Experimental and Numerical Analysis of Deep Cryogenically Treated Weldox700 Steel Used Hatch Opening Crane Hooks

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Keywords：FEM, Weldox700 steel, cryogenic treatment, mechanical properties, numerical analysis, tensile strength

ABSTRACT

In this study, a special hook for hatch opening cranes, which provide the opening and closing of the hatches in the hold areas of ships, has been designed. The static analysis of the modelled special crane hook was carried out using the Finite Element Method (FEM) to determine the negative effects on the hook under static loading conditions. High strength Weldox700 steel was used for the hook material. To improve the mechanical properties of the hook, Conventional Heat Treatment (CHT), complementary by Deep Cryogenic Treatment (DCT), Deep Cryogenic Treatment and Tempering (DCTT) were applied. After these heat treatments, some mechanical properties of the test samples were analysed for the improvement of the material strength of the hook and the sample with optimum improvement was selected. As a result of the study, experimental data were analysed using the ANSYS 2019 R2 analysis program with the FEM analysis to determine the safety factor of the yield strength of the hook under the loading conditions of the hook. After the heat treatment of the test samples, there was an improvement of 59.71% in yield strength and 33.58% in tensile strength. Under the loading conditions of the hook, it has shown 6.37 times safety factor after DCT process.

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INTRODUCTION

In the marine industry, the hatch opening crane hook is a critical component of cargo lifting and handling processes in the marine industry. This hook works in integration with crane systems, usually located on the deck of the ship, allowing cargo to be safely and efficiently lowered and lifted into and out of holds. Thanks to its functional design, it could adapt to the variety of cargoes carried by the ship. In addition, the hatch opening crane hook is manufactured from special metal alloys to withstand static and dynamic loads, which not only increases safety, but also allows cargo to be transported without damage (Bitiktaş, 2020).

In operational processes, the hatch opening crane hook plays a vital role with its functionality. Controlled via a crane system, the hook grips the load firmly, making it a reliable means of transport in maritime transport. The uniqueness of the hook's design is also in line with the principles of load engineering, as it optimizes the load distribution of the hook while at the same time resisting the adverse effects of sea conditions (Sitompul et al., 2024; Korucuk et al., 2024). This contributes to overcoming the difficulties that arise in the maritime industry, especially in the transport of heavy loads.

The dry cargo transported by ship is stored in these areas, known as warehouses, located on the hull of the vessel. These areas must be closed with hatch covers to prevent the ingress of factors such as sea water, rain, sun heat and to create areas on the deck (Görgün, 2022; Richards, 2025). In many different designs and functions, cranes are designed and built according to industry development and application areas. The primary challenge in the design of cranes specific applications is the development of hooks that are suitable for the intended use. In the case of hatch opening cranes, a specialized hook required (Kum et al.,2015; Saraç, 2019).

The marine industry is a vast and complex field, and the use of hatch opening crane hooks fulfils many critical functions in this industry. Firstly, these hooks have an indispensable role in the cargo transport process. They allow for the safe lifting and placing of cargo transported on cargo ships, tankers, container ships and various other marine vessels. Durable and capable of carrying many different weights and shapes, crane hooks adapt to the required safety standards and loading capacities in each new ship design thanks to advances in engineering. Especially in the carriage of heavy loads, it is critical that the loads are securely and safely attached to the crane hooks. In this context, the design and materials of hooks are constantly evolving in line with the requirements of the maritime industry. Load handling is a critical function that forms the backbone of the maritime industry. Hatch opening crane hooks play a vital role in this process, as they enable the safe and efficient handling of large tonnage cargoes. Modern cargo handling systems form the basis of commercial activities carried out on the sea, thanks to the high carrying capacity and control precision of the hooks. These crane hooks allow for the efficient manipulation of various types of cargo - from containers, bulk cargo, dangerous goods to specialized equipment transported from area to area. This is of great importance not only for the safety of the materials being transported, but also for the efficiency of the transport process. In addition, the design and functionality of the crane hook is also an important factor in the loading and unloading processes (Chaikovskaia et al., 2025). Modern crane systems are equipped with a range of hooks optimised for the weight, type and volume of the load, which guarantees maximum performance and safety in different loading scenarios.

In the production of hatch opening crane hooks, utilizes a variety of materials, including St37, St52 and St72 building steels (Şengül and Kam, 2020). These building steel materials are commonly used in the construction of ships, aircraft, and vehicles. Some hooks are manufactured from cast iron (Slahshour et al., 2025). However, the low yield strength and strength values of such structural steels result in numerous challenges (Çetinkaya et al., 2023).

Although the work carried out in the construction of hooks is functionally different, they are very similar in design and manufacturing methods.

The construction and heavy lifting industries have continuously researched materials that offer superior performance and reliability. Among the various options available, Weldox steel has emerged as a favored option for crane applications due to its outstanding properties. This paper will examine the advantages of Weldox steel such as its enhanced strength and durability, weight reduction without compromising performance, and superior weldability. In addition, it will address counterarguments regarding its cost, suitability for low demand applications and limitations in certain environmental conditions, ultimately arguing that the advantages of Weldox steel far outweigh its disadvantages. Weldox steel significantly increases strength and durability in crane applications, making it a superior choice for heavy lifting tasks. One of its most notable characteristics is its high tensile strength, which enables cranes manufactured with this material to lift significant loads without compromising structural integrity. This is particularly important in industries that require reliable performance under extreme conditions, such as construction, mining and heavy manufacturing (Zhou et al., 2025).

Finite Element Analysis (FEA) is a method used to obtain numerical analysis of a wide range of engineering problems (Berndtsson et al., 2019). In literature various types of hook designs and numerical analyses are available (Şengül and Kam, 2020; Zhou et al., 2025). In the numerical analysis of these hooks, the accumulation of stress in the material under static and dynamic loading conditions of the hook and deformation zones in the material were examined. In some literature studies, the wear behavior and breakage points of the hook that occur during loading have been experimentally studied (Şengül and Kam, 2020; Zhou et al., 2025).

The analysis of the special hatch release crane hook, which has been designed, is conducted using the Ansys 2019 R2 software program. The ANSYS software program is integrated with other cad software programs. A variety of custom hooks, including those designed in Catia and Solidworks, were created using design software and analyzed using the software. The analysis utilizes data pertaining to high-strength Weldox700 steel as the material of choice.

MATERIAL AND METHOD

Material and Mechanical Properties

In this study, Weldox700 high-strength steel is employed as material data for the static analysis of the Finite Element Method (FEM) of the hook. Table 1 presents the mechanical characteristics of Weldox700 steel.

Table 1: Mechanical properties of Weldox700 steel (Şengül and Kam 2020).

Material	Weldox700 steel
Density (g/cm^3)	7.850
Young Module (MPa)	205000
Tensile Strength (MPa)	780-930
Yield Strength (MPa)	650
Poisson Rate	0.3
Elongation (%)	14

It will examined the key benefits of heat treatments and highlight how they can improve tensile strength, hardness and ductility. Furthermore, it will touch on different heat treatment processes and highlight their various effects on mechanical properties and the resulting impact on component life and performance. However, it is equally important to address the opposing arguments surrounding heat treatments, including residual stresses, possible cost inefficiencies and the risk of neglecting material selection. By examining both sides, it can gain a comprehensive understanding of the role of heat treatments in modern engineering and materials science (Thakar et al., 2024).

Heat treatments can significantly improve the mechanical properties of materials and make them more suitable for demanding applications. In steel in this study, the transformation from austenite to martensite during quenching resulted in a material that can withstand forces greater than flexure. heat treatments can increase hardness by changing the microstructure of materials. The hardening process involves creating a fine dispersion of hard phases within the material, which inhibits dislocation movement, one of the primary modes of deformation in metals. As a result, the treated material exhibits a higher threshold against scratching and abrasion, making it more durable in applications where surfaces are subjected to intense friction or impact (Shi et al., 2022). Moreover, heat treatments increase ductility, allowing materials to deform without fracture.

It was analyzed the heat treatment processes applicable to Weldox 700 steel, explain the temperature-time dynamics involved and examine how changing these profiles can affect material performance, thus providing insights into the practical applications of Weldox 700 steel in industry. Heat treatment processes play an important role in modifying the properties of Weldox 700 steel and understanding these methods is important to achieve the desired mechanical properties. Among the common heat treatment techniques, quenching and tempering are of particular importance. Quenching involves heating the steel to a high temperature, usually between 900°C and 950°C, followed by rapid cooling, usually in water or oil. This process converts the steel into a martensitic structure, increasing its hardness. However, the resulting brittleness requires subsequent tempering, which involves reheating the steel to a lower temperature (approximately 200 °C to 650°C) to remove internal stresses and improve ductility. For Weldox 700 steel, certain parameters such as heating rate, cooling medium and tempering time are critical. These factors directly affect the microstructural properties of the steel, including grain size and phase distribution. The aim of these heat treatments is not only to increase hardness, but also to ensure a balance of mechanical properties suitable for high-stress applications. By optimizing these processes, manufacturers can tailor the properties of the steel to meet the stringent demands of various industrial applications, thus ensuring reliability and performance (Adin and Okumuş, 2022; Singh et al., 2025).

The temperature-time relationship during heat treatment is fundamental to understanding how Weldox 700 steel responds to thermal treatments. The temperature-time curve, which defines the heating and cooling rates, is critical in determining the phase transformations that occur within the steel. For example, critical temperatures for Weldox 700 steel mark transition points where the microstructure changes, particularly the transformation from austenite to martensite during quenching. This transformation is not instantaneous; instead, it depends on the time the steel spends at certain temperatures. The time duration at high temperatures affects the diffusion of carbon atoms, which is crucial for achieving the desired hardness and strength (Polekhina et al., 2025).

In this study, Weldox700 steel samples were subjected to CHT process, DCT process, and tempering process after DCT process. The mechanical properties of the material are analyzed in detail in the accompanying figure, which present the results of these samples. The safety factor of the material in static loading conditions after the manufacture of the hook has been determined by comparing the FEA results.

It has become a critical tool in understanding the complexity of engineering and physical systems. In this study, a broad review of the choice of mesh density, boundary conditions and loading conditions is presented, detailing the effects of these factors on the analysis results. The mesh density is a factor that directly affects the resolution accuracy of the model and must be carefully chosen both to optimize the information flow and to manage the computational load. A fine mesh can provide higher precision, while a coarse mesh offers faster computations, creating an important balance point depending on application preferences. The nature of the applied loads can radically affect the analysis results. Considering static, dynamic or thermal loading in accordance with the conditions observed in the field increases the validity of the results. Loading conditions are among the critical factors in structural analyses as well as in studying the behavior and durability of materials (Özorak et al., 2020). Ultimately, synthesizing these findings leads to effective results in the design and improvement of systems, providing higher reliability and accuracy in engineering applications. In this context, the elements that should be considered in the application of FEA provide innovative solutions in engineering disciplines (Aguilar et al., 2025).

In this study, 60,000 Newton static charges were applied to the hatch release crane hook in the analysis. General mesh was used as a mesh structure. Figure 1 is shown assigning and property entries for the ANSYS R2 2019 analysis program of the hook. Figure 2 illustrates the FEA of the hatch opening crane hook.

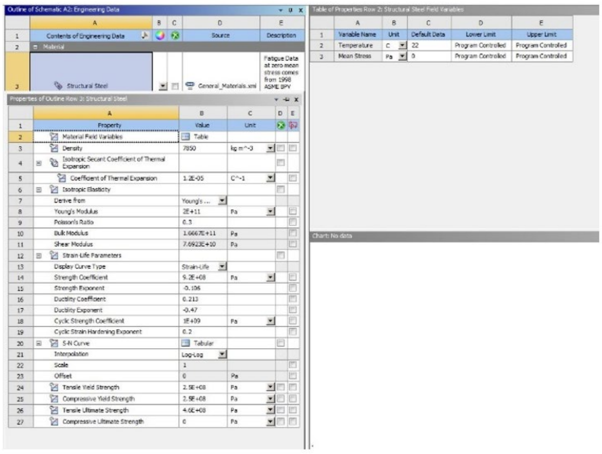


Fig. 1. Material data entry into the analysis program.

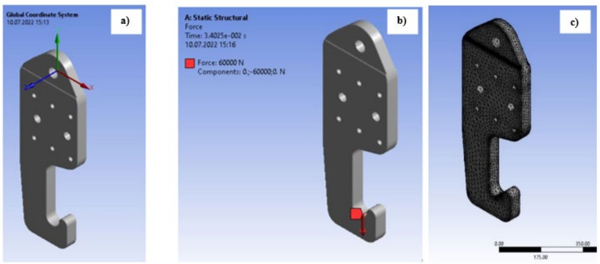


Fig 2. FEA of the hatch opening crane hook, a) Coordinate system b) Load conditions and boundary conditions, c) Mesh structure.

Experimental Study of Heat Treatments Applied to Weldox700 Steel Samples

In this study, the Weldox700 high-strength steel was selected for experimental analysis. A spectral analysis of the Weldox700 steel was conducted using an XFR spectrometer tester on LECO brand CS744 model.

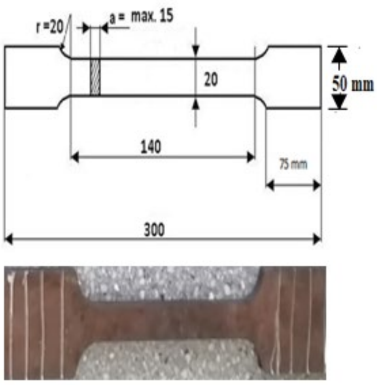
A series of heat treatments were applied to the Weldox700 steel samples. The first sample underwent standard material treatment, the second sample; underwent conventional heat treatment at 850 ºC the third sample underwent DCT process at -180 ºC for 240 minutes, followed by tempering 200 ºC for 120 minutes. Table 2 also presents the process steps and associated codes applied to the material

Table 2. Heat treatment process of Weldox700 steel samples.

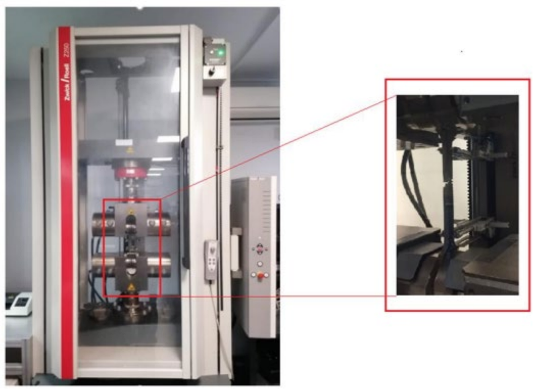
No	Sample Code	Applied Heat Treatment Process
1	S	Standard
2	CHT	Conventional Heat Treatment
3	DCT	Deep Cryogenic Treatment (240 minutes)
4	DCTT	Deep Cryogenic Treatment (240 minutes) + Tempering (120 minutes)

Upon the acquisition of data pertaining to the hardness a given the material, it becomes possible to provide a more precise assessment of its characteristics, including its toughness, yield strength, and tensile strength.

The TS EN ISO 6892-1 flat-type tensile test sample was employed for tensile testing applications, and a sample image and technical illustration of the tensile test sample are provided in Figure 3 (a). Tests were carried out on five samples for each process with the Zwick Roell Z250 brand tester, as depicted Figure 3 (b). In the tensile tests, the tensile speed was set at 2 mm/min.



(a)



(b)

Fig 3. Test devices. (a) Tensile test sample and technical drawn, (b) Tensile testing device and testing of test samples.

RESPONSE RESULTS AND DISCUSSIONS

Subsequent discussion pertains to the design of cranes intended for the opening and closing of hatch covers, as well as the use of hook and steel data Weldox700 steels in loading conidiations of 60,000 Newtons. Upon analysis of the results, the mass of the hook was determined to be 112.24 kg, the number of nodes was found to be 201.973 and the number of elements was calculated to be 127.973. Upon examination of the limit conditions of the hook, it was determined that the x-axis; length was 350mm the y-axis and length was 980 mm, and the z-axis length was 60 mm. The volume of the hook material is calculated to be 142,990,000 mm³. upon examination of the mesh structure results. It was found that the element size was 51.96 mm, the minimum edge length was 1.51 mm, the average surface area was 5402.80 mm2, and the normal angle of curvature is 70.40. The analysis results are shown in Table 3, the equivalent strain (von mises) findings and images in the loading condition are shown in Figure 4, and the total deformation findings and images are shown in Figure 5.

Table 3: Finite element analysis results.

	Maximum	Minimum	Average
Equivalent Stress (Von Mises) Analysis (MPa)	175.40	0.00306	6.096
Total Deformation (mm)	0	0.259	0.129

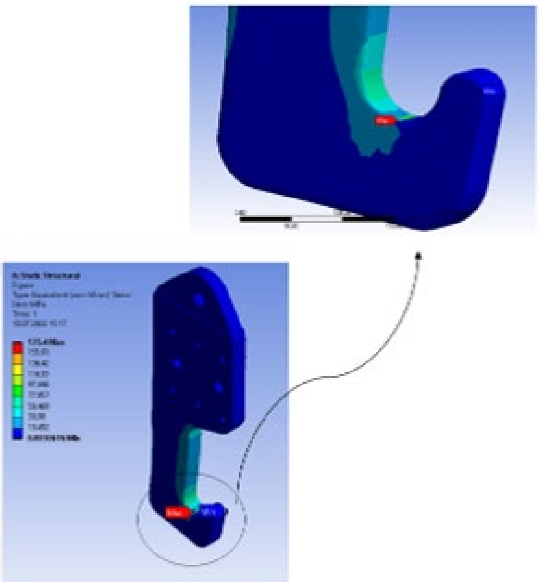


Fig 4. Stress and total deformation findings; Equivalent stress under loading condition (von mises) analysis.

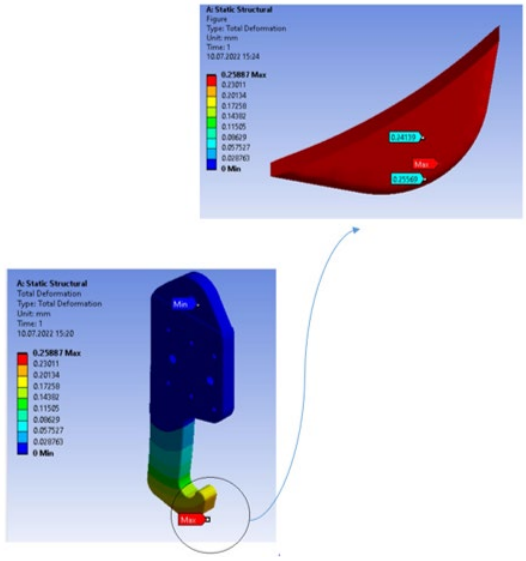


Fig 5. Stress and total deformation findings.

analysis findings of total deformation under loading condition.

The design of the hook, which was specifically created for the ANYSIS 2019 R2 software, has been enhanced and optimized through the incorporation of simulation results. The hook can withstand a 60,000 Newton loading.

The Weldox700 steel test samples were subjected to the combination of CHT and DCT holding times (240 minutes) and a tempering process for 120 minutes, in addition to the CHT process. Figure 6 illustrates the average strength values of the samples according to the heat treatment conditions.

There was a notable enhancement in the micro and macro-hardness and strength values of the samples. This can be attributed to the transformation of the austenite phase within the internal structure of Weldox700 steel with deep cryogenic treatment into a martensite phase with a hard structure, which is a consequence of the formation of a more brittle structure (Slame et al.,2025). Upon examination of the hardness values of the samples it was observed that the hardness values decreased because of the tempering process. The outcomes of tests demonstrate correlation with the findings of previous studies (Şener et al., 2021).

To determine the effect of CHT and DCT process with different holding times on the mechanical properties of weldox700 steel, tensile testing was applied to different heat-treated samples. Tests were carried out on five samples for each process. The arithmetic average values of these five samples were determined. The results obtained are shown in Figure 6. When the results were examined, the sample with the optimum level of improvement was determined as the DCT sample. The reason for the high strength values of this sample is that with DCT process, the austenite phase, which is in the soft structure found in the internal structure of weldox700 steel, turns into the martensite phase, which is in a hard structure (Yumak et al., 2022). Comparisons with literature shed light on the compatibility of the study findings with existing knowledge. While in line with this study, some new findings harbour the potential to contribute to previous understandings of heat treatment phenomena. In particular, the different microstructures obtained by applying different heat treatment strategies and their effects on mechanical properties provide important information that adds to the existing literature. Differences in the microstructure of steel provide a new perspective, especially in understanding the balance between hardness. This study provides new insights into the mechanical properties of Weldox 700 steel and the determining factors in the heat treatment process, thus supporting the optimum use of steel in engineering applications and laying the groundwork for future research (Altuntaş et al.,2024). In studies conducted in the literature, it has also been found that improvements have occurred in the mechanical properties of the DCT process and, in addition, the tempering process.

Fig 6. Tensile test results of the samples.

It has been observed that the percentage extensions given in Figure 5 are also the lowest value in the CHT sample and the highest percentage extension is in the standard unprocessed (S) sample. It is concluded that the sample of this state (S) is in a more ductile state than other samples. These results have shown that the DCT process has similarities in literature studies of strength in steel materials. According to the tensile test results, an improvement of 59.71% in yield strength and 33.58% in tensile strength was observed in the DCT sample, which showed an optimal improvement. When analyzing the results of the Weldox700 hooks of the hook and heat treatment, deep cryogenic processing and deep cryogenic treatment additional tempered samples with the FEM analysis, the result of the deep cryogenic treatment, sample has been determined to have optimum safety during loading conditions.

Figure 7 shows the safety factor changes of the hatch opening crane hook in loading conditions. Safety factors are fundamentally important for ensuring structural integrity in engineering designs. One of the key roles of safety factors is to consider the uncertainties inherent in material properties. Materials do not always behave in a predictable manner; changes in composition, manufacturing processes and environmental conditions can significantly affect their performance. By applying safety factors, engineers can create a buffer that accommodates these uncertainties and thus protects against possible failures. Moreover, safety factors provide a basic buffer against unexpected loads or conditions that a structure may encounter during its life cycle.

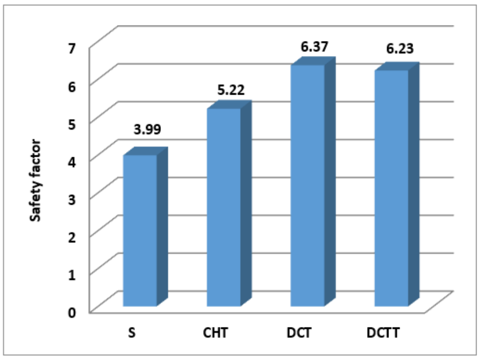


Figure 7: Safety factor and percentages of the hook in loading conditions.

It is possible to say that in the literature studies (Şengül and Kam 2020, Adin and Okumuş 2022; Shi et al. 2022), these values show consistent and similar results. The theoretical and experimental operation of the hook produced from the findings here shows that it supports each other.

CONCLUSIONS

In this study, the strength results of heat-treated weldox700 steel samples were compared with numerical analysis data by finite element method to determine some mechanical properties, especially in tensile testing.

According to the tensile test results, it has been determined that the most appropriate tensile strength is realized in the DCT sample.

According to the yield strength, the strength of the material was improved by 59.71%.

According to the tensile strength, 33.58% improvement occurred in the material.

According to the yield strength in the experimental data, when compared with the numerical analysis results, it will provide 6.37 times reliability under hook loading conditions.

It was observed that there was a significant increase in the strength values of the sample by DCT. Thanks to this, a good increase in mechanical properties was observed at a lower cost in a short time.

As the world rapidly evolves, the strategic application of design principles promises to unlock a multitude of benefits that can improve our quality of life, promote sustainable growth, and enhance global competitiveness. This study explores the anticipated future benefits of design in three critical areas: technological innovation, societal well-being, and economic growth.

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