



# Grain structure formation in static & continuous casting

## ◇ Grain structure analysis

*Physical properties of metals not only depend on composition but are also strongly linked to microstructure and especially to grain structure. Parameters such as mechanical properties vary with the size and shape of the grains.*

*Like most of the metallurgical characteristics, grain structure is first determined during solidification in the casting process. Subsequent mechanical and thermal treatment can modify these grains. However, it is difficult to fundamentally change the initial structure.*

*This e-Tip will concentrate on the control over grain structure during casting operations. Gold casting is taken as an example in order to illustrate the difference between static and continuous casting.*

Grain structure is ruled by nucleation and growth. Nucleation rate determines the number of sites where new grains will start growing in a given amount of liquid metal. Nucleation sites can be located at the surface of the mould, in the bulk, on impurities or on specifically added inoculation elements. The growth of each grain is mainly influenced by isotherm velocities and thermal gradients. The latter ones being perpendicular to the solidification front.

In static casting, the solidification front moves in the casting during cooling. As cooling is applied at the same time on the whole casting, solidification will start from the walls with grains growing against the heat flux. These grains are known as columnar grains. Eventually, and depending on the local solidification conditions, equiaxed grains can form in the bulk. These new grains have a random orientation and they can, in certain cases, block the progression of the columnar grains. Figure 1 shows three different solidification cases.

Case a) shows a purely columnar grain structure. Case b) presents some equiaxed grains whereas case c), strongly inoculated, presents a quasi exclusively equiaxed structure. This simple example shows that the amount of inoculation elements has a strong influence on the final structure. Only



Figure 1: a) Purely columnar grain structure. b) Low inoculation, columnar-to-equiaxed transition. c) Strong inoculation, small columnar structure, mainly equiaxed grains. Grain structure predicted with the simulation software calcosoft®-2D.

the case with strong inoculation shows some degree of structure homogeneity.

In continuous casting, the solidification front is kept at a constant location, within the crystalliser. Temperature control in the solidification area as well as casting speed are two important parameters influencing grain structure. The two following sets of pictures illustrate the combined influence of casting speed and inoculation element concentration. The first set of pictures grouped in figure 2 correspond to a low casting speed and represent:

- the solidification front (a1)
- a grain structure obtained with no inoculation elements (a2)
- a grain structure obtained with inoculation elements (a3).



Figure 2: Solidification pattern at low casting speed (1mm/s). (a1) Solid / Liquid transition (solid = red; liquid = yellow). (a2) Grain structure without inoculation. (a3) Grain structure with inoculation. Structure predicted with the simulation software calcosoft®-2D.

Figure 3 shows a similar bar cast five times faster than the previous one. (b1) still shows the position and shape of the solidification front whereas (b2) and (b3) illustrate the grain structure obtained without, resp. with inoculation elements.



Figure 3: Solidification pattern at high casting speed (5mm/s). (b1) Solid / Liquid transition (solid = red; liquid = yellow). (b2) Grain structure without inoculation. (b3) Grain structure with inoculation. Structure predicted with the simulation software calcosoft®-2D.

A careful look at the shape of the solid front on a1 (figure 2) and b1 (figure 3) reveals a change from a flat front for the low speed, to a more curved front for the higher speed. The influence of this change on grain structure is

dramatic if no inoculating elements are used. A low casting speed will tend to generate long central grains. A higher casting speed will tend to favour a "chevron-type" grain structure with a marked central line. The use of inoculation elements tends to dampen the influence of casting speed, generating a finely dispersed equiaxed grain structure.

### ◆ Case study: gold alloys

Static casting consists of pouring liquid metal into a cavity and letting it cool until everything is solid. It is a rather simple process, easy to set up and secure. Nevertheless it has also some drawbacks, such as the formation of porosity and the poor homogeneity in composition and grain structure. It is a batch process and therefore necessitates repetitive manipulations. As composition needs to be controlled accurately in gold alloys, it is not possible to strongly inoculate the castings. Therefore, the grain structure generated tends to be inhomogeneous.

Continuous casting on the other hand consists of extracting metal through a crystalliser. It is no longer a batch

process as liquid metal can be added on top of the crystalliser, at the same rate as the solid bar is extracted. The advantages of this process are the control over quality, the homogeneity of the final product and the constant grain structure generated. The tuning capabilities offered by continuous casting machines allow to produce at constant quality. The complexity of operation and set-up can be a drawback, depending on the skills of the operator. The grain structure generated with this process is generally constant from the beginning to the end of the casting.

Static casting is a simple process allowing to produce gold ingots rapidly and safely. Grain structure is mainly controlled by the amount of inoculation elements. This process tends to form inhomogeneous structures. In continuous casting, on the other hand, as the solidification front is confined within the crystalliser, it is possible to tune the grain structure more accurately. Parameters such as casting speed allow to tune the final structure. The structures generated with this process are generally homogenous along the casting, allowing therefore easier subsequent forming.



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