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Experimental Study on Tribological Characteristics of AA 6061 Alloy Reinforced with Al_2O_3 and B_4C Particles

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ABSTRACT

Two different composite materials were prepared by stir casting method of AA 6061 alloy as a matrix reinforced with two addition different ceramic materials Al_2O_3 and B_4C of grain size 20 µm by 2.5, 5, 7.5 and10% in weight. The composite material with aluminum alloy as a matrix possesses a unique mechanical properties such as: high specific strength and hardness, low density, and high resistance to corrosion and friction wear. This composite is widely used in automotive parts space and marine applications.

Pin-on-disc technique was used to calculate the wear rate for each addition of Al_2O_3 and B_4C particles. Rockwell hardness test and optical micrographs examinations were carried out to analyze, compare, and evaluate the addition of reinforced particles. The results of this investigation appeared that the 7.5% of ceramic particles addition give highest values of the hardness and wear resistance.

Keywords: Composite materials, AA 6061, Al2O3, B4C, Stir casting, wear

دراسة تجريبية للخصائص الترايبولوجية لسبيكة AA 6061 المقوّاة بدقائق Al_2O_3 و B_4C

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الخلاصة

تم تحضير مادتين مركبة بطريقة السباكة بالمزج لسبيكة ألمُنيوم AA 6061 كمادة أساس مقوّاة بنوعين من الدقائق السيراميكية المضافة Al_2O_3 و B_4C بحجم حبيبي 20 ميكرون وبنسبة وزنية 2.5، 5، 7.5 و 10%. تمتلك المادة المركبة من الألمُنيوم كمادة أساس خواص ميكانيكية فريدة مثل: مقاومة نوعية وصلادة عاليتين، كثافة منخفضة، ومقاومة عالية للتآكل، والتآكل الاحتكاكي. غالباً ما تستعمل هذه المواد المركبة في الفضاء، أجزاء السيارات، والتطبيقات البحرية. تقنية المسمار-على-القرص قد استخدمت لحساب نسبة معدل البلى لكل من الدقائق المضافة Al_2O_3 و B_4C. اختبار روكويل للصلادة وفحص الصور المجهرية تم إجراؤها لتحليل، مقارنة، وتقييم إضافة الدقائق المقوّاة. نتائج هذا البحث أظهرت أن نسبة إضافة 7.5% من الدقائق السيراميكية أعطت قيم عالية للصلادة ومقاومة البلى.

الكلمات الرئيسية: المواد المركبة ، AA 6061 ، B_4C ، السباكة بالمزج ، البلى

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1. INTRODUCTION

Metal Matrix Composites (MMCs) are a mixture of two or more constituent phases, in which meal is, reinforced with high strength material like aluminum oxides, silicon carbides etc. However, this leads to develop MMCs with improved the mechanical properties such as high elastic modulus, high strength and wear resistance, **Sachin Mohal, 2017** and **Nithyanandhan, 2017.**

Aluminum-matrix composites are produced by many different processes such as: powder metallurgy, squeeze casting, and stir casting, **Kumar, et al., 2010**. Many different materials are added to Al alloys to improve and enhance the mechanical and physical properties, corrosion resistance, and wear resistance such as: SiO_2, SiC, B_4C, and TiO_2, **Bharath, et al., 2012**. AA 6061 is one of the most important aluminum alloys since it is easily heat treated and possesses high resistance to corrosion and wear, moreover this alloy has high creep (high strength with elevated temperature). Therefore it can be used in many applications especially with high temperature application if it is reinforced with suitable ceramic particles, **Sarada, et al., 2016.**

Stir Casting is the preferred method to produce the aluminum metal matrix composites (Al-MMCs) because it is a simple and economic method. Also, it is produced a composite materials with precision final dimensions and can be used for a wide range of materials. Moreover, it gives good wettability between the reinforcement particles and the matrix, **Nimbalkar, et al., 2015.**

Many researches were published in this field such as **Ramesh, et al., 2005**, who studied the influence of TiO_2 on wear behavior of AA 6061, they concluded that increasing TiO_2 leads to increase the hardness and wear resistance. While, **Sri Pryia** and **Yogeshwaran**, recommended that adding SiC more better than Al_2O_3 as a reinforced particles of AA 6061 matrix by enhancing the tensile strength and the hardness. Likewise, **Basavarajappa, et al., 2006,** investigated the effect of SiC on the wear behavior of AA 2219 alloy as a metal matrix, and they showed that increasing SiC particles leads to increase the wear resistance.

Hariharan and **Nimal**, **2012,** studied the effect of TiB_2 on the microstructure of metal matrix composites produced by stir casting method and the wear characteristics, the results of the study showed that improving the mechanical properties and wear resistance with increasing in volume fraction of TiB_2. **Sozhamannan, et al., 2012,** studied the influence of stir casting process parameters such as processing temperature and holding time on the uniform distribution of particles and resulting mechanical properties, the tensile test revealed that ultimate strength increased gradually from 700°C to 800°C and starts to decrease gradually due to the porosity in the liquid matrix due to the vortex of molten stirrer which entrapped the gases inside the matrix.

The objective of this study is to evaluate the adding of Al_2O_3 and B_4C as reinforced particles on the matrix of AA 6061 alloy by performed the hardness test and microstructure examination, and wear rate.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

In this work, AA 6061 alloy was used as a matrix to produce the metal matrix composite (MMCs) material, while the reinforced ceramic materials were Al_2O_3 and B_4C. **Table 1** shows the chemical composition of the AA 6061 alloy, which supplied from Iraqi market and analyzed by spectrum analyzer in State Company for Inspection and Engineering Rehabilitation (SIER). While **Table 2** shows the properties of Al_2O_3 and B_4C, which the particles size are 20 μm.

2.2 Stir Casting

Melting of AA 6061 alloy was done by using an electrical furnace. AA 6061 was putting in Alumina crucible, then heating at 750°C for 3-4 hours to melt it entirely. At the same time, Al_2O_3 and B_4C were heated at 900°C and 1000°C respectively for 1-3 hours to oxides the particles surfaces.

Stir casting was done by using stirring technique, in which the molten metal of the AA 6061 alloy was stirring for 10 min. with rate stirring about 750 rpm. In the end of the stirring, the particles of B_4C and Al_2O_3 were added individually with different contents by 2.5, 5, 7.5, and 10 in wt% to the molten metal AA 6061 alloy to produce the composite material. After stirring process, the mixture was poured in metal mold in shape of the test specimens.

Table 3 shows the specimen number and the fraction in wt% of the reinforced particles Al_2O_3 and B_4C, which added to the AA 6061 alloy.

2.3 Microstructure Examination

Microstructure examination was done by using optical microscopy (OM) with magnification force is equal to 250 X for each specimen. This examination was done at lab of University of Technology.

2.4 Hardness Test

Rockwell Hardness test was carried out by with applied load 10 kg at 15 s at (lab strength of material) University of Technology. The average of four readings was recorded for each specimen.

2.5 Wear Test

Wear test was performed by using pin-on-disk technique. Specimens of wear test were prepared by lathe machine, the dimensions of the specimen are; 2 cm in height and 1 cm in diameter. Wear specimens were grinded and polished before the test. The loads were changed from 5 to 25 N with step of 5 N, the times also were changed from 5 to 30 min. with step 5 min. respectively. The specimens of this test were fixed and rotated against the hardened tool steel disc, which has hardness of 60 HRC. The disc rotated at 720 rpm.

Wear rate was calculated by using weight loss method. In this method, the loss in weight for each specimen was measured by sensitive electric balance with accuracy about 0.1 mg, (type Mettler AE-60). The wear rate of each specimen was calculated by using the following formula [**Lorenzo-Matin]**:

$$wear\ rate = \frac{\Delta\, w}{2\pi rnt} \quad (1)$$

$$\Delta\, w = w_1 - w_2 \quad (2)$$

where: $\Delta\, w$: the changing in weight (g).

w_1, w_2: the weight of the specimen before and after the wear test (g).

r: the radius of the distance from the center of the disc to the center of specimen.

n: Number of rotating of the disc (rpm).

t: time of the test (min).

3. RESULTS AND DISCUSSION

3.1 Microstructure Analysis

Micro Images were used to examine the microstructural variations before and after the addition of Al_2O_3 and B_4C. The Photomicrographs showed that the additive particles of Al_2O_3 and B_4C are distributed uniformly in molten metal of AA 6061 alloy as a matrix of composite material with little amount of porosity through the casting.

Increase the content of the Al_2O_3 and B_4C particles up to 7.5% leads to agglomerate the additive particles. The formation of porosity is attributed to the poor wettability between the ceramic particles and the molten metal AA 6061 alloy, in turn it leads to poor dispersion of the ceramic particles and forming the porosity, and this is in line with **Sajjadi** and **et al**., **2011**.

It is attributed to the differences of density of the AA 6061 alloy matrix and the reinforcement particles.

Fig. **1** shows the photomicrographs of AA 6061 reinforced by Al_2O_3 and B_4C with different contents; 2.5, 5, 7.5, and 10 wt%. It illustrates that the homogenous distribution of Al_2O_3 and B_4C particles in the alloy matrix. The homogeneity of distribution of the particles with uniaxial particles is due to the stirring action in the time of pouring the particles and then improving the wettability between the particles and molten alloy matrix. Also, the micrographs indicate that the grains of the prepared composite material are smaller than the grains of the origin AA 6061 Alloy, because the additive particles act as more nucleation of the molten metal during the solidification process, which leads to more and fine grains.

3.2 Hardness Characteristics

Increasing the percentage of Al_2O_3 and B_4C particles in the alloy matrix leads to improve the hardness because the reinforcement ceramic particles are harder than AA 6061 alloy matrix and in turn leads to increase the plastic deformation between the matrix and the additive of ceramic particles and this is in line with **Wu** and **Li, 2000**. **Fig**. **2** shows the relation between hardness and the percentage of the ceramic particles additive. They clearly illustrate that increasing in the content of reinforcement ceramic particles leads to increasing the hardness of the composite material. As well as, the composite material with reinforcement ceramic particles of Al_2O_3 is obviously harder than composite material with reinforcement ceramic particles of B_4C.

3.3 Wear Characteristics

Surface topographic of composite materials were examined by optical microscope (OM). Increasing the amount of Al_2O_3 and B_4C particles leads to increase the hardness of the produced composite materials because of the increasing in dislocations density, which in turn increase the hardness. This is because of the good binding between the reinforcement particles and molten metal alloy, and finally improving the wear resistance of the produced composite materials. Plastic deformation occurs as a result of the strain hardening during the wear test.

The variation in wear resistance is considered as a result in changing the applied load and the time for wear test. Increasing the load and time rises the heat temperature between the rubbing surfaces (the pins which made from the (AA 6061 + Al_2O_3 and AA 6061 + B_4C) and the rotating disc) and forming oxidization layer, which fragment and making grooves at the worn surfaces, this is in line with **Pramila, et al., 1992**. **Fig**. **3** shows the grooves of the worn surfaces of composite materials. The grooves for the composite material of the AA 6061 with Al_2O_3 finer than composite material of AA 6061 with B_4C, because of harder reinforced Al_2O_3.

3.4 Wear Rate

In this work, wear test was carried out by two stages: First stage included the changing in normal load, while the second stage included the changing in sliding time, which describes as following:

1. Increasing the content of Al_2O_3 and B_4C particles leads to increase the fragment of the worn surfaces especially at the high value of loading, which in turn forming this layer between the pin of composite material and the rotating disc to make mutual transfer between the mating surfaces and thus increasing the wear resistance. Wear resistance for the composite material AA 6061 + Al_2O_3 and AA 6061 + B_4C higher than AA 6061 alloy. The increasing in applied load leads to increase in plastic deformation and then the wear characteristics transfer from mild wear to severe wear and make more damage in the worn surfaces as a delamination layers especially AA 6061 alloy. But for composite material specimens, the pretenses of ceramic particles (Al_2O_3 and B_4C) increase the hardness thus increasing the wear resistance simultaneously. Many researchers investigated that the additive ceramic particles to Aluminum matrix reduces the wear rate and the transmission from mild wear to severe wear, **Axen** and **Jacobson**, **1994**. **Fig**. **4** illustrates the increasing in applied load leads to increase the wear rate for all specimens and transmission from the mild wear to severe wear. However, the wear rate for composite material reinforced with Al_2O_3 is lower than composite material with B_4C. As well as, the wear rate of the two types of composite materials are lower than origin AA 6061 alloy.
2. The effect of increasing in sliding time on wear rate for all specimens of this work is the same for that increasing in the loads as discussed previously. **Fig**. **5** shows the increasing in sliding time leads to increase the wear rate for all the specimens. Also, it is clearly shown that the wear rate for composite material reinforced with Al_2O_3 is less than composite material with B_4C. As well as, the wear rate of the two types of composite materials are lower than origin AA 6061 alloy.

4. CONCLUSIONS

1. Stir casting method is a successful technique to synthesize composite material of AA 6061 as a matrix with different percentages of Al_2O_3 and B_4C.
2. Increasing the amount of Al_2O_3 and B_4C leads to forming the porosity when producing composite materials.
3. The hardness of the composite increases with increasing in Al_2O_3 and B_4C. However, the preferred content of the reinforcement particles of Al_2O_3 and B_4C is 7.5%.
4. It was shown that the composite material with Al_2O_3 harder than composite material with B_4C.
5. Wear rate for composite material reinforced with Al_2O_3 is less than composite material with B_4C.
6. Micrographs of the manufactured composite shows the homogenous distribution of Al_2O_3 and B_4C in the AA 6061 alloy with little amount of porosity.

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Table 1. (A). Chemical composition of AA 6061 alloy (wt. %).

Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
0.62	0.23	0.22	0.03	0.84	0.22	0.1	0.1	Rem.

Table 1. (B). Mechanical properties of Al6061, **Veeresh Kumar, et al., 2010**.

Tensile strength (MPa)	Elastic Modulus (GPa)	Density (g/cc)	Poisons Ratio	Hardness HB500
115	70-80	2.7	0.33	30

Table 2. Properties of Al_2O_3 and B_4C.

Properties	Elastic Modulus (GPa)	Density (g/cm^3)	Poisson's Ratio	Hardness (HV)	Tensile Strength (MPa)	Compression Strength (MPa)
Al_2O_3	300	3.69	0.21	20	330	2100
B_4C	470	2.55	0.21	30	569	5687

Table 3. Specimens number according to the weight fraction of composite materials.

Specimen No.	1	2	3	4	5	6	7	8
AA 6061	97.5	95	92.5	90	97.5	95	92.5	90
Al_2O_3	2.5	5	7.5	10				
B_4C					2.5	5	7.5	10

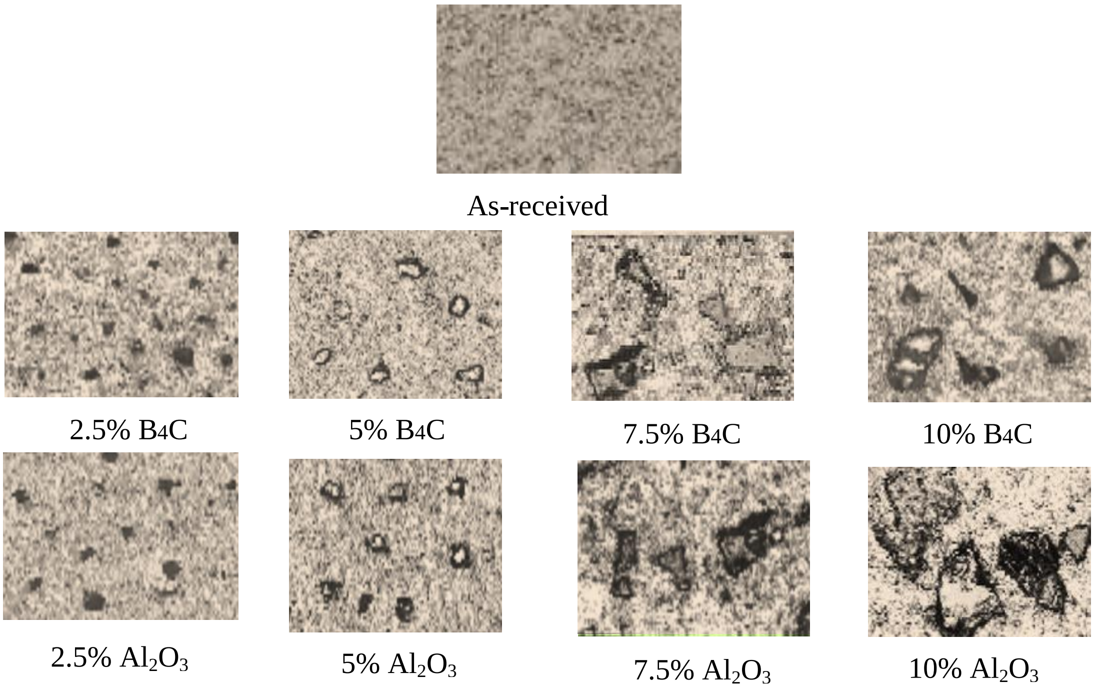


Figure 1. Photomicrographs of all the specimens for power with magnification (250 X).

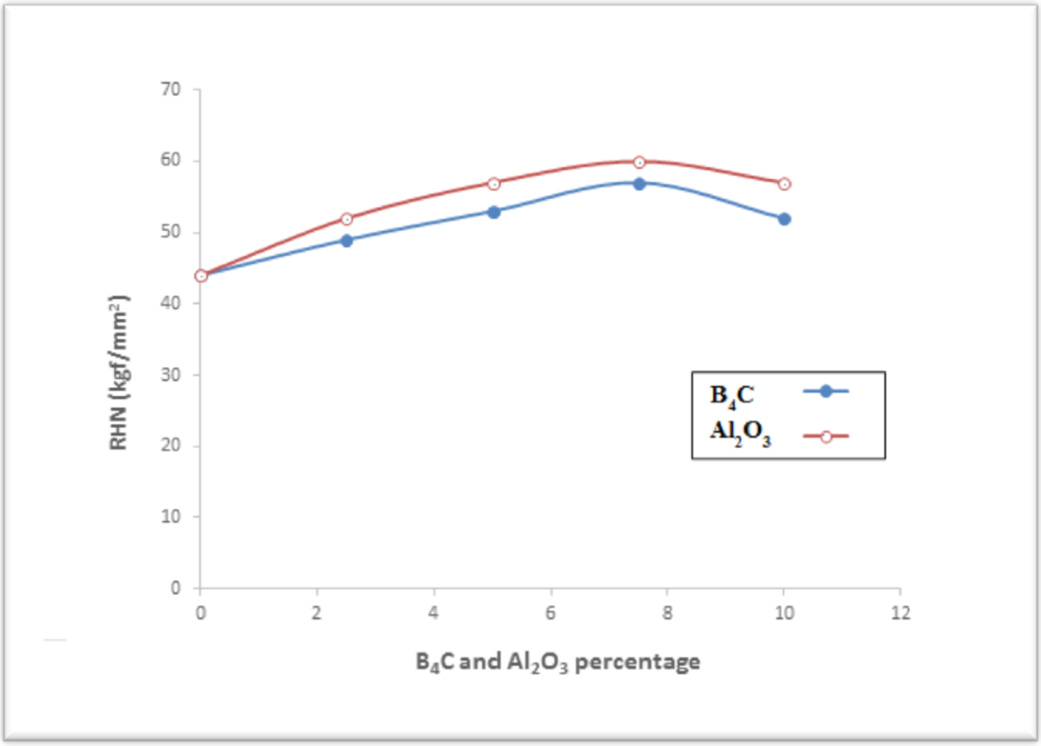
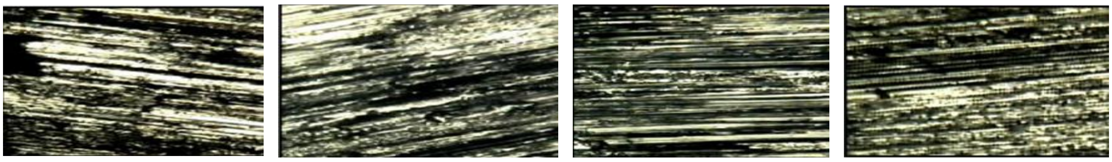
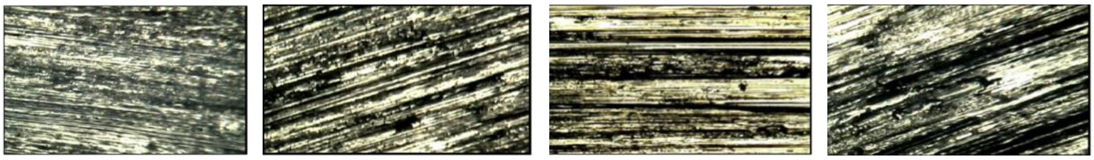


Figure 2. Relationships between Rockwell Hardness Number of %B_4C and Al_2O_3.



2.5% B_4C 5% B_4C 7.5% B_4C 10% B_4C



2.5% Al_2O_3 5% Al_2O_3 7.5% Al_2O_3 10% Al_2O_3

Figure 3. Photomicrographs of worn surfaces of all the specimens.

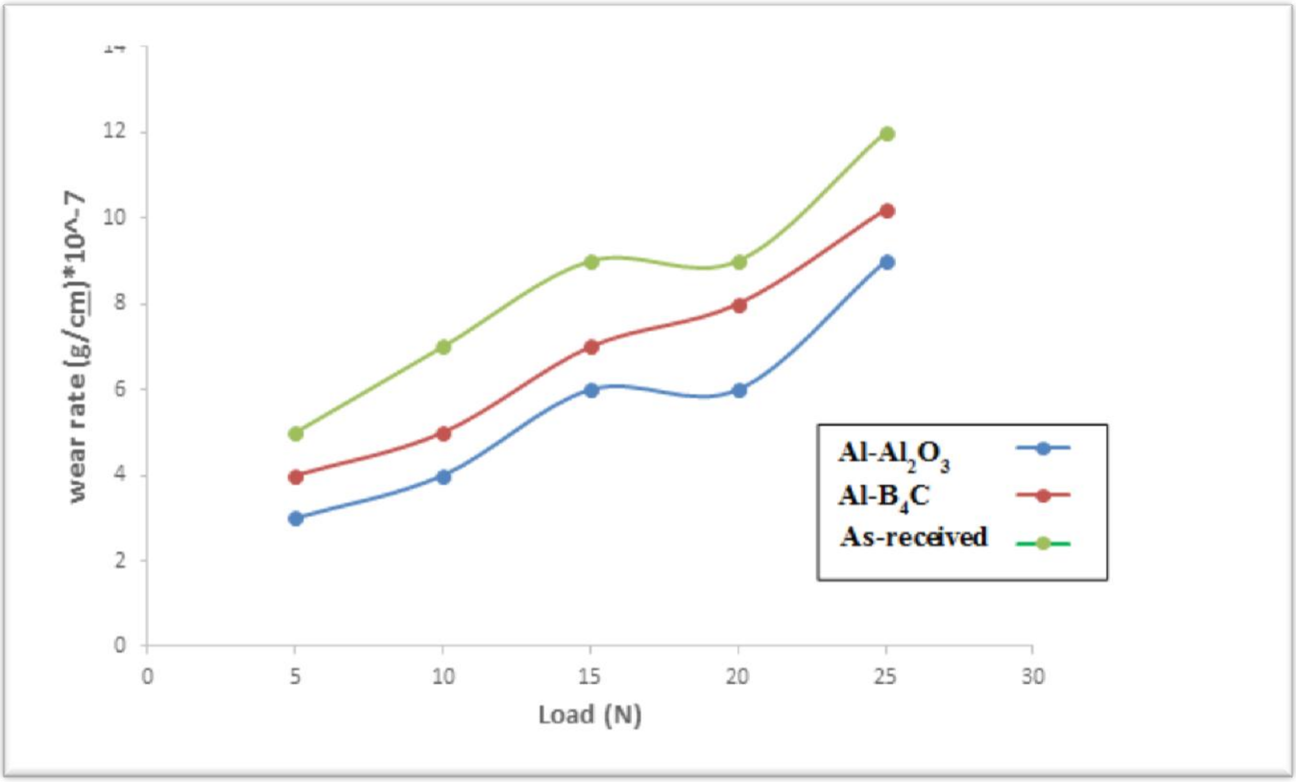


Figure 4. Relationships between wear rate and load for all the specimen.

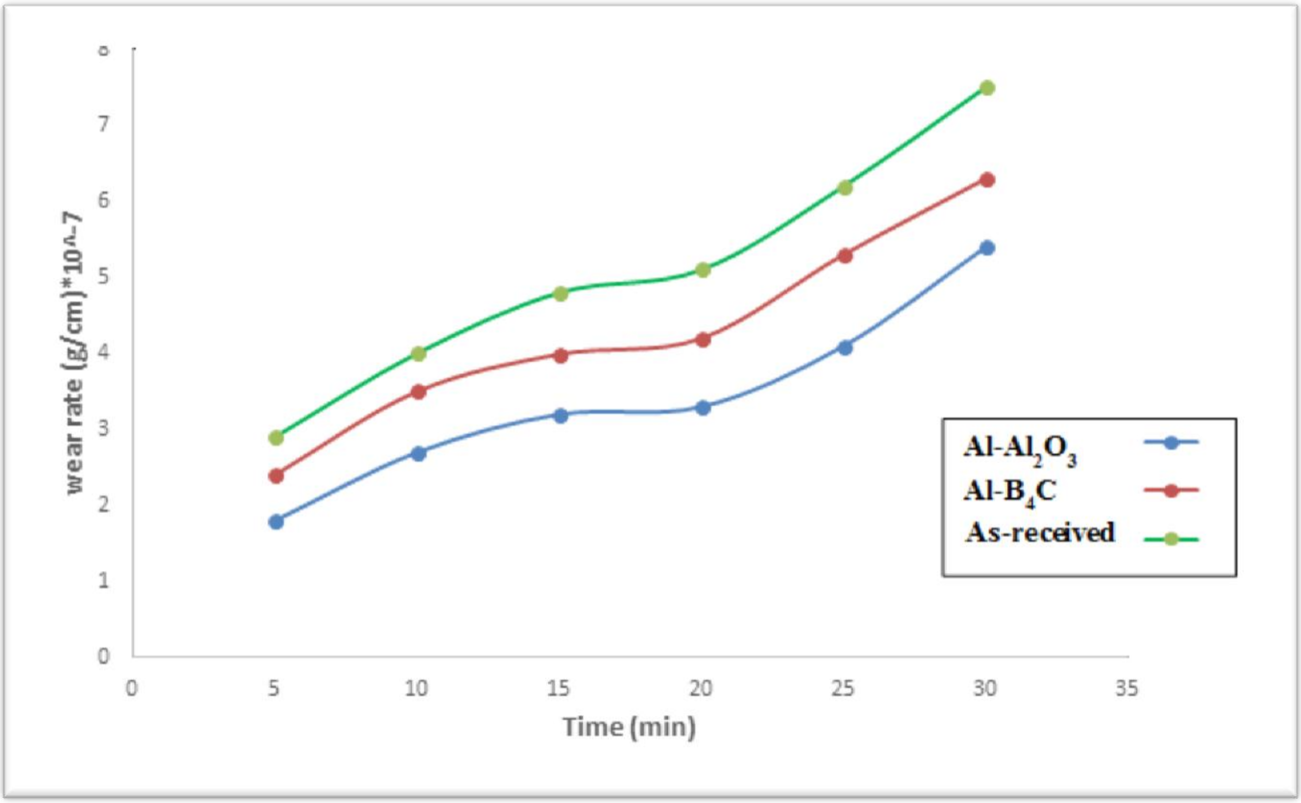


Figure 5. Relationships between wear rate and time for all the specimen.