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VIBRATIONS INFLUENCE OVER THE METALLIC ALLOYS CRYSTALLIZATION

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ABSTRACT:
Metal materials casting is influenced favorably under the mechanical vibrations influence applied over the liquid alloy bath. Vibrations producing methods may be different, by using mechanical vibrations, or pneumatic, hydraulic or electrical. The mechanical vibrations in the particular case we've studied are obtained by means of an element that is in translation for a wide range of forces and frequencies up to 75 Hz.

The aluminum-silicone and aluminum-copper alloys are among the most used nonferrous cast alloys.

The present study (paper) presents the main phenomena occurring under the mechanical vibrations influence over the alloys especially the dendrites break and the superficial strain influence over the germinate particles.

1. INTRODUCTION

Crystallization, as any other process (chemical or physico- chemical) is studied from the static and kinematicl point of view. The statics structures the balance relationships between the crystals, the solution they are formed from. The statics deals with the solubility of the phase that is pure, in the presence of other phases, with the kinds of crystals balance and their composition.

The kinematics is specific to the speed the processus takes place at, it characterizes the speed taken by the processus to deploy, respectively the mechanism of germination and solidification of the metallic alloys. In connection with this fact, you have to examine the main factors that influence the germination, the break of the dendritic branches, the influence of the superficial tensions of the germinated particles, all under the vibrations influence over the metallic alloys.

2. DOCUMENTARY STUDY

The processus of crystallization from metallic melts has two stages: formation of crystallization germs and their growth.

The kinematics of the crystallization processus may be characterized mainly by two ratings: speed of germs formation and speed of crystals growth. To have a clearer image over the processus mechanism, each and every of these ratings have to be examined separately, as well as the influence of various factors over the speed needed by these processus to deploy. The vibrations influence is a research factor. Further on we shall refer to the vibrations influence (mechanical vibrations) over the germination and crystallization of cast alloys.

The strong connection between the germs formation and their development, the impossibility to separate exactly these stages, makes difficult the study of the crystallization processus. This explains the fact that neither of the theories proposed over the formation of crystallization germs and their growth cannot be considered complete for stating clear all the particularities of this heterogeneous processus so complex.

A high oversaturation of the melt favors, evidently, also the occurrence of the forms of dendritic growth. Indeed, the inflow of the substance that crystallizes from the solution is achieved easiest towards the crystal peaks, that is why the growth speed of the crystal peaks supersedes by far the growth speed of the edges and sides, which finally leads to the formation of the dendritic crystal having arborescent shape. In the dendrites growth, the substance that crystallizes (gets solid) can fill gradually the clearance between the branches, that is why the final shapes of the dendritic growth can be of a great variety, from compact crystals to those resembling to a hedgehog, function of the nature of the melt and of the growth conditions. Out of the conditions that favor the germination, besides the nature of the melt, a very significant influence is generated by the influence of the vibration with frequency (pulses) amplitude and acceleration as its main parameters. Lately, the acceleration is a working parameter since it can be measured and controlled easier. It is worth being mentioned that the connection between the frequency (f), pulsation (ω), amplitude (A), speed (v) are in well defined relationships, this is the reason why one can work unitarily with each of them. By vibrating the melt, a uniform affluence of the solution that crystallizes at various faces is ensured, by this annihilating the influence of the concentration currents, which favors the formation of crystals with a regular shape.

The action of accelerating the vibration over the germs formation becomes more and more efficient by increasing the crystals speed that gets lower gradually.

It is established that the mechanic erosion of the crystals, as a sequence of rubbing between each other, as well as to the molds (matrix) sides, increases with the mechanic vibration intensification. The crystals obtained thus have a round shape with rounded corners and edges, and finally increases sudden the quantity of the fine fractions.

3. ANALYSIS, INTERPRETATION - EXPERIMENTAL PART

The expression of the compact state by the density of the metallic material melt has a significant importance because it influences the structure and features of the material obtained. The discontinuities that may occur when the alloy gets solid are due to the phenomenon of contraction, characteristic to the majority of the alloys, together with a strong decrease of the solubility of the gases within the melt at the crystallization temperature.

Obtaining a compact metallic material is guaranteed if the penetration speed v of an alloy in the capillaries of the biphasic zone is equal to the contraction speed $v_{contr.}$:

$$V_{contr} = \alpha \cdot m \cdot R \text{ [m/s]} \tag{1}$$

where: α - contraction coefficient of the alloy when it gets solid;

m – relationship between the volume at the liquid state within the biphasic zone and the volume of this zone;

Under common circumstances, the speed v is expressed thus:

$$v = \frac{r^2}{8\eta} \cdot \frac{P_e + P_m - P_g + \frac{2\sigma}{r} \cdot \cos\theta}{l} \text{ [m/s]} \tag{2}$$

r - radius of the capillary [m/s]; P_e – external pressure [Pa]; P_m - metal static pressure [Pa]; P_g - pressure of the gas in the capillary [Pa]; σ - alloy superficial tension [N/m]; θ - humectation (moistening) angle [rad]; η - alloy dynamic viscosity [Pa·s]; l – length of alloy penetration into the capillaries [m].

From the equality between the relations (1) and (2) it results:

$$\frac{r^2}{8\eta} \cdot \frac{P_e + P_m - P_g + \frac{2\sigma}{r} \cdot \cos\theta}{l} = \alpha \cdot m \cdot R \tag{3}$$

Where from:

$$l = \frac{r^2 \cdot \left(P_e + P_m - P_g + \frac{2\sigma}{r} \cdot \cos\theta\right)}{8\eta \cdot \alpha \cdot m \cdot R} \tag{4}$$

The mechanical oscillations decrease the superficial tension σ at the liquid solid interface, the humectation angle θ and renders to the alloy an initial speed $v_i = A \cdot \omega$.

Under the vibrations physical action, the biphasic zone gets fragmented, thus lowering the capillaries length that must be run by the liquid alloy in order to fill the clearances provoked by the contraction and increasing thus the flow speed of the liquid alloy in these clearances, improving the conditions of supplying the micro cavities. Thus the overall volume of the micro blisters (shrinkage cavities) and the macro blisters concentrate at the top (large opening angle and low penetration depth fig.1), reducing the volume of the liquid alloy for the crop ends, phenomena that can be explained if it is considered that the alloy solidification under the influence of the mechanical oscillations takes place according to the following mechanism:

- the inertial forces generated by the vibrations render into pieces the solid phase in course of getting constituted and disperses it into the liquid alloy placed in front of the solidification front;

- the liquid alloy penetrates between the broken and dislocated fragments; it determines a temperature rise in the crust of solidified alloy, thus improving the conditions of thermal transfer at the interface alloy mould;
- the descendent circulation of the solid phase fragments and their storage at the bottom of the mould leads to the concentration of the macro blisters and porosities diminishing.

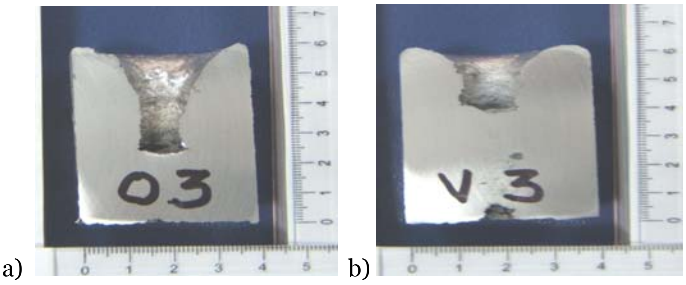

Fig. 1 Aspect of blisters without vibration and with vibration

blisters volume O_3= 9,5cm^3; V_3=6,5cm^3
blisters height h O_3= 34mm; V_3=24mm
blisters diameter d O_3=22mm; V_3=24mm
relation h/d O_3=1,5 V_3=1
relation blisters volume /sample vol.; O_3= 3,15; V_3=2,16
sample volume 301,44cm3 ;

Note: for the vibrated sample (V3) the blister height decreased versus the non vibrated sample (O3).

The general movement diagram of the liquid and solid phase flow in the conditions of applying the action of the mechanical vibration in the solidification procesus is shown in figure 2.

In the course of the observations it was established that oriented fluxes (circulation currents) are formed in the area next to the melted mass surface.

By means of these fluxes the most minute particles of the crystals that are broken are taken away within the volume of the melted mass, and the larger ones are precipitated at the bottom. The dendrites destruction mechanism, the diagram of the dendrite cell that develops in the solid- liquid area and temperatures distribution in it is shown in figure 2.

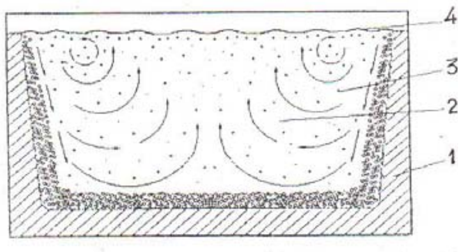

Fig. 2. Diagram of the movement of the fluxes in the liquid and solid phase in the solidification process
1 – crystallizer side walls, 2 - liquid phase, 3 - solid particles in the flux, 4 - crust

The growth of the thinnest branches of the second degree dendrite takes place in the surrounding liquid phase, figure 3.a, and between the peaks of these derivations the dendritic structure is sufficiently open for the liquid phase outlet. As long as the solidification advances, the dendritic cell derivations get thicker, and the liquid phase within it is in the state of small movement. The temperature along the length of each dendrite is modified from the liquid temperature T_{lic} (according to the axe of the clearance between the dendrites) up to the temperature of the solid mass T_{sol} at its basis. By applying vibrational force on the vibrant table on which the mould is mounted a phenomenon is produced: the liquid phase mixes and the dendrite branches are destroyed figure 3.b.

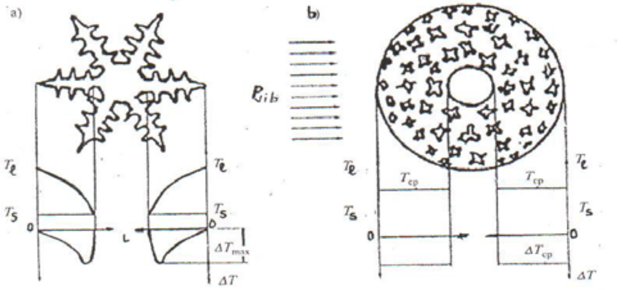

Fig.3. Conditions of growth of the dendrites axes in state of rest and in the conditions of pressure exertion P_{vib} over the melted mass.
a) dendrite growth in the melted mass;
b) breaking of the dendrite branches when applying the mechanical vibrations

The temperature within the solidification interval is established at the average values over the entire mould cross-section, and in the clearance available between the dendrites crystallization germs occur, that, afterwards, under the action of the mechanical vibrations, move within the volume of the unsolidified part of the alloy. Each one of these disintegrations (breakings) of dendrites is serving the crystallization centre in the melted mass volume. Thus, the under cooling around each breaking is considerably higher than within the surrounding liquid. The amount of this under cooling is equal to:

$$\Delta T_B = \left(\sigma_{l-s} \cdot T_{lic}\right) / r \cdot \rho \cdot q_{crist} \qquad (5)$$

where: σ_{l-s} - superficial extend at the limit between phases [N/m^2];
T_l - melted mass liquid temperature [^{o}K];
r - broken dendrite radius [m];
ρ - melted mass density [kg/m^3];
q_{crist} - crystallization temperature of the melted mass [^{o}K].

Out of the equation (5) it can be seen that the lower the radius of the broken dendrite is the higher the under cooling is around it. That is why, by increasing the vibration frequency, the destruction of the dendrite branches, the under cooled liquid volume and the melted mass crystallization speed increase incessantly.

The characteristic peculiarity of ingot forming under the mechanical vibrations action is the small constant thickness of the crust on the vertical, lateral sides (surfaces) of the ingot. This fact ensures the constant, intense exhaustion of the crystallization heat and the incessant growth of the horizontal area thickness of the crystals that fall down. After the solidification is finished, the even crystalline dispersed structure is obtained over the entire ingot cross-section that is characteristic for the crystallization of the alloys volume. In the research process the variant of the moulded part complete solidification duration has been studied function of the alloy overheating under usual circumstances and by applying the mechanical oscillations.

4. CONCLUSIONS

The solidified part of the dendrite represents a solid body and in it longitudinal waves occur (of strain/elongation and compression), that create variable pressures and that determine the elastic deformation, respectively the occurrence of fragmenting strains. The critical force at which the crystal gets fragmented is given by the relation:

$$F_{cr} = p_{max} \cdot \pi \cdot r^2, \text{ [N]};$$

The break of the dendritic branches is possible, having in view their low withstand at high temperatures. Due to the vibrations, the speed the alloy moves with from the biphasic zone in front of the solidification front is much higher, which determines an intense fragmenting of the dendritic branches. The solid particles movement speed depends upon:

- solidified crust thickness;
- alloy kinematic viscosity;
- melting temperature;
- dimensions of the part;
- conditions of the heat exchange;
- oscillations energy, respectively the acceleration, their amplitude and frequency.

The physical-mechanical treatment, applied to the liquid sate alloy intensifies the vibrations layers at the edges, which produce side currents, hydro-dynamic phenomena at the limit between the solidified layer and the mould side walls, the speed increases and the solidification time decreases. Among the most important technological effects of applying the mechanical vibrations within the solidification process we can list: homogenization and finishing of the structure, molded material getting compact, alloy degassing, segregations contraction, separation of the nonmetallic inclusions and growth of the capacity of achieving a high quality alloy as well as improving certain mecano-physical characteristics.

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