Comparison the Physical and Mechanical Properties of Composite Materials (Al /SiC and Al/ B_4C) Produced by Powder Technology

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ABSTRACT

In this investigation, metal matrix composites (MMC_s) were manufactured by using powder technology. Aluminum 6061 is reinforced with two different ceramics particles (SiC and B_4C) with different volume fractions as (3, 6, 9 and 12 wt. %). The most important applications of particulate reinforcement of aluminum matrix are: Pistons, Connecting rods etc. The specimens were prepared by using aluminum powder with 150 µm in particle size and SiC, B_4C powder with 200 µm in particle size. The chosen powders were mixed by using planetary mixing setup at 250 rpm for 4hr.with zinc stearate as an activator material in steel ball milling. After mixing process the powders were compacted by hydraulic unidirectional press type (Leybold Harris No. 36110) at 250 Kg/cm^2 according to (ASTM-D 618). Finally the green compacts were sintered at 500 ℃ for 3 hr. by using electrical furnace with argon atmosphere. There are many examinations and tests were done for the produced metal matrix composites (MMC_S), (Al/ SiC and Al/B_4C) such as examination of the microstructure, mechanical tests (hardness and compressive strength), physical tests (density test before and after sintering, also porosity test). The results of this investigation showed that improving the physical properties (theoretical density, experimental density, porosity) and mechanical properties (Rockwell hardness and compressive strength).

Keyword: Composite materials, Powder technology, Physical Properties, Mechanical Properties.

مقارنة الخواص الفيزياوية والميكانيكية لمواد مركبة (المنيوم/ كاربيد السليكون، المنيوم/ كاربيد البورون) منتجة بطريقة تكنولوجيا المساحيق

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الخلاصة

في هذا البحث تم تصنيع مادة مركبة بطريقة تكنولوجيا المساحيق. تمت تقوية الألمنيوم 6061 بنوعين مختلفين من الدقائق السيراميكية (كاربيد السليكون ، كاربيد البورون) بنسب حجمية مختلفة 3، 6، 9، و12 % . من أهم تطبيقات التقوية بالدقائق لأرضية من الألمنيوم هي: المكابس، أذرع التوصيل . . الخ. تم تحضير العينات بأستخدام مسحوق الألمنيوم بحجم حبيبي 150 مايكرون ومساحيق كاربيد السليكون و كاربيد البورون بحجم حبيبي 200 مايكرون. تم خلط

المساحيق المستخدمة باستخدام خلاط كوكبي بسرعة 250 دورة / دقيقة لمدة 4 ساعات مع مادة سترات الزنك كمادة منشطة مع كرات طحن من الفولاذ. بعد عملية الخلط تم تدميج المساحيق بمكبس هيدروليكي أحادي الأتجاه نوع (Leybold Harris No. 36110) بمقدار 250 كغم/ سم^2 بموجب المواصفة (ASTM-D 618). أخيرآ تم تلبيد المدمجات الخضراء عند درجة حرارة 500م^o لمدة 3 ساعات بأستخدام فرن كهربائي في جو من الآركون. أجريت العديد من الأختبارات والفحوصات للمواد المركبة المنتجة (ألمنيوم / كاربيد السليكون ، ألمنيوم/ كاربيد البورون) مثل فحص البنية المجهرية ، أختبارات الصلادة ومقاومة الضغط، أختبارات الكثافة قبل وبعد التلبيد، كذلك أجري أختبار المسامية. أظهرت نتائج هذا البحث تحسن واضح في الخواص الفيزياوية (الكثافة النظرية ، الكثافة التجريبية، المسامية) والخواص الميكانيكية (صلادة روكويل، مقاومة الأنضغاط).

الكلمات الرئيسية: مواد مركبة، تكنولوجيا المساحيق، خواص فيزيائية، خواص ميكانيكية.

1. INTRODUCTION

In recent years an important researches were done to enhance the mechanical properties of aluminum alloys by reinforcing them with ceramics particles such as SiC, B_4C, TiC and Al_2O_3, **Zhenga, et al., 2014**. Since the aluminum and its alloys have an attention as an important metal to obtain metal matrix composites (MMC_S) and more applications in technology. To combine the light weight, corrosion resistance with mechanical properties such as the strength, hardness and impact resistance leads to make the aluminum and its alloys important matrix materials, **Muthukrishnan, et al., 2008, Khairaldien**, **et al., 2008**, **and Ahmed, et al., 2009**. There are many reinforcement materials used for aluminum matrix because of their strength are related with their particle size, the microstructure and how they are distributed in the matrix which in turn improving the mechanical and physical properties of the producing aluminum matrix composites, **Attar**, **et al., 2015**. Powder metallurgy is an important technique using to obtain metal matrix composites with high homogeneity more than for other methods, **Nazik, et al., 2016**. There are many researches were published in this field like, **Ekiki, et al., 2010**. Investigated the effect of SiC and B_4C on the characteristics of the surface for the composites material. This study concluded that there are many factors affected on the produced composites materials such as particle size, volume fraction of the additive reinforced material. While **Nagard, et al., 2013**, studied the effect of the addition of Al_2O_3 on the mechanical and wear behavior of the composites materials of 6061 Al alloy metal matrix composites. The results of this work showed that the wear resistance of B_4C is lower than that of SiC particulate reinforcement of metal matrix composites (MMC_S). The aim of this work is to study the physical and mechanical properties of metal matrix composites reinforced by two different of particulate reinforced materials SiC and B_4C for the matrix Al – 6061 alloy.

2. EXPERIMENTAL PROCEDURE

In this work, the composite materials Al/SiC and Al/ B_4C are manufactured by using powder technology as the following stages:

2.1 Preparing the Powders

The aluminum 6061 powder at 150 µm was in particle size, while the particulate reinforcement SiC and B_4C at 200µm in particle size. Table 1 shows the characteristics of the powders used in this investigation.

2.2 Mixing the Powders

Two different composite materials were prepared by mixing the aluminum 6061 powders as a matrix at 150µm in the particle size with SiC and B_4C as a reinforcement material at 200µm in the particle size and adding zinc stearate as activator. Mixing process was carried out by using planetary mixture as shown in **Fig.1** with steel ball mill in 10 mm diameter at 250 rpm for 3 hr.

2.3 Compacting Process

Compacting process for a mixture of the powders about 30gm in uniaxial hydraulic press type (Leybold Harris No.36110), and then the mixed powders were pressed at 250 Kg/ cm^2 in punch – die set assembly as shown in **Fig.2**. Inside die wall and the surface of punch touch with the die were lubricated with graphite powder to prevent the green compacts from adhesion with die wall and don't crush during get out the die. The green compacts were weighing by accuracy balance to calculate the density of them.

2.4 Sintering Process

Sintering process was done at 500℃ for 3 hr. in electrical furnace with inert atmosphere (argon), sintering temperature increases with increasing the percentage of particulate reinforcements to obtain the composites with high strength. After sintering, it must be to calculate the density by divided the weight of the specimen to the volume.

2.5 Examinations and Tests

2.5.1 Microstructure examination

Microstructure examination of the Al/ Si and Al/ B_4C composites were done by using optical microscopy, before the examination of the microstructure, the specimens were cutting and machined by lathe, and then grinded by grinding device with emery paper (500 and 1000) µm in particle size. Following the grinding, the specimens were polished by polishing device using diamond paste at size 0.7 µm for 30 min to obtain surfaces like mirror. Final stage for preparing the composite specimens is etching them with 1% Keller reagent for 30 sec and then washing with water before the examination for the microstructure.

2.5.2 Density test

Density test was carried out for the specimen before and after sintering. The differences in values of density mean that there is porosity in the specimens. Porosity of the specimens before and after sintering was calculated by using Archimedes formula.

The theoretical densities of metal matrix composites are measured by using the following equation, **Venkatesh, and Harish, 2015.**

For Al/SiC $$\rho_c = \frac{1}{\frac{W_{Al}}{\rho_{Al}}+\frac{W_{SiC}}{\rho_{SiC}}} \qquad (1)$$

For Al/B_4C $$\rho_c = \frac{1}{\frac{W_{Al}}{\rho_{Al}}+\frac{W_{B4C}}{\rho_{B4C}}} \qquad (2)$$

While the actual density after the sintering was calculated by using the following equation, **Jain, et al., 2016.**

$$\rho_s = \frac{m_{a} \times \rho_w}{m_{a-} m_w} \qquad (3)$$

The porosity of the specimen was calculated by the following equation:

$$Porosity\ \% = 1 - \frac{\rho s}{\rho th} \qquad (4)$$

2.5.3 Hardness test

Hardness test was carried out for the specimens before and after sintering by using Rockwell hardness equipment (Wilson Hardness machine, USA Model: LM 2481 T). Composites specimens were tested by using (B) scale of Rockwell machine with hardened steel ball as an indenter of 100 Kg were used for all the specimens. For each specimen, three readings were taken at least and then determine the average of the three readings.

2.5.4 Compressive test

Compressive test was carried out for the specimens before and after sintering by using Instron Universal Tester (type Instron 1195 machine with full capacity 2.5 ton). The specimens were manufactured with 1.5 cm in height and 1 cm in diameter. All the specimens were compressed at 1 ton until the specimen were crushed. Stress – Strain curve was plotted for each composite material to obtain modulus of elasticity, yield strength and compressive strength. Compression strength is calculated by the following formula:

$$\sigma = \frac{2F}{\pi dh} \qquad (5)$$

3. RESULTS AND DISCUSION

3.1 Microstructure Analysis

The morphology of the sintered metal matrix composites was done by using optical microscopy. SiC and B_4C particulates were agglomerated in small volume fractions of them, while increasing the volume fractions of SiC and B_4C lead to make the particles to distribute homogeneously in aluminum matrix and strong bonding was created between the particulate reinforcement material and matrix as shown in **Fig.3**. As a result of compacting and sintering, there are pores defects were obtained in the composites materials. During sintering the particles of the mixing powders were joining together as a result of the welding between them, also during sintering process, zinc stearate evaporated and then causes to form porosity as a substitution of it is observed from **Fig.4** that the increasing wt% of Sic and B_4C leads to increase % porosity, and then decreasing % porosity for SiC and B_4C more than 9% of them. It is perhaps at attributed to that the porosity acts as internal stresses at the interfaces between the Sic, B_4C particles and aluminum matrix.

3.2 Compacting and Sintering

The particulate reinforcement material increases the density during compacting and sintering. Condensation occurs during compacting process and the particles close together with increasing the pressing force, while during the sintering process as a result of thermal welding between the particles, and then forming the necking between them which in turn causes the shrinkage of the sintered specimens and in turn lead to improve the density which represents an important of physical property, **Khairaldien, et al., 2007**. At the same time the temperature of sintering process created a strong binding between the particulate reinforcement materials and the matrix which affected on mechanical properties such as yield strength, ultimate tensile strength and hardness because of the dispersion of particulate reinforcement materials in the matrix, which causes a higher density of dislocation and make dislocation loop around a reinforcement particles preventing them from any motion between them. **Sun, et al., 2011**, in general, the density of composite material decreases with increasing the volume fraction of the additive nanoparticles; it is attributed to that the decreasing of the wettability with increasing the volume fraction of SiC, B_4C and at the same time forming the pores at the interfaces between SiC, B_4C and the matrix, the density with SiC more than for B_4C and also higher than for the aluminum matrix. **Fig.5** shows that obviously.

3.3 Effect of SiC and B_4C on the Hardness of Composite Material

Mechanical properties of composite material dependent strongly on the volume fraction, properties of the particulate reinforcement material, size of the additive particles. Increasing the volume of SiC and B_4C leads to increase the hardness of the manufactured of composite manufactured of composite material. The hardness of composite material with SiC higher than for composite material with B_4C, it is return to that the SiC was made strong binding with aluminum matrix higher than for B_4C, also the particles of SiC prevent the dislocations and pining them at their sites, and then increasing the hardness of the manufactured composite material. This result is agreed with that of **Jeevan, et al., 2012**. **Fig.6** shows that increasing the volume fraction of SiC and B_4C leads to increase the Rockwell hardness.

3.4 Effect of SiC and B_4C on Compressive Strength

The compressive strength of a particle reinforced metal matrix composite is extremely dependent on volume fraction of the additive particles and their sizes. Increasing the percentage of SiC and B_4C leads to increase the yield strength and compressive strength, it is attributed to that the reaction between particles and the matrix which created thermal stresses because of the differences between the melting point of SiC, B_4C and aluminum as a matrix, and then in turn increases the dislocation density. The reinforced particles obstacle the dislocation to move from one particle to another and then increases the yield strength and compressive strength. **Fig.7** shows that the increasing of volume fraction of SiC, B_4C increases the compressive strength. SiC increases the compressive strength more than B_4C for the same reasons mentioned previously. The result of this test is agreed with **Shorowordi, et al., 2003**.

4. CONCLUSIONS

Increasing the volume fractions of SiC and B_4C for 6061 Al matrix leads to improve the mechanical properties such as hardness and compressive strength.

1. Increasing the volume fractions of SiC and B_4C for 6061 Al matrix leads to improve the physical properties such as theoretical density, experimental density and porosity.

2. Small volume fractions of SiC and B_4C were agglomerated in 6061 Al matrix, while increasing the volume fractions of SiC and B_4C were distributed homogeneously in 6061 Al matrix, and the prefer percentage of SiC and B_4C is (9%).

3. Improving the mechanical properties and physical properties for SiC more than for B_4C.

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NOMENCLUTURE

d: diameter of the specimen(mm).

F: applied load (N).

h: height of the specimen(mm).

m_a : weight of the specimen in air (gm).

m_w: weight of the specimen in water (gm).

WAl: weight fraction of aluminum.

W SiC: weight fraction of silicon carbide.

W B_4C: weight fraction of boron carbide.

ρc : composite density (g /cm^3).

ρAl: density of aluminum (2.7 g/ cm^3).

ρSiC: density of silicon carbide (3.1 g/ cm^3).

ρB_4C: density of boron carbide (2.51 g/ cm^3).

ρ_s: density of sintered specimen (gm/ cm^3).

ρ_w: density of water (gm/ cm^3).

ρs : density of sintered specimen (gm/cm^3).

ρth: theoretical density of the specimen(gm/ cm^3).

Table 1. Showing characteristics of the powders, **Callister, W. D., and JR., 2003**.

Specimen No.	Powder	Size (µm)	Density (gm/cm^3)
1	Al 6061	150	2.7
2	SiC	200	3.1
3	B_4C	200	2.51

Figure 1. Show the mixture for the powders.

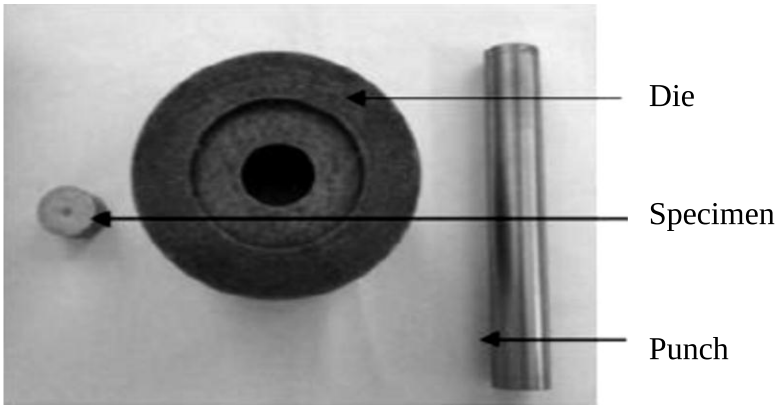

Figure 2. Show the mould for compacting process.

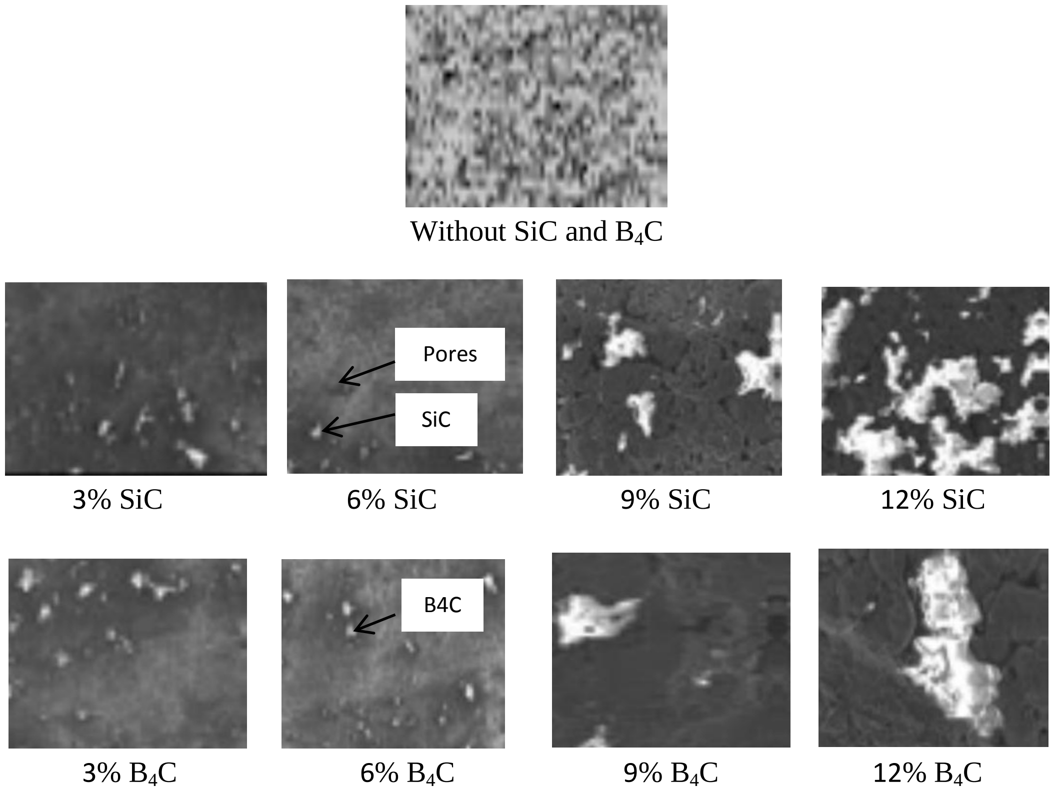

Figure 3. Showed that the micrographs of the specimens before and after adding SiC and B_4C with different weight frictions.

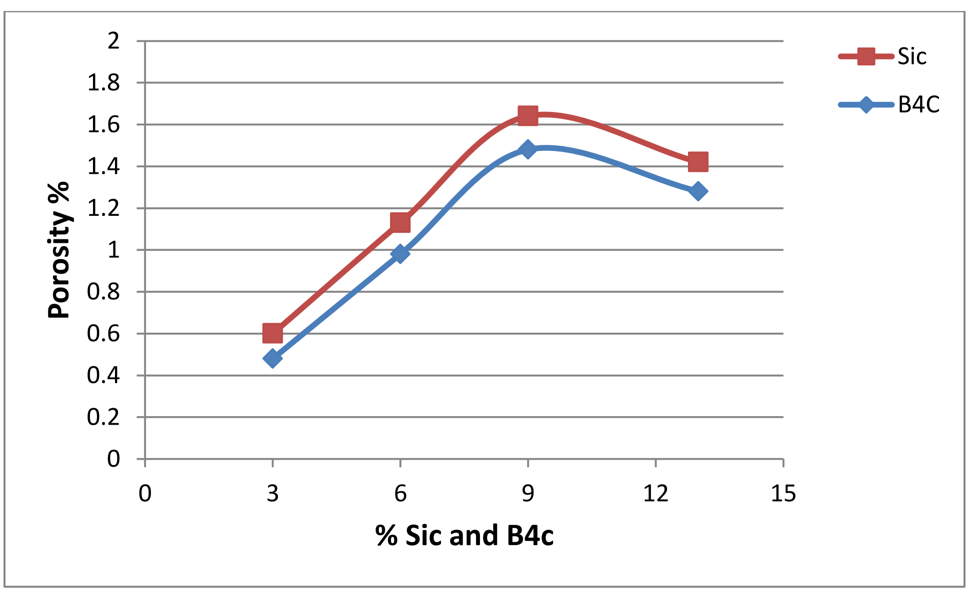

Figure 4. Showed the porosity % forming in composite materials.

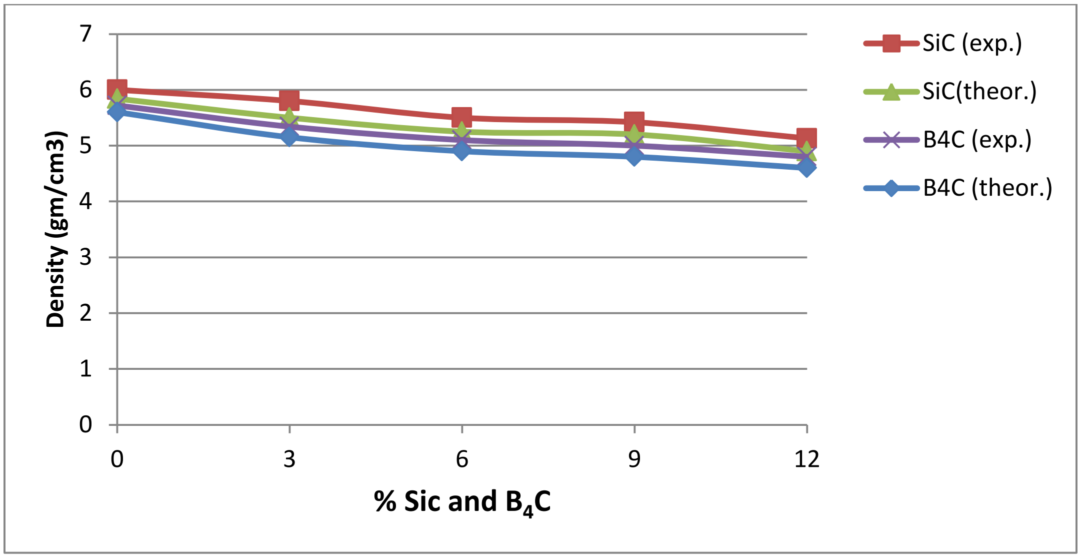

Figure 5. Showed the density forming in composite materials.

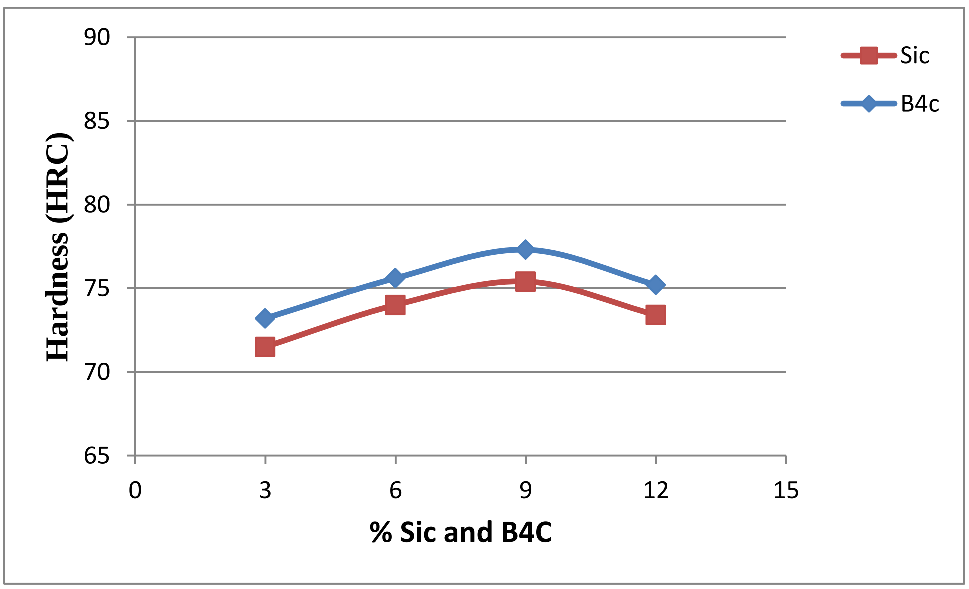

Figure 6. Showed the hardness forming in composite materials**.**

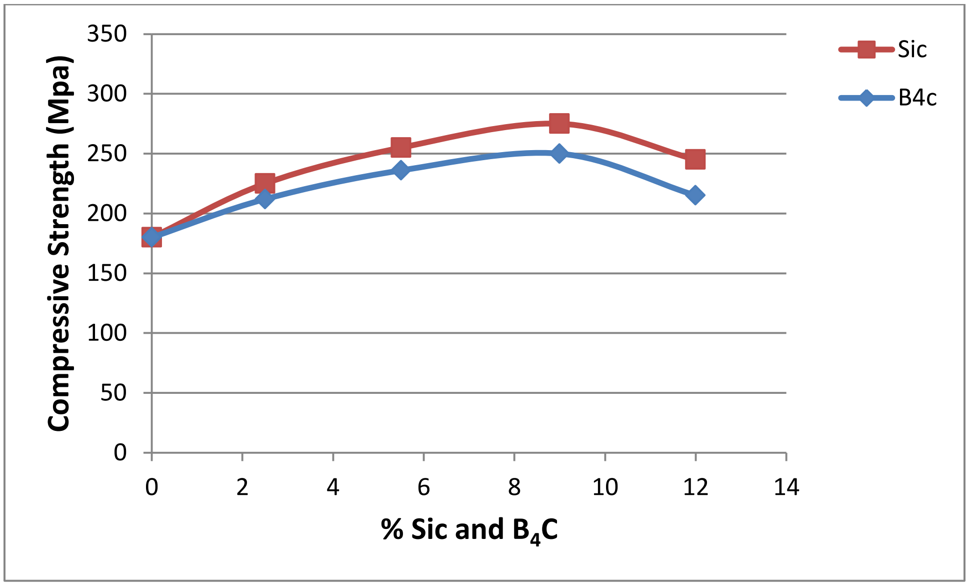

Figure 7. Showed the compressive strength forming in composite materials.