Crack analysis in as cast large size ingot of a high strength steel

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Abstract
The mechanism of crack apparition of an as cast high strength low alloy steel ingot was investigated. Elemental, mechanical and crystallographic analyses proved that tensile stresses accumulated during casting and annealing are responsible of crack generation. The crack propagation is favored by the formation of chromium carbides at prior austenite grain boundaries.

1. Introduction

Cracking during solidification of slabs in continuous casters have been studied extensively in the literature [1]; however, little data is available on the root causes of crack appearance in ingot casting after solidification or homogenization treatment [2]. The data is even more scarce when it comes to large size ingots (i.e. 1.5 m diameter and 40 MT and above) [3]. In general, depending on the location, size and morphology of the crack different sources and mechanisms have been proposed such as hot tearing, contraction during solidification and formation of secondary phases (carbides, nitrides, phosphorus and sulfites). In the present study, the cracking after casting and annealing of a large size ingot made from high strength low alloy steel is investigated. The objective of this research was to characterize and analyze the cracks in order to understand root causes for their initiation and propagation mechanisms.

2. Results

A sample containing cracks was cut from the surface of the investigated ingot. Different techniques of characterization were employed to analyze crack patterns. The microstructure of the sample was analyzed using optical microscope after conventional polishing preparation. The sample was etched with 3pct Nital solution in order to reveal the microstructure. Investigations were done on FEG-SEM Hitachi SU-8230 at 15 kV, equipped with EDS capability, for detailed microstructure and chemical analysis of cracks, phases compositions and inclusions. X-ray diffraction experiments were conducted on X'Pert3 MRD PANalytical using Cu Kα radiation.

Microstructure observations indicate that main cracks follow prior austenite grains boundaries which are surrounded by a white phase (Figure 1). This phase has been identified as ferrite by XRD analysis and Vickers microhardess measurements. The analysis of the results indicated that tension stresses generated during solidification, reheating and cooling associated with phase transformation of austenite to proeutectoid ferrite led to the crack initiation [4]. SEM investigation indicated that crack propagation is enhanced by the presence of chromium carbides (Figure 2) revealed by SEM-EDS analysis at prior austenite grain boundaries. Also, chromium and manganese oxides were detected on main cracks. Such presence was related to their respective high diffusion coefficient in austenite and ferrite [2].

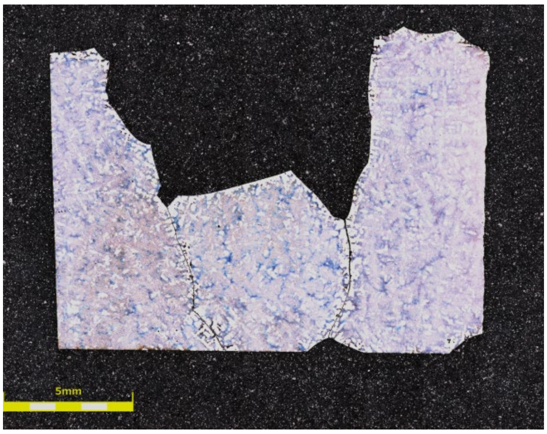

Figure 1. Microstructure of a sample with main intergranular crack surrounded by ferrite grains

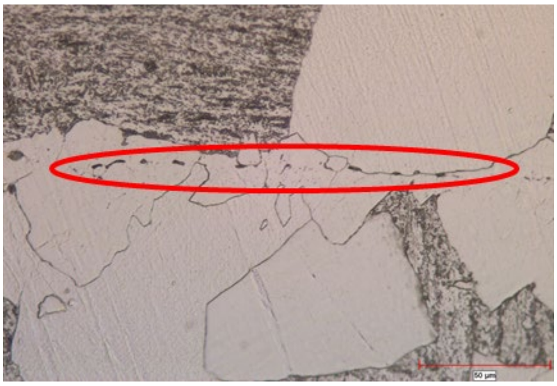

Figure 2. Presence of chromium carbides (encircled in red) at prior austenite grain boundaries surrounded by ferrite

3. Conclusions

The mechanism of cracking in high strength as cast low alloy steel has been identified, as the result of the generated tension stresses during solidification and the volume change due to phase transformations during annealing. It has been shown that the presence of chromium carbides can enhance the propagation of cracks through the ingot. The cracking phenomena observed implies the fact that low alloy high strength steels are sensitive to heating and cooling rates during solidification and annealing processes; and therefore these rates should be controlled.

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