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SIMULATION STUDY ON THE SOLUTE ELEMENTS MICRO-SEGREGATION AT SOLID-LIQUID INTERFACE OF CONTINUOUS CASTING STEEL SLAB

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Based on the Fick second law and the law of conservation of mass, one-dimensional mathematical model on micro-segregation with dendritic crytals growing during the solidification of liquid steel was established. The effects of solute elements on the interdendritic segregation, zero strength temperature, and zero ductility temperature of the steel were discussed with the model used, in which the transition of ferritic/austenitic solidification was considered. The results show that carbon content has a great influence on interdendritic segregation at the solidifying front. Zero ductility temperature decreases with the content of manganese and phosphorus increasing. In order to avoid the cracks, the content of manganese and phosphorus should be controlled in production.

Key words: continuous casting, mathematical model, micro-segregation, zero strength temperature, zero ductility temperature

INTRODUCTION

The segregation has great effect on the quality of the billets, so it is significant to study the segregation for improving the billet quality. The segregation can be studied by experimentation and mathematical modeling. The models are analytical model, the calculation process is simple and it is easy for coupling heat and mass transfer equation [1-2]. But the calculation precision of that equation is lower and as a result only the current solid solute concentration in particular position can be calculated. The numerical model is of high calculation precision, furthermore, the solid phase distribution can be solved at any time [3-5]. In this paper, based on the Fick second law and the law of mass conservation, one dimensional numerical model of the dendrite growth solidification segregation was established with considering δ phase and γ phase changing during the solidification. According to the research problem, the initial and boundary conditions were determined, and the mass transfer equation was discretized by the direct difference method. The discretization equation was solved by the VB program. The effects of C, S and P content varying on the interdendritic segregation, zero strength temperature, and zero ductility temperature of the steel were discussed with the model established.

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MICROSEGREGATION MATHEMATICAL MODEL DESCRIPTION

In this paper, the solidification model of dendritic crystals is based on the orthohexagonal cross section put forward by Ueshima[4], as shown in the Figure 1a. Assuming the solutes partly diffuse in solid phase and completely diffuse in liquid phase, the convection of liquid among dendritic crystals is neglected and the mass of solute elements is conservation. There are local equilibriums of solute elements in two-phase surfaces

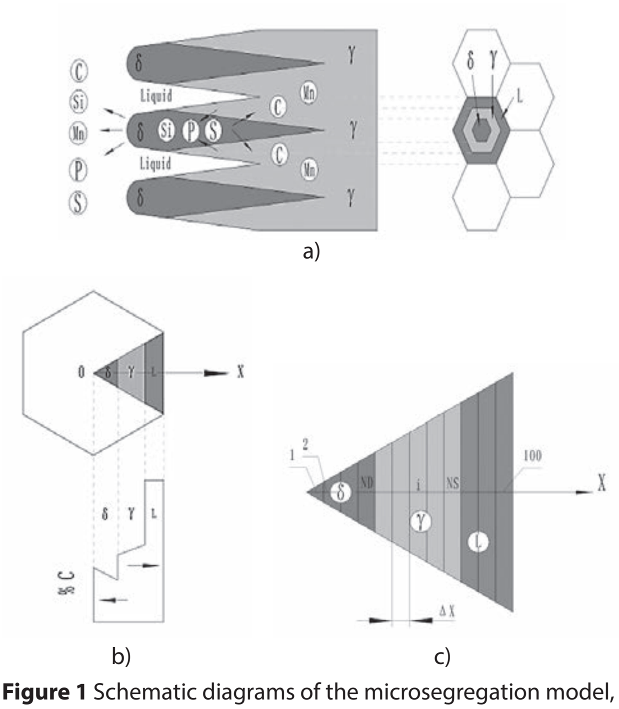

Figure 1 Schematic diagrams of the microsegregation model, a, b and c

of liquid /δ, liquid /γ and δ/γ. And the γ phase is come into being in the phase surface of δ/γ. The solid solute phase diffuses reversely along the direction of cooling at one-dimensional. As shown in Figure 1b , the origin of coordinates is in the center axis of secondary dendrite arms and the end is in interdendritic axis, moreover, coordinate direction is perpendicular to the growing direction of secondary dendrite arms.

Based on hypotheses above and the Fick second law, the solute diffusing equation and mass conservation equation were used here. As Figure 1b,c shows, considering the symmetry of the orthohexagonal cross section, 1/6 section is taken as the research object, and divided the half size of dendrite arm into 100 grids. During the solidification process, within the scope of the triangle as shown in Figure 1c, there is no heat exchange between inside and outside, the sum of quality of solid and liquid phase is conservative. If the carbon content is in the range of 0,1 % to 0,5 %, there will be a transition for δ to γ phase. When the temperature of γ/liquid phase (NS) in Figure 1c and δ/γ interface(ND) in Figure 1c are the same as the cross section temperature, the interface unit is completely solidified or Ar4 is completely transformed, then the interface moves to the next node.

STUDY ON BEHAVIOR OF MICROSEGREGATION AT TWO-PHASE ZONE

The interdendritic solute segregation ratio variation with carbon content change

Under the condition of 0,5 / s cooling rate, the interdendritic segregation ratio of the steel liquid solute elements changing along with carbon content under different solidification process were calculated. The calculation results are shown in Figure 2. Contrasting the Figure 2a, b, c, with the solid ratio increaseing, the solute segregation ratio increases, the sulfur and phosphorus segregation rate increase significantly. At the same solidification condition, manganese segregation is minimum, sulfur segregation is maximum. When carbon content is less than the $w^{s}_{\delta/\gamma}$, liquid steel is solidifying in δ mode, each solute elements segregation rate decreased with carbon increasing, When carbon content is more than the $w^{s}_{\delta/\gamma}$, peritectic reaction happens and γ phase separates from the phase of（δ+ *l*）. When the carbon content is more than the $w^{s}_{\delta/\gamma}$, and less than $w^{e}_{\delta/\gamma}$, carbon segregation rate reduces along with carbon content increasing, other elements segregation rate increases; When carbon content is greater than $w^{e}_{\delta/\gamma}$, peritectic reaction ends, all phase of（δ+ *l*） transfer into the phase of（γ+ *l*）, then carbon and manganese segregation ration decrease, sulfur and phosphorus segregation rate increases, but the segregation changing is little.

The effect of sulfur content on the interdendritic sulfur segregation ratio

Figure 3 shows the influence of the sulfur content change on the sulfur segregation under the different solidification conditions. Sulfur segregation rate increases with the solidification ratio increasing. When the solidification rate is 0,6 and 0,75, the carbon content is less than $w^{s}_{\delta/\gamma}$, liquid steel is solidifying in δ mode, the changing of the sulfur content has lilltle effect on the segregation rate. When carbon content is more than the $w^{s}_{\delta/\gamma}$, the γ phase separates from the phase of (δ+ *l*), sulfur segregation increases with the sulfur content increasing, but the effects of the sulfur content change on segregation is less. When the solidification rate is 0,98 and the carbon content is greater than $w^{e}_{\delta/\gamma}$, phase (δ+ *l*)

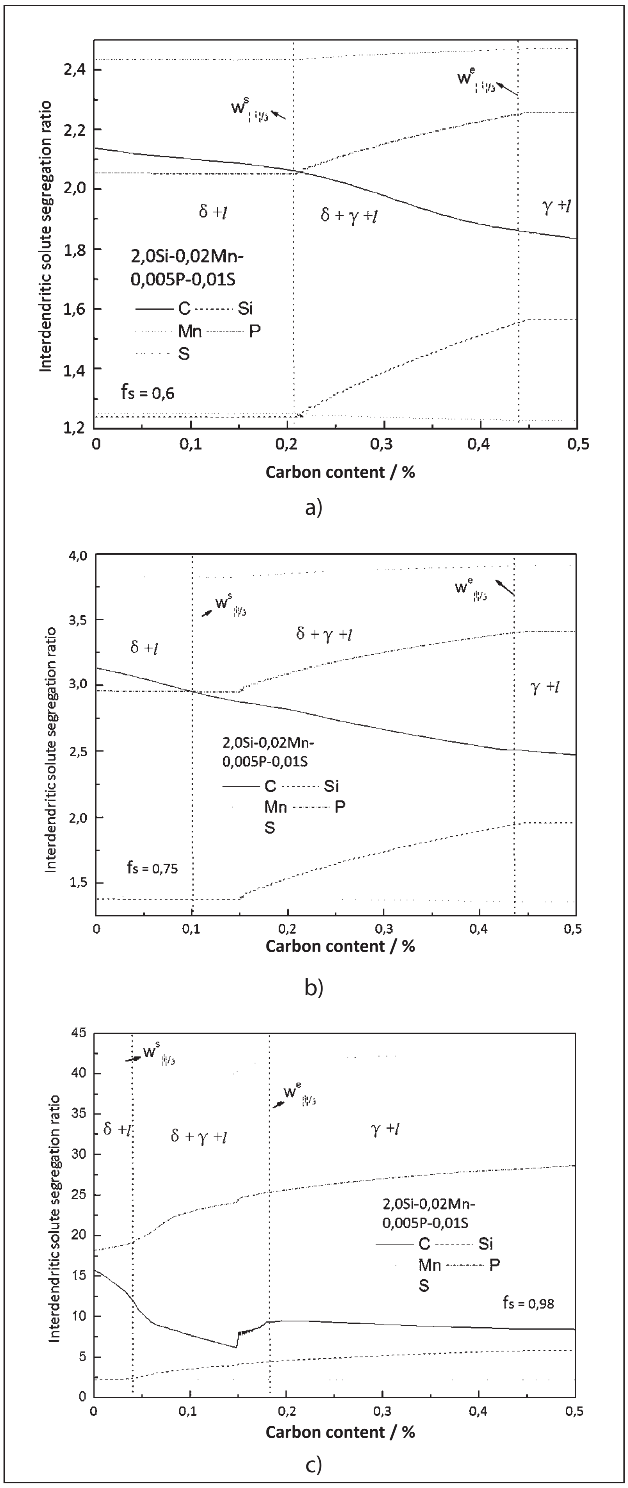

Figure 2 The solute segregation ratio variation with carbon content change at different solid fraction, a), b) and c)

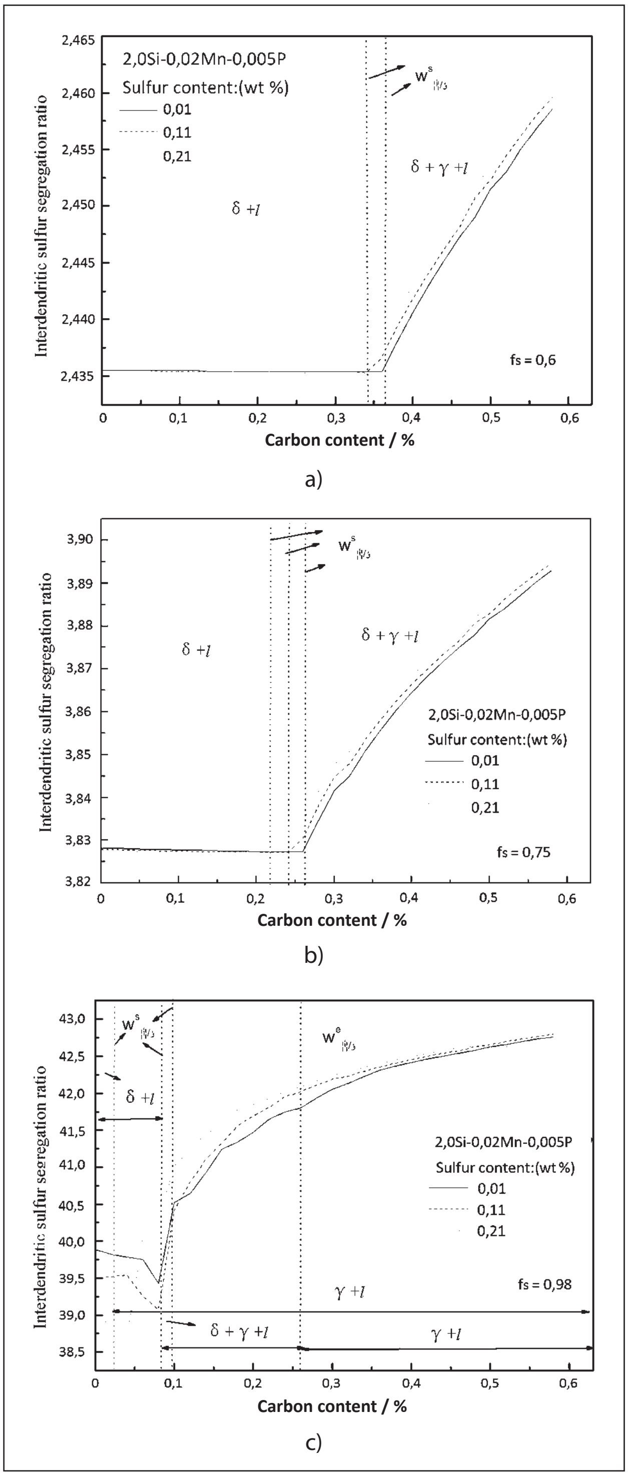

Figure 3 The effect of sulfur content on the sulfur segregation ratio at different solid fraction, a), b) and c)

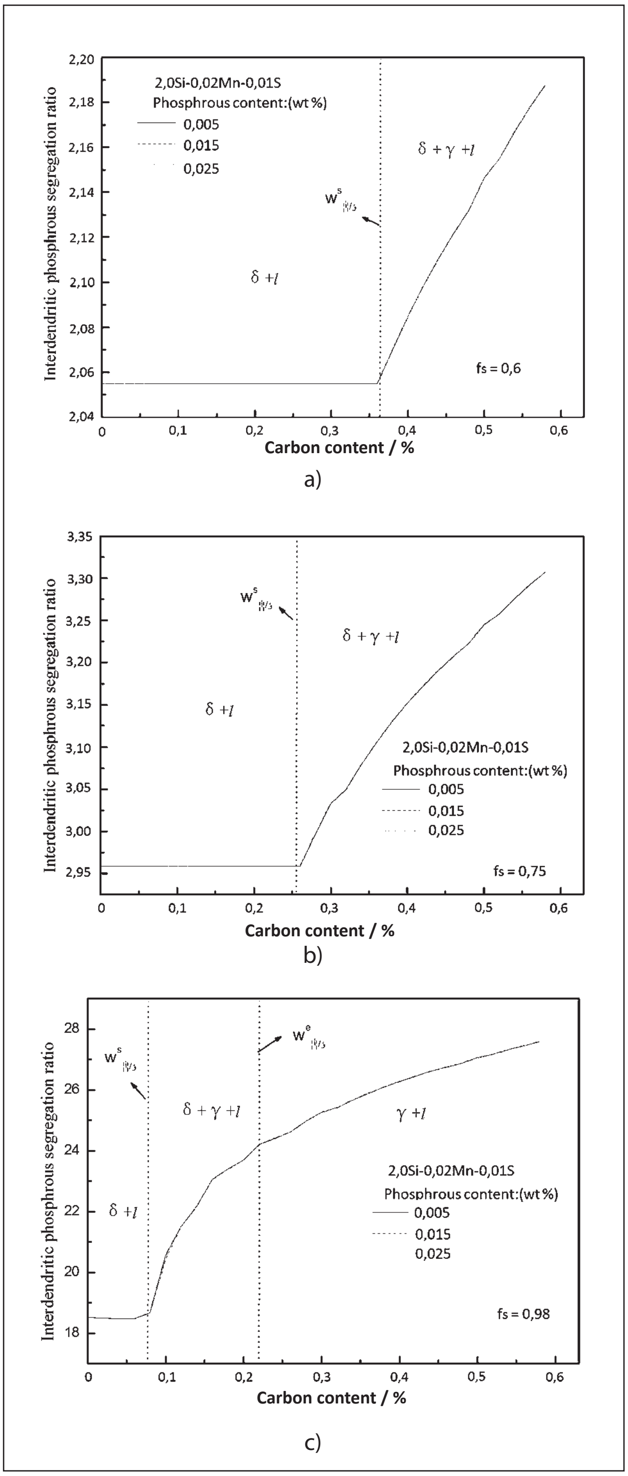

Figure 4 The effect of phosphorus content on the phosphorus segregation ratio at different solid fraction, a), b) and c)

all transfers to （γ+ l） phase and the sulfur segregation ratio decreases with the carbon content and sulfur content increasing. When carbon content is more than 0,4 %, the influence of the change of sulfur content on the segregation is less.

The effect of phosphorus content on the interdendritic phosphorus segregation ratio

Figure 4 shows the change of phosphorus content change effect on its segregation ratio at the different solidification condition. As shown in the Figure 4, the carbon content affects the phosphorus segregation ratio significantly, but the phosphorus's effect is less. Phosphorus segregation ratio increases with the solidification rate increasing. When the carbon content is less than $w^{s}_{\delta/\gamma}$, phosphorus segregation ratio changes a little with the carbon content changing. But when the carbon content is less than $w^{s}_{\delta/\gamma}$, the phosphorus segregation ratio increases significantly with the carbon content increasing.

THE CHANGE OF ELEMENTS EFFECT ON HIGH TEMPERATURE MECHANICAL PROPERTY

Zero strength temperature (ZST) and Zero ductility temperature (ZDT) are two important parameters to measure steel high temperature mechanical behavior. The figure6 shows the change cures of ZST and ZDT with the carbon, sulfur, phosphorus content. As shown in the figure: ZST and ZDT decreases and the width of the two-phase zone increases along with the change of carbon content, moreover, the crack sensitivity increases. Effect of the sulfur content increasing on the ZST is little, but the effect on the ZDT is big. With the increasing of sulfur content, the ZST decreases, the width of two-phase zone increases, it is because there is significant segregation at the end of solidification, so that the temperature fall sharply. Similarly, with the increasing of phosphorus content, the ZDT decreases, two phase zone width also increases, the crack sensitivity increases. (Figure 5)

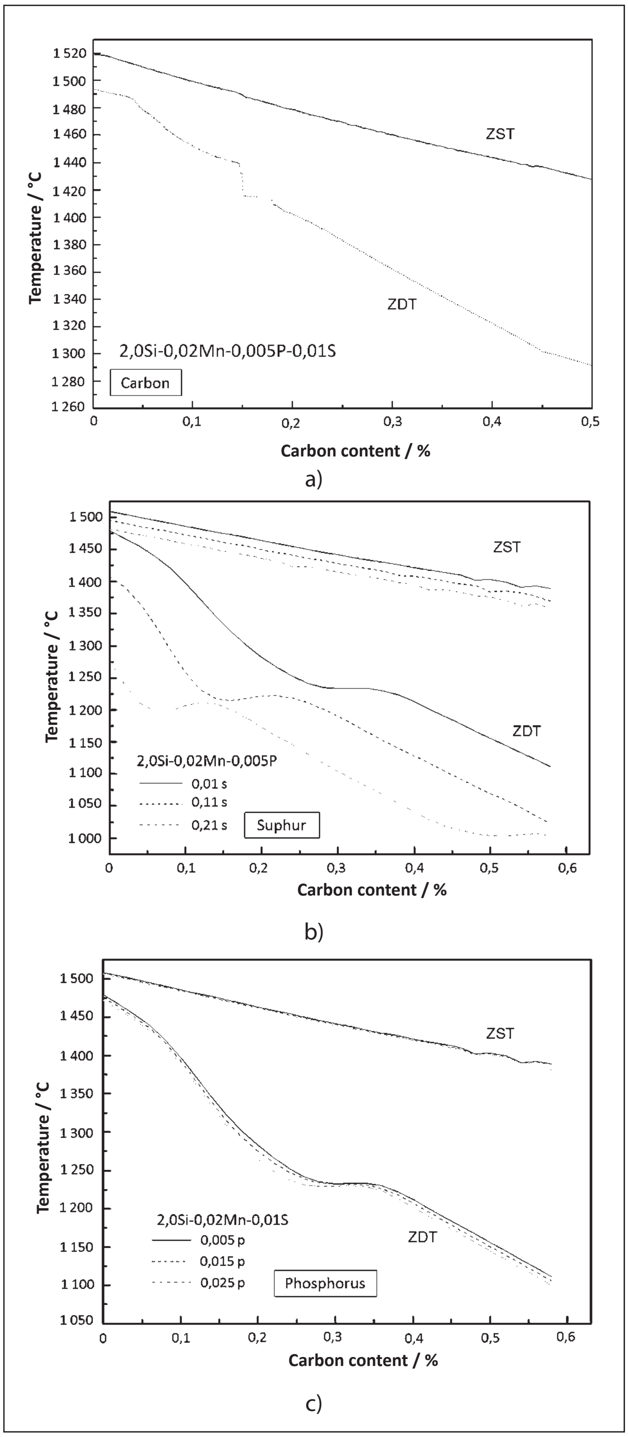

Figure 5 Effect of carbon, suphur, phosphorus content on solidification process of molten steel, a), b) and c)

CONCLUSION

Based on the dendrite hexagon section model and the solute diffusing equation, the segregation behaviors and the high temperature mechanical properties with the C, S, and P content change are analyzed, the conclusions are drawn as follows:

(1) The segregation behaviors are closely related to the solidification mode. The disciplines of segregation are different because of different solubility in the phase δ and phase γ.

(2) The segregation ratio of C, Si, Mn, S and P elements are increasing with the increasing of carbon content and the proceeding of the solidification, the segregation of S and P increase significantly.

(3) The phase change and segregation of elements affect the ZST and ZDT directly during the steel solidification. The width of two-phase zone increases with the carbon content increasing, the ZDT decreases with the sulfur and phosphorus content increasing, and the increasing of the width of two-phase zone make the inner crack increase.

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