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Evaluation Microstructure and the Mechanical Properties of Composite Material for Al-Matrix Reinforced by Ceramic Materials (Sic And Al_2O_3)

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ABSTRACT

In this investigation, the mechanical properties and microstructure of Metal Matrix Composites (MMCs) of Al.6061 alloy reinforced by ceramic materials SiC and Al_2O_3 with different additive percentages 2.5, 5, 7.5, and 10 wt.% for the particle size of 53 μ_m are studied. Metal matrix composites were prepared by stir casting using vortex technique and then treated thermally by solution heat treatment at 530 ^{0}C for 1 hr. and followed by aging at 175 ^{0}C with different periods. Mechanical tests were done for the samples before and after heat treatment, such as impact test, hardness test, and tensile test. Also, the microstructure of the metal matrix composites was examined by optical microscopy before and after heat treatment. The results of this work showed that precipitation of Mg_2Si as a secondary phase and improvements in mechanical properties with increase in the percentage of SiC and Al_2O_3. Also, the results of SiC revealed an improvement in mechanical properties more than for Al_2O_3 such as hardness, impact strength, yield strength, tensile strength, increasing the plasticity constant (k) and decreasing the strain hardening exponent (n).

Key Words: Composite materials, Al-6061, SiC and Al_2O_3, mechanical properties.

تقييم الخواص الميكانيكية لمواد مركبة ذات أساس من الالمنيوم مقواة بمواد سيراميكية (Al_2O_3 ,SiC)

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الخلاصة

في هذا البحث تمت دراسة الخواص الميكانيكية والبنية المجهرية لمواد مركبة ذات أساس معدني من سبيكة الألمنيوم نوع 6061-A المقواة بمواد سيراميكية (SiC, Al_2O_3) وبنسب أضافات وزنية مختلفة (2.5، 5، 7.5، و 10%) وبحجم حبيبي 53 مايكرون . تم تحضير المادة المركبة بالسباكة بالتحريك بأستخدام التقنية الدوامة، ومن ثم تمت معاملتها حراريا بالمعالجة الحرارية المحلولية عند درجة حرارة ($530\ ^0C$) لمدة (1hr.) والتعتيق عند درجة حرارة ($175\ ^0C$) لفترات زمنية مختلفة. أجريت أختبارات ميكانيكية للعينات قبل وبعد أجراء المعاملة الحرارية، مثل اختبار الصدمة، اختبار الصلادة وأختبار الشد. كذلك تم فحص البنية المجهرية للمادة المركبة ذات الارضية المعدنية قبل وبعد المعاملة الحرارية. أظهرت نتائج البحث ترسيب الطور Mg_2Si كطور ثانوي و تحسن الخواص الميكانيكية بزيادة نسبة المواد السيراميكية من , (SiC,Al_2O_3) . كذلك أظهرت النتائج أن SiC

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يبدي تحسن في الخواص الميكانيكية أكثر مما هو عليه Al_2O_3 مثل الصلادة، مقاومة الصدمة، مقاومة الخضوع، مقاومة الشد، ثابت اللدونة k مع نقصان أس الاصلاد الانفعالي (n).

1. INTRODUCTION

Composite materials are considered as one of the important materials. There are three types of composite materials: The first is metal matrix composites (MMC_S) which are composed of a metal matrix and reinforcing phases such as Al/Al_2O_3, Al/SiC, and Ni/Al_2O_3. While the second is ceramic matrix composites (CMCs) are composed of the ceramic matrix in the form of nitrides, oxides, silicides, and borides. Whilst the third is polymer matrix composites (PMCs) composed of the polymer matrix either thermoplastic or thermoset, **Koli, 2013**. There are many investigations published in this field. **Haider, et al., 2015,** studied the effect of Al_2O_3 and SiC reinforcement particles on the mechanical and physical properties of aluminum 6061 alloy fabricated by stir casting. While **Ram Prahu, 2017** investigated the properties of AA7075 Al/SiC composition (Al/6.5%SiC and Al/9.5%SiC) alloys fabricated by centrifugal casting technique generated during the mold rotation which plays an important role in creating a continuous gradient in the composite, **Prabhu, 2017**. **Qiyao, et al., 2017**, compared the microstructures and properties of A356 – SiC and 6061-SiC composites produced by vacuum assisted high pressure of die casting technique. The results of this work revealed that the uniform distribution of SiC under the action of high pressure with the little amount of porosity. **Hariharan,** and **Nimal**, **2012**, reported that aluminum metal matrix composites with ceramic particles as reinforcement materials have been the subject of many research workers. Because of their properties such as low density, high specific strength, low melting point and high thermal conductivity of aluminum alloys.

The main ceramics used as reinforced particles are SiC, Al_2O_3, TiC, and graphite. TiB_2 has emerged as an important reinforcement; because of it does not react with aluminum, stiff hard and does not make any reaction between the reinforcement and matrix, **Sri Priya, et al., 2016.**

Recently composite materials are important popular advanced materials due to their improved properties more than a conventional material such as low density; good wear resistance, good tensile strength, and high surface finishing. Among composites, Aluminum as a matrix to gain wide application in defense and automotive industries like high specific strength, wear resistance, strength to weight strength and thermal conductivity, **Vykuntarao, et al., 2015**.

There are many processes used to produce composite material such as stir casting and powder technology. Stir casting method is considered as an important for processing the composite material for large component and its economical process. Stir casting is widely used for producing large quantity due to its simplicity and flexibility, **Gupta,** and **Surappa, 1995**.

The aim of this work is to compare the effect of SiC and Al_2O_3 on microstructure and mechanical properties of composite material fabricated by stir casting.

2. EXPERIMENTAL PROCEDURE

2.1 Materials Used

In this work, Al 6061 alloy is used in sheet form as a matrix. **Table 1** shows the chemical composition of Al 6061 alloy, and **Table 2** shows the mechanical properties of Al 6061 alloy respectively. While **Table 3** shows the mechanical properties of SiC and Al_2O_3 respectively.

Each of SiC and Al_2O_3 was added with different percentages 2.5, 5, 7.5, and 10 wt. % respectively with a particle size of (53 μ_m).

2.2 Preparation of the Metal Matrix Composites (MMCs)

Metal Matrix Composites (MMCs) is prepared by stir casting using vortex technique. The sheets of Al 6061 alloy were cut to small pieces and then melted at 750 ^{0}C by using the electric furnace. Ceramics reinforcement particles will be pre-heated at 300 ^{0}C and stirring by using an electric mixer to obtain a uniform distribution. Stir casting is done at 500 rpm for 1 min to each additive percentage. After adding the reinforcement particles, the molten alloy with the additive particles re-melting at 800 ^{0}C for 10 min and followed by pouring in a suitable mold, as shown in **Fig.1**.

2.3 Manufacturing Tensile, Impact and Hardness Test Specimens

Tensile specimens are manufactured by using lathe machine according to ASTM E8N standard, **Annula, 1988**, as shown in **Fig.2.** While impact specimen was manufactured according to ASTM BS 131-1 as shown in **Fig. 3**. The hardness of the samples was manufactured at 10 mm in length and 10 mm in diameter.

2.4 Solution Treatment

The prepared metal matrix composites specimens were heated by solution treatment at 530 ^{0}C for 1 hr. and then quenching in water followed by aging at 175 ^{0}C for different aging periods (2-10 hr.) by 2 hr. of each step.

2.5 Microstructure Examination

The specimens for microstructural observation were mounted with Backelite and ground with grit papers of grade 320, 500 and 1000 μ_m. This was carried out by using wetting mechanical grinding and moving the specimen on the grit paper. The polishing was carried out using a polishing machine, which had a rotating wheel carrying a circular cloth pad on its surface with alumina polishing paste at 1 μ_m in particle size and then washing by water and alcohols. Finally, the prepared specimens were etched by using etching solution (1% HF + 99% H_2O) for 1 min. Photomicrographs were taken for the specimens by using optical microscopy provided with a computer.

3. MECHANICAL TESTS

3.1 Hardness Test

In this investigation, Vickers pyramid method was used to measure the hardness before and after heat treatments of the composites materials by using 0.5 kg for 15 sec. Four readings were recorded for each sample, and then the average diameter of indentation was recorded. Vickers hardness number of each specimen was calculated by using the Eq.(1) **Bolton, 1988**.

$$V.H.N = 1.8544 \times \frac{F}{d_{ave}^2}\ (Kgf/mm^2) \quad (1)$$

3.2 Impact Test

The impact test was conducted on the Hounsfield balanced impact machine. The hammer was moved out of position by raising the pawl release lever. The inner tup was lifted to the right while the outer tup was moved upward to the left. The test specimen was then inserted into the slot in the inner tup by pulling the notch register backward and ensuring that the V-notch was actually engaged.

3.3 Tensile Test

The tensile test was carried out for the samples before and after heat treatments using the Instron Universal Tester (type Instron 1195 machine with full capacity 2.5 ton). The original diameter and original length were recorded for each sample. The sample was loaded till fractured, however, the load and the diameter at the fracture point was measured. **Table 4** shows the mechanical properties of all specimens which were tested in this work.

4. RESULTS AND DISCUSSION

4.1 Effect of SiC, Al_2O_3, and Treatments on the Microstructure

Fig.4 shows the microstructure before and after heat treatment with an addition of SiC and Al_2O_3 as reinforcement elements to Al-matrix. This figure indicates that the stir casting followed by heat treatment with solution treatment and aging leads to create a good bonding between the matrix and reinforcements elements for SiC more than Al_2O_3, it is perhaps attributed to the wetting between Al/SiC better than for Al/Al_2O_3. Also, perhaps the heat treatments lead to precipitate Mg_2Si which in turn enhance the wetting between Al/ SiC more than for Al/Al_2O_3 as agreed with **Shamkhy, 2000**.

4.2 Effect of SiC, Al_2O_3, and Treatments on the Hardness

Fig.5 shows the relationship between the hardness and aging periods, the hardness increases with increasing aging time until reaching the highest value and then decreasing because of precipitation during the second phase Mg_2Si. This second phase distributed homogenously in Al-matrix causing an interaction with dislocations, however, this leads to pinning the dislocations and preventing them to move and in turn increases the strength and the hardness of the alloy. Simultaneously the hardness decreases with increasing aging time because of missing the coherency stain between the precipitation particles and Al-matrix. This result agreed with **Wang, et al., 1998.**

4.3 Effect of SiC, Al_2O_3, and Treatments on the Mechanical Properties

Solution treatment followed by aging leads to diffusion of alloying elements and simultaneously precipitation the secondary phase (Mg_2Si), however increasing the hardness after heat treatment because of the hardness of SiC substantially greater than for Al_2O_3. For this reason, the dislocation density increases and tends to prevent the dislocations to move. High dislocations density in Al-matrix encourage the diffusion reactions between the dislocations and alloying elements during aging processes, hence this result agreed with, **Vykuntarao, et al., 2015**, this emphasizes that the reinforcement particles tend to create heterogeneous unstable phase.

Increasing the load for tensile test leads to increase the plastic deformation and causes increasing the density of dislocations and increases the strength of the resultant composite material.

This is attributed to the reactions between SiC, Al_2O_3, and Al-matrix. Increasing the percentage of SiC and Al_2O_3 leads to increase the yield strength and tensile strength, which in turn influenced the increase in the strength of the composite materials. In spite of that SiC and Al_2O_3 are hard phases, the secondary phase has been created to improve the strength, which made that a good combination between phases and in turn increases the yield strength, ultimate tensile strength and the percentage of elongation. **Fig.6** shows that increasing the percentage of SiC and Al_2O_3 leads to increase the yield strength and tensile strength for Al/ SiC and Al/Al_2O_3 composite materials. While **Fig.7** shows that Al/ SiC give the maximum value of plasticity constant (k) for Al/Al_2O_3, hence the value of strain hardening exponent (n) for Al/ SiC is less than that of Al/Al_2O_3. It is perhaps attributed to that the hardness for Al/SiC is more than for Al/Al_2O_3, also the precipitation of the secondary phase Mg_2Si leads to increase (k) and decrease (n). Finally increasing the wt.% of SiC and Al_2O_3 leads to increase impact strength of Al/ SiC and Al/Al_2O_3 composite materials as shown in **Fig.8** for the same reasons mentioned previously.

5. CONCLUSIONS

The following conclusions are made based on this investigation:

1. Heat treatment by solution heat treatment followed by aging treatment leads to precipitate the secondary phase (Mg_2Si).
2. Increasing aging periods leads to increase the hardness of Al/ SiC composite material more than for Al/Al_2O_3 composite materials.
3. Improving the mechanical properties such as yield strength, tensile strength and also increasing impact strength for Al/ SiC composite material more than for Al/Al_2O_3 composite materials.
4. Increasing the percentage of SiC and Al_2O_3 leads to increase the plasticity constant (k) and decreasing the strain hardening exponent (n).

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Table 1. The chemical composition of Al 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 2. The mechanical properties of Al 6061 alloy **Kumar, et al., 2010.**

Young Modulus (MPa)	**Tensile strength (MPa)**	**Hardness (HV)**	**Position ratio (%)**	**Elastic Modulus (GPA)**	**Density (g /cm^3**
68	115	31	0.33	70-80	2.7

Table 3. The mechanical properties of SiC and Al2O3 **Kumar, et al., 2010.**

Ceramic material	**Compressive strength(Mpa)**	**Hardness (HV)**	**Poissons Ratio (%)**	**Elastic Modulus (Gpa)**	**Young Modulus (Gpa)**	**Density g/cm^3**
SiC	3009	2800	0.14	410	415	3.1
Al_2O_3	2100	1175	0.21	300	350	3.69

Table 4. The mechanical properties for all specimens.

Specimen	**Yield modules (MPa)**	**Tensile strength (MPa)**	**Impact energy (J)**	**Hardness (HV)**	**K (MPa)**	**n**
As-received	**68**	**115**	**21**	**30**	**612**	**0.32**
With Al_2O_3	72	148	34	58	635	0.29
With SiC	77	205	42	70	647	0.25

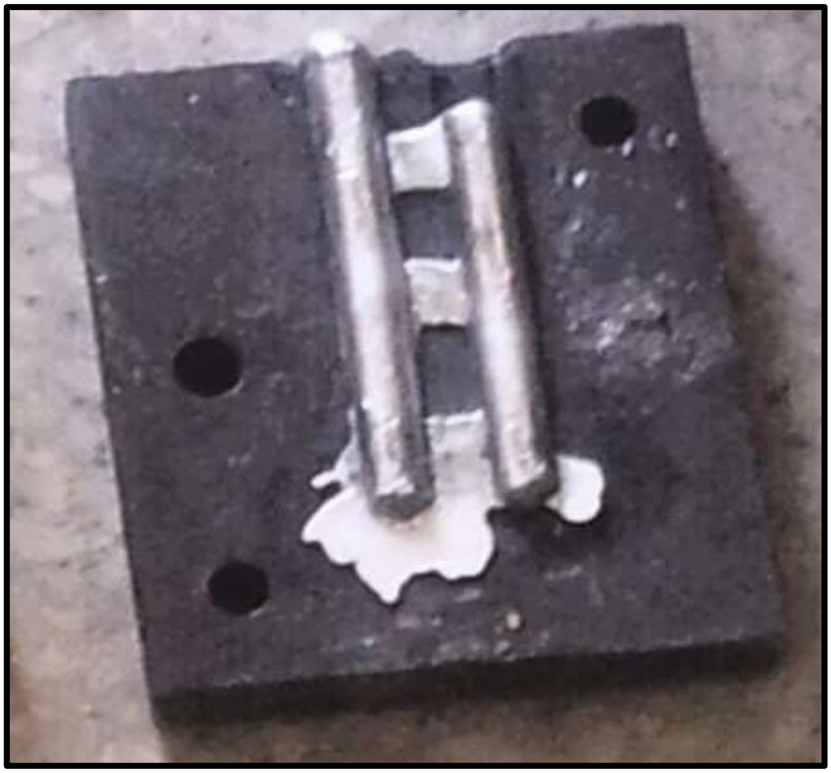


Figure 1. The mold for pouring the composite specimens.

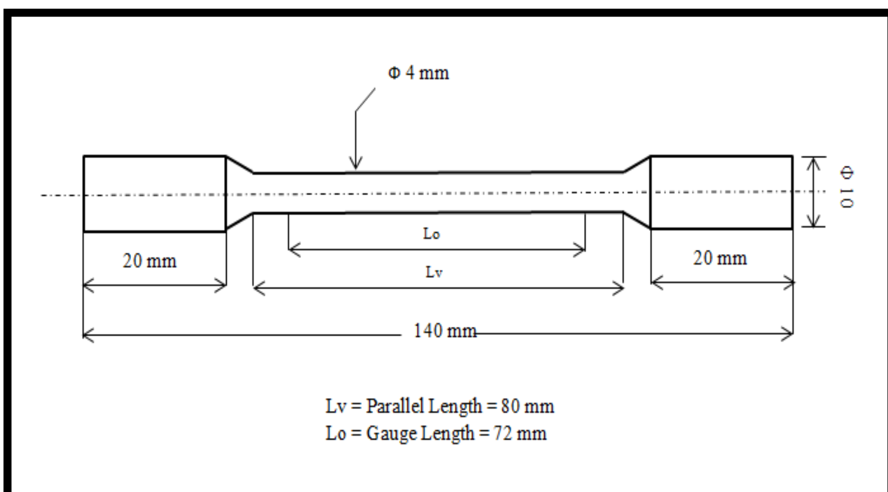


Figure 2. Show tensile test specimen, **Annula, 1988**.

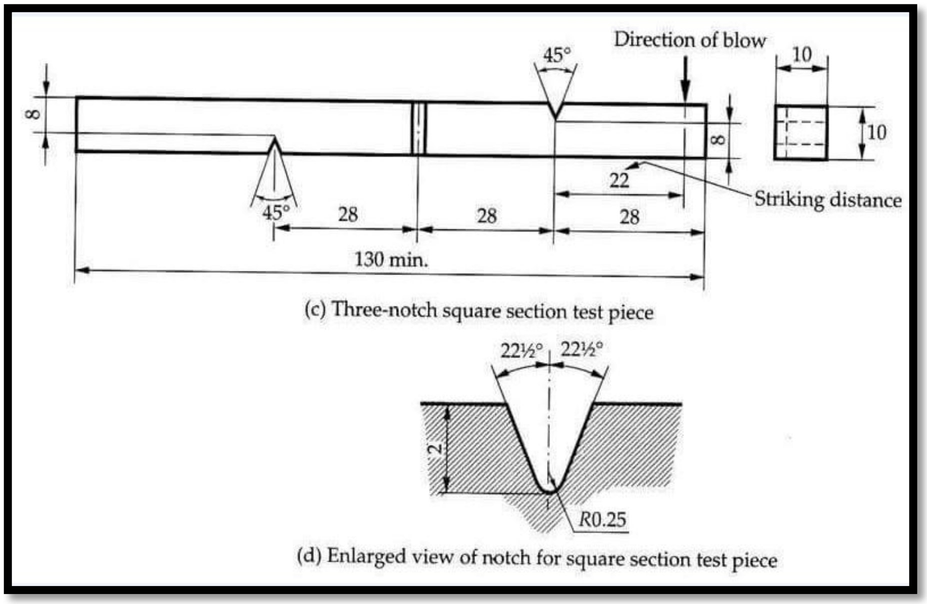
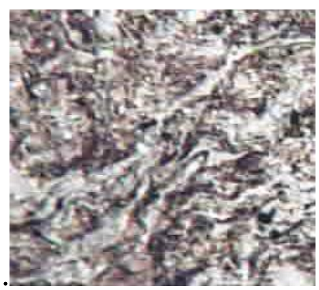
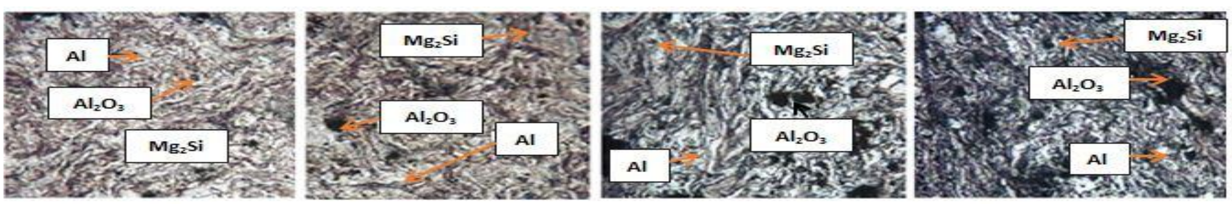


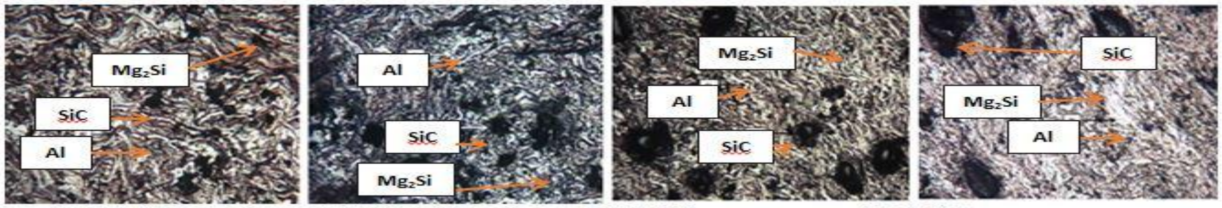
Figure 3. The specimen of impact test **ASTM, 2004**.



As received



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



2.5 % SiC 5 % SiC 7.5 % SiC 10 % SiC

Figure 4. Photomicrographs of Al/Al_2O_3 and Al/ SiC.

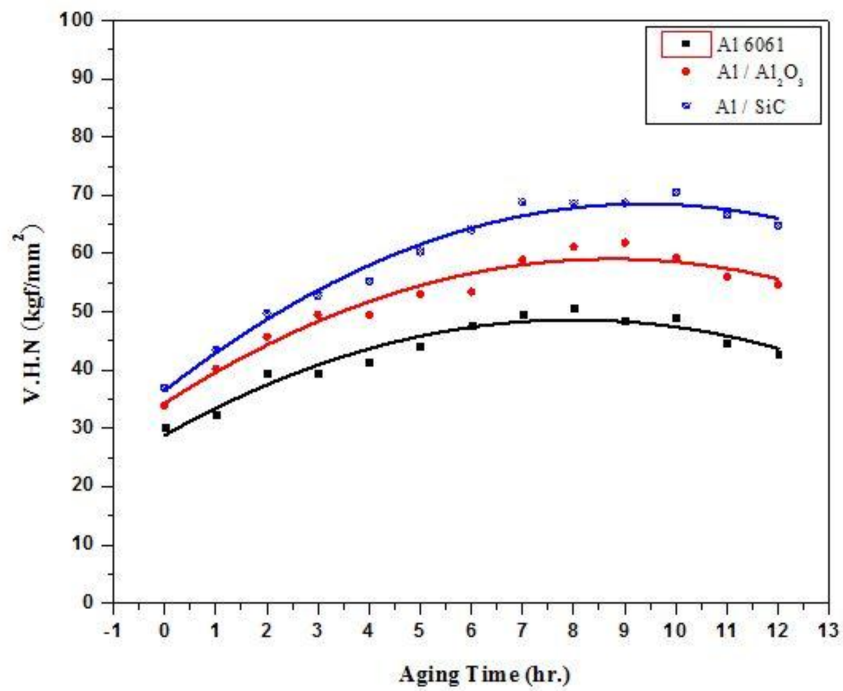


Figure 5. The relationship between Vickers hardness and aging time.

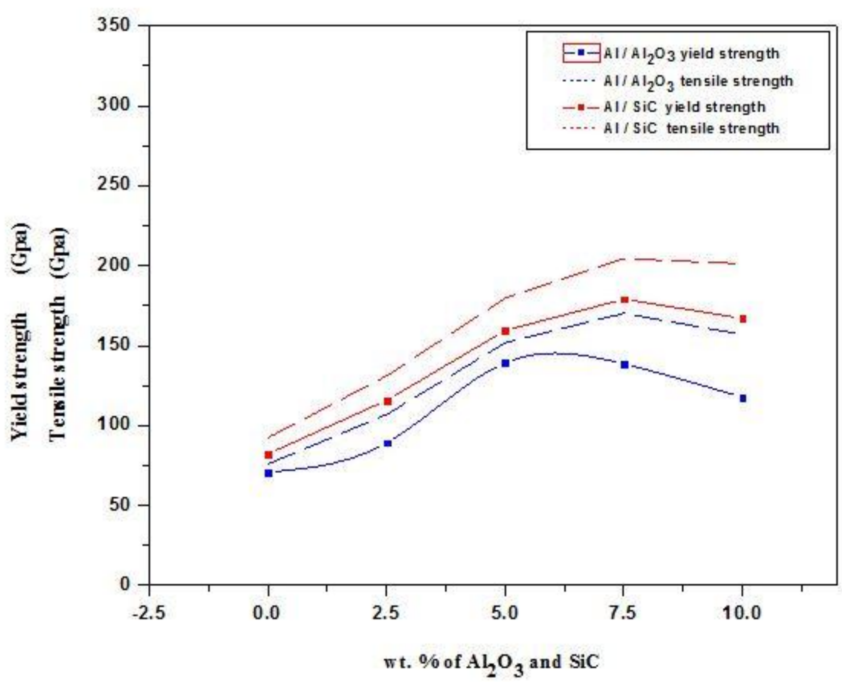


Figure 6. The relationship between yield and tensile strength and percentage of Al_2O_3 and SiC.

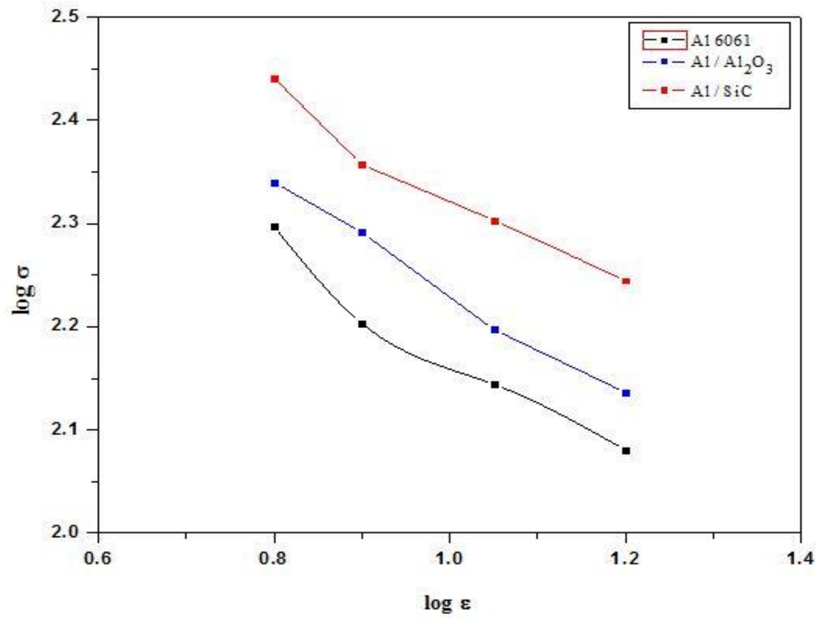


Figure 7. The relationship between Log σ and Log ε.

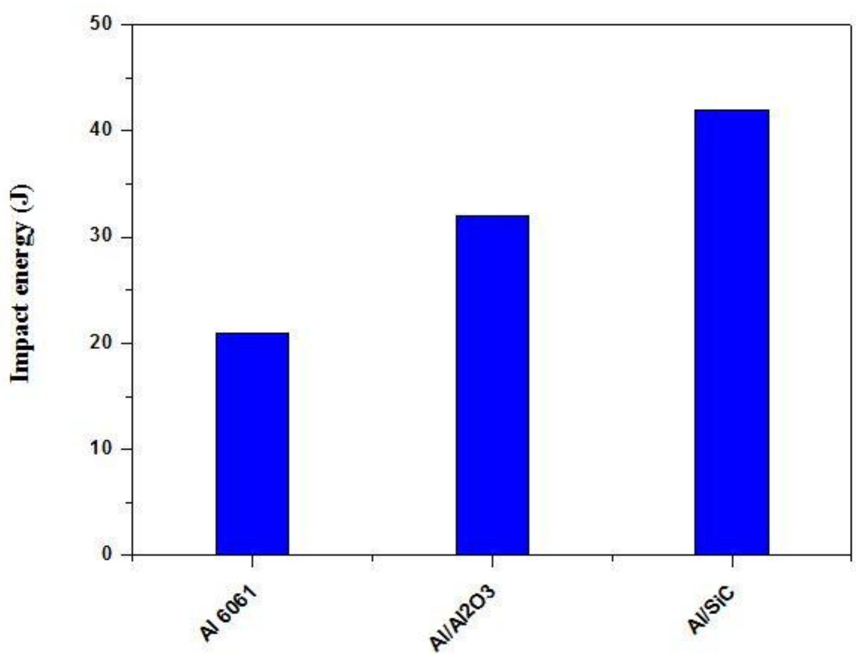


Figure 8. The relationship between impact energy and all the specimens.