Investigation of the effect of thin films of aluminum nitride on the stone-like destruction of cast steel

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Abstract. The article deals with the features of the formation of a stone-like fracture, which is formed at an elevated temperature and enriched with partially soluble in austenite phases. They represent small particles, the film or the molten eutectic. To study the regularities of the appearance of this defect, 8 different melts were selected and micro-plates were made for further research. The study of the structure helped to identify the main components that have a destructive effect on the metal, as well as to find out which structures predominate to a greater or lesser extent for the development of microlocal deformation, provoking destruction.

1. Introduction

Today, there are many industrial plants that are engaged in the manufacture of parts from metal materials. In order to produce high-quality products, the main operation is to identify certain defects that can subsequently disable the parts.

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

In fact, in any metal and alloy there are defects, but some of them are minor, which can not affect a particular product. To do this, many standards have been created to determine the severity of defects.

Defects refer to the individual compliance of the product with established requirements. Casting defects are divided into five groups: mismatch in geometry, surface defects, discontinuities in the casting body, mismatch in structure, inclusions [1].

In addition to casting defects, defects in fractures can be detected in castings, such as intergranular interlayers (chips, layered fractures), decarburized and carbonized layer, black fracture, naphthalene and stone-like fracture, and others.

For a more complete understanding of the causes of the appearance of a stone-like fracture, it is necessary:
- to investigate the structure of separately cast samples of steel 35HGSL.
- identify the causes that contribute to the formation of a stone fracture to prevent its occurrence.
- To achieve this goal, it is necessary to perform the following tasks:
  - to study in a comparative way the essence of the stone-like fracture;
  - to find out the effect of thin nitride films of aluminum on the stone-like fracture of cast steel;
  - to make metallographic and chemical analyses, and also mechanical properties of investigated separately cast samples.
2. Materials and methods

A rock-like fracture is a relatively uniform fracture surface. Usually, the stone-like fracture passes along the grain boundaries and is enriched with partially soluble in solid solution of the introduction of carbon into γ-iron phases. They represent small particles, the film or the molten eutectic. The stone-like fracture is formed after high-temperature heating, over 1250 °C.

On the surface of the stone-like fracture, you can often find a matte light gray color, with a metallic luster. Clear stone-like grains appear after heat treatment: hardening and tempering, normalization, etc.

Stone-shaped fracture in cast steel is divided into two types: primary and secondary.

The primary stone-like fracture is formed after overheating and cooling, that is, before heat treatment. This is due to the special granulation structure of austenite during prolonged cooling. At the same time, nitrides, carbides and certain alloying elements, which are limited soluble in austenite, are isolated in the border zone.

Secondary fracture occurs after overheating of the metal before hot deformation, such as forging, rolling, stamping, and also manifests after overheating during heat treatment.

The mechanism of formation of a secondary stone-like fracture is as follows. Upon reaching a temperature of 1300...1350 °C, the grains of γ-iron grow to 2...4 mm and take the form of a convex polyhedron. Further, carbides, sulfides and nitrides are dissolved in them. Nitrogen and sulfur form at the near-phase boundary and form thin films of manganese and iron sulfides that persist after cooling. The combination of these factors increases the fragility of the metal on impact. In addition, the fracture most often passes along the boundaries of these grains [1-3].

Such a stone-like fracture is prone to electric arc smelting, as opposed to open-hearth, as well as electric arc smelting followed by electroslag remelting.

It is customary to distinguish between a stable and unstable stone-like fracture. A stable stone-like fracture is of the first and second kind.

A stone-like fracture of the first kind can be corrected only to the lower temperatures of phase transformations. Under heat treatment this is happening rarely. Stone-like fracture of the second kind is corrected more easily by applying subsequent homogenization or high-temperature normalization.

It is possible to trace such regularity: at increase of stability of a kamnevidny break, speed of cooling in the course of crystallization decreases, temperature and duration of overheating increases, the content of refractory compounds which enrich grain boundary volumes increases.

Unstable rock-like fracture during tempering embrittles grain boundaries during overheating. High-purity steel does not allow the development of tempering brittleness.

The development of primary stone-like fracture of cast steel can be prevented in the following ways:

- to reduce the Nickel content and increase the content of manganese;
- to bind the sulfur from refractory compounds, with the deoxidation of steel with rare earth elements;
- to modify the steel and treating the steel with synthetic slag;
- to make accelerated cooling of steel at hardening to temperature of 1000 ... 1200 °C.

The formation of a secondary stone fracture can be prevented by the following methods:

- limit the heating temperature of steel;
- to conduct high holidays above the temperature at which the phenomenon of temper embrittlement.

Steel can be improved in two ways. The first way consists of high-temperature homogenization, at temperatures of 1100...1200 °C [1, 4].

The second way is hot deformation. In superheated steel, as the degree of deformation increases, a gradual decrease in the stone-like fracture is observed [1, 5].

Steel 35HGSL is a structural alloy steel for shaped castings. This steel is mainly used in aircraft assemblies, engines and their assemblies.
Castings are produced by methods of precision casting, investment casting and ceramic form of constant models. Steel smelting is carried out in induction furnaces with the main lining in open conditions and in vacuum.

Steel has a distinctive feature—good fluidity. The casting temperature is 1500 ... 1570 °C, depending on the configuration and wall thickness of the part. The solidification temperature varies between 1486...1495 °C.

The method of spectral analysis of the chemical composition is based on the study of the spectra of the interaction of the material with radiation.

This analysis provides data on the chemical composition of the material brand. By this method it is possible to obtain the percentage of a chemical element other than carbon.

For spectral analysis, the optical emission spectrometer Belec Vario Lab was used, which is based on the emission spectral analysis method, which has a dependence of the intensity of the spectral lines on the element content in the sample. To excite the emission spectrum of the elements used in the sample, a spark electric discharge is used between the rod electrode and the surface of the sample itself. The electrode is blown with argon.

As mentioned above, the stone-like fracture manifests itself after heat treatment, consisting in annealing, which is a preparatory operation before further hardening and tempering.

The heat treatment was carried out after all the Gating systems were removed and the surface was cleaned of ceramics.

According to the instructions, a mode of preliminary heat treatment for 35hgsl steel is proposed. It is carried out in two ways, normalization and annealing [1, 6].

Normalization occurs at temperatures of 900±10 °C followed by tempering at 680±10 °C, air cooling.

Annealing is carried out at a temperature of 780 °C, with cooling to 670°C in the furnace, and then in the air.

These methods are not used, as in the castings often manifests a stone-like fracture.

Instead of the above methods, the samples were subjected to preliminary thermal testing, according to the map of the typical technological process:

- heated castings to 640 ... 650 °C;
- stood for 1 hour;
- heated castings to 910±10 °C;
- aged 12 to 13 hours (depending on the details of the party);
- cooled with the furnace to 670±20 °C.

This preliminary heat treatment took longer, but the probability of a stone-like fracture was reduced.

The next stage is the final heat treatment, consisting of hardening and tempering, which will determine the mechanical properties of the steel.

The final heat treatment of 35HGSL steel was performed according to the instructions consisted of two stages. The first stage was hardening at a temperature of 890±10 °C with cooling in oil. The second stage – vacation at a temperature of 570...630 °C.

Mechanical properties show, on what resistance are capable those or other metals to carry out from external environment. The main mechanical properties of metals and alloys include: hardness, viscosity, strength, creep, ductility, wear resistance and toughness. Tests are carried out in various ways: stretching, twisting, bending, compression and impact bending [1, 7].

Preparation of the microstructure sanding consisted of two stages: grinding and polishing. Grinding took place on a special machine, with alternating sandpaper, from coarse to fine-grained. In this case sandpaper with grit was used: 180, 320, 400, 600, 800, 1000. Polishing was carried out by means of cloth moistened with polishing paste mixed with water.

When the concentrate was ready, a solution of 4% nitric acid in ethyl alcohol was used as an Etchant to determine the structure. Etching was carried out using a cotton swab.
The ZEISS AXIO Vert light microscope was used to study the microstructure Al MAT, with which the microstructure was examined at magnification up to 2000.

The appearance of a stone-like fracture can be caused due to a deviation from the standards of chemical composition. To identify the regularities of the appearance of a stone-like fracture, 8 heats were selected, in one of which a stone-like fracture was found (melting 4).

Figure 1. The Structure of the melting of steel 35HGSL: a-melting number 1; b-melting number 4.

Figure 2. The Structure of the melting of steel 35HGSL: a-melting number 3; b-melting number 7.

The next stage was metallographic examination of samples. When studying the structure allows: to identify the structural components that have a destructive effect on the metal; which structures prevail to a greater or lesser extent for the development of microlocal deformation, which provokes destruction.

Melting 1, 3, 4, 7 were chosen for metallographic study. Data on batches produced thin sections and etched to reveal the microstructure. Figures 1 and 2 show the microstructures of four samples [7].

Microscopic analysis of the samples showed that the metal structure of all samples is almost identical and formed by sorbitol grains [1, 8].

When studying the fractures of melting samples 4, it was assumed that the stone-like fracture was formed by specific films formed by aluminum nitrides (the analysis of the chemical composition of this steel revealed an aluminium content of about 0.08%), which can be formed in alloyed steels during overheating [1, 9].

To confirm this version, the fracture was examined using scanning electron microscopy with a cathode of lanthanum boride [10-13]. A photograph of the rock-like fracture using scanning electron microscopy is shown in figure 3.
Figure 3. Photograph of a rock-like fracture using scanning electron microscopy.

Based on the analysis of the experimental data, the assumed film of aluminum nitrides was not detected, so this version of the formation of a stone-like fracture was not confirmed.

3. Conclusion
On the basis of the conducted researches and the analysis of results of experimental data the film of nitrides of aluminum was not found. In General, the regularities of the appearance of this defect relate to the grain boundaries, which are enriched with partially dissolved in austenite phases, which are small particles, films or melted eutectic.

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