Comparison of characteristics of St3 in a free and annealed state

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Abstract. For the manufacture of field pipelines, low-carbon steel grade St3 is often used. It welds well, almost never hardens, and therefore is very convenient for working in structural elements. Studies of samples from this steel grade were carried out for the initial and heat-treated state by the following methods: study of mechanical properties (tensile test, hardness test); microstructural analysis. At the beginning of research, annealing was carried out in the work to obtain an equilibrium structure. According to the results of the experiment, it was noted that after annealing, the steel structure acquired low strength and hardness with high plasticity. After annealing, tensile tests were carried out on steel samples. Tensile tests of the metal were carried out in order to determine the main indicators of mechanical properties and to compare these properties in the initial and heat-treated state. Hardness measurements were carried out according to the Rockwell method. The microstructure of steel samples was studied using an optical microscope “Metam RV-21-1”, which made it possible to study the microstructure at a magnification of 200 times. It is shown that the structure of steel is ferritic-pearlite. In the initial state, there is a segregation banding and segregation streamer. The structure of the steel under study in the initial state is fine-grained. After annealing, it becomes more homogeneous, and the deformation texture disappears.

1. Introduction
For the manufacture of field pipelines, low-carbon St3 is often used [1-3]. It welds well, almost never hardens, and therefore is very convenient for working in structural elements.

The problem of corrosion of oilfield equipment has been particularly relevant in recent years [2, 4-6]. This is due to the fact that the application of methods for intensifying the development of oil fields is accompanied by a continuous increase in the water cut of well production and an increase in its corrosiveness. Under such operating conditions, there is a significant decrease in the service life of oilfield equipment, an increase in the number of failures due to corrosion [7-9], and product loss. In these conditions, the losses from the elimination of ruptures and the premature replacement of pipelines are also very significant. In addition, the outflows of oil products and wastewater causes irreparable damage to the environment [10-14], and reduces the efficiency and pace of development of oil fields.

Field pipelines are capital engineering structures designed for a long service life and designed for the uninterrupted transportation of natural gas, oil, water and their mixtures from their production sites to integrated treatment facilities and further to the points of tie-in into the main pipeline or for supply to another mode of transport - railway, river, sea.

The technical equipment of pipeline transport and the pace of pipeline construction are inextricably linked with the development of the gas, oil and oil refining industries [15-18]. Pipeline transportation of
gas, oil and oil products is the most economical. In this regard, both in Russia and abroad, there has been a tendency for the outstripping growth of pipeline transport in comparison with its other types.

2. Experimental procedures

2.1. Materials
The object of the study was samples from steel St3. According to its chemical composition (table 1), the steel under study can be deciphered as follows: about 97% contains iron, and the amount of carbon is 0.14-0.22%. The strength and hardness of steel primarily depends on the carbon content. However, carbon reduces plasticity and weldability, therefore, in building steels, which, according to the conditions of their work in structures, must be sufficiently plastic, it is allowed a little - no more than 0.22%. This also ensures good weldability of these steels.

Table 1. The chemical composition of steel.

| C, %  | Si, %  | Mn, %  | S, %  | P, %  | Cr, %  | Ni, %  | Cu, %  | N, %  | As, % |
|------|-------|--------|-------|-------|--------|--------|--------|-------|-------|
| 0.14 | 0.15  | 0.40   | <0.050| <0.040| 0.03   | <0.30  | <0.30  | <0.010| 0.08  |
| 0.15 | 0.30  | 0.65   |       |       |        |        |        |       |       |

The purpose of steel St3 is sheets for electric-welded pipes operating at temperatures up to 300°C and pressures up to 1.6 N/mm². Parts of boilers and pipelines made of sheet up to 12 mm thick, and forged parts designed for operation at temperatures up to 200°C and pressures up to 1.6 N/mm². Table 2 shows the temperatures of the critical points of the studied steel.

Table 2. Temperature of critical points, °C

| Ac₁  | Ac₃  | Ar₁  | Ar₃  |
|------|------|------|------|
| 735  | 850  | 680  | 835  |

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Investigations of samples from steel grade St3 were carried out for the initial and heat-treated state by the following methods:
1) study of mechanical properties:
   - tensile test;
   - hardness test;
2) microstructural analysis.

2.2. Experiment Techniques
At the beginning of research, annealing was carried out in the work to obtain an equilibrium structure. Annealing of the II type of steel products was carried out at a temperature of 880°C, followed by slow cooling in a furnace. According to the results of the experiment, it was noted that after annealing, the structure of St3 steel acquired low strength and hardness with high plasticity.

After annealing, tensile tests were carried out on samples of steel St3. Tensile tests (GOST 1497-84) make it possible to determine the strength and ductility characteristics of metals under static uniaxial loading. The testing machines are equipped with lever-type (or indicator) devices for recording the tensile diagram (change in the length of the sample depending on the applied stress).

The determination of the yield point of the metal is carried out at a constant rate of relative deformation of 1 mm/min. Tensile and universal machines that comply with GOST 7855-74 are used as testing machines.

Hardness measurements were carried out according to the Rockwell method (GOST 9013-59). The essence of the method consists in indenting an indenter with a hardened steel ball with a diameter of 1.5875 mm into the sample, under the action of two successively applied loads - preliminary P₀ and main P₁, which is added to the preliminary one, so that the total load P = P₀ + P₁. After holding for
several seconds, the main load is removed and the residual depth of penetration of the indenter is measured, which is still under the action of the preload.

Microanalysis is an indispensable tool for assessing structural changes in the size, shape and orientation of grains, individual structural and phase components. The microstructure of the St3 samples was studied using an optical microscope (GOST 10243-75) “Metam RV-21-1”, which made it possible to study the microstructure at a magnification of 200 times. The structure before and after heat treatment was studied in the surface and deeper layers of the metal.

3. The results of studies and their discussion

Tensile tests of the metal were carried out to determine the main indicators of mechanical properties and to compare these properties in the initial and heat-treated state.

The values of the following characteristics were determined: ultimate strength (σ\text{u}), yield point (σ\text{y}), relative elongation (δ\text{r}), relative contraction (ψ\text{r}).

The measurement results are shown in Table 3.

|                      | σ\text{u}, MPa | σ\text{y}, MPa | δ\text{r}, % | ψ\text{r}, % |
|----------------------|----------------|----------------|--------------|--------------|
| The initial state    | 564.1          | 344.7          | 19.4         | 60           |
| Annealing            | 461.7          | 298.2          | 24.2         | 60           |

The tensile curves of steel samples are shown in Figure 1.

![Figure 1. Tension curves of St3 specimens in the initial and heat-treated state.](image)

The results of the tests carried out showed that the samples without heat treatment have higher strength properties than the heat-treated samples.

Determination of hardness at its moderate values on products of small thicknesses, as well as when using a steel ball as an indenter, the number of hardness HRB is determined on the B scale, i.e. at P_0 = 98 H, P_1 = 882 N, P = 980 N. Rockwell hardness number for the B scale is recorded as HRB. Table 4 shows the results of measuring the hardness of steel samples.
Table 4. Results of hardness measurement

| Measure number | The initial state | Annealing |
|----------------|------------------|-----------|
|                | HRB  | HB    | HRB  | HB    |
| 1              | 88   | 170   | 83   | 152   |
| 2              | 88   | 170   | 84   | 156   |
| 3              | 89   | 174   | 84   | 156   |
| 4              | 88   | 170   | 84   | 156   |
| average        | 88.25| 171   | 83.75| 155   |

Looking at the data presented, we can draw a conclusion. That after annealing, the St3 structure acquired low hardness and strength, but high plasticity.

Microstructural analysis of the steel was also performed. The microstructure is shown in Figure 2-3.

The structure of the steel is ferrite-pearlite. In the initial state, there is a light segregation banding. The structure of St3 in the initial state is fine-grained. After annealing, it becomes more homogeneous, and the deformation texture disappears. The decarburized areas, which in the initial state are visible as light areas of ferrite, increase the grain size upon annealing to form large ferrite grains.

4. Conclusions

As a result of the studies (tensile and hardness tests), the main mechanical properties of St3 steel in the initial and heat-treated state were determined. The ultimate strength in the initial state was 564.1 MPa, the hardness was 171 HB, in the heat-treated state, 461.7 MPa and 155 HB, respectively.
As a result of conducting annealing of the II kind at a temperature of 880°C, the grain size increased in comparison with the initial state.

As a result of the conducted microstructural analysis, it was revealed that the structure of the steel is ferritic-pearlite. In the initial state, there is a light segregation banding and segregation streamer. The structure of St3 in the initial state is fine-grained. After annealing, it becomes more homogeneous, and the deformation texture disappears. The decarburized areas, which in the initial state are visible as light areas of ferrite, increase the grain size upon annealing to form large ferrite grains.

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