Alex. Eng. J., Alex. Univ., Volum 27 No.4, pp. 131 - 144 (1988)

PROPERTIES OF A SIC WHISKERS REINFORCED Al-Si ALLOY PRODUCED BY COMPOCASTING

G.A. Nassef* and M. Suery

Institut National Polytechnique de Grenoble

ENS de Physique de Grenoble

Laboratoire Genie Physique et Mecanique des Materiaux

(Unite Associee au CNRS n° 793)

Domaine Universitaire - BP 46

38402 SAINT MARTIN D'HERES CEDEX -France

* Present address: Department of Production Engineering, Alexandria University, Alexandria, Egypt.

Abstract

An Al-7% Si alloy was reinforced by SiC whiskers added to the melt using the compocasting technique. After addition, the material was completely remelted and either gravity cast or squeeze cast using pressure of 50MPa

The technique was found to be satisfactory for additions of whiskers up to 5 wt% after which agglomeration was often observed in the castings. With 5% whiskers the material exhibits 30% improvement of the room temperature yield stress whereas the strength at 300°C is increased by about 50%. The agglomerations of whiskers lead to a decrease of the strength and the elongation of the composites. This decrease is however less important for the squeeze cast materials because of the infiltration of the agglomerated zones by the liquid metal during pressurized solidification.

1. Introduction

In recent studies (1-13) the rheocasting technique has been used for the preparation and casting of metal matrix composites. The reinforcing elements are added to the vigouresly agitated, partially solidified matrix alloy. The high viscosity of the slurry due to the presence of a high volume fraction of the primary solid phase prevents the reinforcing elements from floating, settling and agglomerating (6).

Most of the previous studies, have been concerned with the incorporation of either particles or fibers into metallic materices, but only limited results (13,16) are available dealing with the addition of whiskers using this method.

Reinforcement by whiskers is interesting, since they have a very high strength (from the fact of being perfect crystals) as compared to particles and fibers. Moreover the transverse properties of whisker reinforced composites are nearly as high longitudinal properties which allow better design flexibility with fiber reinforced composites.

This paper presents the work undertaken to prepare and cast composites of aluminium-silicon (AS7GO3) matrix reinforced by various amounts of silicon carbide whiskers. Properties of the composites were investigated with the aim of identifying new promising compositions for future work in this area.

2. Experimental Technique

2.1 Materials

An AS7G03, aluminium-Silicon alloy is used as the matrix material; it is

1. Introduction

In recent studies (1-13) the rheocasting technique has been used for the preparation and casting of metal matrix composites. The reinforcing elements are added to the vigouresly agitated, partially solidified matrix alloy. The high viscosity of the slurry due to the presence of a high volume fraction of the primary solid phase prevents the reinforcing elements from floating, settling and agglomerating (6).

Most of the previous studies, have been concerned with the incorporation of either particles or fibers into metallic materices, but only limited results (13,16) are available dealing with the addition of whiskers using this method.

Reinforcement by whiskers is interesting, since they have a very high strength (from the fact of being perfect crystals) as compared to particles and fibers. Moreover the transverse properties of whisker reinforced composites are nearly as high longitudinal properties which allow better design flexibility with fiber reinforced composites.

This paper presents the work undertaken to prepare and cast composites of aluminium-silicon (AS7GO3) matrix reinforced by various amounts of silicon carbide whiskers. Properties of the composites were investigated with the aim of identifying new promising compositions for future work in this area.

2. Experimental Technique

2.1 Materials

An AS7G03, aluminium-Silicon alloy is used as the matrix material; it is a foundry alloy widely used in industry especially for various automobile parts. The alloy was supplied by PECHINEY in the form of large ingots of about 10 kg and with the following chemical composition:

Si	Mg	Fe	Cu	Mn	Ni	Zn	Ti	Pb	Sn
6.5-7.5	0.25-0.4	0.2	0.1	0.1	0.05	0.1	0.1-0.2	0.05	0.05

SiC whiskers made by Tokai Carbon Co., Ltd. were used as reinforcing elements. Their diameter ranges between 0.2 to 3μm and their length was about 50 m.

2.2 Preparation of The Composite

The apparatus used to prepare the composite is similar to that proposed in previous studies (12, 14, 15, 17, 18), it is shown schematically in

1) - driving pulley of the rotor
2) - feeding device of fibres
3) - graphite crucible
4) - rotor
5) - semi-solid alloy
6) - induction coil
7) - thermocouple

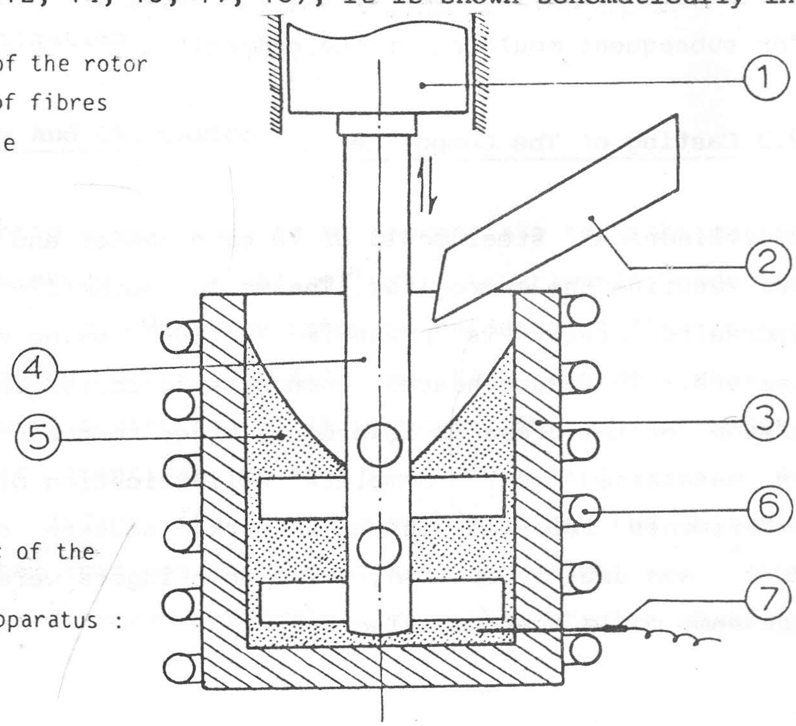

Figure 1 : Schematic of the compocasting apparatus :

figure 1. The crucible is induction heated to 700°C, and a charge of 700 g of the matrix melt is poured into it. About 0.02 wt percent Sr in the form of a Al 5% Sr master alloy is added to the melt for the modification of the Simorphology. The stirrer is then lowered in the melt and rotation begins. The temperature was gradually dropped at a specified rate until the melt reaches the desired temperature in the liquid-solid range (about 600°C). The temperature controller is adjusted to hold the slurry at this temperature while stirring is continued. The SiC whiskers, preheated at 600°C, are gradually added to the slurry with a feeding device at a rate of 300-350 g/h. The amount of SiC whiskers added to the melt was such that ingots containing 1.5, 3, 5, 7 and 10 weight percents were prepared. During addition, the temperature was gradually increased to keep the viscosity of the slurry roughly constant. The melt was allowed to mix isothermally for 15 minutes after the end of addition. The temperature was then rapidly raised to 700°C in order to provide sufficient superheat and fluidity for subsequent moulding of the composite.

2.3 Casting of The Composite

A cylindrical steel mould of 70 mm diameter and 120 mm height was used for casting the composites. The mould, mounted on the table of a 65 ton hydraulic press, is preheated to 600°C using electrical resistance heaters. The superheated composite is poured inside the mould and the piston of the press is lowered in order to press the melt. The pressure is maintained until complete solidification of the composite. In the experiments reported in this work, squeeze casting pressure of 50 Mn/m^2 was usually applied, while some ingots were gravity cast inside the same mould for comparison.

2.4 Mechanical Tests

Compression specimens of 8 mm diameter and 10 mm height were machined from the cast ingots. Tests were performed at constant crosshead speed at temperatures of 20, 135 and 315°C. In all tests, the compression plates were lubricated with born nitride.

Tensile test specimens of 4.5 mm diameter and 35 mm gauge length were also prepared from the cast composites. The elongation during tension was measured using an extensometer over an initial gauge length of 20 mm.

2.5 Metallographic Observations

Specimens taken from the cast ingots were cut, polished and etched for microscopic examination. Both optical and scanning electron microscopy were used in the investigation.

3. Experimental Results And Discussion

The compocasting technique was found to be appropriate for fabricating composites of SiC whiskers in Al-Si alloys. Experiments made for incorporating up to 5 wt% whiskers show on evidence of floating or settling of the elements during or after addition. Figure 2 shows a micrograph of a composite containing 5 wt% whiskers. The microstructure is homogeneous and is identical to that of the matrix alloy with no evidence of whiskers. Indeed, it was not possible to see the whiskers even in a deeply etched specimen containing a higher weight percent of whiskers. They probably disperse uniformly inside the eutectic phase of the alloy.

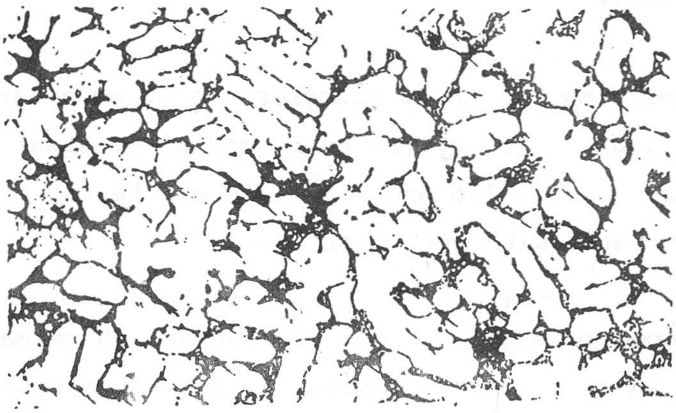

Figure 2 : Optical micrograph of a specimen containing 5 wt% whiskers. (X100)

However, experiments made to incorporate more than 5 wt% whiskers were not successful. Indeed whiskers were not completely dispersed by the stirring action or they segregate during remelting to form agglomerated areas which can be seen macroscopically on a polished sample as shown in figure 3 for a specimen containing 10 wt% whiskers.

The effect of whisker content on the stress-strain diagram in compression is shown in figure 4. Compression strength increases with increasing whisker content up to 5 wt% then it decreases with further increase of whisker content. It is clear from the figure that the effect of whiskers on the yield strength is much more pronounced than on the stress at higher compression strain. Figure 5 shows the evolution of the offset yield strength with whiskers weight percent for both gravity cast and squeeze cast ingots. Addition of 5 wt% whiskers increases the yield strength by about 30 %. Such an improvement is larger than that obtained by addition of the same amount of SiC particles (15, 17) or SiC fibers (13, 14, 18) to the same matrix. The decrease of compression strength beyond 5 wt% whiskers is attributed to the agglomeration of whiskers

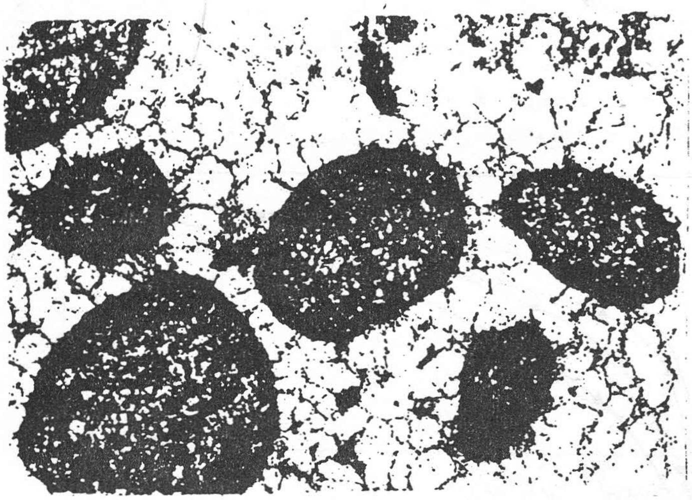

Figure 3 : Optical micrograph of a specimen containing 10 wt% whiskers showing agglomerated zones of whiskers.(X 100)

which has been found in both gravity cast and squeeze cast ingots. This decrease is however steeper for gravity cast than for squeeze cast specimens. During squeeze casting, pressure forces the matrix melt to infiltrate the agglomerates which makes them stronger than for gravity cast specimens. It is to be noted moreover that the pressure increases the yield strength of the matrix quite significantly compared to the specimens solidified under atmospheric pressure. Such an improvement can be explained by several effects (19,20): firstly, pressurized solidification refines the structure of the alloy as shown in figure 6 by forcing the metal against the mould walls thus increasing the heat transfer coefficient at the metal-mould interface; secondly, pressure reduce or completely eliminates porosities due to gas or solidification shrinkage; finally, pressure increases the solubility of Si in the primary Al rich phase while decreasing the proportion of the eutectic mixture.

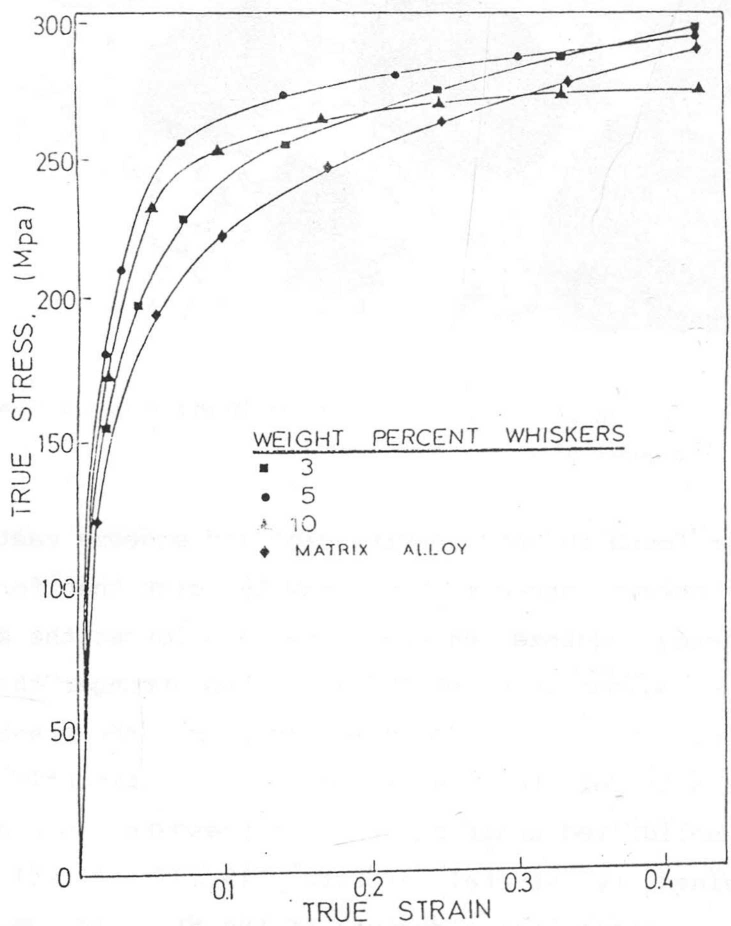

Figure 4 : Compression test results at room temperature for AS7G03/SiC whisker composites.

The variation of the tensile yield strength with whisker content is shown in figure 7. The yield strength in tension is lower than that in compression and the difference can probably be attributed to the effect

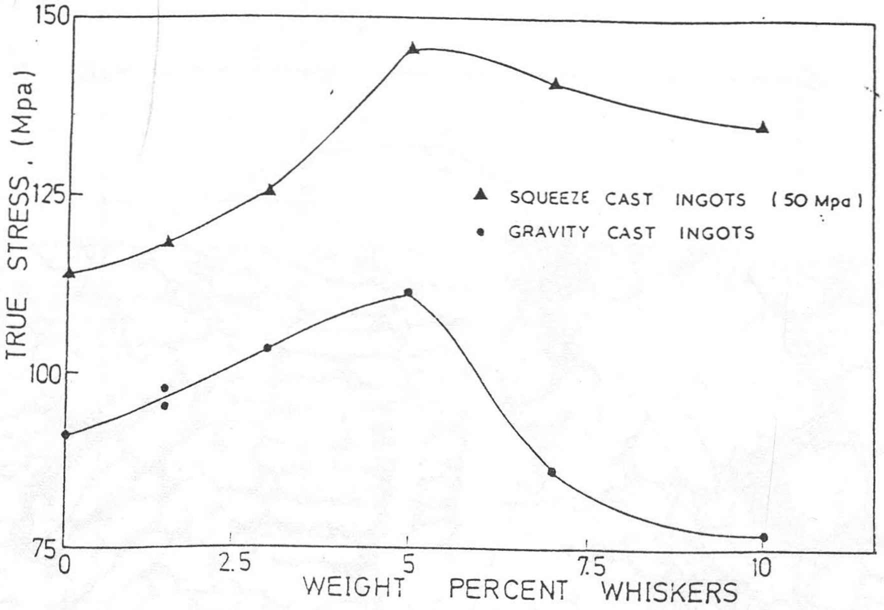

Figure 5 Influence of whisker content on compressive yield stress for gravity cast and squeeze cast composites.

of the residual stresses (21) which are created in the composites due to the difference between the thermal expansion coefficients of the matrix and the SiC whiskers. The variations of both tensile and compressive yield strengths with whisker content show similar trend up to 5 wt% whiskers beyond which the former drops more steeply than the latter, becoming very small for 10 wt% whiskers. This result indicates that the tensile strength is very sensitive to the non homogeneous distribution of the reinforcing elements in a composite; the agglomerated zones are in fact very weak during tensile straining, as confirmed by SEM observations which show that the fracture surface contains many whisker agglomerations which have probably initiated the rupure of the composite. This result explains also the drastic decrease of the elongation with whisker beyond 5 wt% as shown in figure 7.

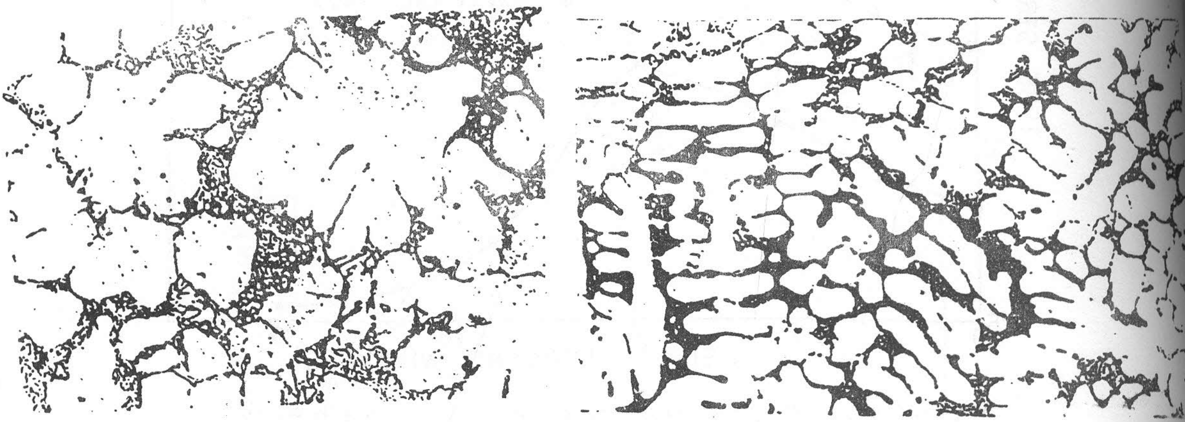

Figure 6 : Refining effect of the pressure on the structure of the AS7G03 alloy : (x100)
a) - p = 0.1 MN. m^{-2}
b) - p = 50 MN. m^{-2}

The mechanical behaviour of the composites at elevated temperature has been studied in compression and the results are shown in figure 8. This figure shows two plots for the variation of the offset yield stress with temperature for the matrix alloy and for the composite containing 5 wt% whiskers. The decrease in yield strength between room temperature and 300°C is 30% for the matrix alloy whereas it is only 13% for the composite. Consequently at 300°C, the strength increase due to the presence of 5 wt% whiskers is about 50%. Similar results were previously reported in composites made with the same matrix and SiC fibers (12, 14,18) or SiC particles (15,17). However, comparison between the present results and the previous ones shows that whiskers are more efficient at

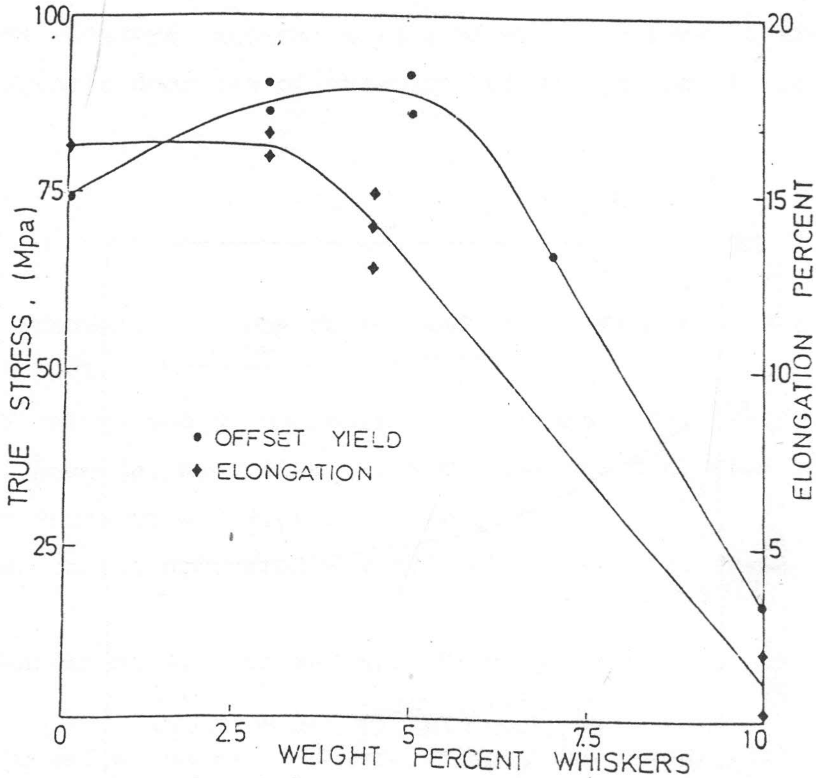

Figure 7 : Influence of whisker content on tensile yield stress and elongation for AS7G03/SiC whisker composites.

improving the high temperature strength than fibers and particles. This result is consistent with the very high value of the mechanical strength of the SiC whiskers.

Conclusion

Al-Si alloys reinforced by up to 5 wt% SiC whiskers can be fabricated. Using the compocasting technique.

Addition of 5 wt% whiskers improves the yield strength at room temperature by about 30% and that at 300°C by more than 50%.

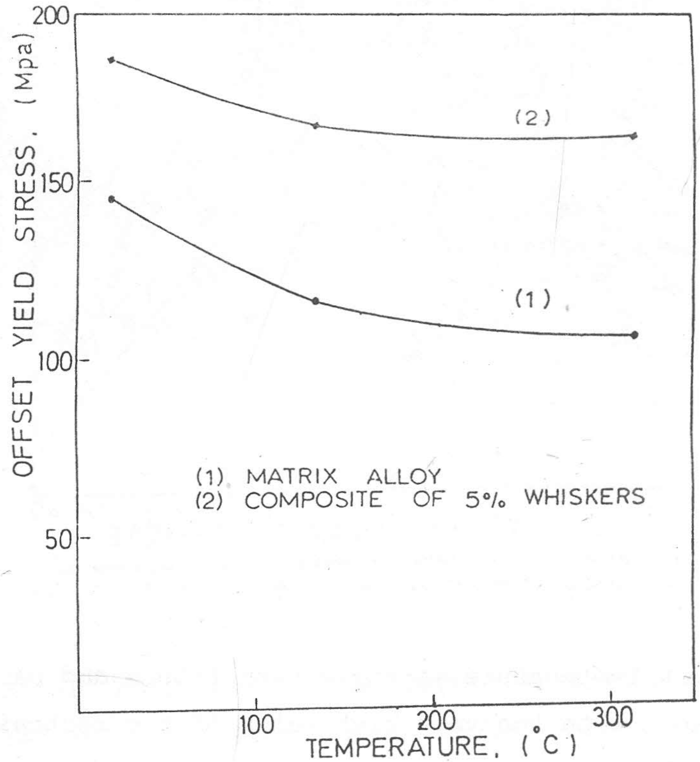

Figure 8: Compressive yield stress versus temperature for the matrix alloy and for a composite containing 5 wt % whiskers.

Beyond 5 wt% whiskers, agglomerations of whiskers form in the melt which result in drastic decrease of strength and elongation of the composites.

References

[1] D.B. Spencer, R. Mehrabian and M.C. Flemings: Met. Trans., 3, (1972) 1925.

[2] M.C. Flemings and R. Mehrabian; "AFS Trans., 81, (1973), 81

[3] E.F. Fascetta, R.G. Riek, R. Mehrabian and M.C. Flemings: ASF Cast Metals Research J., 9, (1973), 167.

[4] R. Mehrabian, R.G. Riek and M.C. Flemings: Met. Trans., 5, (1974), 1899.

[5] R. Mehrabian, A. Sato and M.C. Flemings: Light Metals, II, (1975), 177

[6] A. Sato and R. Mehrabian: Met. Trans., 7B, (1976), 443

[7] R. Mehrabian and M.C. Flemings: Aluminium, 51, (1975), 710

[8] R.G. Riek,A. Varchnos, K.P. Young, N. Matsumor and R. Mehrabian AFS Trans., 19, (1975), 25

[9] K.P. Young, R.G. Riek, J.F. Boylan, R.L. Bye, B.E. Bond and M.C. Flemings: AFS Trans., 128, (1976), 169

[10] P.A. Joly and R. Mehrabian: J. Mater. Sci., 11, (1976), 1393

[11] M.C. Flemings, R.G. Riek and K.P. Young: AFS. cast Metals J., 9, (1976), 11

[12] C.Millire and M. Sury in "Advanced Materials Research and Developments for Transport" Composites. Ed. P. Lamicq, W.J.G. Bunk and J.G. Wurm (1985), 241, Les Editions de Physique, les Ulis France.

[13] F. Girot. Thesis universite de Bordeaux I, France, Jan. 1987.

[14] C. Milliere, Thesis Institut National Polytechnique de Grenoble France, May 1986.

[15] M.A. Bayoumi and M. Sury in Proc. "6th International Conference on Composite Materials" Londres, (July 1987), 2481 Ed. F.L Matthews et al. Elsevier Applied Science, London.

[16] F. Girot, J.M. Quenisset, T. Naslain, B. Coutand and T. Macke ideam Ref. 15, 2.330.

[17] M.A. Bayoumi, Thesis Institut National Polytechnique de Grenoble France, Nov. 1987.

[18] C. Milliere and M. Suery. Mat. Sci. Technol, 4, (1988), 41

[19] S. Chatterjee and A.A. DAS. British Foundrymen 65, (1972), 420

[20] S. Chatterjee and A.A. DAS. British Foundrymen 66, (1973), 118

[21] R. Arsenault and M. Taya. in Proc. "International Conference on Composite Materials," San Diego, (July 1985) 21 Ed. W.C. Harrigan et al. The Metallurgical Society, Warrendale.