Effect of annealing temperature on corrosion resistance of metal steel samples St52-3

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Abstract. In the context of increased pace of modern production, the role of heat treatment is increasing, as it is the main method for producing steels with a given structure and mechanical properties. Parts used in production must have a long service life not only at room temperature, but also have high strength characteristics at low and high temperatures. In this regard, special attention is paid to steel used for the manufacture of such parts. One of them is steel grade St52-3 (rus 17Г1С). The aim of the work was to determine the effect of quenching at various temperatures onto corrosion resistance of St52-3 steel. To achieve this goal, tasks such as studying the effect of different tempering temperatures of St52-3 steel on the value of hardness according to the Rockwell method were undertaken. After-treatment gravimetric studies were performed to identify the temperature regime of tempering that minimizes the corrosion rates. It was shown that after tempering, the hardness of the samples decreases with increasing temperature. To assess the corrosiveness of the medium for the test samples, the mass and depth corrosion indicators were calculated. The maximum corrosion rate is observed during quenching and subsequent tempering at a temperature of 300 °C, the minimum at a tempering temperature of 500 °C.

1. Introduction

During a heat treatment a change in the structure of the metal occurs as a result of heating to a certain temperature and cooling, resulting in a change in the metal’s mechanical and physical properties [1–4].

The use of St52-3 steel is extensive due to its high strength indicators, satisfactory mechanical properties in various temperature ranges [5, 8]. After heat treatment, this steel acquires various properties [6, 7]. Steel St52-3 is used in mechanical engineering and in many other industries. So a number of metal structures are made of this steel, for example, pipelines for transporting various liquids and gases, various machine parts, steam boilers, oilfield equipment, tanks.

To bring the tests closer to the actual operating conditions of the metal structures after the heat treatment, the steel samples are immersed in the corrosive medium of a 3% NaCl solution. Most often, the corrosion rate is determined by the gravimetric method or by the weighing method [9–12]. Its essence consists in measuring the surface area of the samples in contact with an aggressive environment, weighing them before and after testing at a fixed exposure time [13, 14].

2. Experimental procedures

The paper presents the test results on samples of steel grade St52-3. This steel is low-alloyed silicon-manganese structural steel.
To study the hardness of steel, hardening was carried out, followed by tempering. Samples of St52-3 steel were loaded into a furnace heated to a temperature of 950 °C, held at this temperature for 35 minutes for uniform heating and complete recrystallization, and then instantly cooled in water.

After quenching, the end surfaces of the samples were cleaned from scale with sandpaper to a metallic lustre. The hardness values are presented in table 1.

Table 1. Hardness value of samples after quenching.

| Steel grade | Heating temperature, °C | Cooling method   | HRC 1 | HRC 2 | HRC 3 | Av. |
|-------------|-------------------------|------------------|-------|-------|-------|-----|
| St52-3      | 950                     | instantly in water | 16    | 16.1  | 15.9  | 16  | 214.5 |

The tempered exemplars were exposed to annealing at various temperatures, for this purpose exemplars were located in the furnaces heated to temperatures of 100, 200, 300, 400, 500 °C. Further exemplars were maintained at these temperatures for 35 minutes, then taken out from furnaces and cooled on quiet air.

After cooling, the released samples were cleaned with sandpaper to a metallic luster and hardness was measured. The values obtained are listed in table 2.

Table 2. Hardness of samples after tempering.

| Steel grade | Heating temperature, °C | Cooling method | HRC 1 | HRC 2 | HRC 3 | Av. |
|-------------|-------------------------|----------------|-------|-------|-------|-----|
| St52-3      | 100                     | On air         | 22.3  | 22.7  | 21.8  | 22.3 | 239 |
|             | 200                     |                | 20.1  | 20.1  | 19.8  | 20.4 | 230 |
|             | 300                     |                | 18.7  | 18.7  | 18.2  | 19.1 | 222 |
|             | 400                     |                | 15.9  | 14.5  | 15.3  | 15.2 | 212 |
|             | 500                     |                | 12.8  | 12.4  | 12.2  | 12.5 | 199 |

Hardness is the most important characteristic of the mechanical properties of materials and testing for it is one of the most common types of testing.

Hardness is the property of a material to resist the penetration of another, more solid body (indenter) into it. A tip made of hardened steel, diamond or hard alloy of various shapes (ball, cone, pyramid, needles) was used as an indenter. The hardness of the material was determined on a special device - a hardness tester [5-10].

The main components of the hardness tester are a bed, a work table, an indenter, a loading device, and a device for measuring the amount of deformation. The essence of the method (GOST 9013–59) for measuring Rockwell hardness consists in pressing an indicator with a diamond or carbide cone with an angle at the apex of 120 °C or a hardened steel ball with a diameter of 1.5875 mm into the surface of the material.

The rate of corrosion was determined with the gravimetric method, by the loss of mass of metal samples during their stay in the test medium. Figure 1 (a, b) shows the studied samples placed in a solution of 3% NaCl before and after exposure.

To study the influence of the heat treatment of St52-3 steel on its corrosion resistance, samples were weighed with an analytical balance, then their initial mass m₁ was recorded after heat treatment with an accuracy of 10⁻⁴ g, then their area was determined, kept in a corrosive environment. Exposure
time is 168 hours. After exposure of the samples in a corrosive environment, it is necessary to remove them from flasks, rinse with distilled water, then clean the surface from corrosion products and determine the weight of the samples (weighing on an analytical balance) \( m_2 \) with an accuracy of \( 10^{-4} \) g.

![Figure 1. Type of test samples immersed in 3% NaCl: a - samples at the initial stage of the experiment; b - samples after exposure.](image)

3. Results and discussion

To determine the hardness, one sample was selected after quenching, as well as five samples after tempering. The hardness of the samples was determined by the Rockwell method. At least three measurements were performed on each sample. As a result, it was found that the maximum value of hardness is observed after quenching and subsequent tempering at 100 °C, the minimum value at tempering temperature is 500 °C.

In order to evaluate the aggressiveness of the corrosive medium acting on the test samples, the mass and depth corrosion indicators are calculated.

During gravimetric tests, the corrosion rate is described with the mass indicator \( K_m \) (g/m\(^2\)-h). This indicator establishes how much the mass of the sample under investigation is referred to as a unit of time and the surface area of the metal as a result of the corrosion process.

Mass corrosion rate is calculated by the formula:

\[
K_m = \frac{m_1 - m_2}{S \cdot T}
\]
where $m_1$ is the initial mass of the sample, g; $m_2$ is the mass of the sample after the test, g; $S$ is the surface area of the sample, $m^2$; $\tau$ is corrosion time, h.

Using the depth indicator of corrosion, you can identify the depth of corrosion damage over a specified period of time. It is calculated by the formula:

$$P = \frac{K_m}{\rho} \cdot 8,76$$

(2)

where $\rho$ is the density of the metal, g/cm$^3$.

To assess the impact of a corrosive medium on the test samples, the mass and depth corrosion indicators were calculated. The results are listed in table 3.

| Type of HT | Heating temp., ºC | Hardness, HRC | $m_1$, g | $m_2$, g | $\Delta$m, g | $K_m$, g/m$^2\cdot$h | $P$, mm/year |
|------------|-------------------|---------------|---------|---------|-----------|-------------------|-----------|
| Annealing  | 100               | 22.3          | 59.27   | 59.24   | 0.03      | 0.0668            | 0.0743    |
|            | 200               | 20.1          | 57.69   | 57.66   | 0.03      | 0.0571            | 0.0635    |
|            | 300               | 18.7          | 59.01   | 58.98   | 0.03      | 0.0728            | 0.0810    |
|            | 400               | 15.2          | 59.34   | 59.31   | 0.03      | 0.0678            | 0.0754    |
|            | 500               | 12.5          | 59.19   | 59.16   | 0.03      | 0.0667            | 0.0742    |

Figure 2 shows the dependencies of the corrosion depth index ($P$) on the heat treatment temperature.

![Figure 2. Depth corrosion index versus tempering temperature.](image)

As it can be seen from the post-heat-treatment data, an increase in the hardness of the test samples after quenching is observed. According to the obtained experimental data, it is also seen that after tempering, the hardness of the samples decreases with increasing temperature.

4. Conclusion
In the work, heat treatment was carried out, which resulted in a change in the structure of the metal and, as a result of this, a change in its mechanical and physical properties.

Steel St52-3 is fine-grained and contains a small amount of carbon. These two factors allow this steel to have a significant viscosity reserve, which allows you to vary the temperature of the heat
treatment, and therefore to control the phase composition. Heating under quenching to a temperature of 950°C allows austenite to be obtained with increased homogeneity without increasing grain size. Slightly lowered tempering temperature allows, in turn, obtaining higher strength characteristics without fear of reducing plastic properties. As a result, it was found that the maximum value of hardness is observed after quenching and subsequent tempering at 100°C, the minimum tempering temperature is 500°C. The increase in strength during low-temperature tempering is explained by the tempering of St52-3 steel. This phenomenon, apparently, is associated with the presence of an alloying component in it, namely, chromium, which is confirmed by GOST 1050-88 Carbon structural quality steel gauged bars with special surface finish. General specifications.

After quenching of the samples at a temperature of 950°C, the corrosion rate was 0.0756 mm/year. The highest corrosion rate after tempering was observed for a temperature of 300°C, it amounted to 0.0810 mm/year.

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