MICROSTRUCTURE FORMATION IN THIN SLAB CASTING

R. G. Santos*, J. L. Peralta**, M. D. C. Sobral***, S. R. Andrade*, P. R. Mei*

*Universidade Estadual de Campinas, Brazil
**Centro Federal de Educação Tecnológica do Pará - CEFET-Pa, Brazil
***Centro Federal de Educação Tecnológica da Bahia - CEFET-Ba, Brazil

ABSTRACT: New processes have been developed in the last years to produce near net shape steel products by continuous casting. This work deals with the analysis of the effects of liquid core reduction during the solidification in the microstructure of thin slabs obtained by continuous cast process. An equipment able to simulate the liquid core reduction during the solidification was projected and constructed. This instrumented simulator consists of a water-cooled mould with a moveable side wall driven by a hydraulic piston. Experiences were carried out using steels with different compositions, with and without liquid core reduction, in order to analyze the influence of the solidification parameters in the microstructure formation. The alloy temperature during solidification was monitored by thermocouples positioned within the slab. From experimental results of temperature variation close to metal/mould interface and numerical simulation, the variation of heat transfer coefficient at this interface was estimated. Samples from the as cast slabs were examined after polishing and etching to characterize the microstructure. Comparisons between microstructures of slabs obtained under different solidification conditions were carried out. A numerical method based on finite difference was applied to simulate the solidification process and the results were compared with the experimental data.

KEYWORDS: Numerical simulation, Near Net Shape Casting, microstructure, microalloyed steel, thin slab continuous casting.

1 INTRODUCTION

Thin Slabs Continuous Casting and Thin Strips Continuous Casting are considered near-net-shape processes for steel production. They are based on manufacturing products with the final or almost final dimensions. This tendency is related to the requirements of mayor productivity, maintaining the quality and mainly reducing energy consumption. The Thin Slabs Continuous Casting (TSCC) has been developing since 80's, and it has been applied in several countries. In Brazil the first researches had begun in 1997 with the numeric modeling of simultaneous solidification and deformation [1]. The TSCC allows the energy reduction consumption when links directly the continuous casting to the rolling. The thin slabs have final thickness in the range of 40 to 90 mm, and the cooling and pre-heating stages required before rolling are eliminated. This change in the process route introduces microstructure changes, which by its turn influences the mechanical properties of the material. Although in the TSCC process the microstructure is more refined than in conventional continuous casting (250 to 320mm final thickness), the rolling will be performed with the as-cast structure, besides because of the thinner thickness, the total deformation in rolling is reduced, loosing an important way to improve the microstructure. Two factors can be used to reduce the effects of rolling the as-cast microstructure. One of them is the liquid core reduction [2]. It has been affirmed that the reduction of the thickness of slabs during solidification increases the equiaxial structure, the refinement of grain, reduces the centerline segregation [3] and improves a more homogeneous distribution of micro segregation [4]. Another factor is the cooling rate during solidification, which can reach values above 1,9ºC/s [5], due the small thickness slab. One of the steels that have been produced by TSCC is the microalloyed HSLA, although the changes that occur in terms of solubilization and precipitation of carbonitrides are being yet studied [5,6,7].

The TSCC Group of the Materials Engineering Department of the Mechanical Engineering Faculty of State University of Campinas has been studying mathematical and physical simulation since 1997, and an equipment was built [8] in order to reproduce solidification under liquid core reduction conditions [9,10]. In this paper are presented the results of experiences, which were carried out using different alloys, with and without liquid core reduction, in order to analyze the influence of the solidification parameters in the microstructure formation. The slab temperature during solidification was monitored by thermocouples positioned in the solidifying alloy. From experimental results of temperature variation close to metal/mould interface and numerical simulation, the variation of heat transfer coefficient at this interface was estimated. Samples from the as cast slabs were examined after polishing and etching to characterize the macro and microstructures. Comparisons between microstructures of slabs obtained under different solidification conditions were carried out. A numerical method based on finite difference was applied to simulate the solidification process and the results were compared with the experimental data.

2 EXPERIMENTAL PROCEDURE

The simulations were carried out using thigh strength and low alloy steels with some differences in composition, supplied by CST (Companhia Siderúrgica de Tubarão). The full chemical composition of the materials after melting in an induction heat furnace and solidified in the equipment is shown in table 1.

Table 1. Chemical composition of the steels wt%

Placa	C	Mn	Si	Al	Nb	V	Cu	Cr	Ni	N
TS20%d	0.07	1.15	0.41	0.05	0.03	0.07	0.02	0.02	0.01	0.017
1TSWd	0.07	1.72	0.10	0.03	0.02	0.08	0.02	0.02	0.02	-
2TSWd	0.07	1.32	0.08	0.03	0.02	0.05	0.03	0.02	0.01	-

The simulation of the effects in the microstructure of core reduction during the solidification of thin slabs was carried out in the equipment developed. The main characteristic of the apparatus is the possibility of squeezing the liquid core of the slab during solidification. The mold has two water-cooled copper walls, which guarantee solidification rates compatible to those of typical industrial near net shape casting. The two lateral walls and bottom of the mold were built of refractory material, in order to promote unidirectional heat transfer. The dimensions of the thin slabs obtained are: width 160 mm (constant), height: 240 mm (max.) and thickness varying from 38 to 90 mm [8]. Figure 1 shows an overview of the equipment.

After painting the inner copper walls with chromium oxide coating, the moveable wall was fixed in the specified position, 59mm, for 1TSWd (first thin slab without deformation) and 2TSWd. For TS20%d (thin slab with 20% deformation) the initial thickness was around 57 mm. Type S thermocouples were positioned inside mold. Electrical heaters heated the refractory walls to about 220ºC in order to eliminate the humidity inside mold. The superheat of the melting steel was of 50 to 100ºC before introducing the additions and deoxidizers. After the additions the steel was poured into the mold.

In the TS20%d experiment, after about 10 seconds from the beginning of the pouring, the hydraulic cylinder was moved to previous defined position 42mm thickness. Figure 2 shows schematic slab draw, detailing the positions of samples used for macrostructure, microstructure, chemical composition analysis and thermocouples positions.

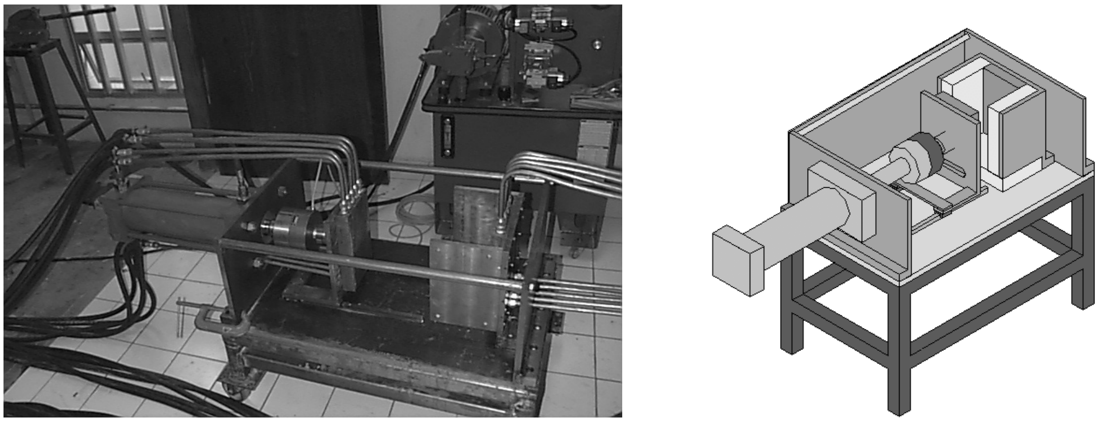


Figure 1 Overview of the equipment used to obtain the thin slab.

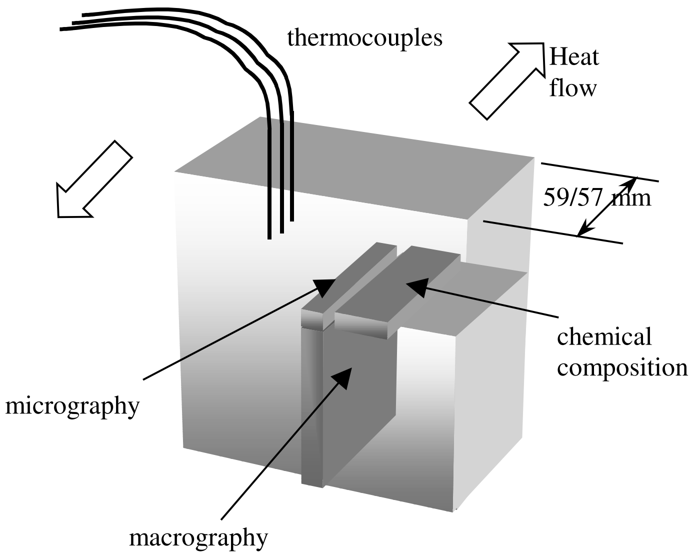


Figure 2 Schematic view of the thin slab showing termocouples and samples positions.

3 RESULTS AND DISCUSION

3.1 Macrostructure

The macrostructures of the slabs are shown in Figure 3. The pictures revealed homogenous sections without porosity in both slabs and it is observed that the TS20%d, which was submitted to liquid core reduction, shows a more refined structure than the other one. This is probably due to the break-up of dendrites arms during the reduction, increasing the equiaxed zone and leading to small grains and better homogeneity. Also the reduction of thickness of the slab affects the macro and microstructures [11], since small thickness induces faster solidification.

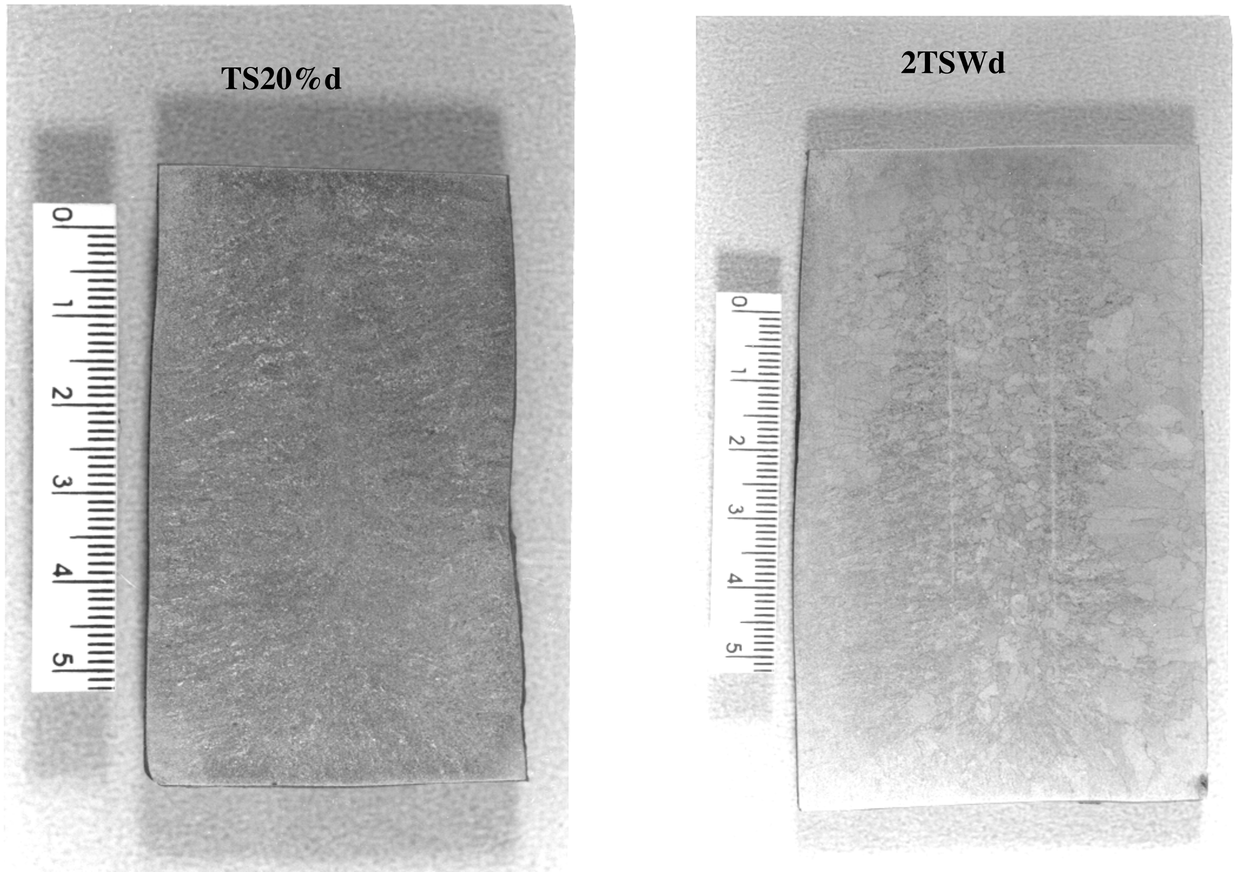
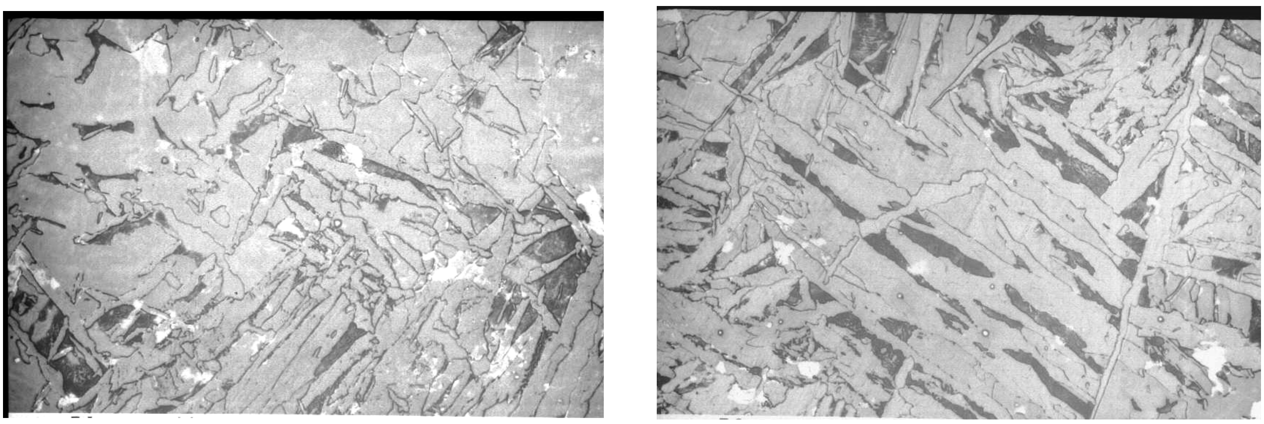


Figure 3 Macrostructure of the TS20%d and 2TSWd thin slabs (Nital 10% etch).

3.2 Microstructure

The microstructures of the slabs were investigated through optical and electronic microscopy in different positions of the transversal section.

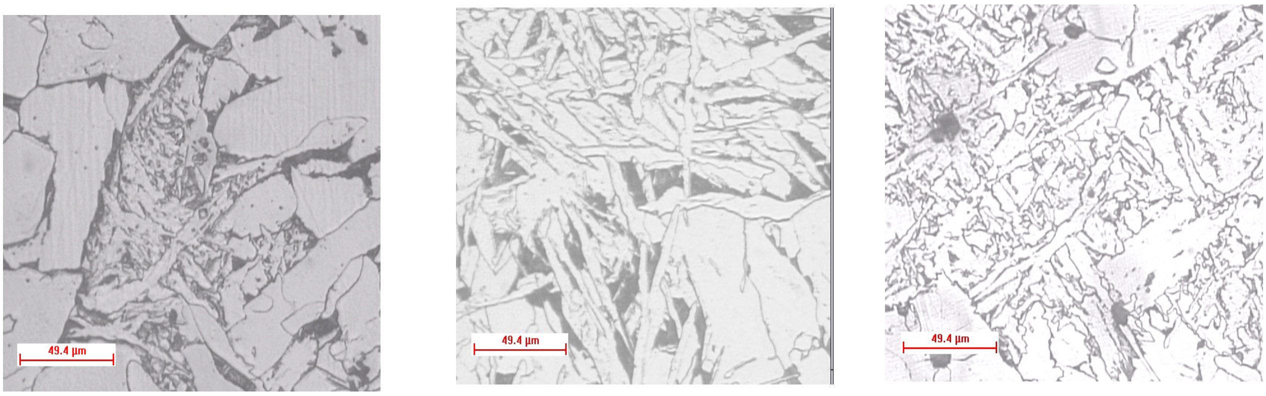


(a) (b)

Figure 4 Microstructure of the slab 2TSWd: (a) close to the mold and (b) center (Nital 2% etch/Magnification 400×)

Figure 4 shows the micrography of the 2TSWd slab in two different positions: close to the mold wall and in the center, obtained by scanning electronic microscopy. It seems that the microstructure consists of acicular ferrite and pearlite. This structure is probably consequence of a limited amount of carbon available and high cooling rates observed in the thin slab casting. No difference is observed in the microstructure in these positions.

Figure 5 presents the microstructures in the center of the three slabs, obtained by optical microscopy. It is observed that the variation on chemical content of manganese doesn't affect considerably the microstructure. It is also observed that the microstructure of the slab obtained with liquid core reduction shows a more homogeneous and refined. The reason is probably the detached fragments of dendrites arms dragged by the liquid metal motion during the reduction.



(a) (b) (c)

Figure 5 Microstructures of the slabs: (a) 1TSWd, (b) 2TSWd and (c) TS20%d. (Nital 2% etch/ Magnification 250×)

3.3 Numerical simulation

From experimental results of temperature variation close to metal/mould interface and numerical simulation, the variation of heat transfer coefficient at this interface was estimated [12,13]. A numerical method based on finite difference was applied to simulate the solidification process and the results were compared with the experimental data. Figure 6 shows the simulated variation of temperature in the metal during solidification compared with experimental results for the thin slab without deformation. It can be observed a good agreement between experimental and simulated results. The numerical method is now being adapted to treat the slabs deformed during solidification.

4 CONCLUSIONS

The results showed that the equipment developed is able to simulate the effects of liquid core reduction in the microstruture of thin slabs continuous casting. The initial experiences using HSLA steels confirmed that it is possible to obtain a more homogeneous structure applying liquid core reduction. In the present stage the numerical method developed is able to simulate the solidification without liquid core reduction, fitting well when compared to experimental results. Efforts have been carried out in order to extend the model to treat solidification with liquid core reduction.

ACKNOWLEDGEMENTS

The authors would like to thank for the financial suport: FAPESP- Fundação de Amparo à Pesquisa do Estado de São Paulo, CST- Companhia Siderúrgica de Tubarão and FINEP- Financiadora de Estudos e Projetos .

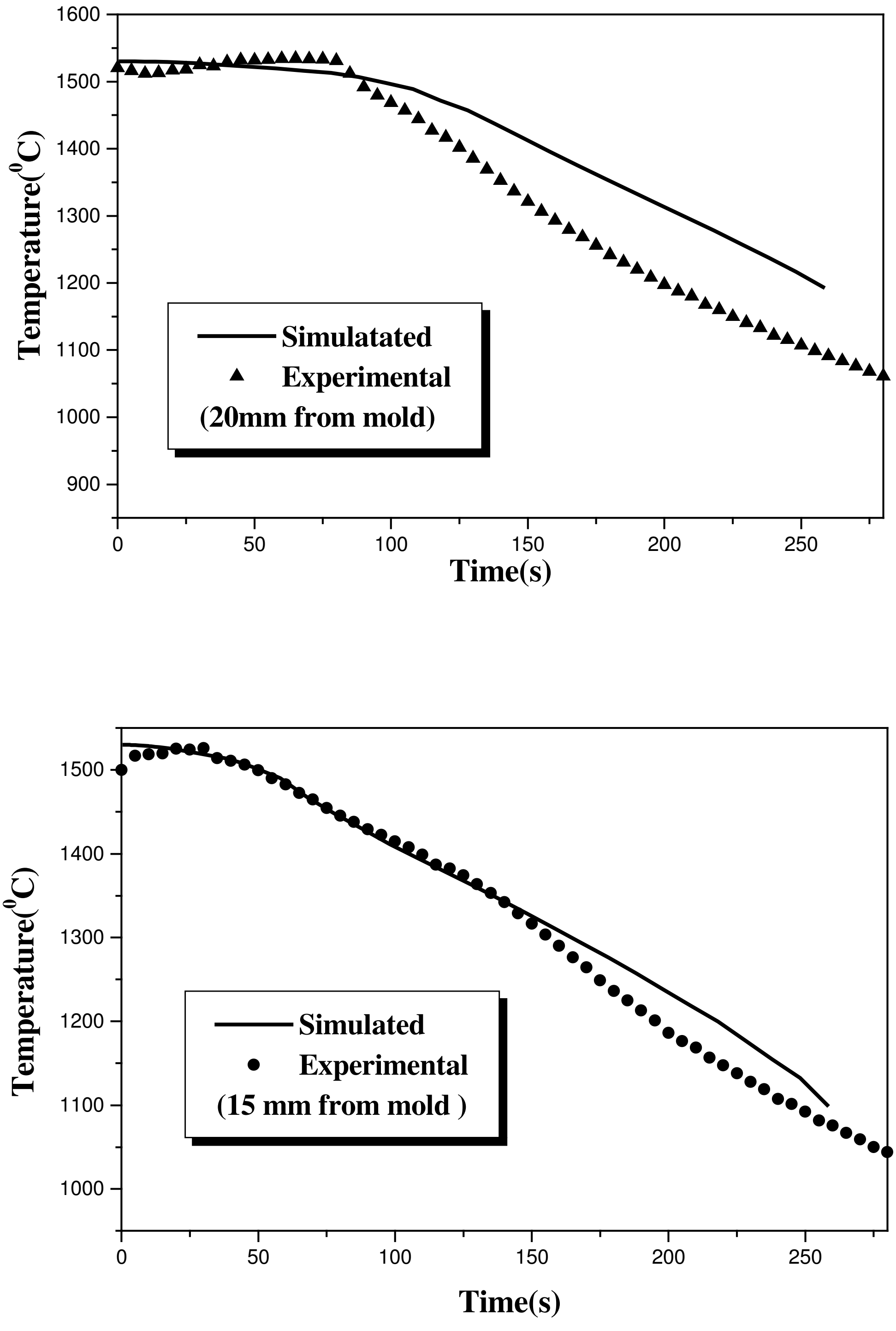


Figure 6 Comparison between experimental and simulated results for temperature variation in two different positions in the metal during solidification.

REFERENCES

[1] E. M. Rizzo and R. G. Santos, Proc. 13rd CBECIMAT,Brazil, (1998).
[2] D. Kothe *et. al*., Steelmaking Conf. Proc. (1995), 23.
[3] T. El-Gammal *et al*., Proc. Symp. Continuous Casting Res., Egypt (1992) 323.
[4] R. Kaspar and P. Flüß, Steel Res., 62 (1991) 501.
[5] R. Priestner and C. Zhou, Ironmaking and Steelmaking, 22 (1995), 326.
[6] R. Priestner, Mat. Sci. Forum, 284 (1998) 95.
[7] E. Essadiqi *et al*., 39 MWSP Conference Proceeding ISS, 35 (1998) 883.
[8] F. C. Gentile, Desenvolvimento de protótipo para simulação do processo de lingotamento contínuo de placas. Campinas UNICAMP, (1999).
[9] W.Palmieri and R. G. Santos, 53rd Proc. ABM, Brazil (1998).
[10] F. C. Gentile *et al*. Proc. COBEM, Brazil (1999).
[11] E. Essadiqi *et al*.;L. E. Collins, and M. T. Shehata, Mod. Steelmaking and Casting Techniques, (1994) 251.
[12] M. L. N. M. Melo, E. M. S. Rizzo and R. G. Santos, Mater. Sci. Forum, 242 (1997) 83.
[13] J. A. Spin and A. Garcia, Mater. Sci. Eng., 277 (2000) 198.