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تحليل الإجهادات الحرارية في البنية الماكروية لهيكل ناقلة النفط الخام الفولاذي

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الملخص:

تُحلل هذه الدراسة تأثير البنية المجهرية والمعالجة الحرارية على الخواص الميكانيكية لنوعين من الفولاذ المستخدم في الهياكل الصناعية (AH36) (الفولاذ عالي القوة) و(Q235B) (الفولاذ الكربوني منخفض القوة). تم تحضير عينات معدنية بأبعاد محددة وخضعت للمعالجة الحرارية، التي تضمنت تسخينها إلى 600°C يليها التطبيع (Normalizing). شمل إعداد العينات عمليات السَّنفرة، التلميع، الحفر الكيميائي، والفحص المجهري باستخدام المجهر البصري .أظهرت النتائج أن المعالجة الحرارية حسّنت تجانس البنية المجهرية، وقلّلت حجم الحبيبات، وحدّدت حدود الحبيبات بوضوح، مما أدى إلى تحسين الخواص الميكانيكية للمواد. تؤكد هذه النتائج أهمية تحسين البنية المجهرية في زيادة مقاومة الإجهاد والتآكل، وهو أمر حاسم في تطبيقات مثل ناقلات النفط الخام. توصي الدراسة باستخدام AH36 في تصميم ناقلات النفط الخام نظرًا لأدائه المتفوق مقارنة بـ.Q235B

الكلمات المفتاحية : المعالجة الحرارية • Q235B • AH36 • البنية المجهرية • الخواص الميكانيكية

Macrostructural Thermal Stresses Analysis-of crude oil tanker steel structure

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Abstract:

This study analyzes the effect of microstructure and heat treatment on the mechanical properties of two types of steel used in industrial structures: AH36 (high-strength steel) and Q235B (low-strength carbon steel). Metal specimens were prepared with specific dimensions and subjected to heat treatment, which included heating to 600°C followed by normalizing. The preparation process included grinding, polishing, etching, and microstructural examination using an optical microscope. Results showed that heat treatment improved the uniformity of the microstructure, reduced grain size, and clarified grain boundaries, thereby enhancing the mechanical properties of the materials. The findings highlight the importance of these improvements in increasing the stress and corrosion resistance of steel, which is critical for applications such as crude oil tankers. The study recommends the use of AH36 in the design of crude oil tankers due to its superior performance compared to Q235B.

Keywords • Heat treatment • AH36• Q235B•Microstructure • Mechanical properties

1.ntroduction

A crude oil tanker is a vessel designed to transport unrefined oil from production sites to refineries or distribution centers worldwide. These ships are essential to global oil trade but pose environmental risks, particularly through oil spills, which heavily pollute oceans and coastal areas. Studies highlight the need for effective measures to minimize their impact on marine ecosystems.[1][2] The relationship between the microstructure of materials and their physical and mechanical properties is a fundamental topic in materials science and engineering. This area focuses on understanding how the regulation of atoms and crystalline defects within materials affect their diverse performance and functions. By studying crystalline defects, granular boundaries, and composite materials, a material design with improved properties that meets the requirements of modern industries is reached. Advanced characterization techniques, such as electron microscopy and X-ray diffraction, also play a pivotal role in the analysis and study of microstructure, contributing to the development of new materials with advanced properties.[3] In modern mechanics, the integration of microstructure with continuum models is an important step in understanding and analyzing complex materials. This field focuses on the study of materials that possess microscopic structures that significantly affect their mechanical and physical behavior. This approach allows a more accurate description of materials that cannot be ideally represented as homogeneous continuums, such as composite materials or materials with nanoproperties. By combining traditional concepts of connected mechanics and microstructure, a comprehensive framework is offered for the study of phenomena such as diffusion, torsion, and deformation at different scales, opening up new avenues for designing materials with improved performance in advanced engineering applications.[4]

2.Literature Review

2.1. Introduction

Recent research has focused on the structures of crude oil tankers, examining the challenges they face, including thermal and mechanical stresses from both the oil inside and external sea conditions. Studies have analyzed the internal components of the tanks to understand the effects of temperature changes, mechanical loads, and vibrations. Yamada et al. (2005) [5] conducted a numerical study on the effectiveness of buffer bow structures in reducing ship-to-ship collision damage. The study showed that these structures absorb more energy during impact, improving ship safety in collisions. Paik (2007) [6] examined oil tanker structures designed according to the IACS common structural rules. The study concluded that these rules ensure safety and stability under extreme conditions, preventing catastrophic failures. Lin et al. (2009) [7] investigated vibration control in ship structures, highlighting the importance of controlling vibrations to maintain structural integrity and comfort, as well as reduce fatigue damage for long-term performance. Matsunaga et al. (2009) [8] analyzed the stress in functionally graded plates under thermal and mechanical loads. The study found that the interaction of these loads significantly affects stress distribution, emphasizing the importance of precise analysis for structural integrity. Ahmmad and Sumi (2010) [9] studied the strength and deformation behavior of corroded steel plates under tensile loading. The findings showed that corrosion reduces the strength and deformability of steel, stressing the need for regular maintenance, especially in marine environments.Yue et al. (2010) [10] focused on optimizing cargo oil heating systems in tankers to enhance operational efficiency. The study highlighted that efficient heating prevents crystallization and improves cargo flow, safety, and operational performance.Yip et al. (2011) [11] assessed the effectiveness of double hulls in minimizing oil spills, confirming their role in reducing spillage by adding an extra protective layer in case of accidents.

The study on double hull designs showed their effectiveness in reducing oil spillage during vessel accidents. These structures provide an additional layer of protection, improving marine environmental safety.Lee et al. (2011) [12] investigated the effect of induction heating on thick metal plates, emphasizing the need for precise control during heating to maintain material integrity. Kalogeropoulos et al. (2012) [13] studied thermal stress in steel joints and highlighted the importance of thermal stress analysis for ensuring the structural integrity of steel structures. Cho et al. (2013) [14] examined the effects of thermal loading on tanker structures, noting that temperature differences could lead to stress areas that may cause material fatigue or structural failure. They concluded that thermal loading should be considered in the design and maintenance of tankers for long-term durability and safety.

2.2 Summary

Research over the past decades has focused on understanding the thermal and mechanical stresses on crude oil tankers, using advanced simulations and programs like ANSYS and ABAQUS. Studies have examined stress distribution, heat effects, and vibrations on tanker structures, aiming to improve their design and safety. The research also tested various metals used in tanker construction to enhance material efficiency under harsh conditions. This thesis aims to further analyze the mechanical and thermal properties of two key metals to improve tanker performance and lifespan.

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:

• **AH36:**

Carbon (C): 0.18 Manganese (Mn):0.9 Silicon (Si): 0.1 Phosphorus (P): 0.035 Sulfur (S): ≤ 0.035 [15]

• **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:

the specimens have dimensions of (20 × 20 × 30) mm

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 [17].

3.2.3 Grinding :The samples were grinding on the MPD200 Dual Speed Grinder Polisher, used for grinding the samples by placing water sheets (Mylar sheets). The device is made in China and is located at the University of Basra, College of Engineering, Department Chapter Four Experimental Work of Materials, Materials Laboratory. After finishing the grinding stage, the samples send to polishing.

3.2.4 Polishing: The samples were tested on the MPD200 Dual Speed Polisher, used to smooth the samples after the grinding process by using shammy paper, diamond paste, and a small amount of oil. The device is made in China and is located at the University of Basra, College of Engineering, Department of Materials, Materials Laboratory.

3.2.5 Etching :After finishing polishing stage , the samples send to Etching. Nital solutions are used for etching the microstructure. It consist of (2%Nitric Acid , 98%Ethanol).

3.2.6 Microstructure:

Examination The samples were examined on optical microscope type NOVEL device, made in China, which is an electric microscope equipped with Scopephoto software. The device is located at the University of Basra, College of Engineering, Department of Materials, Materials Laboratory, NOVEL. The samples were washed with soapy water, then immersed in a nital solution, and afterward, placed in distilled water to remove the nital, in order to capture an image of the crystalline structure.

4. Objectives:The aim of microstructure tests is to study the internal composition of materials to understand its impact on their physical and mechanical properties, after and before heat treatment. Performance improvement, defect detection.

5. Result and Discussion: In this section, the results of the microstructure test for pre- and post-heat data will be reviewed forAH36 AND Q235B.

5.1 Q235B :

Fig. (5.1) Q235B 40X and Fig. (5.2) Q235B 50X highlights the microstructure of Q235B steel before and after the heat treatment procedure (according to theformula). In the micrograph shown in Fig. (5.1) Q235B 40X and Fig. (5.2) Q235B 50X the raw material consists of large and visible areas of ferrite (α), which have a bright appearance, while around it are scattered small and irregular

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areas of pearlite (P), which appear dark and do not show clear boundaries. In contrast, Fig. (5.3) Q235B 40X heat treatment and Fig. (5.4) Q235B 50X heat treatment shows the microstructure after the material has undergone heat treatment. It is clear from the image that the structure is made up of fine ferrite-pearlite grains with very clear grain boundaries, which is due to the increased cooling rate during the rapid cooling process, which contributed to improved homogeneity and identification of granules.

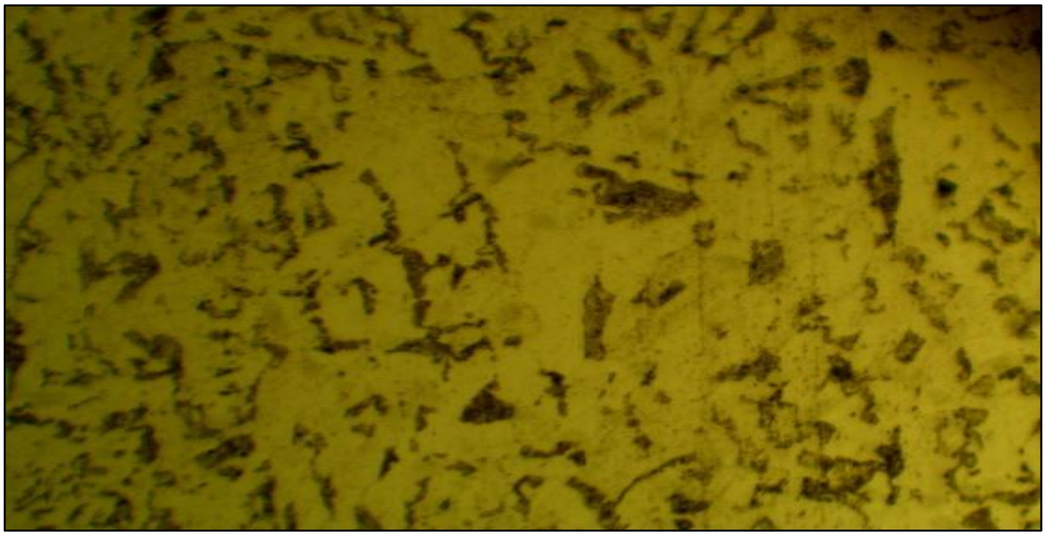

Fig. (5.1) Q235B 40X

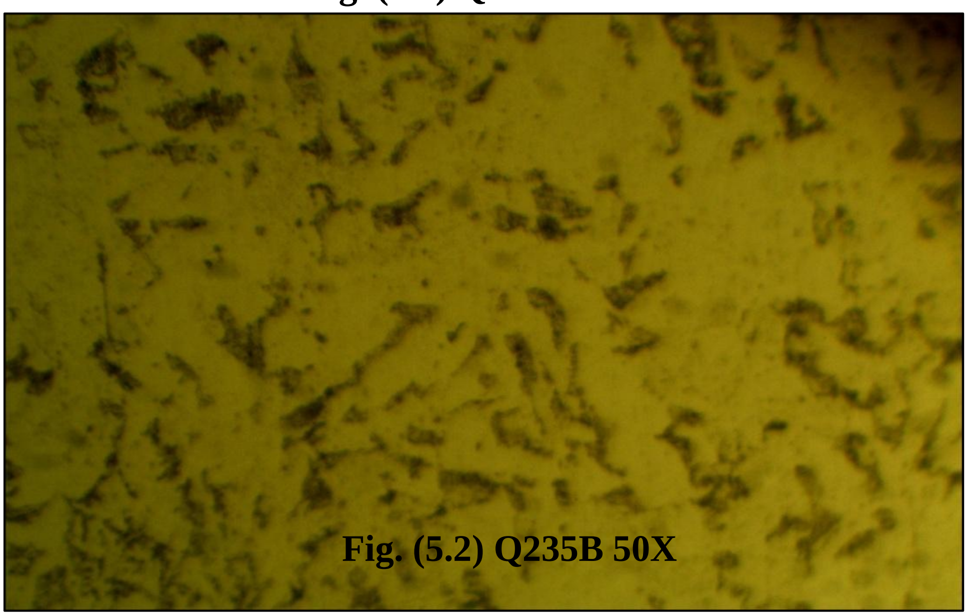

Fig. (5.2) Q235B 50X

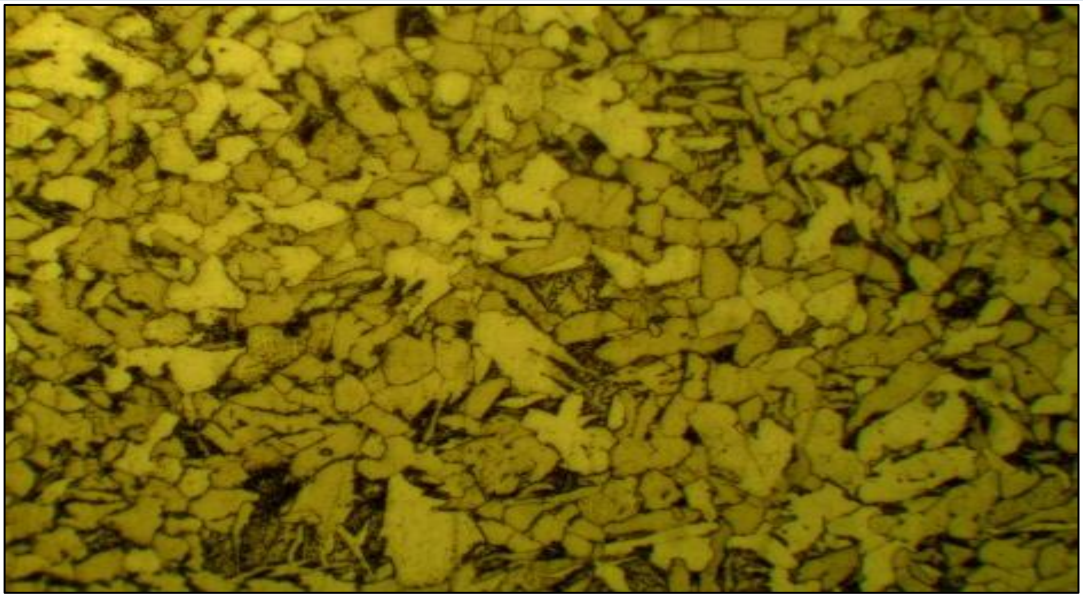

Fig. (5.3) Q235B 40X Heat Treatment

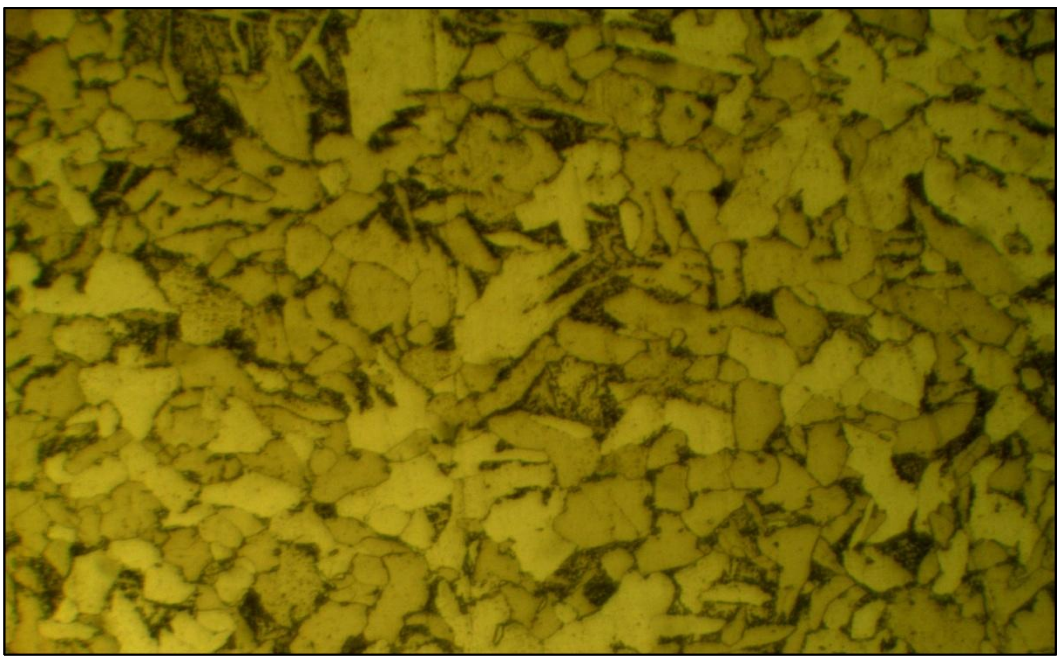

Fig. (5.4) Q235B 50X Heat Treatment

5.2 AH36

Fig. (5.5) AH36 40X and Fig. (5.6) AH36 50X illustrate the microstructure of AH36 steel prior to heat treatment, showing large areas of ferrite (α) with a shiny appearance, surrounded by small, irregular areas of perlite (P) that appear dark and blurred in boundaries. After heat treatment, as shown in Fig.(5.7)AH36 40X and Fig.(5.8) AH36 50X , the microstructure changes to produce fine grains of ferrite and perlite with clear boundaries. This change is due to an increase in the cooling rate during the rapid cooling process, which contributed to improved homogeneity and better granule identification. The difference between Q235B and AH36 lies in the grain size, which is due to the chemical composition and carbon content of both metals.

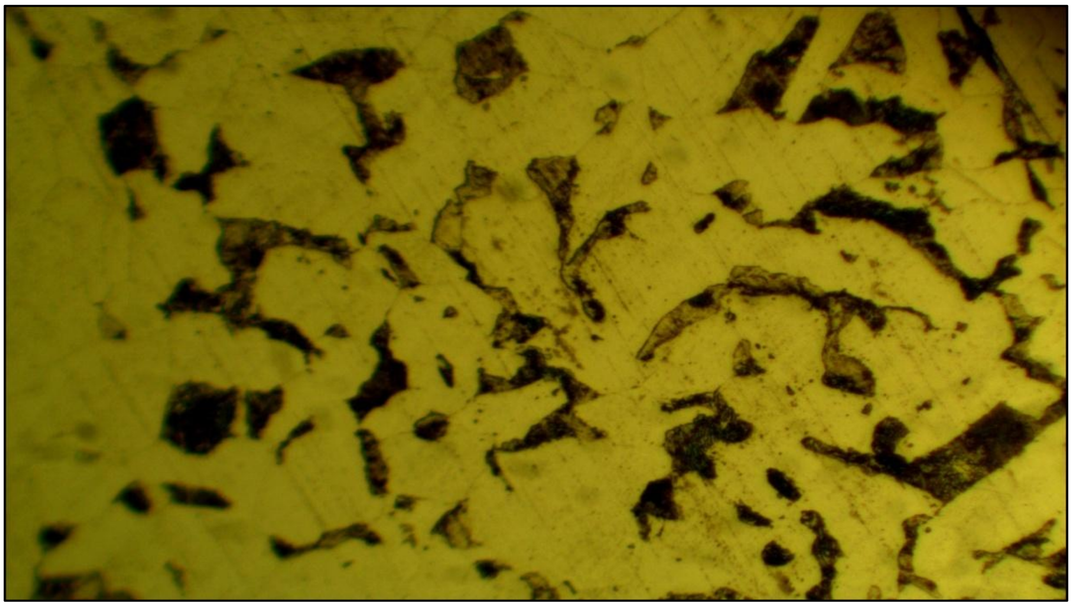

Fig. (5.5) AH36 40X

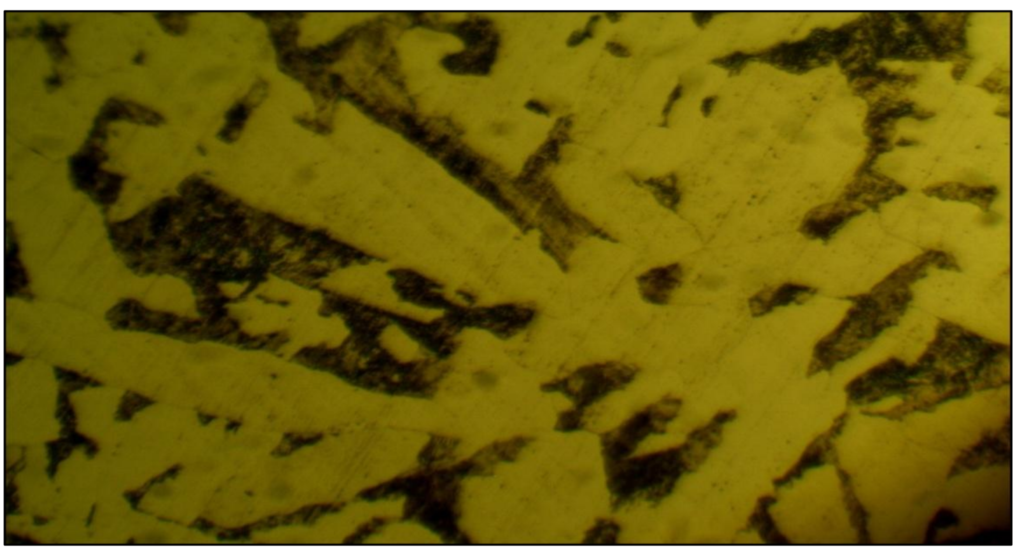

Fig. (5.6) AH36 50X

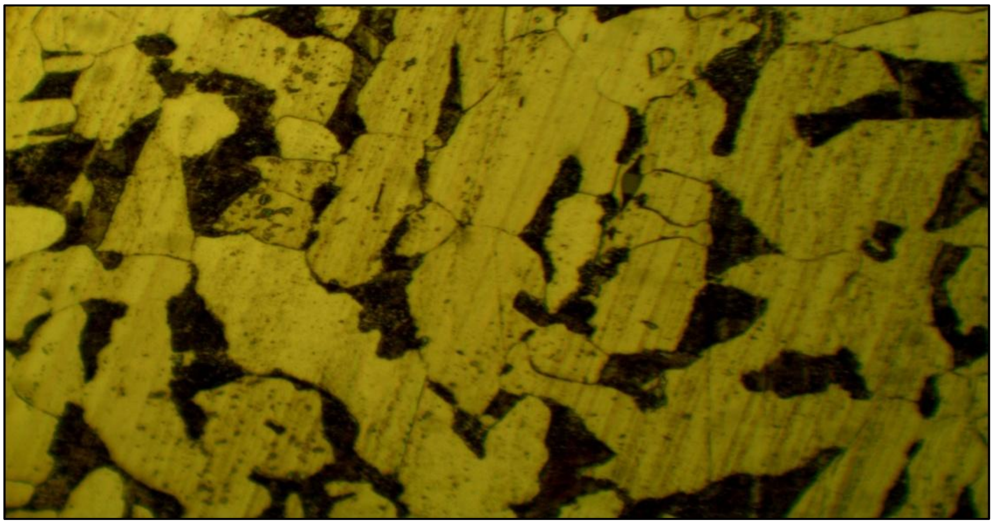

Fig. (5.7) AH36 40X Heat Treatment

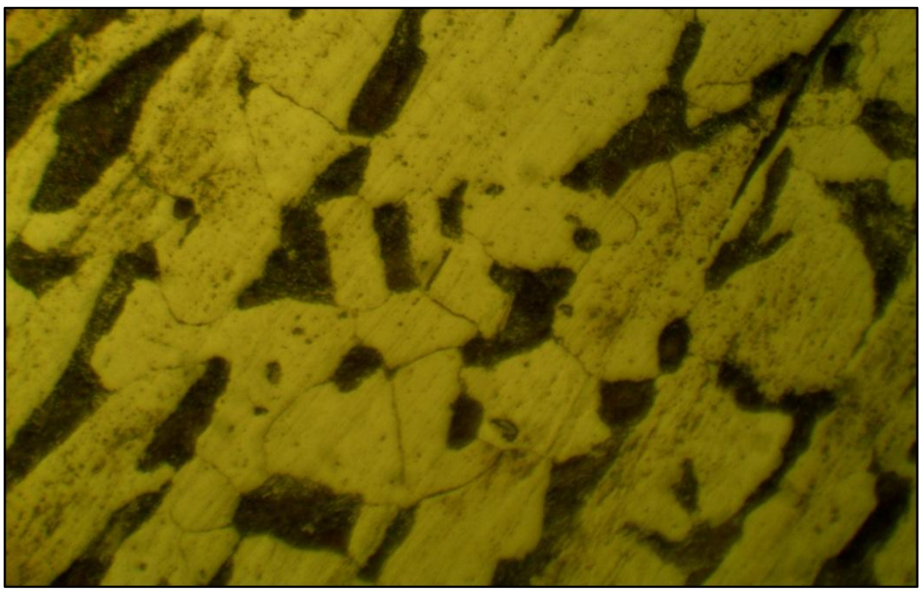

Fig. (5.8) AH36 50X Heat Treatment

Conclusion:

This study highlights the importance of microstructure and heat treatment in improving the mechanical properties of steel used in marine applications, particularly crude oil tankers. Microstructural analysis results revealed that heat treatment contributed to grain size reduction and increased uniformity, leading to enhanced material resistance to stress and corrosion. AH36 steel demonstrated superior performance due to its higher resistance, making it an ideal choice for crude oil tankers operating in harsh environments. The study enhances the understanding of the relationship between microstructure and mechanical properties and recommends applying appropriate heat treatments to meet performance requirements in marine structures. These findings can serve as a reference for improving the design of materials used in crude oil tankers, contributing to their efficiency and increasing their operational lifespan.

Recommendations:

1.Use AH36 steel in crude oil tankers due to its high resistance to stress and corrosion.

2.Apply heat treatment to improve microstructure and enhance durability.

3.Conduct regular microstructural examinations to monitor changes in mechanical properties.

4.Test materials under simulated marine conditions to ensure performance.

5.Study the development of new steel alloys to enhance corrosion and stress resistance.

6. Strengthen collaboration between researchers and the maritime industry to develop innovative solutions.

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15. The results were obtained from testing using the SPECTROPROT device, available at the University of Basra, College of Engineering, Department of Mechanical Engineering, Mechanics Laboratory.

16. The results were obtained from testing using the SPECTROPROT device, available at the University of Basra, College of Engineering, Department of Mechanical Engineering, Mechanics Laboratory.

17. The furnace is called HYSC, with a temperature capacity of up to 1200°C and equipped with a timer system, made in South Korea. It is located in the Mechanics Laboratory, Department of Mechanical Engineering, College of Engineering, University of Basra.