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Research into the Causes of the Cracking of Large Workpieces Low Carbon Steel by Pressure Treatment

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Abstract. Research using electronic microscope was carried out to study the structural and phase and deflected mode of material of hot-forged billets. It was revealed that the scalar density of dislocations in ferritic grains and in ferritic perlite layers of forging steel which cracked after manufacturing operations is one and a half time higher than in conditions material. Metal in this condition has higher content of sulfide of plate-type morphology. It has established that the reason of unwanted structural and phase condition is high carbon content, which lead to overheat of metal both in plastic working and final heat treatment.

Introduction

The most important physical factors determining the structural strength of steel products are: the type of defect substructure, morphology of the major components of the phase, morphology and crystal-chemical nature of the precipitates of secondary phases, the value of long-range internal stresses. They largely determine the susceptibility to cracking of blanks and finished products during hot forging [1].

Comparative electron-microscopic study of the fine structure of steel St52.3N (an analog of the Russian steel 17Г1С) of the conditional (state I) and cracked after the manufacturing operations (state II), forging a transmission microscope UMV-125K in the bright and dark field. Determined by the type of dislocation substructure in ferrite grains and ferrite interlayer of pearlite, the structure of pearlite colonies, shape, size, location and composition of particles of secondary phases, the level of long-range internal stresses.

Preliminary analysis of the mechanical properties [2] showed that if the strength characteristics of both states are located on the same level, the state II is characterized by low plasticity. On fractures formed during the impact test, in this state, there are significant areas of brittle fracture. Standard metallographic studies revealed [2] that in both states steel is ferrite-pearlite aggregate. Perlite is presented as a plate and globular modifications. In both states the size as the ferrite grains, pearlite colonies and did not significantly differ. In the ferrite grains are observed separation of the secondary phases, and the pearlite colonies and at the interfaces - the pore size of 10 microns. Condition II has high porosity by 5-7% higher content of perlite and coarser structure of the latter.

The results of electron microscopic studies were St52.3N

Typical of the state II electron microscope images of ferrite, pearlite, and pearlite lamellar globular morphologies shown in Fig. 1, a, b, c, respectively.

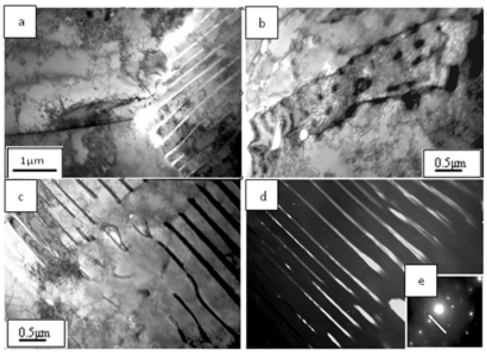

Fig. 1. Electron microscopic images of the structure began to St52. 3N able II. a-c) brightfield image, d) dark-field image obtained in the reflex [130] Fe_3C; e) mikroelektronogramma to (c), indicated by the arrow analyzed reflex

In most cases, pearlite colonies are located in the joints of the ferrite grain boundaries, or stretched along these boundaries, separating adjacent ferrite grains, such as globular pearlite colony in Fig. a, b. Lamellar morphology of pearlite is predominant. An important feature is the high level of defectiveness of cementite plates, which are strongly curved, containing ferritic jumpers, and their cross-sectional dimensions vary along the length of the plate (Fig. 1c).

Type of dislocation substructure was determined separately in the grains of ferrite and pearlite in the ferrite plates. It was found that the ferrite plates of pearlite exhibit higher levels of defects. If you are registered in the ferrite grains and coiled mesh substructure and scalar density of dislocations is ~$2.6 \cdot 10^{10}$ cm^{-2} (Fig. 1 a), the ferrite plates of pearlite is observed only netted dislocation substructure with the scalar density of $3 \cdot 10^{10}$ cm^{-2} (Fig. 1c).

The particles of secondary phases are fixed in the body of grains of ferrite and pearlite ferrite plates, on the boundaries and triple junctions. If the particles are located in the volume of the grains, they are always rounded, globular shape (Fig. 2a, b). The average size of these particles constitute ~13 nm.

Microdiffraction electron-microscopic analysis shows that these particles are sulphides of iron compounds FeS and FeS_2. The particles along the grain boundaries are divided into three morphological types: a particle with a crystal facet (Fig. 2c), thin layer (Fig. 2d) and globules (Fig. 2e). At the junction of the grain boundary ferrite particles of the second phase, almost all have a globular shape. Microdiffraction analysis shows that the morphology of the globular particles, regardless of their location, are iron carbide cementite type. Do the particles in the form of thin layers of more complex chemical composition. They can be as sulphides of iron, chromium and sulfides such as MeS. Finally, the particles are always faceted forms of iron sulfide FeS.

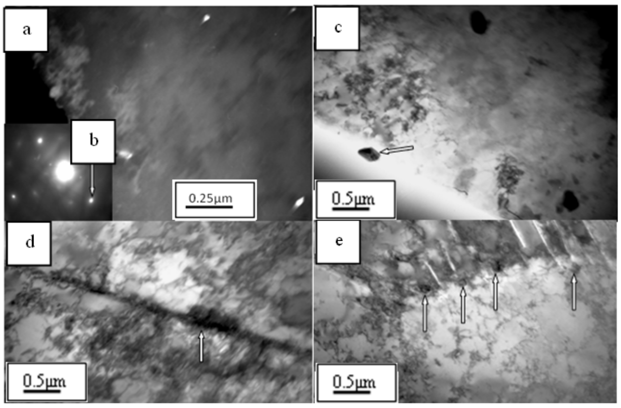

Fig. 2. The particles of secondary phases in the steel (state II). a - dark-field image obtained in the reflex [200] FeS_2, b - mikroelektronogramma to a, c, d, e - Brightfield image

An important feature of the electron-microscopic images of the structural components of the material in a state of II is the presence of bending extinction contours that reflect the curvature-torsion of the crystal lattice. The sources of the curvature-torsion are interphase boundaries (Fig. 1a) or chains of particles of secondary phases (Fig. 2d, e). In [3] describes a method for determining the value of long-range internal stresses in the geometric parameters of bending extinction contours. This long-range internal stresses can reach 300 ... 350 MPa, which is comparable and even exceeds the yield strength of steel [4]. The authors of [5] indicate that the long-range voltage, determined by electron-microscopic method, reflect the state of the material in the microvolumes, therefore, as a rule, they are far above average. It is these processes control the voltage of plastic flow and fracture at the micro level.

Steel in the state II has a relatively high content of perlite. Judging by the frequency of meetings of pearlite colonies in the foils of carbon concentration in the material must be higher than 0.3 wt. %. This fact was noted and the results of optical microscopy [1].

Electron-microscopic studies were St52.3N in the state I have shown that its structure with an overall qualitative similarity is markedly different from the structure of the metal in the state II. This material is also a ferrite-pearlite aggregate (Fig. 3), but the amount of pearlite is smaller and corresponds to the vintage carbon content of 0.2 wt. %. In addition, the predominant granular (Fig. 3c), and the plate is not pearlite (Fig. 3b).

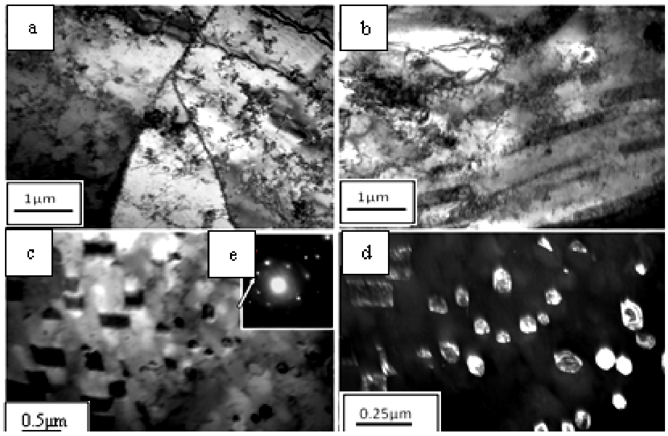

Fig.3. Electron microscopic images of the structure began to St52.3N able to I; a-c) brightfield image, d) dark-field image obtained in the reflex [031] Fe_3C; e - mikroelektronogramma to (c), the arrow indicated the analyzed reflex

In most cases, pearlite colonies are located in the joints of the ferrite grain boundaries, or stretched along the ferrite grain boundaries, separating them. The dislocation substructure in the ferrite grain volume mesh or coiled (Fig. 3a), but the scalar dislocation density is slightly lower than in state II, and is ~ $2.3 \cdot 10^{10}$ cm^{-2}. In the ferrite plates of pearlite is observed dislocation substructure of chaos, or a mesh dislocation substructure (Fig. 3b). They scalar dislocation density below – $1.8 \cdot 10^{10}$ cm^{-2}, while in the steel forging ratio of cracked dislocation density in the ferrite and pearlite was the opposite.

The size and grain boundary ferrite particles observed in the second phase. The particles located in grain volume, as shown by microdiffraction electron microscopic analysis, are in most cases of iron sulfides. The particles along the grain boundaries, have two morphological varieties - globules and thin layer. At the junction of the ferrite grain boundaries are almost always second-phase particles have a globular shape. Globular morphology of the particle, regardless of their location, as well as state II, are cementite. A more complex chemical composition of the particles are in the form of thin layers. These layers often formed of iron carbide Fe_3C, at least - the composition of silicon carbide SiC. It should be noted that the second phase in the form of thin layers along the grain boundaries is rare and is found in about one in thirty-ferrite grain boundaries. In general, for in the state I have the location of the second phase precipitates at the grain boundaries is not typical.

Discussion of results

Electron-microscopic studies were St52.3N in both states have established:
1. Analyzed samples were polycrystalline aggregates are formed by grains of ferrite and pearlite colonies. Perlite in morphology can be divided into plate and globular.
2. Volume fractions of pearlite in the states I and II are significantly different. In the second case, the relative volume fraction of pearlite in the 1.5 ... 2 times more, and this means that the carbon concentration is too high relative to the branded content, it can be ~ 0.3 wt. %. The morphological features in the state II predominates plate perlite.
3. Local long-range voltage, estimated by electron microscopy method, in a state of great and II are comparable to the yield strength of the material.
4. In both states are observed dispersed carbides and sulfide inclusion type. In a sample of cracked steel forgings (state II) sulfides are located in the body of ferrite grains and interphase boundaries, whereas in the conditioned media from forgings (state I) - only inside the grains. Their content in state II is significantly higher than in state I.
5. At the same types of dislocation substructures (coiled-mesh and mesh), the level of defects in state II is much higher than in state I. The scalar dislocation density in ferrite grains and ferrite interlayers of defective forgings $2.6 \cdot 10^{10}$ cm^{-2}, and $3 \cdot 10^{10}$ cm^{-2}, respectively, which is 1.1 ... 1.7 times more than at standard metal.

These electron microscopy results suggest that the defect substructure and phase composition of steel in the state II are unfavorable. Local long-range high voltage, high scalar dislocation density, a large amount of sulfides in the lamellar morphology of grain and interphase boundaries, high porosity, the predominance of lamellar pearlite formation of cracks as a trigger for pressure treatment and thermal treatment and the operation of products.

If we generalize the results of mechanical tests, optical metallography [1] and electron microscopy, we can come to a definite conclusion - the cause of the formation of an unfavorable structural-phase state of forgings of steel St52.3N is incomplete compliance requirements of the chemical composition of the vintage. The material was the high content of carbon and, apparently, of sulfur. The first factor was confirmed as the results of optical metallography and electron microscopy. The second factor is set only by the diffraction of electron-microscopic studies. A consequence of the first factor was the reduction in temperature of the critical point A_3, which can reach 30 ... 70° C. For example, according to [6, 7] with the carbon concentration of about 0.2 wt. % And in the absence of other alloying A_3 = 860° C, while the carbon content of ~ 0.3 wt. % A_3 = 830° C. As a result, when using the standard technology of superheated steel is heated by a final heat treatment. In addition, changing the stability of supercooled austenite. At the same rate of cooling of the steel with high carbon content are always formed a non-equilibrium structures, with a high level of defects and residual long-range stresses. Austenite in this steel has increased strength, and therefore requires a higher degree of reduction in hot pressure treatment. Otherwise, a large amount of time. The relatively high temperature of hot metal forming and finishing thermal treatment leads to an intense release h impurities (primarily sulfur) in interphase and grain boundaries. As a result, there selection of secondary phases in the form of thin layers.

Thus, it was found that the steel St52.3N of the cracked piece is non-optimal structure-phase state, which leads to a decrease in fracture toughness as in hot forming, heat treatment, and upon further use of the material. The formation of such structures due to the complex variety of reasons, the leading of which is the high content of carbon and sulfur.

The reason for the formation of large-scale chemical and structural in homogeneities in the small-rodistoy low-alloy steel is the carbon and sulfur in the upper allowed by TU levels. This view was noted in the papers [8-9]. It has a direct confirmation of the practice of LLC "Yur-ginsky Machine-Building Plant." 72% of the heats of these chemical composition have been partially or completely discarded.

Table 1 shows an extract from the statistics on marriage at the factory.

Table 1. Statistics of the marriage of large pieces of steel grade St52.3N

№	Chemical element	C, %	Mn, %	Al, %	P, no more %	S, no more %	Si, no more %	Cr, no more %	Mo, no more %	Ni, no more %
	Specifications	0.16-0.22	1.0-1,6	0.02-0.06	0.035	0.035	0.55	0.4	0.1	0.4
1	№1 01474 L0-1180, c accumulation of defects №5,5; h100-210 cut 1180.	0.21	1.30	-	0.028	0.035	0.35	0.15	-	0.15
2	№4 01494 L0-720, h200; 4 defect. Ø5-7 and an extended defect .h200-240 Ø7.2 cut 720	0.20	1.15	-	0.030	0.037	0.30	0.20	-	0.10
3	№2 01492 along the entire length h90-220 accumulation of defects Ø 5-6.5 more 100 defect Ø7 (A/A)	0.23	1.20	-	0.030	0.035	0.30	0.35	-	0.20
4	№3 01492 throughout L accumulation of defects more 100 units Ø7-8 (A/A)	0.21	1.35	-	0.035	0.035	0.35	0.23	-	0.25

It is evident that the chemical composition of the melting meet all specifications (exceptions are the 2 and 3, which allowed a small excess of sulfur and carbon, respectively). At the same time, bars 3 and 4 after treatment consisted of a full marriage, and were sent to the facility. Ingots 1 and 2 were used for further operations after the removal of large pieces of 1180 and 720 mm, respectively. That is, all four of the ingot contained a large-scale phase separation band, only in bars 1 and 2, it was located near the head and was removed, and in bars 3 and 4 - in the middle of the ingot.

Conclusion

Thus, if the steel carbon, sulfur and phosphorus are located at the upper limit, takes on the necessary measures even in the metallurgical industry. The authors of [9-10] suggest a method of inoculation of the melt, which is in charge of metal powders in the process of casting. This method gives good results, but not worked in a factory practice and requires scarce powders of rare-earth metals. In the Company "Yurga Machine-Building Plant" is easier after taking the last sample of carbon in the liquid metal bucket to the processing of synthetic slag, this operation is well established in the metallurgical, chemical industries [11-12] and reduces the content of both elements.

If the shop forming and heat treatment of metal joined with the content of carbon and sulfur in the upper permissible levels, to eliminate the band separation of sulfur and carbon, and thus reduce the likelihood of cracking of the workpiece should be held under the regime of homogenizing annealing: heating at 1100° C, holding 10 hours to eliminate the segregation of carbon and sulfur. In addition, when working with this metal is extremely If required to strictly follow the process map of hot forging and heat treatment. If possible, you should be hammering at the lower limit of heating temperature and the degree of effort and increase the compression.

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