PREPARATION OF PISTON ALLOY-BASED COMPOSITES BY ADDITION OF BOTH Al-Ti5-B1 AND Ni PARTICLES AND APPLICATION OF PRESSURE DURING SOLIDIFICATION

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ABSTRACT

Series of piston alloy / Ni composites (10 and 16wt%Ni) were prepared using stir casting and application of low pressure (20 ksi) during solidification. The reinforcing particles (Ni) were added to the matrix melt (piston alloy containing 9.8% Si, 2.26 Cu, 0.92% Ni, 0.79 % Mg, 0.26% Fe, 0.02% Mn, 0.015% Zn, 0.015% Ti, 0.009% Cr) at 740 °C. During the preparation of some composites, Al- Ti5-B1 master alloy was added to the matrix melt.

The application of pressure causes refinement of α- phase. For the composites prepared by addition of Ni particles and application of pressure during solidification, the α- phase of matrix and the reinforcing phase are refined due to the application of pressure. In the case of composites prepared by the addition of both Al-Ti5-B1 and Ni particles and the application of pressure during solidification, fine, equiaxed and homogeneously distributed reinforcing particles, and fine α- phase were obtained.

The hardness of the material was increased by the application of pressure during solidification. This method is more effective in the case of addition of Ni particles. A remarkable improvement (about 110 %) in hardness was obtained by the addition of 16 wt % Ni and application of pressure. Further, in the case of addition of Al-Ti5-B1 and Ni particles and application of

pressure, the hardness was improved.

KEYWORDS: Composites, Particulate composites, Ni reinforcing particles, Grain refiner, Solidification under pressure.

1- INTRODUCTION

Metal matrix composites have been one of the key research subjects in materials science. Most of the work has been dealing with aluminum and other light metals as matrices for applications requiring light weight in combination with high strength and/or stiffness [1]. It was reported [1] that, the particulate reinforced Al matrix composites have moderate properties but they are much more inexpensive than continuous fiber reinforced materials. The liquid state processes such as various casting methods, and powder metallurgical methods are used in production of particulate reinforced Al matrix composites. However, new deposition and in situ processes are potentially very efficient and economical and, therefore, they are actively studied [1]. Powder metallurgical route is difficult to be automated and thus, it is very probably not the right answer for economical production of Al matrix composites [1]. Hence, the most promising processes are found among on the liquid state, deposition and in situ processes [1]. The most simple, inexpensive and widely used methods for monolithic Al parts are various casting techniques [1]. It is therefore natural that a lot of emphasize is put on developing these techniques for Al matrix composites as well [1]. A major use of metal matrix composites in the crowns of pistons used in diesel engines [2]. The major problems are fiber wetting and weakness of the interface between the metal and the fiber [2]. The incorporation of the perform into the piston requires the use of high casting pressures, so squeeze casting is normally used [2]. The fiber wetting and the strength of interface are improved by the application of pressure during squeeze casting [2]. Direct squeeze casting is the name given to that casting process in which molten metal is solidified under the direct action of a pressure that is sufficient to prevent the appearance of either gas porosity or shrinkage porosity [3]. Further, the major advantages of direct squeeze casting over other processes can be summarized [3] as: (i) No feeders or risers are required and, therefore, no metal wastage occurs. (ii) The inherent "cast ability" of the alloy is of little or no concern, since the applied pressure obviates the need for the customary "high fluidity" : both common casting and ostensibly wrought alloys can be squeeze cast to a finished shape. (iii) The microstructure can be manipulated easily by careful process control, such as the pouring temp. and the applied pressure, to acquire the desired optimum properties. (iv) Because there are no defects on a properly produced squeeze-cast component, costly post-solidification examination by non-destructive testing techniques is not required. (v) Squeeze cast products can have mechanical properties as good as, and in some cases even better than, wrought products of the same composition by virtue of their isotropic behavior. (vi) Squeeze casting provides the most effective and efficient route to produce near-net-shape composite engineering components. Although the squeeze casting technique has many advantages, it is more costly casting technique [2]. If the use of cast metal matrix composites is to be increased, fiber wetting must be improved to allow the use of low cost casting techniques, such as gravity or die casting [2].

Cast pistons for internal combustion engines generally are made by the permanent mold process of aluminum-silicon alloys with additions of other elements [4]. The high silicon and nickel contents of alloy A 132 (12% Si-2.5% Ni – 1.0 % Mg – 1.0% Cu) impart improved elevated-temperature properties and low thermal expansivety [4].

In industry, both wrought and cast aluminum alloys are grain refined prior to casting [5]. The commonly used grain refiners are commercially available nucleants or master alloys like Al-10Ti , Al-5% Ti-1%B alloys [5]. Grain refinement improves the mechanical properties [5-7] and surface finish of cast products [6]. A fine grain structure is often required in commercial alloys to facilitate forming operations or to ensure good service properties (e.g., fracture toughness and corrosion resistance [7]).

A study by the authors (under publication) showed that, the nickel particles have a promising effect as new reinforcing particles for AA 4032 and AA 6063 aluminum alloys.

The short and comprehensive review in the fields of chemical grain refinement, reinforcement and application of pressure during solidification, showed that there are no papers in the area of the combined effect of these treatments. The present work aims to investigate this effect. The work has been planned to prepare piston alloy/Ni composites and to investigate the combined effect of addition of both Al-Ti5-B1 and Ni particles and application of low pressure during solidification on microstructure and hardness of the resulting composites.

2- EXPERIMENTAL WORK

2-1- Preparation of Composites:

A group of piston alloy /Ni composites (10, and 16 wt % Ni) was prepared using stir casting and application of low pressure (20 ksi) during solidification. The reinforcing particles (Ni) were added to the matrix melt at 740 °C. During the preparation of some composites, Al-Ti5-B1 master alloy was added to matrix melt. The percentages of AL-Ti5-B1 were 0.6 and 1.0 wt %. The Al-Ti5-B1 was added before the addition of Ni particles, and the holding time was 10 minutes.

2-2- Metallography:
Microstructure features were investigated using optical Microscope.

2-3- Hardness Test:
Hardness test was applied for some specimens.

3- RESULTS AND DISCUSSIONS

3-1- Effect of Application of Pressure During Solidification on Microstructure:
Fig. (1) shows the microstructure of cast piston alloy. The microstructure revealed an essentially primary α-Al dendritic structure. Some micro porosities were found to be widespread throughout the microstructure. As reported by Chatterjee and Das [9], most commercial casting alloys of aluminum show some tendencies toward porosity. The potential sources of porosity include: (a) precipitation of dissolved gases, (b) solidification shrinkage, (c) combination of both gas and shrinkage [9]. Whichever the source, porosity (gas and/or shrinkage) develops during the course of solidification of the cast alloys. Fig. (2) shows the microstructure of the piston alloy solidified under pressure of (20 ksi). The microstructure of the alloy solidified under pressure revealed a smaller average dendrite size when compared to that for the alloy solidified under atmospheric pressure. Further, it was observed to be a structure of fine interdendritic space. Similar results were obtained by other investigators [8 & 9]. As described by Chatterijee and Das [9], under the application of pressure during solidification, there exists a steep temperature gradient coupled with an increased rate of heat abstraction. This, in effect, gives rise to a short local solidification time and, in turn limits the diffusion process, resulting in overall refinement of the structure. The percentage of porosity is reduced due to the application of pressure which closes the cavities [9&11].

3-2- Combined Effect of Additions of Both Al-Ti5-B1 and Ni Particles and Application of Pressure During Solidification on Microstructure:
Fig. (3) shows the microstructure of piston alloy / 10 wt% Ni composites. The addition of Ni particles plays an important role in refinement of α-

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Fig.(١) Microstructure of piston alloy

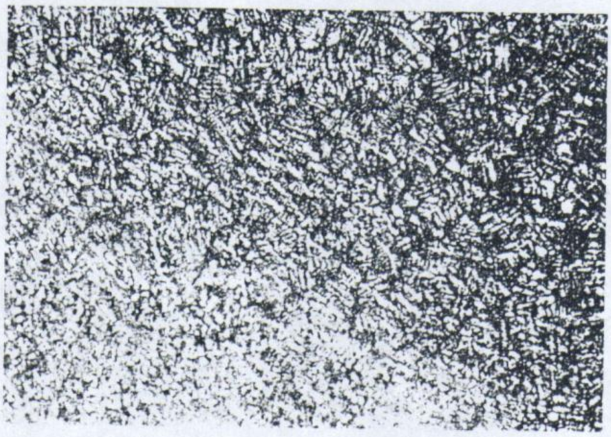

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Fig. (٢) Microstructure of piston alloy solidified under pressure.

phase of matrix alloy [Fig. (1) and (3)]. Similar results have been obtained by Han et al. [10] in the case of A356-SiC particle MMC. Fig. (4) shows the microstructure of piston alloy – based composite prepared by addition of 10wt % Ni and application of pressure during solidification. It is evident that, the application of pressure causes refinement in both α and reinforcing phase. In this case, more refined α has been obtained due to the combined effect of the presence of reinforcing particles and the application of pressure during solidification.

The features of the microstructures shown in Figs. (2), (3) and (4) show that, the effect of pressure in refinement of α-phase is enhanced by the presence of reinforcing particles. Further, the effect of reinforcing particles in refinement of α-phase is enhanced by the application of pressure during solidification.

Fig. (5) shows the microstructure of piston alloy – based composite prepared by addition of 0.6wt % Al-Ti5-B1 and Ni particles and application of pressure during solidification. Fine, equiaxed and homogeneously distributed reinforcing particles are shown in the Fig.. Further, the α- phase is refined.

Fig. (6) shows the microstructure of piston alloy/ 16 wt % composite prepared under the application of pressure during solidification. Fig. (7) shows the microstructure of the piston alloy – based composite prepared by addition of both 1.0 wt % Al-T5-B1 and 16 wt % Ni and application of pressure (20 ksi) during solidification. Comparison between the microstructures shown in the two Figs. (6 and 7) leads to similar results that obtained in the case of composite prepared by addition of both 0.6 wt % Al-T5-B1 and 10 wt % Ni and application of pressure during solidification (Fig.5). However, the distance between the adjacent reinforcing particles shown in Fig. (7) is smaller than that shown in Fig. (5). This result can be attributed to the higher percentages of addition of both Al-Ti5-B1 and Ni particles.

3-3- Effect of Addition of Both Al-Ti5-B1 and Ni Particles and Application of Pressure During Solidification on Hardness of Material:

Fig. (8) shows the effect of application of low pressure (20ksi) during solidification on hardness of piston alloy. The hardness of material is increased by the application of pressure. As reported by Karnezis et al. [11], the pressure results in excellent feeding of solidification shrinkage and high cooling rates, which gives rise to a fine microstructure and low porosity content. The cast alloy solidified under pressure therefore has better mechanical properties than conventionally cast material.

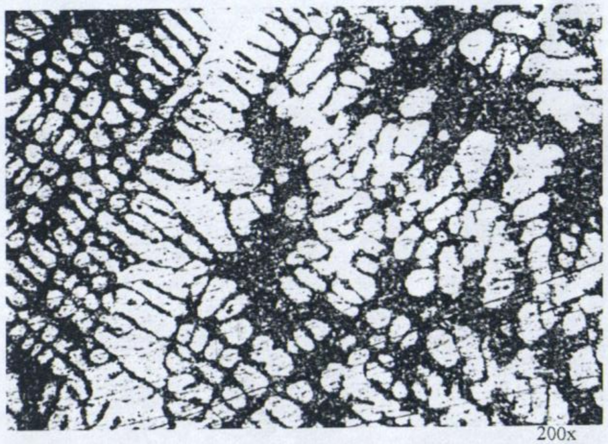

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Fig. (1) Microstructure of piston alloy

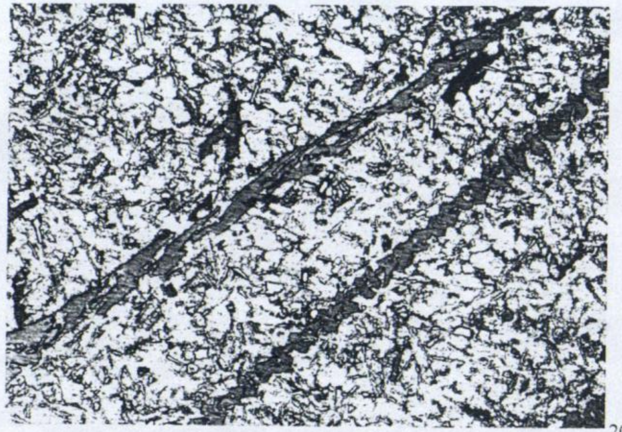

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Fig. (3) Microstructure of piston alloy/10 wt.% Ni composite

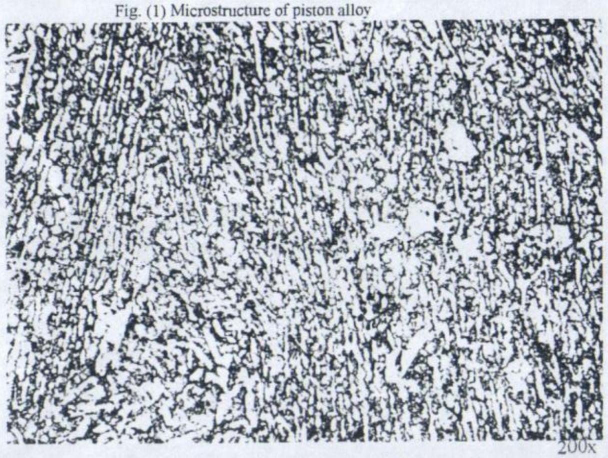

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Fig.(4) Microstructure of piston alloy-based composite prepared by addition Of 10 wt.% Ni and application of pressure during solidification

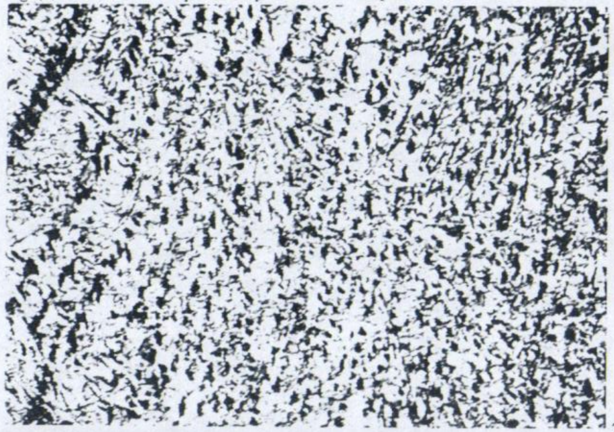

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Fig. (5) Microstructure of piston alloy-based composite prepared by addition of both 0.60 wt.% Al-Ti5-B1 and 10wt.% Ni and application of pressure during solidification.

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Fig.(6) Microstructure of piston alloy/16 wt.% Ni composite prepared under application Of pressure during solidification.

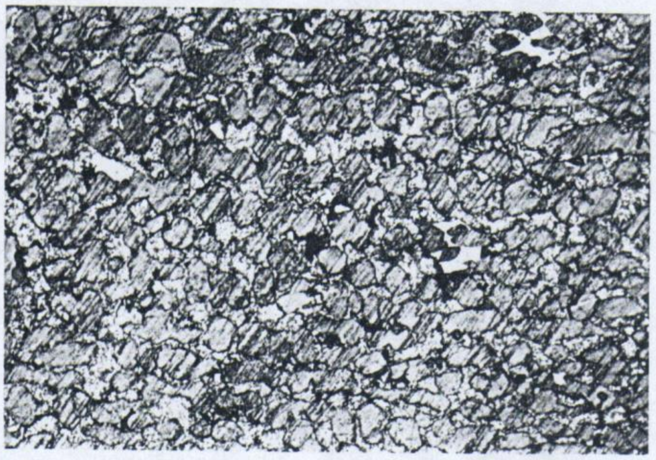

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Fig. (7) Microstructure of piston alloy-based composite prepared by addition of both 1.0 wt.% Al-Ti5-B1 and 16 wt.% Ni and application of pressure during solidification.

Fig. (9) shows the hardness of two composites prepared by two different methods. A composite was prepared by addition of 10 wt % Ni and application of pressure (20ksi) during solidification and another one was prepared by addition of both 1.0wt % Al-Ti5-B1 and 10 wt % Ni and *application of pressure during solidification. The hardness was improved by* 42.8 % in the case of material prepared by addition of 10 wt % Ni and application of pressure. Comparison between this improvement in hardness; 42.8%, (due to the addition of 10 wt.% Ni and application of pressure) and that of Fig. (8); 14.28%, (due to the application of pressure without addition of Ni particles) shows that, the addition of reinforcing particles improves the hardness and enhances the hardening effect of pressure. The presence of reinforcing particles increases both load carrying capacity of the composite and work-hardening of the matrix and as a result the hardness of material is increased [12 & 13]. In the case of composite prepared by addition of both

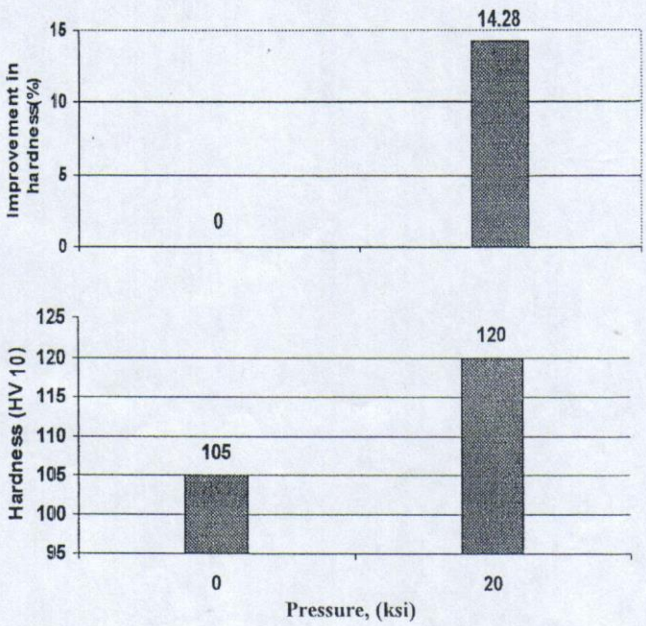

Fig. (8): Effect of application of low pressure during solidification on hardness of piston alloy .

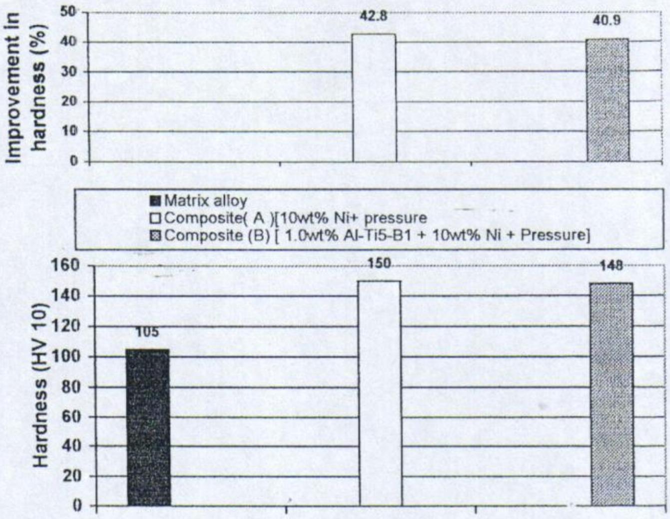

Fig. (9): Hardness of materials prepared by different methods.

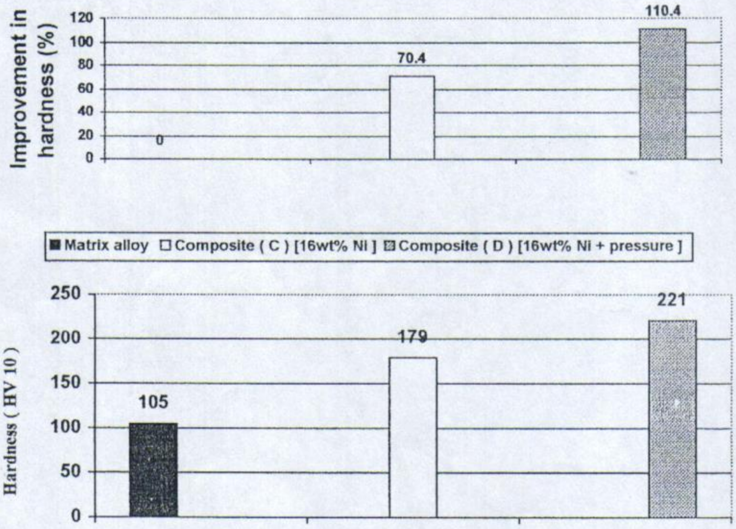

Fig. (10) : Hardness of materials prepared by different methods

1.0 wt% Al-Ti5-B1 and 10 wt% Ni and application of pressure during solidification, the improvement in hardness is 40.9%. In this case, the addition of Al-Ti5-B1 is accompanied by an increase in the percentage of porosities. The low pressure applied in the present investigation is not sufficient to eliminate the porosities and as a result some porosities are remained in the microstructure which reduce the improvement in properties. Fig. (10) shows the hardness of materials prepared by different methods. The hardness of material was improved by 70.4% in the case of addition of 16 wt% Ni. However, in the case of addition of 16 wt% Ni followed by application of pressure during solidification, the hardness was improved by 110.4%. The results of Figs. (8) and (10) show that the application of pressure is more effective in the case of addition of Ni particles.

The results of Figs. (9) and (10) show that, the improvement in hardness increases by the increase in percentage of Ni particles.

The analysis of the results of Figs. (8), (9) and (10) shows that, 14.28% improvement in hardness is obtained only by application of pressure during solidification, while the addition of 10 wt.% Ni followed by application of pressure resulted in 42.8% improvement in hardness. Further, 70.4% improvement in hardness is obtained by addition of 16 wt.% Ni, while the application of pressure after the addition of this quantity of Ni particles resulted in 110.4% improvement in hardness. These results show that the effectiveness of application of pressure during solidification in hardening of composite material is increased by the increase of percentage of reinforcing particles.

4- CONCLUSIONS

The results of the present study lead to the following conclusions

1- The application of low pressure (20 ksi) during solidification of matrix melt causes refinement of α- phase.

2- Both α- phase and reinforcing phase are refined by the application of pressure during solidification.

3-Addition of Al-Ti5-B1 and application of pressure during solidification of matrix melt resulted in considerable changes in structural morphology:
   i.The α- phase is refined.
   ii.The reinforcing particles are refined, rounded and uniformly distributed in the matrix.

4- The application of pressure during solidification improves the hardness of the material. This method is more effective in the case of addition of reinforcing particles.

5- As a general conclusion of the above, there are two routes to improve the hardness of the proposed composites:

i- Addition of 1.0 wt % Al-Ti5-B1 and low percentage of Ni particles (e.g.10 wt %) with application of pressure during solidification.

ii- Addition of high percentage of Ni (e.g. 16 wt %) with application of pressure during solidification. In this case, the improvement in hardness was about 110 %.

REFERENCES:

[1] Lindroos V.K. , and Talvitie M.J., (1995), "Recent advances in metal matrix composites", Journal of Materials Processing Technology 53 , pp. 273-284.

[2] Papworth A. , Green A., and Fox P. , (January 1998) , "Interface reactions in squeeze cast Saffil fibre/piston alloy composites", Material Science and Technology, Vol. 14, pp. 47-53.

[3] Yue T.M., and Chadwick G.A., (1996), "Squeeze casting of light alloys and their composites", Journal of Materials Processing Technology 58 pp. 302-307.

[4] Sicha W.E., (1967), "Properties of commercial casting alloys", Aluminum, Vol. I : Properties, Physical Metallurgy and Phase Diagrams, Edited by Kent R., Van Horn, American Society For Metals, Metals, Park, Ohio, pp. 277-302.

[5] Kashyap K.T. , and Chandrashekar T., (August 2001), "Effects and mechanisms of grain refinement in aluminium alloys", Bull. Mater. Sci, Vol. 24, No. 4, Indian Academy of Sciences, pp. 345-353.

[6] Jones G.P., and Pearson J., (June 1976), "Factors affecting the grain-refinement of aluminium using titanium and boron additives", Metallurgical Transactions B, Volume 7B, pp. 223-234.

[7] Encyclopedia of Materials Science and Engineering (1986), Vol. 3 UK pp. 2051-2055.

[8] Lim C.S., and Clegg A.J., (1997), "The production and evaluation of metal-matrix composite castings produced by a pressure-assisted investment casting process", Journal of Materials Processing Technology 67 pp. 13-18.

[9] Chatterjee S. , and Das A.A., (November 1972) , "Effects of pressure on the solidification of some commercial aluminium-base casting alloys", Conference paper, The British Foundryman, pp. 420-428.

[10] Han N., Pollard G., and Stevens R., (January 1992), "Microstructural characterization of sand cast aluminum alloy A 356-SiC particle metal matrix composite", Materials Science and Technology, Vol. 8, pp. 52-56.

[11] Karnezis P.A., Durrant G., and Cantor B., (February 1998), "Microstructure and tensile properties of squeeze cast SiC particulate reinforced Al-7 Si alloy", Materials Science and Technology, Vol. 14, pp. 97-107.

[12] Kanetake N., and Ohira H., (1990), "Analytical study on deformation behaviour of metal matrix composites", Jounal of Materials Processing Technology, 24 pp. 281-289.

[13] Myshlyaev M.M., McQueen H.J., and Konopleva E.V., (September-October, 1998), "Heterogeneous microstructures in A 356+15 vol. % SiCp and in A356 alloy", Materials Science and Technology, Vol. 14, pp. 939-948.