Analysis of cracks and failure during solidification of a high strength low alloy steel

Abdelhalim Loucif, Davood Shahriari, Kanwal Chadha, Mohammad Jahazi, Rami Tremblay and Louis-Philippe Lapierre-Boire

Article published in procedding of 14TH International Conference on Fracture (ICF 14), P. 770-771. June 18-23, 2017, Rhodes, Greece

Analysis of cracks and failure during solidification of a high strength low alloy steel

Abdelhalim Loucif[1], Davood Shahriari[1], Kanwal Chadha[1], Mohammad Jahazi[1], Rami Tremblay[2] and Louis-Philippe Lapierre-Boire[2]

[1] École de technologie supérieure, Département de Génie Mécanique, 1100, rue Notre-Dame Ouest Montréal, QC, H3C 1K3, Canada
[2] Finkl Steel - Sorel, 100 McCarthy, Saint-Joseph-de-Sorel, QC, J3R 3M8, Canada

Abstract
The present study investigates the analysis of cracks and failure that appeared during solidification experiment in the segregated zones of the cast structure of a large size ingot made of high strength alloy steel. Solidification experiments were conducted, using Gleeble 3800 thermomechanical simulator, on samples taken from the hot top of 40 MT ingot. Optical and scanning electronic microscopies were used to analyze the cracked regions. Microstructural observations revealed that contraction during rapid solidification of melted grain boundaries led ultimately to the initiation and propagation of cracks.

1. Introduction

Ingot casting is the main manufacturing process for the production of high strength materials including high strength steels used in energy and transportation industries. Cracking in the cast ingot could result in the complete fracture of the ingot during subsequent open die forging and quench and temper operations [1]. This could lead to failure of the final product and inevitably leads to higher costs (scrapes, inspection and repair). Thereby, it is necessary to minimize the presence of cracks at the initial stage itself. In general, the poor mechanical properties of the mushy zone, and the formation of tensile or shear mechanical stress during solidification has been reported as the main source of crack formation in cast structures [2, 3]. In the present work, solidification experiments were performed to study the effects of chemical heterogeneities and cooling rates on the microsegregation and microstructural properties of a as cast high strength low alloy steel ingot. The mechanisms governing crack occurrence during heating to temperatures close to the solidus are discussed.

2. Results

Solidification samples (Figure 1) with the dimensions of 10 mm (diameter) × 120 mm (length) were prepared from a segregated region in the hot top of a 40 MT large size ingot of medium carbon low alloy steel [4]. Solidification experiments were carried out using Gleeble 3800 thermomechanical simulator. The phase fractions calculated using Thermo-Calc® software, showed that the solidus and liquidus temperatures correspond to 1409 and 1483 °C, respectively. The typical thermal cycle consisted in automatic heating from the ambient temperature to 1385 °C with a constant heating rate of 2 °C/s followed by a free cooling.

Theoretically, at 1385 °C the sample is still at the solid state; however, during solidification experiments, the sample broke completely approximately at its center. Therefore, the free cooling could be considered as a very fast cooling which could result in very high contraction which induces cracking and failure damages. Figure 2 shows the cracks of the failed sample to be intergranular in nature. However, observations using FEG-SEM showed the presence of melted and solidified grains boundaries on the surface of the sample and some partially melted and solidified small zones in the crack view. This means that the melting occurred and persisted for few seconds before reaching the solidification interval. The presence of the segregation, especially at grains boundaries could result in undercooling and combine with the high cooling rate, which induces high levels of contraction, could be at the origin of the crack formation. The presence of large size cracks and different modes of failure such as intergranular and interdendritic were also observed in the cracks view.

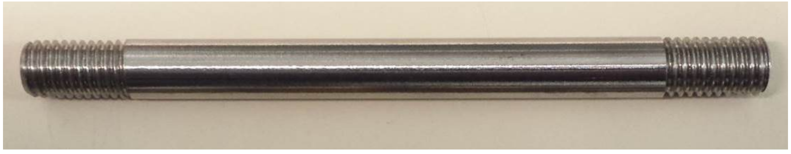

Figure 1. Solidification sample prepared from the hot top of 40 MT of high strength low alloy steel

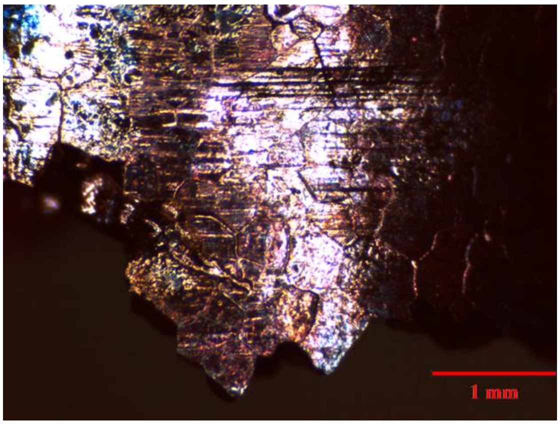

Figure 2. Crack propagation in the surface of the failed solidification sample

3. Conclusions

In this research, experimental characterizations were conducted in order to understand the mechanisms of crack and failure damages during solidification experiments of a as cast high strength low alloy steel. It is concluded that the presence of segregation and the occurrence of fast cooling were the main causes of the propagation of the cracks.

References

[1] M. Bitterlin, A. Loucif, N. Charbonnier, M. Jahazi, L-P. Lapierre-Boire, J-B. Morin. Cracking mechanisms in large size ingots of high nickel content low alloyed steel, *Eng. Fail. Anal*. 2016;68:122-131.

[2] B. Santillana, R. Boom, D. Eskin, H. Mizukami, M. Hanao, M. Kawamoto. High-temperature mechanical behavior and fracture analysis of a low-carbon steel related to cracking, *Metall. Mater. Trans. A*. 2012; 43A:5048-5057.

[3] M. B. Böttger, M. Apel, B. Santillana, D.G. Eskin. Relationship between solidification microstructure and hot cracking susceptibility for continuous casting of low-carbon and high-strength low-alloyed steels: a phase-field study, *Metall. Mater. Trans. A*. 2013;44:3765-3777.

[4] A. Loucif, D. Shahriari, C. Zhang, M. Jahazi, L.-P. Lapierre-Boire, R. Tremblay. Macrosegregation of alloying elements in hot top of large size high strength steel ingot, *Mater. Sci. Forum*. 2017;879:1176-1181.