MICROSTRUCTURAL ANALYSIS OF THE REINFORCED AL-CU5MGTI/TIB_2 6 WT. % ALLOY FOR INVESTMENT CASTING APPLICATIONS

P.Egizabal[1], M. García de Cortazar[1], J.F.Silvain[2], J. Douin[3], A. Torregaray[4]

[1] Fundación Inasmet, E-20009 Donostia-San Sebastián
[2] Université Bordeaux I, ICMCB, 33608 Pessac, France
[3] CEMES – CNRS, 31055 Toulouse, France
[4] University of Basque Country UPV/EHU, E- 48012, Bilbo-Bilbao

KEYWORDS: MMC, TiB_2, Al-Cu alloys, Al_2Cu, grain refining, investment casting

ABSTRACT

The paper analyses the effect of titanium diboride (TiB_2) particles in a 6 wt. % content into the microstructure of a Al-Cu alloy. The main aim of the addition of the particles is to improve wear properties of the alloy as well as the mechanical properties at high temperatures and to produce a decrease in the coefficient of thermal expansion CTE following the pattern of other well known particulate reinforced metal matrix composites (MMC). The present paper deals with the analysis of the microstructural differences of the reinforced alloy and its non reinforced counterpart. In addition to well known effects such as the decrease in the grain size of the α-aluminium grains and the tendency of forming agglomerates in the grain boundary regions, the current work has permitted to observe other less known important effects such as the role of TiB_2 particulates in the solidification of the alloy and in the precipitation of Al_2Cu phases.

1. INTRODUCTION

TiB_2 particles incorporated in Al-Ti-B grain refiners are extensively used by aluminium foundries to improve the properties of the castings. The addition of only 0.15 wt. % is enough to refine the grains [Ref.1-2]. Even though the main effect of the addition of TiB_2 particles into aluminium alloys is the refinement of the aluminium grains, there are other additional microstructural changes that can also be explained by the presence of these particles. TiB_2 particles that have not participated in nucleation events tend to be pushed by the solidification front and lie at grain boundaries. Furthermore the porosity of the samples decreases through the addition of grain refiners. The average size of the pores is lower and the remaining porosity is more evenly distributed and the hot tearing tendency and quality surface improves [Ref. 3-4].

The alloy studied in this work contains up to 6 wt. % of TiB_2 particles, though. This amount exceeds the level necessary for grain refining with the aim of improving the properties of the alloys following the patterns shown by other particle reinforced aluminium matrix composites (AMC). The influence of these particulates on the microstructure of the alloy has been analysed and the microstructure has been compared to that of the corresponding non reinforced alloy Al-Cu5MgTi. The microstructure of the reinforced alloys has been thoroughly studied through all Optical Microscopy (OM), Scanning Electronic Microscopy (SEM), Transmission Electronic Microscopy (TEM) and Auger Electron Spectroscopy (AES). Image The identification of the elements composing the different phases have also been carried out. It has been observed that apart from the grain refining effect the particulates play an important role in solidification events, selection of precipitating phases and decrease of defects.

2. TECHNICAL APPROACH

The alloy containing 6 wt. % TiB_2 particles is not commercially available and has been produced by the company London & Scandinavian Co. Ltd through a proprietary process based on their technology to produce aluminium master alloys [5-6]. The addition of two salts to aluminium that react with each other to produce TiB_2 particles is the basis of this process. Nevertheless and due to the difficulties to remove the salts and obtain clean materials having a TiB_2 content higher than 5 wt. % it was decided that the reaction were adjusted so that only 1 wt. %. of the TiB_2 particles were formed in situ. Subsequently 5 wt. % of commercially available TiB_2 particles of around 5 μm were added to obtain a material that could keep the sufficient castability and provide the best possible combination of mechanical and thermal properties.

The Al-Cu5MgTi alloy presents good machining properties, is heat treatable and is mainly used in aircraft parts when better mechanical properties than those provided by Al-Si alloys such as Al-Si7Mg0.3 are required. Nevertheless it is not so extensively applied as the latter due to its lower castability. Its solidification range is very large and this makes it prone to hot tearing related problems. The Al-Cu5MgTi alloy is mainly applied when high mechanical properties are needed at high temperatures. The use of grain refiners in these alloys is highly recommended due to the clear benefits they provide. The hot tearing related problems become alleviated, mechanical properties get improved and surface quality and the answer to thermal treatments is better. Al-Ti-B type grain refiners have been used with this alloy in different foundry processes. Their use is even more essential in the case of low cooling rate processes like sand casting or lost wax processes as the large solidification intervals of the alloy (650-450ºC) [7] together with the low heat dissipation capacity of the moulds tend to create problems related to hot tearing and poor mechanical properties.

Magnesium increases the strength and hardness of this alloy through thermal treatment and Titanium is used as a grain refiner so that the insoluble constituents can be better dispersed as well as the porosity and defect distribution. Its main properties in the T6 condition are listed below [8]:

- Density (g/cm^3): 2.80
- Coefficient of thermal expansion (10^{-6} ºC^{-1}): 25
- Thermal Conductivity (W/mºC): 140
- Young Modulus (GPa): 72
- Yield stress 0,.2% (MPa) : 220
- Ultimate tensile strength (MPa): 340
- Elongation (%): 4

Table 1 presents the composition of the reinforced alloy and the non reinforced alloy used for comparison purposes.

Al-Cu5MgTi + TiB_2 6 wt. %								
	Al	Si	Fe	Cu	Mg	Zn	Ti	B
wt. %	Balance	0.08	0.11	5	<0.01	<0.01	3.4	1.7
Al-Cu5MgTi								
wt. %	Balance	0.10	0.10	4,94	0	0,01	0,15	0

Table 1: Composition of the reinforced and non reinforced Al-Cu5MgTi alloy

The production of the samples has been carried out through the plaster casting process. The process consists of producing a replica on wax or plastic of the part to be produced. This replica or pattern is assembled with a filling and feeding system of similar material. This assembly is coated or invested with a hard-setting plaster based refractory slurry. After allowing the plaster to set, the mould is placed into a furnace at around 150-180ºC to be dewaxed. The mould is then heated or fired to burn off the residual wax and to obtain the refractory properties needed to withstand the casting step. When the firing cycle is completed molten metal is cast into the preheated mould.

The production route chosen was optimised in order to obtain sound samples with a correct and homogeneous distribution of TiB_2 particles. The casting temperature was established at 730ºC for the Al-Cu5MgTi and Al-CuMgTi + TiB_2 6 wt. % materials. The plaster mould temperature was kept at 250ºC and the rest of parameters were kept unchanged through all the casting trials (time to fill the moulds, vacuum applied during the castings and amount of plaster used to build the moulds). Figure 1 shows an Al-CuMgTi + TiB_2 6 wt. % component from which four tensile specimens were machined together with the specimens for the microstructural analysis.

Figure 1: Al-Cu5MgTi + TiB_2 6% wt. component obtained through plaster casting

Subsequently both reinforced and non reinforced samples were submitted to different microstructural and chemical analysis: SEM, TEM. AES and EDS mapping (reinforced alloy specimens prepared with the FIB technology).

3. DISCUSSION OF RESULTS

Figure 2 presents optical microscopy images of both alloys. The alloy is known to be prone to hot tearing mainly due to its large solidification interval that is further affected by the low heat dissipation capacity of the plaster mould [8]. Microshrinkages appear that tend to disappear in the presence of the TiB_2 particulates. Furthermore TiB_2 has a grain refining effect (the grain size decrease from 315-200 μm in the non reinforced alloy down to 125-200μm). It can also be seen that the particles are mainly located in the grain boundary region pushed by the solidification front.

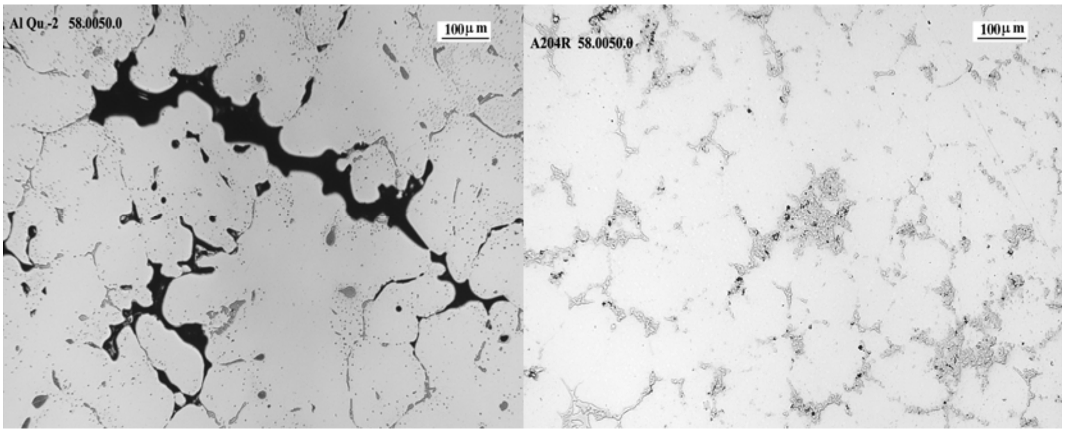


Figure 2: Optical microscope images of the non reinforced (left) Al-Cu5MgTi alloy showing a region with microshrinkages and the equivalent reinforced material (right).

Figure 3 shows a general aspect of the microstructure of the reinforced alloy. An isolated grain is pinpointed that contains TiB_2 and Al_2Cu phases that are also found in the grain boundary regions. Al_2Cu phases appear somehow connected to the TiB_2 particles. This phenomenon can be more clearly seen in the detailed micrographs of the regions where there is an agglomeration of TiB_2 particles (See fig 4).

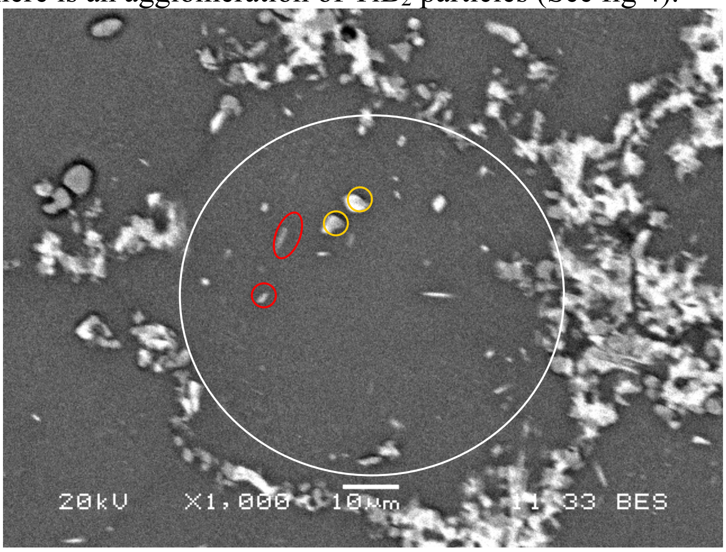


Figure 3: Image of the reinforced alloy showing an isolated α-Al grain surrounded by TiB_2 and Al_2Cu particles. TiB_2 particles signaled in red and Al_2Cu particles linked to small TiB_2 particles can be observed signaled in yellow.

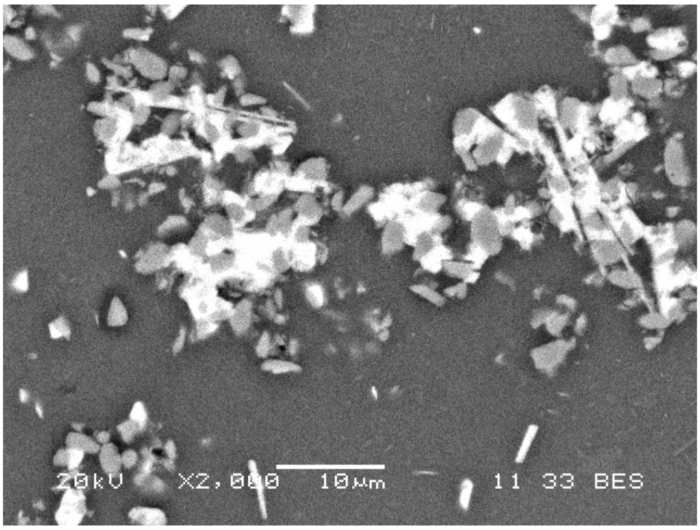


Figure 4. Grain boundary region showing a high concentration of particles. Grey particles are TiB_2 and white phases are Al_2Cu.

The TEM analysis of samples prepared with the Focused Ion Beam FIB technology and the EDS analysis provided additional information on the interaction of the TiB_2 particles and the Al-Cu matrix.

Figure 5 shows a TEM image of an isolated TiB_2 particle. It can be observed that the TiB_2 particulate presents rather sharp edges and this leads to think that it may be an ex-situ particle. The density of dislocations around the particulate is small in spite of the CTE mismatch between the particulate and the Al-Cu matrix (8.1 and 25.3 10^{-6} C^{o-1} respectively). On the other hand, the grain size of the particles around the TiB_2 particulate is small.

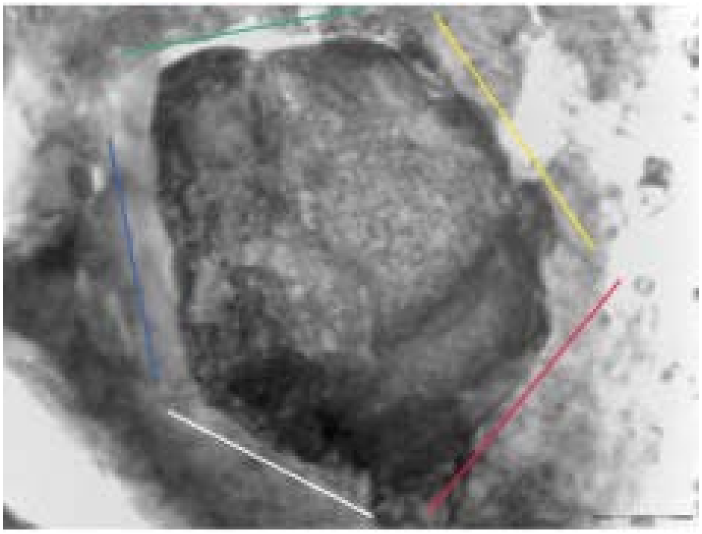
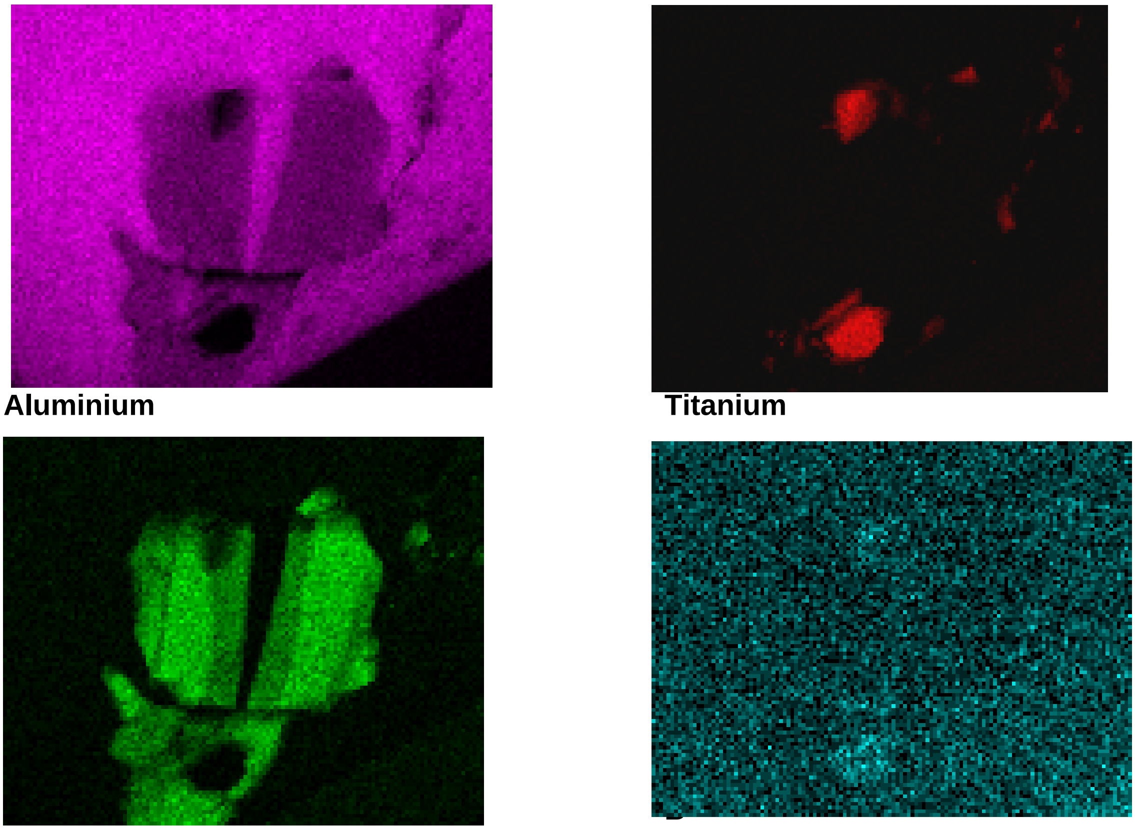


Figure 5: TEM image of an isolated TiB_2 particle within the Al-Cu5MgTi matrix.

The analysis was completed with the EDS mapping of the main elements (Al, Cu, Ti and B). The results are shown in figure 6. Two large TiB_2 particles can be seen that are surrounded by Cu and Al. TiB_2 particles act as nucleation sites for Al_2Cu precipitates.



Aluminium Titanium

Copper Boron

Figure 6: EDS images of Al, Cu, Ti and B

The two large rounded black areas in the aluminium EDS mapping image represent two TiB_2 particles surrounded by Al (pink) and Cu (grey). The image representing the copper shows that a compound composed of this element and aluminium surrounds completely the TiB_2 particulate located in the lower central region of the image. Finally the mapping of B and Ti shows that they form a compound identified as TiB_2 by XRD.

Eventually the AES technology was also applied to complete the microstructural analysis. Figure 7 shows different TiB_2 particles (dark areas) that are identified by the characteristic Ti and B peaks in the line profiles. The profile shows that some Al-Cu i phases are formed in the interface of the TiB_2 particles. It is difficult to define their composition as they may also contain some Fe, Mg or Si. Nevertheless and according to other data obtained in previous analysis (SEM and XRD) of these materials it may be deduced that most of them are Al_2Cu precipitates.

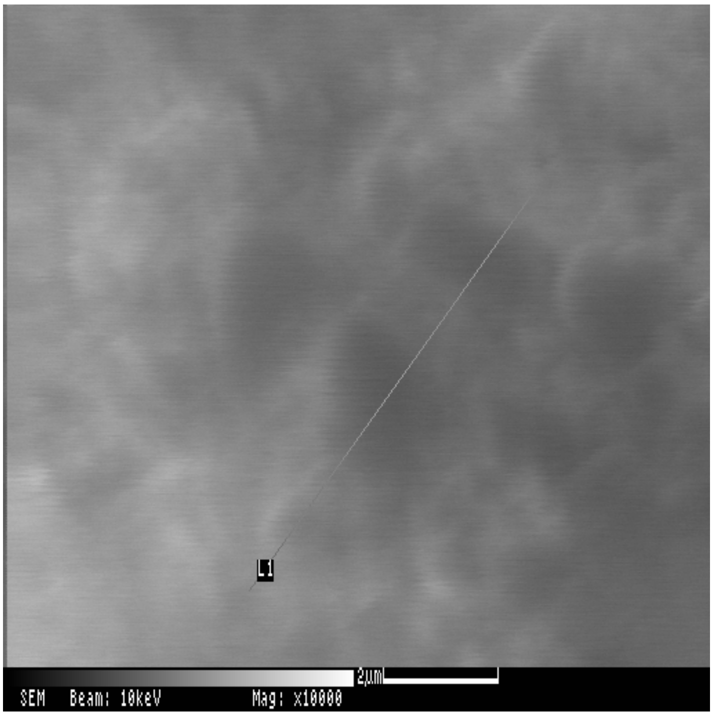


Figure 7: AES image of the Al-Cu7MgTi + TiB_2 alloy. Clear regions are Al and dark areas are TiB_2 and intermetallics.

In order to obtain more information a non linear least squares fitting (NLLSF) software was applied to the region represented in the figure 7. The results presented in figures 8 and 9 show that there are two different aluminium species related to two different chemical environments. These aluminium species have been marked as Al_1 and Al_2. The analysis of the resulting profile indicates that Al_1 corresponds to α-aluminium and Al_2 corresponds to an intermetallic that is formed by Al-Cu (therefore it is probable to be Al_2Cu) that segregates on the interface of the TiB_2 particles. These results are in agreement with the observations of the X-ray diffraction where Al_2Cu crystals were observed in the Al-Cu7MgTi + TiB_2 material as well as the results obtained with optical microscopy and the image analysis of SEM specimens.

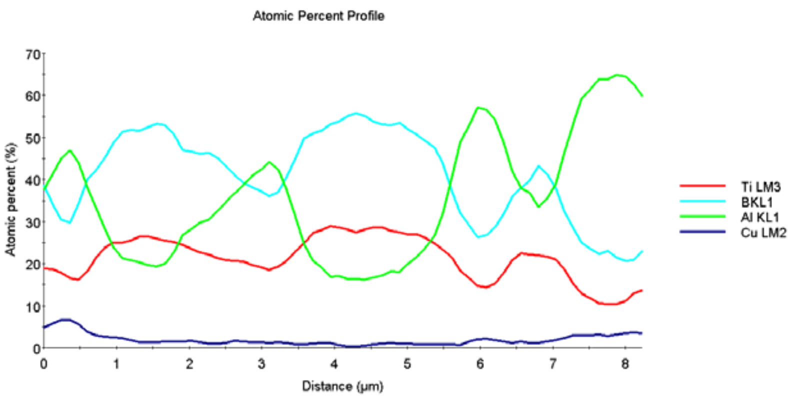


Figure 8: Line profile analysis of the region represented in the image of figure 7 showing the presence of Al, Ti, B and Cu.

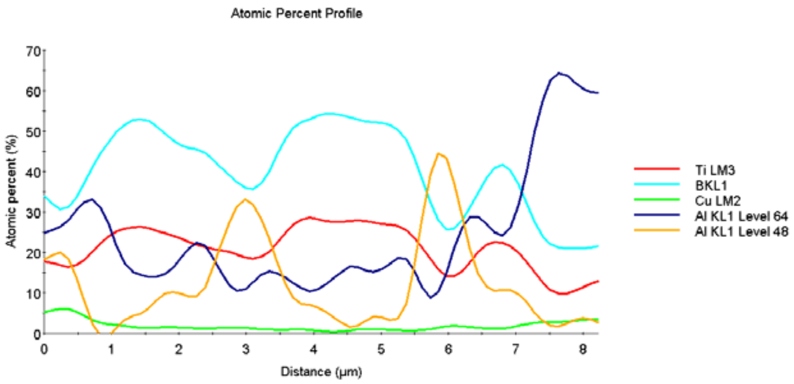


Figure 9: Line profile obtained by applying the NLLSF software. Two different aluminium species can be appreciated. The Al linked to Cu appears to be segregated on the interface of the TiB_2 particulate.

4. CONCLUSIONS

The comparison of the reinforced alloy with the corresponding non reinforced counterpart makes clear that the presence of TiB_2 particles has a large influence in the final microstructure. This influence is furthermore not limited to the grain refining phenomena that were previously known to take place when small amounts of TiB_2 particles were incorporated as part of Al-Ti-B grain refiners. It has been seen that TiB_2 particles play an important role in the precipitation events of the different phases that are formed during solidification. Furthermore they have a beneficial influence on the decrease of porosity and solidification shrinkage related defects. Moreover TiB_2 particles play a role in the selection and amount of precipitations that are formed.. The Al_2Cu phase precipitates on the surface of the TiB_2 particles. The mapping of the elements in the samples has demonstrated that Al_2Cu precipitates appear associated with the TiB_2 particles. This effect is directly related to mechanical properties as it is known that the control of the size and distribution of this phase (Al_2Cu) has a direct effect on the mechanical properties as they impinge dislocations avoiding their movement and increasing the strength of the material.

ACKNOWLEDGEMENTS

This work has been partially funded by the EC FP6 project IMINCAST (project number CRAF-1999-72448) under contract number G1ST-CT-2002-50268

REFERENCES

[1] Hardman A. and Hayes F.H. "Al-Ti-B Grain refining alloys from Al, B_2O_3 and TiO_2. Materials Science Forum, Vols. 217-222, pp. 247-252, 1996.

[2] Schumacher P., Greer A.L., Worth J., Evans P.V., Kearns M.A., Fisher P. and Green A.H. "New studies of nucleation mechanisms in aluminium alloys: implications for grain refinement practice". Materials Science and Technology May 1998 Vol. 14. pp 394-404.

[3] Kashyapk K.T. and Chandrashekar T., Effects and mechanisms of grain refinement in aluminium alloys, Bulletin Material Science, Vol. 24 N°4, August 2001,pp. 345-353.

[4] Marcantonio J.A and Mondolfo, Grain refinement in aluminium alloyed with titanium and boron, Metallurgical Transactions, Vol 2, February 1971, pp 465-471.
[5] Tjong S.C. and Ma Z.Y. "Microstructural and mechanical characteristics of in situ metal matrix composites". Materials Science and Engineering, Nos. 3-4, 15 August 2000.
[6] Taghiabadi R., Mahmoudi M., Emamy Ghomy M. and Campbell J. "Effect of casting techniques on tensile properties of cast aluminium alloy (Al-Si-Mg) and TiB_2 containing metal matrix composite". Materials Science and Technology, April 2003 Vol.19.

[7] Grandier Vazeille P. and Morice J. "Mise au point d´eprouvettes technologiques pour l´aptitude au moulage des alliages d´aluminium". Revue de l´aluminium.Fevrier 1971. pp.177-187

[8] Beeley P.R., Smart R.F. "Investment casting ". Investment casting. The institute of Materials 1995. ISBN 09 0171666 9. pp. 262-265