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INFLUENCE OF CONVECTION ON THE INTERFACIAL HEAT TRANSFER COEFFICIENT IN UPWARD SOLIDIFICATION OF HYPOEUTECTIC AL-SI ALLOYS

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Abstract. *The study of the variables that influences the heat transfer coefficient (hi) applied on directional solidification of metal alloys are of major relevance due its effect on the macrostructure and the microstructure of the castings. Based on the literature, papers that involves upward solidification do not exposes attention in the use of momentum conservation equations based on the hypotheses of non-convection in upward solidification. That research explains that the gravity vector, which is vectorially opposite from the development of the solid, prevent the convection ahead the front of solidification. However, no paper was made in order to evaluate the convection on the phenomenon. This paper aims to propose an analysis of the upward solidification phenomenon using the software ANSYS®FLUENT in order to identify the relevance of the convection on this phenomenon. For this propose, was considered the binaries Al-3, 5 and 9wt.%Si. The results show that hi defined by the literature does not match with the thermal profile simulated, exposing high divergence. The magnitude of the convection is more relevant as much as the increase of solute in the solvent.*

Keywords: *upward solidification, Al-Si alloys, ANSYS®FLUENT, heat transfer coefficient, convection.*

1. INTRODUCTION

The solidification is the technological and scientific description of the transformation of the material from liquid phase to the solid phase. Although it represents a generic study of this transformation in the whole field of materials, it is more associated to the study of metals and their alloys, due to the importance that it exerts on the structures and properties of the metals and their alloys, and also on the scale by which they are produced metals in modern industry (Müller, 2002). Studies were made to understand the influence of the casting process on the macrostructure, microstructure and mechanical properties of metal alloys employed industrially. Due to research, was considered that the direction ingots is solidified represents an important consideration on the mechanical evaluation of this material, also thermophysical properties of the material could change the way that these castings is cooled. In order to control the thermal parameters of the phenomenon and, from this, the microstructure, the study of the heat transfer coefficient is of major relevance. However, in directional solidification, particularly in vertical upward device, researches were made considering that phenomenon is not influenced by thermosolutal convection.

Peres (2004) presented the behavior of the primary and secondary dendritic spacing arm with respect of the interfacial heat transfer coefficient (*hi*) and thermal parameters from thermal history of the alloy. Beyond the clear dependence of metallurgical properties of the material, was exposed that *hi* can be expressed by a power function of time, which can be obtained by Finite Difference Method (FDM) and, with more relevance, shows that *hi* is not dependent of the convection in vertical upward solidification.

Despite of that, no confirmation or paper clearly shows that vertical upward solidification, either horizontal or vertical downward solidification, is independent of thermosolutal convection, opening wide discussion on the subject,

mainly with respect to the percentage of solute content in the alloy, which is relevant when solute convection is observed in the heat transfer. Even papers (Silva, 2011) that compare vertical upward solidification, which is more stable considering convection, and horizontal solidification, which is strongly influenced by the exposed phenomenon, does not consider the flow on the analysis, based only on the physical intuition to define the disparity of the thermal profile and *hi* of one and the other solidification apparatus.

In order to verify the influence of the convection in upward solidification, finite volume method could be applied and, in a comparison with the experimental profile, identify the importance and relevance of the flow on the liquid ingot.

2. COMPUTATIONAL PROCEDURE

The thermophysical properties of Al-Si alloy and the mold plate material utilized in the simulation are presented in Tab. 1. It was not considered back diffusion. The software ANSYS/FLUENT 16 was used to develop the simulation of the vertical upward solidification with water-cooling. A cylindrical mold with 25 mm of radius, 150 mm of length was considered. These dimensions are given by experimental setup of Peres (2004). The geometry has approximately 110.000 nodes, as shown in the Fig. 1. The geometry was previously sliced in four objects, which three of them were suppressed in order to reduce the time simulation, without losing precision.

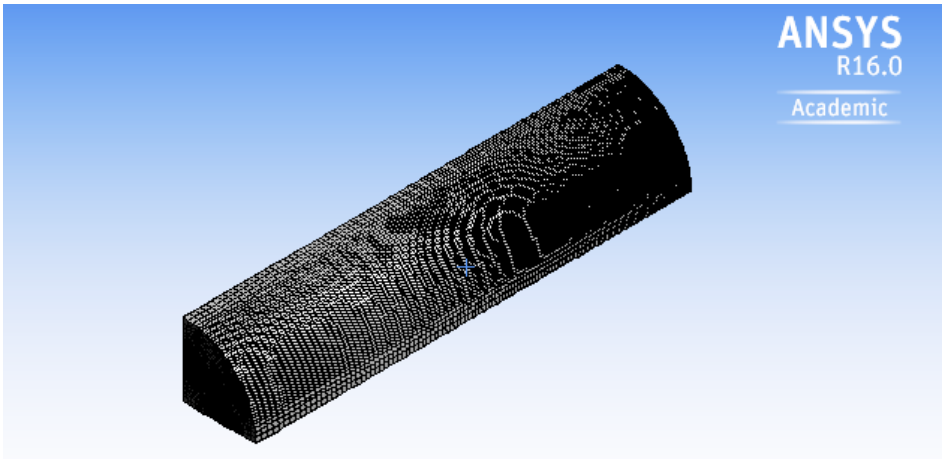

Figure 1. Mesh designed for the solidification simulation.

The simulated cylinder was thermally isolated from all the walls, except the base where it in direct contact with a cylindrical metal plate of 4 mm width, which was cooled by water at ambient temperature, about 300 K. The pouring temperature (or initial temperature) of simulation can be seen in the Tab. 1, as used in the experimental setup presented by Peres, 2004. The results were obtained for a total time of 100 seconds, with 0.02 seconds time step. During this simulation the laminar fluid, flow, energy and solidification models were active, as presented in ANSYS (2013).

Table 1. Thermophysical properties of the metals analysed in the paper.

Properties	Symbols	Al	Si	Al-3wt.%Si	Al-5wt.%Si	Al-9wt.%Si
Thermal conductivity of solid [W/m.K]	K_S	222	141	121	104	81
Thermal conductivity of liquid [W/m.K]	K_L	92	430	91	90	89
Solid specific heat [J/kg.K]	C_S	1123	-	963	963	963
Liquid specific heat [kg/m³]	C_L	1086	-	1084	1082	1078
Solid's density [kg/m^3]	ρ_S	2550	2330	2695	2690	2670
Liquid's density [kg/m^3]	ρ_L	2380	2530	2385	2389	2399
Latent heat of fusion [°C]	L	385000	-	389187	393083	405548
Melting temperature [°C]	T_L	660	1414	-	-	577
Liquidus temperature [°C]	T_F	-		644	632	604
Eutectic Temperature [°C]	T_E	-		577	577	577
Pouring Temperature [ºC]	T_V	-		646	634	606
Partition Coefficient	k	-		0,1307		

For the simulation was used the heat transfer coefficient based on the literature of Peres (2004), which is, for Al-3wt.%Si, Al-5wt.%Si Al-9wt.%Si, respectively, $4800*t^{-0.09}$, $4500*t^{-0.09}$ $3300*t^{-0.09}$. Is relevant to explain that this paper

is not considering, neither establishing, that this heat transfer coefficient is adequated for this alloy. Our attention is focused on the influence of the convection on the thermal profiles based on a simplification that is exposed on Peres (2004), which is: melt convection and solid transport were not considered in the heat transfer coefficient analysis.

3. RESULTS AND DISCUTTIONS

The experimental and numerical thermal profiles of the alloys exposed above are shown on the Figure 2. The colored dots represents the experimental, the dark line the simulation without considering melt convection, and the red line, the numerical simulation considering melt convection.

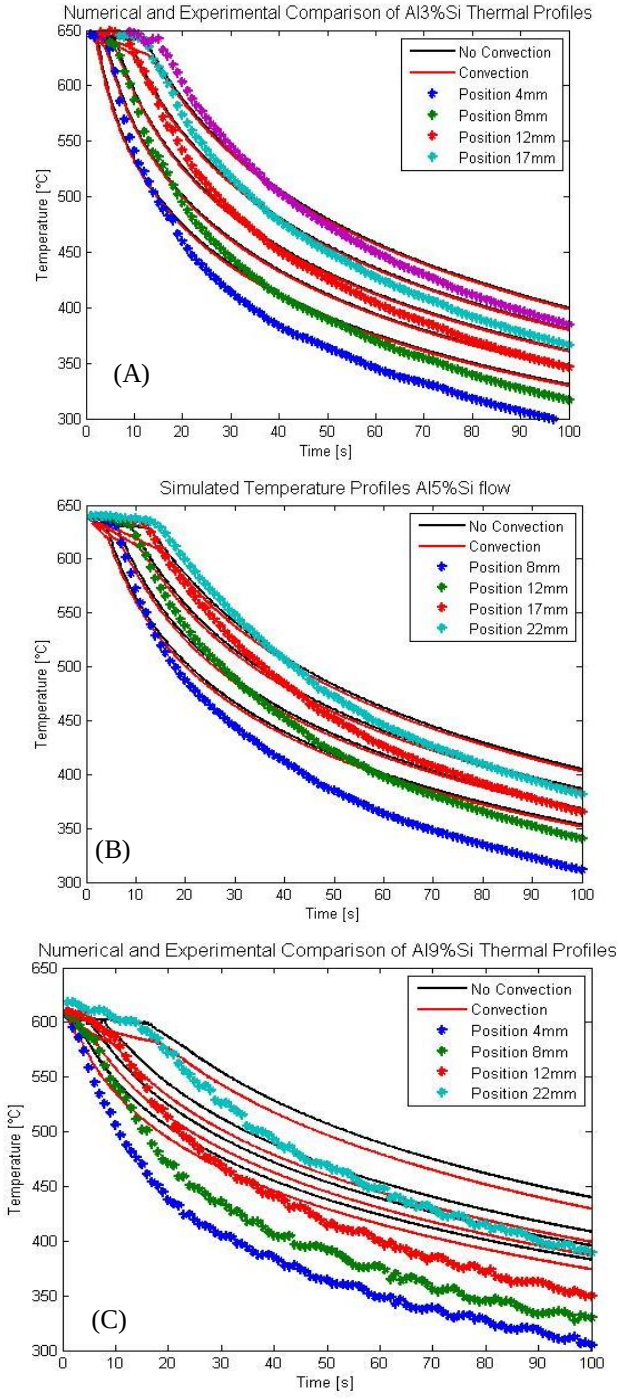

Figure 2. Comparison of numerical and experimental thermal profiles of (A) Al-3wt.%Si, (B) Al-5wt.%Si and (C) Al-9wt.%Si.

Based on the curves of Fig. 2, can be said that the hi exposed in the literature has an extremally difference from the experimental thermal profile. The hypothesis that the error from Finite Difference Method (FDM) applied in the determination of the constants of the At^B fuction is huge is not controversial. The strongest difference of the simulated thermal profiles occur in the first seconds of solidification, when the heat transfer passes through several modifications due phase modifications. Figure 2 clearly shows that the increase of solute in the alloy visibly modify A and B constants, corroboration the fact that simulations based on solidification of alloys must be made using Navier-Stokes approach.

4. CONCLUSIONS

The numerical thermal profiles exposed in the results shows that the Al-9wt.%Si suffered an intense influence of convection, mostly in the beginning of the solidification, between 0 and 20 seconds, while the Al-3wt.%Si do not presented visible modification in the simulated thermal profiles. It can be conclude that alloys content considerable quantity of solute in the matrix must be treated numerically as a convective flow, while alloys that contend a little percentage of solute can be treated as a solidification without convection, due to the little influence on the experimental thermal profile. However, due to the fact that this paper do not present parameters that specify a solute level where the phenomenon can be considered as non-convective is recommended that, when possible, apply convection on the analysis.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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