NUMERICAL FAILURE ANALYSIS FOR THE REFRACTORY LINING OF A TUNDISH

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ABSTRACT

For a T-shaped tundish, the transition zone between the inlet port and the linear part of the side wall is a critical area. Here the permanent lining may show severe damage by cracking. A thermomechanical calculation by the finite element method was applied to investigate the failure mechanism, the reasons for the material damage, and possible counter measures. The calculation showed that a shear-type failure occurs due to the restricted thermal expansion. One important parameter is the preheating temperature. A rise of the preheating temperature tends to decrease the degree of failure. If further necessary, an additional decrease of failure probability may be achieved by introduction of an expansion allowance. For the case investigated here, a minimum expansion allowance of 1.8 millimeters showed to be necessary.

INTRODUCTION AND PROBLEM DESCRIPTION

The investigations described here have the goal to clarify the reasons for a special failure type of the permanent lining of a T-shaped tundish. Moreover they ought to show possible countermeasures.

Figure 1 shows a simplified ground plot of the T-shaped five strand tundish investigated here. Mechanical failure of the permanent lining occurs in the transition zone between the inlet port and the plain side wall of the bath. A photographic documentation of a typical failure case may be seen from figure 2. Cracks propagate through the whole thickness of the safety lining and are penetrated by hot metal up to the cold end. This crack formation increases the probability of failure during breaking out of the working lining.

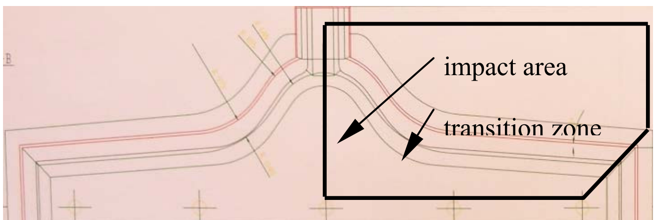

Fig.1: Structural drawing of the tundish with the simulated section (black framed)

Fig.2: Failure of the safety lining of a T-shaped tundish

THE FINITE ELEMENT MODEL AND THE BOUNDARY CONDITIONS

The finite element model includes the steel shell of the tundish, an insulating board with the brand name Pyrostop 1260, a safety lining with a hydraulically bonded bauxite castable of ULC type (brand name Ancocast SV90) and a slurry spray mix with low thermal conductivity for the working lining. To achieve realistic results calculations have to allow for nonlinear material behaviour with respect to its thermal and mechanical properties. Temperature dependence of the thermal properties has been considered. For material failure under tensile loading a strain softening behaviour according to Hordijk was applied. Under multi axial compression behaviour according a Mohr-Coulomb model has been assumed. Details about the methodology applied may by seen from [1].

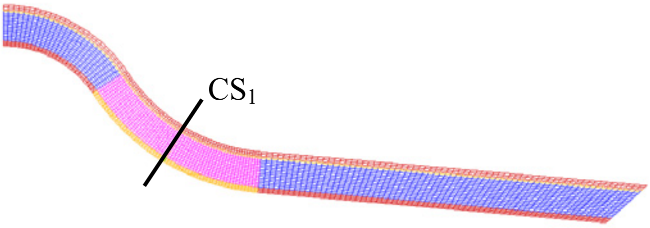

Fig.3: Two-dimensional model of a representative part of the tundish; the position of the cross-section CS1 refers to Fig. 5

To simulate the thermomechanical behaviour of the lining, a previous calculation of the transient temperature distribution is necessary. For this purpose, thermal boundary conditions have to be chosen. With respect to the hot face temperature these conditions are subdivided into three phases: Preheating, service period and idle period. At the cold end, heat exchange between the steel shell and the ambient air was simulated by radiative and convective heat transfer. To investigate the influence of the preheating, two different heating schedules were calculated. The temperature of the hot face for the two heating schedules is shown in figure 4. For the first schedule it takes 12 hours to reach a temperature of 500°C. The second schedule needs 27 hours to reach a temperature of 1100°C at the hot face. The heating rate is the same in both cases. The temperature of the liquid steel was assumed to be 1580°C and the service period was 15 hours. Calculations have been performed for an idle time of another 15 hours with an ambient temperature of 50°C.

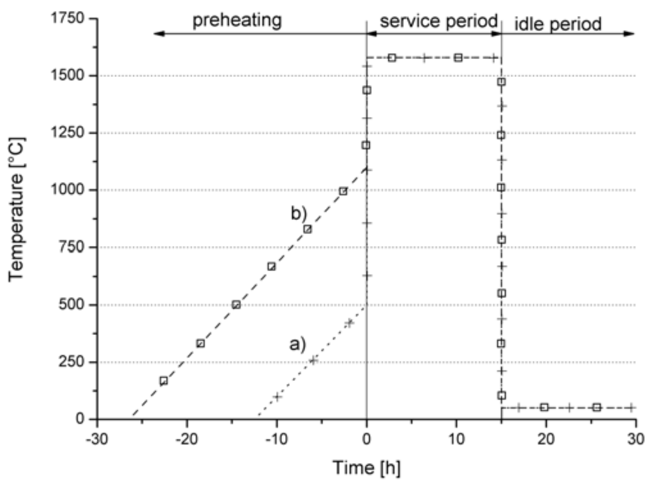

Fig.4: Operation schedule of the tundish for a) low preheating temperature and b) for high preheating temperature

RESULTS OF THE CALCULATIONS

Figure 5 shows the temperature distribution in the lining after preheating for the two heating up schedules. In case of preheating up to a temperature of 1100°C the thermal shock during the first contact of the lining with liquid steel is by far less severe, compared with the preheating up to 500°C.

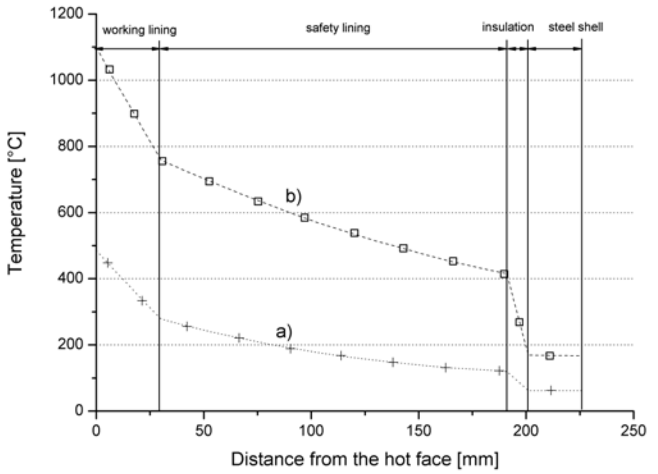

Fig.5: Temperature distribution in the cross-section CS1 (see Fig. 3) at the end of preheating a) for low preheating temperature and b) for high preheating temperature

The different temperature distribution after preheating results in a different behaviour even after the idle period. In case of preheating up to 500°C a strongly damaged area arises at the marked area in figure 6. This type of failure was also observed under service conditions. The crack patterns in other areas of the tundish are for both simulations nearly the same. Furthermore a delamination between steel shell and safety lining can be observed in the transition zone (see Fig. 1). For the lower preheating temperature this is accompanied by failure of the anchors. It is caused by the restricted thermal expansion.

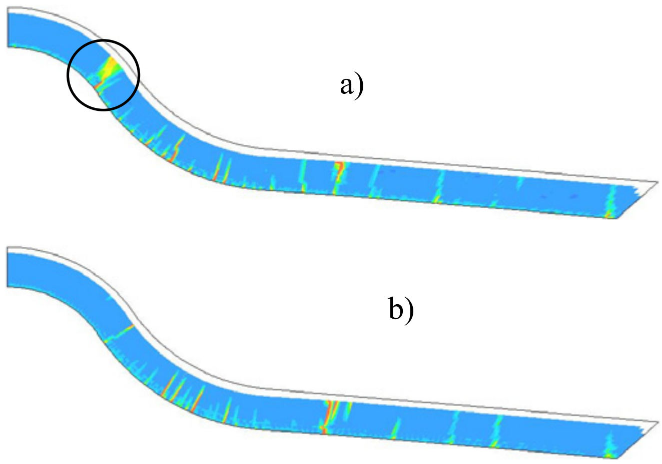

Fig.6: Crack formation after idle period a) for the low and b) for the high preheating temperature of Fig.4

To reduce cracking and to avoid the delamination quoted above, calculations with an additional expansion allowance were performed with a preheating up to 1100°C on the hot face. The results of these calculations are shown in figure 7.

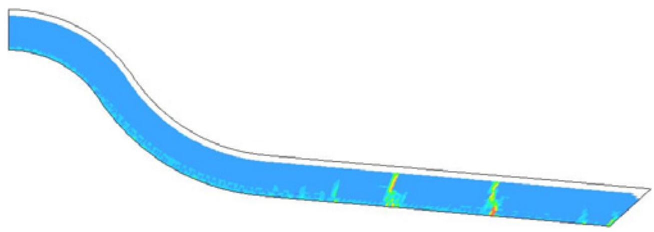

Fig.7: Crack formation after idle period for the improved lining with expansion allowance, for a preheating temperature of 1100°C at the hot face.

It is obvious that the additional expansion allowance reduces the crack formation appreciably even though the anchoring remains unmodified. The delamination which accompanies the severe damage in the lining without expansion allowance cannot be observed in large scale. In figure 8 a comparison of the delamination for the two cases is shown.

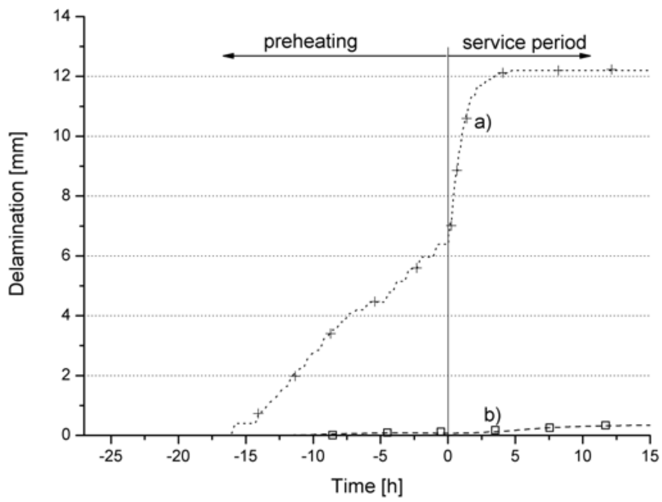

Fig.8: Delamination of the safety lining from the steel shell in the transition zone for a standard lining concept a) and a lining with additional expansion allowance b).

The required size of the expansion joint is of great importance. The closure of the expansion joint on the hot face is plotted in figure 9.

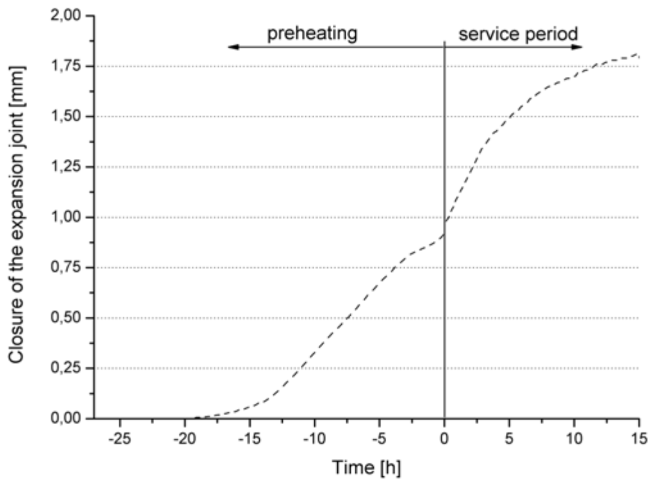

Fig.9: Closure of the expansion joint on the hot face during the preheating time and the service period

At the end of preheating the temperature at the hot face is 1100°C and as shown in figure 9 the closure of the expansion joint is about 0.9mm. When the liquid steel is poured into the tundish the temperature rises to 1580°C as can be seen from figure 4 and additional closure of the expansion joint is the consequence. At the end of the calculated service period of 15 hours the closure of the expansion joint is about 1.8mm, which is equal to the necessary minimum gap.

CONCLUSION

Using a geometrically simplified Finite Element model it is possible to analyse the thermomechanical behaviour of a T-shaped tundish. With low preheating temperatures a shear type damage of the safety lining was observed in the side wall of the tundish, especially in the transition zone after the inlet port. Material failure is accompanied by a delamination of the safety lining from the steel shell. The investigation shows that the degree of failure depends among others on the hot face preheating temperature of the tundish lining. A longer heat penetration period leads to a more homogeneous temperature distribution at the moment of the thermal shock and this circumstance decreases thermomechanical load in the transition zone. A further possibility to improve the thermomechanical behaviour of the lining is to implement an additional expansion allowance. With this selective measure cracking and delamination of the safety lining can be reduced.

REFERENCES

[1] Auer T, Gruber D, Harmuth H, Triessnig A. Numerical investigations of mechanical behaviour of refractories. proceedings of the Unified Int. Tech. Conference on Refractories (UNITECR), Orlando, USA, 2005.