Mechanisms of construction machines and selection of steels for the manufacture of welded metal structures

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Abstract. The paper is devoted to the study of the working mechanisms of construction machines from the point of view of the selection of structural steels for the manufacture of welded metal structures. Special attention is paid to the operational reliability and durability of modern construction machines. It was found that the most suitable for the manufacture of welded structures are complex-alloyed low-carbon steels. They have high strength (σ₀.²≥600 MPa, σₜ≥800 MPa), are characterized by sufficient plasticity and increased resistance to brittle fracture at low temperatures. In the selection process, special attention was paid to the properties that structural steels should simultaneously have, specifically: low sensitivity to various stress concentrators; adaptability to perform service functions that are envisaged in the development of the project and directly in the process of manufacturing the welded metal structure, good weldability. The experiments were carried out using the example of low-carbon and low-alloy steels. Special attention was paid to the analysis of the optimal modes of thermal cycling with the aim of obtaining final structures with a given degree of dispersion, typical of real metal structures. Taking into account the requirements for the reliability of construction machines in operating conditions at high and low temperatures, as well as taking into account various operational characteristics, the expediency of using ferromagnetic structural steels was substantiated.

1. Introduction

One of the main problems of modern technical development is the need to improve the technical and economic indicators of machines, mechanisms and engineering structures due to a decrease in their specific metal consumption, an increase in operational reliability and durability. In solving this problem, an important role is played by the widespread use of welded metal structures made of high-strength steels in mechanical engineering, which, according to the international classification, include steels with a yield strength of 350 MPa and more [1].

These issues are of particular relevance in the manufacture of construction machines. One of the key features of welded steel structures for construction machines is that they typically operate in a...
variety of weather and climate conditions, while experiencing static, dynamic and cyclic loads. Under such conditions, it is obvious that parts of welded structures are exposed to the influence of corrosive environments, leading to corrosive wear, which entails a change in the physical and mechanical properties of structural steels.

In this regard, considerable attention is constantly paid to ensuring the technological strength and operational reliability of welded joints of parts and assemblies of construction machines, their hull structures, as well as those used for the manufacture of steels. Complex alloyed low-carbon steels are among the most widespread ones.

In addition to high strength (σ0.2≥600 MPa, σB≥800 MPa), they are characterized by sufficient plasticity and increased resistance to brittle fracture at low temperatures [2-3]. To obtain such a complex of properties, these steels are subjected to heat treatment - quenching followed by tempering. High technological strength, i.e. resistance to the formation of “cold” and “hot” cracks in the manufacture of welded parts of machines and structures made of such steels, is most often provided by preheating to a temperature of 80 ... 150°C [4]. To obtain proper performance, especially in the case of dynamic and alternating loads, a complete post-weld heat treatment is recommended.

Without the above measures, there is a great risk of destruction of parts of construction machines, individual units and structures as a whole due to the formation of cracks, both technological and operational ones. Numerous cases of destruction of heavily loaded welded assemblies of powerful construction machines, excavators, high-pressure vessels, and casing strings are known. However, frequent use of heating or heat treatment is irrational and sometimes impossible.

Some researchers and scientists believe that the key vector for the development of mechanical engineering at the present stage should be an increase in the technical level of machinery and equipment. At the same time, based on the analysis of the study of machine testing stations, it was found that 95-97% of machine samples were manufactured with a deviation from technical requirements, 80-85% did not meet safety and ergonomics requirements, every fourth sample has a readiness factor below the technical requirements for manufacturing [5].

For example, the proportion of failures due to the fault of equipment manufacturing plants is 60%, in particular, construction cranes - 67%, excavators - 84%, milling cutters - 61%. The produced equipment has low reliability and maintainability indicators, requires a large number of lubrication, adjusting and commissioning works. Up to 60% of machine failures occur due to manufacturing defects, and it takes from 2 to 30 days to fix them.

Much attention is paid to the problem of choosing high-strength steels for construction machines, which determines the choice of the topic of this paper, and also confirms its practical and theoretical significance.

Unfortunately, today the complex problems of ensuring the reliability of construction equipment are solved empirically, without a proper theoretical foundation of mathematicians, physics of metal, mechanics. Only in some universities, the term “reliability” appears to a limited extent in the names of departments and in the curricula of engineering faculties, which can mean one of two things: all theoretical and applied reliability problems are completely solved, or vice versa - they are only at the initial stage of solution.

Thus, the purpose of the paper is to study the features of the selection of structural steels for the manufacture of welded metal structures of construction machines.

2. Materials and methods
At the first stage, it is necessary to determine the properties that structural steels must simultaneously have, used for the production of welded metal structures of construction machines.

First, to have a low sensitivity to various stress concentrators that arise during the operation of machines, which is very important for construction machines. The metal of the welded structure must have these properties both before and after welding. Moreover, this requirement is relevant not only for the base metal, but also for the weld, as well as for the heat-affected zone [6-8].

Secondly, steels must be adapted to perform service functions that are envisaged during the
development of the project and directly in the process of manufacturing the welded metal structure. These structural functions are directly dependent on the plastic and strength properties of steels under various types of loads, impact strength, cold resistance, corrosion resistance, etc.

Thirdly, steels must be characterized by good weldability. In this case, weldability is understood as such properties of a metal or a combined composition of metals that make it possible to form, with the selected welding technology, a joint capable of satisfying the requirements determined by the design of the product and its operation. In this case, such additional actions as forging, heating and heat treatment should not be required. It is known that the weldability of steels is most influenced by their chemical composition. An increase in the content of carbon and sulfur reduces the weldability of steel, leads to the appearance of hot cracks in the welding process. Therefore, for the manufacture of welded metal structures, low-carbon steels are used, containing no more than 0.25% carbon and low-alloy steels in which carbon is not more than 0.18% [9].

Assessment of the weldability of high-strength steels comes down to determining the optimal welding conditions, which exclude the possibility of cold cracks in the welded joints, and in the metal - the heat-affected zones of structures that will contribute to ensuring the strength, ductility and impact toughness in this section of the welded joint at the level of requirements for welded structures.

Unlike steels, which acquire mechanical properties both due to the choice of certain alloying systems and as a result of the choice of special conditions for their rolling or heat treatment, the same metal in welded joints should have similar properties in the state after welding.

The steel required for the manufacture of a metal structure should be selected in such a way as to ensure the operability of the structure of the construction machine with minimal manufacturing costs and long-term operation.

One of the key requirements for steels that are used for the manufacture of welded metal structures, as noted above, is to ensure high ductility. This is due to the fact that because of the effect of various concentrators, the formation of local zones of concentration of stresses and residual welding stresses, local plastic deformations can occur in some parts of the metal structures during loading. In this regard, the steel must have a sufficient reserve of ductility to withstand the loads without destruction.

If a metal structure is used at low temperatures, the steel from which it is made must have sufficient ductility at the lowest of the permissible operating temperatures.

It is known that, working at low temperatures, the performance of welded joints, namely the heat-affected zone, the weld, usually decreases: the hardness increases, the tensile strength increases, the fatigue and yield limits increase, the impact strength and plasticity decrease.

In the case of lower temperatures, the sensitivity of steel to stress concentrators increases. Both external and internal defects of the welded joint, which can lead to the formation of cracks, can act as concentrators.

Also, the following stress concentrators can have a significant effect on the appearance of cracks: abrupt changes in cross-sections of some parts of welded joints, concentration of welds, abrupt transitions from the base metal to the weld, closed contours, intermittent seams, non-welded craters, etc.

Taking into account the above, for the purpose of the experiment, low-carbon steel 08ps and St3 widely used in the manufacture of welded metal structures of construction machines were selected. The chemical composition of the steels is shown in Table 1.

| Steel type | Chemical composition, % |
|------------|-------------------------|
|            | C  | Mn | Si  | Al | P   | S   |
| 08ps       | 0.06| 0.27| 0.05| 0.0011| 0.019| 0.022|
| St3        | 0.19| 0.53| 0.21| -   | 0.032| 0.034|

The choice of these steels is caused by the following:
• steels are widely used in the manufacture of welded metal structures of construction machines,
in mechanical engineering and other industries;
  - have high plasticity characteristics at normal and low temperatures;
  - have a different chemical composition;
  - have different strength categories and a different tendency to cyclic hardening and softening;
  - have good weldability;
  - have increased and normal anti-corrosion properties;
  - the choice of the steels under study makes it possible to extend the obtained regularities to all steels close to them both in composition and in properties;
  - due to the low carbon content, the selected steels can be used to study the physics of the magnetomechanical phenomenon.

In order to carry out mechanical tests, flat tensile specimens were made of steel St3 and 08ps.

To obtain welded samples, plates of steel St3 and 08ps with a width of 30 mm and a thickness of 3, 5 and 10 mm were used. One-sided abutting welded samples were obtained by manual arc welding with coated electrodes. In some samples, using milling, the bulge of the weld was removed, while the removal of the base metal on the entire surface of the sample to a depth was no more than 15% of the thickness of the base metal. The metal was removed across the weld. For mechanical tests, in central parts of some samples, a weakening of the cross section by 20% was carried out due to lateral radius grooves (Fig. 1).

![Figure 1. Main samples used for the test.](image)

### 3. Results and discussion

Metallographic studies have shown that, regardless of the chemical composition and initial structure of the studied steels, after thermal cycling, in all cases, a fine-grained structure is formed with varying degrees of dispersion. Typical structures of steel 08ps after thermal cycling are shown in Fig. 2.

![Figure 2. Change in the structure of steel 08ps during thermal cycling, x650: a) - condition (supply + annealing at 900°C); b), c) - after three and six cycles, respectively.](image)

The greatest changes in the structure of steels occur during the first 3-6 cycles of thermal cycling. A further increase in the number of cycles less significantly increases the degree of refinement of the
structure, but decreases the uneven grain size of the steels.

The presence of a deformed structure of structural steels before the thermal cycling treatment introduces significant changes in the process of structural transformations for both low-carbon and low-alloy steels. This results in a finer-grained structure in contrast to other types of pretreatment.

It should be noted that a finer-grained structure is formed in low-alloy steels after six-fold thermal cycling in comparison with low-carbon steels. However, in low-alloy steels, to obtain a fine-grained structure without noticeable grain size variation, a greater number of thermal cycling cycles is required than for low-carbon steels, which is probably due to the influence of alloying elements on the formation of the final microstructure during thermal cycling.

In alloy steels, the thermodynamic activity of carbon is lower than in carbon steels. Therefore, their structural changes during thermal cycling occur more slowly. Thus, with an increase in the number of alloying elements in steel, to obtain an equiaxed fine-grained structure, a larger number of thermal cycling cycles is required.

Taking into account the fact that in the region of low temperatures, the yield strength, strength, impact strength and fatigue strength increase with a decrease in the grain size, then obtaining a fine-grained structure in the process of thermal cycling can be used to strengthen the elements of welded metal structures and welded joints of construction machines in local hazardous stress concentration zones due to the refinement of the metal structure according to the developed modes of thermal cycling.

4. Conclusion

Thus, summing up the results of the study, we note the following. The paper identified and analyzed the key requirements that apply to structural steels used for the manufacture of welded metal structures of construction machines. Taking into account the requirements for the reliability of construction machines in operating conditions at high and low temperatures, as well as taking into account various operational characteristics, the expediency of using ferromagnetic structural steels was substantiated.

It has been established that, irrespective of the chemical composition and initial structure of low-carbon and low-alloy steels, a fine-grained structure with a different degree of dispersion is formed during thermal cycling, which is characteristic of real welded metal structures of construction machines. The greatest structural changes in the metal occur during the first 3-6 cycles of thermal cycling. A further increase in the number of cycles slightly increases the degree of refinement of the structure, but reduces the grain nonhomogeneity.

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