Influence of the chemical composition of steel on the formation of a stone-like fracture and the microstructure of cast steels

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Abstract. The article presents the main regularities of the formation of a stone-like fracture of cast steels. The peculiarity of the formation of this defect is the presence of high temperatures and enrichment of the main alloy with small particles and austenitic phases. On the surface of a rock-like fracture, you can often find a matte light gray color, with a metallic sheen. The primary rock-like fracture can be observed after overheating and cooling, that is, before heat treatment. Secondary fracture occurs after metal overheating before hot deformation, such as forging, rolling, and stamping, and also occurs after overheating during heat treatment. The study of patterns of formation of a stone-like fracture in cast steels is one of the most important tasks of modern engineering.

1. Introduction
A stone-like fracture formed during the manufacture of cast blanks is a homogeneous fracture surface that passes along the grain boundaries. It is formed at high temperatures and is enriched with highly soluble austenite phases in the form of small particles or films-fused eutectic. On the surface of a rock-like fracture, you can often find a matte light gray color, with a metallic sheen. Clear stone-like grains appear after heat treatment: quenching and tempering, normalization, and other types of heat treatment [1-3].

2. Types of stone-like defects in foundry
A stone-like fracture in cast steel is divided into two types: primary and secondary. The primary rock-like fracture can be observed after overheating and cooling, that is, before heat treatment. This fracture is due to the formation of the granulation structure of austenite, which is formed after crystallization under slow cooling at high temperatures. At this time, excess sulfides, nitrides, phosphides, carbides, and some alloying elements, which are limited soluble in the gamma phase, are released at the grain boundaries [4, 5].

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

The mechanism of formation of a secondary stone-like fracture is as follows. When heated to 1300-1350 °C, the austenite grain grows to a significant size, approximately 1-5 mm, and takes the form of regular polyhedra. At these temperatures, the carbide phase, aluminum nitrides, and sulfides are dissolved. Due to the high surface activity, sulfur and nitrogen are adsorbed at the borders of large austenitic grains and form excess phases-films of iron and manganese sulfides with the conversion of
iron sulfide and aluminum nitrides, which were preserved after cooling at the borders of former austenite grains. This leads to the brittleness of the metal under shock loading and the fracture passes partially or completely along these boundaries. Subsequent heat treatment does not eliminate the formed phases [6, 7].

The critical superheat temperature at which the formation of a secondary rock-like fracture begins depends on the chemical composition, the melting method, the deoxidation method, the degree of purity of the steel, the nature of non-metallic inclusions, and the grain size.

Parts after electric arc melting, in contrast to open-hearth, as well as electric arc melting with subsequent electroslag remelting, are subject to such stone-like destruction.

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

A rock-like fracture of the first kind requires heating to a temperature slightly below the critical temperature in order to correct it. This rarely happens during heat treatment. The second type of stone fracture is corrected more easily by applying subsequent homogenization or high-temperature normalization [8-10].

We can trace this pattern: when the stability of the rock-like fracture increases, the cooling rate decreases during crystallization, the temperature and duration of overheating increases, and the content of refractory compounds that 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 release brittleness.

The development of a primary stone-like fracture of cast steel can be prevented in the following ways [11, 12]:

- reduce the Nickel content and increase the manganese content;
- 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;
- produce accelerated cooling of steel when solidified to a temperature of 1000-1200 °C.
- The formation of a secondary stone-like fracture can be prevented by the following methods:
  - limit the heating temperature of steel before hot deformation and during heat treatment;
  - conduct high tempering above the temperature range of the reversible tempering brittleness.

3. Ways to solve the problem

Steel can be improved in two ways. The first way consists of high-temperature homogenization, at temperatures of 1100-1200 °C, 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. In the process of homogenization, grain boundary separations gradually dissolve, 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 as facets [13, 14].

The second way is hot deformation. In superheated steel, as the degree of deformation increases and the temperature of its end decreases, and fractures after thermal improvement, a gradual decrease in the stone-like fracture is observed. First, there are individual faces, then with an increase in the degree of deformation – particles of these faces in the form of matte facets, and with a sufficiently intense deformation corresponding to the temperature of its end, the traces of a stone-like fracture completely disappear [15-17].

There are methods of research on stone-like fracture with the addition of rare metals. Experiments were carried out on medium-carbon steels to detect the influence of the sulfide phase on the formation of a stone-like fracture. All melts were characterized by the content of certain deoxidizers, such as aluminum, titanium, manganese, and rare earth materials. After casting, the castings were subjected to overheating to high temperatures of 1250-1400 °C, followed by cooling in oil. After the breakdown, it was found that the formation of a stone-like fracture is prone to steel, melted with aluminum deoxidizer. The fracture of this steel is shown in figure 1, and the structure of this steel is shown in figure 2, 3.
Figure 1. Fracture of a separately cast sample of medium-carbon steel before heat treatment.

Figure 2. Microstructure of a separately cast sample of medium-carbon steel after preliminary heat treatment.
Figure 3. Microstructure of a separately cast sample of medium-carbon steel after final heat treatment.

During metallographic research, iron sulfides were found in the structure of steel that is prone to forming a stone-like fracture, which were not detected in the structure of steel that contained manganese and rare earth metals [18, 19].

Overheating and subsequent cooling of a variety of sulfides behave differently. If we take, for example, manganese sulfides or sharp-earth metal sulfides, they are located along the direction of deformation. Iron sulfides behave differently, they are sharply rearranged and located on the borders of the former austenitic grains.

In addition to medium-carbon steel, experiments were performed with steel grades 20G2, 45G2 and 60G, where the results were also confirmed for the absence of a stone-like fracture tendency with the addition of manganese.

The next study was the steel grade 18X2H4VA, where deoxidizers were added not to the bucket, but to the molds. In this case, the steel was deoxidized with rare earth elements and titanium, which reduces the tendency to form a stone-like fracture, but it is impossible to say this about sulfur. It easily dissociates at low temperatures and contributes to the formation of a stone-like fracture, since sulfur is not soluble in austenite [20-22].

To confirm the effect of sulfur on the formation of a rock-like fracture, studies were conducted on 40G2 steel. Different sulfur content was added to different melts. The steel was subjected to overheating at temperatures of 1200-1375°C, followed by its improvement, quenching at 860°C, cooling in oil and tempering at 600°C. After this operation, the fracture on all the smelters was homogeneous and viscous, without hints of a stone-like fracture.

In addition to experiments on 40G2 steel to determine the effect of sulfur on the formation of a rock-like fracture, studies were conducted on 18X2H4VA steel, which was smelted with a small amount of titanium [23-26].
4. Conclusion
Analyzing the conducted research, it should be noted the appearance of sulfide phases that contribute to the formation of a stone-like fracture in casting alloys:

– in the presence of low-temperature sulfides in the steel structure, a stone-like fracture is formed due to overheating of the metal;
– to reduce the stone-like fracture, the presence of refractory manganese sulfides, titanium, and rare-cement metals is necessary;
– with increasing purity of steel for sulfur and nitrogen, the tendency to stone-like fracture increases.

It also reveals one of the main features of the formation of a stone-like fracture – the presence of phases that are concentrated along the borders of the former austenitic grains. For the final deoxidation of steel, it is necessary to use different elements in turn, such as: cerium, lanthanum, calcium, zirconium and yttrium. When melting steel from the charge, use one deoxidizer during the entire processing cycle of the workpiece, which was obtained from previous smelts.

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