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A Review on the Effect of Heat Treatment on Mechanical and Microstructural Properties of Steels

Samuel Ladejo[1], Samet Özdoğru[1], Mehmet Şahbaz[1*]
[1]Karamanoglu Mehmet Bey University, Faculty of Engineering, Department of Mechanical Engineering, 70100, Karaman, Türkiye

Abstract

This study is a review of studies that have investigated material changes as a result of heat treatment of the steel materials that are most commonly used in a wide range of applications. A summary is given of the steel material used in the studies, the heat treatment applied and the resultant changes in microstructure and corresponding changes in mechanical properties. It has been observed that heat treatments are applied at different temperatures and procedures to harden or soften the material. The cooling process of the material after heat treatment has also been reported in studies to affect the microstructure and mechanical properties. It has been observed that the growth of the grain structure reduces the mechanical properties, resulting in a decrease in strength and hardness values. It has also been determined that the phase transformations that occur depending on the cooling conditions of the material also affect the material properties. It has been observed that tensile, compression, flexure, impact and hardness tests are most commonly used to determine the mechanical properties of materials after heat treatment. It has been observed that optical and electron microscopes are used in the investigation of microstructural properties. In this literature review, many different heat treatments have been applied to many different types of steel and their results have been collected in a single study.

Keywords: Heat Treatment, Mechanical Testing, Microstructural Analysis, Steel.

Çeliklerin Mekanik ve Mikroyapısal Özellikleri Üzerindeki Isıl İşlemin Etkisine İlişkin Bir Derleme

Samuel Ladejo[1], Samet Özdoğru[1], Mehmet Şahbaz[1*]
[1]Karamanoglu Mehmet Bey Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği, 70100, Karaman, Türkiye

Özet

Bu çalışmada birçok alanda en yaygın kullanılan çelik malzemelerin ısıl işlem sonucu malzemede meydana gelen değişimleri inceleyen çalışmalar derlenmiştir. Her bir çalışmada kullanılan çelik malzeme, uygulanan ısıl işlem ve bunun neticesinde meydana gelen mikro yapısal değişimler ve buna bağlı olarak mekanik özelliklerindeki değişimler özetlenmiştir. Isıl işlemlerin malzemeyi sertleştirme ya da yumuşatma için farklı sıcaklıklarda ve prosedürlerde uygulandığı görülmüştür. Konu ile ilgili çalışmalarda ısıl işlem sonrası malzemenin soğutulma sürecinin de mikro yapıyı ve mekanik özellikleri etkilediği ifade edilmiştir. Tane yapısının büyümesinin mekanik özellikleri düşürdüğü, mukavemet ve sertlik değerlerinde düşüşe sebep olduğu görülmüştür. Ayrıca malzemenin soğuma şartlarına bağlı olarak meydana gelen faz dönüşümleri de malzeme özelliklerini etkilediği ifade edilmiştir. Malzemelerin ısıl işlem sonrası mekanik özellik tespitinde en sık çekme, basma, eğme, darbe ve sertlik testlerinin uygulandığı görülmüştür. Mikro yapısal özelliklerin incelenmesinde ise optik ve elektron mikroskoplarının kullanıldığı gözlemlenmiştir. Bu literatüre araştırması ile birçok farklı çelik türüne uygulanan birçok farklı ısıl işlem ve bunların sonuçları tek bir çalışmada toplanmıştır.

Anahtar Kelimeler: Çelik, Isıl işlem, Mekanik testler, Mikroyapı analizleri.

* Corresponding Author: Mehmet Şahbaz, e-posta: mehmetsahbaz1@gmail.com, ORCID: https://orcid.org/0000-0001-6379-8345
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1. Introduction

Stainless steels are preferred in various applications because they are generally corrosion resistant, resistant to high temperatures and aesthetic. Heat treatment is usually applied to modify the internal structure of the steel to relieve stresses, improve machinability, or harden the material and increase strength. Heat treatment of stainless steels is usually carried out at high temperatures, but there are some important points and limitations. Stainless steels are resistant to heat but can rust above a certain temperature. Heat treatment of steel generally consists of two steps, heating and cooling. The first is heating, in which the steel is brought to a certain zone, usually by heating. This zone produces a change in the steel crystal structure and helps to achieve the desired properties. This temperature is determined by the material and the heat treatment to be performed. The second is controlled speed cooling. The heated steel is kept at this temperature for a certain period of time and then cooled in a controlled manner. This provides the desired changes in the steel crystal structure. These processes are usually carried out in industrial furnaces and the temperature and time to be used should be determined depending on the specific properties of the steel and the application requirements. Therefore, the type of steel and intended use should be taken into account before applying the heat treatment. This study is a review of studies that have investigated material changes as a result of heat treatment of the steel materials that are most commonly used in a wide range of applications.

2. Low Carbon (Mild) Steel

The main purpose of heat treatment applications for steels is to change the mechanical properties of steels and make them suitable according to the place where they will be used. Steels can be found in a soft or hard structure depending on the carbon ratio they have. Nazma Sultana et al. (2014) used mild steel as a material for testing various mechanical properties in this study. The selected samples are subjected to heat treatment at different temperatures above the austenitic zone and left to cool with water. Later, the tempering process is applied because there will be an increase in the hardness of the cooling steel. Toughness is gained to the steel with the tempering process. Various mechanical tests are performed to examine the change in the mechanical properties of steel after heat treatment applications. In addition, the hardness of steel is measured with a hardness measuring device. As a result of the research, a decrease in tensile strength and hardness values and an increase in ductility occurred.

Aninda et al. (2023) observed the phase changes in the mechanical properties and microstructure of mild steel plates welded using electric arc welding after heat treatment. The specimens to be heat treated were selected from the steel material group in accordance with ASTM A370 standards. In the heat treatment process, firstly, preheating was performed due to the stresses in different parts of the weld zone and then full annealing was performed using furnace cooling for cooling purposes. Since the weld zone is a critical zone, Brinell hardness measurements were made from this zone after heat treatment. The results obtained from the research showed that the applied heat treatment caused an increase in the yield and tensile strength of the material. The heat treatment caused an increase in ductility and a decrease in hardness values. The microstructure of the specimens was examined using an electron microscope.

The areas of use of low-carbon steels are quite wide. Ajide and Oluwole (2018) investigated the effects of heat treatment on low carbon steels in these studies. Two different samples of these steels have been prepared for use during heat treatment. While heat treatment was applied to one of these prepared samples, no treatment was applied to the other. The heat treatment application was carried out at 850°C. After these procedures, tensile, notch impact and Brinell hardness tests were applied to the samples. The heat-treated sample has reached the highest hardness number of 434 BHN. In the notch pulse experiment, it absorbed energy in the amount of 65.43 joules. There have been changes in the grain size of the sample subjected to heat treatment. These changes have made the microstructure more stable and orderly. Thus, it was affected by this change in mechanical properties due to the effect of change in microstructure.

Steels must have low carbon density in order to be easily welded. Steels with carbon content lower than 0.22 can be welded more easily without preheating. Köse and Topal (2020) used AISI 410S ferritic stainless steel to combine it with the plasma arc welding method in their study. In this study, the effects of heat treatment applied to these steels before or after welding were examined. It has been determined that there are mechanical and microstructure changes in the welded steel samples due to the effect of heat treatment. The results obtained at the end of the study showed that the grain sizes of the welded joining steels increased, resulting in decreases in tensile strength and hardness.

A study explores the impact of cryogenic treatment and tempering temperature on AISI 431 martensitic stainless steel, focusing on microstructure and mechanical properties. Results indicate a notable increase in hardness (3.89% and 3.52%) after cryogenic treatment following conventional heat treatment. Tensile strength experiences a modest rise (1.44% and 1.18%), while yield strength sees a notable increase (up to 7.03%). Cryogenic treatment significantly enhances wear resistance, reducing wear by up to 62%. Post-cryogenic treatment, tempering at 200°C and 300°C shows no significant changes in hardness, tensile strength, or yield strength. However, tempering temperature notably influences wear resistance. The findings underscore the effectiveness of cryogenic treatment in enhancing hardness, yield strength, and wear resistance in AISI 431 martensitic stainless steel, with tempering temperature playing a pivotal role in wear resistance outcomes (Yıldız and Altan Özbek, 2022).

3. Medium Carbon Steel

Steels may have different properties according to the manufacturing procedures in which they are produced. A hot-rolled steel and cold-drawn steels may show different properties. In this study, the differences in the strength and internal structure of a hot-rolled steel and a cold-drawn steel after heat treatment were compared. The steels to be used during the heat treatment application are prepared from steels produced by cold drawing method in accordance with C1040 standards. The samples prepared for use in the experiment were subjected to heat treatment at three different temperature values. Then, the differences between these samples and Decontaminated samples were compared. Cold drawing rods have shown greater tensile strength than hot rolled rods. At the end of the research, decreases in hardness and strength values occurred in the samples that were subjected to heat treatment. The ability to shape and elongation ability have increased (Köksal, 1999).

Another study explores the impact of heat treatment on AISI 1040 and AISI 1060 steel, focusing on mechanical and microstructural changes. In AISI 1040, hardness increased solely in quenched specimens, while a decline was noted in others. Optimal strength and toughness were observed in quenched and quenched + tempered samples, respectively. For AISI 1060, tempering time had a minor effect on hardness, with tempering temperature identified as the critical parameter. Annealing and tempering times in the austenite zone minimally affected hardness. Overall, the research underscores the nuanced relationship between heat treatment parameters and mechanical properties in these steels, emphasizing the importance of specific treatments for desired outcomes in hardness, strength, and toughness (Ekşi, 2020).

Turgut (2013) in his thesis study, examined the effect of heat treatment on the microstructure and mechanical properties of the material after applying welding process to C1040 steels and heat treatment applied to welded samples and samples not subjected to welding process. The specimens to be used in the experiment are two specimens, one without welding and the other two with welding process. Gas metal arc welding and shielded electrode welding, which is a type of fusion welding, were used to weld the specimens. The specimens were subjected to full annealing, normalization annealing and stress relieving annealing. After the specimens were heated to various temperatures, they were cooled in a container filled with water or oil, thus different internal structures were formed. According to the areas of use, sometimes it is desired that the steel has a hard structure and sometimes it is desired to have a soft texture. Therefore, after the martensite transformation of the quenched steel, tempering heat treatment was applied to remove the hardness of the steel. Finally, tensile, bending, hardness and notch impact tests were performed on the samples.

Bolts are machine elements that connect machine parts and are suitable for disassembly. Since bolts are frequently used parts in the industry, it is desirable to have a long service life. For this reason, it is desired to be good in terms of material quality and performance used in bolt production. The materials used in the production of bolts are generally AISI 5140 reclamation steel with reclamation processes. The treatment process, also known as tempering and quenching, increases the hardness and strength of the part to which it is applied. Yıldız (2022) monitored the changes in the mechanical and microstructure of samples made of AISI 5140 steel with heat treatment in his experiment. During the heat treatment, the specimens were preheated in a conventional furnace at a certain temperature and then kept at 860 °C for half an hour and subjected to oil quenching. After the circular cross-sectioned shaft-shaped specimen was threaded, heat treatment was applied again, and the changes in mechanical properties were evaluated.

4. High Carbon Steel

Steels may have different properties according to their carbon content and alloying elements. The methods used in the production stage of steel are also a condition that should be taken into consideration in determining the properties of steel. Phase changes occur in heat treatment applications in steels, and these changes first include the transition to the austenite phase. This phase transformation will be one of the important factors in determining the mechanical properties and appearance of steel. Kuzyaka (2014) selected a C70-quality high-carbon steel sheet material to be used in annealing applications in this study. Heat treatment temperatures were determined from the iron-carbon diagram, and then the samples were subjected to heat treatment at these temperatures. After these processes, the specimens were tested for their strength and performance by bending, tensile, and compression tests. Experimental results showed that the bending and toughness values of our material increased.

Steels gain their hardness properties according to their high carbon content. In this respect, reclamation steels, which have an important place in this steel group, are steels suitable for hardening. Reclamation steels are divided into two groups as alloyed or unalloyed according to the presence of alloying elements. Altan Özbek and Saraç (2019) determined the material to be examined in their study as AISI 4140 reclamation steel in this steel group. The samples were heat treated at a temperature of approximately 810 °C and then cooled by quenching. After these processes, the steel samples cooled with water were subjected to tempering at different temperatures for a certain period of time. Rockwell hardness measurements were made on the tempered samples, and then mechanical tests were carried out to examine their mechanical properties. The results obtained from this study show that the samples with the lowest tempering temperature reach the maximum hardness value. With the increase in tempering temperature, the tensile and yield strength values of the samples decreased.

5. Austenitic Stainless Steel

Austenitic steel is one of the widely used steel due to its corrosion resistance, high ductility and desirable mechanical properties. Austenitic steels are commonly used in the automobile, aerospace, marine, nuclear and chemical industry. However due to the low yield strength of austenitic steels, their applications are limited. The yield strength of austenite steels can be increased by rolling at high and low temperatures. Microstructural changes of the material depend on the amount of stack fault energy. Low stack fault energy increases density of dislocation in the structure and doesn't allow dynamic recovery during deformation. The strength of a material increases with an increase in the density of dislocation, formation of mechanical twinning and strain induced martensite. This however decreases the plasticity of the material significantly. To eliminate this undesirable case annealing is done to better the ductility of deformed stainless steel. Annealing at a particular temperature transforms the martensite microstructure into an austenite microstructure (Amininejad et al., 2022).

Austenitic stainless steel, a high-alloy steel comprising chromium, nickel, manganese, nitrogen, and molybdenum, is renowned for its mechanical and corrosion-resistant properties. The formation of a passive film, primarily from chromium content, contributes to its corrosion resistance. Alloying elements such as nickel, manganese, nitrogen, and copper play vital roles in stabilizing the austenitic structure, enhancing mechanical properties, and controlling corrosion resistance. Manganese improves tensile strength and hardness, nitrogen boosts resistance to pitting and stress corrosion cracking, and copper acts as an austenite stabilizer. The passive chromium oxide layer on the steel surface provides high oxidation resistance, ensuring durability in atmospheric and acidic conditions. Austenitic stainless steel is characterized by excellent corrosion resistance, formability, and a metallic glossy appearance conferred by the transparent protective layer (Palabıyık, 2013).

To gain Knowledge on the effect of heat treatment on the microstructure of nickel free austenitic stainless steel, a solution annealing experiment is carried out on the materials. Considering industrial conditions, the process of hardening austenitic steel is not an equilibrium process. The result of this process is a two face austenite and a ferrite structure being formed. Looking at the microstructure of the ingot specimen before the heat treatment, it can be discovered that a two austenite and a ferrite microstructure was formed. It can also be seen that chromium nitrides are formed at the grain boundary in form of a precipitate or in lamellae form in the austenite grain. They also from as carbide precipitates at the grain boundary. The purpose of aforementioned experiment is to obtain a complete austenitic microstructure. The annealing process involved in this experiment removes the precipitates and the ferrite content. As the samples are heated the delta ferrite undergoes decomposition into carbides and the sigma phase (Sprecic et al., 2023).

Alloy steels produced by dispersion hardening method are expected to increase in melting point and strength values. Zhao et al. (2023) identified the dispersion hardened and strengthened austenitic steels for use in experimental methods. However, since these steels are produced by mechanical alloying, the grain size in the microstructure of ODS austenitic steels is not homogeneously distributed. This research was carried out to show how heat treatment of such steels will change the microstructure and mechanical properties. Before heat treatment, 15Cr-15Ni ODS austenitic steel was formed by cold rolling method and then subjected to heat treatment. After heat treatment, tensile test was applied to the material and the microstructure of the material was examined under the electron microscope. The results obtained from the research show that the average grain size of the material decreased after heat treatment and the grain distribution showed a more homogeneous behavior.

5.1. AISI 304 Steel

Since the properties metallic materials vary under different conditions it's very important to choose a suitable heat treatment to obtain the desired mechanical properties. The effect of quenching with and without tempering heat treatment on the microstructure of an AISI 304 austenitic steel is observed. Steels quenched from 950ºC after a holding time of 15min, reveals the presence of martensite laths, carbides as well as some residual austenite. With an increase in quenching rate it was discovered that there was no grain size increment. As seen in the chemical analysis, when air and oil was used for quenching there was a relatively significant increase in the chromium and nickel percentage. The micro structure of non-treated and quenched samples are seen to contain ferrite and martensite laths (Tukur et al., 2014).

Another study explores surface enhancement of AISI 304 stainless steel through nitriding for improved mechanical properties. Nitriding, cost-effective and versatile, offers three processes: liquid, gas, and plasma nitriding. The experimental material's composition is C-0.05 Cr-18.06 Ni-7.98 Mn-1.51 Si-0.34 Mo-0.23 S-0.04 Fe (in mass%). Microstructure evaluation utilized a Neophot 32 optical light microscope. Three-point cyclic bending fatigue tests compared untreated and plasma-nitrided samples. The unconventional 26-hour plasma nitriding process at 450°C was employed. Test samples, notch-free 55x10x10 mm bars, underwent Vibrophores Amsler 150 HFP Zwick/Roell cyclic loading with varying amplitudes at approximately 85 Hz, revealing the impact of chemical-thermal treatment on fatigue behavior (Uhríčik et al., 2023).

An investigation on the impact of pseudo spark pulsed electron beam (PSPEB) treatment on AISI 304 austenitic stainless steel, varying the number of pulses. PSPEB features rapid current growth, high power density, short pulse duration, and self-focusing is carried out. EDS analysis revealed dissolution of precipitated ferrite into the matrix, achieving a homogeneous composition. Microstructure observations demonstrated submicron grains with slip bands, replacing original coarse grains after 5000 pulses. Abundant microstructures, including dislocations and nanotwins, were induced. The micro hardness increased with pulse number, attributed to grain refinement and plastic deformation strengthening. Corrosion behavior in 5 wt.% NaCl solution indicated that the 5000-pulse-treated specimen exhibited the highest corrosion potential and polarization resistance, attributed to the homogeneous alloying element distribution in the modified layer. This comprehensive investigation highlighted PSPEB's influence on microstructure, mechanical properties, and corrosion behavior of AISI 304 stainless steel. Following fatigue tests, broken samples underwent SEM analysis to determine initiation locations, assess the micro mechanism of fatigue crack initiation, and understand evolution. Evaluation of fracture surfaces utilized a TESCAN VEGA 2 LMU scanning electron microscope. The Bruker X-ray microprobe, integrated with the SEM, aided in identifying selected particles within the structure. This comprehensive examination aimed to provide insights into the microscopic aspects of fatigue-induced fractures, offering a detailed understanding of initiation sites and crack evolution. The use of advanced microscopy tools, including SEM and X-ray microprobe, enhanced the precision of the analysis, contributing to a thorough investigation of material behavior under cyclic loading. The study aimed to ascertain the fatigue life of austenitic steels in their initial state and after plasma nitriding. Surprisingly, austenitic steel post-plasma nitriding exhibited a reduced number of cycles to fracture compared to the initial state. This difference is attributed to the higher applied load on samples subjected to plasma nitriding, impacting their fatigue performance (Cao et al., 2021).

Another comprehensive study investigates the impact of deep cryogenic treatment (DCT) on the microstructure and surface properties of AISI 304 L austenitic stainless steel across various length scales. Utilizing techniques like light microscopy, SEM, EDS, EBSD, HRTEM, XPS, and ToF-SIMS, the research reveals DCT-induced modifications, including enhanced Cr7C3 carbide precipitation, induced twinning, and α-martensite formation. XPS/AR-XPS and ToF-SIMS analyses demonstrate altered oxidation dynamics in DCT samples, with increased Fe-oxide fraction and decreased Cr-oxide fraction in the surface oxide layer compared to conventionally heat-treated samples. The evaluation of oxidation states and ions distribution, along with nitrogen diffusivity changes induced by DCT, correlates with microstructural variations. These findings contribute to a deeper understanding of how DCT influences the overall microstructure and surface behavior of AISI 304 L stainless steel (Jovičević-Klug et al., 2022).

An experiment is conducted on some samples, 10mm in diameter and 2mm thick, polished with 3µm diamond suspension. This samples passed through two treatments: ultrahigh vacuum heating and high vacuum heating. In ultrahigh vacuum, using a molybdenum holder with tungsten filament, samples reach 1200°C in 30min, treated for 10min. XPS and AES/SEM/EDX analyses follow. In high vacuum, a brazing furnace heats samples to 1150°C in 180min. AISI 304 and 446 steels are tested, some with silver-copper braze for wetting experiments. The text outlines detailed experimental conditions, temperature control, and analytical methods, emphasizing vacuum levels, heating procedures, and material choices for surface analysis and treatment. The initial spectrum of untreated samples indicates organic contamination, minimal iron (3.0%), and chromium (0.9%), with likely calcium artifacts. Post-heating, organic impurities vanish, revealing a grain structure on the steel surface with enriched iron and oxygen at grain boundaries. Auger spectra, despite surface organic presence, lacks molybdenum, sulfur, and nickel, suggesting XPS molybdenum detection is likely from the sample holder. EDX bulk analysis of UHV-heated AISI 304 confirms surface sulfur enrichment (0.5%), surpassing nominal limits, while iron content increases and chromium decreases compared to nominal composition. SEM images support these findings, highlighting the impact of in situ cleaning and heating on surface composition (Strauß et al., 2019).

AISI 304 steel underwent cold rolling and subsequent heat treatment up to 7.2×10^4 seconds at 673 K, with X-ray diffraction (XRD) and Mössbauer spectroscopy (MS) employed to assess ferromagnetic phase content. Both methods exhibited a similar trend in ferromagnetic phase content over annealing time, revealing two peaks. The initial peak was attributed to martensitic zone growth due to micro stress relaxation, inducing a stress gradient at the a%/g interface. The second peak suggested local composition variations from carbide precipitation, potentially leading to new martensitic phase formation during cooling. MS data, including increased hyperfine field and constant austenite isomer shift, along with precise XRD peak profiles, supported these conclusions. Additionally, MS measurements in cold-rolled samples indicated layers with decreasing martensite content towards the interior. The combined XRD and MS analyses provided detailed insights into the evolution of phases in the steel during heat treatment (Gauzzi et al., 1999).

AISI 304 steel, with an α'+γ biphasic structure induced by room temperature plastic deformation, exhibits an unusual martensite evolution when heated to 400 °C. High-temperature X-ray diffraction reveals a progressive martensite-to-austenite transformation during isothermal treatment. However, after cooling to room temperature, an unexpected increase in martensite content occurs. This phenomenon indicates that heat treatment induces composition inhomogeneity, leading to local increases in the martensite start temperature (MS) in alloying-depleted zones. Consequently, some martensite forms during room temperature cooling. The martensitic transformation temperature range (240–190 °C) was determined via dynamic modulus measurements, providing insights into the steel's thermal behavior (Gauzzi et al., 2006).
Due to a 0.03% carbon content difference, AISI 304 and AISI 304L are different from each other. 304L stainless steel are usually preferred because it reduce carburization. 304L stainless steels reduce carburization by reducing the negative effects of high temperature generated while machining the material. One of the common heat treatment carried out on AISI 304 & AISI 304L is recrystallization. Recrystallization brings back the properties of materials hardened due to Cold rolling to their original state. This heat treatment is performed at a temperature range of 600-700⁰C and takes about an hour. In order for this heat treatment

to be performed the material must be 10% cold formed. This is done to ensure that the material recrystallizes in a solid state without any distortion. At the end of this process the hardening of the material as a result of cold forming is removed, thereby making the material ductile and ready for another cold forming process (Çoban, 2023).

In another experiment, the microstructures of AISI 304 before and after annealing at 700⁰C for 80 min is observed. It is revealed that the grain size of the specimen before annealing is about 6.9μm, this later decreased as result 65% cold deformation. The resulting microstructure contains equated austenite grains having a size of about 1.7μm with the grain size being more uniformly distributed. From another observation, the specimen after being annealed at a temperature range of 700-850⁰C for 10, 20 and 70min. It can be clearly noticed that there is an increase in grain size. It can also be seen that the martensite volume fraction is reduced as the annealing time and temperature increased (Bakhsheshi-Rad et al., 2013).

Another heat treatment type performed on AISI 304 steel is post weld heat treatment. An experiment was carried out on three weldments. The weldments were heated in a furnace up to 1050⁰C. Weldments are then soaked at the same temperature for 30 minutes before been cooled at different speeds. After the furnace has been switched off in other to anneal the weldment sample the weldment is left the furnace to cool slowly. The second specimen was cooled in the air to normalize it. While the last was cooled rapidly by quenching with water after this it was reheated to about 400⁰C and left in the furnace to cool. The heat affected zone of all the welded joints seemed to be coarser than the weld zone. This is as a result of the rapid cooling at the weld zone this brings about better grain refinement. The heat affected zone represents a heat sink. For this reason, larger grain can be observed in this zone. The size of grain in the post annealed specimen appears to be the largest in comparison other two specimens. This is due to the slow cooling in the furnace which favors the grain coarsening. The size of grain in the post tempered specimen reduced significantly due to rapid cooling which comes after the tempering process. The weld zone of the post annealed specimen appears to have larger dendrites compared to the post tempered and base metal specimen. This is a result of the slow cooling in the furnace during the post annealing process (Abioye, et al., 2020).

6. Specific Steels

Yangaz (2019) conducted heat treatment studies on stainless steel material with the symbolic designation GX12CrMoVNbN9-1 or C12A, which is used in valves operating under high temperature conditions or other special parts. The changes in mechanical properties and microstructure changes in the material after heat treatment were investigated. In the experiment, welding process was applied to the steel before heat treatment and then annealing was performed. Tensile and hardness measurements were made after the experiment. Finally, the changes in the fracture, crack and shear bands formed in the surface structure of the part were revealed by scanning electron microscopy.

Li et al. (2023) demonstrated the mechanical and microstructural changes after heat treatment of a spring steel with 60Si2CrVNb designation. The temperatures to be applied during heat treatment were selected according to the iron-carbon phase diagram. Spring steel was heated up to 900 °C during the first heat treatment and as a result of this heating, it transitioned to austenite phase. Then, maximum tensile strength and yield limit values were obtained by tempering at 350 °C. For 60Si2CrVNb spring steel, the most efficient mechanical properties were obtained by quenching at 900 °C for 30 minutes and tempering at 400 °C for 90 minutes. As a result of the research, the tensile strength of the steel decreased while the ductility increased. Since St37 has a low carbon content, it is very efficient in terms of weldability, so its usage areas are wide. Akduman (2021) wanted to observe how the mechanical properties and microstructure of St37 steel would change after heat treatment. Four square section specimens of the same dimensions, each representing a different experiment, were prepared to be used in the experiments. Four samples were subjected to recrystallization annealing and cooled under different conditions and for different periods of time. The specimens were left alone and cooled at ambient temperature or by quenching. Mechanical tests were applied to the samples in the laboratory environment. As a result of these tests, the change in mechanical properties of the material such as tensile strength, yield limit, resistance to abrasion was examined.

6.1. Dual Phase Steels

Dual phase steels consist of ferrite and martensite microstructure phases. Dual phase microstructure is obtained by cooling in liquid nitrogen after annealing. Due to their high strength and elongation properties, these steels can be used in areas requiring high strength and forming. Since they are easy to be shaped in the automotive industry, they are used in the production of automobile parts. The parts to be used in the experiment were selected from sheet materials that do not have too much thickness. Thus, after the heat treatment is applied to our material, the temperature can be distributed homogeneously. After the annealing process, the material was cooled by the effect of ambient temperature and liquid nitrogen. The samples were subjected to mechanical tests. The results obtained at the end of the experiment show that the martensite phase of these steels increases the strength values while the ferrite phase gives a good elongation ability (Aydın, 2006).

Dual phase steels, which are very good in terms of formability and have high strength resistance, are frequently used and demanded in industrial areas. In his study, Özcan (2019) applied heat treatment or, in other words, annealing process to steels between critical temperatures and at the end of the study, a dual phase steel structure was observed. As a result of this study, it was examined how the mechanical properties of the steel will be affected when the production parameters such as annealing temperature, annealing time, cooling rate are changed during the production phase of this dual-phase steel. Tensile and notch impact tests were applied to our dual phase steel material and as a result of these mechanical tests, the effect of the change in parameters on mechanical properties was revealed. The steel material subjected to annealing treatment has a ferrite-perlitic microstructure and an increase in the strength of the steel was observed after heat treatment.

6.2. Other Steels

The microstructures of cold-drawn stainless steel wire were annealed at 700^{o}C at different times. It can be discovered that after the annealing process, the average grain size and the grain boundary density of the 33% deformed samples were significantly larger compared to the 65% and 77% deformed sample. This reveals that the recrystallization behavior of low strain stainless steel samples did not happen 700^{o}C. The 65% deformed sample even at different annealing times still had larger grains, this tells us that the deformed structure remained non-uniform under low strain. While the rate of deformation is raised to 77%, the number of large coarse grains decreased. This brought about a uniformity in grain size. With an increase in annealing time the grain size of stainless steel wire with the same amount of deformation remained the same (Xu et al., 2021).

Another study investigates the corrosion behavior of annealed stainless steel mesh subjected to thermal oxidation treatments at various temperatures. The surface morphology of annealed and non-annealed meshes was compared, revealing increased roughness post-heat treatment. Corrosion properties were assessed using linear sweep voltammetry in different electrolytes. In alkaline conditions, heat-treated stainless steel exhibited higher corrosion susceptibility than non-heat-treated steel. Pitting corrosion varied between annealed and non-annealed steel, yet corrosion potential and current were consistent for non-annealed and 500°C/700°C annealed meshes. In acidic medium, non-annealed steel demonstrated corrosion characteristics similar to the 500°C annealed steel mesh. This study highlights the nuanced corrosion behavior influenced by thermal oxidation treatments and electrolyte conditions in stainless steel mesh (Yavuz et al., 2020).

Hot work tool steels are steels containing alloying elements such as chromium, nickel, molybdenum, tungsten, vanadium and cobalt. The amount of carbon in it affects the structure and phase transformations that occur during heat treatment. It is used in the industry where high temperatures are used. Since these steels are adapted to high temperature working conditions, their wear, tensile strength, toughness and impact resistance are quite high. Since our material works at high temperatures, shortening of their life may occur, so their working life should be kept as long as possible. Albaraz (2010) followed the process of changes in the mechanical properties of hot work tool steels after heat treatment in his thesis study. At the end of this process, the parameters such as the durability and service life of our material that should be considered when choosing hot work tool steels.

Micro alloyed steels contain a moderate amount of carbon in their chemical structure. Titanium (Ti), Niobium (Nb) and Vanadium (V) are used as alloying elements in these steels. Yahyaoğlu (2021) investigated the effect of heat treatment applied to micro alloy steels on mechanical properties in this study. The parts to be heat treated were prepared by casting method in casting molds and two samples with different carbon ratios were prepared. Heat treatment application was completed by heating the steel in a conventional furnace at a certain critical temperature. In order to change the microstructure of the steel, accelerated or normal cooling processes were applied after heat treatment. At the end of these processes, the samples were checked for changes in mechanical properties by tensile, hardness, notch impact tests. As a result of these processes, an increase in hardness and strength was observed in the first group with micro alloy addition and double quenching heat treatment.

7. Conclusion

This review summarizes some of the studies investigating steel materials and the effects of heat treatments on them. The changes in microstructural and mechanical properties of many steels alloyed with different elements or simply classified according to the carbon content are reported. It has been determined that some heat treatments are carried out to harden the material and increase its strength values, while others are carried out for the opposite purpose. In most of the studies reviewed, the change in mechanical properties was associated with microstructural changes. This study is a literature review that will help researchers to determine the parameters for the heat treatment of steel materials.

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