Microstructure Evolution in Co-Base Alloys Solidified in Wedge Shaped Cu-Mold

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Statement of purpose: Cast and/or wrought Co-alloys have wide application as biomaterials, such as dental and prosthetic implants, due to its excellent biocompatibility, mechanical properties, corrosion resistance and wear. Most Co-biomaterials are obtained by casting, and its variables such as alloy composition, casting temperature and cooling rate, will have an impact on microstructure and properties. As-cast microstructures of Co-alloys consisted mainly of α-Co columnar dendrites with interdendritic segregation. This interdendritic segregation not only may reduce properties but also can cause failure. Therefore, in this work, it is reported, the effect of cooling rate, during solidification of Co-20, 30, 35 and 41 wt.% Cr alloys casted into a wedge shaped copper mold, on the resulting microstructure, solute distribution, second phase precipitation, with special attention to the reduction and/or elimination of interdendritic segregation. Additionally a dendrite growth model was incorporated to predict dendrite tip radius and solute distribution during the growth of dendrites, including growth rates in the range of the limit of absolute stability.

Methods: Co-alloys were melted into an induction furnace under vacuum using high purity Co and Cr elements, which were placed into an alumina crucible, melted under an argon atmosphere and casted into a wedge shaped copper mold. The resulting ingots were sectioned longitudinally and centrally in the plane normal to the diverging wedge faces, and then mechanically polished and etched in a solution of 10 g of Fe_3Cl+2 ml of HCl in distilled water. Microstructure was observed under a scanning electron microscope coupled with microanalysis facilities. The microstructure was characterized under a scanning electron microscope with microanalysis facilities. Solidification dendrite growth (1) was modeled and tip concentration in the melt is given by:

$$C^*_L = C_o / [(1-p)\ Iv(P)] \quad (1)$$

where Iv(P) is the Ivantsov function, P(=VR/2D) is the Peclet number, where V is the growth velocity, R the dendrite tip radius and D_L the liquidus diffusion coefficient, p(=1-k with $k=C^*_S/C^*_L$). The unknowns P and R are given by the solution of:

$$V^2A + VB + G = 0 \quad (2)$$

where $A=\pi\Gamma/P^2D^2$, $B=m_LC_op\xi_c/D[(1-p)\ Iv(P)]$, with $\xi_c=1-2k/\{[1+(2\pi/P)]^{1/2}-1+2k\}$ and G the temperature gradient.

Results: Locations of characteristic structure zones obtained in ingots of Co-Cr alloys are summarize in Fig. 1a, where the main microstructure consisted of α-Co dendrites and depending of its Cr-content and ingot location, dendrites showed an equiaxed (tip) or columnar (middle and top) morphology with dendrite dimensions decreasing from top to bottom. Also, it was observed during microstructural characterization of ingots that interdendritic segregation is reduced from columnar to equiaxed dendrites.

Additionally, it was detected the presence of precipitates of ε-phase in all ingots. Because the main purpose of this research is to find experimental conditions to reach Co-Cr alloys in the as-cast condition with suppression of both interdendritic segregation and ε or σ precipitates, to be used as dental implant, in order to avoid corrosion problems as a result of direct contact with the saliva and/or bacteria, a dendrite growth model was incorporated to predict dendrite tip radius and solute distribution during solidification of Co-Cr alloys.

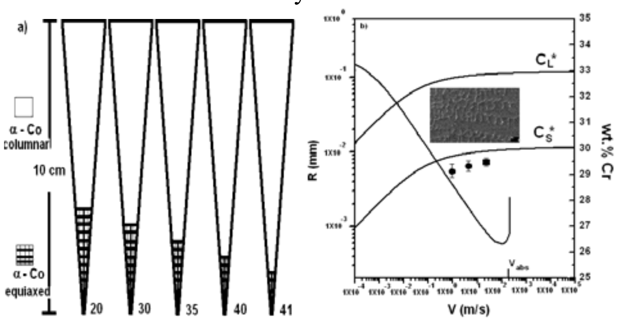

Fig. 1 (a) Microstructure of Co-20, 30, 40 and 41 wt. % Cr alloys solidified in a wedge shaped copper mold, (b) dendrite tip radius and solute concentration as a function of growth velocity. ● columnar dendrites, ■ cellular dendrites.

Fig. 1b shows results of the dendrite growth model in terms of tip radius and Cr-concentration as a function of solidification front velocity with fixed G=0 and 10 K/m for the Co-30 wt.% Cr alloy. Solid lines represent prediction while figures represent experimental results. As can be observed, experimental results can be predicted by the model between experimental errors.

Conclusions: Wedge shaped ingots of solidified Co-Cr alloys showed microstructure maps as a function of alloy composition and cooling rate, where it was detected that Co-30 wt. % Cr alloy showed the presence of equiaxed dendrites with interdendritic segregation <1%, from tip to 30 mm to top of ingot and with a solute concentration in α-Co dendrites close to the parent melt. Experimental results were predicted between experimental errors by the dendrite growth model, which allow us to model solidification of a wide range of Co-Cr alloys.

References: Kurz W, Giovanola B. and Trivedi R. Acta Metall. 1986;34:823-830.