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The assessment of hot cracking susceptibility of ferritic-austenitic cast iron

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Abstract

An inspiration to the research work has arisen from the problems related to cracking of massive castings made of ferritic-austenitic cast steel. The shape and the character of crack trajectories indicate that they are hot cracks. Investigations have included two cast steel grades, namely GX2CrNiMoN25-6-3 and GX2CrNiMoCuN25-6-3-3, because some customers had demanded for copper addition which makes possible the ageing treatment; also the alloys with increased carbon content have been investigated and this resulted from difficulties in obtaining sufficiently low carbon content (C_{max} 0,03%) in many Polish foundries which are not equipped with argon-oxygen devices for cast steel decarburizing. The method of critical size of a specimen similar in shape to the Hall test specimen has been applied to examine the cast steel susceptibility to hot cracking. The examination results undoubtedly indicate the negative influence of the increased carbon content, especially in the presence of copper. The intercrystalline character of cracks which propagate along the dendritic austenite precipitates suggests that the peritectic reaction occurs in the final stage of solidification, being induced by segregation of the strong austenite-forming alloying elements. The increased hot cracking susceptibility of the ferrite-austenite cast steel containing copper, particularly with simultaneously increased carbon content, indicates that the implementation of production technologies concerning this material should be started with production of castings made of alloy grades without copper addition.

Keywords : Innovative Foundry Materials and Technologies, Duplex Cast Steel, Hot Cracking, Solidification, Segregation

1. Introduction

One of the reasons of small and occasional only production of ferritic-austenitic (called also duplex) cast steel castings are the problems related to their hot cracking [1÷3]. Unlike the cold cracks generated at such cooling temperature at which the material of a casting already exhibits distinct elastic properties, the hot cracks arise in the solid-liquid state, especially when the temperature of a solidifying casting is close to the equilibrium solidus temperature. There exist a temperature range close to solidus temperature for which the solidifying metal exhibits very low deformation ability and little strength. Therefore already small stresses occurring in the course of solidification due to the restricted shrinkage and diversified temperature gradients can be a sufficient reason for hot cracking of the casting. A characteristic feature of hot cracks is their intercrystalline trajectory within the range:

$$\Delta T = TZW\text{-}TZC \tag{1}$$

where TZC is a temperature of the linear shrinkage beginning (the so-called temperature of zero strength) and TZC denotes the lowest temperature at which brittle intercrystalline fracture can occur (the so-called temperature of zero ductility), lower than the equilibrium solidus temperature.

According to the authors of References [4÷6] hot cracks occur as a result of interrupting the continuity of thin films occurring between dendrites in the final stage of solidification, and their intensity and propagation is promoted by a wide range of solidifying temperature.

The elements, mainly S, P, and C, which enrich the remnants of the liquid phase due to segregation proceeding in the course of solidification lower the melting point thus widening the solidification temperature range, what promotes hot cracking.

Table 1.
Chemical composition of the examined cast steel grades

No.	C	Cr	Ni	Cu	Mo	Mn	Si	S	P	N
1	0,021	26,70	6,48	0,02	3,10	1,46	0,93	0,012	0,008	0,24
2	0,088	25,58	7,29	0,04	2,94	0,96	1,22	0,009	0,014	0,25
3	0,024	25,19	6,48	2,87	2,98	0,85	1,07	0,009	0,007	0,27
4	0,08	24,52	6,42	2,62	2,98	0,67	0,96	0,009	0,008	0,26

Authors of Ref. [7] have found that it is the phosphor and carbon segregation to the ferrite boundaries which is decisive for occurring of hot cracks within the heat affected zone of welded duplex cast steel. The alloying elements present in duplex cast steel cause the widening and the shifting of the temperature range in which hot cracking can occur down towards the temperature in which the intermetallic phases, mainly the σ phase, precipitate.

A selection of examination method is an important problem for hot cracking examination, as over the years many types of them have been developed. According to J. Telejko and A. Chojecki [8] the tests of hot cracking susceptibility for alloys and castings can be divided into two groups: conventional technological tests where contraction is restricted by the mould, and special tests where the shrinkage restraint is realised by the external means. The advantage of special tests consists in the possibility of controlling and continuous measuring of the force restraining the contraction of the solidifying specimen with simultaneous temperature recording.

2. The material and the method of examination

The work undertakes a trial of evaluation of the hot cracking susceptibility of two selected grades of ferritic-austenitic cast steels: GX2CrNiMoN25-6-3 and the one with copper addition, i.e. GX2CrNiMoCuN25-6-3-3. Examinations have been performed also for cast steel with carbon content increased to a value of about 0,08%, taking into account the technological difficulties which Polish foundries meet in obtaining sufficiently low carbon content (C_{max} = 0,03%) according to the demands of the Standard PN-EN 10283:2002. The cast steels has been melted under laboratory conditions in the J31/III type induction middle-frequency crucible furnace of 10 kg crucible capacity made by Leybold-Heraus. Laboratory scrap – cast steel obtained from the high purity charge materials – has been used for the examination. Chemical compositions of cast steels have been determined by means of optical emission spectroscopy, and the sulphur and carbon content has been evaluated by LECO analyser. The results of analyses are gathered in Table 1. The microscope analysis of cast steel structure has been held by means of the Zeiss Axiovert 25 light microscope. Microsections intended for microstructure examinations have been etched with Mi21Fe etchant of the following composition: 30 g of potassium ferricyanide, 30 g of potassium hydroxide, and 60 g of distilled water.

The method of critical specimen size [8] has been applied for examining the hot cracking susceptibility of cast steel, the specimen being similar in shape to the Hall test specimen, however as far as conventional Hall method is regarded, the specimen is of cylinder shape with expanded head ends and is cast in core sand, while for the present examinations the specimen has been cast in a two-part gravity die with moulding sand inserts of specified lengths and has a rectangular cross-section with expanded heads at the ends (Fig. 1).

Solidification of cast steel in the test die proceeding under the conditions of restricted contraction due to the die arrangement has led to the occurring of stresses in the regions of slow cooling i.e. those reproduced by moulding sand inserts.

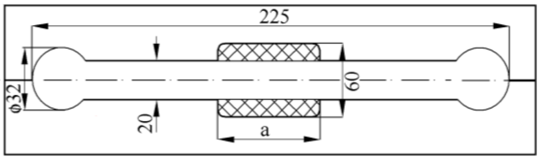


Fig. 1. A scheme of the die for testing the hot cracking susceptibility

The characteristic features of the test dies are the inserts of various length, here denoted as ‘a’ (40 mm; 45 mm; 50 mm, 80 mm), prepared of CO_2-hardened moulding sand. The surfaces of both the die and the inserts have been protected from metal adherence with ZrO_2-based coating. The moulds have been screwed together prior to pouring and placed on a base made of moulding sand. The PtRh-Pt thermocouples and the Flir P65 thermovision camera have been applied for temperature measuring. Figure 2 presents the poured dies equipped with moulding sand inserts of 40 mm and 80 mm lengths.

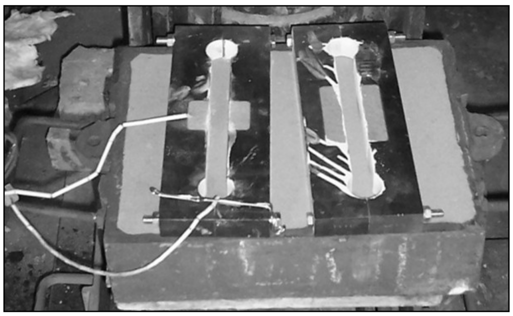


Fig. 2. Metal moulds for testing of hot cracking susceptibility directly after pouring

The performed test can be classified as a qualitative one, and the hot cracking susceptibility is determined by occurring of a crack within that specimen region which is reproduced by the moulding sand insert of specified length (test part). The material for which the cracking occurs only in the specimen of possible shortest test part is considered the best one among the compared cast steel grades. Occurring of cracks in longer and longer test parts indicate the increasing hot cracking susceptibility of cast steel.

Examination results are gathered in Table 2. Taking the quoted data into account it is worth noticing that the applied method is quite helpful and reliable in evaluating the hot cracking susceptibility of cast steel. If the 'measure' of the considered tendency e.g. for the cast steel denoted as No. 3 (see Table 2) has been the occurring of cracks at the 50 mm length of test part, then they have also occurred for shorter test parts i.e. those reproduced in moulding sand inserts of 40 mm and 45 mm length.

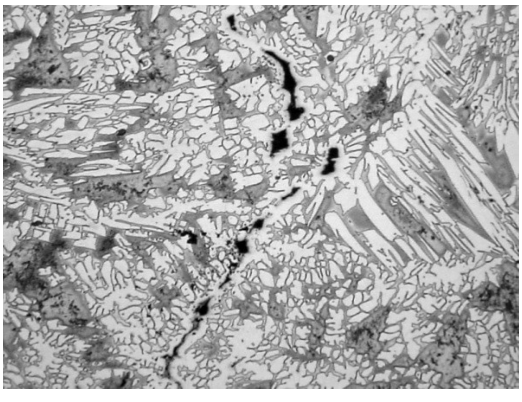
Table 2.
Test results for the assessment of the hot cracking susceptibility of cast steel

No.	Cast steel	Pouring temperature [°C]	Insert length [mm]			
			40	45	50	80
1	0,02%C, without Cu	1520	+			
2	0,08%C, without Cu	1524	+	+		
3	0,02%C, with Cu	1518	+	+	+	
4	0,08%C, with Cu	1522	+	+	+	+

Crack occurring +

Figures 3 and 4 illustrate the character of the crack trajectories in the examined specimens. The hot cracks are very long, continuous, and they pass between large primary solidification grains. It should be stressed that the figures present the secondary cracks, not the main ones, which are much wider and strongly oxidized. This does not create a basis for conclusions with regard to their morphology depending on the examined cast steel grade. The figures present photos of the specimens cast in the dies with 40 mm inserts; this makes possible some comparison between the microstructures. Metallographic examinations have revealed exclusively the presence of ferrite and austenite, with austenite grains of various morphology, i.e. dendrites, lamellae, and tiny Widmannstätten-type precipitates within γ' phase, particularly numerous in cast steel grades containing Cu.

a)



b)

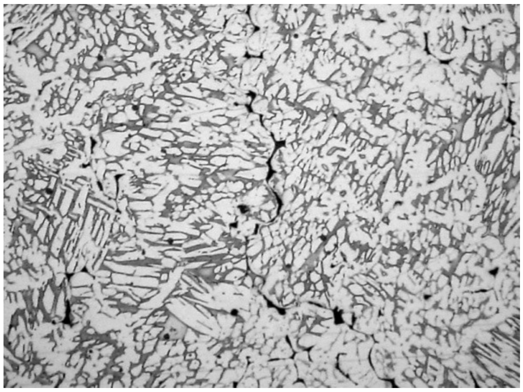


Fig. 3. The crack trajectories in specimens a) cast steel containing C=0,02%; with Cu b) cast steel containing C=0,02%; without Cu, magnification 100x

The σ phase has not been found in the cracked regions due to the high cooling rate, equal to about 100°C/min within the temperature range of σ phase precipitating i.e. 600÷900°C.

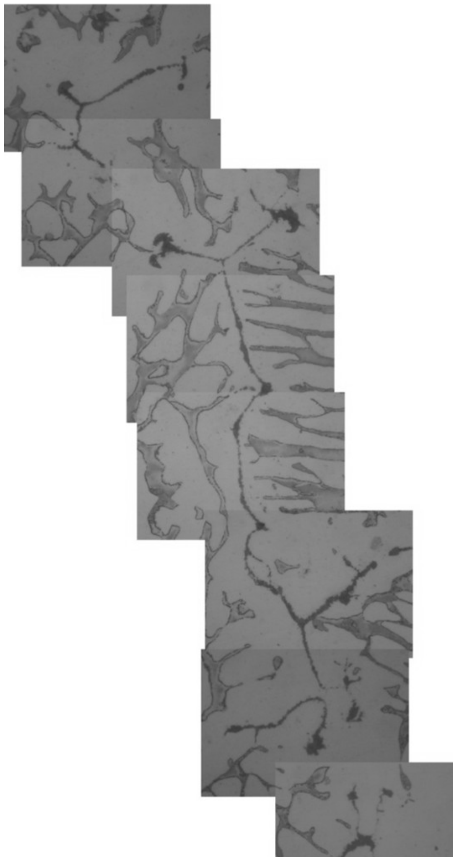


Fig. 4. A hot crack in the cast steel No. 4 containing 0,08% C and 2,62% Cu, magnification 100x

3. Conclusion

The tests of hot cracking susceptibility of duplex cast steel carried on during the examinations prove the strongly negative influence of an increased carbon content, particularly if copper is also present. Cracks have occurred in all specimens in the case of cast steel containing about 0,08% of carbon and about 2,6% of copper. On contrary, only the shortest specimen has revealed cracks during the Hall test performed for the alloy with low carbon content. This indicate the relatively low hot cracking susceptibility of such an alloy.

It seems that the possibility of peritectic reaction proceeding in the course of the final stage of non-equilibrium – under the actual conditions – solidification should be reckoned with the factors promoting hot cracking of the duplex cast steel castings. The negative influence of the peritectic reaction occurring in the course of solidification of carbon steels is well-known, as the reaction occurrence is accompanied by the increased number of defects. The presence of as many as five elements (Ni, Cu, N, Mn, and C) which can enter the peritectic reaction with iron during the alloy solidification can be a reason of the increased hot cracking susceptibility [9÷14]. It seems that the synergetic effect of their combined interaction can be expected for this reaction.

The characteristic feature of duplex cast steel grades described in the PN-EN 10283:2002 Standard is very low carbon content (C_{max}=0,03%), and only for the cast steel without Mo and Cu additions (1,4347) the allowable carbon content reaches 0,08%. This fact should be peculiarly stressed, because it results from the conditions of thermodynamic equilibrium of molten high-chromium steel that as the carbon content in the melt decreases, the equilibrium chromium content also decreases, and the excess of the element over its equilibrium content is strongly oxidized. The problem solution consists in decreasing the partial pressure of CO in the work space of a furnace or applying the expensive low-carbon ferrochromium which would reduce to the great degree the period of burning out the carbon. But in the practice of many cast steel foundries obtaining of carbon content at the level of 0,03% is very difficult both due to the lack of equipment for argon-oxygen decarburizing of steel or for other ladle treatment and due to using scrap, also of corrosion resistant steels, as a charge material. Therefore the so far produced massive duplex cast steel castings have contained carbon in the quantity of 0,05÷0,12%.

The increased hot cracking susceptibility of duplex cast steel containing copper, particularly in the presence of the increased carbon content, indicate that special attention should be paid to the implementing the production technology of castings made of this type of cast steel.

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