Project Report: Heat Treatment of Medium Carbon Steel

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Abstract

This project investigates the effects of four fundamental heat treatment processes—annealing, normalizing, quenching, and tempering—on the mechanical properties and microstructure of a medium carbon steel. Samples were subjected to controlled thermal cycles, and the resulting changes were quantified using Rockwell hardness testing and analyzed through optical microscopy. The results demonstrate a strong correlation between the cooling rate, the resulting phase transformation, and the material's final ha...

1. Introduction

Medium carbon steels are widely used in engineering for components like gears, axles, and shafts because their properties can be precisely controlled through heat treatment. This process involves controlled heating and cooling to alter a material's internal crystalline structure, known as its microstructure. The primary goal of this experiment is to practically demonstrate and quantify how different cooling rates after heating the steel into its austenite phase region (≈850°C) directly influence its fina...

2. Experimental Methodology

Materials and Equipment: Five identical samples of AISI 1045 medium carbon steel; Muffle Furnace; Water and Oil as quenching media; Rockwell Hardness Tester (C-scale); and Optical Microscope with metallographic preparation equipment (grinding, polishing, 2% Nital etchant).
Procedure: 1. A baseline "as-received" sample was analyzed for control. 2. The remaining four samples were heated to 850°C and held for 60 minutes to ensure a uniform austenitic structure. 3. Cooling Cycles Executed: - Annealing: Slow furnace cool overnight. - Normalizing: Cooled in still, ambient air. - Quenching: Rapidly submerged in a water bath. - Tempering: The quenched sample was reheated to 450°C, held for 60 minutes, and cooled in air. 4. Post-Treatment Analysis: The hardness of each sample was measured, and its microstructure was examined after metallographic preparation.

3. Results

Hardness Measurements:

Sample Treatment	Average Hardness (HRC)
As-Received (Control)	22
Annealed	15
Normalized	28

Quenched	55
Tempered	48

Microstructural Analysis:
- As-Received: A standard structure of light ferrite and darker, layered pearlite. - Annealed: Slow cooling resulted in coarse pearlite and large ferrite grains. - Normalized: Moderate air cooling resulted in a more refined fine pearlite structure. - Quenched: Rapid cooling trapped carbon to form a hard, brittle, needle-like structure called martensite. - Tempered: Reheating the martensite formed tempered martensite, a structure that reduces brittleness while retaining high hardness.

4. Discussion & Conclusion

The results clearly demonstrate that the final mechanical properties of the steel are a direct function of the microstructure, which is controlled by the cooling rate from the austenitic phase.
The hardness increase from annealed (15 HRC) to quenched (55 HRC) is attributed to the phase transformation from pearlite to martensite. The strained, needle-like martensite structure provides significantly more resistance to dislocation motion, thus increasing the material's hardness. Tempering provides a balance, slightly reducing the hardness to 48 HRC but improving the material's toughness by allowing some of the trapped carbon to precipitate into fine carbides.
In conclusion, this experiment successfully demonstrated that significant and predictable improvements in a material's mechanical properties are achievable through the precise application of heat treatment cycles.