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CORRELATION BETWEEN THERMAL VARIABLES, SECONDARY DENDRITIC SPACE AND MICROHARDNESS OF AL-1%FE ALLOY UNIDIRECTIONALLY DESCENDING SOLIDIFIED

ABRANTES, F. C. M. [1]
charlesabrantes@hotmail.com

LIMA, R. A. [1]
robsonal@hotmail.com

LIMA, D. F. [1]
diegoferreira_09@hotmail.com

NETO, M.A.B.[1]
manoel0562@gmail.com

SIQUEIRA, C. A[1]
claudio.siqueira.filho@gmail.com

[1]: Federal University of Paraiba -UFPB, João Pessoa-PB, Brazil

Abstract. *The aim of this paper is to present an a experimental stdy that aimed to analyze the tehermal variables and their influence on the secondary dendritic spacing and microhardness of a unidirectionally descending solidified Al-1%Fe alloy. It was found that during the alloy solification process, the dendritic spacings increase with the decrease of the solidification velocity, VL, and the cooling rate, TR, (both importante termal variables in the solidification process), which resulted in a decrease of microhardness.*

Keywords: *secondary dendritic spacing, microhardness, solidification.*

1. INTRODUCTION

Casting became increasingly present in the history of human evolution, through the appearance of cast iron in China in 600 BC and its appearance in Europe in the fifteenth century, although its use as a structural material occurred only extensively in the century XVIII in England. The various casting processes make it possible to produce from millions of small pieces to a few pieces weighing several tons (GARCIA, 2007; MURAKAMI, 1985, 1991).

Knowing this, the increasing demands of modern industry for materials with increasingly higher properties, the knowledge and, consequently, the control of the kinetics of the solidification process of metals and alloys has been consolidating itself as an object of study extremely important for obtaining materials with homogeneous properties and increasingly suitable for practical use. Thus, an approach to some basic principles involving the solidification process of metallic materials is essential. For example, the unidirectional solidification technique, which has been widely used in the experimental study of solidification phenomena, can be highlighted, which can be approached in both steady state and transient regimes (Gomes, 2012).

Taking into consideration the transient heat extraction, we can highlight the vertical unidirectional solidification, which can be studied considering the direction of the extracted heat flow and the direction of advance of the solidification front that can be ascending or descending (Gomes, 2012).

In ascending solidification, the solute is discarded on the solidification front and, depending on the solute/solvent pair, an interdendritic liquid may be denser than the rest of the overall volume of liquid metal, thus ensuring from the point of view of movement of liquid, the stability of the solidification process. In this situation, metal cooling occurs at the bottom, which produces an upwardly increasing liquid temperature profile, forcing the denser liquid to be located near the solid/liquid transformation boundary, minimizing both convective currents by temperature differences as well as concentration differences. It is noteworthy that in this solidification process, heat transfer occurs essentially by unidirectional thermal conduction (Gomes, 2012).

In the downward vertical solidification, due to the gravitational force, the weight force acts to displace the ingot of contact with the refrigerated base, causing earlier a situation of greater thermal resistance at the metal/mold interface, influencing the kinetics of the liquid/solid transformation. The convective motion in this situation will be present as the temperature profile in the liquid is descending in, which is thermally insulated. Thus, if the rejected solute causes an interdendritic liquid with a density greater than that corresponding to the liquid at the nominal concentration of the alloy, in addition to convection due to temperature differences, convection due to solute concentration differences will also occur (Gomes, 2012).

In relation to iron and being extremely important in the industry, it is usually considered as an impurity in aluminum alloys due to contamination in materials used or in the recycling process (GOULART 2010). However, iron may also be beneficial for improving mold life and increasing the high temperature properties of aluminum alloys, as well as being used as an alloying element. Moreover, in relation to Al-Fe alloys themselves, it is noteworthy that under conditions of out-of-equilibrium solidification (transient solidification), a wide range of thermodynamically metastable Al-Fe phases may occur due to their lower super-cooling values, than the Al3Fe phase in the nucleation and growth stages. Consequently, in Al-Fe alloy castings/ingot the combination of cooling rate and local chemical composition can lead to regions with different microstructural arrangements consisting of metastable equilibrium and intermetallic phases (KEONG, 1979, AHRAVCI, 1998).

Knowing that the solidification process of the present work is descending unidirectional, this work aims to contribute to a better understanding of the correlations between the thermal variables (Solidification Speed (VL) and Cooling Rate (TR)) and secondary dendritic spacing, as well as their influence on the microhardness of unidirectionally solidified Al-1% Fe alloy.

2. METHODOLOGY

2.1 OBTAINING THE ALLOY

The alloy was made with relative proportions of the following composition of Al-1% Fe (% by weight), where raw materials considered commercially pure were used. After weighing the ingot preparation material, which corresponds to 1200g of material, the aluminum and iron were placed in an alumina-coated silicon carbide crucible to prevent molten alloy contamination, and taken to the muffle furnace. After heating the aluminum for one hour, the alloy was homogenized every 30 minutes remaining in the oven for about 2 hours.

The ingot mold was inserted into the descending unidirectional solidification device together with the coupled thermocouples at the 3 mm, 12 mm, 24 mm, 48 mm and 72 mm positions from the metal/mold interface considering the upper surface. Then the molten alloy was poured into the ingot mold, where the temperature was monitored through the data acquisition system of Figure 1. When the alloy reached a temperature of 5% of the melting temperature (TL = 655°C), the cooling system was started, where all solidification was monitored. Figure 1 below outlines a descending unidirectional solidification device:

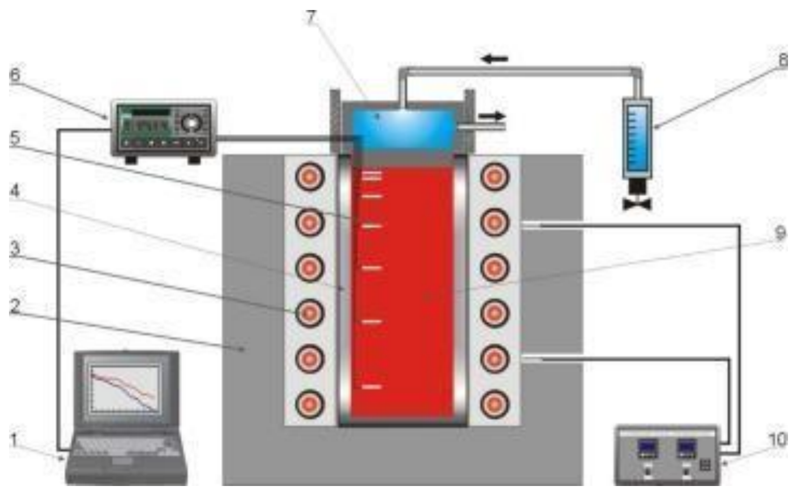


Figure 1 - Descending vertical unidirectional solidification device: 1, Data acquisition system; 2, refractory material; 3, electrical resistances; 4, ingot mold; 5, thermocouples; 6, data logger; 7, refrigerated chamber; 8, rotameter; 9, metal; 10, oven control (Spinelli 2005; Rosa, 2007).

2.2 MICROSTRUCTURAL CHARACTERIZATION

For the microstructural analysis, the ingot was sectioned into 5 parts according to the position of the thermocouples, the positions being 3 mm, 12 mm, 24 mm, 48 mm and 72 mm, with an area of 70 mm² each sample, according to Figure 2. Then we sandpaper the samples with the grit sandpaper of 100 to 1200 mesh size. Then polishing with ¼ µm alumina was carried out and, with the parts properly polished, the chemical etching was carried out with 5% sodium hydroxide (NaOH) reagent diluted in water for 10 minutes of immersion of each sample. Secondary dendritic spacing was measured by averaging and standard deviation of 10 measurements on all parts using the center-to-center method of secondary dendritic spacing. Figure 2 exemplifies the shape the ingot was sectioned, considering the 5 samples studied.

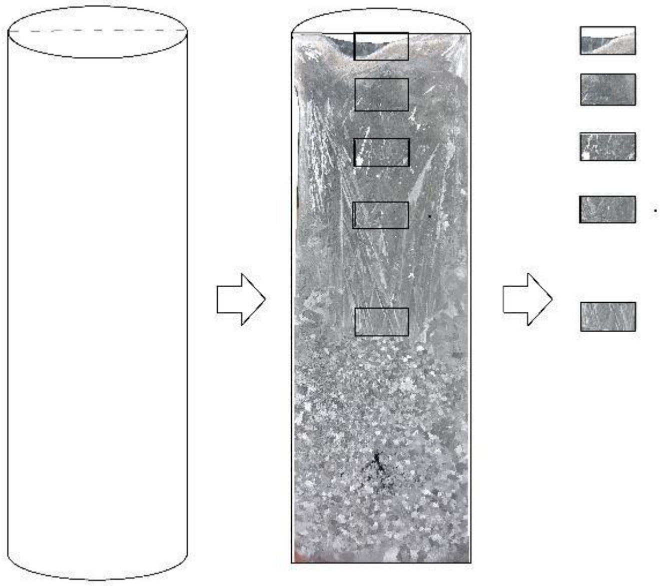


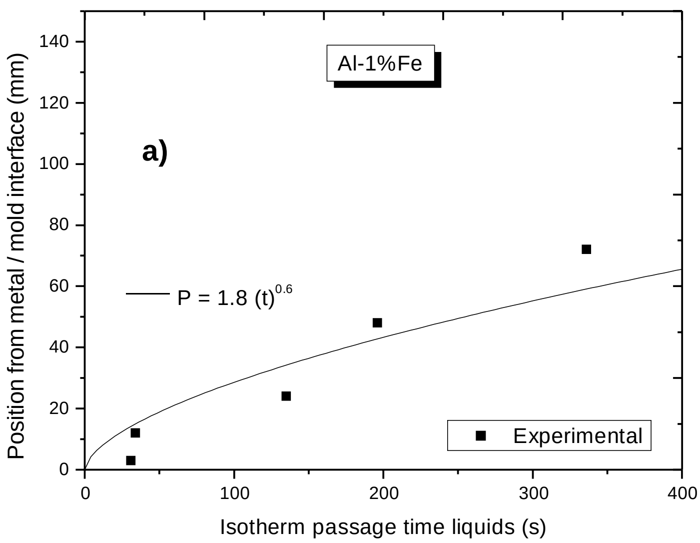
Figure 2 - Sectioned Ingot

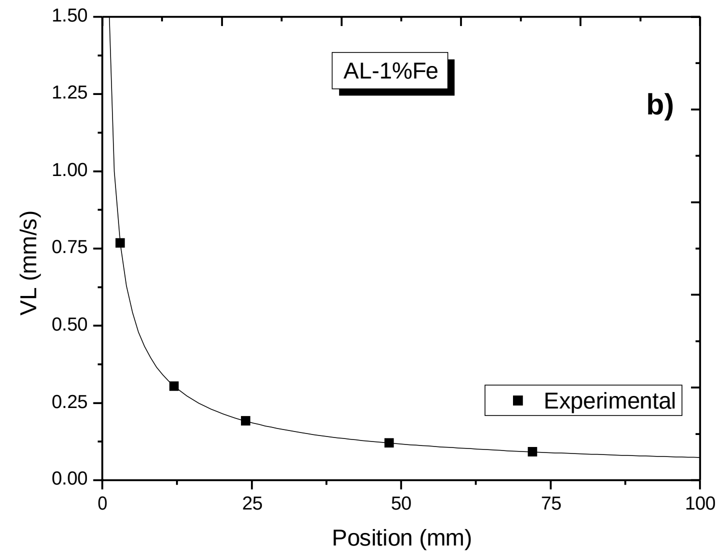
2.3 MICROHARDNESS VICKERS

Microhardness measurements were performed using a Shimadzu HMV-2 hardness tester using a 200 g (1961 N) load with 15 s time. The Vickers microhardness adopted was the average of 10 indentations distributed throughout 70 mm² area measured in each sample.

3. RESULTS AND DISCUSSIONS

According to Figures 3 and 4, we can state that there is a tendency for the liquid isotherm velocity to decrease when moving away from the position from the metal/mold interface, as well as the cooling rate. This behavior is observed in most unidirectional solidification studies, where the difference is that in downward solidification there is a larger gap between the plate and ingot due to gravity, causing variations in velocities and rate.





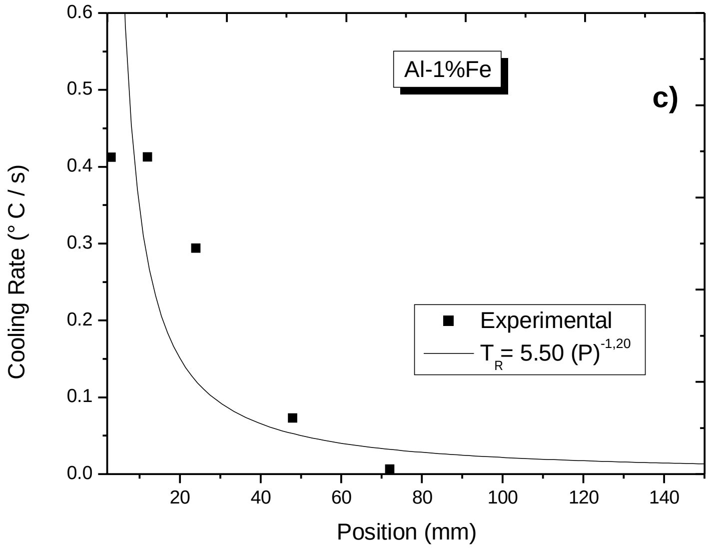


Figure 3 - Graphs obtained by monitoring the descending vertical solidification process for the Al-1%Fe alloy: a) Position x Isotherm Time, b) Liquid isotherm Speed x Position, c) Cooling Rate x Position.

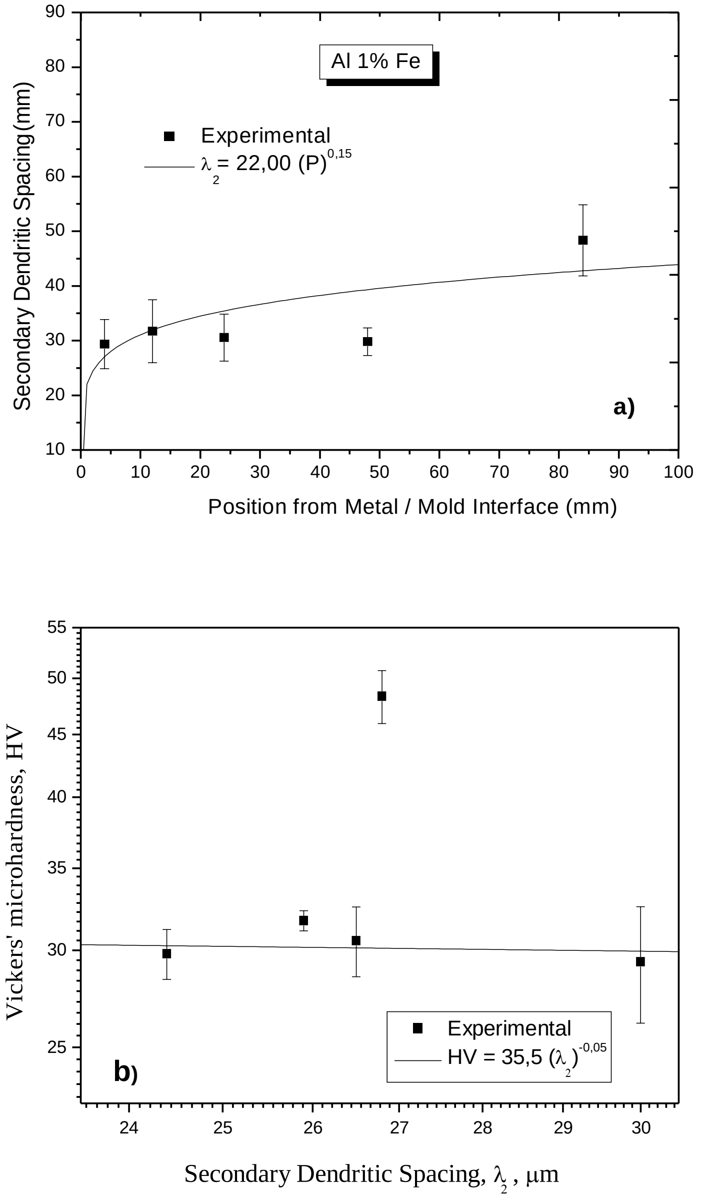


Figure 4 - Graphs obtained from experimental measurements for Al-1% Fe alloy: a) Secondary dendritic spacing x Position, b) Microhardness (HV) x Position.

Fig. 3 - (a) present the experimental results of the displacement of isoterma liquidus to the studied alloy. Experimental position points from the metal/refrigeration chamber interface for each of the thermocouples inserted into the solidified ingot as a function of the passage time from the isoterma liquidus to the Al-1% Fe alloy solidified in the descending vertical unidirectional device.

In addition, the graph of Fig. 3 - (b) shows the gradual decrease of the velocity of the isoterma liquidus to the farthest positions of the metal / mold interface. The experimental equations of isotherm liquidus velocity (VL) as a function of position (PL) were determined by obtaining two functional relationships, which describe the position and velocity of isoterma liquidus with time.

In relation to Fig.3-c, the cooling rates (•T), for each position monitored by the thermocouples, were obtained experimentally and determined by calculating the slope of the cooling curves considering all thermal data recorded immediately after the passage of the isoterma liquidus. (TL) and the corresponding times, then, •T = dT/dt. The functional relationship that describes the evolution of the cooling rate at the moment of passage of the isoterma liquidus with the position for the Al-1% Fe system alloys surveyed. The graphs show that there is also a tendency of stabilization in the values and that the initial moments are of fundamental importance for the characterization of the solidification kinetics.

In general, analyzing Fig. 4 - (a), we observe that the secondary dendritic spacings increase according to the distance from the metal/mold interface and according to the ratio λ2=22.00(P)0.15, having thus a longer growth time for positions further away from the metal / mold interface. This growth may be due to less uniform distribution of the solute and also to the formation time of the microdendritic structure.

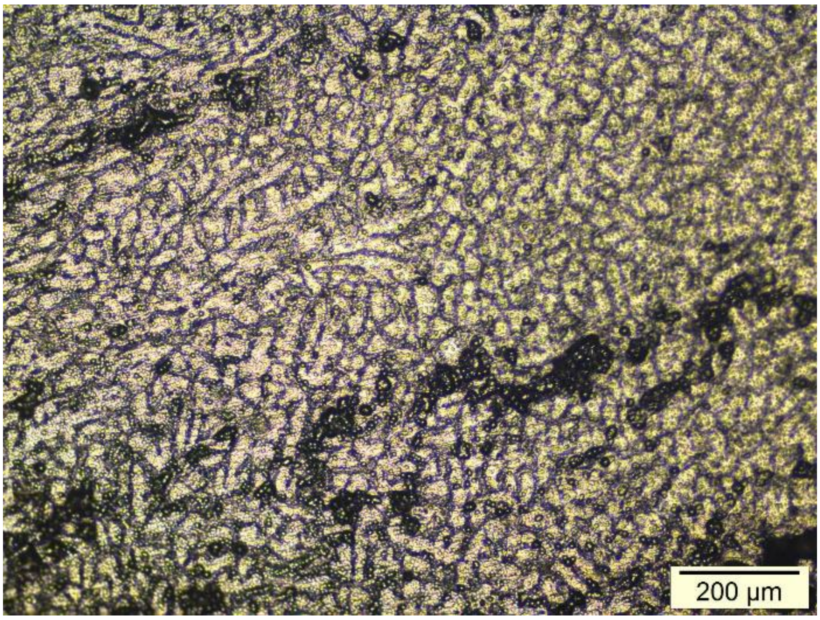
For microhardness the relationship is the opposite: it is observed from Fig. 4 (b) that the farther from the metal/mold interface, the lower the microhardness. This fact can be explained due to the final microstructural arrangement (coarser dendritic ramifications), as well as the solute redistribution along the inderdendritic spacing, so in the initial positions we have a greater uniformity in the distribution of the solute giving greater uniformity in the microhardness values compared to the farthest positions.

Therefore, analyzing the experimental results obtained, we can state that:

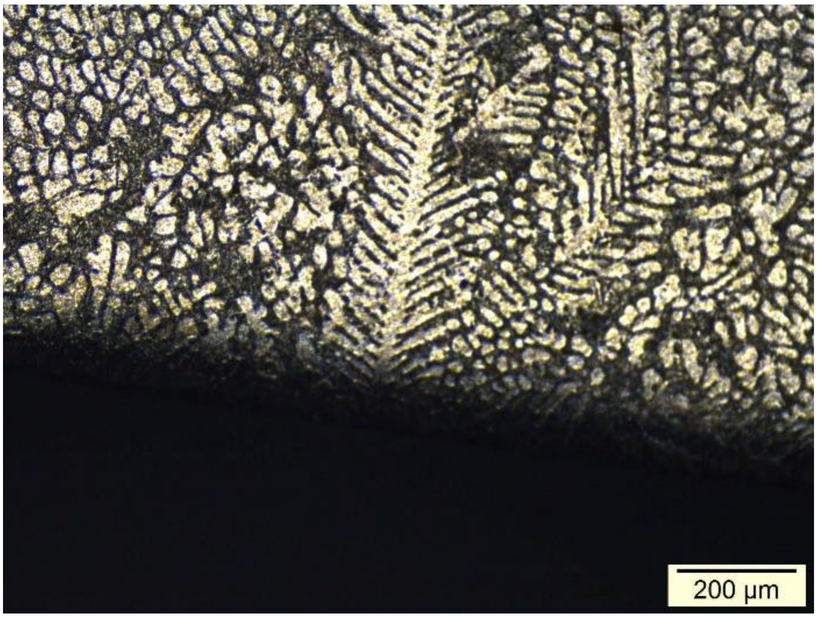
- The velocity values of the isotherm liquid decrease as a function of the distance of the metal/mold interface due to the air gap formed between the surfaces. In addition, gravity causes this space to increase during solidification;
- Under the transient solidification conditions examined, it was found that secondary dendritic spacings increase as the displacement velocity of the isotherm liquidus decreases, as does the cooling rate;
- Microhardness decreases as secondary dendritic spacing increases due to less uniformity of solute distribution and increased formation time of the microdendritic structure.

The following images show some micrographs obtained from the microstructure of the alloy in question, from positions 3 mm, 48 mm and 72 mm from the metal / mold interface position, where a cellular structure is initially noticeable at the initial position and then the appearance of secondary dendrites. Where the secondary dendritic spacing increases as the distance increases downward.

a)



b)



c)

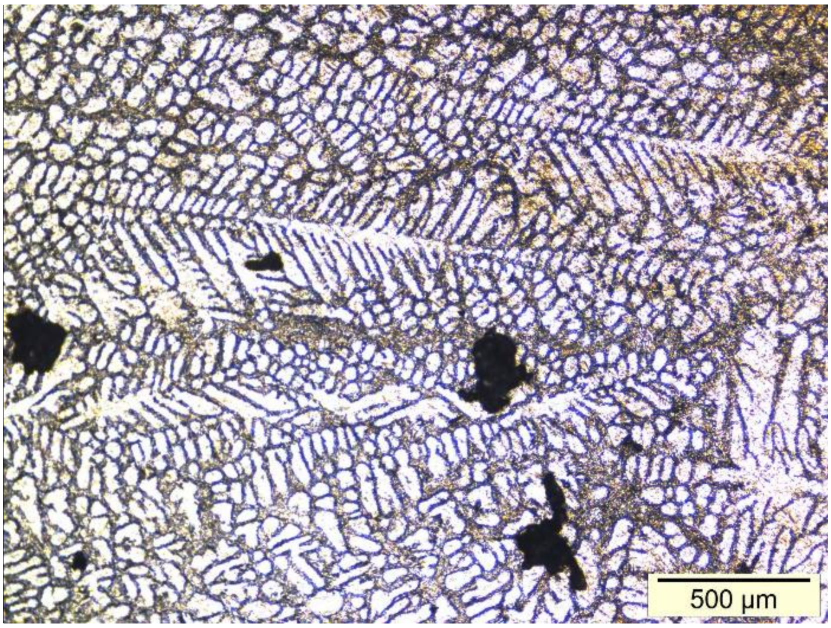


Figure 5 – micrographs: a) position 3 mm, b) position 48 mm, c) position 72 mm.

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5. RESPONSIBILITY NOTICE

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