Effect of Titanium Carbide Particles on Mechanical Properties of Aluminum Matrix Composites

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Abstract. In this research aluminum matrix composites (AMCs) was reinforced by titanium carbide (TiC) particles and was produced. Powder metallurgy technique (PM) has been used to fabricate AMCs reinforced with various amounts (0%, 4%, 8%, 12%, 16% and 20% volume fraction) of TiC particles to study the effect of different volume fractions on mechanical properties of the Al-TiC composites. Measurements of compression strength and hardness showed that mechanical properties of composites increased with an increase in volume fraction of TiC Particles. Al-20 % vol. TiC composites exhibited the best properties with hardness value (97HRB) and compression strength value (275Mpa).

Key Words: Aluminum matrix composites, Titanium carbide particles, Mechanical properties, Compression Strength, Rockwell hardness, Powder metallurgy technique.

تأثير حبيبات كاربيد التيتانيوم على بعض الخواص الميكانيكية لماده متراكبه ذات اساس المنيوم

الخلاصه. تم في هذا البحث انتاج مادة متراكبة ذات اساس المنيوم مدعم بكاربيد التيتانيوم .تقنيه ميتالوجيا المساحيق استعملت في تصنيع المادة المركبة التي اساسها الالمنيوم المدعمة بنسب حجميه مختلفة تتراوح من ماده التقوية ,0%) 4 ,%8%, 12%, 16% and 20%) كاربيد التيتانيوم لدراسة تأثير هذه النسب الحجمية المختلفة على الخواص الميكانيكية للمادة الجديدة. تم فحص الخواص الميكانيكية (قوه الانضغاط والصلادة) وحصلنا على النتائج , وبصوره عامه وجدنا أن الخواص الميكانيكية تزداد مع زياده النسب الحجمية لحبيبات كاربيد التيتانيوم. وكانت أفضل خواص ميكانيكيه لعينات المواد المتراكبة Al (20%TiC+ حيث غير المدعم مقارنه بعينات الالمنيوم 80%) كانت اعلى زياده بقيمه الصلادة (97HRB) وقوه الانضغاط Mpa) . (275

الكلمات الأساسية :متراكبات الالمنيوم , حبيبات كاربيد التيتانيوم ,الخواص الميكانيكية , صلادة روكويل , قوة الانضغاط , عمليه ميتالوجيا المساحيق.

1. Introduction

After 2007, metal matrix composites (MMCs) were increasingly used around the world to reach up 4.4 million-kg and this number is in continuous growth [1].

Particulate reinforced aluminum matrix composites (AMCs) have many applications in varied fields such as forgings for suspension, mechanic structures, chassis, besides advanced automotive components which are exposed to huge difference of environment. Aluminum reinforced with carbides, nitrides, ceramic, mineral silicate and oxides particulates possess amazing properties such as low cost, high specific strength, superior corrosion resistance, low thermal expansion, high specific modulus and light weight [2].

Particle reinforced metal matrix composites such as TiC, SiC and B4C are probably to find high volumes of mechanical applications. Improved properties, ease of fabrication and isotropic properties are the fundamental for metal matrix composites [3].

Particle reinforced metal matrix composite is one of collection materials which the high hardness, resistance of the reinforcement is gathering between the toughness and ductility of matrix materials. Aluminum is number one use as matrix material because it's easy fabricability, low density, and good engineering properties. Therefore, AMCs have been applied successfully to structural components, [4, 5].

The best physical and mechanical properties of aluminum matrix composites make great interest as a result to hard ceramic particle. Some ceramic reinforcements have been known for aluminum matrix

composites, but lately TiC has got attention over others because of its wear resistance, ductility, stiffness, toughness and high hardness [6].
TiC particle-reinforced MMCs have been developed by many researchers because of the thermodynamically stability of TiC and the hardness and low density which it imparts to the composite, also TiC reinforced aluminum matrix composites (AMCs) are increasingly being used in the cutting tools , aircraft , space industries and automobile.
World general attention has been focused on the fabrication and processing of MMCs due to both performance and favorable manufacturing costs [7].
Titanium carbide reinforced aluminum matrix composites (AMCs) can be produced by different processes. But powder metallurgy process is particularly attractive as it is practical and economical.
Powder metallurgy technique consists of 3 steps; mixing powders, compacting those powders in a suitable die at room temperature and later heating or sintering the sample in a controlled atmosphere furnace [8].
The powder metallurgy fabrication of AMCs gives best mechanical properties and also to obtain AMCs with ideal properties which is cheap process [9].

M. Ali et al. in 2011 studied the influence of various weight fraction of TiC particles (0%, 5%, 15%, 25%) on mechanical, electrical and microstructure properties of Al –TiC composites and exhibited the aluminum with 25% TiC had best properties such as micro-hardness value (63.7Hv) and wear rate (0.043mm^3/s) [7].

P. Dhanasekaran et al. in 2015 selected the Al alloy (AA6063) as matrix and TiC particles with different weight percentage (2%, 4% and 6%) as reinforcement by stir casting process. It is concluded the increasing of TiC particles lead to increase in the mechanical properties [10].

S. Mohapatra et al. in 2016 investigated the uniform distribution of titanium carbide particles in aluminum matrix with various volumes fraction (5%, 10%, and 20%) and showed that the compressive strength increasing with the increased volume fraction of TiC reinforcement from 5% to 20% , maximum value of compressive strength recorded (360Mpa) at 20% Vol. [11].

R. N. Rai et al. in 2016 used the weight fraction of TiC particles (0%, 3%, 5%, and 10%) and studied the effect of these percentages of TiC on yield stress of Al-TiC composites .It is observed that the increasing in wt% of TiC lead to increase in amount of the tensile strength and yield stress of Al- TiC composite but decrease in the elongation of Al- TiC composite [12].

The present work Al-TiC composites have been fabricated and examined the effects of TiC ratio on mechanical properties and selected the optimum percentage of TiC particle which can be used to obtain maximum values of hardness and compressive strength.

2. Experimental Work

2.1 Materials

Commercial pure aluminum powder can be considered as matrix because it is low cost, easily formable and desirable properties such as chemical reactivity at high temperature, density, and irritability**.** Aluminum was procured from Sigma, Aldrich /Germany. The chemical composition of Aluminum as shown in the below table (1).
Titanium carbide powder is selected as reinforcement material. Titanium carbide was supplied by M/s Alfa Aesar, India. The chemical composition of titanium carbide as shown in the below table (2).
Al and TiC powders have been inspected at Ministry of Sciences and Technology – Baghdad, the results were found in the below table (3).

Table (1): The chemical composition of aluminum.

Elements	Si	Fe	Cr	Cu	Mn	Zn	Mg	Al
Percentage%	0.1	0.07	0.03	0.04	0.03	0.01	0.02	Balance

Table (2): The chemical composition of titanium carbide.

Elements	Ti	C	Nb	O	Fe	N
Percentage%	79.91	20.03	0.01	0.03	0.01	0.01

Table (3): The results of powders inspection.

Powders	Purity%	Average particle size (µm)	Density (gm/cm³)
Aluminum	99.7	~39	2.6
Titanium carbide	99.9	~24	4.8

2.2 Process

Al/TiC composites were prepared by powder metallurgy process as shown in figure (1). Initially, TiC particulates were added to Al powder in various volume fractions (0, 4, 8, 12, 16 and 20 vol. %) by using sensitive balance of (4 digits) with an accuracy of (± 0.1 mg) as shown in figure (2).
The percentages of TiC (0, 4, 8, 12, 16 and 20 vol. %) were chosen in consideration of the above research and showed that the higher percentage of TiC particles (higher than 30 wt. %) lead to decrease in the mechanical properties. When lower composition of Al-TiC best properties are exhibited this can be explained by strong interfacial bonding between TiC particles [10].
The powders were perfect and they were mixed for (3 hours) in a ball mill at (300 rpm) as shown in figure (2) with the addition of n-hexane (n-C6H14) so that prevent powders oxidation because frictional heat. After that the mixed powders were dried for (10 hours) in the furnace at (75 °C).
Mixed powders with various percentages of volume fraction (0%, 4%, 8%, 12%, 16% and 20%) of TiC particles were pressed at (250 Mpa) in a special die from tool steel (Ø 20mm × 50mm) to get the compression strength test samples when the specimens dimensions (Ø 20mm × 15mm) as shown in figure (3) according to ASTM E 9 – 89a standardization[13] (Suggested Solid Cylindrical Specimens) by using hydraulic press type ICI international crystal laboratories, made in USA. Die wall lubrication was applied by (zinc stearate) over die cavity and the top punch as shown in figure (4).
Sintering was executed for (3 hours) in the argon atmosphere furnace at 600 °C and cooling carried out by slow until reached room temperature as shown in figure (5).

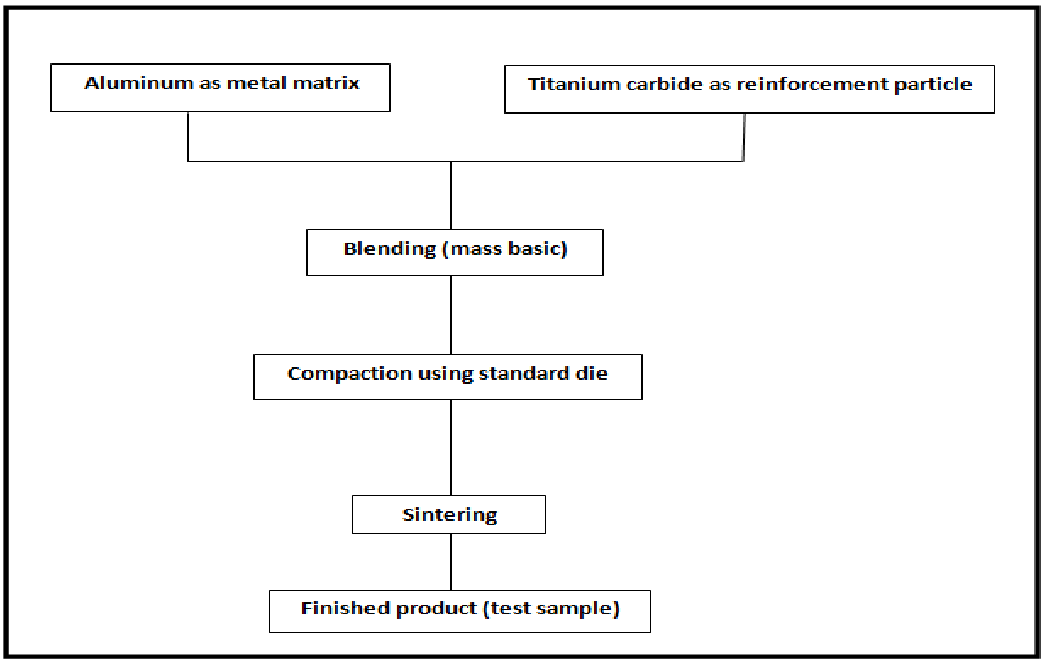

Figure1: Step by step method of powder metallurgy process.

Figure 2: Blending process (sensitive electronic balance and ball mill).

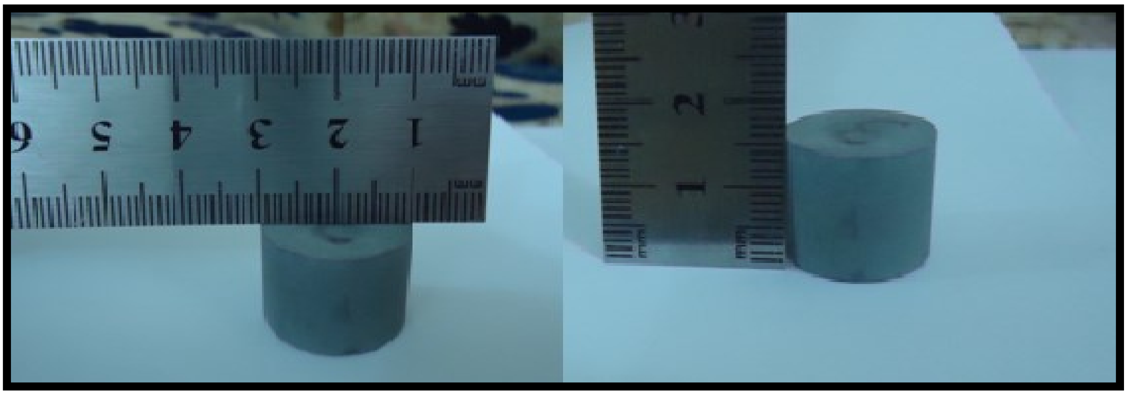

Figure 3:Dimension of sample.

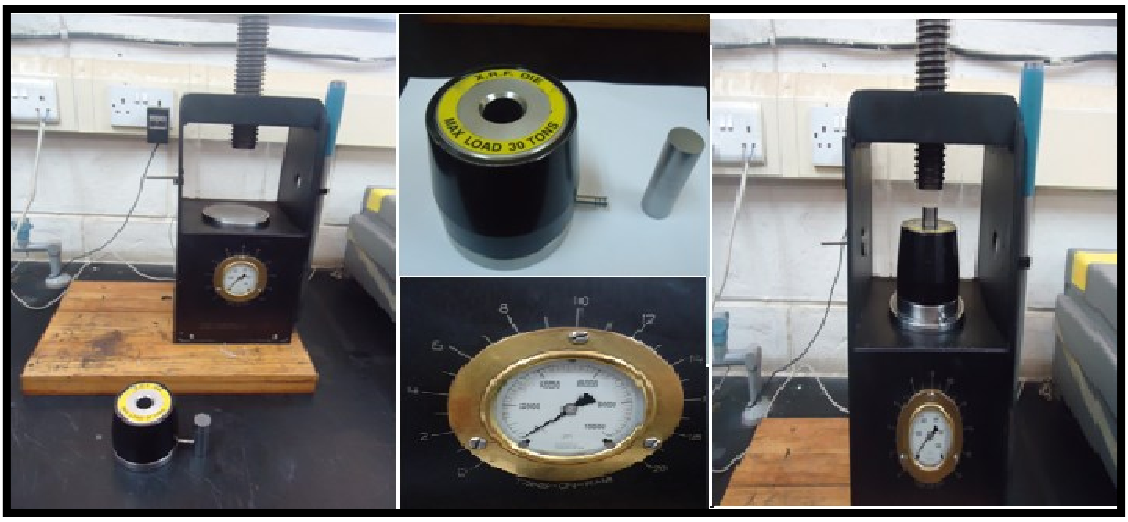

Figure 4: Compaction process (hydraulic press and standard die).

Figure 5: Sintering process (furnace and argon atmosphere).

2.3 Mechanical Properties Test

2.3.1 Hardness Test

Hardness of the samples was determined using Rockwell hardness (HRB) testing machine. The Rockwell hardness values of the three samples were measured on the polished samples. The indenter used was 1.588 mm (1⁄16 in.) diameter of steel ball and total test force 981 N (100 kgf).
The general principles of the Rockwell hardness test are illustrated in figure (6) when used ball indenters and the accompanying table (4) according ASTM E18-02 [14].
Inspection processes of samples hardness carried out by taking nine readings for each sample from the center to areas around to appear homogeneity of property across section area .After that the average of reading samples was calculate and find the mean value of each section as shown in figure (7).

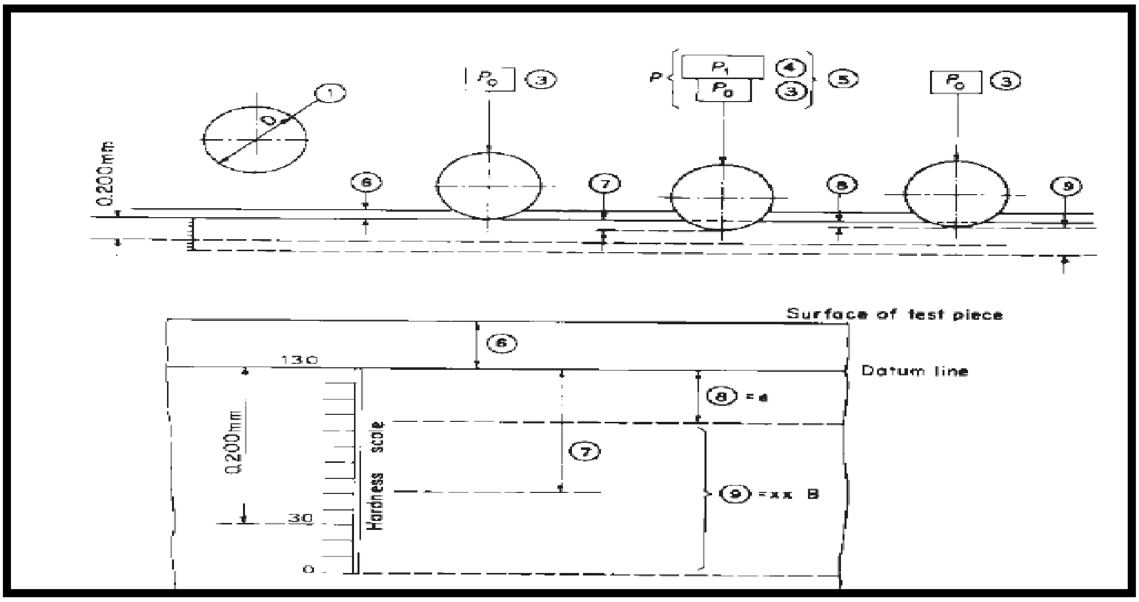

Figure 6: Rockwell hardness test with ball indenter [14].

Table 4: Symbols and designations associated with figure 6 [14].

Number	Symbol	Designation
1	*D*	Diameter of ball = 1⁄16 in. (1.588 mm)
3	P_0	Preliminary Test Force = 10 kgf (98 N)
4	P_1	Additional force = 90 kgf (883 N)
5	*P*	Total Test Force = $P_0 + P_1$ = 10 + 90 = 100 kgf (981 N)
6	...	Depth of penetration under preliminary test force before application of additional force
7	...	Increase in depth of penetration under additional force
8	*e*	Permanent increase in depth of penetration under preliminary test force after removal of the additional force, the increase being expressed in units of 0.002 mm
9	xx HRB	Rockwell B hardness = 130 − *e*

Figure 7: Rockwell hardness test device and the specimens, after hardness test.

2.3.2 Compression Strength Test

The summary of test method, when samples are put under an increasing compression load; both strain and load may be noted either in finite increments or continuously, after that the mechanical properties in compression estimated.

Compression tests were used for estimating both nature and mechanical properties of the composites. Five Compression samples of 15 mm length and 20 mm diameter according to ASTM E 9 – 89a standardization for short specimen with L/D (length/diameter ratio) equal 0.8 were used to calculate the ultimate Compression and the yield strengths of the specimen [13].

The samples should be centered with respect to the testing machine heads and both ends of the compression sample shall bear on blocks with parallel and surfaces flat.
The compression test apparatus as shown in figure (8), which include the testing machine and when applicable the following; the jig, the alignment device, and the strain measurement system.
Compression strength was estimated by the universal testing machine, made in England .The test was conducted using strain rate of 0.5 mm/min at room temperatures and max load capacity is 50 KN as shown in figure (9).

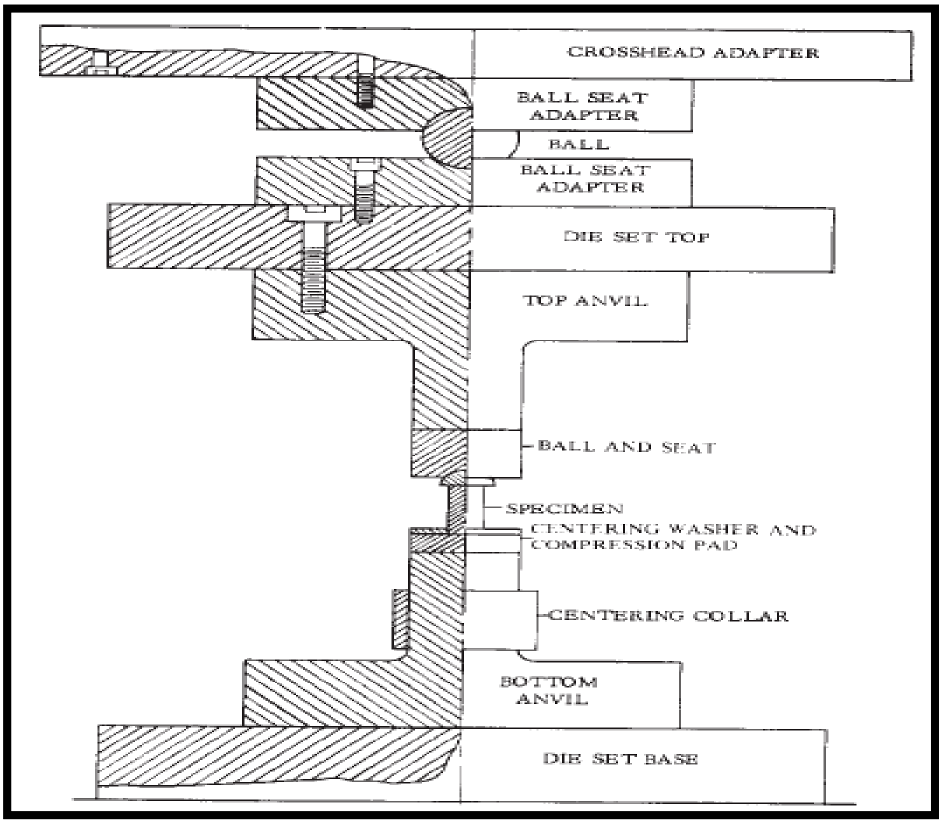

Figure7: Example of compression testing apparatus [13].

Figure 8: Universal testing machine for compression test.

3. Results and Discussion

The hardness test is the most informative and fast way to recognize the mechanical properties of composite materials. Hardness results of aluminum matrix composites with 0, 4, 8, 12, 16, and 20 vol. % of TiC are shown in figure (9).

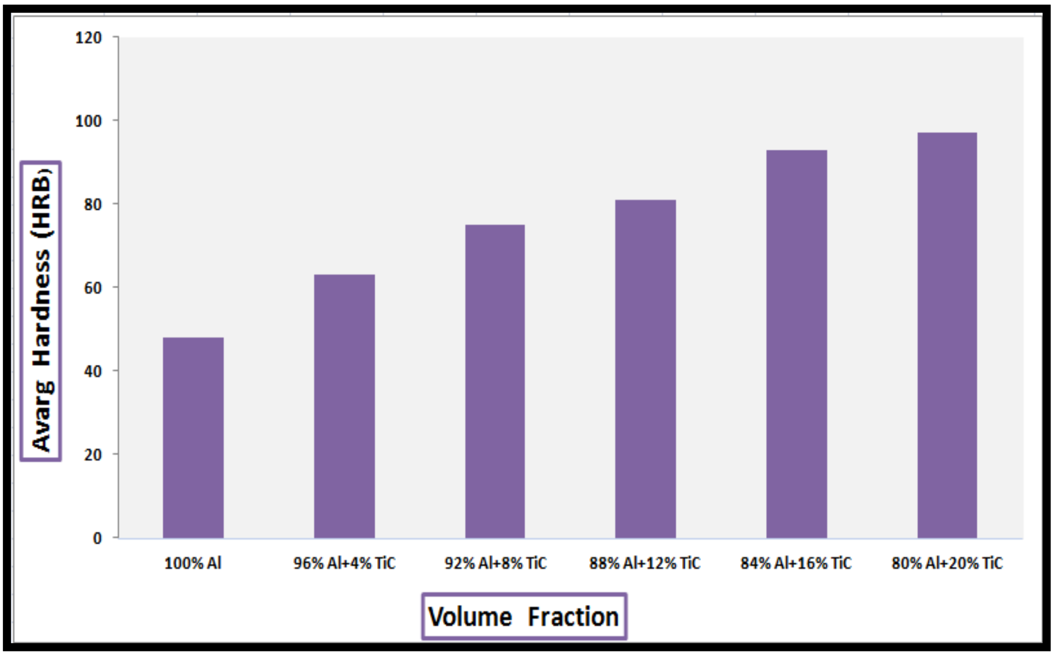

Figure 9: Effect different vol % of TiC on average hardness value.

The composite materials show high hardness if they are compared with only aluminum. The cause of this increasing to hard particles TiC, in the same time the ductility of composites is decreased. The higher hardness belongs to lower porosity between particles. Also finer grain size of matrix and reinforcement according table (3) leads to higher hardness [15]. TiC particles reinforced AMCs are very important because TiC is stable material, lightness of the composite and enhance the hardness. When TiC particles homogenize distribution in aluminum matrix, it imparts thermodynamic stability to AMCs and increases the hardness.

Absolutely, the increasing in the hardness of composite is because of the increased percentage of particles (TiC) in the matrix (Al). The improvement in the hardness refers to the distribution of particles TiC uniformly in the aluminum and increased the hardness of composite due to specific surface of TiC by volume fraction [11].

The finding of hard ceramic particles (TiC) in the matrix is not only the reason to raise the hardness of the composites but also depends on grain size of reinforcement, good interface bonding and the structure of the composite [16]. The decreasing in the depth of indentation which improves the hardness turn to the fact that the increased of hardness with increase in the volume fraction of TiC.

The compressive strength versus different percentage of TiC curve for the matrix and composites have been shown in figure (10).

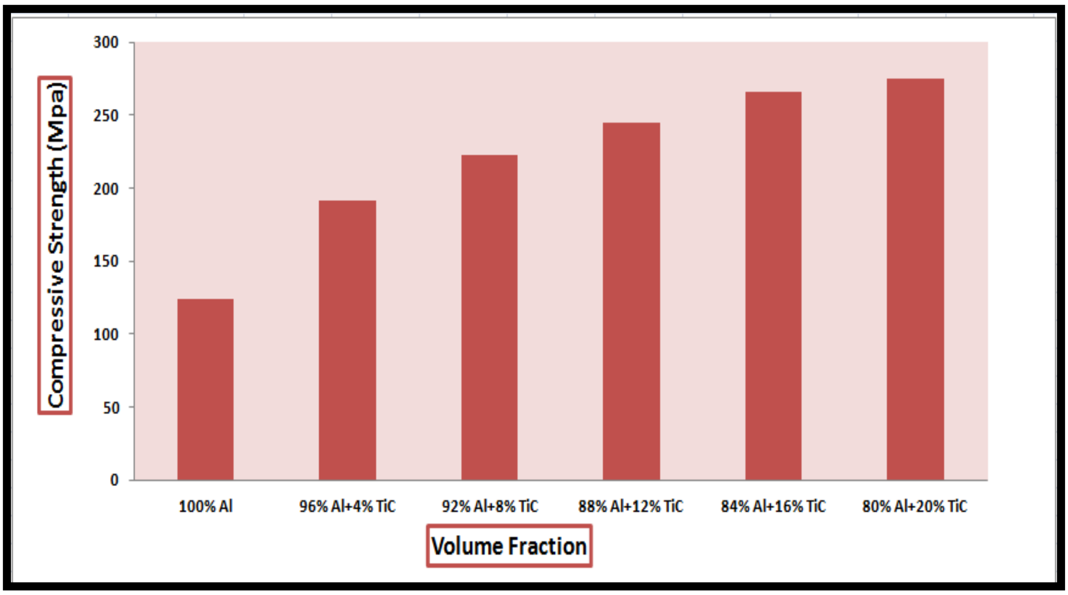

Figure 10: Effect different vol % of TiC on compressive strength value.

From the matrix to the composites values of compressive strength has been increased .The compressive strength increases from 124 MPa for Al matrix to 191, 223, 245, 266 and 275MPa with 4, 8, 12, 16 and 20 vol. % of reinforcement, respectively. That means the compressive strength of composite materials with 4% of TiC increases approximately (54%) higher than the matrix material.

Presence of TiC particulate offers resistance to deformation and it may also due to better bonding between particle and matrix interfaces. Generation of large clusters of reinforcement was minimized due to better mixing in the adopted technique and it might also due to grain refining nature of TiC [17].

Similarly, the yield strength increases with adding the particle reinforcement (TiC) from 69 MPa for Al matrix to 126,153,179,202 and 209 MPa for the composites with 4, 8, 12, 16 and 20 vol. % of reinforcement, respectively. That means the compressive strength of composite materials with 4% TiC increases approximately (83 %) higher than the matrix material. This shows clearly that the yield strength increases with more vol. % of TiC additions as shown in figure (11).

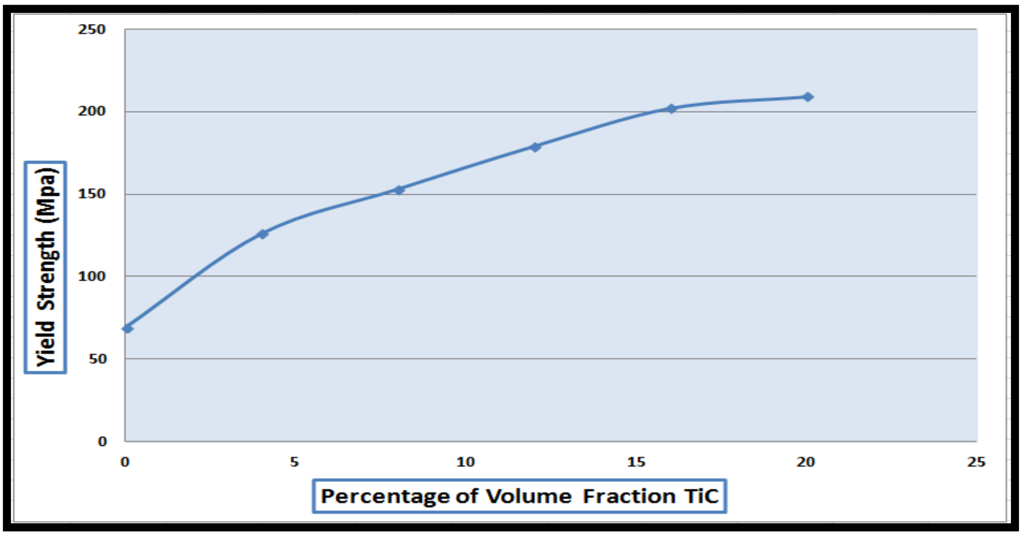

Figure 11: Effect different vol % of TiC on yield strength value.

Ductility is the important mechanical property in most of the engineering applications. The ductility of ceramic reinforced composite is typically less than that of matrix material. Effect of vol % of TiC addition in aluminum matrix on % elongation is shown in figure (12). From the figure, it is clear that the addition of TiC generally decreases % elongation. The strain of composite materials is lower than matrix material by percentages of 20% (from 20.5 to 16.3), 37% (from 20.5 to 13), 44% (from 20.5 to10.1), 63% (from 20.5 to 7.6), and 71% (from 20.5 to 6) for 4, 8, 12, 16 and 20 vol. % of reinforcement, respectively.

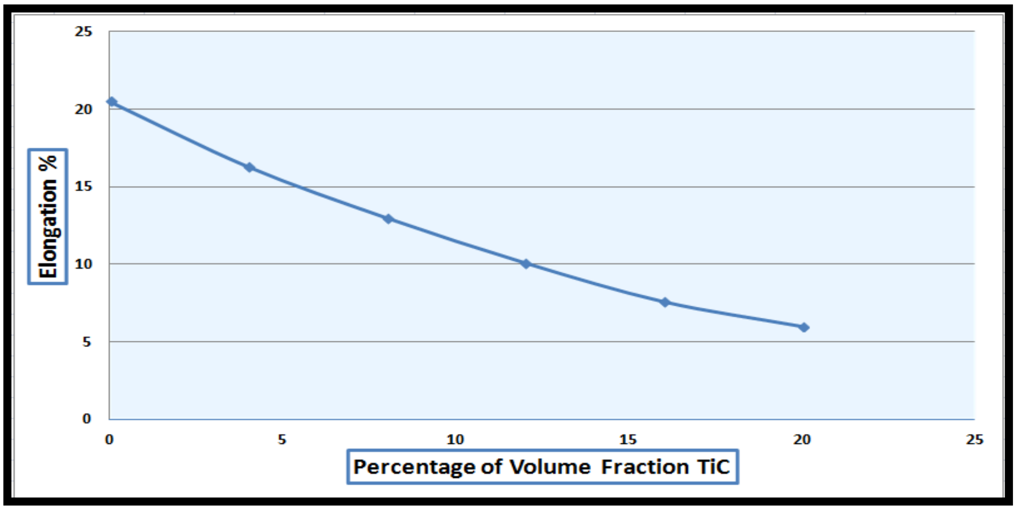

Figure 12: Effect different vol % of TiC on elongation value.

4. Conclusion

1- (Al-TiC) aluminum matrix composites have been prepared successfully at pressure 250 Mpa, temperature 600 °C and time 3 hours by powder metallurgy process.
2- The samples have shown from the matrix to the composites values of Rockwell hardness has been increased. The composite material (80% Al+20%TiC) has the highest Rockwell hardness value of (102%) relative to matrix material.
3- The samples have shown from the matrix to the composites values of compressive strength has been increased. The composite material (80% Al+20%TiC) has the compressive strength value of (122%) relative to matrix material.
4- The same previous indication was obtained in the yield strength and increased with adding TiC particles to reach maximum value at 20% vol. of TiC**.** The composite material (80% Al+20%TiC) has the yield strength value of (203%) relative to matrix material.
5- But the strain decrease with increasing particle reinforcement (TiC) to reach minimum value at 20% vol. of TiC. The composite material (80% Al+20%TiC) has the elongation value of (71%) relative to matrix material.
6- From the results and indications of compression strength ,yield strength and hardness properties can be estimated the optimum percentage of TiC particles was 20% vol., that means the best mechanical properties reach maximum increases for (80% Al+20%TiC).
7- Notice that the increase starts low when travel from 16% vol. of TiC to addition 20 %vol. of TiC, therefore most of searches not exceed 20% or 30% of reinforcement particles for studying the effect of addition because the higher percentage of TiC particles (higher than 30 wt. %) lead to decrease in the mechanical properties.

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