fabricated die**

**B.Preparing the powder**

Preparing the Powders i will be taking the 15grams powder of aluminium alloy at a particle size of 50um, and also be taking the same quantity powder of reinforcement boron fiber particles (Coarse and fine) are at 125 and 50 size respectively. Table 2&3 shows the preparation of the samples in the various powder ratio of the experiment.

**Table 2: Show the combination of both Al 2024/BC (Boron fiber coarse) particles ratio**

| Sample name | Al2024 (%) | Boron fiber coarse (BC) particles (%) | Total (%) |
|---|---|---|---|
| AL | 100 | 0 | 100 |
| A5BC | 95 | 5 | 100 |
| A10BC | 90 | 10 | 100 |
| A15BC | 85 | 15 | 100 |

**Table 3: Show the combination of both Al 2024/BF with (Boron fiber fine) particles ratio**

| Sample name | Al2024 (%) | Boron fiber fine (BF) particles (%) | Total (%) |
|---|---|---|---|
| AL | 100 | 0 | 100 |
| A5BF | 95 | 5 | 100 |
| A10BF | 90 | 10 | 100 |
| A15BF | 85 | 15 | 100 |

**C. Blending of the powders**

By preparing composite samples various mixing of the particle sizes of aluminium alloy (2024) matrix at 50µm and boron fiber (coarse and fine) as a reinforcement at particle sizes are 125µm and 50µm respectively, and adding bonding material. The powders of Aluminum 2024 with Boron fiber coarse particles (BC) and Boron fiber Fine particles (BF) were blended in a ceramic mortar with pestle consistently.

**E. Compacting Process**

The particles of Aluminum 2024 and boron fiber coarse particles and boron fiber, fine particles were blended in a ceramic mortar with pestle uniformly.
Compacting process for a mixture of the matrix and reinforcement powders about quantity of 15gm, the 15grms powder of matrix and reinforcement the mix was compacted in die on a universal testing machine (UTM) at a pressure of 256 maps to get the samples of size of the diameter is 25 mm.

And after that, the blended powders were slowly compacted at 256 maps in die set to get together as shown in Fig. 2. Inner side dies wall and the outside of punch wall contact with the pass on were engine oil or greased up with powder to keep the green compacts from grip to pass on die wall and don't pulverize during get out the pass on. The green compacts sample was weighed by exact dimensions equalization to calculate density of the samples. The reason for the compacting powder is to combine the powder into the ideal shape and as close as conceivable to conclusive measurements;

it is intended to confer the ideal level and kind of porosity and to give sufficient strength to hardening. Compacting was done in UTM (Universal Testing Machine) as appeared in Figure 2. The different compacting load of 36KN, 50KN and finally 125 KN was utilized for compaction.


**Fig. 2: Universal Testing Machine utilized for compacting process**

### F. Sintering Process

Samples were sintered at a raised temperature of 440°C in Electric heater (muffle furnace) as appeared in Fig.3 for 7 hours and the samples were permitted to cool in the heater itself for 15 hours. Sintering procedure was done at 460°C - 480°C for 7 hours in an electric heater with idle environment (argon), sintering temperature increments at various levels of expanding, The particles reinforcements to get the composites with increasing strength. The sintering density must be calculated by partitioning the weight of the samples to the volume. Conventional sintering has likewise been finished utilizing a tube furnace at a temperature of 460°C-480°C for 360mins in argon gas environment to avoid oxidation.

**Fig. 3: Muffle Furnace used for sintering process** **Fig.4. Sintered samples**

### F. Microstructure examination

Microstructure examine of the composite samples were done by using scanning electron microscope used. Before examine the microstructure of the samples, the sample first machining process is over after that different graded of the emery papers is 250,500and 1000 μm in particle size and following the samples were polished by disc polishing machine used. After that alumina paste applied to the surface of the samples and to get surface like a mirror. The final stage the composite samples is etching them, after 10sec washing with water and clean surface by using dry cotton. This process is done before examine the microstructure of the composite samples.

### G.Density test

After sintering processes is completed on the samples the density test was conducted. Estimation of density means that there is porosity in the sample, the porosity of the samples when sintering was determined by using Archimedes principles. The calculation of the theoretical densities of MMC by using following formulas

Density of AL = 2.78 g/cc;

Density of boron fiber = 2.34 g/cc

Theoretical Density, (2.78×0.95) + (2.34×0.05) = 2.758g/cc

Density = The ratio of mass in to volume (mass/volume)

% Densification =

(Density of the sample/Theoretical density) ×100

A5BC (Al- 5% Boron fiber coarse particles) at 12.5ton load before sintering

Height of the sample = 12.7mm

Mass of the sample = 14.542 gram

Diameter of the sample = 25mm

Volume of the sample = (3.14×D2×h)/4

= (3.14x25x25x12.7)/4 = 6.234cc

Green Density of the sample = 14.542(g)/1.79(cc)

= **2.33g/ cc**

### H.Hardness test

Hardness test will be conducted for the specimen after completing the sintering process by using the Rockwell hardness test machine (ASTME18-07). The MMC samples were tested by using a B - scale of Rockwell hardness machine with 1/16 inch diameter (1.58mm) of the steel ball as an indent of 100kgf (initial load 10kgf and major load of 90kgf) were utilized for all the samples. For every sample taken three values and then calculate the average of the three readings.

## IV. RESULTS AND DISCUSSION

### A. Microstructure

The analyzing the sintered MMC was by using optical microscopy. Boron fiber particles (coarse and fine) were agglomerated in little volume divisions of them, while expanding the volume portions of Boron fiber particles (coarse and fine) lead to make the particles to circulate homogeneously in aluminum alloy matrix and strong bonding was made between the particles reinforcement material and matrix as appeared in Fig.5 (a) and Fig.5 (b). It is perhaps at attributed to that the porosity acts as internal stresses at the interfaces between the BC, BF particles and aluminum matrix.

The typical microstructures of the aluminium alloy (2024)/Boron fiber coarse particles composites and aluminium alloy (2024)/Boron fine particles are presented in Fig. 5. In the microstructures, dark color represents the Boron (coarse and fine) particle and light color represents the aluminium alloy (2024) matrix. The boron coarse particles are randomly dispersed in the Al 2024 matrix for as can be shown in Fig.5 (a). Additionally, it is likewise seen that agglomeration of Boron coarse particles inside aluminum composite (2024) matrix can't be stayed away from totally, Examination of boron fiber coarse (fig.5 a-c) and boron fiber fine (fig.5 d-f) particles are appeared in fig.5.

The number of Boron coarse particles bunch expanded with expanding Boron coarse particles Content from 5%, 10% and 15% as saw from Fig.5 (a), 5(b) and 5(c). It very well may be seen that porosity of fig 5(a) sample is higher than that of fig 5(c) sample. By examination, evident groups expanded in the fig 5(a) sample, which shows that expanding boron coarse particles substance could build the porosity content. Additionally, there are no naturally visible interfaces in the boron fine particles. Therefore, SEM perceptions of the microstructures uncovered that the scattering of the coarse sizes was progressively uniform while the finer particles prompted agglomeration and segregation of the particles, and porosity.

The purpose behind the particle segregation is proposed as pursues: the Al dendrites harden first during solidification of the composite, and the particles are dismissed by the solid and liquid interface, and subsequently are segregated to the inter dendritic locale. This occasion happened all the more effectively with the better particles [30].

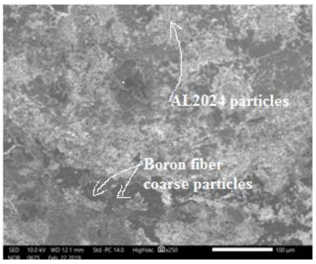


**Fig.5 (a): scanning electron microscopy (SEM) of 5 wt. % boron fiber coarse Particles- reinforced Composite with 125um particle size, this shows particle Segregation, black regions are reinforced particles.**

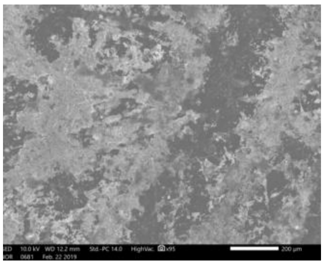

**Fig.5 (b): scanning electron microscopy (SEM) of 10 wt. % boron fiber coarse particles-reinforced Composite with 125um particle size.**

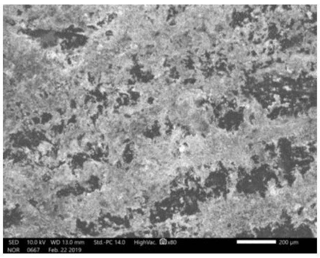

**Fig.5(c): scanning electron microscopy (SEM) of 15 wt. % boron fiber coarse Particles- reinforced Composite with 125um particle size.**

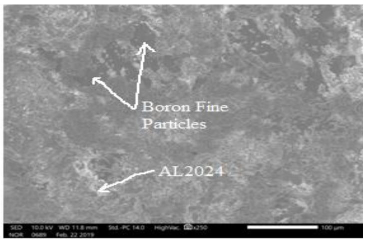


**Fig.5(d):scanning electron microscopy (SEM) of 5 wt. % boron fiber fine Particles-reinforced Composite with 50um particle size, this Shows particle Segregation, black regions are reinforced particles.**

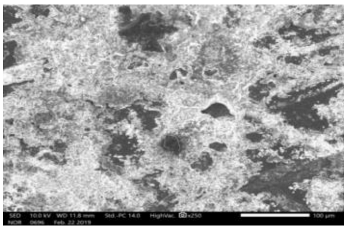

**Fig.5 (e): scanning electron microscopy (SEM) of 10 wt. % boron fiber fine Particles-reinforced Composite with 50um particle size.**

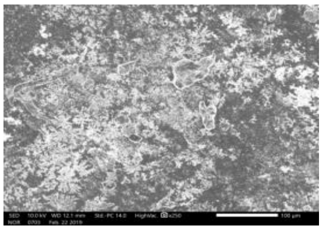

**Fig.5 (f): scanning electron microscopy (SEM) of 15 wt. % boron fiber fine Particles-reinforced Composite with 50um particle size.**

**B. Energy Dispersive x-ray (EDX)**

Energy-dispersive X-ray spectroscopy (EDX or EDS) is an analytical technique utilized for the elemental analysis or chemical characterization of a sample. It is one of the variations of X-beam fluorescence spectroscopy which depends on the examination of a sample through collaborations between electromagnetic radiation and matter, breaking down X-ray beams discharged by the issue accordingly by hitting the charged particles. EDX maps are obtained from Boron fiber fine and coarse particles samples as shown in Fig.6 (a), 6(b), 6(c), 6(d), 6(e) and 6(f). Boron fine particles regions can be lead as shown at the AL2024 grain boundary from EDX maps samples. This can be described with the impact of different squeezing during the densification procedure. Contingent upon the number of layers, the number of squeezing additionally increments with expanding the number of layers. This can be credited to the expansion in the numbers of agglomeration areas produced by hard boron particles

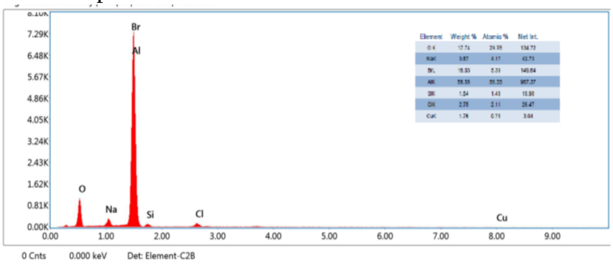


**Fig. 6 (a): EDX Analysis of 5% Boron fiber Fine Particles with AL2024 Composite**

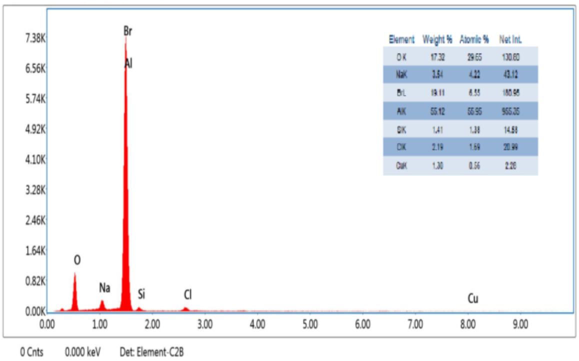


**Fig. 6 (b): EDX Analysis of 10% Boron fiber Fine Particles with AL2024 Composite**

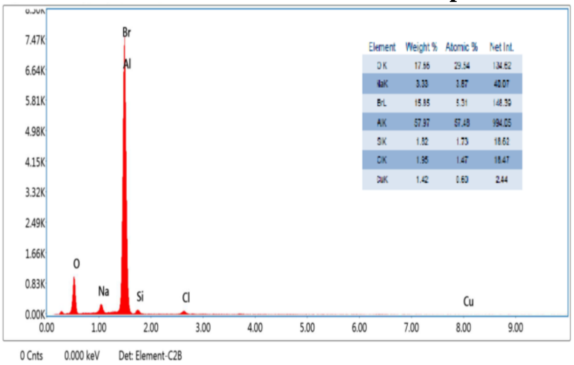


**Fig. 6 (c): EDX Analysis of 15% Boron fiber Fine Particles with AL2024 Composite**

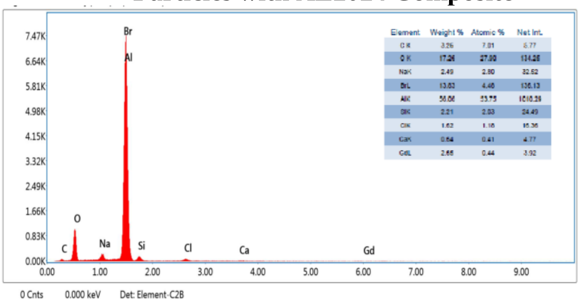


**Fig. 6 (d): EDX Analysis of 5% Boron fiber coarse Particles with AL2024 Composite**

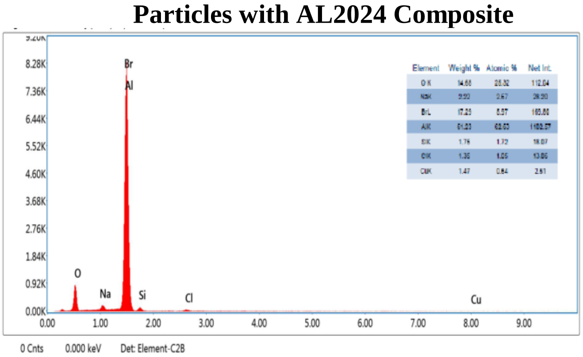


**Fig. 6 (e): EDX Analysis of 10% Boron fiber coarse Particles with AL2024 Composite**

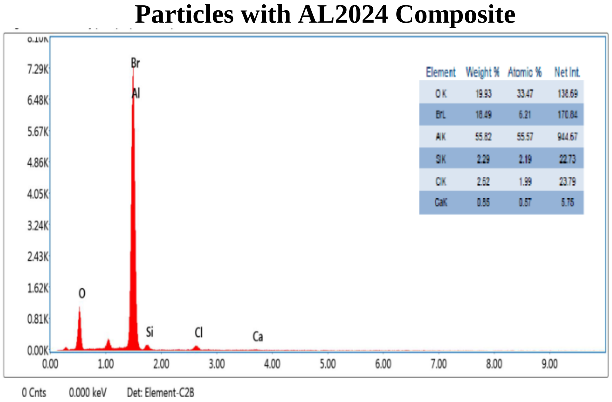


**Fig. 6 (f): EDX Analysis of 15% Boron fiber coarse Particles with AL2024 Composite**

## C. Hardness test

The mechanical properties of MMC materials depend on the volume fraction, i.e., the percentage of reinforcement of boron fiber (coarse and fine) particle content in the entire volume of a metal matrix composite. And also properties of reinforcement of boron fiber (coarse and fine) particle. Increasing the weight% of reinforcement of boron fiber (coarse and fine) particle, increasing hardness of the composite material. The hardness of composite material with boron fiber, fine particles higher than the hardness of composite material with boron fiber fine particles. Boron fiber. That is boron fiber; fine particles strong bonding with matrix material is higher than boron fiber coarse particles, and the manufactured composite material is increasing the hardness. Agreed with this results in that of [31]. Increasing the weight% of boron fiber (fine and coarse) particles to increase the hardness as shown in the Fig 7 (a). Also The volume % of reinforcement increase the increase hardness and reveals that better hardness of the sintered samples compared to a un sintered sample. After sintering good bonding of particles in there between the reinforcement and the matrix phase. Hardness tests were performed on a Rockwell Hardness machine and the results of the tests are shown in Fig.7 (a).

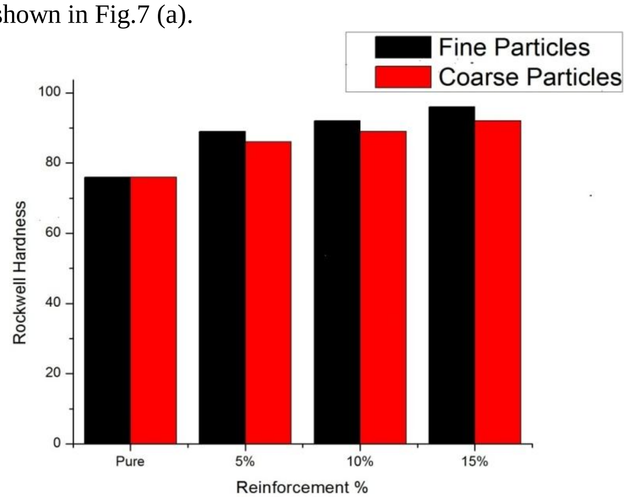


**Fig.7 (a): Bar graph of hardness values of AL2024/Boron fiber reinforcement (Fine and Coarse particles) metal matrix composites**

## D. Density

In this fig. 8 (a), 8 (b), and 8 (c) shows that the metal matrix composites of sintered density, theoretical density and green density values decrease linearly (as expected from the rule of mixtures). With increasing weight percentage of reinforced and size of particles.

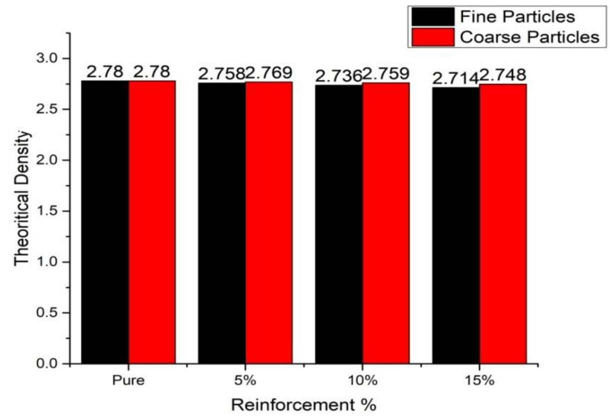


**Fig. 8 (a): Bar graph of theoretical density values of AL2024/Boron fiber reinforcement (Fine and Coarse particles) metal matrix composites**

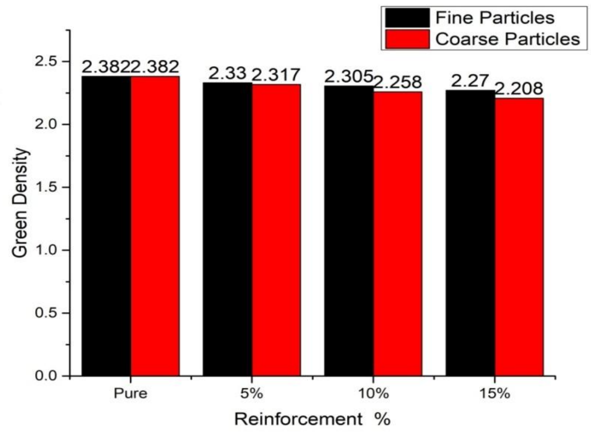


**Fig. 8(b): Bar graph of green density values of AL2024/Boron fiber reinforcement (Fine And Coarse particles) metal matrix composites**

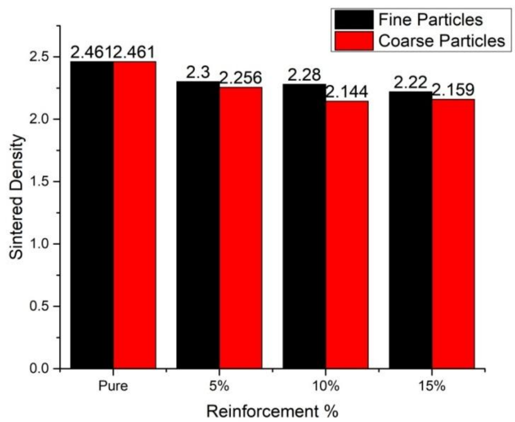


**Fig. 8(c): Bar graph of sintered density values of AL2024/Boron fiber reinforcement (Fine and Coarse particles) metal matrix composites**

**Table 4: Average Physical properties of composite**

| Sample | Particle size | Theoretical density | Green density | Sintered density |
|---|---|---|---|---|
| Pure Al | 50µm | 2.78 | 2.382 | 2.461 |
| Al-5wt.%Boron fiber particle | 50µm | 2.758 | 2.33 | 2.3 |
| Al-10wt.%Boron fiber fine particle | 50µm | 2.736 | 2.305 | 2.28 |
| Al-15wt.%Boron fiber fine particle | 50µm | 2.714 | 2.27 | 2.22 |

## V. X-RAY DIFFRACTION (XRD)

X- ray diffraction (XRD) beam is a non-destructive kind of systematic procedure which gives significant understanding about the lattice structure of a crystalline substance like unit cell measurements, bond points, synthetic creation and crystallographic structure of regular and produced materials. X-ray powder diffraction (XRD) is fast logical strategy principally utilized for stage distinguishing proof of the crystalline material and can give data on unit cell measurement and nuclear dividing. The X-ray beam are created by cathode ray tube, filtered to deliver monochromatic radiation, collimated to think, and coordinated towards the sample. The connection of the episode monochromatic beams with the example produces useful obstruction (and diffracted beam) when condition fulfill Bragg's Law $n\lambda = 2d \sin\theta$ This condition relates the wavelength ($\lambda$) of electro-attractive radiation to the diffraction edge ($\theta$) and the cross section separating (d) in a crystalline example by examining the example through course of action of $2\theta$ edges. All the conceivable diffraction bearings of the cross section are achieved because of the irregular direction of the powdered materials.Fig.9 investigation the X-ray diffraction (XRD) examples of the underlying powders particles. The diffuse pinnacle saw around 2-Theta = $45^0$ shows the undefined idea of the boron fiber (coarse and fine) particles, in concurrence with the DSC consequences of Fig.9. Furthermore, the XRD example of the Al-2024 combination powder indicates sharp Bragg tops which relate to the average FCC structure of AL.

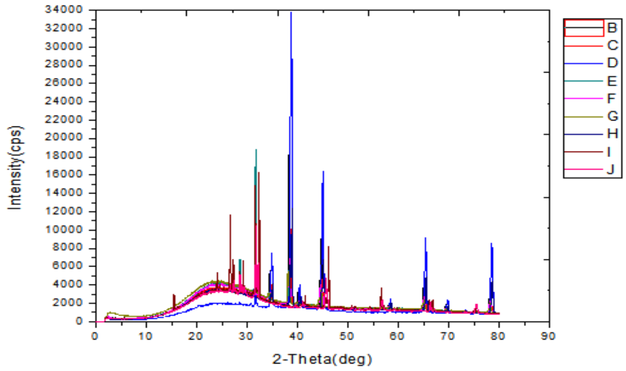


**Fig. 9: XRD Analysis of AL2024/Boron fiber reinforcement 5%, 10%and15% of (Fine and Coarse) particles metal matrix composites**

## VI. CONCLUSIONS

AL2024 composite MMCs fortified with various sizes and weight rates of - Boron fiber (Coarse and fine) particles have been effectively manufactured

1) The hardness of MMCs expanded with decreasing sizeAnd expanding weight Percentages of the particles.

2) The hardness of MMCs expanded to the fine and coarseParticles, the hardness increments with the amount ofBoron fiber particles present and decreasing particlesize.
3) The density of the composites decreased with expanding Weight percentage and size of particles, while the porosity of the composites expanded with decreasing size and expanding weight Percentage of particles.
4) Theoretical density, Green density and Sintered density is reduced to the coarse and fine particle of the Composites with increasing weight percentage.The Varying the particles size, the density is also varying
5) Observations of the microstructures demonstrated that The fine particles and coarse particle consistently dispersed MMCs; however, the fine particles were dispersed all the more consistently, while the coarse Particles prompted agglomeration and segregation of Particles and porosity. 6) The wettability and the bonding force between AL2024/Boron fiber (Coarse and fine) particles were improved by the applied pressure after the powder Metallurgy method and the porosity was additionally decreased because of this pressure.
7) The EDX results reveal the distribution of AL2024 and boron fiber phase in the composite. Boron fiber is identified as the predominant boron fiber phase in the AL2024 matrix. The same is confirmed by the results (Fig.6a).

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## AUTHORS PROFILE

**R. Ramanjaneyulu**' Research Scholar, Department of Mechanical Engineering, JNTUA, Ananthapuramu, Andhra Pradesh -515002, IndiaQualification: M.Tech Experience: Teaching: 10 Years and Research: 2 Years Publication's : International Journals is 06 and International Conferences is 01 Research work: Composite materials

**Dr. K.Raja Gopal[2],** Professors, Department of Mechanical Engineerin KSRMCE (Autonomous), Kadapa, Andhra Pradesh-516003,India.Qualification: B.Tech, M.Tech, Ph.D Experience: Teaching: 30 Years and Research: 04 Years Publication's : International Journals is 10, national Journals is 30 and Conferences is 10 Research work: Operation Research Membership : Fellow in institutional of engine Achievements : Best paper awards in 1997 and 1998

**Dr. B.Durga Prasad[3],** Professors, Department of Mechanical Engineering, JNTUA Ananthapuramu, Andhra Pradesh -515002, India.Qualification: M.Tech, Ph.D Experience: Teaching: 25 Years and Research: 16 YearsPublication's : International Journals is 70 and International Conferences is 30 Research work: Internal Combustion Engines, Thermal Engineering.