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The Effect of (α-Al_2O_3) Volume Fraction on The Mechanical Properties of (Al-Alumina) Metal Matrix Composite

Dr.Fawziea M. Hussien*& Baydaa Abdul-Hassan Khalaf**

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Abstract

This research tends to study the effect of change in volume fraction of alpha phase alumina on mechanical properties of a metal matrix composite specimens contain (Al-αAl_2O_3). Specimens were prepared with the following volume fractions (10, 15, 20, 25, 30, 35, 40, and 45). Then effectof this change on hardness, maximum stress and strain, Young's modulus, impactand wear resistance has been studied. Results of testing showed that while hardness, maximum stress, Young's modulus, and impact strength increased markedly with volume fraction of alumina, wear rate, and maximum strain decreased with increasing of volume fraction.

Keywords:- Metal MatrixComposite(MMC), Aluminum-Matrix Composite, Ceramic Reinforcement.

تأثير الكسر الحجمي للألفا ألومينا (α-Al_2O_3) على الخواص الميكانيكية لمادة مركبة ذات أساس معدني مكونة من (الألمنيوم + ألألو مينا)

الخلاصة

يهدف هذا البحث الى دراسة تأثير التغير في الكسر الحجمي لمادة الألومينا بطور الألفا (α-Al_2O_3) على الخواص الميكانيكية لعينات مكونة من مادة مركبة ذات أساس معدني (Al-Al_2O_3) اذ تم تحضير العينات بالكسور الحجمية التالية (45,40,35,30,25,20,15,10)% ثم دراسة تأثير هذا التغير على كل من الصلادة،الإجهادوالانفعال الاعظم،معامل يونك،مقاومة الصدمة، اضافة الى مقاومة البلى حيث أظهرت نتائج الاختبارات انه بينما تزايدت كل من الصلادة،الإجهاد الأقصى، معامل المرونة، و ومتانة الصدمة مع تزايد الكسر الحجمي فأن معدل البلى،و الانفعال الاعظم تناقصت مع زيادة الكسر ألحجمي.

الكلمات المرشدة:- المواد المركبة ذات الأساس المعدني، المواد المركبة ذات الأساس الألمنيوم، التدعيم بالسيراميك.

Introduction

An increased interest is observed in the last years in metal matrix composite (MMC) mostly light metal based especially aluminum, which have found their applications in many industry branchs, among others in the air craft industry, space ships, and several technical and medical applications.[1]

Particle reinforced composites have a better plastic forming capabilitythan that of the whisker or fiber reinforced ones, and thus they have emerged as most soughtafter material with cost advantage and they are also known for excellent heat and wearresistance applications.[2]Metal-matrix composite are the subject of extensive research and development activities mainly because of their interesting

*Technical College, Foundation of Technical Education/ Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

specific properties. Most of the work has been dealing with aluminum and other light metal matrices for applications requiring light weight in combination with high strength and stiffness.[3]The metal matrix composite (MMC) can be reinforced with particles, dispersions or fibers. However the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribiological- heat –or mechanical properties by selection of the volume fractions, size and distribution of the reinforcing particles in the matrix.[4-6]. Reinforcements for metal matrix-composite have a manifolds demand profile, which is determined by production and processing and by the matrix systems of the composite material.[7] Ceramic materials reinforcement are used more often compared with the composite materials of other metals, due to the broad range of their properties, and also to the possibility of replacing the costly and heavy elements made from the traditionally used materials.[8] Aluminum is the most frequently used matrix material due to its low density .Because of its extreme hardness and temperature resistant properties ,Al_2O_3 ceramic particles are often used as reinforcement within the aluminum matrix.[9]Several researchers found that the addition of a non-metallic phase like ceramic into the metal matrix increased the yield strength of the composite. Compressive and tensile strengths, as well as the hardness at both room, and elevated temperatures are also increased significantly, resulting in an improvement in the wear resistance of the composite.[10,11]The aim of this work is to investigate the effect of ceramic reinforcement volume fraction on the tensile, hardness, impact, and wear resistance of a composite material contain (Al metal matrix + Al2O3 as a reinforcement).

Experimental

Aluminum metal with purity of (99.9) and partical size of (35 µm) supplied from (MERCK, Germany) was used as a matrix. α-alumina with purity of (99.92%) and partical size of (30 µm) supplied from (CLI, UK) was used as a reinforcement, mechanical properties of both aluminum, and alumina are listed in table (1).

Specimens for hardness, and wear resistance were formed by powder metallurgy technique. Fine powders of matrix and alumina with volume fraction of (10, 15, 20, 25, 30, 35, 40, 45) were mixed using paraffin as a binder , and compacted to (10mm*10mm) cylindrical shapes using steel molds and single end pressing type (Dutch, Finland) under a pressure of (5 ton), then sintered in an evacuated tubular furnace type (ZLUH, Germany) for (3hr) at (1200oC) and allowed to cool in furnace. Specimens of impact and tensile tests were formed by slip casting method, a slurry composed of (Al + Al2O3 + 50% water + Arabic gum as a defloculent agent) were prepared using a slip casting machine type (ADM, U.S.A) with a speed of (500rpm) for (30 min) then poured in molds with standard dimensions, dried in an oven type (NORBIK, UK) at (250oC) for (3 hr), then they were sintered in an evacuated tubular furnace type (ZLUH, Germany) for (3hr) at (1200oC) and allowed to cool in furnace.

Testing

Brinell testing device type (Wilson instrument, , Hardness tester, USA) with a ball diameter according to (ASTM D730 – 98). The device was connected to a digital system type (Sony 210) which give direct results.

Tensile test was occurred according to (ASTM E 623 – 92), using a set type (Instron 1195 Tensile Test)with load of (5KN) and strain range of (0.5 mm/min). The device was connected to a digital reading and graphing unit type (PLC 1800).Charpy impact test device type (CDM, U.K) results were calculated according to equation (1).

$$E = mg\,(h_1-h_2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where (m) mass of the pendulum (25 kg), (g) acceleration (9.8), (h1,h2) are the height of the pendulum before and after striking the specimen respectively.

Pin- on disc device was used to study wear resistance of the specimens with constant loading of (50 N), slipping speed of (3mm/sec), slip diameter (9cm), and hardness of steel disc was (HRC 30). Wear rate was calculated by means of weight loss, weight of the specimens was measured before and after testing using sensitive electric balance type (Dunhill, USA, 0.0001 gm).Wear resistance was calculated using equation number (2).

$$\text{Wear rate} = \Delta W / 2\pi rnt \ldots\ldots\ldots\ldots\ldots (2)$$

$$\Delta W = W_1 - W_2$$

Where (W1,W2) weight before and after testing, (r) slip radius (4.5 cm), (n) slip speed (500 rpm), (t) slip time (30 min).

Results and discussion

Figure (1) illustrates the effect of (α-Al2O3) volume fraction on hardness of the metal matrix composite specimens. Hardness number increased with the increasing of volume fraction because of the high hardness of alpha alumina comparing to aluminum metal. However the increasing starts in rather slowly pattern till the volume fraction reaches up to (25%) where sharp increase. From the figure may see that hardness number increased from (50 MPa) at volume fraction of (10%) up to (>350 MPa) at volume fraction of (45%).

Tensile test gives several indication as can see from figures(2,3,and 4) which are indicate the effect of (α-Al2O3) volume fraction on maximum stress, maximum strain, and Young's modulus of metal matrix composite respectively. Figure (2) shows that the increasing of maximum stress is nearly linearly with increasing in alumina volume fraction, this is an expected behavior because of the high mechanical properties of alumina.

In figure (3) it is clearly seen that increasing in Al2O3 volume fraction lead to a slow decrease in maximum strain at first stages, but when the volume fraction exceeds (25%) the decreasing become very sharp until it reach its lowest value (0.1) at maximum volume fraction (45%), this behavior related to the difference between the soft nature of soft aluminum metal comparingto stiff ceramic reinforcement (Al2O3).While in figure (4) which shows the effect of alumina volume fraction on young modulus of specimens, it shows that young modulus increased with volume fraction in a similar pattern to the hardness. Young modulus increased from (75 to 225)MPa when alumina volume fraction increased from (10%) to (45%).

Figure (5) shows the effect of alumina volume fraction on wear rate of metal matrix composite specimens at first stages (volume fraction < 30% Al2O3) there is no significant difference in wear rate but above this value wear rate significantly decreased down to (4.5 *10-6gm/cm) when volume fraction reaches to (45%).

Figure (6) shows the effect of alumina volume fraction on impact strength of the specimens from the figure we may indicate a direct relation between volume fraction of alumina reinforcement and impact strength, impact strength increased ,when volume fraction is (10%) , the impact strength <10) when volume fraction is (45 %)the impact increased to > 50.

Conclusions

Hardness, maximum stress, Young modulus, and impact strength increased with increasing in (α-Al2O3) volume fraction. Wear rate, and maximum strain decreased withincreasing in (α-Al2O3) volume fraction. In both case of increment or decrement starts when volume fraction exceeds (25%) Al2O3.

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Table(1) Mechanical properties of Alumina(Al_2O_3) and Aluminum(Al)

Property / Material	Hardness (Mpa)	Maximum Stress (Mpa)	Maximum Strain	Young Modulus Mpa	Impact Strength (J)	Wear Resistance (gm/cm)
Al	215	210	22	240	295	$2.8*10^{-6}$
Al_2O_3	625	440	8	490	390	$1*10^{-6}$

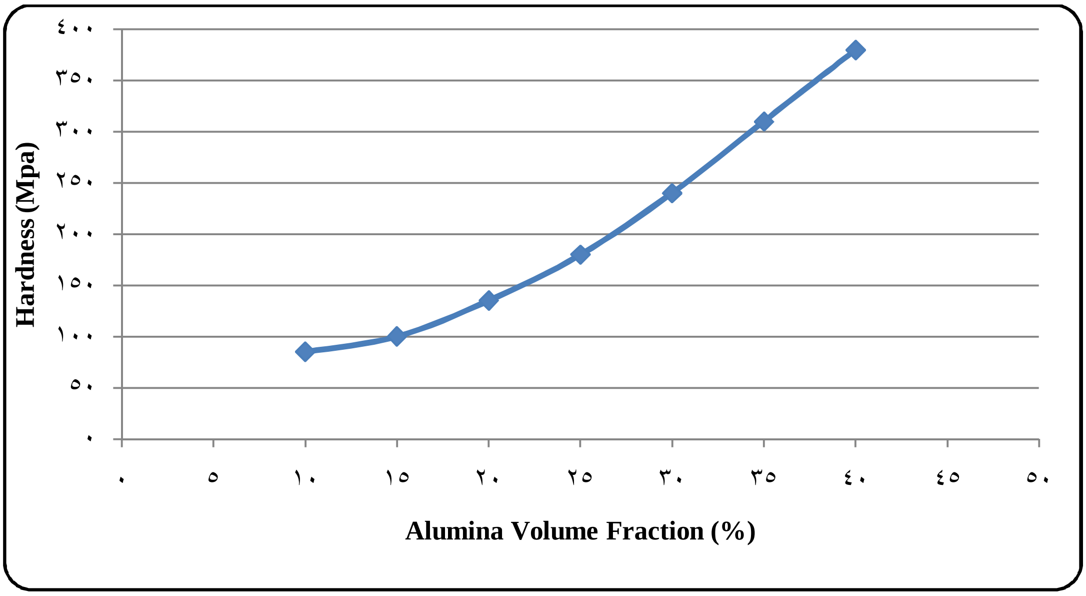

Figure (1) Effect of Alumina Volume Fraction on Hardness

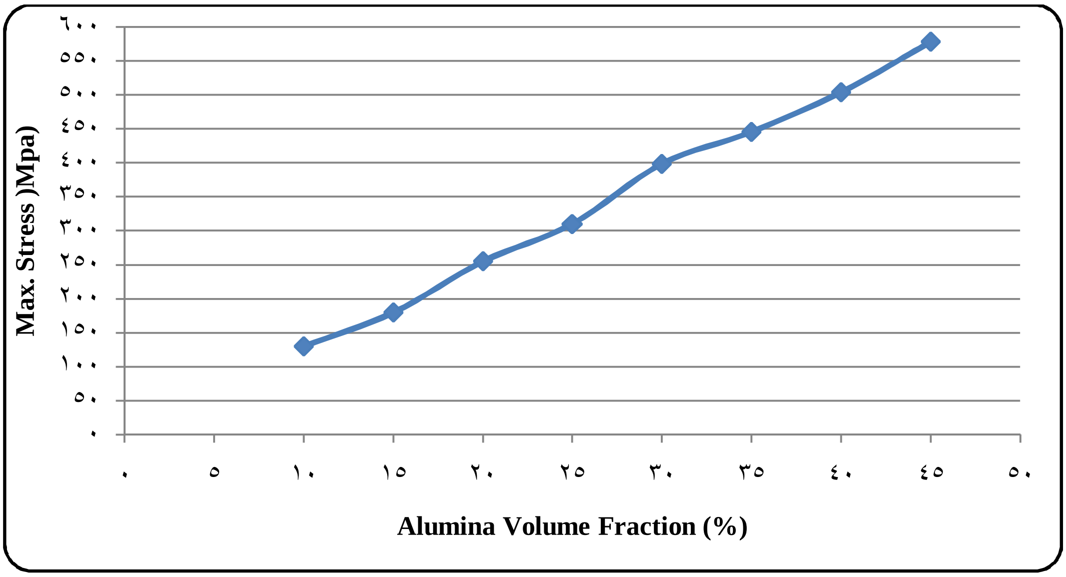

Figure (2) Effect of Alumina Volume Fraction on Maximum Stress

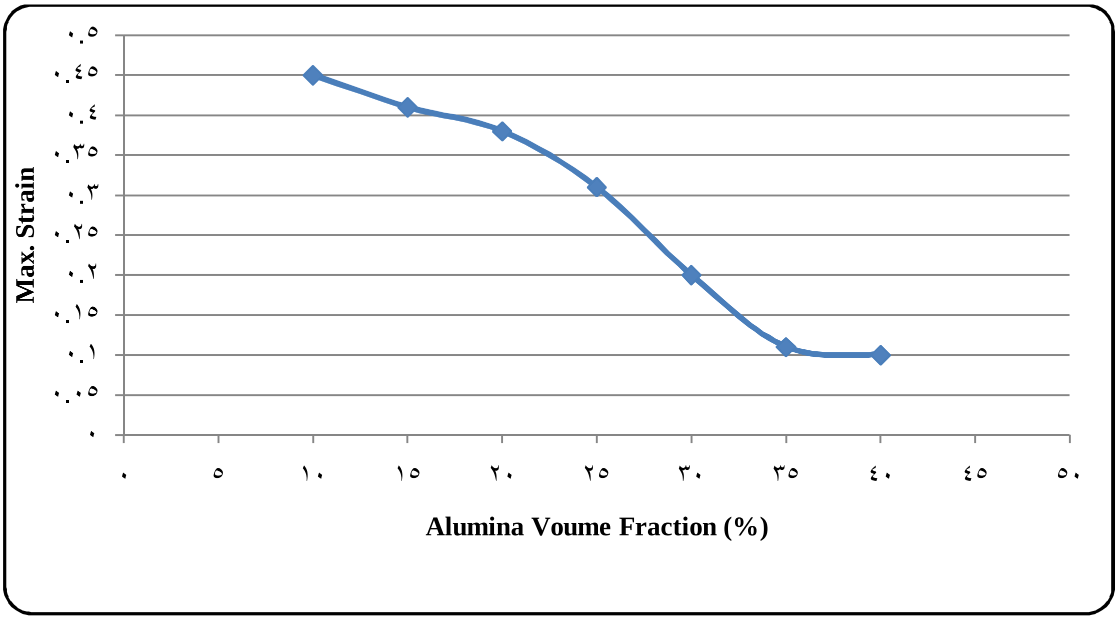

Figure (3) Effect of Alumina Volume Fraction on Maximum Strain

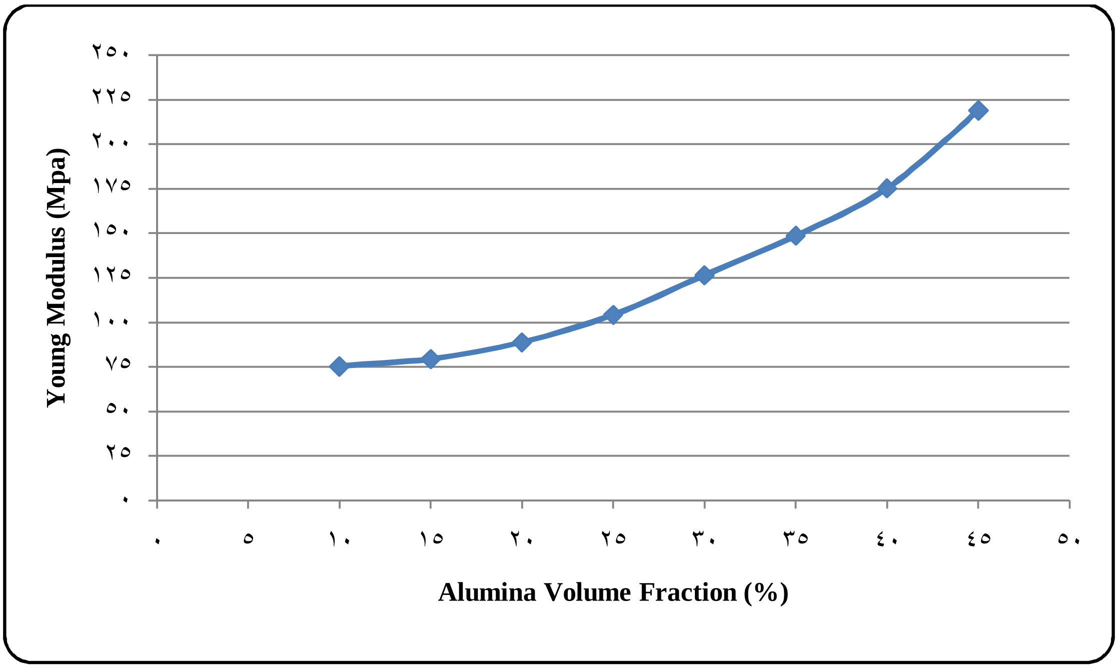

Figure (4) Effect of Alumina Volume Fraction on Young Modulus

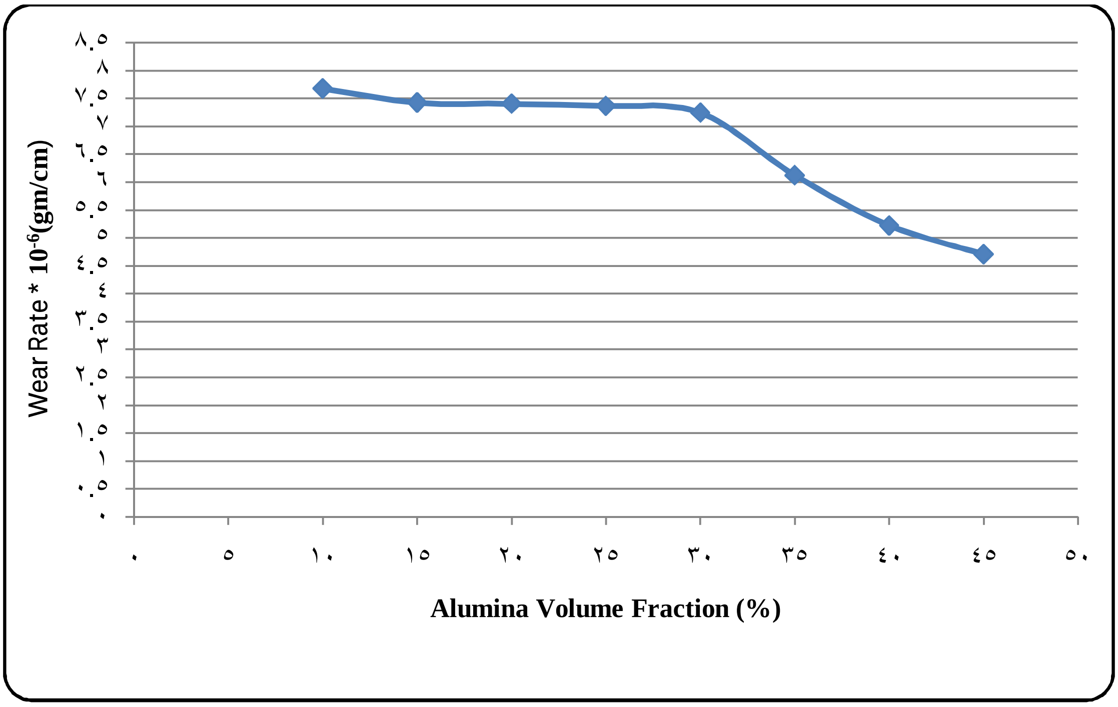

Figure (5) Effect of Alumina Volume Fraction on Wear Rate

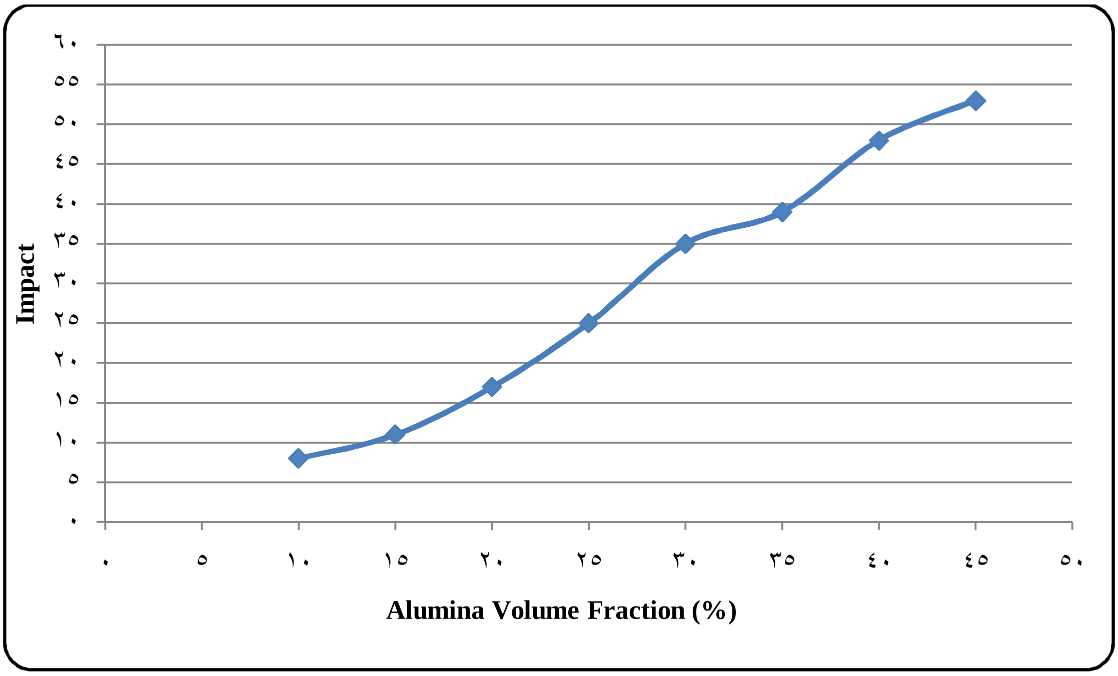

Figure (6) Effect of Alumina Volume Fraction on Impact