OBSERVATIONS OF THE COLUMNAR TO EQUIAXED TRANSITION IN DIRECTIONALLY SOLIDIFIED ZINC-ALUMINUM ALLOYS AND COMPOSITES

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Introduction

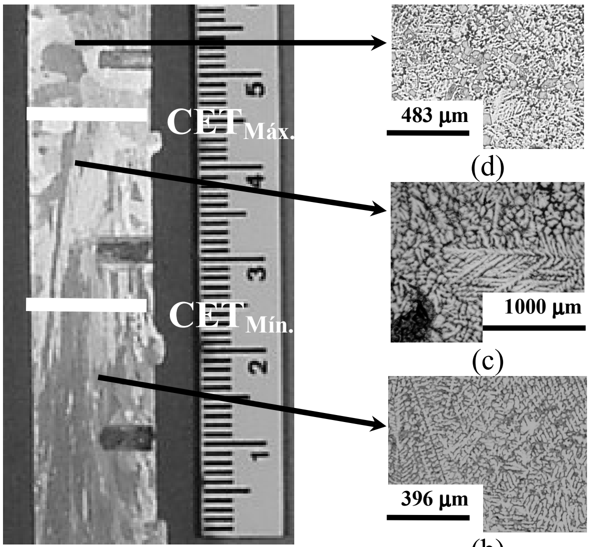
In general, equiaxed structures have bigger resistance, longer durability to fatigue, second phases more finely dispersed, better impact properties and workability. On the other hand, columnar structures commonly obtained in the production of turbine blades, have bigger resistance to traction and compression, larger resistance to flexion and larger resistance to torsion [1]. The interaction between the parameters involved in the columnar to equiaxed transition (CET) has gained considerable attention over the last three decades in order to understand the structure of ingot castings and to optimize the industrial practice [2].
There are no studies of the CET in composites directionally solidified in the literature. The results presented in this paper focus on the CET studies in Zn-Al alloy systems with different compositions and with reinforcing particles of silicon carbide and alumina. The effects of several solidification parameters on the transition are determined and discussed. Such parameters include the position of the solidification fronts given by the liquidus and solidus temperatures, cooling rate of the liquid, temperature gradient, superheat, heat flow and recalescence.
After solidification the structure was analyzed. The analyses were done performing quantitative metallography and composition analysis of the different alloying elements along solidified samples utilizing SEM (Scanning Electron Microscopy) and EDXA (Energy Dispersive X-Ray Microanalysis).

Experimental

Alloys of different compositions were prepared from zinc (99.98 wt pct) and commercial aluminum (99.96 wt pct), the composites were prepared by adding SiC and Al_2O_3 particles to the alloys. The compositions of the alloys and composites are shown in Table I.
The alloy samples were melted and solidified directionally upwards in an experimental setup described elsewhere [3]. The temperature measurements were performed using K-type thermocouples which were protected with ceramic shields. The thermocouples were previously calibrated. The liquidus and solidus temperatures for each alloy were determined using two methods: 1. the differential thermal analysis system, NETZSCH STA 449 C with calibrated cells with pure elements, 2. determining the start and the end of solidification at each thermocouple. Both points were detected by the changes in the slopes of the cooling curve at the start and the end of solidification.
After solidification, the samples were cut in an axial direction, polished with emery paper up to 1000 grit and 1-μm alumina using a low speed machine and etched with a mix containing chromic acid (50 g Cr_2O_3, 4 g Na_2SO_4 in 100 mL of water) during approximately 10 seconds at room temperature [4]. The position of the transition was located by visual observation and optical microscopy and the distance from the chill zone of the sample was measured with a ruler.
The average grain size and volume fraction were determined according to ASTM E 112-88 and ASTM E 562-89 techniques, respectively. The size, volume and number of particles in three dimensions were determined utilizing Saltykov`s modification of Johnson's method. The determination of the number of particles by means of a grid method was done dividing one section in 64 squares of 20 X 20 mm uniformly distributed. The number of repetitions in each case ensured a representative distribution in each sample. The particle volume distribution was obtained utilizing the standard norm ASTM E562-89.
The determination of the density of averages sizes of particles was found quantifying the repetitions of size of different particles in the grid utilized. An average of the distribution of sizes was obtained. The range of particles size is between 1.56 μm to 20.79 μm of average diameter.
The microstructure was analyzed with optical and scanning electron microscopy (SEM). The distribution of elements in the microstructure was determined using EDXA. A Rigaku X-ray diffraction (XRD) system (Rigaku MSC, the Woodslands, TX) was used for the XRD analysis of the alloys and composites.

Results and Discussion

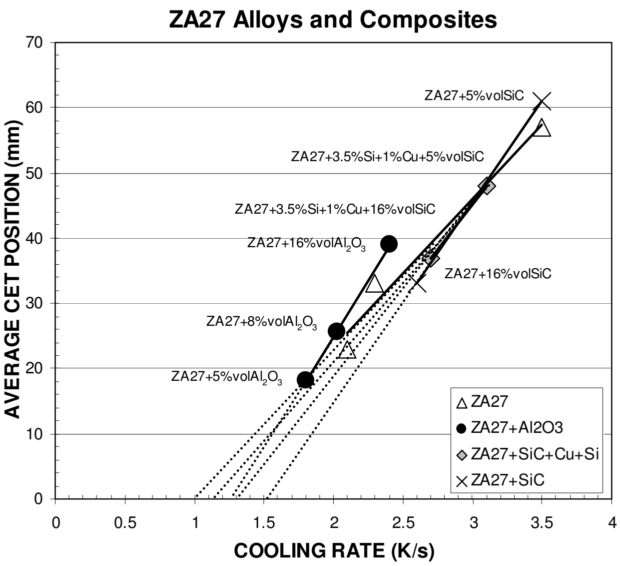
A number of thirty-eight experiments in a range of alloy and composite compositions and cooling rates were performed. As an example, a typical macrostructure of the transition is shown in Figure 1 (a) for ZA27+3.5wtpctSi+1wtpctCu+16volpctSiC composite. In Figures 1(b) to 1(d) it is possible to appreciate the resultant microstructures in the columnar, CET and equiaxed zones of the sample in Figure 1(a).



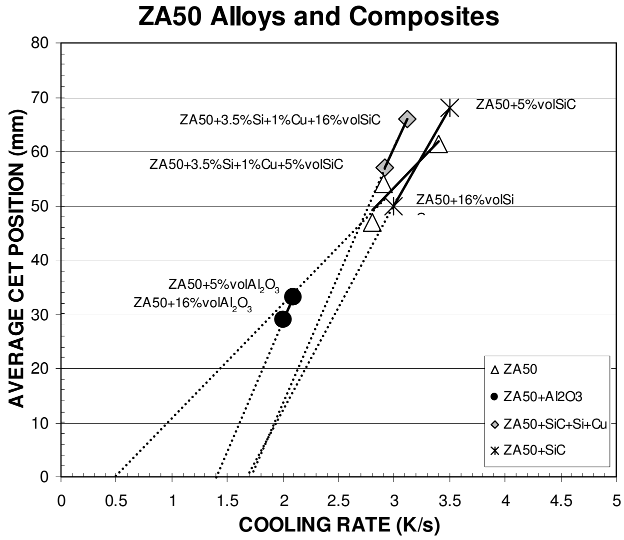
(a) (b)

Fig. 1 (a) Macrostructure of ZA27 + 3.5 wt pct Si+1wt pct Cu +16 vol pct SiC. (b-d) Representative finer microstructures in each zone of the sample.

The cooling rate in the liquid, $\dot{T}$, was determined from the temperature versus time curves at each thermocouple position and taking the average slope. Comparing the cooling velocities with the distances, which correspond to the length of the columnar zone, for all alloys, was observed that increasing the velocity increases the length of the columnar grains. The results are shown in Figure 2 (a) and (b) for ZA27 and ZA50 alloys and composites, where for each cooling rate the maximum columnar lengths, L_{Col}, are presented; with these values regression lines were obtained, which are calculated fitting the experimental points ($R^2 > 0.98$). These relationships are useful to correlate the length of the columnar zone with the cooling rate. These results show the strong effect of cooling rate in the melt on columnar length. In addition, by extrapolating the lines to the abscise in Figure 2 (a) it is possible to predict the minimum cooling rate for which columnar growth is no longer possible and the resultant structure is fully equiaxed.



(a)



(b)

Fig. 2 Length of the columnar zone vs. cooling rate for alloys and composites (a) ZA27 and (b) ZA50.

Conclusions

From the results and discussion of the previous sections the main conclusions of this investigation on the columnar to equiaxed transition in Zn-Al alloys and composites are:

1. It was possible to obtain values of the thermal parameters associated with the CET of ZA composites and compare them with those obtained for ZA alloys. These parameters are useful for foundry industry and also for modeling purposes.
2. The transition occurs in a zone rather than in a sharp plane, where both columnar and equiaxed grains in the melt co-exist.
3. The length of the columnar zone increases with cooling rate increase. Regression lines were obtained for ZA alloys and composites.

Acknowledgements

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References

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