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The Cracking Mechanism of Ferritic-Austenitic Cast Steel

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Abstract

In the high-alloy, ferritic - austenitic (duplex) stainless steels high tendency to cracking, mainly hot-is induced by micro segregation processes and change of crystallization mechanism in its final stage. The article is a continuation of the problems presented in earlier papers [1 - 4]. In the range of high temperature cracking appear one mechanism a decohesion - intergranular however, depending on the chemical composition of the steel, various structural factors decide of the occurrence of hot cracking. The low-carbon and low-alloy cast steel casting hot cracking cause are type II sulphide, in high carbon tool cast steel secondary cementite mesh and / or ledeburite segregated at the grain solidified grains boundaries, in the case of Hadfield steel phosphorus - carbide eutectic, which carrier is iron-manganese and low solubility of phosphorus in high manganese matrix. In duplex cast steel the additional factor increasing the risk of cracking it is very "rich" chemical composition and related with it processes of precipitation of many secondary phases.

Keywords: Duplex cast steel, Hot cracking, Solidification, Sigma phase

1. Introduction

The current environmental regulations on CO_2 emissions as well as the geopolitical situation have increased interest in the so-called. alternative energy resources. As indicated by geological data [5]. Poland has a large energy potential in the field of geothermal sources, and is a potential place of industrial boreholes. Start of commercial mining requires handling of a large number of deep drillings, reaching 3000 m. Due to the nature of the deposits (some are sulfated) materials dedicated to these conditions are corrosion resistant steels and especially ferritic - austenitic steels and cast steels. Duplex steels contain about 21 ÷ 28% Cr, 3.5 ÷ 8% Ni, max. 0.08% C and up to 4.5% Mo. The main areas of application of ferritic-austenitic steels and cast steels, also called duplex are constructions and components subjected to high loads and environments conducive to the formation of stress corrosion, pitting or crevice. In these conditions, these materials with comparable share basic ferrite and austenite phases, have better mechanical properties in comparison to conventionally used ferritic or austenitic steels [6-12].

A problem that must face the constructor and then caster is a multitude of grades of stainless cast steel linked to their area of application. Due to globalization of market and production the most commonly used next to national standards (PN - EN 10283: 2002) are ASTM A-744 or AISI A995 / 995M-09, although there are also many company grades.

2. Research material and methodology

The subject of research was the AISI grade A3 cast steel with the addition of about 2.5% copper, the chemical composition is presented in Table 1. The presented results include macroscopic and micro fractography analysis of fracture, and microstructural analysis made on the opposite part of sample. Microstructure analysis was made with use of a Nikon 200 Ma optical microscope, and the macroscopic evaluation with use of Olympus SZ 61 macroscope for the micro fractography study was used JEOL JSM-6610LV scanning electron microscope. The analysis of solidification mechanism analyzed alloy was made using FactSage®.

Table 1.
Chemical composition of the examined cast steel

No.	C	Cr	Ni	Cu	Mo	Mn	Si	S	P	N
Cast	0,0613	23.38	8.58	2.41	2.94	0.063	1.07	0.0331	0.0262	0.064

3.Research results and their discussion

The phenomena occurring during solidification and cooling of ferritic-austenitic cast steel determined on the basis of numerical analysis for the state of equilibrium is shown in Figure 1.

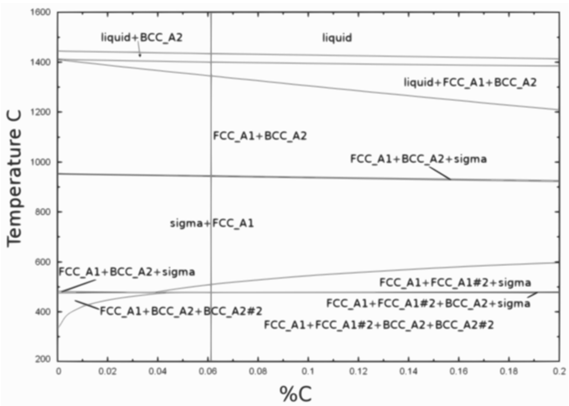

Fig. 1. The results of numerical analysis for the equilibrium state made in the FactSage®

Crystallization of the alloy, which chemical composition is indicated by the vertical line begins at about 1436 °C and is associated with the precipitation of ferrite to the temperature of about 1400 °C. Below this temperature begins peritectic reaction, which in multi-component systems do not run at a constant temperature, and that why the area of the coexistence of three phases: a liquid, ferrite, austenite extends to about 1345 °C. Here begins the partial transformation of ferrite into austenite, decisive of the unique, distinctive duplex cast steels from other stainless steels, functional properties. At about 936 °C begins to precipitate the intermetallic σ phase, which ends for the analyzed chemical composition of about 510 °C. This range of temperature generally correspond to literature value [13,14], a little too low is the temperature 510°C. According to the data obtained in the FactSage for the equilibrium conditions there are no other intermetallic phases.

Figures 2 and 3 presents fractures of massive casting of F-A cast steel cracked during the production, which the chemical composition is show in Table 1. Noteworthy are very large columnar solidification grain of dendritic structure disclosed with the Oberhoffer's reagent (Figure 2). The same structure is observed for equiaxial grains what was show in Figure 3.

As appears from Figure 1, even in the equilibrium conditions in the final stage of solidification occurs change in solidification mechanism from ferritic to mixed with the peritectic reaction. In the case of non-equilibrium solidification the temperature area of peritectic reaction is expanded. In casting practice, is widely known the high susceptibility to cracking casting solidified in the peritectic range.

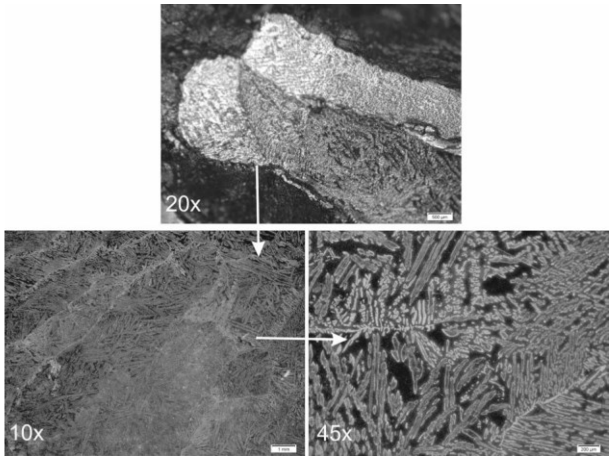

Fig. 2. Macrophotography of columnar grains area above and the microstructure etched with Oberhoffer's reagent below

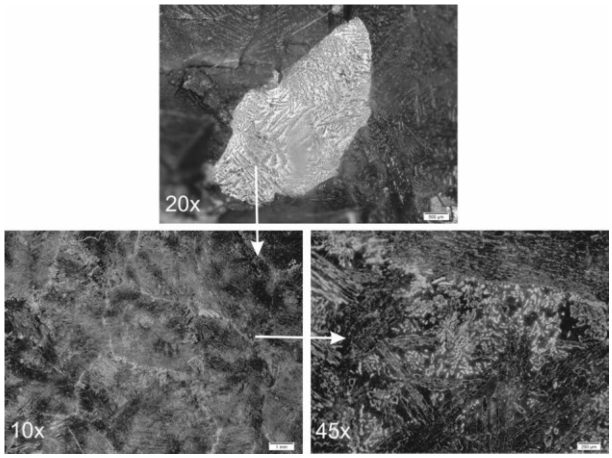

Fig. 3. Macrophotography of equiaxial grains area above and the microstructure etched with Oberhoffer's reagent below

If the value and stress state in the solidifying and cooling down cast exceeds the strength of the cast steel, which at temperatures below the solidus temperature is very low, appear the initiation and propagation of cracks. Limitation of harmful dopants in the steel or earlier concatenating in the stable compounds substantially reduces the tendency to hot cracking.

The tendency of the cast steel to create hot cracking tends to be reduced if the interdendritic liquid has high values of surface tension and contact angle, and during the primary crystallization is followed by extensive fragmentation of the structure as a result of modification of the alloy. The tendency of cracking initiation and propagation is increased by micro-pores associated with the residual liquid phase. Also the presence of σ phase not only increase possibility to generate hot crack but also if such crack appear can lead to its propagation. Intercrystalline crack may be both formed at high temperatures in the final phase of the solidification as well as during cooling time through the generation of secondary phases, often generating significant internal stress. Results obtained in the micro fractography analysis of cracks are shown in Figures 4 and 5.

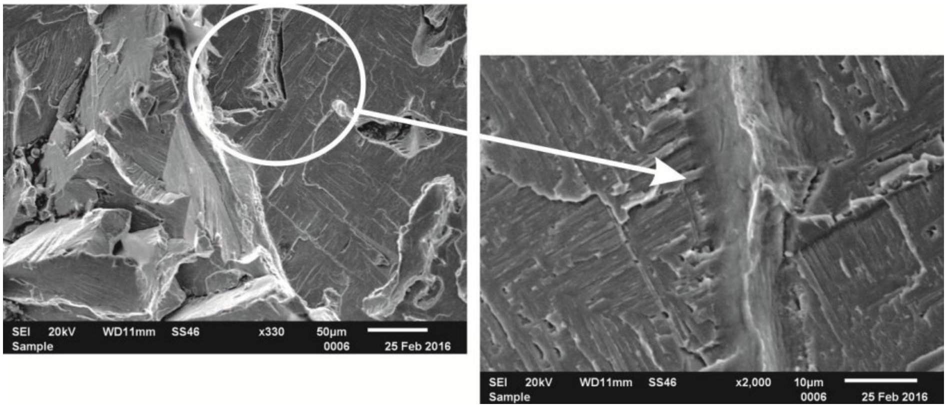

Fig. 4. Area of columnar grains. The transcrystalline brittle cracking with numerous faults on the borders sub grains

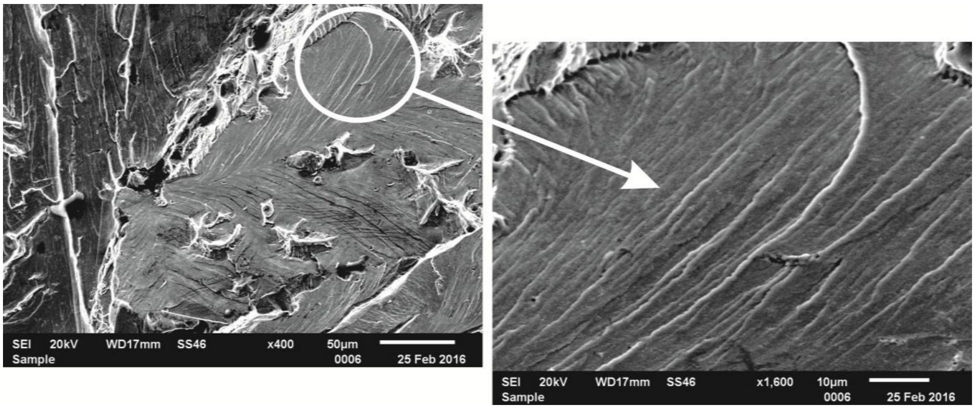

Fig. 5. Area of equiaxed grains. The transcrystalline brittle cracking with many "rivers lines "

The results of microstructural analysis is shown in Figures 6 and 7. Dendritic austenite precipitation within a wide angular grains particularly visible in Figure 7 confirm the occurrence of peritectic reaction in the final stage of solidification. It was found high concordance of fracture morphology, Figures 2 and 3 and the structure observed on the metallographic microsections, Figures 6 and 7.

The microstructure analysis showed, next to the primary phase of ferrite and austenite, presence of the sigma phase, which negative interaction is generally known [13,14]. In the tested material were found two types of sigma phase precipitates in the form of single precipitates or a single colony in ferrite and in the form of a thin, more or less continuous film on the border of ferrite - austenite. Such an arrangement is particularly unfavorable and was observed at brittle fractures presented in Figures 4 and 5. The arrangement as more or less continuous film is a major problem because if in high temperature appear any crack through such precipitation will propagate the crack. Moreover this very tough phase generating high tensile can provide to delaminating such structure as is present in duplex cast steels.

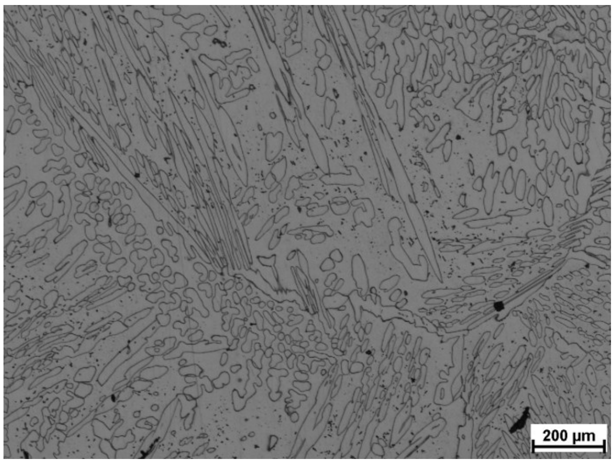

Fig. 6. Microstructure of equiaxal grains area, mag. 50x

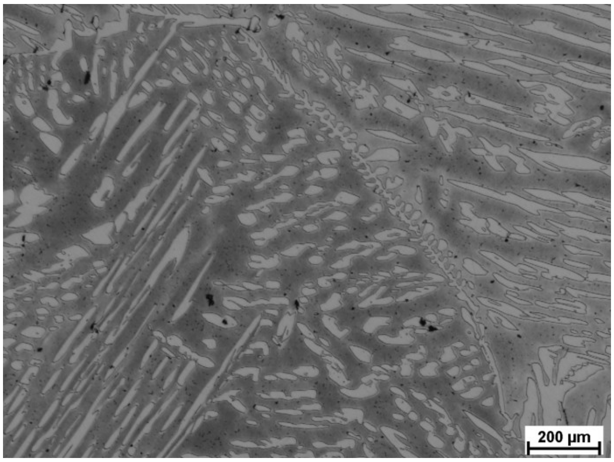

Fig. 7. Microstructure of columnar grains area, mag. 50x

4. Conclusions

The presence of intergranular fracture indicates that the crack initiation was at high temperature and can be initiated by the braked shrinkage associated with the geometry of the casting. The occurrence of brittle transcrystalline cracking presented in Figures 4 and 5 shows that a further crack propagation is caused by brittle precipitates of secondary phases, particularly sigma phase capable of generating stress up to 2.0 GPa. For the analyzed material a form of more or less continuous film on the border of ferrite - austenite is one the worst because as it was mentioned can provide to the delamination of ferritic-austenitic structure. For large slowly cooling casts change in the morphology of the sigma phase precipitation is almost impossible. The solution seems to be the acceleration of cooling in the range of this phase secretion by opening the mold. But this solution is often impossible to be input because of the apprehension of engineers.

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