pISSN:2349-5707 Volume:13,Issue 4, April -2026 eISSN:2349-5715

THE INFLUENCE OF THERMAL TREATMENT PROCESS ON THE STRUCTURE AND MECHANICAL PROPERTIES OF STEEL

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Abstract

This study explores the effects of heat treatment on the microstructure and mechanical properties of steel. The research involved applying quenching and tempering processes to various steel samples. The microstructure before and after quenching was examined using the Oxion Inversion OX.2653 PLMi metallographic microscope. Hardness was measured using the THBRV-187.5DX testing device. The results show that cooling rate, heating temperature, and cooling media have a direct impact on the resulting structure. It was found that the formation of metastable structures such as martensite, sorbite, and troostite significantly improves the mechanical strength of steel

Keywords
Steel, heat treatment, quenching, tempering, microstructure, martensite, sorbite, troostite, austenite, hardness, cooling rate, metallography, mechanical properties, structural transformation, thermal process.

Introduction

Heat treatment processes for metals radically change their phase state and the resulting mechanical properties. Steels are the most widely used materials in technology, and heat treatments such as quenching and tempering are widely used to control their properties. The main goal of thermal treatment is to achieve the required strength, hardness and brittleness limits by controlling the microstructure.

Based on the iron-carbon phase diagram, equilibrium structures such as ferrite, pearlite, cementite and austenite are formed in slowly cooled steels. In practice, metastable (non-equilibrium) states such as martensite, troostite and sorbite are more important, since they have high mechanical properties. Tempering is a method of obtaining metastable structures by heating steel to a certain temperature and cooling it at a certain rate. The cooling rate ensures the transition from austenite to martensite, i.e., a phase change without diffusion. If the cooling is slow, pearlite, sorbite, or troostite are formed as a result of diffusional changes.

The hardness and structure of steel depend on the quenching regime (temperature and cooling rate), the quenching medium (water, oil, nitrate), and the composition of the steel. For example, the martensite structure is acicular, very brittle, and has high hardness (HB 500–650).

Quenching is used to soften the quenched steel and reduce internal stresses. It is divided into three types: low (150–300°C), medium (300–500°C), and high (500–700°C). Depending on the temperature, the microstructure transforms into quenched martensite, troostite, or sorbite.

In this work, the microstructure and hardness of steels, which change during heating at high temperatures and cooling in various cooling environments, were studied. These processes are of great importance for the mechanical strengthening of materials widely used in mechanical engineering.

pISSN:2349-5707 Volume:13,Issue 4, April -2026 eISSN:2349-5715

All changes in alloys according to the iron-carbon phase diagram occur with slow cooling and are completely completed at the temperatures indicated in the diagram, resulting in equilibrium structures (ferrite, austenite, pearlite, cementite):

In practice, it is of great importance to obtain metastable unstable steel structures with higher strength and hardness, but with reduced ductility. For this purpose, quenching is often used in mechanical engineering and railway transport enterprises, and tempering is used to regulate properties.

By changing the heating and cooling regimes of steel, it is possible to change its phase structure on a large scale without changing its chemical composition.

Tempering is a type of heat treatment that involves heating steel to an optimum temperature, holding it there, and then cooling it at a certain rate to obtain an unbalanced metastable structure.

Tempering requires rapid cooling to the temperature at which austenite transforms to martensite, and cooling is not carried out over the entire temperature range, but only within the range of 650-400^{0}C, that is, in the temperature range where austenite is least stable and rapidly transformed into a ferrite-cementite mixture. Above 650^{0}C, the rate of austenite transformation is low, and therefore, during tempering, the mixture can be cooled slowly in this temperature range, as ferrite separation or austenite transformation into pearlite begins.

The mechanism of action of the quenching medium (water, oil, water-polymer quenching medium, as well as cooling of parts in salt solutions) is as follows.

The product is immersed in the quenching medium, a superheated vapor layer is formed around it, cooling occurs through this vapor layer, that is, relatively slowly. When the surface temperature reaches a certain value (determined by the composition of the quenching fluid), the vapor layer breaks, the liquid begins to boil on the surface of the part and cooling occurs rapidly.

The first stage of relatively slow boiling is called the film boiling stage, the second stage of rapid cooling is called the bubble boiling stage. If the surface temperature of the metal is below the boiling point of the liquid, the liquid can no longer boil and cooling slows down. This stage is called convective heat transfer.

The structure of the quenched steel depends on its chemical composition and the quenching regime (heating temperature and cooling rate):

The cooling rate is of great importance in the heat treatment of steels, since with rapid continuous cooling, austenite decomposes with the formation of the following structures, namely sorbite, troostite and martensite: They are called metastable or non-equilibrium structures.

Depending on the cooling rate, the processes of diffusional decomposition of austenite or its non-diffusional transformation can be observed. With slow cooling at a rate of up to 10C/s, austenite turns into a coarse ferrite-cementite mixture - pearlite, the hardness of pearlite is 180-250 HB.

Diffusional nature of austenite decomposition

Austenite decomposes during rapid continuous cooling, forming the following structures: sorbite, troostite and martensite.

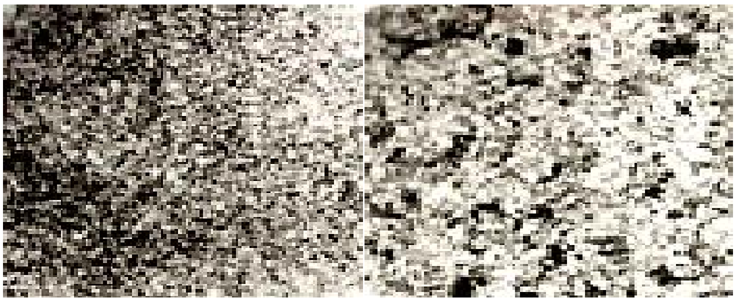
Troostit - 1 soniyada 80-100^{0}Cgacha sovutish tezligida austenitning parchalanishi paytida hosil boʻladigan struktura. Troostitning HB qattiqligi 350-450ni tashkil qiladi. Troostit tuzilishga (1b-rasm) konstruksion poʻlatlar toblangandan soʻng va moyda sovitilganda yoki toblab 350-450^0 C haroratda oʻrta boʻshatishda ega boʻladi.

Sorbite is formed during the decomposition of austenite at a cooling rate of up to 50^{0}C per 1 second. The hardness of sorbite is 250-300 HB. The sorbite structure (Fig. 1a) is observed

pISSN:2349-5707 Volume:13,Issue 4, April -2026 eISSN:2349-5715

in structural steels after quenching in oil and during high, and 500-6800C, tempering of quenched steels.

Troostite is a structure formed during the decomposition of austenite at a cooling rate of 80-100^{0}C per second. The HB hardness of troostite is 350-450. The troostite structure (Fig. 1b) is obtained by quenching structural steels after quenching and oil cooling or by tempering at a temperature of 350-450^{0}C.



a *b*

Figure 1. Microstructure of sorbite and troostite quenched structural steels.

Non-diffusional decomposition of austenite.

When the cooling rate is 150-180^{0}C per second, diffusional decomposition of austenite becomes impossible, in which case austenite transforms into martensite due to non-diffusional decomposition, that is, decomposition occurs at a very fast cooling rate. Martensite (Fig. 2) is a supersaturated solid solution of carbon in α-iron, characterized by a needle-like structure, high brittleness and high hardness HB 500-650.

Figure 2. Martensite microstructure at a cooling rate of 150–180^{0}°C/s.

The structure of the steel obtained after quenching depends on the cooling rate and the heating temperature. In fully quenched pre-eutectoid steel, martensite is formed, which when examined under a microscope has a small-sized needle-like structure. The martensite structure of post-eutectoid quenched steel has small-sized needles, which are difficult to distinguish under a low and medium magnification microscope. Pearlite, sorbite, and troostite, formed during the diffusion decomposition of supercooled austenite, are ferrite-cementite structures, have a plate-like structure and differ only in the degree of fineness of the structure. Sorbite and troostite, unlike pearlite, do not have equilibrium structures. Tempering is a heat treatment process in which the forged steel is heated below the Ac1 critical point, held at this temperature, and then cooled. The changes in the structure that occur depend on the tempering mode.

There are three types of tempering: low, medium, and high. Low-temperature tempering - heating the forged steel to temperatures of 150-300^{0}C. At such temperatures, the steel structure remains in the form of a modified lattice - tempered martensite. Medium-temperature tempering - heating the forged steel to temperatures of 300-500^{0}C. At these temperatures, the steel

pISSN:2349-5707 Volume:13,Issue 4, April -2026 eISSN:2349-5715

structure consists mainly of tempered troostite. High-temperature tempering - heating the forged steel to temperatures of 500-700^{0}C. At these temperatures, the steel structure consists mainly of tempered sorbite.

Methods and Materials

Various steel samples;

-equipment: STA 1700 high-temperature furnace, THBRV-187.5DX hardness tester, Oxion Inversion OX.2653 PLMi metallographic microscope;

Steps performed:

1. Initial microstructure and hardness were measured.
2. Steels were heated to the required temperature for tempering.
3. Cooled in cooling media (water, oil, saltpeter).
4. After heat treatment, microstructure and hardness were measured again.

The procedure for testing the change in the microstructure of steel during thermal processing using an Oxion Inversio OX.2653 PLMi inverter metallographic microscope and mechanical properties (hardness) using a THBRV-187.5DX hardness tester is carried out in the following stages:

1. Initially, the hardness of the existing steel samples is determined using a THBRV-187.5DX hardness tester.
2. The initial microstructure of the sample is studied using an Oxion Inversion OX.2653 PLMi inverter metallographic microscope.
3. After determining the thickness of the samples, the quenching and normalizing time for a sample with a diameter and thickness of 1 mm for 1 minute (for carbon steels) is calculated.
4. The steel sample is normalized and fully quenched. The samples are heated to the required temperature in a high-temperature STA 1700 furnace, held hot, and then cooled in air or water.

Results and Discussion

According to the experimental results, significant changes were observed in the microstructure of the heat-treated steel samples. Depending on the cooling rate and the type of environment, different structures (martensite, troostite, sorbite) were formed. The samples cooled rapidly in water had a martensite structure and showed the highest hardness (around HRC 60). The samples cooled in oil had troostite and sorbite, and their hardness was medium (HRC 40–50). The samples cooled in nitrate formed high-temperature released sorbite, and the hardness was lower. This indicates that the heat treatment regime has a significant effect on the mechanical properties.

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