MECHANICAL AND STRUCTURAL BEHAVIOR OF ALUMINUM MATRIX COMPOSITE REINFORCED BY B_4C UNDER DIFFERENT PROCESSING TEMPERATURE AND VOLUME FRACTION OF REINFORCEMENT

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ABSTRACT

Aluminum matrix composites are very common engineering materials in automotive, aerospace and other applications due to their low weight, high strength, and excellent wear resistance. In this work, different amount of ceramic particles (B_4C) were incorporated into A356.1 (aluminum alloy) by stir-casting route. Processing temperature was 750, 850, and 950°C. This method was in order to achieve the homogeneous composite material and better solidification conditions. SEM micrographs show that reinforcing particles were dispersed homogeneously in the samples (not clustered). The hardness and tensile strength of B_4C reinforced aluminum were higher than those of the monolithic aluminum. The hardness and tensile strength were changed with increasing the processing temperature.
keywords: vortex method, B_4C, A356.1, aluminum matrix composite, SEM, hardness.

1. INTRODUCTION

There are several fabrication techniques available to manufacture MMC materials. Depending on the choice of matrix and reinforcement material, the fabrication techniques can vary considerably. Fabrication methods can be divided into three types. These are solid phase processes, liquid phase processes and semi-solid fabrication processes. Solid state processes are generally used to obtain the best mechanical properties in MMCs, particularly in discontinuous MMCs. This is because of segregation effects and also intermetallic phase formation is less for these processes, when compared with liquid state processes [1]. Among the variety of manufacturing processes available for discontinuous MMC production, stir casting is generally accepted, and currently practiced commercially [2, 3]. Stir casting of MMCs generally involves producing a melt of the selected matrix material, followed by introduction of a reinforcing material into the melt and obtaining a suitable dispersion through stirring. Vogel et al. [4] gave the term "stir-casting" to the production of metals with spheroid like microstructure by a shearing action induced by stirring. The terms "stir-casting" and "compo-casting" are used interchangeably in this work. Its advantages lie in its simplicity, flexibility and applicability to large scale production. It also, in principle, allows a conventional casting route to be used. This semi-solid metallurgy technique is the most economical of all the available routes for MMC production. It allows very large sized components to be fabricated, and is able to sustain high productivity rates. According to Skibo et al. [5], the cost of preparing composite materials using a casting method is about one third to one half that of competing methods, and for high volume production, it is projected that costs will fall to one tenth [6]. Metal-matrix composites are currently in service using matrix based on alloys of aluminum, titanium, iron, cobalt, copper, silver, and beryllium. Copper, silver, and beryllium MMCs are mostly used for thermal management and electrical contacts; iron MMCs are used for industrial wear-resistant applications, such as rollers and tool dies; and titanium MMCs are used primarily for automotive, aerospace, and recreational products. Cobalt MMCs (cemented carbides, or cermets) are included here as an MMC, although not all agree upon this classification, while oxide-dispersion strengthened nickel is explicitly excluded, because strengthening in these alloys occurs by a dislocation mechanism rather than a load-sharing mechanism. By far the most widely produced, MMCs are based on aluminum alloy matrix, and these are in current use for automotive and rail ground transportation, thermal management and electronic packaging, aerospace, and recreational applications. A wide range of cast and wrought aluminum alloys are used as matrix in aluminum MMCs [7]. The aluminum matrix composites reinforced by ultra-fine particles could be produced simply by smelting processing combined with stirring. This is an interesting method because of low price and its ability for the vast materials at different conditions. The primary duty of reinforcement particles in MMCs is resisting and transferring the incoming charge onto composite, in the boundary of particle and matrix [8].

The suitable wetability is a fundamental condition for combination of reinforcement particles with matrix aluminum throughout composite casting that guaranties the transfer and distribution of charge without the fracture of composite. These combinations could be formed by dissolution or chemical reaction of reinforcement particles with matrix metal. The chemical reactions are usually harmful because of reducing the mechanical properties [9]. For production of metal matrix composites reinforced by particles, the smelting methods are more attractive. In despite of its simple procedure, some parameters introduce that could be divided in tow groups: (a)- the parameters due to used materials (viscosity of molten mixture, chemical reaction of particles with molten metal and their movement); (b)- the parameters due to composite fabrication method (stirring temperature, stirring rate, situation and time of stirring) [10, 11].

Many studies have been made in fabrication of secondary phase particles reinforced materials [12-19], but there are few studies on Al/$ZrSiO_4$, Al/B_4C and Al/TiB_2. The A356.1 alloy which has been used in present research, has good casting and fluidity in aluminum matrix composites producing process [20]. In the present study, the effects of B_4C reinforcing particles on microstructure and mechanical properties of this alloy have been investigated and compared.

2. EXPERIMENTS

The major raw materials used in this research were aluminum (A356.1) and boron carbide (B_4C). The billets of Al-356.1 were used as matrix metal of composites. The chemical composition of this alloy is shown in table 1. B_4C powders with a mean particle size of 1 micron were used as reinforcement phase.

Table 1: Chemical composition of A356.1

Element	Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Ni	Pb	Sn
Percentage	91.73	7.23	0.32	0.18	0.02	0.38	0.05	0.01	<0.01	0.05	0.02	0.01

For casting the composite samples, a resistance furnace equipped with a stirrer system was used. After smelting the aluminum ingots, 3-5 gr. keryolit was added to molten metal and the stirring was established for 3 minutes. B_4C powders with 5, 10 and 15 gr. weights were poked into the aluminum foils and added to melt separately to produce Al-B_4C composites. The processing temperatures have been chosen 750, 850 and 950^oC. Stirring was continued another 11-13 minutes for homogenous dispersion and to prevent agglomeration of particulates. The metallic molds are used for casting the molten slurries. The equipments by which the tests were done are as below:

Phillips X-ray diffractometer (PW-1800 model) and Oxford scanning electron microscopy (CAMSCAN-MV2300) for analysis the specimens; Instron tensile test system 1195 model in order to measure of tensile strength; Hard meter system DVRB-M model in order to determine the Brinell hardness of samples.

The experimental methods have been as below:

Samples were made in a cylindrical shape based on ASTM.B557 standard [21]. Five samples of each casting were selected in order to make tensile tests and the average of results determined the final value. For determining the hardness of specimens, after grinding of samples, they were polished up to 1 micron. Two samples were selected of each casting and each sample was tested seven times. The average of results, determined the hardness value.

3. EXPERIMENTAL RESULTS

3.1 XRD Results

The XRD results of some specimens are shown in figures 1-3. For Al-%5B_4C case, the results were similar together, thus just the 3 pattern is presented. The presence of reinforcement particulates is obvious; thus the feasibility of method is clear.

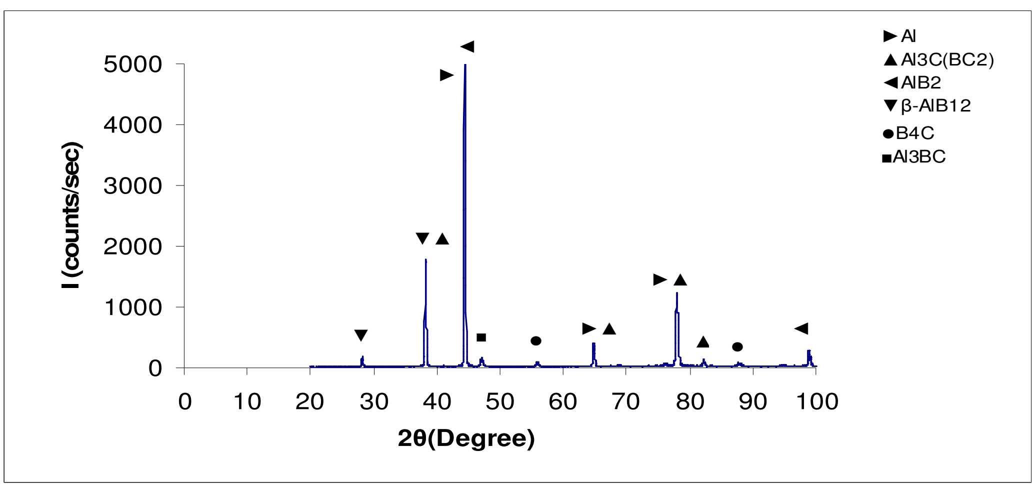

Figure 1: XRD pattern of Al- 5%B_4C composite casted at 750^oC

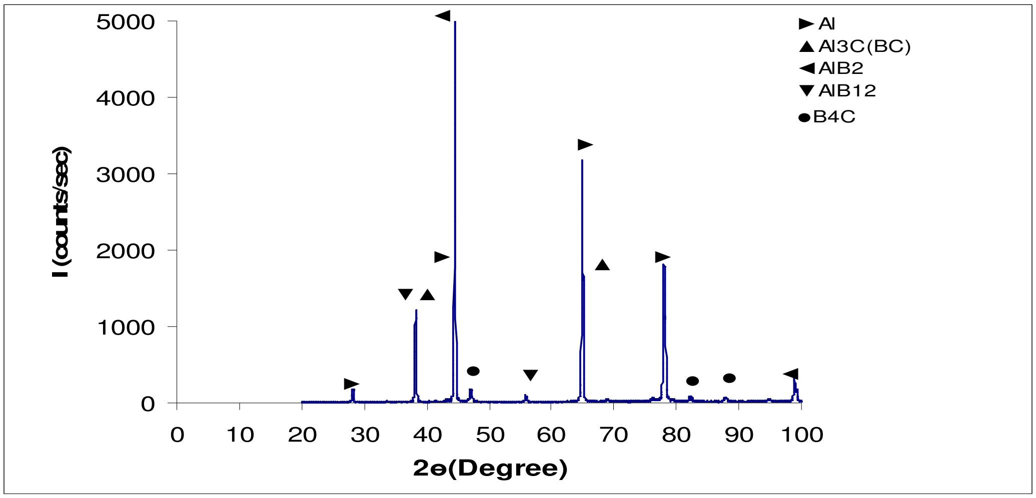

Figure 2: XRD pattern of Al- 5%B_4C composite casted at 850°C

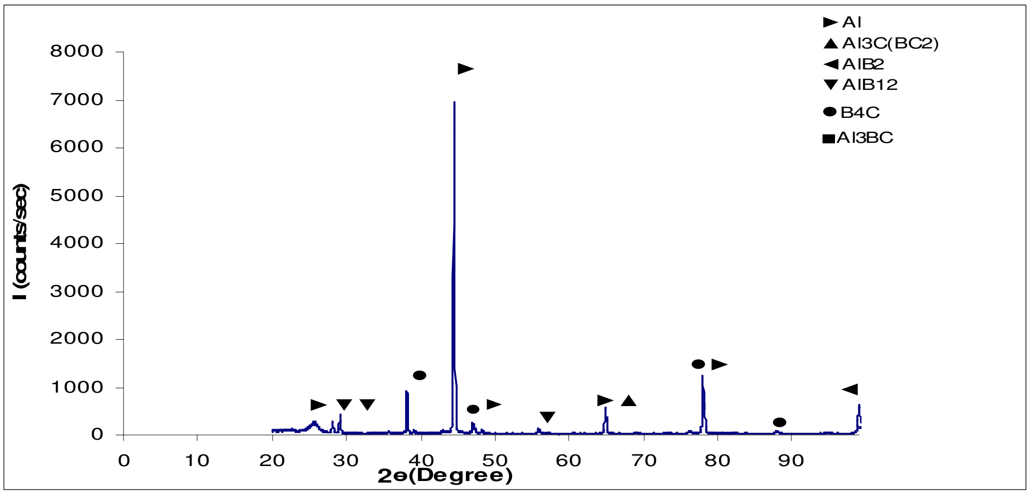

Figure 3: XRD pattern of Al- 10%B_4C composite casted at 950°C

B_4C picks on XRD patterns show increasing by increasing of pouring temperature. This shows that by increasing of pouring temperature, the wetability of B_4C particles by aluminum increases. Thermodynamically, the AlB_2 phase in Al-B_4C system presents at above 600°C, but it decomposes at 900-1000°C. From XRD pattern of specimens, the presence of AlB_2 phase can be seen at 750 and 850°C, but in 950°C case it decomposes. In usual conditions, B_4C has a low wetability in melted aluminum and large amount of B_4C powders doesn't incorporate into liquid.

3.2 SEM microstructure results

The SEM images of the specimens (figures 4-9) show the homogenous dispersion of ceramic particulates into matrix aluminum.

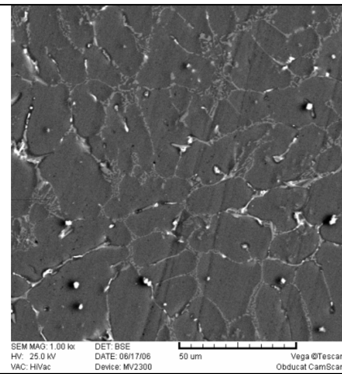

Figure 4: Micrograph of Al- 5%B_4C composite casted at 750^oC

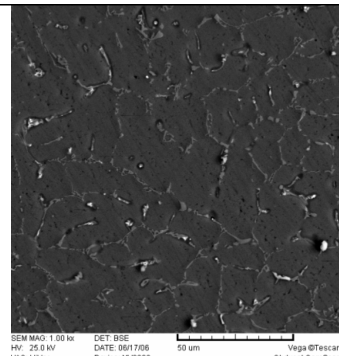

Figure 5: Micrograph of Al- 10%B_4C composite casted at 750^oC

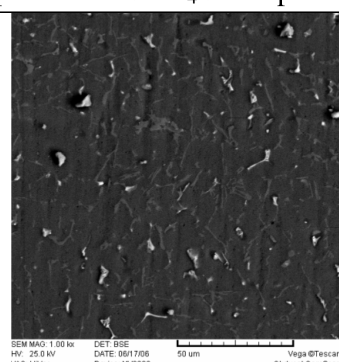

Figure 6: Micrograph of Al- 5%B_4C composite casted at 850^oC

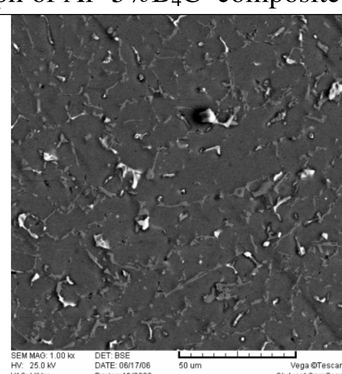

Figure 7: Micrograph of Al- 15%B_4C composite casted at 850^oC

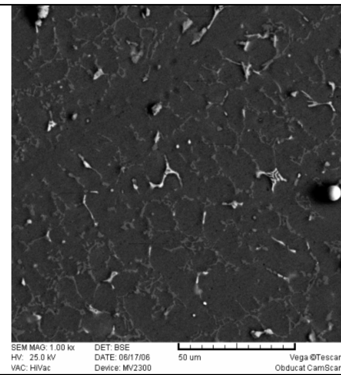

Figure 8: Micrograph of Al- 5%B_4C composite casted at 950°C

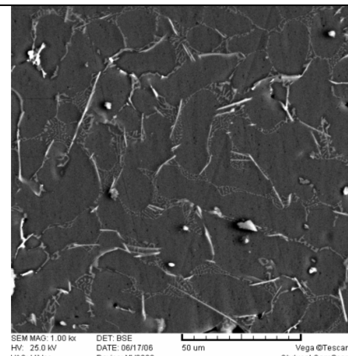

Figure 9: Micrograph of Al- 15%B_4C composite casted at 950°C

Uniform particle distribution across the samples has a significant effect on the composite properties, therefore is a critical and very important factor in composite manufacturing. Even in stir casting method in which the particles dispersed uniformly in the melt, particle clustering and sedimentation may occur. It can be revealed from the figure 4-9, that B_4C particles agglomerate in the specimens containing 15 Vol.%. The amount of unabsorbed particles increased with increasing of B_4C additive. Particle agglomeration, high viscosity, and gas entrapping can be considered as the main causes. In these figures, the black matrix is aluminum and the white spots represent B_4C particles. The microstructures also show that the grains size of the composites produced by stir casting technique are almost identical and equiaxial.

In the cases of large amounts of reinforcement, a hard barrier is made and hence aluminum can not wet the reinforcement. However, dark spots in figures indicate the pore existence in the interface of aluminum matrix and B_4C particles. This was also confirmed by their lower densities. SEM micrographs of the samples also indicate that the grain size of aluminum composites decreases with increasing of the volume percent of B_4C particles. It seems that reinforcement particles increase the number of nucleus and solidification speed. Therefore, the grain size of the aluminum reinforced with ceramic particles is smaller than that of the monolithic one.

3.3 Mechanical properties

Hardness variations of the composites by increasing of ceramic particles are shown in figure 10. Hardness value increasing of composites compare to matrix aluminum can be due to poor heat expansion factor of ceramic particles compare to aluminum that produces a lot of mismatches at the boundary of particles and matrix. Thus, increasing of the particles results increasing of hardness value due to more quantity of mismatches. Tensile strength variations of composites by increasing of ceramic particles are shown in figure 11 (the tensile strength value for matrix aluminum is 148 MPa). Increasing the volume percent of B_4C, results varying the tensile strength value for the composites incorporated with 10 and 15Vol.% of B_4C particles. These porosities could be due to method of process (vortex technique) in which the melt absorbs the air that results gaseous voids. Much more porosity could be the cause of this decreasing so that more value of particles could not opposite the effect of porosity.

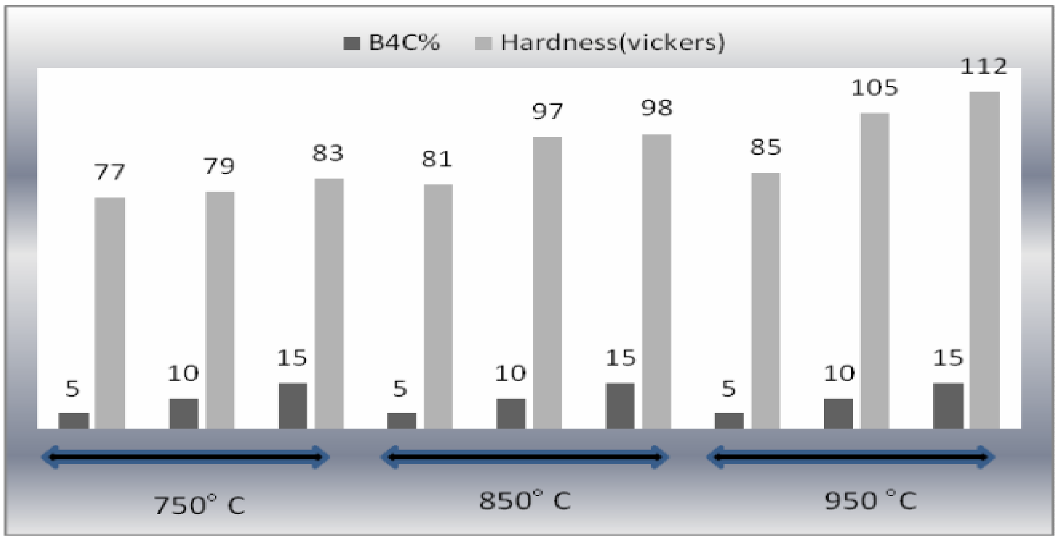

Figure 10: Hardness value of composites versus amount of reinforcement.

There is the improvement of its mechanical property for all composite samples compare to matrix metal that seems be due to increasing of work-hardening.

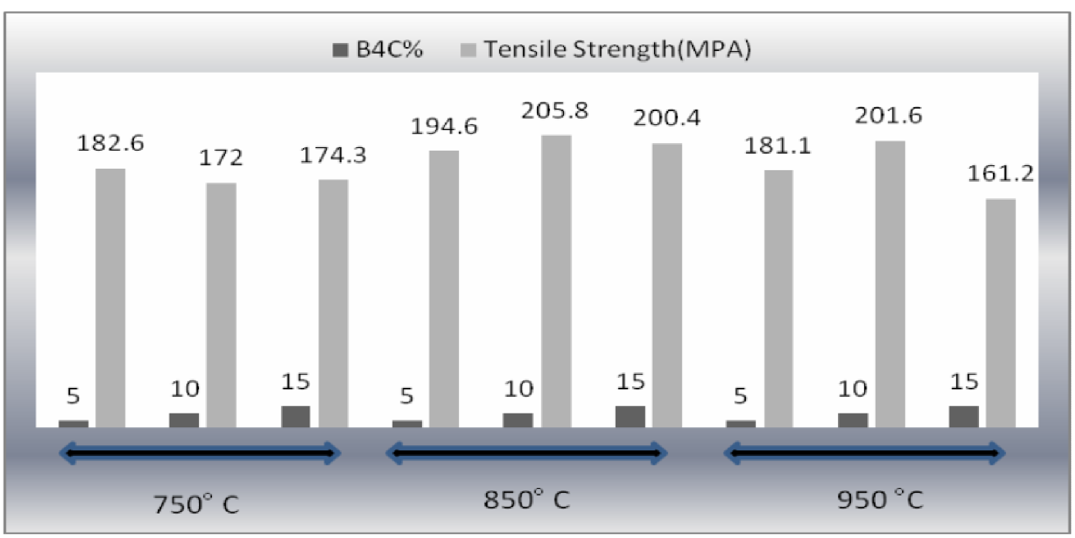

Figure 11: Tensile strength value of composites versus amount of reinforcement.

This could be related to effects of elastic properties of ceramic particles and inhibition of plastic deformation of matrix by them; because ceramic particles can only deform elastically while aluminum matrix can deform plastically. So if the boundary assumed to be strong, ceramic particles inhibit plastic deformation of matrix and this leads increasing of work-hardening.

4. CONCLUSIONS

1- The improvement of hardness and tensile strength of aluminum by incorporating of B_4C particles is due to the high work-hardening phenomena at low strain in the composite system. This is caused by elastic properties of these ceramic particles that prevent to plastic deformation of matrix metal.
2- The best tensile strength values for Al-B4C is achieved at 850ºC (best strength and good hardness value compare to other specimens) but the best hardness value for hardness is achieved at 950ºC for 15% B_4C.
3- It seems that because of better wetability of B_4C by Al-356.1 compare to pure aluminum, more value of B_4C particulates will remain into the matrix and cause the greater value of hardness and tensile strength.
4- The porosity of composite specimens was increased by increasing temperature because of their high pouring temperature (200-300ºC above melting point) and very small B_4C particles in melted aluminum.

REFERENCES

1- P.K. Ghosh and S. Ray, "Fabrication and properties of compo-cast aluminum-alumina particulate composites", *Indian J. Technol.*, 26(1988) 83–94.

2- Y.H. Seo and C.G. Kang, "Effects of hot extrusion through a curved die on the mechanical properties of SiC*p*/Al composites fabricated by melt-stirring", *Composites Sci. Technol.*, 59 (1999) 643–654.

3- M. Yilmaz and S. Altintas, "Properties of Al–Mg–SiC composites produced by a modified compocasting technique", in: Proceedings of the 2nd Bienniel European joint conference on Engineering Systems, London,UK, 1994, pp. 119–124.

4- A. Vogel, R.D. Doherty, and B. Cantor, "Stir-cast microstructures and slow crack growth", in: Proceedings of the Conference on Solidification and Casting of Metals, Sheffield, July 18–21, 1977.

5- M. Skibo, P.L. Morris, and D.J. Lloyd, "Structure and properties of liquid metal processed SiC reinforced aluminum", in: Proceedings of the World Materials Congress, Chicago, 1988, pp. 257–262.

6- B. Ralph, H.C. Yuen, and W.B. Lee, "The processing of metal matrix composites: an overview", *J. Mater. Process. Technol.*, 63 (1997) 339–353.

7- ASM Handbook, Volume 21, Composites.

8- G.S. Hanumanth and G.A. Irons, *J. Mate. Sci.*, 28(1993)2459-2465.

9- H. Leistner, D. Ratcliffe, and A. Schuler, "Improved Material and Design Refractories", 2nd Edition, Verlag Stahleisen, Dusseldorf, (1991), pp.316-319.

10- O.C. Standard and C.C. Sorell, "Densification of Zirconia Conventional Method", *Key Engineering Material.*

11- D.L. Mc Danels, "Analysis of stress-strain fracture and ductility silicon carbide", *Metal Trans.*, 1985,16A:1105.

12- A.T. Alpas and J. Zhang, "Wear rate transitions in cast aluminum – silicon alloys reinforced with SiC particles", *Scripta Metal Mater.*, 1992, 26:505-509.
13- H. Akbulut, M. Durman, and F. Yilmaz, "Dry wear and friction properties of Al_2O_3 short fiber reinforced Al-Si (LM 13) alloy metal matrix composites", *Wear*, 1998, 215:170-6.
14- S. Skolianos and T.Z. Kattamis, "Tribological properties of SiC –reinforced Al-4.5% Cu-1.5% Mg alloy composites", *Mater. Sci. Eng. A*, 1993, 163:107-12.
15- Y. Sahin, M. Kok, and H. Celik, "Tool wear and surface roughness of Al_2O_3 particle-reinforced aluminum alloy composites", *J. Mater. Process Technol.*, 2002,128:280-91.
16- M.K. Surappa, S.C. Prasad, and P.K. Rohatgi, "Wear and abrasion of cast Al- Alumina particle composites", *Wear*, 1982, 77:295-312.
17- A. Sato and R. Mehrabian, "Aluminum matrix composite: fabrication and properties", *Metal Trans. B*, 1976, 7B:443-51.
18- J.K.M. Kwok and S.C. Lim, "High–speed tribological properties of some Al/SiC composites": Wear Mechanisms, *Comp. Sci. Technol.*, 1999, 59:65-75.
19- J.K.M. Kwok and S.C. Lim, "High–speed tribological properties of some Al/SiC composites: Frictional and wear-rate characteristics", *Comp. Sci. Technol.*, 1999, 59:55-63.
20- A. Banerji, S.V. Prasad, M.K. Surappa, and P.K. Rohatgi, "Abrasive wear of cast aluminum alloy-zircon particle composites", *Wear*, 1982,82:141-151.
21- Handbook of the American Society for Testing and Materials, "Standard Test Method of Tension Testing Wrought and Cast Aluminum and Magnesium Alloy products - B557", 1994, Vol. 03, page 91.