Influence of Boron Carbide Reinforcement on Mechanical Properties of Aluminum Base Composite Prepared by Stir and Squeeze Casting

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Abstract

Aluminum metal matrix composites reinforced by ceramic particles have a wide acceptance in engineering applications due to their mechanical and physical properties. The present work aims at investigating the effect of B4C particles ons ome mechanical and physical properties of Al –base matrix. All samples were prepared by two-step stir casting method with squeezing the melt during its solidification. Aluminum metal matrix samples of 2wt%Mg with (0,2,4,and 6wt%) ofB4C particles were prepared. The effect of such additions of these particles on hardness, tensile properties were investigated, also the microstructures were analyzed using optical microscopic and (SEM-EDS) analysis. The results showed a maximum increase of (53%) in Brinel's hardness by adding 6% of boron carbide, while the yield stress, tensile strength and the modulus of elasticity were increased by 11%, 51% , and 51% respectively due to add 4% of boron carbide. The SEM-EDS analyses confirm the presence of B_4C particles within the Al-base matrix. The microscopic tests indicated the homogenous dispersion of the addition of 4wt% B_4C.

Key words: Aluminum Composite, Squeezing, Stir Casting, B_4C

الخلاصة

الالمنيوم المقوى بالدقائق السيراميكية يمتلك مقبولية واسعة في التطبيقات الهندسية لما يمتلكه من خواص ميكانيكية وفيزيائية . الهدف من هذا العمل هو التحقيق في تأثير دقائق من (B_4C) على بعض الخواص الميكانيكية والفيزيائية لمادة متراكبة ذات اساس الالمنيوم .كل العينات حضرت بخطوتين طريقة السباكة الدوامة مع عصر المذاب خلال تجميد المذاب. عينات اساس الالمنيوم المحضرة تحتوي على(2%Mg) وتحتوي(0,2,4,6%) من دقائق(B_4C) .التحقيق في تأثير كل اضافة من الدقائق على الصلادة ،خواص الشد وكذلك البنية المجهرية التي حلل باستخدام المجهر الضوئي وتحليل(SEM-EDS).النتائج تظهر اعلى زيادة (53%) في صلادة برينل باضافة 6%من كاربيد البورون ،بينما اجهاد الخضوع ،مقاومة الشد،معامل يونك تزداد 11%،51%و51% على التوالي باضافة 4% من كاربيد البورون. تحليل SEM-EDS يؤكد وجود دقائق من B_4C داخل مصفوفة الالمنيوم . اختبار المجهر اشار الى التشتيت المتجانس لاضافة 4%من B_4C.

الكلمات المفتاحية : مركبات الالمنيوم ،العصر،السباكة الدوامة ،B_4C.

1.Introduction:

Metal matrix composites (MMCs) are metals reinforced with other metal, ceramic or organic compounds. Aluminum and its alloys have attracted most attention as a base metal to produce metal matrix composites with low density, superior malleability, high specific strength, excellent corrosion resistance and good thermal and electrical conductivity. In recent years, aluminum matrix composites (AMCs) have gained importance in aerospace, structural and automotive applications due to their light-weight and good mechanical properties(Rao *et.al.*,2016). Aluminum alloys reinforced with ceramic particles exhibit superior mechanical properties and hence are candidates for many engineering applications (Shuvendu ,2009; Rino *et.al.*, 2012). Most often reinforcement materials for MMCs are ceramic particles like carbides, graphite [Al-Ethari and Njem,2014), oxides as (Al2O3), nitrides as cubic boron nitrides (CBN) (Askeland *et.al.*,2010), and fly ash (Hayyawi *et.al.*, 2016). Such ceramic reinforcements are characterized by their high strength and stiffness both at ambient and elevated temperatures (Behera *et.al.*, 2011).The main objective of this work is to prepare aluminum metal matrix composites (AMMCs) with increased mechanical properties using particles of B4C as reinforcement. Two-step stir casting as well squeezing the melt during solidification will be used to prepare composites with various percentages of the reinforcing particles. Physical and mechanical properties as hardness, tensile properties of such composites will be studied. Physical tests include XRD, particle size analyses for the used powder, optical microscopic as well as SEM-EDS analyses for the prepared samples.

2. Experimental Procedure:

2.1.Tests for Basic Materials:

The materials used in this work are aluminum wire and powder of boron carbide, B4C. The chemical composition of used aluminum wire is demonstrated in table (1) according to the test of (UR State Company for Engineerin Industries\Nassyria-Iraq).

Table (1): Chemical composition of used aluminum wire

Si	Fe	Cu	Mn	Mg	Zn	Ti	B	v	Cr	Others total	Al
0.06	0.12	0.01	0.01	0.02	0.03	0.01	0.005	0.01	0.01	0.015	Bal

Powder of B4C with an average particle size of 0.387µm was used as a reinforcement. X-Ray diffraction and particle size analyses had been carried out for the used B4C powder. The analyses were achieved at the laboratories of the Materials Engineering College /University of Babylon. Fig (1) represents the chart of the XRay diffraction for the used powder , while table (2) demonstrates the analyzed material data due to the test . The speed used was (5deg/min), the step was (0.02 deg.), and the used angle 2θ was 10º to 60º with Cu target, wave length of 1.54060 Aº, voltage and current of 40 KV and 30 mA respectively.

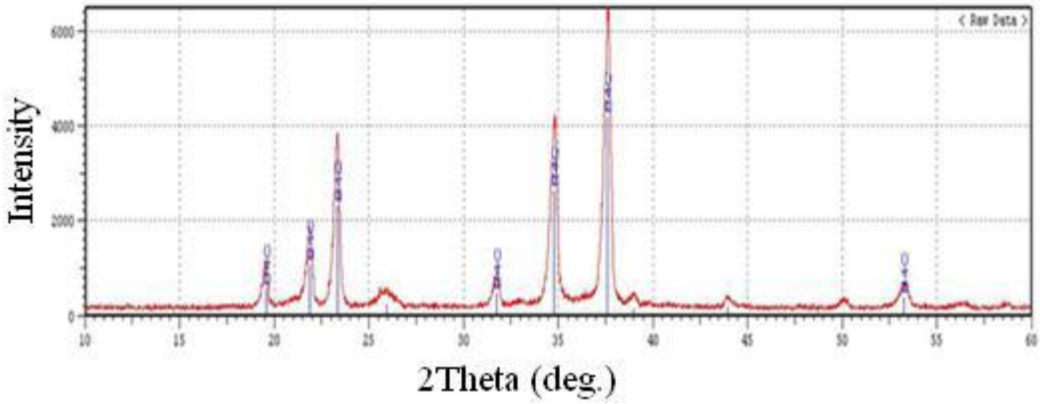
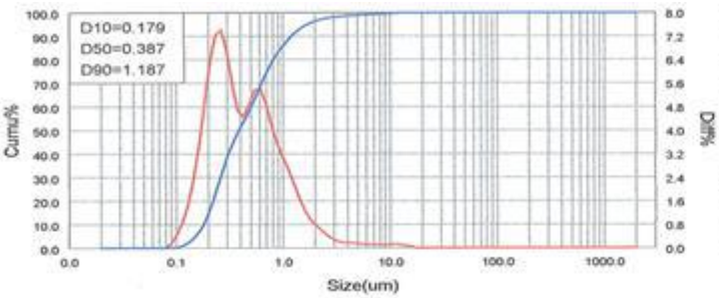


Fig. (1): XRD Pattern of the used B4C powder

Table (2):Results of XRD analyses for B4C **powder**

Peak no	2 Ɵ	d_{hkl}(A˚)	Phase
1	19.62	2.39005	B_4C
2	21.89	2.57733	B_4C
3	23.41	3.80750	B_4C

Particle size analysis result is shown in Fig (2) .It is clear that the B4C powder has an average particle size of 0.387µm(or 387nm). The test was achieved via laser particle size analyzer type (Better size 2000) at the laboratories of Materials Engineering College/University of Babylon.



Diam um	Percent
0.100	0.31
0.200	14.65
0.500	59.83
1.000	85.97
2.000	96.32
5.000	98.89
10.000	99.59
20.000	100.00
45.000	100.00
75.000	100.00

Fig. (2): Particle size analysis for B4C powder

2.2.Preperation of Al-base Composite:

To study the effect of B4C particles on mechanical and physical properties of Al– base composite, samples with 2wt% of Mg and (0, 2, 4, and 6wt%) of B4C were prepared. All samples were prepared and tested at the laboratories of Materials Engineering College /University of Babylon. Two-step stir casting method was used for preparing the samples. The weighted B4C particles were divided to groups, covered with aluminum foil and preheated to (3000C) for 2 hours in dry oven. Pieces of aluminum wires were charged in to graphite crucible, and the furnace temperature was raised up to liquidus temperature (7500C). Slags were removed using alumina spoon, and further the melt temperature was dropped to just below the liquidus temperature (6200C) to attain the semi-solid state. The magnesium ribbon was rolled and covered by aluminum foil, and then immersed inside the melt. The molten aluminum slurry was stirred with four-blade mild steel stirrer with a speed of (870 rpm) for (7min).The covered and preheated particles were slowly added to the molten metal. The stirring process was going under a shield of argon gas. The temperature during stirring was observed, using thermocouple type-K, to be (610-6200C.Then, the temperature was raised above the liquidus temperature (7500C) again. The melt was poured into a preheated to (250°C) cast iron die with a cavity of (20mm) diameter and (120 mm) height. During solidification the composite was squeezed for a period of (5 minutes) by using a squeezing pressure of (95 MPa) via electric press(EOH).The cast was left to cool in a still air. The organized stir casting and squeezing systems are shown in Fig. (3). The cast samples were heated to (300°C) for 3 hours for stress relief.

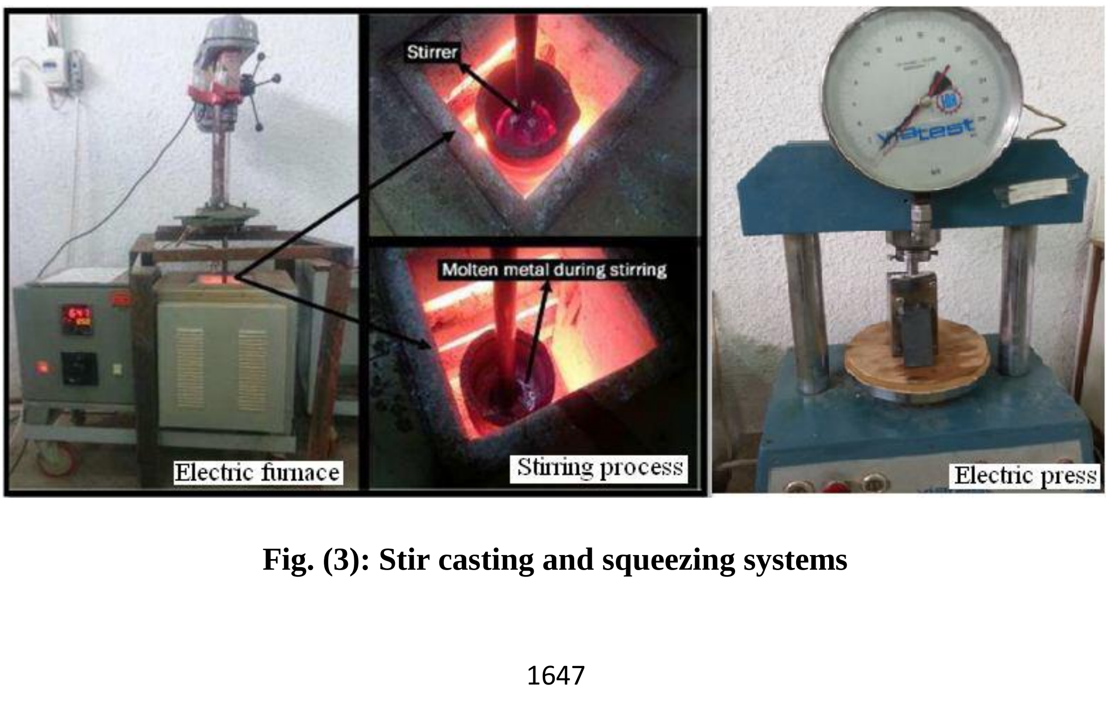


Fig. (3): Stir casting and squeezing systems

2.3. Mechanical and Physical Tests:

2.3.1. Microscope Analyses:

Specimens of 20mm diameter and 12mm height were ground by using paper grinding (180,220,320,400,600,800,1000,1200, 2000,2500) and then polished by using the diamond solution , Grinding and polishing were achieved on a grinding and polishing machine type (MP-2M). Etching solution (Keller) consist of (0.5%HF, 99.5 %H2O) at the room temperature was used. Samples were washed by distilled water and dryed by using electric drier type(TH 6000). Optical microscope type(OLYMPUS) was used to capture the microstructure of the surface samples. SEM images were taken for the failure zone of the specimens. This test was carried out at the laboratory of Pharmacym College/University of Babylon by using scanning electron microscope model (FEI, Quanta 450).

2.3.2. Brinel's Hardness Test:

Appropriate grinding and polishing were carried out before subjecting the specimens (20 mm diameter x 12 mm height) to the hardness test. The test was conducted on Micro Brinel's hardness device using weight of (31.25 Kg) for 10 sec with a diameter ball of 2.5mm. The hardness was recorded as an average of three hardness readings for each specimen . The test was achieved on a hardness tester type (WILSON HARDNESS UH-250).

2.3.3. Tensile Test:

Standard specimens were prepared according to ASTM (B557m-15)[ASTM B557M-15,2015].Computer control universal testing machine model (WDW-200) was used with tensile speed rate of 0.1mm/min at the room temperature. Specimens before and after testing are shown in Fig. (4).

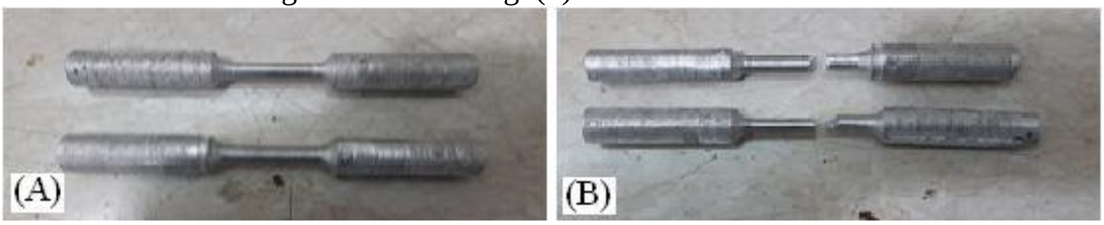


Fig.(4) Tensile specimens: (A) Before testing (B) After testing

3.Results and Discussion:

3.1. Microstructure Analysis:

The results of the optical and the scanning electron microscopic tests of the prepared composites are shown in Fig.(5) and Fig. (6) respectively. A uniform distribution of B4C particles can be observed. It is clear that there is a good bonding between matrix material and the reinforcing particles as there is no gap between them. It is clearly shown that the use of stir casting and squeezing during preparation of these composites induced an acceptable distribution of the reinforcing B4C particles in the matrix with little agglomeration of the particles in the samples.

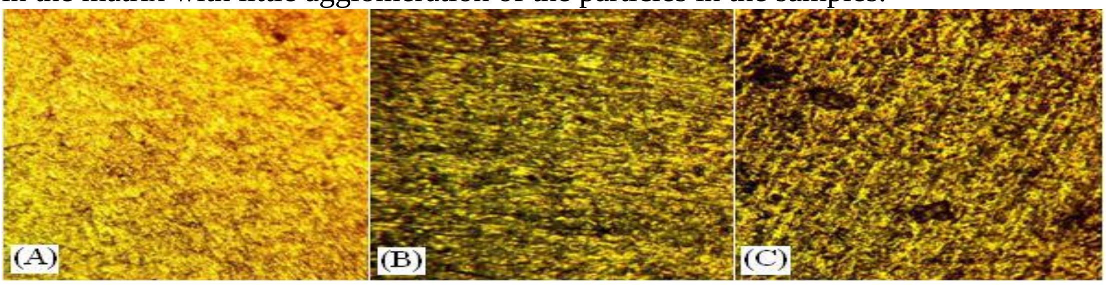


Fig.(5): Optical Microscope Image (x20) for the Specimen With (A) 2Wt%B4C; (B) 4Wt% B4C; and (C) 6Wt%B4C

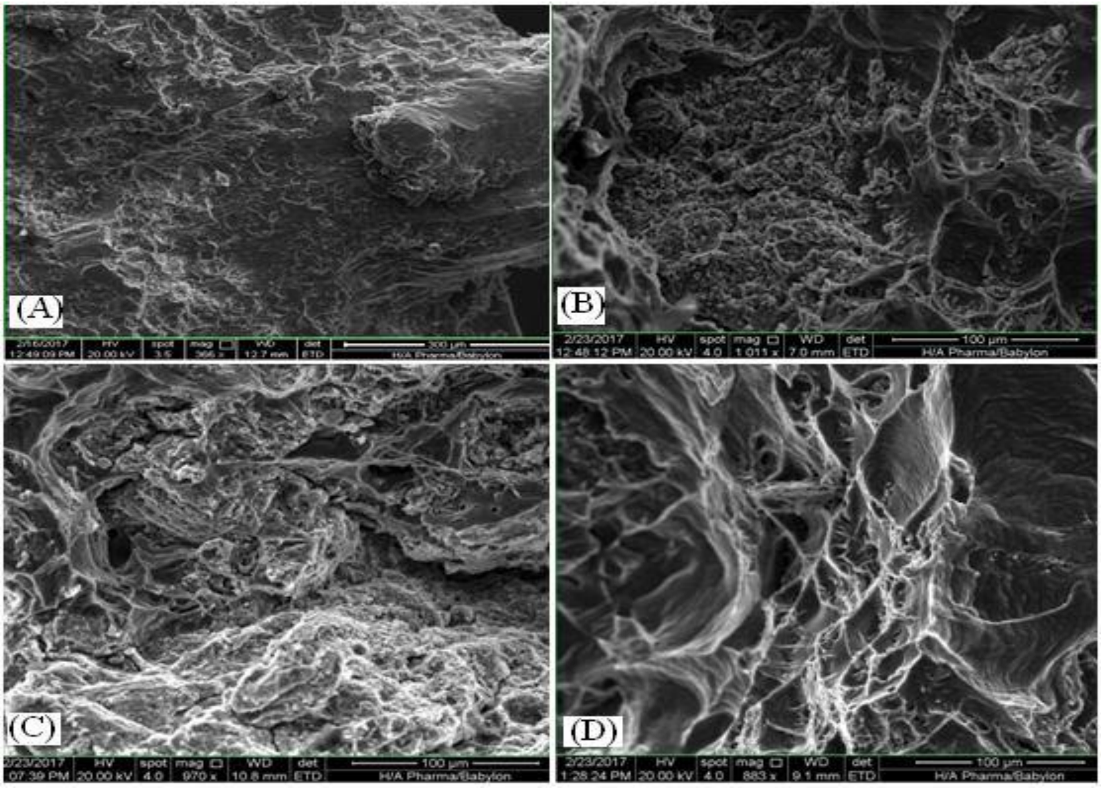


Fig.(6): SEM images of sample: (A) without B4C; (B) with 2Wt% B4C; (C) with 4Wt%B4C; and (D) with 6Wt% B4C

The results of EDS tests confirmed the presence of B4C in the samples. Figure (7) shows the result of EDS test for the sample of 4wt% boron carbide. As shown boron (B) and carbon (C) are clearly noticed in the figure.

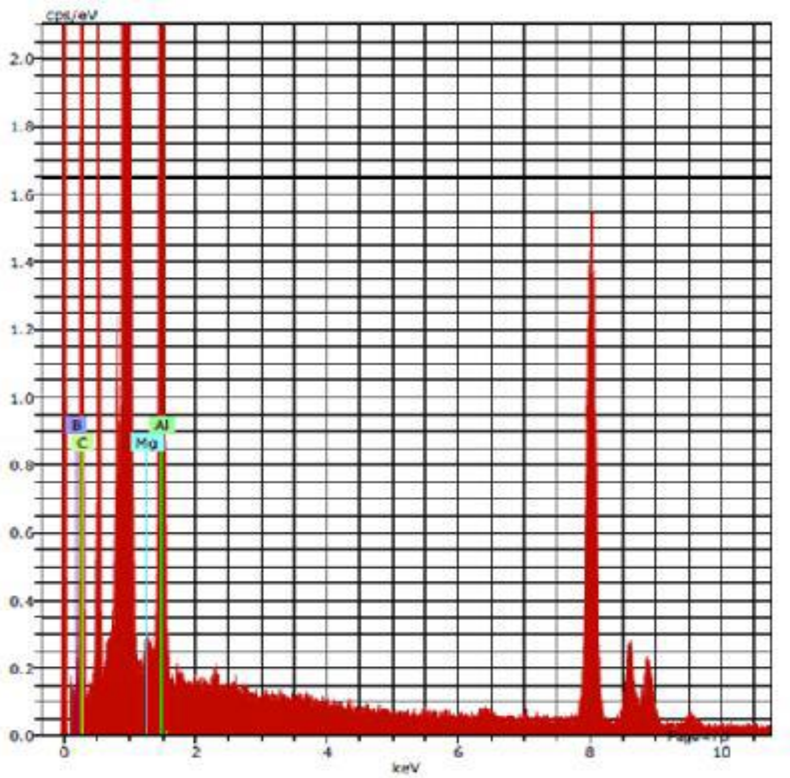


Fig.(7): The EDS analysis of the sample with 4wt% of B4C

3.2. Hardness Test:

The results of Brinell hardness test are demonstrated in Fig.(7). It is concluded that hardness is increased with the increasing of B_4C percentage. The greatest value was recorded for the sample with 6wt% of B_4C. These increment could be attributed to the relatively high hardness of the reinforcing particles which acting as barriers to dislocations motion or the matrix motion. The results are in agreement with what has been state in (Krishna et. al., 2013; Rao and Padmanabhan,2012).

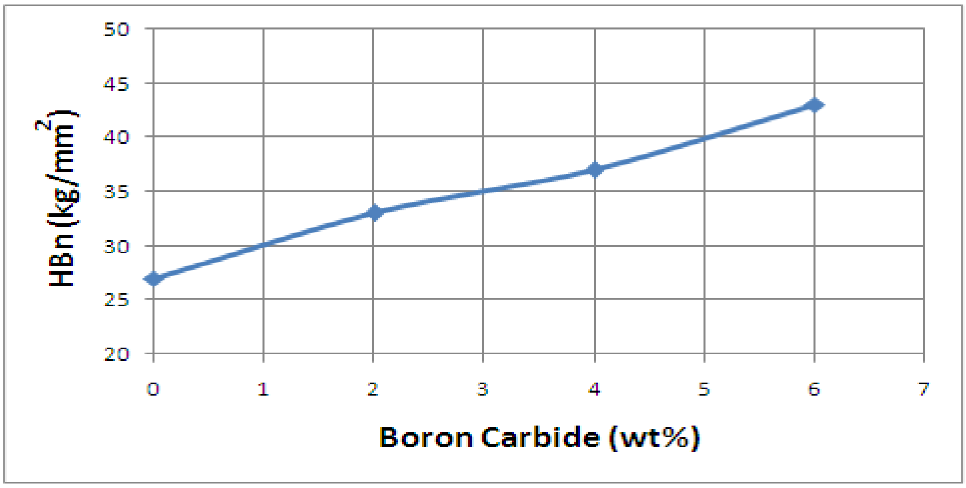


Fig.(7): Effect of boron carbide on the hardness of the composites

3.3.Tensile Test:

The results of the tensile tests are shown in Fig (8).The figure shows the effect of boron carbide on the tensile strength, yield point, and the modulus of elasticity of aluminum matrix. It is clear that the strength and the modulus of elasticity increase with the percentage of boron carbide. This increment is due to the role of B4C particles which tend to restrain the movement of the matrix in their vicinity and tend to impede the dislocation motion. The maximum improvements in the modulus of elasticity, yield point, and the tensile strength were 7%, 51%, and 51% respectively. These improvements were recorded for the specimen of 4wt% B4C. The agglomeration of reinforcing particles in 6wt% sample causes a poor wettability between the particles and the matrix, that the bonding was weekend so the strength was given just a slight increase. The results of the tensile test and the tensile behavior of the prepared composite are in agreement with (Krishna *et.al.*, 2013; Bhandakkar1 *et.al.*, 2014).

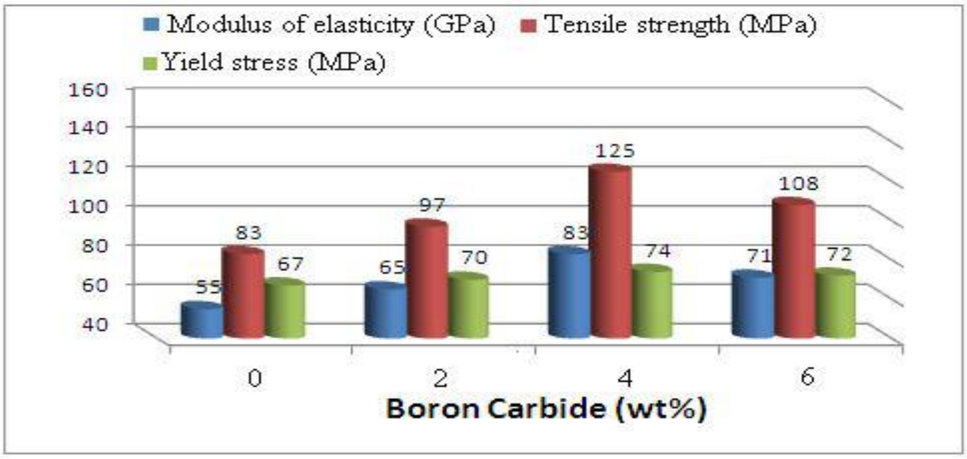


Fig.(8): Effect of boron carbide on the tensile properties of the composites

4.Conclusions:

Based on the results obtained in the present work, the conclusions can be summarized as follows:

1. Stir casting with squeezing during solidification is suitable to prepare MMC reinforced with B4C particles.
2. Particles of B4C improve the mechanical properties of Al-matrix. Among the prepared specimens a greatest improvement of 53% in the hardness was recorded for the specimen with 6wt% of B4C, while an improvement of 50% was achieved via an addition of 4wt% of B4C**.** The maximum improvements in the tensile properties were recorded for the specimen with 4wt% of B4C, so as the yield stress, tensile strength and the modulus of elasticity were increased by 11%, 51% , and 51% respectively.

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