THE FORMATION OF TRANSVERSE CRACKS DURING CONTINUOUS CASTING OF STEELS

Pavliska J., Jonšta Z., Mazanec K.

Faculty of Metallurgy and Material Engineering, Technical University (VŠB-TU),

av. 17.listopadu 15, 708 33 Ostrava 8, Czech Republic

VZNIK PŘÍČNÝCH TRHLIN PŘI ODLÉVÁNÍ OCELI

Pavliska J., Jonšta Z., Mazanec K.

Fakulta metalurgie a materiálového inženýrství, Vysoká škola báňská-Technická Univerzita Ostrava, tř.17.listopadu 15, 708 33 Ostrava 8, Česká republika

Abstrakt

Článek se týká hodnocení fyzikálně metalurgických parametrů ovlivňujících vznik příčných trhlin při plynulém odlévání oceli. Kritická teplotní oblast pro vznik příčných trhlin je 700 až 1150°C.

Byl diskutován všeobecně přijímaný model iniciace těchto trhlin, založený na interakci precipitátů, resp. nekovových vměstků a lokalizované plastické deformace v měkkých oblastech situovaných na hranicích zrn austenitu. Na rozdíl od tohoto mechanismu byly popsány podmínky vedoucí k tvorbě příčných trhlin v případě vzniku velmi úzkých intergranulárních feritických filmů, jejichž objemový podíl byl nižší než 10%. Mikrotrhliny mohou být iniciovány v těchto filmech bez dodatečného účinku precipitátů, resp. nekovových vměstků. Mikrotrhliny nebyly zjištěny v případě vyššího objemového podílu feritu (přibližně 30%) a tvorby širších feritických pásů podél původních austenitických zrn.

Abstract

The paper reports on the physical metallurgy parameters influencing the transverse crack formation during the continuous casting of steels. The critical temperature region of the transverse crack formation is 700-1150°C. The generally accepted model of this crack initiation, based on the interaction of precipitates and/or non-metallic inclusions and localised plastic deformation in soft zones found on the grain boundaries of prior austenite, was discussed. On the contrary to this mechanism, the conditions leading to transverse cracking in case of very narrow intergranular ferrite films (volume faction lower than 10%) are described. The microcracks can be initiated in these films without the detected additional effect of precipitates and/or non-metallic inclusions. The microcraks are not found, when the volume fraction of ferrite is higher (30% approximately) and the thicker ferrite bands are formed around the grain boundary of primary austenite.

1. INTRODUCTION

The hot ductility values have been found to be very useful in evaluation of the steel susceptibility to cracking during the process of continuous casting (CC). The criterion of ductility at high temperature is the reduction in area (RA) determined by the tensile testing. The decrease of this value was observed in two temperature regions. The first critical region is situated close to the solidus

temperature and is limited with the zero ductility temperature (ZDT). The details of physical metallurgy behaviour of CC-steel at very high temperatures, leading to the formation of longitudinal cracks in CC-products, were analysed recently [1,2]. In these contributions, the relation between ZDT and LIT (liquid impenetrable temperature) and additional effect of internal stresses, induced by delta-ferrite to austenite phase transformation, on longitudinal crack formation were presented.

The second critical region is usually connected with formation of precipitates negatively influencing the ductility and bringing about the embrittlement of steel what results in a higher susceptibility to fracture initiation in CC-steel. The CC-processing is commonly carried out with a curved mould and the strand is straightened when steel solidified throughout the cross section. The straightening operation causes tension stress in the top surface of the strand and a high susceptibility to crack formation is a result of this effect [3]. Hot ductility data show that tensile ductility can fall to very low values in the temperature range in which straightening is carried out. The cracks are usually intergranular. They propagate along the prior austenite grain boundaries which are often "decorated" with ferrite bands [4]. The straightening temperature falls commonly within 700°C to 1150°C. It corresponds to the range, in which a hot ductility trough is observed. The low steel ductility and induced tensile strain may cause transverse cracking in CC-products. The measurements of hot ductility of steels at low strain rates, which are analogical with the conditions realised in steel strand during CC-processing, have confirmed immediate connections between the low ductility values and high susceptibility to the transverse cracking [5]. This paper reports on the investigation of physical metallurgy of the ductility through in temperature range corresponding to the straightening operation of strand. The solution is primary based on the microstructure analysis carried out in CC-products (billets and stabs) [6].

2. CHARACTERISTICS OF THE INVESTIGATED STEELS

Beside the basic structural and metallurgical characteristics of CC-steels, the attention will be devoted to the analysis of applied evaluating criteria. The study is carried out on the commercial low-carbon steels melted by use of conventional technology. The chemical composition of the investigated steels is given in Tab.1. The primary austenite grain size was 320 μm in average, what represents a favourable starting structural parameter.

Table 1 Chemical composition of steels (in wt.%)

The metallographics cleanness of these melts is high and corresponds to the area fraction of non-metallic inclusions about 0,0021. The microstructure of CC-billets (180x180mm) consists of a higher volume fraction of ferrite forming thicker zones around the grain boundaries of primary austenite. On the contrary, the microstructure of CC-slabs (150x700mm) consists of very narrow ferrite zones surrounding the primary austenite grains.

On the basis of these microstructural data, we can assume the different cooling intensity of CC-billet and slab, respectively. The casting speed was in case of CC-billets 1,8 m/min and in case of slabs, the casting rate was a little increased. In the secondary section, the specific spray water consumption was about 0,45 l/kg (billets) and about 0,55 l/kg in case of slabs. The specific spray consumption is in case of CC-billets a little lower than the usually used level, which is about 0,48 l/kg. On the contrary, by casting of CC-slabs, the applied level of cooling intensity is higher then above mentioned critical value.

3. RESULTS

The detail analysis of microstructure observed in CC-billets and slabs makes possible to define the influence of microstructure parameters on the transverse crack formation. With respect to the fact, that a majority of cracks was detected in the ferrite zones decorating the austenite grain boundaries, the attention was devoted to the study of ferrite volume fraction on the susceptibility to the crack initiation and to the evaluation of additional effect of precipitates and /or non-metallic inclusions.

Figures 1 and 2 show characteristic microstructures obtained in two compared examples of CC-products. The ferrite volume fraction in Fig.1 is higher than in Fig.2 and ferritic bands are thicker. The volume fraction of ferrite is 25-30% approximately. The matrix microstructure consists of the acicular Widmanstatten ferrite and local pearlite areas. Figure 2 shows, that the microstructure consists of very narrow intergranular ferrite zones. Their volume fraction is only 5-8% in average. The matrix consists of bainite in this case. The grain boundary precipitation of carbides and / or nitrides was not found. The achieved results demonstrate that the higher ferrite content and "softer" matrix microstructure (Fig.1) positively influence the resistance to the transverse crack formation in CC-products [6].

Fig.1 Microstructure of thick ferrite bands

Fig.2 Microstructure of narrow ferrite film

Figure 3 shows the cracks initiated in narrow ferrite film. These cracks were not found to be associated with the presence of fine precipitates or non-metallic inclusions distributed in the narrow ferrite zone as it was proposed recently [4,5]. Figure 4 demonstrates a detail of crack propagating in the ferrite film and its interaction with non-metallic inclusion. Such type of interaction was observed only in a few examples. Although, the frequency of crack formation in ferrite films is not high, the existence of these films represents a critical microstructure parameter degrading the quality of CC-products in such case.

Fig.3 Microcrack initiation in ferrite film

Fig.4 Microcrack in ferrite, interaction with non-metallic inclusion

4. DISCUSSION

The temperature dependence of low ductility trough, found in temperature range of 700°C to 1150°C, represents an enveloping curve of two different mechanisms participating in this ductility degradation. Low ductility values can be found at higher temperature in the single-phase austenite region if elements are present that can precipitate at the grain boundaries and in the matrix. The intergranular precipitation leads to the formation of a precipitate - free zone around the austenite grain boundaries. The formed denuded zone is softer than the precipitate-hardened matrix. Any plastic deformation then is concentrated in this precipitate - free zone. The heterogeneous plastic deformation realised in CC-products during their straightening operation is localised in the soft zone. The precipitates become void initiation sites which subsequently by their growth and the final coalescence lead to fracture.

A ductility trough also can occur at lower temperature when the microstructure consists of austenite plus ferrite. The ferrite grains form at the austenite grain boundaries. Ferrite is softer than austenite and also is characterised with a higher recovery rate. Hence, the very fine ferrite zone represents a critical stage from standpoint of fracture initiation [4]. The ferrite zone acts in the same way as the above mentioned precipitate - free zone in austenite.

These two examples do not include all possibilities of crack initiation in the mentioned critical ductility trough. In the last time, we have found that the crack formation in very narrow ferrite films is not induced by the interaction of localised plastic deformation with precipitates (Fig.3) [6]. As a critical volume fraction of these ferrite films can be held 10%. On the contrary, as it results from Fig.1, the reliable value, leading to the suppression of crack formation in the ferrite zone, is the ferrite volume fraction higher than 25-30%. Under this condition, the thicker ferrite bands are observed around the austenite grain boundaries.

At temperature higher than the critical interval corresponding to the ductility through, the high values of reduction in area are found because the precipitate are now in solution. Therefore, the mentioned problems, connected with precipitates, are not detected. On the contrary, at lower temperatures owing to a increased volume fraction of intergranular ferrite, lower strain is concentrated in ferrite zone. The detail characteristics of mechanisms realised in the region of ductility trough are presented in Fig.5 [5].

The hot ductility of steels depends on their chemistry. The addition of Nb, usually applied as a microalloying element in steel to improve mechanical properties, can initiate transverse cracking by precipitation at austenite grain boundaries as carbonitrides. The addition of Ti has proved to be beneficial in Nb - containing steels. The microalloying with Ti improves hot ductility under certain conditions and may reduce transverse cracking [7].

The low ductility and induced tensile strain may cause transverse cracking. Studies of the hot ductility of steels at low strain rate have been related to the problem of transverse cracking in CC-products [3,4]. On the assumption that transverse cracking is caused by unbending strains, unbending should be conducted at temperatures outside of the ductility trough to avoid cracking. However, the problem with using data from isothermal hot ductility tests is that the thermal history of the surface of CC-steel is unlike that depicted in an isothermal test. For this reason, it is necessary to take into consideration the relationship between the hot ductility and unbending temperature. The predicted thermal history of CC-products reveals a very interesing behaviour [5]. The applied model indicates a large temperature drop T_{min} occurs just below the mould, where the skin surface temperature can be low as 700°C. The temperature of CC-products immediately increases to maximum (T_{max}) and subsequently they cool slightly until the point of unbending. The important parameter is ΔT expressing temperature difference between T_{max} and T_{min}. As shown in [5], the low ductility was attained if T_{min} was low. This may be associated with the onset of the austenite - ferrite transformation. The level of ΔT influences the attained hot ductility as well as thermal history after T_{min} (e.g. the secondary cooling rate). However, the strongest influence has T_{min} [5].

Figures 2 and 3 show, beside the narrow ferrite films, the bainite microstructure of matrix. On the basis of this microstructure type, we can assume the low value of T_{min}. Simultaneously, the low value of ΔT and a higher secondary cooling rate may also partially contribute to the formation of the observed microstructure. On the contrary, the morphology of ferrite and matrix, which was found in Fig.1 (higher ferrite volume fraction), indicates that a lower secondary cooling rate and probably also a higher ΔT-value were applied technological parameters.

The localised stress and corresponding concentrated deformation in the very narrow ferrite film attain the critical values leading to crack initiation. The constraint effect of bainite on ferrite zone reduces the deformation capacity of ferrite [6]. Simultaneously, it is necessary to take into consideration the additional effect of unrelieved and / or only weakly relieved transformation stress which contributes to the embrittlement of ferrite zone. The given findings result in an increased probability to crack initiation in ferrite. The strengthening effects of bainite contributes to the shifting of the low temperature boundary of the hot ductility trough to the lower temperature and to the widening of critical trough. The presumed shape modification of the ductility through (its widening) is depicted in Fig.6. The thick ferrite bands (Fig.1) act positively because such microstructure arrangement does not make possible the realisation of a high localised deformation in ferrite as it was analysed in detail recently [6].

Fig.6 Schematic diagram of the hot ductility trough widening

5. CONCLUSION

The paper summarises the metallurgical and microstructural principles influencing the formation of transverse cracks during CC - process. On the contrary to usually accepted model, based on the effect of precipitates or second phase particles and localised deformation in the soft zones, we have found the microcracks in the narrow intergranular ferrite films formed under specific conditions. The microcracks may be initiated and propagated in the very narrow ferrite films having lower volume fraction than 10% without the additional effect of precipitates or second phase particles (e.g. non-metallic inclusions). At higher volume fraction of ferrite (more than 25-30%), the microcrack formation is suppressed.

Acknowledgement

The authors are grateful to Grant Agency ER for financial support (project 106/96/K032).

Literature

[1] Jonšta, Z., Bůžek, Z. and Mazanec, K.: Contribut. to the physical metallurgy analysis of longitudinal crack formation during continuous casting of steel (in czech), Hut. listy, vol. 52, 1997, No.12, pp 10-14

[2] Jonšta, Z., Hernas, A. and Mazanec, K.,: Contribut. to mechan. metallurgy behaviour of steel during continuous casting, J. Mater. Processing Technology, vol. 78, 1998, pp. 90-94

[3] Mintz, B. and Abushosha, R.,: Effectiveness of hot tensite test in simul. straightening in continuous casting, Mater. Sci. Technol., vol. 8, 1992, No. 2, pp. 171-177

[4] Mintz, B., Abushosha, R. and Cowly, A.,: Preliminary analysis of hot ductility curve in simple C-Mn steels, Mater. Sci. Technol., vol.17, 1998, No.3, pp.222-226

[5] El-wazri, A. M., Hassani, F.and Yue, S.,: Influence of phys. simulation on the ductility behaviour of a microalloyed steel in the continuous casting process, Iron and Steelmaker, vol. 25, 1998, No.1, pp. 37-41

[6] Pavliska, J., Jonšta, Z. and Mazanec, K.,: Contrib. to the transverse cracking in continuously cast steel, Zeszyty nauk. TU Opole, Mechanika, vol. 57, 1998, No. 246/98, pp. 189-192

[7] Abushosha, R., Vipond, R. and Mintz, R.,: Influence of Ti on hot ductility of as cast steels, Mater. Sci. Technol., vol. 7, 1991, pp. 613-621