IMC – B – a new experimental method to predict the crack susceptibility under continuous casting conditions

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INTRODUCTION:

Continuous casting (cc) free of surface defects is still one of the major quality challenges in steel production. Surface cracks usually form when the process-related tensile strain locally exceeds the ductility of the strand shell. With respect to transversal cracks, the so-called second ductility trough is of highest relevance and thus extensively investigated in the well-established hot tensile experiments. But not only the nucleation of precipitation along grain boundaries (or close to grain boundaries) as well as the occurrence of thin ferrite films along grain boundaries may reduce ductility; other factors may also deteriorate the ductility and promote the formation of surface defects and should thus be considered in simulation experiments. These include solidification related (and hence), pre-existing subsurface and surface defects in the strand shell (oscillation marks, depressions, pores etc.).

A further argument for the development of a new testing method results from the need for specific critical strain values both in process models and in the construction of cc machines. A bending experiment provides a more promising way to determine critical strain values. This paper describes a new experiment, the In-Situ Materials Characterization by Bending (IMC-B) test and some initial results.

EXPERIMENTAL AND NUMERICAL SIMULATIONS:

The IMC-B test consists of three steps (Fig.1):

- Melting in an induction furnace and casting of a 180x60x23 mm sample in an ingot mould,
- stripping of the sample and controlled cooling in heat treatment furnaces, and finally,
- a bending experiment inside a heat treatment furnace.

The numerical modelling of solidification; heat treatment; grain growth; precipitation and phase transformation kinetics; the prediction of defect indices were used to simulate the IMC-B test. The defect indices were most recently implemented in the commercial database IDS. These quality indices are powerful tools to predict the surface crack susceptibility in cc process models, and first results will be reported in detail soon. The tensile strain is derived from an FE-simulation of the bending experiment in ABAQUS.

All experimental parameters are adjusted to the simulated process. This comprises the cooling conditions during solidification (by use of a zirconium oxide coating of the mould), and the contact time between the mould and the sample. Furthermore, it includes the surface temperature of the strand and the deformation parameters of e.g. the straightening operation in cc. The simulation of the strand surface temperature demands simplifications. This is because temperature fluctuations caused by contact with water sprays or rolls are not yet reproducible. Nevertheless, heat treatment in a consecutive number of furnaces at different temperatures allows for a wide variation of thermal cycles.

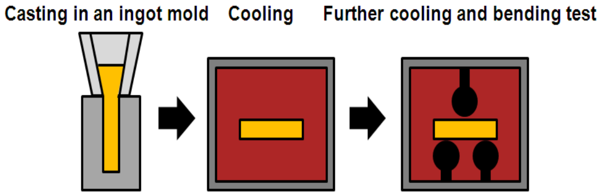

Fig. 1: Three steps of the IMC-B experiment

The sample is put on the bending apparatus once it reaches gauge temperature and after it has been held for 1 minute, the sample is bent with a defined stamp direction and velocity. The bending apparatus with the furnace is shown in Fig.2.

Fig. 2: Bending equipment with the furnace

The lower side of the sample is subjected to tensile strain during the test. After bending, the sample is quenched in water and after descaling, the surface of the sample is examined using a stereo microscope.

The applied strain varies between the individual experiments and the existence or absence of defects allows us to determine a critical strain. This strain depends on solidification, thermal cycle, bending temperature and deformation parameters. In addition, the initial solidification results in the formation of subsurface defects like micropores and in future additional vulnerabilities (e.g. artificial oscillation marks) will be entrapped in the ingot surface in a controlled way.

EXPERIMENTAL PROCEDURE:

The present work focuses on two experimental series on two different steel grades (Tab.1). The experiments were performed at a bending temperature of 750 °C (temperature of the beginning of the straightening zone), after cooling down with a defined cooling strategy as shown in Fig.3. The depicted cooling strategy comprises hard cooling in the initial cooling zones and straightening at unusually low surface temperatures. This cooling strategy is known to cause problems for Nb-micro-alloyed steel grades.

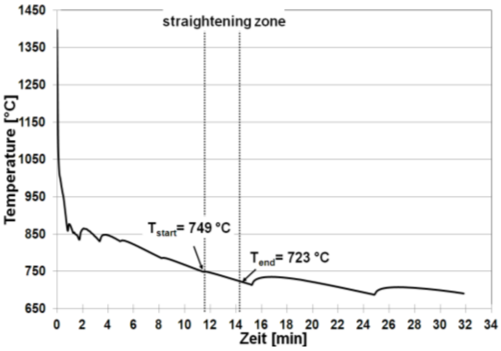

Fig. 3 Cooling strategy used in the experiment

Steel	C	Si	Mn	P	Al	Nb	N
A	0.17	0.43	1.54	0.015	0.03	0.017	0.004
B	0.15	0.015	1.109	0.008	0.04	0.001	0.005

Table 1: Chemical composition of investigated steel grades, in mass-%

A total number of seven experiments were performed. For each experiment the casting temperature was adjusted to 1620 °C. After 30s of solidification in the mould the samples were cooled down in the air to a temperature of 860 °C. Then the samples were placed in a first heat treatment furnace and kept at constant temperature for 2 minutes. The samples were subsequently placed in a second furnace and cooled down to bending temperature. Afterwards the samples were placed in the bending apparatus and bent with a different stamp way yet constant strain rate of $7.25 \cdot 10^{-4}\ s^{-1}$.

DISCUSSION:

The deformation parameters (stamp movement and tensile strain), and the results of the metallographic examinations are summarized in Table 2. The results show that steel B shows little reaction under these experimental conditions. Even a tensile strain of roughly 11.4 % will not result in the formation of surface cracks. Steel A, in contrast, will already display surface cracks under strains smaller or equal 5.8 %, with the critical strain likely to be even lower. The strain values used in the experiments are rather high compared with the tensile strain at the surface of a cc strand during straightening operation (< 1.5 %). However, they are much smaller than the typical strain which would lead fracture in a hot tensile test. The influence of recrystallization should thus be largely prevented.

Steel	Stamp way [mm]	Calculated strain [%]	Cracks yes/no
A	20	23.7	Yes
	10	14.5	Yes
	8	11.3	yes
	6	8.6	yes
	4	5.8	yes
B	10	11.6	yes
	8	11.4	no

Table 2: Summary of the results

Fig. 4 shows examples for the appearance of defects at the surface of samples for different levels of tensile strain.

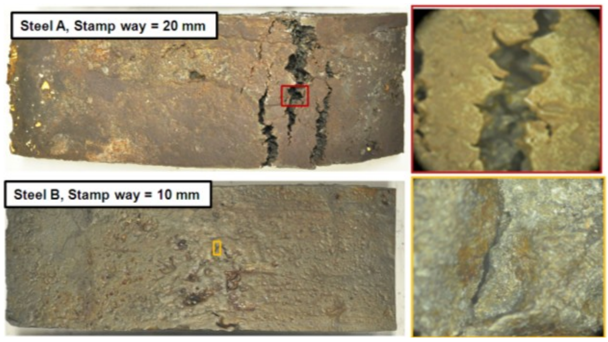

Fig. 4 Examples of the defects at the surface of samples

SUMMARY:

This paper summarized the first results of investigation of crack susceptibility under cc conditions using the new IMC-B method. The results show that cracks can already form under strains smaller or equal to 5.8 % for the first steel grade. The critical strain had not yet been exactly defined and will be further investigated in the following experiments. The second steel grade with the critical strain of 11.6 % does not seem to be very sensitive to surface crack formation under these conditions.

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