

Experimental Investigation of Aluminium Reinforced With Boron Carbide a Metal Matrix Composite and Analysis on Piston

P.Kalai selvi, KVVNN Roa, G.Suresh

M.Tech, Department Of Mechanical Engineering

E-Mail Id: Kalaiselvict111@gmail.com

Abstract

The present work deals with the preparation and mechanical investigation of aluminium alloy boron carbide metal matrix composite. In this work for preparing the MMC aluminium alloy (LM-25) is used as base material having noticeable properties like light weight, good machining properties and ability to resist corrosion. Boron carbide is used as reinforcement as it is one of the most effective ceramic materials due to its promising properties like high strength, low density, extremely high hardness, fracture toughness and good chemical stability. The preparation of the composite is done by stir casting process which involves mixing the required quantities of additives in to stirred molten aluminium. After solidification the samples were prepared and tested for density, hardness modulus of elasticity and tensile strength for various combinations and compared with the base aluminium alloy. It was observed that hardness and tensile strength were significantly improved while the density decreases with increase in boron carbide.

Keywords: Aluminium, boron carbide, MMCs, Stir casting, corrosion, reinforcement, aluminium alloy (LM-25).

1. Introduction

Nowadays, Metal Matrix Composites (MMCs) are under serious consideration to replace conventional materials for a large number of structural applications such as those in the aeronautical/aerospace, transportation, defense, automobiles and sports industries because of their superior properties. The excellent mechanical properties and the comparatively low cost make them as an attractive option. Metal Matrix Composites (MMCs) are suitable for applications requiring combined strength, thermal conductivity, damping properties and low coefficient of thermal expansion with lower density. These properties of MMCs enhance their usage in many applications. In the field of automobile, MMCs are used for pistons, brake drum and cylinder block because of better corrosion resistance and wear resistance. A large number of fabrication techniques are currently used to manufacture the Metal matrix composites based on the type of reinforcement used like a. stir casting b. Electroplating and electroforming c. Squeeze casting d. spray deposition e. Reactive processing. Stir casting process involves the agitation of particulate reinforcement and semisolid metal (SSM). High homogeneity is required to attain optimum mechanical properties for the composite material. Therefore, the important parameters controlling the process must be identified and corrected in order to achieve a good quality composite. There is a growing interest worldwide in manufacturing hybrid metal matrix composites [HMMCs] which possesses combined properties of its reinforcements and exhibit improved physical, mechanical and tribological properties introduction there is a growing interest worldwide in manufacturing hybrid metal matrix composites [HMMCs] which possesses combined properties of its reinforcements and exhibit improved physical, mechanical and tribological properties.

Zong et al. found the increase in shear strength necessary to move a dislocation was less than 1 MPa¹¹. This small increase does not represent a significant increase in the yield strength. In order for the dispersion effects to produce a

noticeable effect on the strength properties, particles in the MMCs need to be two orders of magnitude smaller than the 10 Hm particles that are being added to the Al melt. So, Orowan bypassing is not a strengthening mechanism here. Work has been done by Zhao to create a correlation between the macrohardness and yield strength for particle reinforced MMCs. According to his research, the macro hardness values (HRB) have a linear correlation with yield strength. Once a representative sample of tensile tests has been run, a best-fit line can be made relating hardness and tensile strength. Future testing could use the macrohardness value to calculate the tensile strength properties. This would be much faster and more cost effective than a tensile test and could be done with minimal training.

The controlling factor for creating a composite with desirable properties is the wettability of the particles. This can be improved by using alloying elements, like magnesium, to interrupt the formation of a surface oxide layer.⁷ With low wettability, the particles clump together and do not form a homogeneous microstructure. In addition to the dispersion of the particles, high wettability ensures that the stresses can be transferred from the soft aluminum matrix to the strong B₄C particles. G.G. Sozhamannan, S. Balasivanandha Prabu and V. S. K. Venkatagalapathy 2012 (10) observed that production of Aluminium composite reinforced with discontinuous ceramic particulates by Stir casting route will have homogeneous mix and is cost effective process. The major problem in this technology is to obtain sufficient wetting of particle by the liquid metal and to get a homogeneous dispersion of the ceramic particles.

B.MALLICK, P.C. MAITY and V.K. SINHA 1998 (16) explained that addition of magnesium to the liquid aluminium will reduce the surface tension of the melt facilitating the depression of ceramic particles in to the melt and also increases the wetting properties of metal-ceramic systems through reduction in solid-liquid interfacial energy.

2. Experimental Details

2.1. Materials

In this work for preparing metal–matrix composite, aluminium alloy (LM 25) is used as base material boron carbide in powder form are used as the reinforcements. It is sieved with 53µm and aluminium was taken in the form of ingots.

2.1.1. Aluminium ALLOY (LM 25)

The tensile properties of aluminium alloy (LM 25) at elevated temperatures are influenced by the condition (heat treatment) of the castings and the duration at the elevated temperatures. The heat treated alloy has fairly good machining properties. They are of high resistance to corrosive attack by sea water and marine atmospheres. The chemical composition was shown in table 2.1 among various aluminium alloys **LM25(Al –Si7Mg)** is one of the most popular aluminium alloy used for water-cooled cylinder heads, valve bodies, water jackets, cylinder blocks, fire hose couplings, air compressor pistons, fuel pump bodies, aircraft supercharger covers and similar applications where leak-proof castings having the high strength produced by heat-treatment are required.

Chemical Composition of LM25 ALLOY

According to BS 1490 LM25 the chemical composition and of LM25 alloy is as below:

Table 1 composition of LM- 25

Copper	0.1 max
Magnesium	0.2 - 0.6
Silicon	6.5 - 7.5
Iron	0.5 max
Manganese	0.3 max
Nickel	0.1 max
Zinc	0.1 max
Lead	0.1 max
Tin	0.05 max
Titanium	0.2 max
Aluminium	Remainder

Mechanical Properties of LM25 Alloy

According to BS 1490; 1988 the mechanical properties of LM25 alloy is as below:

Table 2 mechanical properties of LM-25

Mechanical Properties	Values
Tensile Stress (N/mm ²)	130-150
Hardness (BHN)	55-65
Modulus of Elasticity (x10 ³ N/mm ²)	71
Elongation (%)	2

2.2.2 BORON CARBIDE

Boron carbide (**B₄C**) is the third hardest material in the world behind cubic Boron nitride and diamond. And it is extremely hard Boron–carbon ceramic material used in tank armour, bulletproof vests, and engine sabotage powders. B₄C is an extremely hard Boron–carbon ceramic material used in tank armour, bulletproof vests, engine sabotage powders, as well as numerous industrial applications. With a Mohs hardness of about 9.497, it is one of the hardest materials known, behind cubic Boron nitride and diamond. Boron carbide was discovered in 19th century as a by-product of reactions involving metal borides, however, its chemical formula was unknown. It was not until the 1930s that the chemical composition was estimated as B₄C. There remained, however. These features argued against a very simple exact B₄C empirical formula. Because of the B₁₂ structural unit, the chemical formula of "ideal" Boron carbide is often written not as B₄C, but as B₁₂C₃, and the carbon deficiency of Boron carbide described in terms of a combination of the B₁₂C₃ and B₁₂CBC units. The ability of Boron carbide to absorb neutrons without forming long lived radio nuclides makes it attractive as an absorbent for neutron radiation arising in nuclear power plants. Nuclear applications of Boron carbide include shielding, control rod and shut down pellets. Within control rods, Boron carbide is often powdered, to increase its surface area. The properties of Boron carbide are as follows.

Table 3 properties of boron carbide are as follows.

Molecular formula	B ₄ C
Molar mass	2.52 g/cm ³ , solid.
Melting point	2,763 °C (5,005 °F; 3,036 K)
Boiling point	3,500 °C (6,330 °F; 3,770 K)
Acidity (pKa)	6–7 (20 °C)

Appearance	Dark gray or black Powder odorless
Solubility in water	Insoluble

3. Experimentation

3.1 Construction of Stir Casting Furnace

For the present work it requires a stir casting furnace with 4 blade stainless steel stirrer. Since stir casting is not a conventional casting method, a suitable furnace has to be designed. Even though some stir casting furnaces are readily available in the market, a custom made conventional stir casting furnace is much cheaper and is best suited for the present work to vary process parameters according to the requirements. A conventional stir casting furnace consists of the following basic components.

- Furnace
- Crucible
- Stirring Equipment

3.2.1 Preparation of Pit Furnace

A pit furnace is prepared by using a cylindrical oil drum. The inner wall of furnace is lined with refractory bricks to prevent heat losses and is sealed with soft red mud which is separated from stones and lumps. Total furnace was made of two chambers, upper chamber is to incorporate coal and crucible and the lower chamber is to blow pressurised air to upper chamber for achieving higher temperatures and to collect ashes formed due to burning of coal.

3.2.2 Preparation of Stirrer

A 1200 rpm high torque reversible motor is taken and connected with a potentiometer for varying speeds as per the requirement. The motor shaft is coupled to a stainless steel rod and the other end is connected to a stainless steel four-blade impeller and is tested by stirring water in the crucible and bent to the desired angle for producing vortex.



Figure 1: Stirrer arrangement

3.3.3 Consumables and Miscellaneous Materials

An eight litre silicon carbide crucible is bought for this purpose and is preheated to red hot condition to relieve from internal stress. A stand is prepared for mounting of stirrer assembly above the furnace. To avoid vibrations in the stirrer, motor is mounted on springs which damp the vibrations. A ceiling fan hub is used to prevent motor from exposing to

direct heat from the furnace. The stand is made as such that some small adjustments can be made to centre the stirrer to the crucible. A centrifugal blower is used to blow the air into the furnace.

3.3.4 Assembly

Furnace cavity is half filled with lumps of bituminous coal and then crucible is mounted on the coal in concentric with the furnace cavity. The space between the crucible and the furnace is then filled with small pieces of coal. A pipe is connected at the lower chamber and the chamber was sealed with mud and the other end of pipe is connected to the blower. Stirrer rod is connected to the motor and the motor assembly is fixed to the stand. Stand is adjusted such that the stirrer is located at the centre of crucible and the blade is 4 cm above from the bottom of the crucible.



Figure 2: Stir Casting

4. Testing

The following tests are conducted on the aluminium composites to know their mechanical properties. For convenience of presentation and plotting, from here onwards pure LM-25 alloy samples were referred as Group 0, LM25 with 5% B4C samples were referred as Group 1, LM-25 with 7.5% B4C samples were referred as Group 2 .

4.1 Density

Of each sample was measured based on Archimedes principle in a calibrated glass jar. In Figure 3, we can notice that the density of Group 0 is more compared to the other groups because the density of Boron carbide is less compared to aluminium. Further, the density of aluminium is decreased because of the increase of B4C composition in the composite.

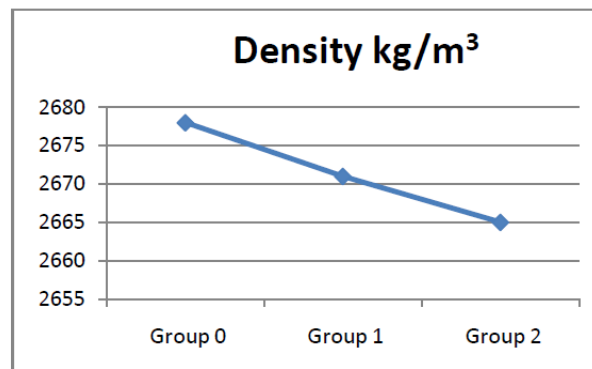


Figure 3: Comparison of density

4.2 Hardness

Since the B4C is superior to aluminium and B4C, in general we can expect the dominance of B4C in increase of hardness of the composite. The practical observations revealed that the hardness of the composite increased considerably. It was noticed that the increase of hardness from Group 0 to Group 1 is from 98 BHN to 107 BHN has a difference of 9 BHN, the increase from Group 1 to Group 2 is from 107 BHN to 113 BHN has a difference of only 6 BHN (see Figure 4). This can be considered that the incorporation of B4C in the aluminium gives hardness to the composite but the further increase of B4C has given a little increase in hardness due to the domination of aluminium alloy over the composite since the composition of B4C is only 7.5% of weight. Further addition of B4C may give a considerable increase in hardness at some point but may affect interfacial strength and uniform distribution of reinforcement and also the other mechanical properties like density, tensile strength.

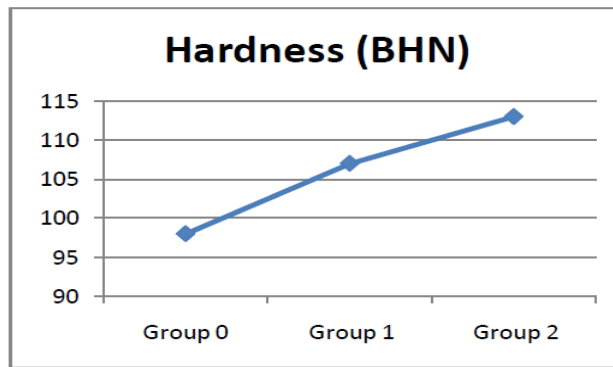


Figure 4 comparison of hardness

4.3 Tensile Strength

As it was the maximum stress that a material can withstand while being stretched, interfacial bonds may affect greatly on the tensile strength of the composite. In Figure 5, we can see that the tensile strength was increased in the composites and have comparable variation. Weak interfacial bonds may result in decrease in tensile strength of the composite, but here the increase of tensile strength shows that there was good interfacial strength. Since the reinforcements were preheated before mixing with aluminium there might be uniform distribution and smooth interface while mixing. From this result we can expect good interfacial strength when we heat the reinforcements at higher temperatures which will facilitate uniform distribution of more amount of composite without losing the strength.

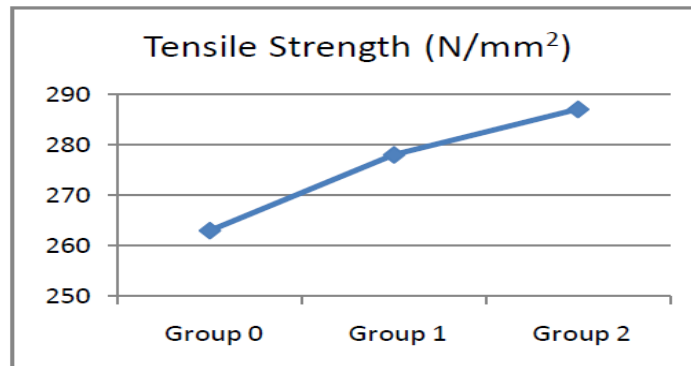


Figure 5: Comparison of Tensile Strength

4.4 Modulus of Elasticity

Modulus of elasticity shows linear relation with tensile strength as same as conventional materials. In Figure 6 we can observe that the modulus of elasticity was increased but not greatly as same as tensile strength. The elongation of material is similar to the base alloy, almost negligible amount of elongation for all the groups. Since all the samples are fully heat treated, the samples will gain brittleness and hardness losing ductility which might be resulted in tendency of brittle failure.

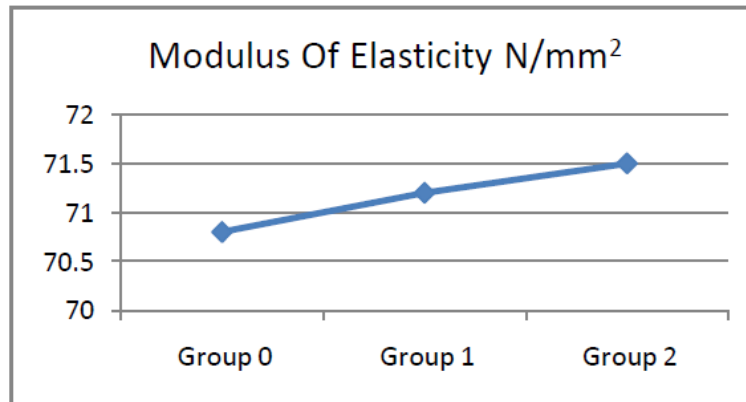


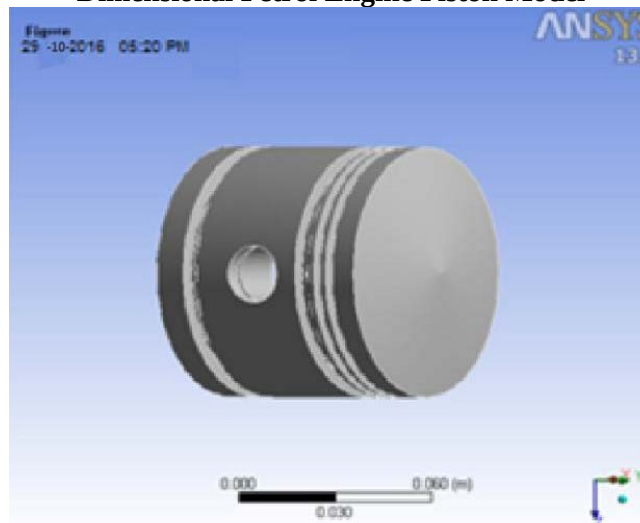
Figure 6: Comparison of Modulus of Elasticity

Even though no particular wear tests were performed on the samples, while removing the risers on a band saw cutting machine Some resistance was observed on both the composite samples.

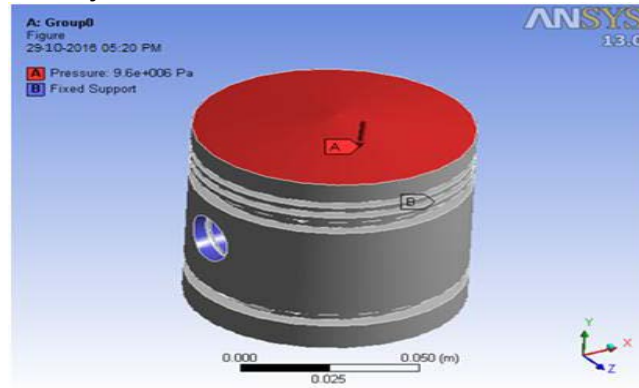
5. Analysis of Composites using ANSYS 13.0

A pre modelled petrol engine piston is taken and is imported to ANSYS WORKBENCH. The model is meshed using a tetrahedral element and is subjected to boundary conditions i.e. forces, contacts, supports etc. The obtained results are imported to the material library and are applied to the model for obtaining the results. Since the design of the piston is not changed, for the given gas pressure the stress developed in the piston will be same for all the compositions, only strain and deformation will change as per the material.

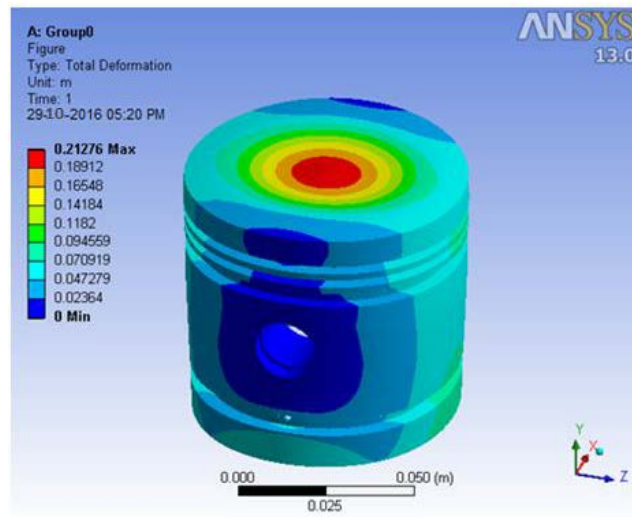
Dimensional Petrol Engine Piston Model



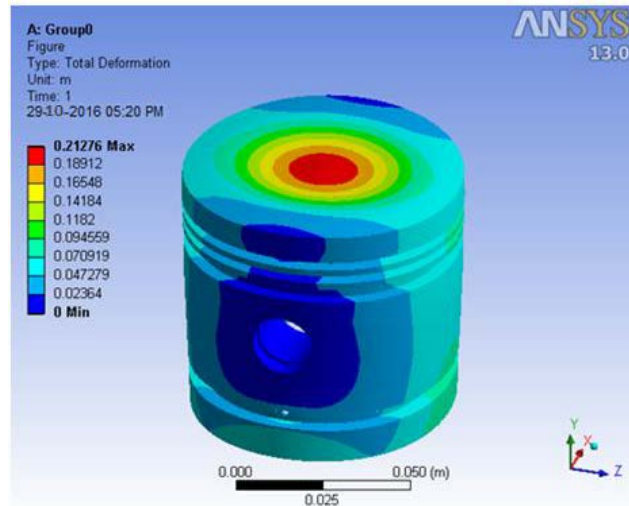
Boundary Conditions and Constraints Defined to Model



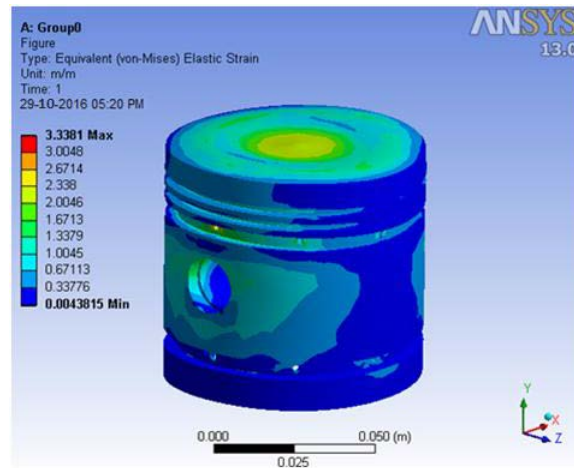
Piston Model after Mesh Generation



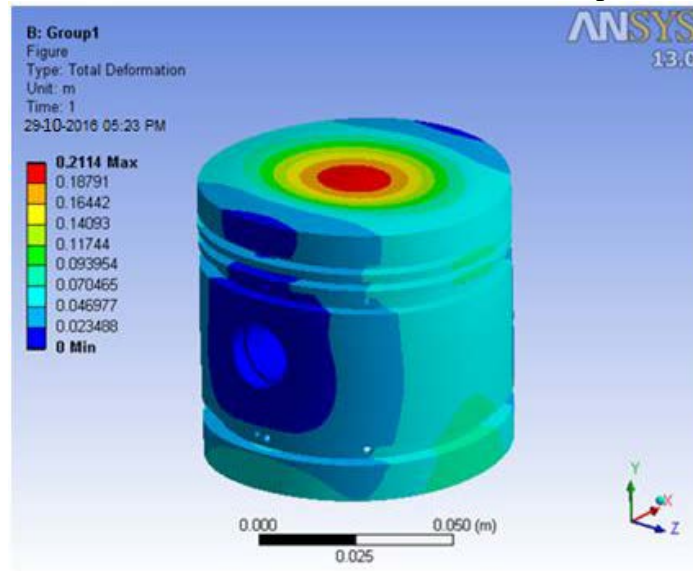
Variation of Total Deformation for Group 0 (Pure Alloy)



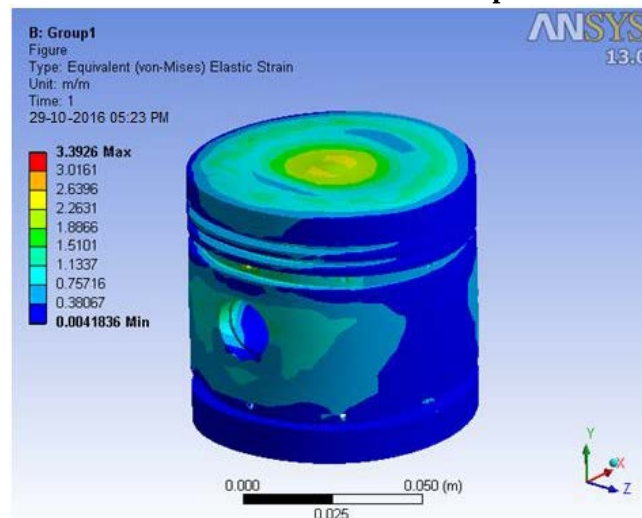
Variation of Strain for Group 0 (Pure Alloy)



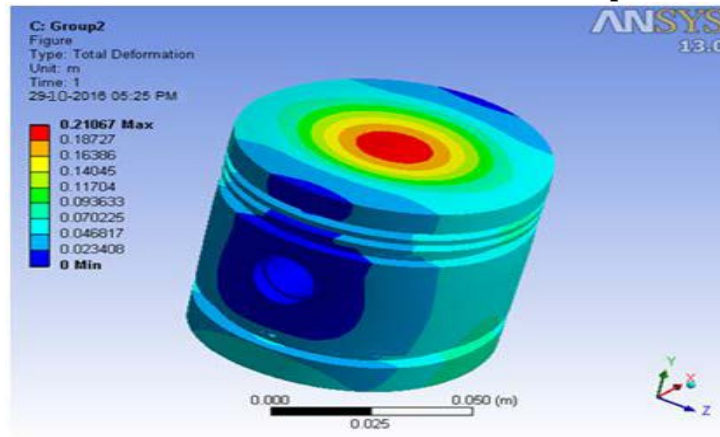
Variation of Total Deformation for Group 1



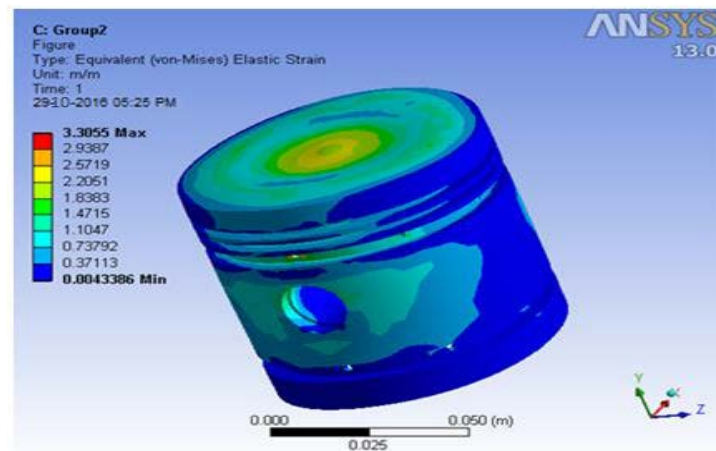
Variation of Strain for Group 1



Variation of Total Deformation for Group 2



Variation of Strain for Group 2



6. Comparison of Total Deformation

It can be clearly observed in Figure 6 that for the given gas pressure the maximum total deformation of the piston model gets decreasing with increase of B4C in the composite. But the decrease of total deformation is not varying linearly. The slope of the curve from Group 0 to Group 1 is steeper than the curve from Group 1 to Group 2.

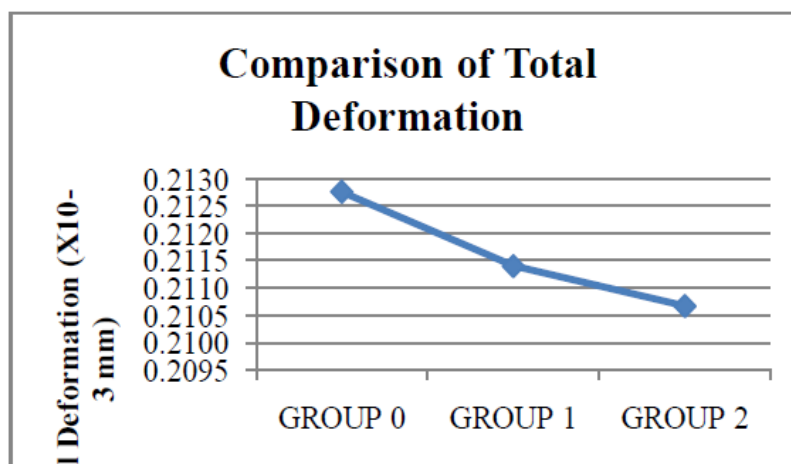
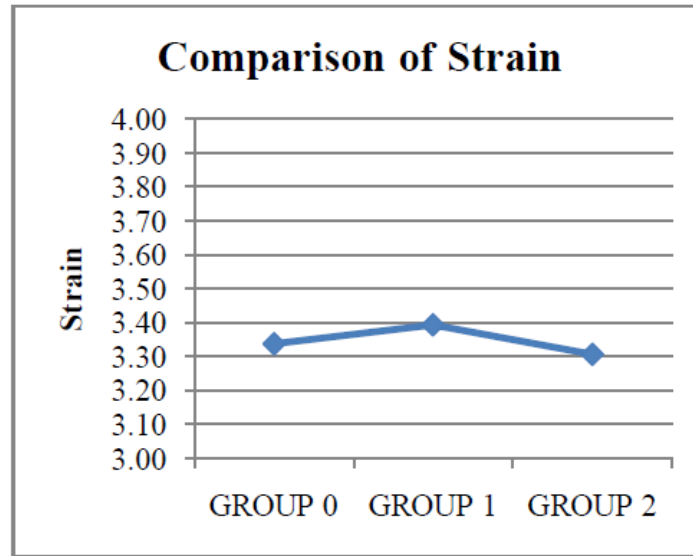


Figure 6 Comparison of Total Deformation

Comparison of Strain

As the deformation is proportional to the strain, the maximum strain developed in the model seems similar to the comparison of total deformation.



7. Conclusion

From the experimental and analysis of present work the following conclusions are drawn.

1. Addition of Boron carbide will definitely increase the mechanical properties of the composite.
2. By comparing with amount of Boron carbide in the composite LM-25 with 5% or 7.5% is most suitable for regular casting process.
3. Hardness of the composite increases with increase of Boron carbide. There might be a chance of decrease of hardness in the composite after some critical value.
4. It was noticed that the density of the composite reduced in the composites due to less density of Boron carbide.
5. With some changes in process parameter like increase in preheating temperature and usage of modifiers like strontium there might be a possibility to develop a composite having the same density of aluminium with more than 50% increase in hardness and considerable gains in tensile strength and modulus of elasticity.

8. References

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