Influence of heat treatment on the presence of a rock-like fracture of steel 35 HGSL

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Abstract. The article discusses the features of the formation of a rock-like fault, which is formed at an elevated temperature and is enriched with partially soluble phases. These are small particles, films, or fused eutectic. To study the regularities of this defect, 8 different melts were studied and micro-samples were made for further research. The study of the structure revealed the main parameters that have a destructive effect on the metal. In general, the studied defect can be corrected by homogenization, which is determined by the degree of stability of the rock-like crack - the more stable it is, the higher the heating temperature should be and the longer the exposure at this temperature.

1. Introduction
Metallurgy is an industry that has seen rapid development in recent years, which cannot but have a positive impact on the development of the industrial complex as a whole. However, for any enterprise with such development, one of the priority tasks is to reduce the number of defective products.

A manufacturing defect is a product identified at the production stage that does not meet the stated requirements.

Today, there are many industrial enterprises that manufacture parts from metal materials. In order to produce high-quality products, the main operation is to identify certain defects that can subsequently cause the parts to fail [1].

A defect in metal materials is any deviation from the stipulated technical conditions for their quality. The defects can be attributed to the inconsistency of chemical composition, structure, surface condition, etc.

In fact, there are defects in any metal or alloy, but some of them are minor, which can not affect a particular product in any way. For this purpose, many standards have been created to determine the severity of defects [2-4].

Defects in injection molding are mainly formed due to improper preparation of the alloy. One of the defects encountered is gas porosity.

In addition to casting defects, the castings may show defects in fractures, such as intercrystalline interlayers (chips, layered fractures), carbonized layer, black fracture, naphthalene and rock-like fracture, and others. The stone-like fracture should be given a special place, since it is the purpose of the study of this work.

Kamnevidny kink-is classified as a matte kink, on the borders of large and small grains that reveal their cut [5].
Naphthalene fracture has the reflectivity of grain faces and is weakly dependent on the direction of illumination. To determine a rock-like fracture, on the contrary, certain conditions of heat treatment of samples enclosed in quenching and tempering are required [6, 7].

A rock-like fracture is a homogeneous fracture surface that passes through grain-boundary volumes formed at high temperatures and enriched with limited phases soluble in austenite in the form of small particles or films - fused eutectic. Observed in cast and deformed steels, the surface of a stone-like fracture of steel, cooled at high temperatures, is smooth, light gray in color, most often with a metallic luster. The lateral tie in the fracture is either absent or very small. The cut of stone-like grains is most clearly visible after quenching and tempering in a wide temperature range, as well as during tests under heating conditions up to 100...200°C. After high tempering in the fracture, along with areas of stone-like grains, there are areas with a viscous fibrous structure inside the grain. In cast steel, the grains may have a more or less regular equiaxed polyhedral shape or an elongated columnar shape. However, in some cases (large castings), there are coarse-grained fractures with an irregular grain shape, the so-called shell shape [5, 6].

In microstructural studies of a rock-like fracture of cast steel that has not been subjected to heat treatment, after cooling it at high temperatures, at which fused eutectics are formed, phases with a lamellar or dendritic (fern-like) shape are observed on the fracture surface along the grain boundaries.

In fractures with stone-like grains that have a shiny surface, for example, after quenching and tempering (500°C), there is a brittle destruction of the grains. The surface of stone-like grains after quenching and high tempering has a pit structure, indicating weakly expressed plastic deformation of metal grains. At the same time, the depth and diameter of the pits are significantly less than in the sections of the fracture with a fibrous structure.

The occurrence of secondary fracture is associated with overheating of the metal before hot deformation (forging, rolling, stamping) and much less often with overheating during heat treatment. When overheating above a certain critical temperature, as in the formation of a primary fracture, the newly formed grains are enriched with various secretions. Boundary separations in the secondary fracture are similar in nature and composition to those observed in the primary fracture, with the exception of compounds whose melting point is higher than the superheat temperature. The particles in the secondary fracture are much smaller than in the primary one. The newly formed secondary fracture grains are not related in orientation to the boundaries of the originally formed grains [7].

2. Heat treatment of 35HGSL steel in the study of a rock-like fracture
The critical superheat temperature at which a secondary rock-like fracture begins to form depends on the chemical composition of the steel, the method of smelting, the method of deoxidation and, consequently, the degree of purity of the steel, the nature of non-metallic inclusions and the grain size. Thus, electric arc steel is more prone to forming such a fracture than open-hearth steel. Even more prone to the formation of a rock-like fracture is the steel of electric arc smelting followed by electroslag remelting.

This is due to the separation of aluminum nitrides along the grain boundaries and an increase in the size of the austenitic grain. Increasing the purity of steel contributes to a more intensive growth of austenitic grain, increasing the density of excess phases and thereby increasing the propensity of steel to form a stone-like fracture [8].

There are stable rock-like fracture, or rock-like fracture of the first kind, which requires to correct heating to a temperature slightly below the critical, which is rarely feasible in the practice of heat treatment of structural steels, and unstable rock-like fracture, or rock-like fracture of the second kind, which is relatively easy to correct by subsequent homogenization or high-temperature normalization. The stability of the stone-like fracture during subsequent heat treatment is higher, the lower the cooling rate during the crystallization process and immediately after it, the higher the temperature and longer the duration of overheating, the more refractory compounds in the steel.

Unstable rock-like fracture is typical for manganese-doped steels. Such a fracture can also be associated with the development of release fragility, while the fragility occurs in the process of release
not at the border of austenite grains, but at the border of grains of various phases formed during the previous overheating [9].

Methods for preventing the formation of primary stone-like fracture in cast steel include: reducing the Nickel content and increasing the manganese content; deoxidation of steel with rare earth elements that bind sulfur into refractory compounds; modification of steel and treatment of liquid steel with synthetic slag; accelerated cooling of cast steel during solidification and after it to temperatures of 1000...1200°C.

Ways to prevent the formation of a secondary rock-like fracture: limiting the heating temperature (to the critical temperature of overheating) steel before hot deformation and during heat treatment; high tempering above the temperature range of reversible tempering brittleness.

Steel that has a rock-like fracture can be improved in two ways: high-temperature homogenization at 1100...1200°C or hot deformation. The homogenization mode is determined by the degree of stability of the rock-like fracture: the more stable it is, the higher the heating temperature should be and the longer the exposure at this temperature. At the same time, during the homogenization process, the discharge at the grain boundaries gradually dissolves, and after thermal improvement against the background of a fibrous fracture, either individual faces of the original grains or sections of these faces are observed in the form of facets [10].

In hot deformation of superheated steel, as the degree of deformation increases and the temperature of its termination decreases, a gradual decrease in the stone shape is observed in the fractures after thermal improvement. There is a gradual destruction of the boundaries of superheated austenite grains. first, there are individual faces, then with increasing degree of deformation - particles of these faces in the form of matte particles, and at a sufficiently intense deformation and the appropriate temperature of its end, the traces of the stone-like fracture completely disappear.

Steel with a stone-like fracture, the formation of which is associated with the appearance of brittleness during tempering, is corrected by normalization and subsequent improvement with high-temperature tempering and accelerated cooling.

At the initial stage of formation of a rock-like fracture and at the final stage of its elimination, facets can be observed in the fracture as elements of the surface of the rock-like fracture. Immediately after high-temperature processing, facets with a light or shiny surface can be observed, which have a brittle nature of destruction at large magnifications. After improvement with a sufficiently high tempering temperature and accelerated cooling, matte facets are observed against the background of a fibrous fracture; the surface of these facets has a viscous character of destruction at high magnification.

A rock-like fracture is a homogeneous fracture surface that passes through grain-boundary objects, formed at high temperatures and enriched with partially soluble in austenite phases in the form of small particles or films – fused eutectic. Also, the appearance of a rock-like fracture may be caused by a deviation from the chemical composition standards [1-3]. To identify the regularities of the appearance of a rock-like fracture, 8 melts were selected, one of which was found to have a rock-like fracture (melting 4). Figure 1 shows graphs of pre-heat treatment of samples.

![Figure 1. Pre-heat treatment schedule: a - normalization; b - annealing.](image-url)
For further research, a qualitative analysis of samples made of 35HGSL steel was performed on an energy-dispersive x-ray fluorescence spectrometer, which allowed the most accurate determination of the chemical composition of the alloy [8].

According to the results of mechanical properties, there are no deviations from the norm of the sample 4. The next stage was metallographic study of the samples.

Melts 1, 3, 4 and 7 were selected for metallographic studies. These melts were obtained and etched until the microstructure was detected. Figure 2 shows the microstructures of two samples.

Microscopic analysis of the samples showed that the metal structure of all samples is almost identical and formed by sorbitol grains.

![Figure 2. Structure of 35HGSL steel melts: a - sample 1; b - sample 4.](image)

When studying the fracturing of melting samples 4, it was assumed that the rock-like fracture is formed by specific films formed by aluminum nitrides, which can be formed in alloyed steels during overheating [9].

If there are areas with a stone-like structure in the fracture that have a shiny or light-gray surface, the impact strength and ductility of the steel are significantly reduced. With a matt-gray surface of stone-like grains, the reduction in impact strength and plasticity is less significant. Most often, there is a pattern: the larger the surface area is occupied by the destruction of grain boundaries, the lower the ductility and toughness of steel.

To confirm this version, the sample was examined using scanning electron microscopy with a lanthanum boride cathode (figure 3).

![Figure 3. A photo of a rock-shaped fracture using a bitmap electron microscopy.](image)
Homogenization helps to correct the stone-like fracture. Therefore, it was decided to conduct high-temperature annealing at different temperatures and exposures [10].

3. Influence of heat treatment on the presence of a rock-like fracture

To achieve this goal, 10 separately cast samples of 35HGSL steel were selected (figure 4), on which a stone-like fracture was detected, with a different percentage of the viscous component. Temperatures were assigned 1050…1150 °C, the time varied from 3 to 10 hours [4-6]. Homogenization was carried out in a special vacuum oven.

![Figure 4. Stone-like fractures of 35HGSL steel melts: a - sample 12; b - sample 16.](image)

After the final heat treatment, the samples were subjected to destruction to detect the presence of a rock-like fracture. On three swimming trunks, namely 14, 15, 16, stone-like fractures were found. For these samples, homogenization was assigned at high temperature and exposure at intervals of 5…7 hours [11-13]. When comparing all the samples, it was noticed that the rock-like fracture remained on those samples that were initially found in the melting, where there was initially a large percentage of the brittle component of the entire viscous component.

4. Conclusion

According to the results of studies of the stone-shaped fracture, the following was revealed: the stone-shaped fracture is the result of a strong overheating of the metal during heat treatment of the metal at temperatures of 1250°C and higher, which can be detected after the final heat treatment; with the help of homogenization, it is possible to correct the stone-like fracture (at temperatures of 1100…1200°C).

Based on the analysis of experimental results, the following conclusions can be drawn: the fracture does not always appear in nitride films; homogenization prevents the fracture, but under the following condition: the larger the defect, the longer the effect should be during homogenization; silico-calcium also helps to prevent the appearance of this defect [10].

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