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Effect of thermal stresses on mechanical properties of structural materials (AH36 and Q235B) in crude oil tanker applications

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Abstract: This research investigates the effect of heat treatment on the mechanical properties of two structural materials, AH36 and Q235B, with a focus on their hardness, stress-strain behavior, and ductility. The study aims to evaluate how heat treatment influences these properties and to determine the suitability of these materials for different engineering applications. Both materials were subjected to heat treatment, and their mechanical properties, including ultimate stress (σmax), yield stress (σyield), ultimate strain (εmax), and hardness, were evaluated before and after the treatment. The results demonstrated significant changes in both materials as a result of heat treatment. For AH36, the yield stress (σyield) before heat treatment was absent, reflecting a gradual transition from elastic to plastic deformation. After heat treatment, the yield stress increased to 231 MPa, indicating a more uniform microstructure. The ultimate stress (σmax) decreased from 445 MPa to 428 MPa after heat treatment, while the ultimate strain (εmax) increased from 28.45% to 30.80%, showing improved ductility. Hardness values for AH36 decreased from 164 HRB to 154 HRB after heat treatment, reflecting a decrease in strength and an increase in ductility. For Q235B, the yield stress was found to be 434 MPa before heat treatment and decreased to 276 MPa after treatment, indicating a loss in strength and an increase in ductility. The ultimate stress decreased from 432 MPa to 424 MPa, and the ultimate strain remained nearly constant, with only a slight decrease from 20.13% to 20.00%. The hardness values for Q235B dropped from 146 HRB to 128 HRB after heat treatment, indicating a reduction in strength and an increase in material flexibility. The findings highlight that heat treatment leads to a decrease in hardness for both materials, which corresponds to an increase in ductility. The heat-treated AH36 demonstrated improved performance in dynamic loading conditions, while Q235B showed enhanced flexibility and resilience after heat treatment. These results suggest that AH36 is more suited for applications requiring high ductility, while Q235B remains effective for applications requiring higher strength and hardness before heat treatment. In conclusion, this study provides insights into the influence of heat treatment on the mechanical properties of AH36 and Q235B, helping to guide material selection for various engineering applications based on the desired balance between strength, hardness, and ductility. This abstract summarizes the effect of heat treatment on two commonly used structural materials, highlighting key changes in mechanical properties and their implications for practical applications.

Keywords: *AH36, Ductility Mechanical properties, Hardness, Heat treatment, Q235BUltimate stress, Yield stress.*

1. Introduction

In materials engineering and industrial applications, studying the mechanical properties of metals is essential for understanding their performance and selecting them for various applications. Among the

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key tests performed on metals are the tensile test and the hardness test, [1, 2] which reflect the material's ability to withstand mechanical forces and operating conditions.

Heat treatment is one of the processes used to improve or modify the properties of metals by heating and cooling them in a controlled manner. This process causes changes in the microstructure of materials, which directly affect their mechanical properties, such as strength and hardness [3].

In this study, two types of metals were selected for testing:

1. AH36: A high-strength steel primarily used in the marine and shipbuilding industries, known for its excellent stress and corrosion resistance [4].
2. Q235B: A low-carbon steel commonly used in engineering and construction applications, recognized for its excellent weldability and formability [5]. The objective of this study is to analyze the effect of heat treatment on the tensile strength and hardness of these two types of metals that can be used in marine or structural industries. By comparing the results before and after heat treatment, the study aims to provide insights into the behavior of these materials and determine their optimal applications.

2. Literature Review

2.1. Introduction

The studies focus on the thermal and mechanical stresses affecting crude oil tankers, analyzing the internal components of the tanks to understand the impact of temperature variations, mechanical loads, and sea conditions.

Hechtman [6] highlighted the impact of thermal stresses on ship structures caused by temperature differences. It found that uneven thermal expansion can lead to stress concentrations, risking structural failure. The study stressed the importance of considering thermal stresses in design and material selection to ensure ship safety and durability. Yucel and Arpaci [7] performed an analysis of free and forced vibrations in ship hulls using the finite element method. The study showed that free vibrations are affected by natural frequencies, while forced vibrations result from external forces such as wave loads, highlighting the importance of understanding them to improve ship design and performance.

Silva, et al. [8] studied the ultimate strength of rectangular steel plates subjected to random localized corrosion. The research, published in Engineering Structures, focused on the effect of localized corrosion on the structural integrity of steel panels. The data showed that corrosion significantly reduces ultimate strength, underscoring the importance of considering it in the design and maintenance of structures, especially in marine environments, to ensure safety and long-term performance.

Cheon, et al. [9] investigated the thermal and metallurgical behavior of GMA-welded AH36 steel within a CFD-FEM framework. The study focused on modeling thermal behavior during welding and the resulting metal transformations. It was concluded that the computational framework accurately predicts heat distribution and microstructure formation in welded steel, which contributes to improving welding techniques, enhancing material properties, and increasing the performance and safety of welded structures, especially in marine applications. Yamamoto [10] evaluated the fatigue performance of ship structures, focusing on the effect of mean stress variations. The research, published in Welding in the World, underscores the importance of considering these changes to improve the accuracy of assessments. The results showed that accounting for mean stress fluctuations enhances the accuracy of fatigue stress predictions, which improves the reliability of the long-term structural integrity of ships. Demirbas [11] performed thermal stress analysis of isotropic panels with temperature-dependent material properties based on elasticity theory. The study focused on the effect of thermal gradients on stress distribution and structural integrity. The results showed that understanding these stresses is essential for designing materials in engineering applications exposed to variable thermal conditions.

Guedes and Schellin [12] studied nonlinear effects on wave-induced loads in tankers, revealing that nonlinearities impact stress distributions and call for better structural design and fatigue analysis in harsh marine environments. Lehmann and Peschmann [13] evaluated the energy absorption of steel structures during collisions, emphasizing that enhancing steel designs improves ship safety and integrity during accidents.

Soares, et al. [14] focused on fatigue damage in ship structures, showing that considering long-term stress distribution improves design and maintenance strategies, enhancing durability and safety. Vel and Batra [15] conducted a three-dimensional analysis of thermal stresses in functionally graded plates, emphasizing the importance of material composition and temperature distribution for improving performance under varying thermal conditions.

2.2. Summary

The research examines thermal and mechanical stresses in crude oil tankers, focusing on high temperatures, fluid movement, and structural integrity. Advanced tools like ANSYS and ABAQUS were used to analyze stress distribution and material behavior, aiming to improve tanker design and efficiency in harsh conditions.

3. Materials and Methods

In this section, we will discuss the materials used and the methods followed to conduct tensile and hardness tests, along with the heat treatment process.

3.1. Materials

3.1.1. Metals Used

AH36 (High Strength Steel): A type of steel primarily used in shipbuilding and marine structures. It is known for its high stress and corrosion resistance. It contains a low carbon content with the addition of elements like manganese and silicon, which enhance its strength.

Q235B (Low Strength Carbon Steel): A type of low-strength carbon steel used in industrial constructions and structural frameworks. It is known for its high formability and weldability, but it is less stress-resistant compared to AH36.

3.1.2. Chemical Properties of Each Metal

3.1.2.1. AH36

Carbon (C): 0.18 Manganese (Mn):0.9 Silicon (Si): 0.1 Phosphorus (P): 0.035 Sulfur (S): ≤ 0.035 [4].

Q235B:

Carbon (C): ≤ 0.22% Manganese (Mn): 0.30% - 0.70% Silicon (Si): ≤ 0.30% Phosphorus (P): ≤ 0.045% Sulfur (S): ≤ 0.045% [16].

3.2. Methods

3.2.1. Sample Preparation

- Samples of AH36 and Q235B were prepared with equal dimensions for testing purposes and Hardness test. The samples were shaped according to international standard specifications [17, 18].
- The samples were divided into two groups: one set before heat treatment and another set after heat treatment.

3.2.2. Heat Treatment

Heat treatment was applied to the samples to enhance their mechanical properties. The process involved heating to a specific temperature (600°C) followed by cooling (normalizing), depending on the type of metal and the requirements [19].

3.2.3. Tensile Test

- The tensile test was performed according to international standards [20]. The sample is gradually loaded until failure to measure the ultimate tensile strength and elongation (deformation).
- The following values are measured:
- Ultimate Tensile Strength
- Yield Strength
- Elongation

3.2.4. Brinell Hardness Test

- The Brinell hardness test was conducted using a Brinell hardness tester, which involves pressing a 2 mm diameter steel ball onto the metal surface under a load of up to 180 kg [21].
- The hardness is calculated using the following equation [22]:

$$HB=\frac{2P}{\pi D\sqrt{D^2+d^2}}$$

Where:

- HB is the Brinell Hardness.
- P is the load (in kilograms).
- D is the ball diameter (2 mm).
- d is the actual diameter of the impression.

3.3. Statistical Analysis

After collecting the data, statistical analysis was performed to compare the samples before and after heat treatment. The comparisons included tensile strength and hardness values to determine the main effects of heat treatment on mechanical properties.

4. Result

In this section, the results of the tensile and hardness test for pre- and post-heat data will be reviewed forAH36 AND Q235B.

4.1. Result Tensile of Test.

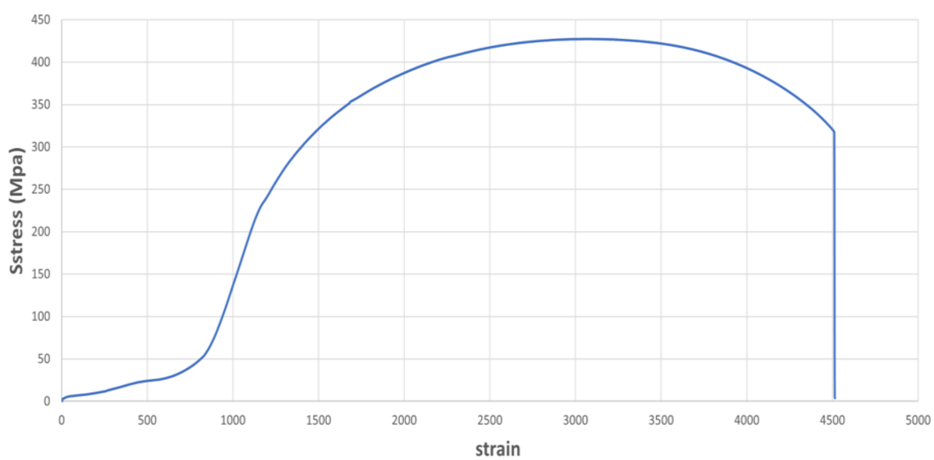

Figure. 1.
AH36 after heat treatment.
Source: Universal Testing Machine [23].

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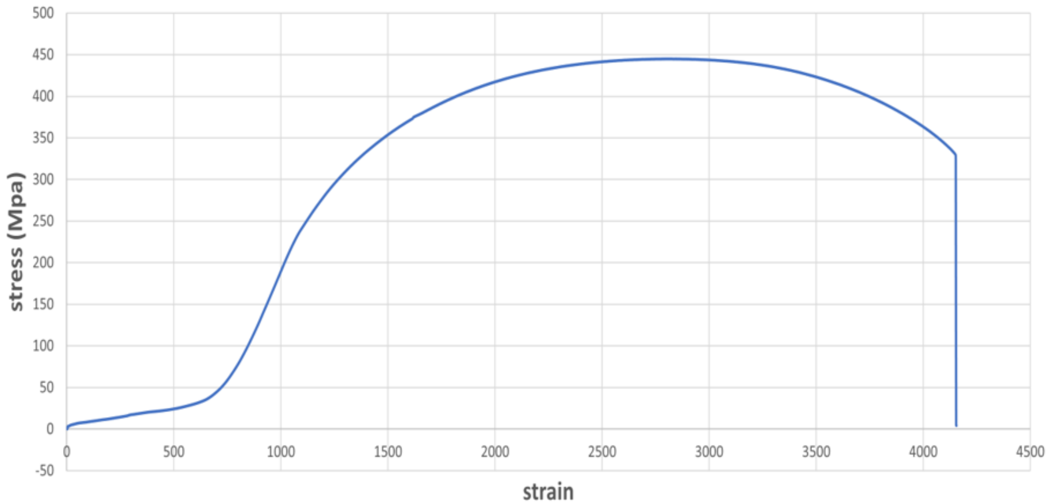

Figure 2.
AH36 before heat treatment.
Source: Universal Testing Machine [23].

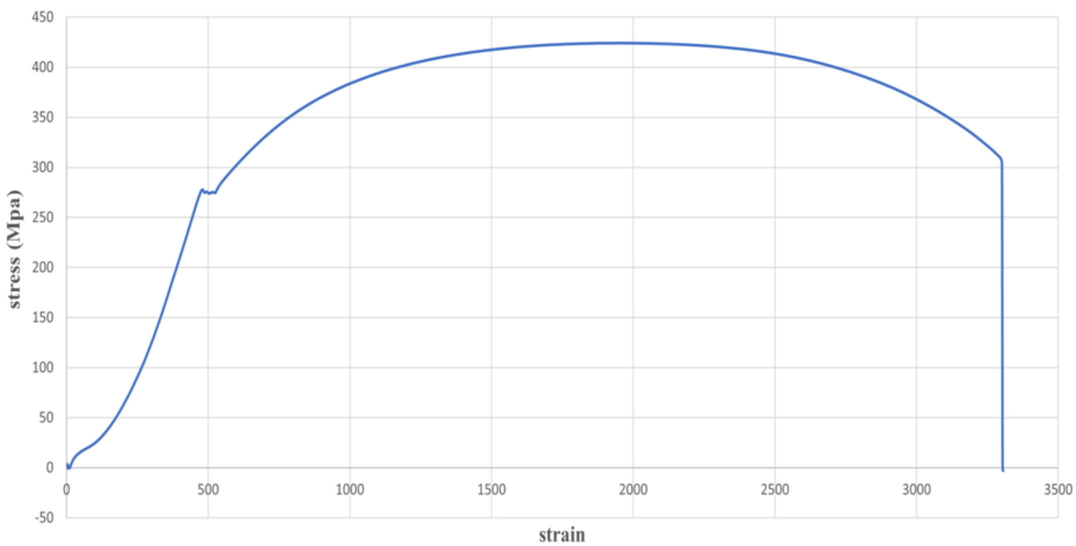

Figure 3.
Q235B after heat treatment.
Source: Universal Testing Machine [23].

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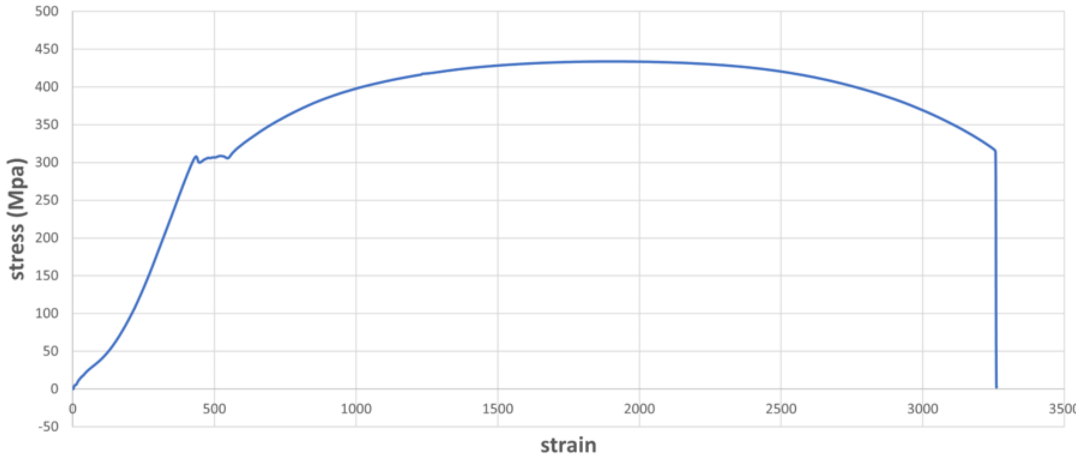

Figure 4.
Q235B befor heat treatment.
Source: Universal Testing Machine [23].

4.2. Result Hardness Test

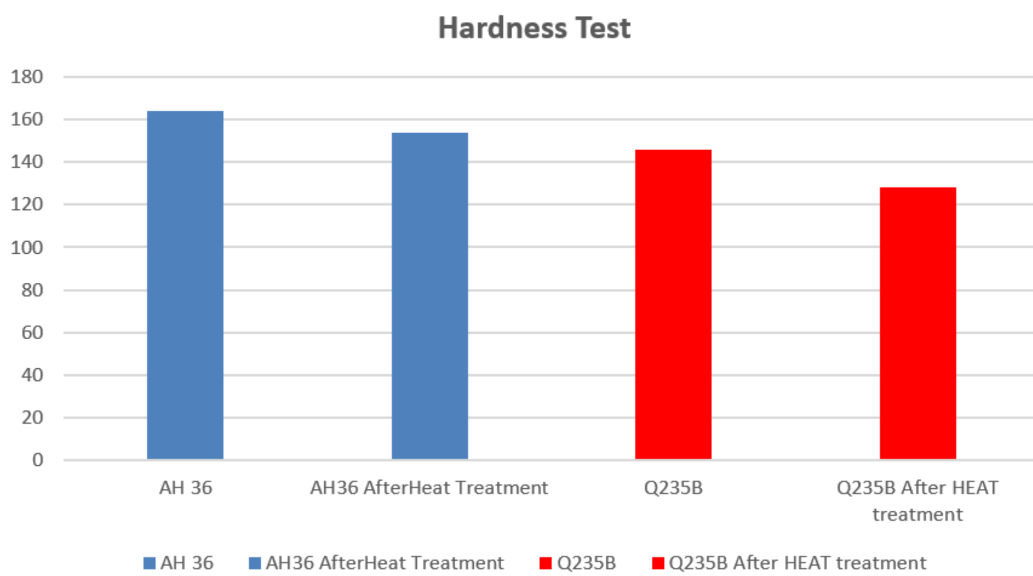

Figure 5.
Hardness Test.
Source: Brinell Hardness Tester Foundrax 1340 [21].

5. Results and Discussions

5.1. Effect of Heat Treatment on the Studied Materials

Heat treatment showed a clear effect on the mechanical properties of both AH36 and Q235B. The changes in microstructure due to heating and controlled cooling led to alterations in stress (σ) and strain (ε), affecting their performance under loading.

5.2. Stress Behavior and Yield Stress

5.2.1. Before Heat Treatment

- AH36 exhibited a clear absence of yield stress (σ_Y) due to the nature of its microstructure and its design to withstand dynamic loads, resulting in a gradual transition from elastic to plastic deformation.
- Q235B showed a high yield stress, with σ_Y around 434 MPa.

5.2.2. After Heat Treatment

- AH36 showed a clear yield stress point after heat treatment, with σ_Y of 231 MPa, indicating improved microstructural uniformity.
- Q235B experienced a significant decrease in yield stress, where σ_Y after heat treatment was 276 MPa, reflecting a decrease in hardness and an increase in ductility.

5.2.3. Ultimate Stress and Ductility

- The ultimate stress (σ_{max}) decreased slightly in both materials after heat treatment:
- In AH36, before heat treatment, the ultimate stress σ_{max} was 445 MPa, while after heat treatment, it dropped to 428 MPa.
- In Q235B, before heat treatment, the ultimate stress σ_{max} was 432 MPa, and after heat treatment, it decreased to 424 MPa.

5.2.3.1. AH36 Showed a Significant Increase in Ductility After Heat Treatment

- In AH36, before heat treatment, the ultimate strain ε_{max} was 28.45%, and after heat treatment, it increased to 30.80%.
- In Q235B, the material maintained almost the same ductility:
- Before heat treatment, the ultimate strain ε_{max} was 20.13%, and after heat treatment, it remained at 20.00%.

5.2.4. Overall Performance of the Materials

AH36:

- Before heat treatment: It is suitable for applications requiring high strength and hardness, with yield stress $\sigma_Y = 0$ and ultimate stress $\sigma_{max} = 445$ MPa.
- After heat treatment: It became more ductile, with the ultimate strain increasing to 30.80%, making it suitable for dynamic applications and marine environments.

Q235B:

- Before heat treatment: It possesses high hardness and resistance to permanent deformation, with yield stress $\sigma_Y = 434$ MPa and ultimate stress $\sigma_{max} = 432$ MPa.
- After heat treatment: It lost some of its hardness, with yield stress dropping to 276 MPa, and ultimate stress decreasing to 424 MPa.

5.2.5. Practical Considerations

5.2.5.1. The Suitability of Each Material Depends on the Application

- AH36 after heat treatment is preferred for environments that require high ductility to withstand fluctuating loads, with the ultimate strain increasing to 30.80%.
- Q235B before heat treatment is ideal for applications requiring high strength and hardness to withstand static loads, with yield stress $\sigma_Y = 434$ MPa.

5.2.6. Conclusion

The results confirm that heat treatment has a significant impact on the mechanical properties of the materials, altering their performance based on the nature of the application.

- AH36 before heat treatment exhibits elastic behavior with high load-bearing capacity, while Q235B shows higher hardness and resistance to deformation before heat treatment.
- Heat treatment improves the ductility of AH36, while it reduces the hardness of Q235B.
- The appropriate treatment should be selected based on the required performance characteristics of each material under different operating conditions.

5.2.6.1. Hardness Results

1. AH36:

- Before heat treatment:
  The hardness was 164 (HRB), indicating that the material was harder before it was subjected to heat treatment.
- After heat treatment:
  The hardness decreased to 154 (HRB), reflecting a decrease in hardness and an increase in flexibility of the material as a result of the transformations in its crystal structure during heat treatment. This decrease makes the material more flexible, but with a decrease in its scratch resistance.

2. Q235B:

- Before heat treatment:
  The hardness was 146 (HRB), meaning that the material was harder than after treatment.
- After heat treatment:
  The hardness decreased to 128 (HRB), reflecting the effect of heat treatment in softening the material and increasing its flexibility.

5.2.6.2. Conclusion

- AH36 and Q235B showed a decrease in hardness after heat treatment, with the hardness of AH36 decreasing from 164 HRB to 154 HRB, while that of Q235B decreasing from 146 HRB to 128 HRB.
- This decrease in hardness reflects an increase in the ductility of the materials after heat treatment, which makes them more adaptable to changing or dynamic loads.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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