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High Speed Casting versus Shell Strength

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The present work discusses the limitation of high speed casting by shell strength. Mould friction data from plant experiments are analysed and compared with measured shell strength from laboratory experiments. The results show, that under regular conditions, mould friction cannot be considered a significant limitation in casting speed. Stability in mould operation should therefore be the key to successful development of continuous casting at highest casting speeds.

Gießgeschwindigkeit und Strangschalenfestigkeit beim Stranggießen von Stahl. Im Rahmen der vorliegenden Arbeit wird die Begrenzung der Gießgeschwindigkeit durch die Festigkeit der Strangschale am Austritt aus der Kokille diskutiert. Die Ergebnisse von Reibungsmessungen an Stranggießanlagen werden analysiert und mit der Strangfestigkeit aus Laborversuchen verglichen. Es zeigt sich, dass unter regulären Verhältnissen und im untersuchten Geschwindigkeitsbereich die Strangfestigkeit keine Limitierung der Gießgeschwindigkeit darstellt. Ziel der Entwicklung des schnellen Gießens sollte somit die Vergleichmäßigung der Bedingungen in der Kokille sein.

1. Introduction

High speed casting (> 4.0 m/min) is a generally pursued target in the development of Continuous Casting (CC) since long time already – for the sake of improved caster productivity and of reduced strand number, realizing a minimum in investment and running costs. As, for instance, documented by the first IISI review, several casters had attained a high speed level in the 1970s, which, however, was difficult to sustain on account of an increased breakout frequency, Fig. 1.

The common reason for high breakout frequency is attributable to *linear* mould tapers generally applied at that time, leading to enhanced gap formation in the corner area followed by corner rotation and off-corner longitudinal cracking in this hot-spot region, but effectively overcome by non-linear (multi- or parabolic) taper[2, 3]. Hence, a renewed attempt of high speed casting is observed since the late 1980s, especially by minimills and regarding both, billet as well as thin slab casting of commercial quality steel products[4]. This has culminated in recent pilot caster trials, attaining 8.0 m/min for slab size 90 by 1000 mm (followed by liquid core reduction to 50 mm thickness)[5]. Assuming a solidification constant of $K = 16\ \mathrm{mm/min^{0.5}}$ an average shell thickness at mould exit (with an active mould length of 0.8 m in the given case) of 5.1 mm can be derived. Apparently such "thin-wall box" suffices to safely contain the liquid core – provided high uniformity of shell growth in circumferential direction (using for example a parabolic narrow face taper in the given case).

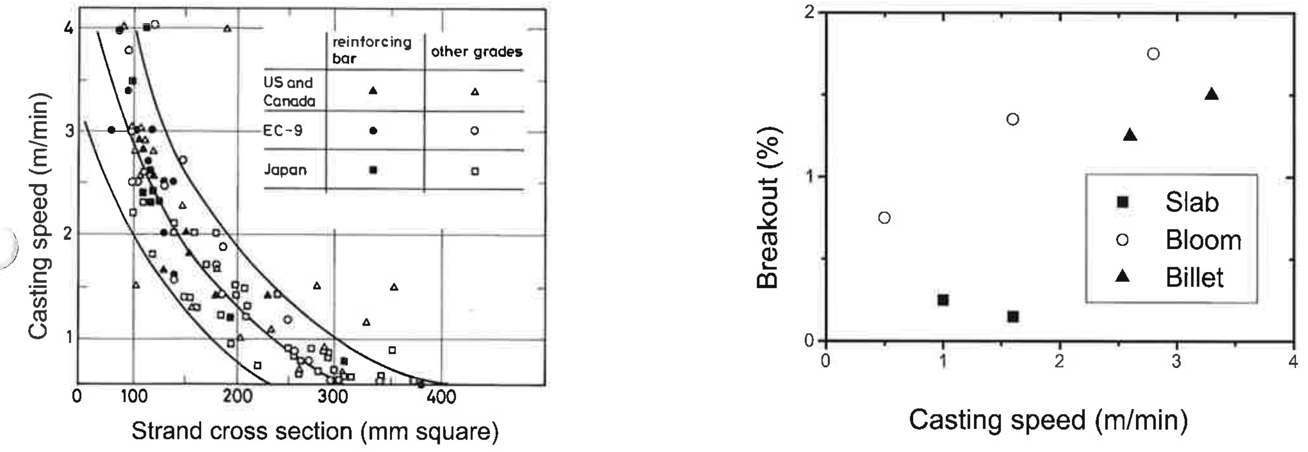

Fig. 1. Casting speed versus cross section (left), and breakout frequency versus casting speed (right) – as reviewed in the 1970s[1]

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2. Experimental Work

Figure 4 gives a schematic view of the experimental setup. A steel test body, split in two halves, submerges into the liquid steel inside an induction furnace. To form a coherent shell on the (coated) chill body, 2–20 s of holding time are maintained before the lower half is subjected to hydraulic force for about 5 s, which yields strain of 1.6 to 4.0 % and strain rate of 3–8 · 10^{-3} 1/s. Resultant stress-strain curves for the example of 0.1 %C – steel with three different P-contents are shown in Fig. 5.

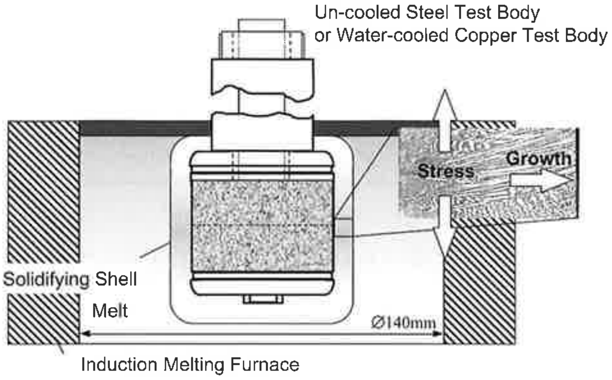

Fig. 4. Schematic presentation of the SSCT test method, geometry of chill body

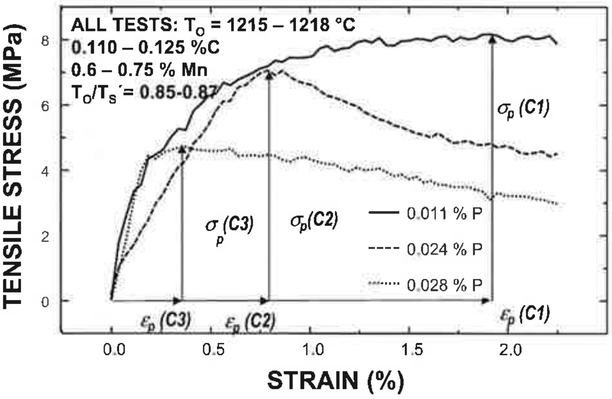

Fig. 5. Example of stress-strain curves in the SSCT test for 0.1 % C – steel and three different P-contents[22]

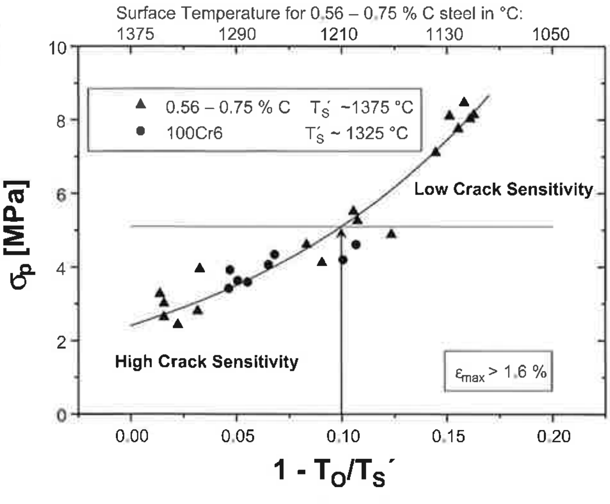

Fig. 6. Maximum shell strength (= peak stress), σ_p of high C-steels in the SSCT test versus homologous temperature (as ration of T_O over T_S')

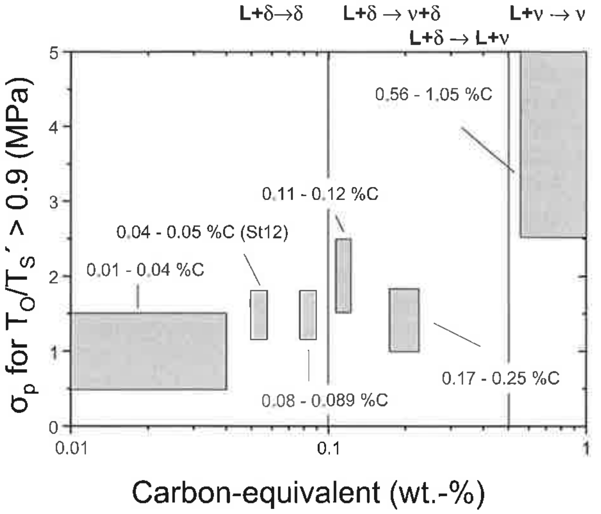

Fig. 7. Meniscus shell strength as a function of steel C-content (log-scale)

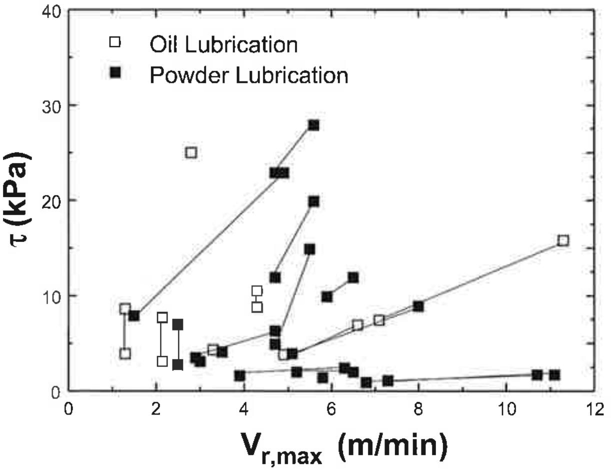

Fig. 8. Measured mould friction data evaluated in [12] for the relation between maximum relative mould strand/mould velocity and friction shear stress τ

For high C-steels, shell tearing is observed between the solidus and the homologous temperature $T_O/T_S' > 0.90$, Fig. 6 (with T_O signifying the shell surface temperature; and T_S' the nonequilibrium solidus temperature including microsegregation), the corresponding range of shell strength (= peak stress), σ_p amounting to 2.5–5.0 MPa. Such tests are performed for a wide range of C-contents with industrial relevance, in order to assess the characteristic meniscus shell strength under CC conditions.

3. Test Results

As a summary of pertinent SSCT-test results, data for the measured peak stress, σ_p near the meniscus i. e. at $T_O/T_S' > 0.90$ are plotted as a function of C-content in Fig. 7, thereby using the "Carbon Equivalent for the Peritectic Reaction" C_P in order to account for the effect of other alloying elements, too.[9]

ISS Trans. *7* (1986) 31–43. – [3] *Bernhard, C.* et al.: Experimental simulation of subsurface crack formation in continuous casting. Rev. Métallurgie-CIT, *97* (2000), 333–344. – [4] *Wolf, M. M.:* Can minimills cope with high speed casting? Steel Times Int. *13* (1989) No. 1, 16–17, 19. – [5] *Kikuchi, H.* et al.: Continuous casting technologies of 8 m/min casting speed by Sumitomo's QSP process. ISS Steelmaking Conference Proc. *83* (2000), 23–28. – [6] *Tsuneoka, A.* et al.: Measurement and control of solidification in continuous casting mould. ISS Steelmaking Conference Proc. *68* (1985) 3–10. – [7] *Itoyama, S.* et al.: Prediction and prevention system for sticking type breakout in continuous casting. ISS Steelmaking Conference Proc. *71* (1988), 87–102. – [8] *Emling, W. H.* and *S. Dawson:* Mould instrumentation for breakout detection and control. In: A. W. Cramb and E. S. Szekeres, Mould operation for quality and productivity. ISS, Warrendale 1991, 161–181. – [9] *Wolf, M. M.:* Mould heat transfer and lubrication control – two major functions of caster productivity and quality assurance. ISS Process Technology Conference Proc. *13,* (1995), 99–117. – [10] *Mills, K. C.* et al.: Causes of sticker breakout during continuous casting. Ironmaking Steelmaking *18* (1991), 253–265. – [11] *Suzuki, M.* et al.: In-situ measurement of fracture strength of solidifying steel shells to predict upper limit of casting speed in continuous casting with oscillating mould. ISIJ Int. *37* (1997), 375–382. – [12] *Wolf, M. M.:* Review of mould friction. BHM *145* (2000), 270–275. – [13] *Ackermann, P.* et al.: In-situ tensile testing of solidifying aluminium and Al-Mg-shells. Mater. Sci. Eng. *75* (1985), 79–86. – [14] *Hiebler, H.* et al.: Inner crack formation in continuous casting: stress or strain criterion? ISS Steelmaking Conference Proc. *77* (1994), 405–417. – [15] *Bernhard, C.* et al.: Simulation of shell strength properties by the SSCT test. ISIJ Int. *36* (1996) Suppl., S. 163–S. 166. – [16] *Hiebler, H.* and *C. Bernhard:* Mechanical properties and crack susceptibility of steel during solidification. Steel Res. *70* (1999), 349–355. – [17] *Bernhard, C.:* Simulation of internal crack formation in continuous casting of steel. BHM *145* (2000), 22–29. – [18] *Bernhard, C.* et al.: Influence of alloying elements and cooling conditions on hot tearing of steel measured by the SSCT test. In: Modelling of Casting, Welding and Advanced Solidification Processes VIII, San Diego, CA, 1998, 923–930. – [19] *Wolf, M. M.:* Mould length in slab casting – a review. I&SM *23* (1996), No. 2, 47–51. – [20] *Riboud, P. V.* and *M. Larrecq:* Lubrication and heat transfer in a continuous casting mould. AIME National Open Hearth & Basic Oxygen Steel Conference Proc. *62* (1979), 78–92. – [21] *Harada, S.* et al.: A formation mechanism of transverse cracks on CC slab surface. ISIJ Int. *30* (1990), 310–316. – [22] *Bernhard, C.* et al.: The influence of phosphorus an the mechanical properties of carbon steels near the melting point at low strain rate. In: J. Herbertson (ed.), ISS Belton Symposium Proc., Sydney/Australia 2000, 263–272. – [23] *Bertoletti, C.* et al.: Meniscus free casting: metallurgical and technological results. Proc. 3rd European Conference on Continuous Casting, Vol. I, Cenim, Madrid 1998, 65–74.