INVESTIGATION OF THE EFFECT OF CEMENTATION ON THE TRIBOLOGICAL PROPERTIES OF TOOL STEELS

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Sharfuldeen Alı Abourawi ALFAYDH

ABSTRACT

M. Sc. Thesis

INVESTIGATION OF THE EFFECT OF CEMENTATION ON THE TRIBOLOGICAL PROPERTIES OF TOOL STEELS

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In this thesis study, the wear behavior of AISI H13 steel materials that cemented by the box cementation method was investigated. AISI H13 hot work tool steel was cemented for 3 and 6 hours at temperatures of 800 ºC and 930 ºC. While the wear cases were examined, abrasion was made in a dry and corrosive environment and the results showed significant increases in wear resistance in samples with 930 ºC cementation. In addition, it was determined that the average hardness of the samples treated at 930 ºC almost doubled on the surface. Considering the hardness and wear values, the surface properties of AISI H13 steel, which was cemented for 930 ºC at 3 hours, were improved in this study.

Key Words : AISI H13 steel, cementation, wear, hardness.
Science Code : 91421

ÖZET

Yüksek Lisans Tezi

SEMENTASYON UYGULANMIŞ TAKIM ÇELİKLERİNİN TRİBOLOJİK ÖZELLİKLERİNİN İNCELENMESİ

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Bu tez çalışmasında, AISI H13 çeliğinin kutu semetasyon yöntemi ile semente edilmiş malzemelerin aşınma davranışları incelenmiştir. AISI H13 sıcak iş takım çeliği 800 ⁰C ve 930 ⁰C sıcaklıklarda 3 ve 6 saat sürelerde sementasyon işlemine tabii tutulmuştur. Aşınma davranışları incelenirken kuru ve korozif ortamda aşınma yapılmış ve 930 ⁰C sementasyon yapılmış numunelerde aşınma dayanımında ciddi artışlar olduğu gözlenmiştir. Tüm bunların yanında yine sertlik değerlerine bakıldığında 930 ⁰C'de işlem görmüş numunelerde ortalama sertliklerinin yüzeyde neredeyse iki katına çıkmış olduğu tespit edilmiştir. Sertlik ve aşınma değerleri göz önünde bulundurulduğunda bu çalışmada 930 ⁰C 3 saat sementasyon işlemi yapılmış AISI H13 çeliğinin yüzey özelliklerinde iyileşme gerçekleştirilmiştir.

Anahtar Kelimeler : AISI H13 çeliği, sementasyon, aşınma, sertlik.
Bilim Kodu : 91421

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

C	: Carbon
Si	: Silicon
Fe	: Ferroous
Cr	: Chromium
Mo	: Molybdenum
V	: Vanadium
Cl	: Chlorine
F	: Fluorine
Na	: Sodium
O	: Oxygen

ABBREVITIONS

AISI : American Iron and Steel Institute

SAE : Society of Automotive Engineers

PVD : Physical Vapor Deposition

CVD : Chemical vapor deposition

TBC : Thermal Barrier Coating

SEM : Scanning electron microscope

PART 1

INTRODUCTION

In this study, the cementation process of tool steels and the improvement of surface properties were carried out and AISI H13 hot work tool steel was used as tool steel. In order to measure the cementation process in improving the surface properties of this tool steel, wear tests were carried out and hardness values were measured. After wear, sem images were looked at and wear mechanisms were examined and abrasion surface analyses were performed. When we looked at the results of the experiment, it was determined that there was an improvement in the surface properties of steel cemented at 930 degrees and it was determined that there was an increase in hardness and wear values following this improvement, and when we looked at the comparison results of the sample that was cemented at 800 C, the absence of any significant changes with the main material indicates that the cementation parameters are inadequate. In addition, the reduction in wear value at 800 C when we compare the wear values with the main material is due to the impaired heat treatment that gives the AISI H13 hot work tool steel feature. In addition, an increase in surface characteristics of samples that are cemented at 930 C is indicative of sufficient cementation parameters. In addition, the increase in hardness properties indicates that the watering process after cementation was successfully performed and ensured the formation of martensitic microstructure on the surface. As a result of all this, the wear and hardness results of an AISI H13 steel with successfully increased surface properties are included in sufficient cementation parameters.

PART 2

TOOL STEELS

Tool steels are called as tamperable and hardanable alloy steels, which are used in the processing, shaping and giving of the desired form of metal or non-metal materials[1].

Steels get this name because of the iron-carbon alloy they contain. The carbon content in steel starts at 0.07 wt.% and reaches levels such as 2 wt.%. However, in some exceptional cases, high carbon ratio steels are in the steel group compared to containing over 2 wt.% carbon. According to its chemical composition, carbon steels classified as alloy steels and non-alloy steels. Alloy steels are divided into two groups as high alloy steels and low alloys steels. For low alloy steels, the total alloying elements are less than 5 wt.%, but this rate reaches up to 30 wt.% in high alloy steels such as stainless steel or tool steels. Tool steels are treated as a different group compared to other steels. This is because their strength, working conditions and characteristics differ from other conventional steels. Tool steels cover a small percentage of total tool steel production. However, even if the ratio is small, it is of great importance because it is used in the production of other steels and engineering materials. Tool steels are used in the construction of tools and molds that shape the hot or cold process part by cutting, forging, drilling, bending, forming, extrusion and similar methods. Tool steels produced with high characteristics are also used in the manufacture of machine parts with superior characteristics. The properties expected from tool steels are high wear resistance, high hardness, high toughness, high temperature strength, high machinability and a homogeneous microstructure. Compared to other steels, tool steels used in heavier working conditions are expected to perform continuously at low or high temperatures, at high speeds, without deformation under high stress, without breaking, without eroding. These high expectations are achieved by the addition of carbon as well as other alloying elements. These alloying elements are mainly chromium, molybdenum, vanadium, tungsten and cobalt. There are also aluminum, zirconium, and titanium as grain refiner elements. Manganese, nickel, and silicon can also be found in steels. Phosphorus and sulfur, which are elements of impurity, are required to be no more than 0.03 wt.% [2].

In most applications, it is not possible to combine properties such maintaining high temperature strength, good toughness, good hardness, non-brittle for tool steels. For this reason, tool selection is important according to the service condition. For example, when selecting the raw materials of tool steels manufactured by forging method, the alloy is not looked at inside and instead the homogeneity and cleanliness of the internal structure should be looked at. The production of tool steels is melted in electrical furnaces with careful quality control infrastructure. After the production of tool steel, destructive and non-destructive examinations are carried out. In addition to examinations, macro structure, hardness, grain size and hardenability characteristics are also examined [1].

Tool steels have had these by products from the past and are generally expected to have the following characteristics.

- Superior resistance to permanent disfigurement when working under high voltages
- Resistance to surface fatigue with abrasive and adhesive wear
- Toughness for fatigue and rupture resistance
- Dimensional stability during use
- The microstructure shows the same characteristics everywhere and in all directions
- Easy machinability in pre-annealed structure
- Acceptable corrosion resistance in conditions of use
- The resistance to cracking in acceptable quantities in its hardened structure, especially in areas under the heat influence of EDM and welding processes [1].

2.1. CLASSIFICATION OF TOOL STEELS

Today, a wide variety of steel types and especially tool steels are available. The American Iron and Steel Institute (AISI) and the Association of Automotive Engineers (SAE) classified steel in 7 main groups. When making this classification, the hardenability environment and the general usage area were taken into account [2].

Table 2.1. Tool steels and symbols.

Mother	Symbol
Shock Resistant Tool Steel	S
Plastic Mold Tool Steel	P
Special Purpose Tool Steel	L
Water Hardening Tool Steels W	
Cold Work Tool Steel Oil Air High Carbon and Chrome	O A D
Hot Business Tool Steel Chromium Tungsten Molybdenum	H10-H19 H20-H39 H40-H59
High Speed Tool Steel Tungsten Molybdenum	T M

2.1.1. Cold Work Tool Steel

Many methods are used for cold processing of metals. Examples include cutting, forming, drilling, separating, cold forging, cold extrusion, cold rolling and dust pressing [3]. Cold work tool steels are usually devices that are expected to operate under 20 ºC. Otherwise, problems such as loss of hardness due to high temperature or softening of the matrix will begin [1].

The carbon content in cold work tool steels varies between 0.30 wt.% and 2.50 wt.%. Carbide is present in nickel and manganese along with carbide-forming chromium, vanadium, molybdenum and tungsten as alloying elements. There are no 26 cobalt that provides high temperature strength. Elements such as chromium, molybdenum and nickel help to increase hardening depth [4].

Cold work tool steels are divided into 3 groups:

- Air-cooled tool steels containing a medium amount of alloying elements (AISI A series)
- Tool steels containing high carbon and chromium (AISI D series)
- Oil-hardened tool steels (AISI O series) [5].

AISI A series, that is, the tool steels that harden in the air are capable of hardening. It has the ability to harden in the air. Air hardening and tempering processes are preferred in case of good wear with high toughness such as forming, pulling and cutting molds. The most commonly used type is A2 type cold work tool steel [6].

In order to increase surface hardness and wear resistance to molds made of A2 quality tool steel, nitration is also applied after traditional heat treatment. Although wear resistance is good, it should not be preferred where satiation is more important than grade 1 [2].

AISI D series tool steels stand out with their high wear resistance. Therefore, cold shaping properties are good. As such, cutting drilling molds are used in areas such as rollers. The most commonly used cold work is tool steel [6].

In other words, the carbon ratio in such steels, called high carbon and high chrome cold work tool steel, varies between 1.40 wt.% and 2.50 wt.% and they contain around 12 wt.% chromium. However, they contain it in alloys such as molybdenum, vanadium, tungsten. When taking hardness in water with steel containing molybdenum, if they do not contain molybdenum, they are hardened in oil. This type of steel has low rates of cracking and multiplication. The increase of alloying elements also increases wear resistance. D7 type steel has high wear resistance but low processing capability. D5 quality steel can be used at high temperatures due to its cobalt content. The widest area of use is D2 tool steel [2].

AISI O series tool steels are used in cutting, pulling and forming molds. Therefore, together with the measuring instruments, it is used after the hardening and tempering process in the oil. The most commonly used type is tool steel O1 [6]. It is a group of steels, also called oil laying. The carbon content is 0.9 wt.% to 1.5 wt.%. It also contains manganese, chromium and tungsten. The risk of distortion and cracking is lower than class W. O6 type of tool steel is suitable for processing [2].

2.1.1.1. Areas of Use of Cold Work Tool Steels

The uses of cold work tool steels are standardized in TS 3921 and ASTM A681. According to these standards, their use; cutting blades, bending molds, plastering molds, cold forming molds, printing reels, staples, press sets, measuring instruments and so on are designated as cold work applications [2]. Some places of use are listed below.

- Drawing tools
- Deep drawing tools (sheet metal forming)
- Columnar or flat cutting benchs
- Scraping blades
- Precision drilling tools
- Paper and plastic knives
- Drilling staples
- Wire bar pipe pulling tools
- Relief tools
- Machining tools (for processing iron or non-ferrous metals)
- Gear tools
- Cutting tools
- Machine blades
- Cold treatment kits of bolts, rivets and nuts
- Rollers or jaws for chip-free manufacture of gears

- Drills and cutters for machining of gears
- Cold squirt press tools
- Sinter pressing tools
- Measuring instruments
- Stretching hives
- Hand tools
- Essentials
- Wood saws
- Compressed air tools
- Plastic processing tools [6].

In general, cold work tool steels are used in areas such as drilling cutting, punching, mowing, printing, pressing, cold crushing, cold forming.

Cutting processes in the industry are very important in terms of the precision of the material. The more sensitive the cut, the less secondary the process, which means gain. As such, a tool that constantly cuts with the same precision should be dimensionally rigid and the tool itself should not wear out, so that the product that is worn in the team must be within the desired tolerance range with the same precision.

Cold work tool steels such as 1.2842 and 1.2419 have high perch and processing capability despite showing low wear resistance. In this case, it is suitable for cutting non-metal materials.

In cold forming method, materials are adjusted to their desired final dimensions by cold forming or extrusion methods under intermittent pressure forces. The materials used in this method are subject to quite a lot of strain.

In the deep pull method, the print edges of the molds and staples are subjected to very high friction stresses. In these tube applications, 1.2379 steel of ledeburitic structure should be preferred.

1.2379, 1.2080 and 1.2363 cold work tool steels are the most suitable materials that can be used to shape metallic strips and sheets. Due to these characteristics, 1.2379 cold work tool steel is the primary preferred material in graining blades, while 1.2842 material is suitable for use in places exposed to relatively low mechanical voltages such as machine blades, blades and hammers [4].

2.1.1.2. Damage to Cold Work Tool Steels

In applications where cold work tool steels are used, there are five different damage mechanisms: wear, mouth loss, plastic deformation, plastering and fracture as a result of crack formation-progression. One of these mechanisms can be seen in the same pattern or team, one or all of them, predominantly. The important thing is to determine the mechanism that determines the life of the mold\tool and to disable this decisive mechanism or to reduce its negative effect, to ensure that the design is made, the tool steel is selected, the heat treatment is done accordingly and a surface work is performed if needed [4].

2.1.2. Hot Work Tool Steels

In hot work tool steels, the AISI classification system indicates whether the metals are sufficiently capable to ensure a high temperature. Steels containing 5 wt.% chromium are used in hot work tool steels, as well as molybdenum wolfram and vanadium as alloying elements. Molybdenum and tungsten give a better result than chromium from hot work tool steels [5] .

Tool steels symbolized by the letter H (Hot Work) in the AISI classification system [1]. In general, they are used in tools whose surface temperature exceeds 200°C and is subject to constant heat between 300 °C and 600 °C [7]. They are tool steels used in forging, forming and separating at high temperatures. Hot work tool steels are a steel alloy of a structure where heat, pressure and abrasive properties can be obtained together [1]. Hot work tool steels are collected under three groups according to the principle alloying process they contain.
These are:

- Chrome (Cr) based hot work tool steels,
- Molybdenum (Mo) based hot work tool steels,
- Tungsten (W) is a based tool steel.

Chrome-based hot work tool steels are among the H10 - H19 types in AISI standards and are resistant to softening by the effect of temperature. This is due to its moderate chromium content and carbide-forming elements (molybdenum, tungsten, vanadium).

The hardening depth of chromed hot work tool steel is high. H11, H12 and H13 steels can harden up to 152 mm and other H types up to 305 mm. Chromed hot work steels are more suitable for use as molding material. They are especially used in aluminum and magnesium extrusion, casting and forging molds. Since most of these steels contain low carbon and alloying elements, they can be cooled without cracking.

The types actively used in molybdenum-based hot work tool steels are H42 and H43 molybdenum hot work tool steels in AISI standards. These steels contain molybdenum, chromium, vanadium, carbon and tungsten. These steels are lower carbon steels than tungsten hot work tool steels and have higher toughness. H42 and H43 type steels cost less than tungsten hot work tool steel. These steels are more resistant to temperature than hot work tool steel with tungsten. However, since they are prone to decarburization, attention should be paid to their thermal processes.

Tungsten-based hot work tool steels are H21 to H26 in AISI standards and contain carbon, tungsten, chromium and vanadium alloying elements. These high-content alloying elements increase the material's resistance to thermal softening and wear at high temperatures. However, these alloy elements adversely affect the properties of the material against breakages and cracks in working hardness (45-55 HRC). They also make the watering process difficult.

These steels can be hardened in the air, but they are usually given water in water and hot salt. In order to harden, they need higher temperatures than chrome hot work tool steels. They are also more durable in the oxidizing atmosphere.

Although these steels have high satiety, most of their properties resemble high-speed tool steels. In fact, the H26 type is a higher carbon version of high-speed tool steel. If hot work tool steels with Tungsten are preheated to operating temperatures, the risk of cracking is reduced. These steels are often used in extrusion molds (nickel, brass and steel extrusion) and forging molds [1].

2.1.2.1. Areas of Use of Hot Work Tool Steels

1. Press casting machines
    a. Mold
    b. Metal wedges and pressing rollers
    c. As sticker parts, spades, thrusters, etc.
2. In mold and pipe presses
    a. In inner and intermediate hives
    b. In press molds
    c. Staples and heads
    d. As a supporting team
3. Profile presses
    a. With the aim of processing light metal
    b. With the aim of processing heavy metal
4. In tattoo molds
    a. In mold bodies
    b. Using in mold auxiliary parts
5. Processing iron and steel alloys
    a. Using in piercing staples and molds
6. Steel tensile pipe production is used in many areas and as well [7].

2.1.3 HSS (High Speed Steel) High Speed Tool Steels

The general common characteristics of high-speed steels are that they have a hardness of 52 HRC to 48 HRC at temperatures between 540 ºC and 595 ºC, and they maintain this hardness. From this, these steels are used for cutting other conventional steels at the appropriate temperature in suitable machines. In addition, they have excellent hot hardness. They contain enough alloys and, if they contain enough carbon, allow alloys to form carbides [5].

High speed steels are also called air steels. They are high alloy tool steels with high hardness, heat and wear resistance with specific alloying and heat treatment. As their name suggests, machining is carried out at higher speeds than other tool steels with these steels. They have high cutting feature with high forced chip removal. The most important characteristics of high speed tool steels are resistance to wear at high temperatures. They are tool steels that are used for high-speed progression of materials. They are resistant to high cutting speeds and are generally used in places where machining is carried out. This classification is the most suitable classification method for tool steels. There is no possibility of separation according to carbon amounts (values between 0.2-2.3 wt.%) or alloy states (non-alloy tool steels such as medium and high alloy tool steels are also available). As seen in the short classification of tool steels, each steel must have different properties for a specific purpose, i.e. a certain tool steel should be used for a specific use [7].

High-speed tool steels are tool materials that are usually developed for cutting at high speed. They are also high alloy steels and contain wolfram or molybdenum as the main alloy element. Its composition can be found in wolfram and molybdenum, as well as chromium, vanadium and cobalt. The carbon content is usually 0.75-1.20 wt.% and can sometimes reach up to 1.50 wt.%.

The beginning of the classification of high-speed tool steels in tool steels was caused by the introduction of T1 (18W-4Cr-1V) material, which is considered one of today's classic high speed tool steels, in 1941. There have been many developments observed for tool steel from the first produced speed steel to the present day, and from 20m/min speeds to 120m/min in powder metal speed steels, today PVD and TiN are coated. Developments in this type of tool steel have gradually diversified with the presence of alloying elements (Mo and Co) and their classification with alloying elements has been improved. The effect of each alloy element was better understood in this process and the results and homogeneity of the combinations of these alloy elements were examined. Of course, the biggest development in this regard has been with the onset of powder metallurgical production. Important dates in the development process of high-speed tool steels.

Molybdenum high-speed steels contain molybdenum, tungsten, chromium, vanadium, cobalt and carbon alloying elements. It has a higher toughness value than the T series of the same hardness. As the carbon and vanadium ratios in the structures of M steels increase, so do their resistance to abrasion. High speed steels are highly alloyed steels; they are used for high cutting speeds of very hard metals. Since cutting speeds related to these steels usually cause red range temperatures at the tool end, tool steels have to resist tempering at these temperatures. The ability of steel to resist softening in the red range is called red hardness and is an important feature of high speed tool steels. These steels must have good wear and high hardness in order to protect sharp cutting ends for a long time. Increasing the cobalt content gives red hardness (resistance to softening caused by high temperatures caused by heat absorption) but reduces toughness. M2 and other species are more resistant to softening at high temperatures because they contain high alloys. Group M high speed tool steels hardening depth is quite good. The temperature of axtenite is lower than that of T-group steels. 1175-1230 ^{o}C are also given maximum hardness when water is given.

The hardness value in M1, M2, M10 (low carbon steel) and M30, M33, M34, M36 obtained by changing the maximum hardness composition is 65 HRC. High carbon ratios such as M3, M4, M7 maximum hardness is 66 HRC. In high carbon-cobalt compositions, the hardness value is 69-70 HRC in M41, M42, M43 and M46. Industrial applications have shown that the highest hardness is achieved in the M40. The hardness value obtained after heat treatment is 66-68 HRC. According to T steels, M steels are more than 42 sensitive in this regard. This is due to the composition of tungsten low from high molybdenum. Group M high speed tool steels hardening depth is quite good. The temperature of austenite is lower than that of T-group steels. Maximum hardness is achieved when water quenched at 1175-1230 ^{o}C. Tungsten contains alloying elements such as chromium, vanadium, cobalt and carbon. The T1 type was developed by Taylor and White. Types with 14 wt.% W, 4 wt.% Cr, 0.3 wt.% V show red hardness. T1 type contains 0.68 wt.% C, 18 wt.% W, 4 wt.% Cr, nor 0.3 wt.% V. After the 1920s, the vanadium rate increased from 1.0 wt.% to 0.75 wt.% after the 30-year period. T high speed tool steels are characterized by red hardness and wear resistance characteristics. Hardening depth is reached at 65 HRC up to 76 mm. When cooled in oil and salt melt, the hardness value can reach higher values. It means a cutting tool with high alloy and high carbon content, high hardness and high wear resistance. Such steels contain more than 1.5 wt.% V and 1 wt.% C of carbon. T15 is T steel with the highest wear resistance. The combination of high wear resistance and high red hardness makes T high speed steels advantageous in cutting processes that require high performance. It also has enough satiety value in gradual cutting processes. T steel type is primarily used in cutting tools such as drill bit, ream, guide. These steels are used in molds, staples, high temperature parts, aircraft parts and pumping equipment. Water quenching at 1205 and 1300 ºC, the T series reaches maximum hardness [1].

2.1.3.1. Areas of Use of High Speed Tool Steels

High speed tool steels in the field of machining; drilling, cutting, turning, milling, stapling, and non-chip manufacturing find application area in cold squirts [7].

- Spiral, drill and threading tools
- In lathe sets and planers
- In mills
- In cold squirts
- Rayba's
- Metal saws

2.1.4. Plastic Mold Steels

The class of tool steels used to make plastic molds includes low or medium carbon steels with a combination of chromium and nickel alloy (with very little vanadium and molybdenum added). The sum of alloying elements in their composition is 1.50-5.00 wt.%. Plastic tool steels stand out for their resistance to corrosion and their polishable properties [8].

Plastic mold steel

- Quick machinability
- Low size change during heat treatment
- Brightness
- Pressure resistance
- Wear resistance

2.1.5 Carbon Steels

In addition to carbon, non-alloy carbon steels contain up to 1.65 wt.% manganese, up to 0.05 wt.% sulfur, up to 0.04 wt.% phosphorus, up to 0.60 wt.% silicon and up to 0.60 wt.% copper. Carbon content in steels has a great effect on mechanical properties. The addition of carbon provides increased hardness and strength in steels, so non-alloy carbon steels are classified as low carbon, medium carbon, high carbon and ultra-high carbon steels according to their carbon content [6].

Steels with between 0.07 wt.% and 0.15 wt.% carbon in very soft steel structures are called very soft steels. These steels are suitable for cold forming.

Soft carbon steels contain approximately 0.15 wt.% to 0.25 wt.% carbon. They are non-alloy steels that are widely used. They are very well welded, but their ability to harden well with watering method is poor.

Medium carbon steels contain between 0.25 wt.% and 0.55 wt.% carbon. They are very suitable steels for heat treatment. In other words, the structure and properties of these steels can be changed very easily thanks to heat treatments. In this respect, the use areas of medium carbon steels are of feature. These steels are divided into 3 groups: general forged steels, shaft steels and abrasion resistant steels according to carbon ratios. In particular, machinery is the preferred steel of production industries. Their ability to process and take shape is lower than low-carbon steels.

They are steels containing between 0.55 wt.% and 0.90 wt.% carbon. They are used in places that require high strength and wear resistance. Examples of usage areas include press mold blocks. Normally, it is with high strength and low ductile steel. Thanks to the ability to harden with heat treatment, very high hardness can be reached. In this aspect, they are wear-resistant and the cutter especially gains properties. They are low in processing and forming. However, their welding capabilities are also low and therefore can be welded with special techniques [7].

2.1.6. Cementation Steel

Cementation steels are low-carbon, alloy or high alloy steels used in the manufacture of variable and impact-resistant parts that are hard and abrasive on the surface and softer and fuller in the core.

- The addition of these properties to the part is carried out by impregnating carbon on the steel surface. Cementation steels; gears, shafts, piston pins, chain diamonds, chain gears and rollers, discs, guide bearings, bearing bearings, rollers, some measuring and control instruments, medium forced and forced parts, parts shaped by cold inflating or squirting, cutting tools are used in the manufacture of parts such as cutting tools. The use of cementation steels provides the following advantages compared to the use of high carbon steels, which will give the same hardness value on the surface:
- The part is quite easy to process, as the cementation process is applied after the part is partially or completely finalized.
- If there are parts on the surface of the part that will be processed later, which are undesirable to harden, these areas are covered with the help of a special cake or electrolytic coating. Since the cementation process cannot influence these regions, they have the ability to be easily processed afterwards.
- After the cementation process, the distortions that may occur during hardening are quite small, since the core area will retain its softness.
- The interiors of cemented steels can be easily processed.
- Cementing steels are cheaper than high-carbon steels, which can give the same hardness on the surface, often in the case of tool steel.

The cementation process is one of the surface hardening processes and is used as the oldest and most suitable. In essence, it is the process of impregnating carbon on the surface of a low-carbon steel part.. This steel group, which we call cementation steel, includes AISI 1015, AISI 3115, AISI 3316, AISI 5015, AISI 5115, AISI 5120, AISI 8620, AISI 1010 steels, which are produced in accordance with AISI standards [7].

3.1.7 Tempering Steel

Tempering steels are non-alloy and alloy machine manufacturing steels whose chemical composition is suitable for hardening, especially in terms of the amount of carbon, and which has high toughness as a result of a certain tensile strength as a result of the reclamation process.

As a result of the tempering process, the steel part will be given high toughness, first as a hardening and then as a whole of tempering processes. Due to their superior mechanical properties acquired at the end of the reclamation process, correctional steels have found their use in a wide range of areas, including various machine and engine parts, forged parts, various bolts, nuts and deviations, crankshafts, axles, control and drive parts, piston arms, various shafts, gears. For this reason, reclamation steels are the type of steel produced and used at the highest rate after construction and non-alloy steels. The hardening process is primarily the process of heating the steel part to the eustachite phase temperature and quickly cooling it in a suitable environment, keeping it at this temperature for a certain period of time. Various environments such as 10% NaCl solution, water, salt bath, oil solutions, oil and air are used as hardening mediums. The tempering process is the process of heating the steel part under A1 temperature for a certain period of time. Since this process can be done up to A1 temperature, there is a possibility that some properties may change in the mechanical properties and microstructure of steel. In the area of tempering temperature, while the temperature rises, generally the hardness decreases to 50 HRC and the toughness increases. Some alloy steels show fragility in certain temperature zones during tempering. In accordance with the American Steel Standards Institute (AISI), AISI 1022, AISI 1035, AISI 1045, AISI 1055, AISI 1060, AISI 1039, AISI 1330, AISI 5045, AISI 5132, AISI 5135, AISI 5140, AISI 4130, AISI 4135, AISI 4150, AISI 9840, AISI 4340, AISI 6150, AISI 4140 steels are produced [7].

PART 3

SURFACE HARDENING METHODS

In particular, surface hardening processes are applied to machine or vehicle parts that work with friction and are exposed to wear and are also under the influence of vibrations. Nitriding is important in terms of improving the hardness and wear resistance of the steel, as well as the corrosion resistance, fatigue life, maintaining its hardness even at high temperatures, and the processing temperature being lower than other surface hardening methods. Let's briefly compare nitriding, or in other words, nitriding, which is a heat treatment method that takes place in the ferritic phase, and other surface hardening methods.

3.1. COMMONLY USED SURFACE HARDENİNG METHODS

Shafts, gears, cams, cutting tools etc. In applications, materials that are hard and wear-resistant on the surface and ductile and vibration-resistant inside are required. In this case, what needs to be done is to improve the surface properties as we want, without deteriorating the properties of the core region of the material or by affecting this region in a beneficial way. This may be possible by applying one of the surface hardening treatments. The main methods used in surface hardening in today's industry are:

- Carburizing (cementation)
- Flame or induction hardening
- Nitriding (Nitriding)

3.1.1. Carburizing

This process is carried out by permeating low carbon (max. 0.20%) steels in a carbon donor medium, mostly at temperatures between 825-950 °C. The carbon donor medium can be solid, liquid, gas or plasma. The carbon that penetrates the surface of the steel at the processing temperature is dissolved in austenite. Hardening is achieved by performing austenite-martensite transformation on the surface of the steel through the subsequent sudden cooling.

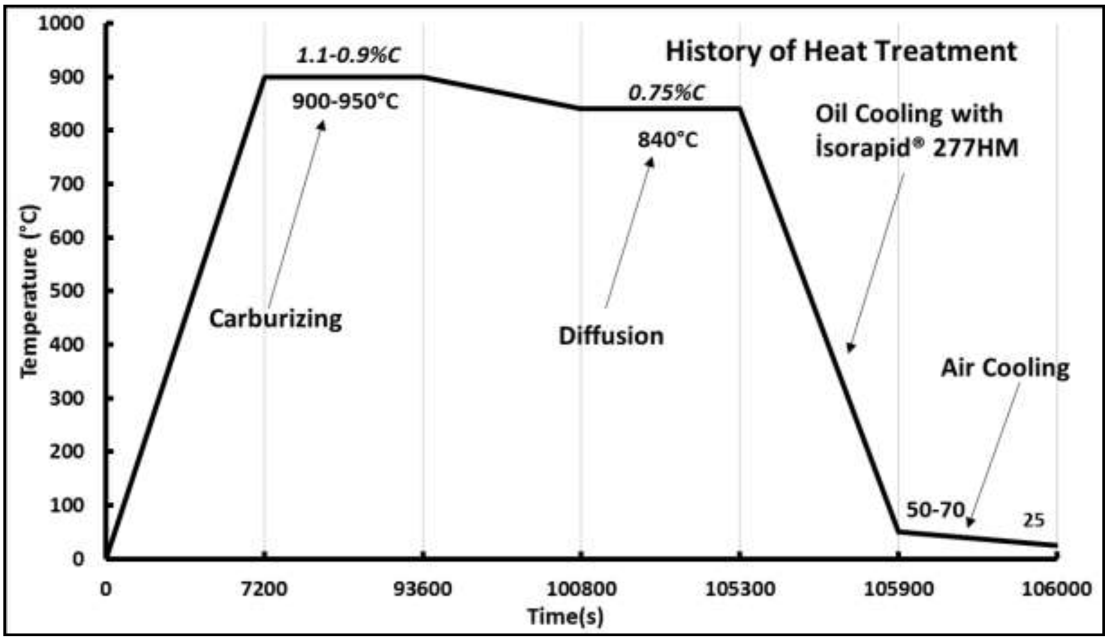

Figure 3.1. Process chart for gas carburization process [9].

The process is based on changing the surface composition of the steel by adding carbon and making it hardenable. Since there is no composition change in the interior of the materials, some hardening takes place in the interior depending on the initial carbon amount. The hardness depth to be obtained in the cementation process can be adjusted by changing the processing temperature and time.

3.1.2. Flame or Induction Hardening

In these methods, the hardenable steels are heated to the hardening temperature by being held in a flame or induction current and then suddenly cooled by quenching. There is no change in the composition of the steel in flame and induction hardening processes. Therefore, the steels to be used must also be hardenable steels. It is ensured that the heating is instantaneous, so that only the desired amount of area on the surface is heated up to the hardening temperature, and the deeper areas are not heated. Thus, during the sudden cooling, austenite-martensite transformation occurs and hardening occurs only in the region that is heated up to the transformation temperature. The hardening temperature varies depending on the composition of the steel.

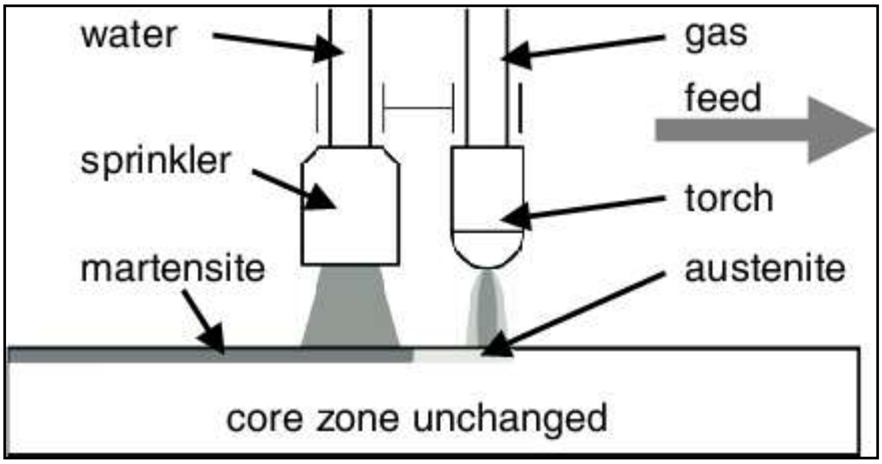

Figure 3.2. Schematic representation of the flame hardening process [10].

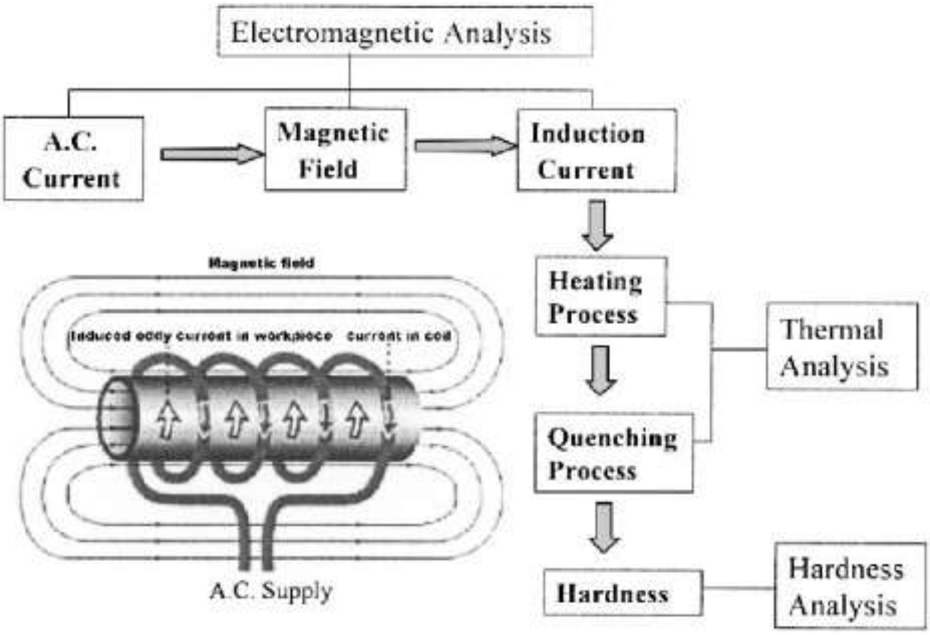

Figure 3.3. Induction hardening processes [11] .

3.1.3. Nitriding

It is realized by the transition of atomic nitrogen to the ferrite phase between the temperatures of 350-580 °C in a nitrogen donor environment. It is a process that provides surface hardening in steel, thanks to the nitride layers formed on the surface, without any phase rotation as a result of cooling to room temperature. Nitriding has found wide application in steel as a surface hardening process that improves properties such as surface hardness, wear resistance, friction heating resistance, corrosion resistance, and fatigue life.

There are also processes such as carbonitriding, nitrocarburizing, sulfonitriding and sulfo-carbon-nitriding, which can be interpreted as different versions of nitriding and carburizing processes.

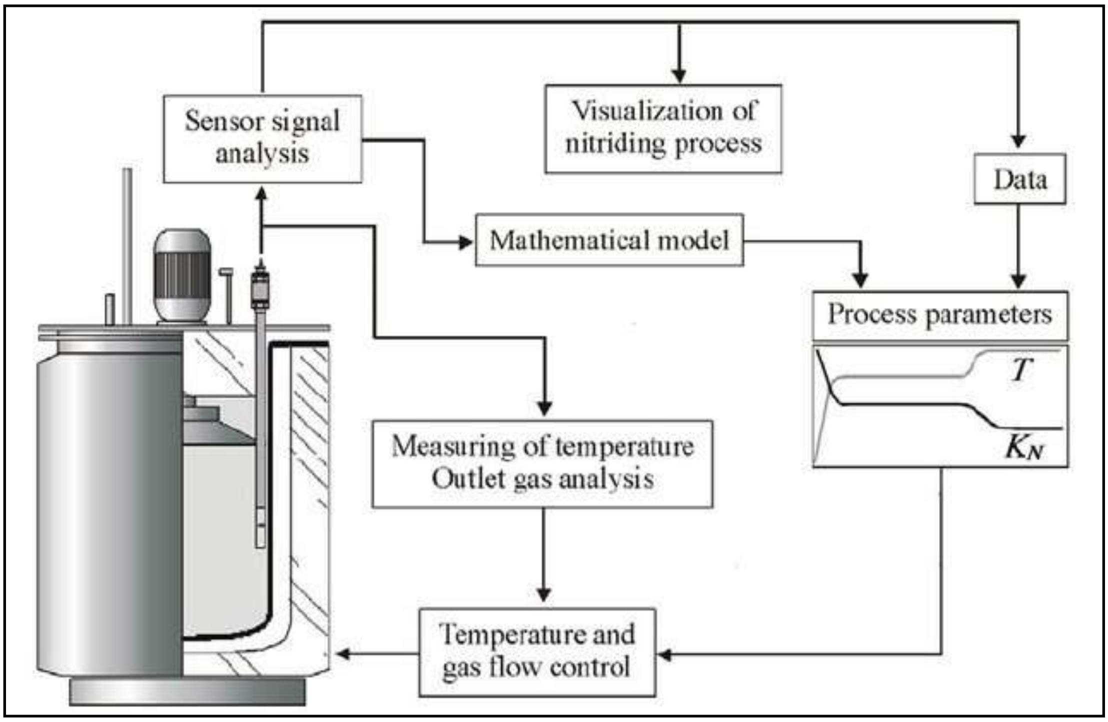

Figure 3.4. Schematic diagram of the automatic system of the nitriding process with the visualization system for the course of the layer growth [12].

PART 4

TRIBOLOGY

Tribology was first used by Jost in England in 1966 to describe friction, wear and lubrication phenomena. The word tribology comes from the ancient Greek word Tribos (Friction). Tribology is the art of applying operational analysis to problems of major economic significance, such as reliability, maintenance, and wear of technical equipment ranging from space analysis to household appliances [13]. Surface interactions at a tribological interface are quite complex and their understanding requires knowledge of various disciplines such as physics, chemistry, applied mathematics, solid mechanics, fluid mechanics, thermodynamics, heat transfer, materials science, lubrication, machine design, performance and reliability [13]. Tribology science helps to maintain our daily life and industrial sector more efficiently and performance by investigating the types of friction as well as how we can minimize them (For example: metal frictions) or how we can increase them in some cases (For example: brake systems). Tribology consists of three subheadings as friction, wear and lubrication [13,14].

4.1. FRICTION

There is generally a state of friction between two functional surfaces that are in contact with each other and perform relative sliding or rolling motion. In many cases the numerical value of friction may be very small, but practically always present. Hypothetically, if there is no force field between the functional surfaces and there is absolutely no medium between them other than absolute vacuum, it can be said that there is no friction. Friction and wear have been observed since ancient times and measures have been taken to reduce them [13,14].

4.2. WEAR

Wear is the biggest cause of malfunctions in machines and out-of-function of construction elements. Just as friction is a cause of energy loss, it is a cause of material loss that cannot be recovered in wear. This indirectly entails an additional energy requirement required for the supply of new material. It is not possible to establish a direct relationship between friction and wear. The frictional resistance between different material pairs may be the same, but the difference in the amount of wear between them can be 100 times or more. Generally, the wear problem is more complex than the friction problem. Many different types of wear patterns are encountered between cooperating functional surfaces, and several of these variations occur at the same time, often in the same condition. For these reasons, it has not been possible to define a generally valid wear law that covers all or some of the wear cases [14,15].

4.2.1. Adhesive Wear

Since the actual contact surfaces of the two bodies in contact with each other are actually very small due to the surface roughness, the pressure acting on the actual contact surface due to the normal force takes quite values. The stresses at these points reach the yield stress limit even under very small loads, and they undergo plastic deformation by flowing. Objects are connected to each other by micro-welds through these plastically deformed surfaces. Meanwhile, the source bond is broken due to the relative motion between the two objects. As a result of this rupture, gaps form on the surface of the object made of soft material compared to the other object, protrusions occur on the other surface and adhesive particles are poured between the two surfaces. Adhesion wear occurs between similar and easily alloyable materials and does not occur at all contact points, but only in some of them. Abrasion wear prepares the ground at the same time as adhesion wear deteriorates the surface roughness and causes adhesive particles. Adhesion wear and abrasion wear do not occur at the same time. Adhesion wear does not occur when hard particles enter between the two surfaces due to the effect of the environment or when adhesive particles are formed, that is, when the necessary conditions for abrasion wear are met. Cohesion and adhesion are force interactions between the atoms of a substance, whether solid, liquid or gaseous, against each other. The attractive force is effective between two atoms that are at a suitable distance between them.

If two atoms get too close to each other due to the effect of this pulling force, they start to repel each other this time. At the distance where the repulsive and attractive forces are balanced, the atoms are in their most stable positions. Energy is needed to separate an atom from its stable position, that is, to move it closer to or away from the other atom. This amount of energy required is negligible for large liquids and small gases for solid atoms. Thus, the solid material maintains its solidity and gains a fluid feature. These attractive forces between atoms of a substance are called cohesion. adhesion wear as shown in Figure 4.1; It is a form of wear that occurs with metal-to-metal contact in insufficient lubrication conditions that occur as a result of not using the oil film suitable for the loading conditions, overloading and losing its properties over time [16].

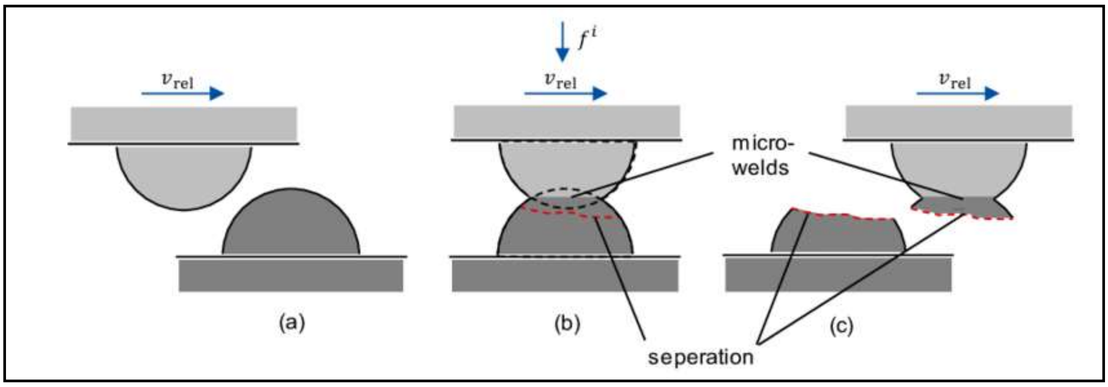

Figure 4.1. Adhesive wear mechanism: (a) before contact; (b) during contact; (c) after contact [17].

4.2.2. Abrasive Wear

Abrasive wear occurs in two forms, two-body and three-body. Two-body abrasive wear is the type of deformation that occurs when a hard and rough surface comes into contact with a softer material, by removing scratches and small particles on the surface of the soft material with the effect of force and pressure (Figure 4.2).

Examples of two-body abrasive wear are excavators, soil tillage tools, filing and sanding. Abrasive wear occurs when a hard, rough surface slides over a softer surface, carving the soft surface and creating a group of grooves. Abrasive wear can also occur in a slightly different situation, when hard abrasive particles get between the sliding surfaces and abrade the material.

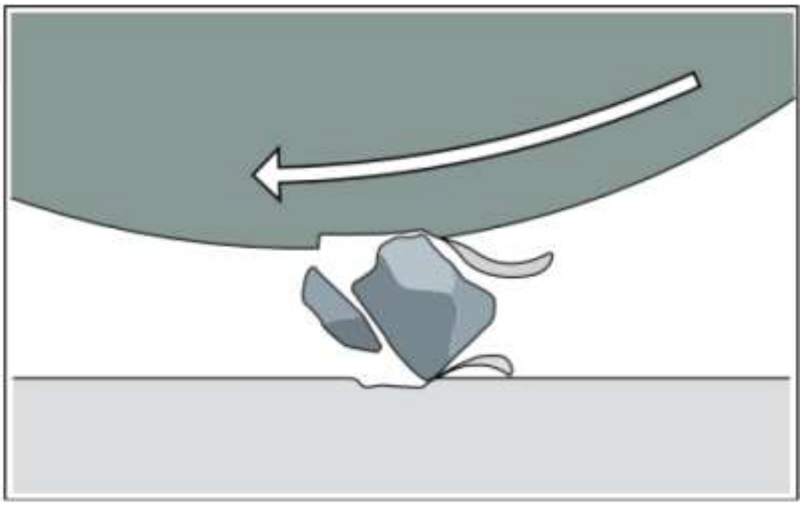

Figure 4.2. Abrasive wear mechanism [17].

There are two types of abrasive wear, two-dimensional and three-dimensional abrasive wear. If the wear is caused by hard bumps on the outer surface, it is called "two-dimensional abrasive wear". In three-dimensional abrasive wear, there are hard abrasive particles that roll and wear between two different sliding surfaces. Wear rates are faster in two-dimensional wear than in three-dimensional wear. The effect of hardness on abrasive wear of metals is given in Figure 4.2. In the case of abrasive wear, there is a correlation between the abrasive particle and the wear mark. When using rounded abrasive particles, the sliding speed is not very high. Hardness is very important in materials to be used as abrasive. The abrasive material must be harder than the material it will abrade. The hardness of the soft material should be at least 1/3 of the hardness of the hard material [13,18].

4.2.3. Erosion Wear

Erosion wear is a type of wear created by abrasive particles in the fluid, high velocity moving liquid droplets and high velocity gas bubbles (Figure 4.3). Liquids and gases break off particles from the surface by colliding with the boundary surfaces of the part they are in contact with during flow and form a wavy surface with the effect of vortices. This accelerates wear even more. It is usually seen in pumps, impellers, fans, nozzles and elbows of pipes and tubes [15,16,18].

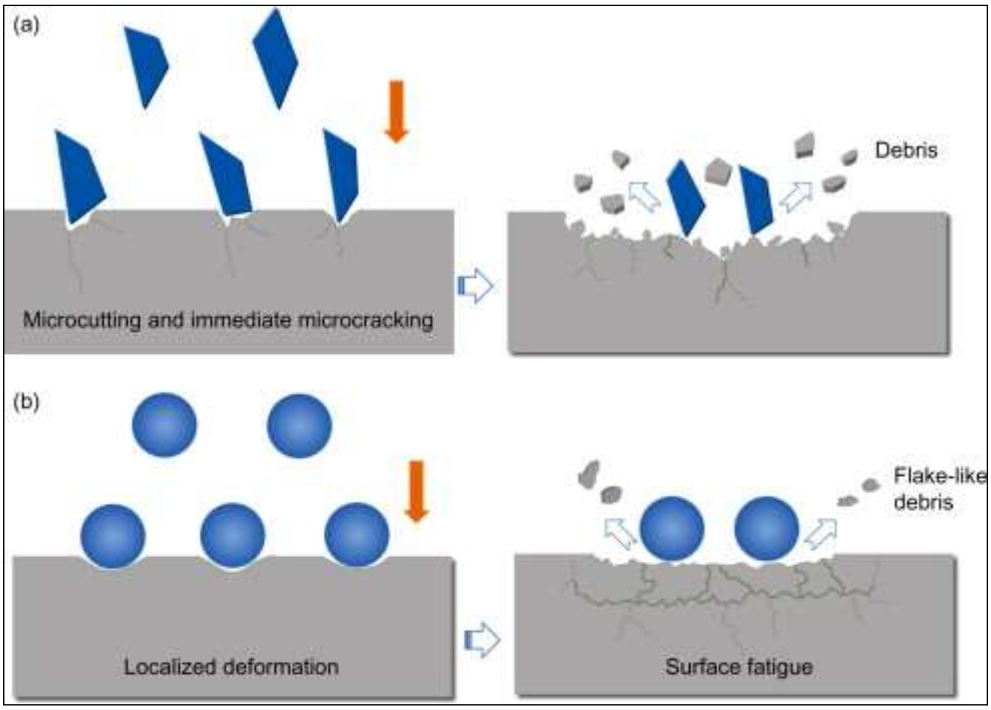

Figure 4.3. Erosion wear mechanism [17].

4.2.4. Fatigue Wear

Pitting wear is a common type of wear on surfaces that are in constant contact with each other, such as gear wheels, rolling bearings and cam mechanisms (Figure 4.4.). Since the contact areas in such machine elements are very small, Hertz pressures occur on the contact surfaces. Under the influence of these pressures, shear stresses occur just below the surface. At the point where shear stresses are maximum, plastic deformation occurs and this deformation progresses to the surface over time and pits occur on the surface [16].

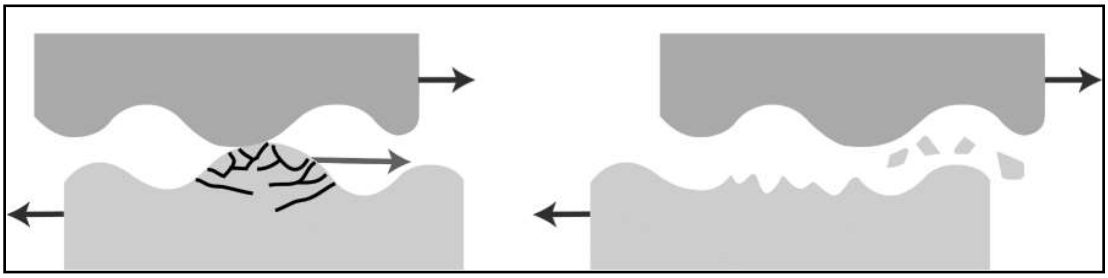

Figure 4.4. Fatigue wear mechanism [17].

4.2.5. Corrosion Wear

Corrosion wear occurs in two ways: low temperature corrosion wear and high temperature corrosion wear. Metallic materials have a natural oxide layer up to 0.1 micron on their surfaces, depending on the type and amount of alloying elements they contain. Thanks to this layer, they show resistance against corrosive environments. During the repeated impacts applied to the metal surface by the abrasive medium, the oxide layer is removed from the surface along with the material. Due to the frequency of repeated impacts or the depletion of the element forming the protective layer in the alloy over time, the oxide layer becomes non-reformable and the metal surface becomes vulnerable to corrosive attacks. This phenomenon, in which wear and corrosion develop together and corrosion contributes to wear damage, is called low temperature corrosion wear [15,18].

4.3. LUBRICANTS

Lubricants are used between machine elements that come into contact with each other in order to reduce friction, prevent wear partially or completely and to ensure that the temperature does not rise. It is therefore very important to select the correct lubricant and the appropriate lubricant viscosity. Lubricants are divided into four groups: solid, liquid, semi-solid (greases) and gaseous lubricants [19].

4.3.1. Oils

It is the lubricants that usually respond best to our demands. The oils we use are obtained from the processing of petroleum products. Animal and vegetable oils, which are of little technical importance today, are also included in this class [19].

4.3.2. Grease Lubricants

They are obtained by esterification of glycerine with a fatty acid in creamy consistency, mineral soap-based organic or synthetic method [19].

4.3.3. Solid Fats

They are powdered lubricants such as graphite, molybdenum disulfide, talc, they adhere well to the surface and lubricate them. Paste-like lubricants are also available, which are obtained by mixing solid lubricants in powder form with oils or greases. Oils such as polyamide PA, polyacetal POM, polytetrafluoroethylene PTFE and Fluorethylenepropylene PFEP [19].

4.3.4. Gases

Air is used as a lubricant in small-sized, very high-speed rolling plain bearings. In practice, additives are added to oil greases or solid lubricants in order to resist oxidation, reduce the viscosity change due to temperature, spread better on the surface, carry high loads, and prevent foaming [19].

PART 5

EXPERIMENTAL STUDIES

5.1. CEMENTATION PROCESS

4 different AISI H13 steels with pre-prepared dimensions of 50X20X20 were cemented by box cementation. They were kept in the furnace for 3-6 hours at 800ºC and 930ºC. Subsequently, quenching was carried out. After quenching, the tests were conducted at least 24 hours later.

5.2. METALLOGRAPHIC PROCESSES

The samples were wet sanded with 400, 800, 1200 and 2500 grit sandpapers, respectively, from the cross-section for microstructure. Then, polishing was done with 3um and 1um diamond solutions. Afterwards, 2% nital solution was prepared and etching was performed.

5.3. HARDNESS TEST

Vickers hardness tests were carried out on a QNESS brand Q250M model hardness device under HV0.1 (100 gr) load for 15 seconds. From the surface to the center, 9 measurements were taken by moving a total of 450 µm from the surface in 50 µm steps. Each measurement was repeated 3 times and averaged. The results were manually processed and graphed in the excel table.

5.4. WEAR TEST

Abrasion tests were carried out in a dry and corrosive environment with linear reciprocating motion type in accordance with ASTM G33 standard on UTS brand wear test device. In the wear test, balls with a diameter of 6 mm in the composition of 100Cr6Al were used. The samples were carried under a load of 20 N, 40 N, with a distance of 20 mm in each cycle and a stroke distance of 10 mm on the sample, 500 m in dry conditions and 200 m in a corrosive environment. The worn area was measured in Mitutoyo brand SJ-410 model surface roughness device according to ISO 4287-1997 standard.

$$wear\ rate = \frac{wear\ volume}{sliding\ distance} = \frac{worn\ area\ x\ stroke\ distance}{sliding\ distance} \quad (5.1)$$

The wear rate (Wr) of the samples was calculated by dividing the total wear volume (Wv) obtained by multiplying the worn area by the stroke distance, according to the formula given in Equation 5.1.

5.5. SEM IMAGING ANALYSIS

In SEM Analysis, images of microstructure and wearing surfaces were taken. Also, Linear EDX is taken from the surface. The change in the microstructure and composition of the cementation process and the subsequent quenching were analyzed.

PART 6

RESULTS AND DISCUSSION

6.1. Microstructure

The figure shows the microstructure images of AISI H13 steel. Figure 1a is taken at 2500X magnification and b at 5000X magnification. Although the microstructure is a bainitic microstructure, it has a small grained structure.

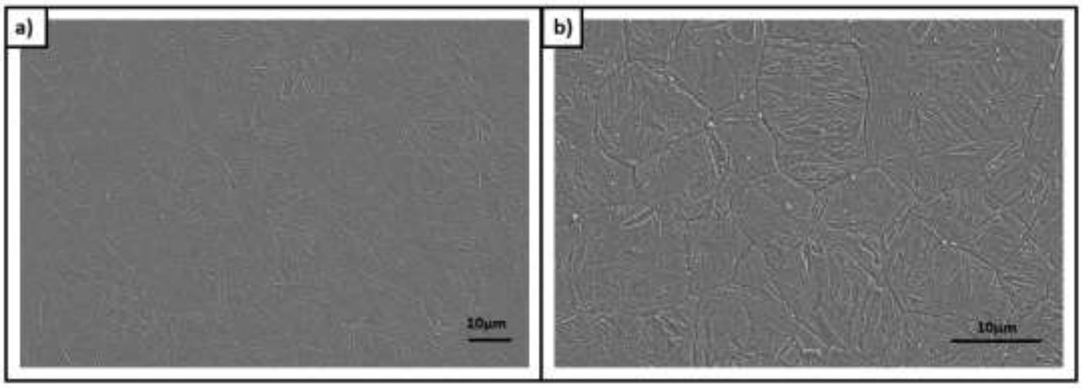

Figure 6.1. SEM microstructure image of untreated material of AISI H13 steel a) 2500X magnification b) 5000X magnification.

In the figure 6.2, SEM analyzes of the samples, which was cemented for 3 hours at 800ºC, are shown at 2500 and 5000 magnifications, and when these images are examined, some micro-structural changes are observed on the sample surface. The reason for this change is due to insufficient cementation temperature and some decarburization on the material surface. SEM-EDX results prove this. This is proof of how important the cementation parameters are.

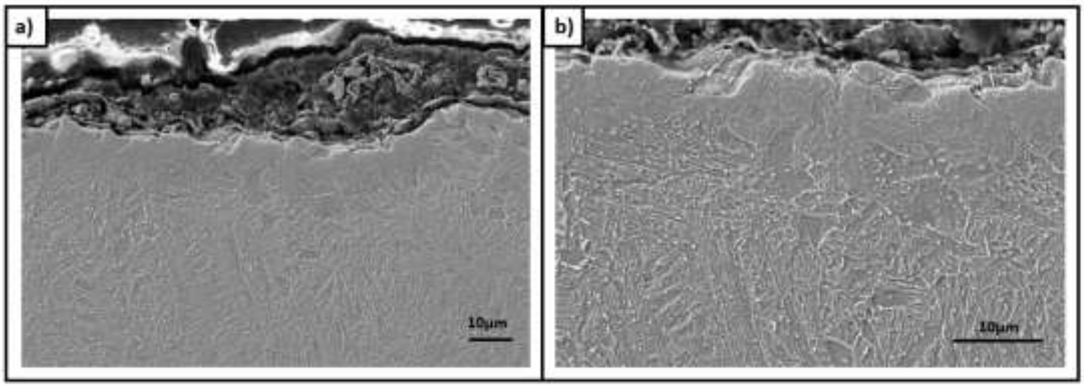

Figure 6.2. SEM microstructure image of AISI H13 steel cemented at 800 °C for 3 hours a) 2500X magnification b) 5000X magnification.

Apart from this, the reason why micro-structural differences are not observed in the sample, which is cemented for 6 hours at 800ºC, although it does not reach sufficient temperature for cementation, is due to the existence of sufficient time for diffusion in the sample. Keeping sufficient time for homogenization in the sample causes micro-structural differences to not occur.

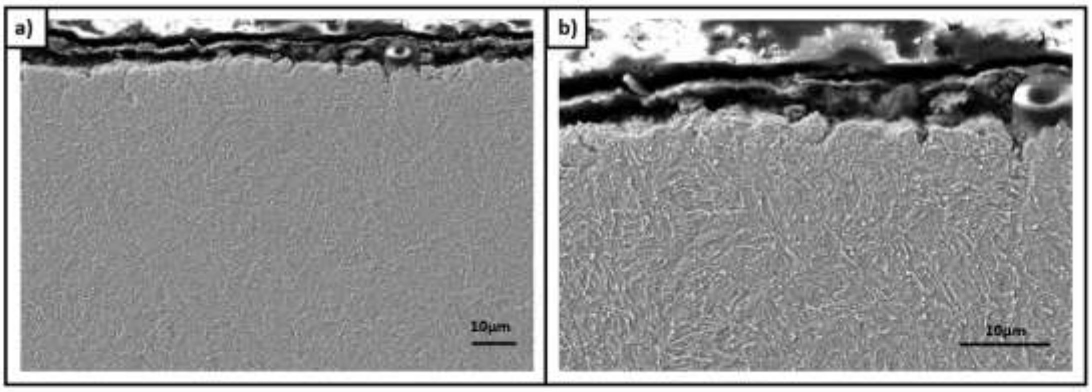

Figure 6.3. SEM microstructure image of AISI H13 steel cemented at 800 °C for 6 hours a) 2500X magnification b) 5000X magnification.

When we evaluate both the presence of micro-structural differences and the hardness results in the cementation processes performed at 930ºC, a successful cementation process was encountered. Here, grain refinement from the surface and conversion of bainitic structure to martensite structure is observed on the material surface. This is the reason for the increase in the wear and hardness values of the material. The figure 6.4 and 6.5 show the SEM image of the sample cemented at 930ºC for 3 hours at 2500X and 5000X magnifications, and the SEM image of the sample cemented at 930ºC for 6 hours at 2500X and 5000X magnifications, respectively.

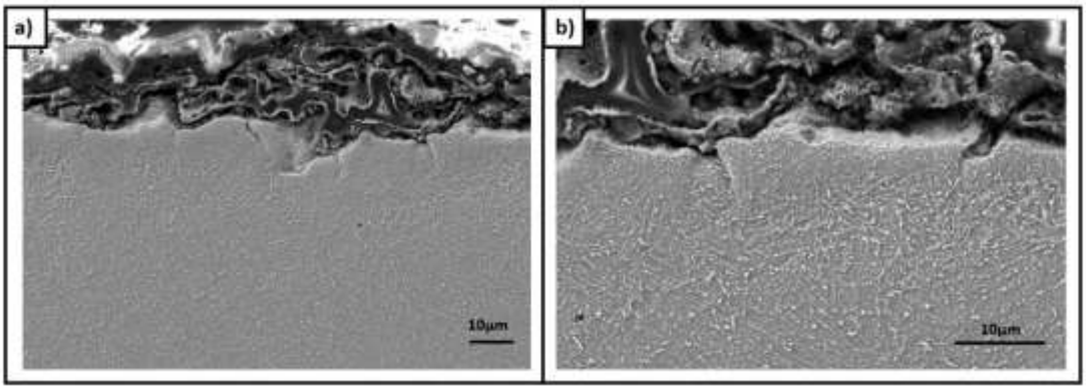

Figure 6.4. SEM microstructure image of AISI H13 steel cemented at 930℃ for 3 hours a) 2500X magnification b) 5000X magnification.

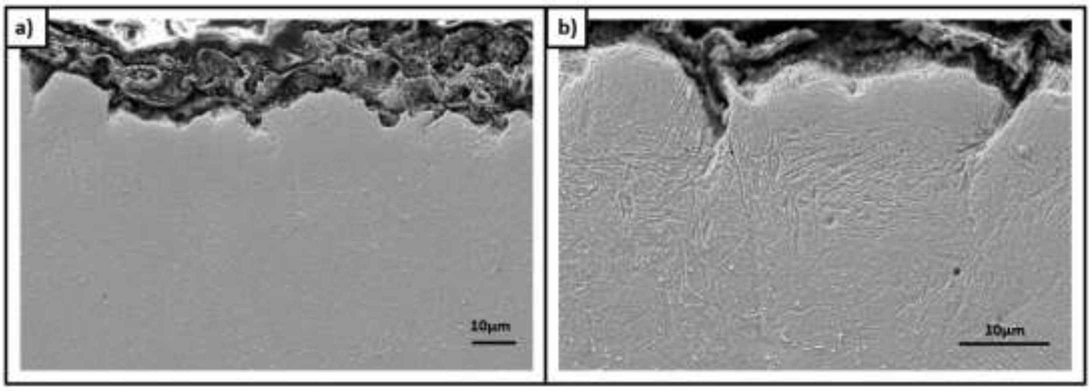

Figure 6.5. SEM microstructure image of AISI H13 steel cemented at 930℃ for 6 hours a) 2500X magnification b) 5000X magnification.

The figure 6.6 shows the SEM EDX results at 800°C, when these results are examined, the values given in the table are seen and a decrease in the carbon ratio from the surface to the inside has been detected, and it has been understood that this decrease has occurred due to the insufficient cementation temperature. In other words, it has been determined that it causes decarburization on the surface. It is also valid for the sample cemented at 800ºC for 6 hours (Figure 6.7).

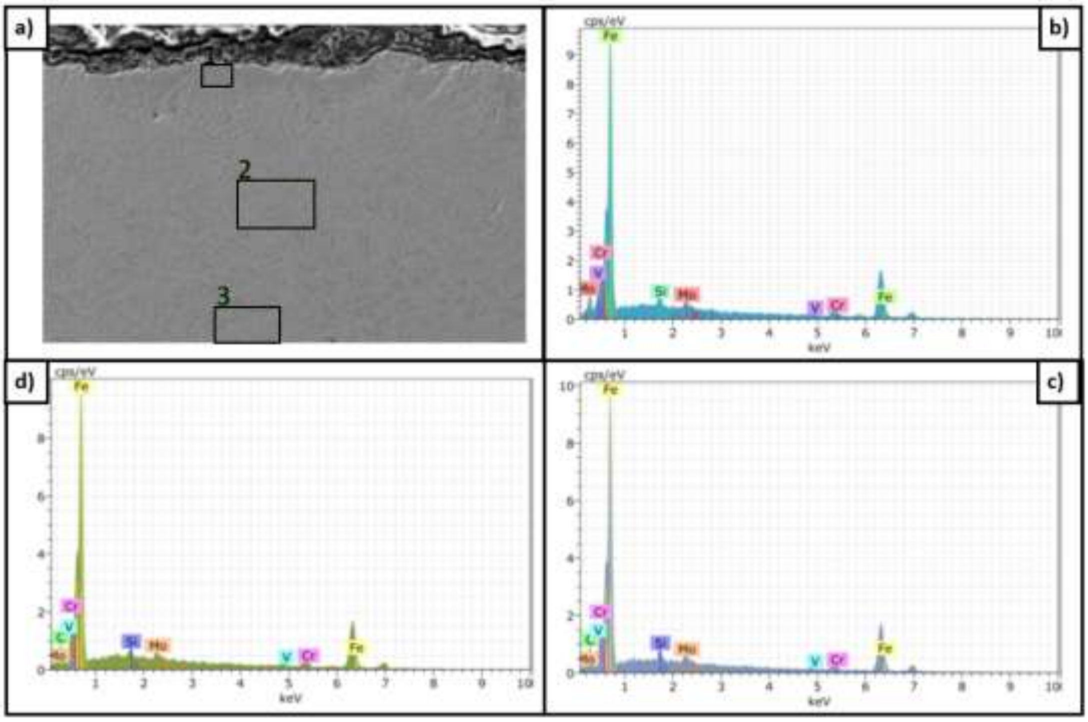

Figure 6.6. SEM EDX results of microstructure image of AISI H13 steel cemented at 800℃ for 3 hours.

Table 6.1. Chemical composition as a result of EDX.

Mass percent (%)Spectrum	C	Si	V	Cr	Fe	Mo
1	3.09	1.14	2.83	4.28	86.85	1.80
2	3.59	1.84	0.95	6.33	85.30	2.00
3	4.51	1.53	1.52	6.54	84.30	1.60

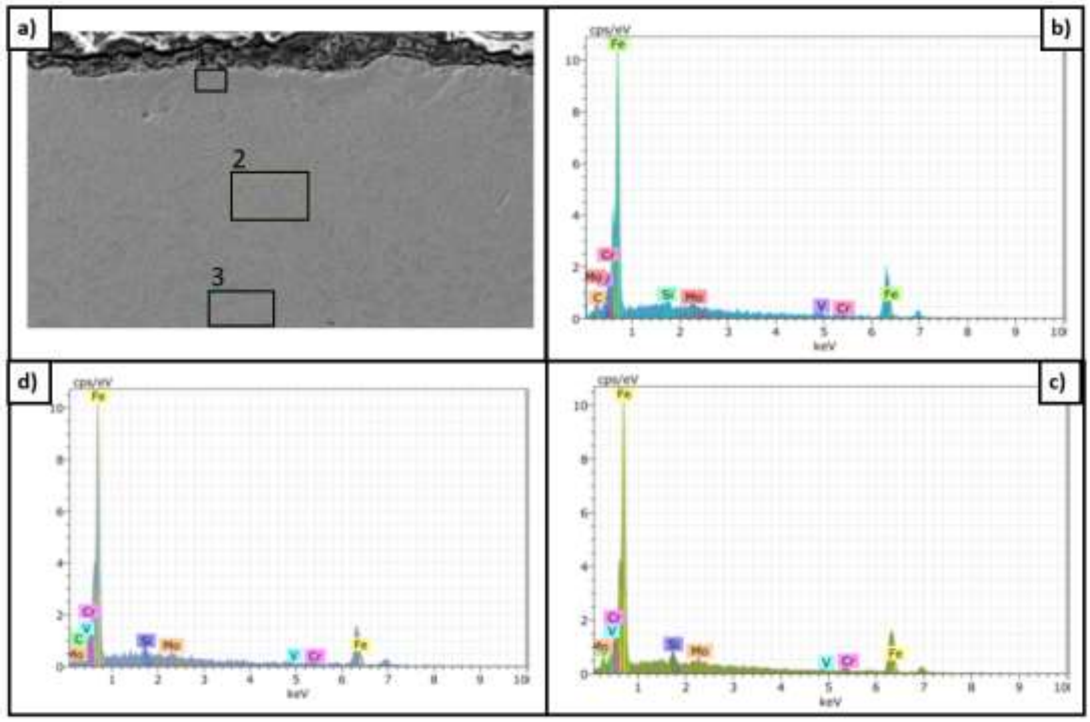

Figure 6.7. SEM EDX results of microstructure image of AISI H13 steel cemented at 800 ℃ for 6 hours.

Table 6.2. Chemical composition as a result of EDX.

Mass percent (%)Spectrum	C	Si	V	Cr	Fe	Mo
1	4.67	1.40	1.51	6.41	83.97	2.05
2	4.82	1.34	1.85	5.76	84.14	2.08
3	4.96	1.41	1.61	5.28	84.48	2.25

6.2. HARDNESS TEST

Figure 6.8 shows the average hardness results of the cemented steels and the base metal. When the hardness results are examined, it is seen that the base metal average hardness result is 615 HV. No change was observed in the hardness of the steels cemented at 800C starting from the surface. The reason for this is that cementation does not actually make a change in the hardness of the material; in fact, it is the tempering process after cementation that increases the hardness. This is because the quenching process5 is insufficient for AISI H13 steel at 800C and structures such as martensite and bainite cannot form on the surface. In the cementation processes performed at 930C, the hardness characteristically reached the maximum hardness at 100 µm from the surface and reached 1148Hv in the sample that was cemented for 3 hours. Then, a linear decrease was observed in the hardness ratios as one descended into the interior. In addition, the maximum hardness value of the steel, which has been cemented for 6 hours, was again measured as 1011Hv at a depth of 100 µm.

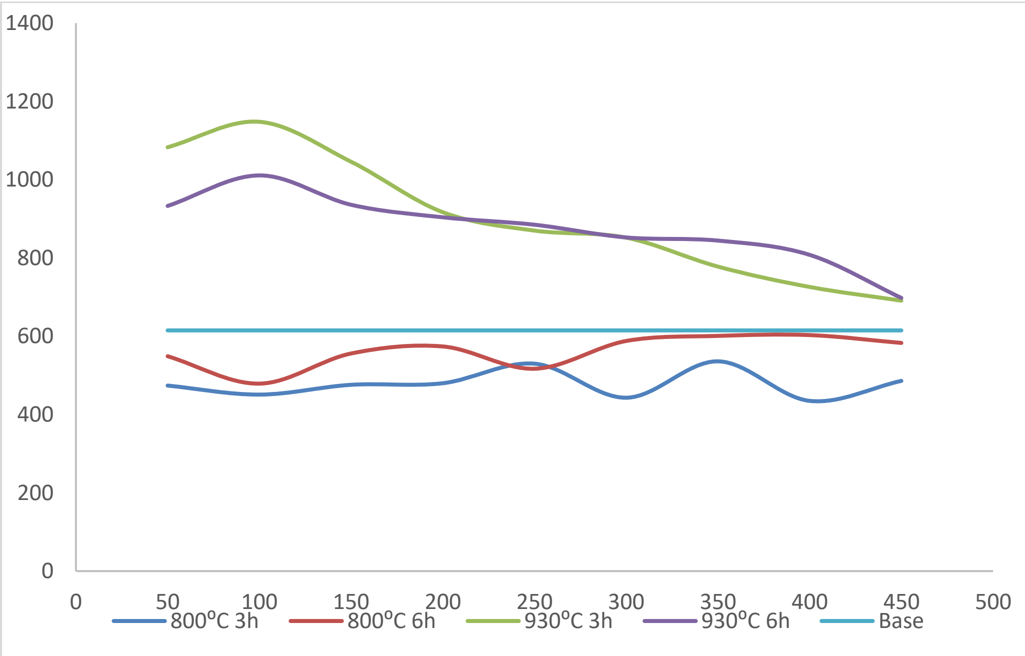

Figure 6.8. Hardness measurement results.

6.3. DRY WEAR

Dry environment wear parameters are made by traveling 500 meters with 20N and 40N. There are 10mm mark length and abrasion area graphs measured on the surface spectrometer of the uninsured specimen as shown in the manner. By looking at these graphs, it is understood that AISI H13 hot work tool steel that has been cemented must be increased to temperatures much higher than 800ºC in order to becemented. When we looked at both surface areas and specific wear loss data,it was determinedthatwhile there wasno increase in wear resistance in AISI H13 steels traded at a temperature of 800º C, there was an increase in wear results inAISI H13 hot work tool steels traded at 930 ºC.

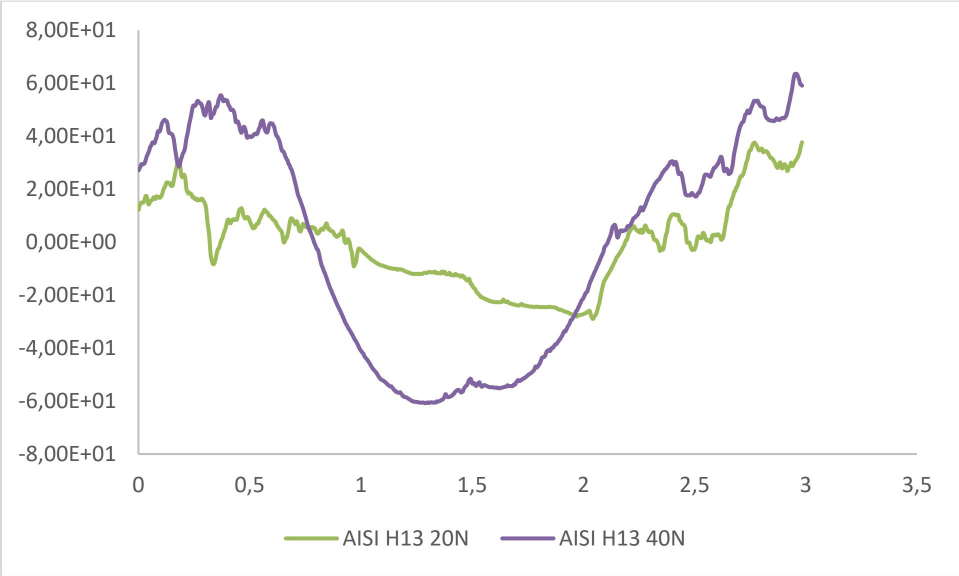

Figure 6.9. AISI H13 steel as a result of surface spectrometer of wear surface.

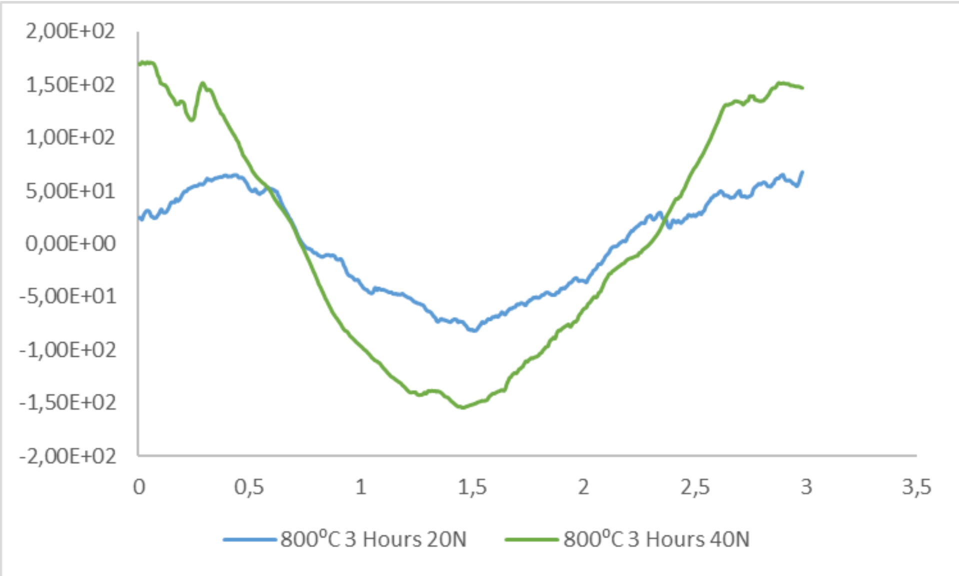

Figure 6.10. AISI H13 800ºC 3 hours cemented sample as a result of surface spectrometer of wear surface.

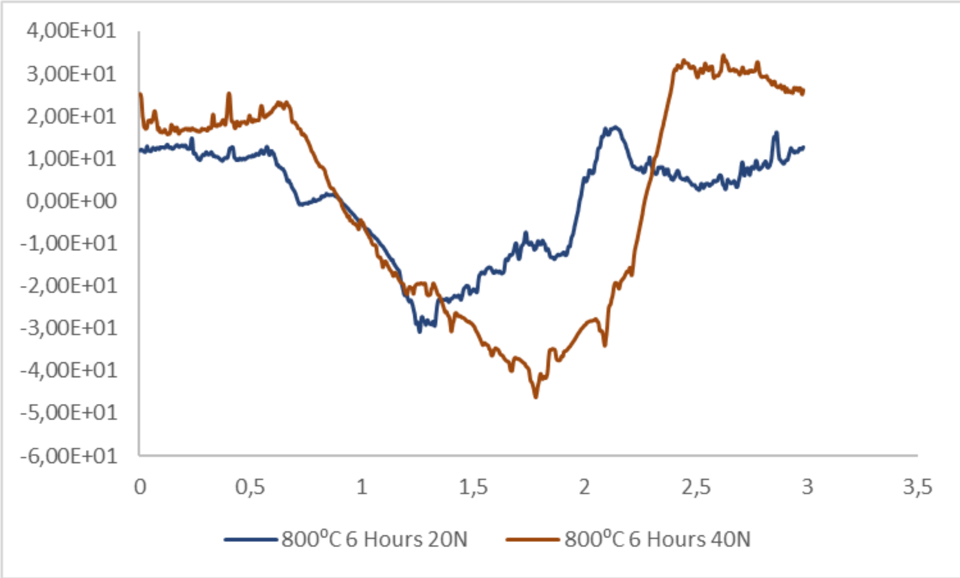

Figure 6.11. ASI H13 800ºC 6 hours cemented sample as a result of surface spectrometer of wear surface.

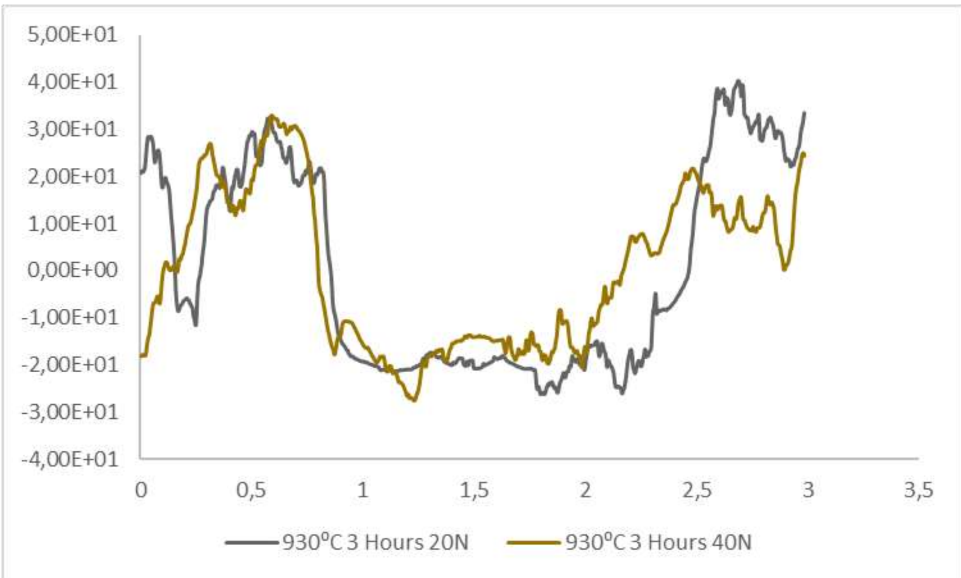

Figure 6.12. AISI H13 930ºC 3 hours cemented sample as a result of surface spectrometer of wear surface.

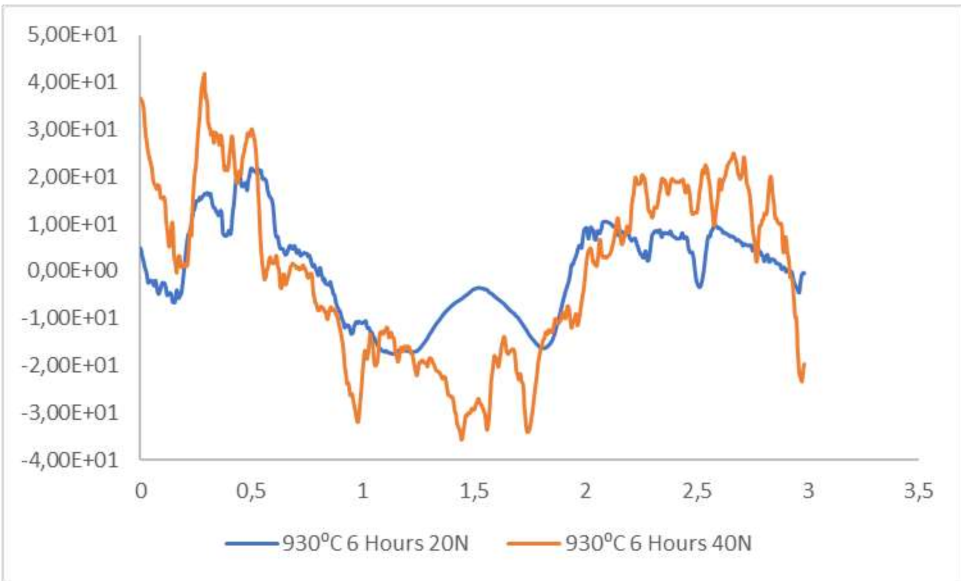

Figure 6.13. AISI H13 930ºC 6 hours cemented sample as a result of surface spectrometer of wear surface.

Figure 6.9 contains a specific wear graph. As can be seen in this graph, the specific wear of the sample, which was cemented for 3 hours at 930ºC, was the most stable and the samples that were cemented for 930ºC 6 hours and 800ºC 6 hours followed a characteristic path almost parallel to each other. In addition, in the sample, which was cemented for 3 hours at 800ºC, its specific wear was very different from the others, and this was due to the presence of decarburization on the surface, as explained in the microstructure, resulting in a noticeable decrease in the wear mechanism.

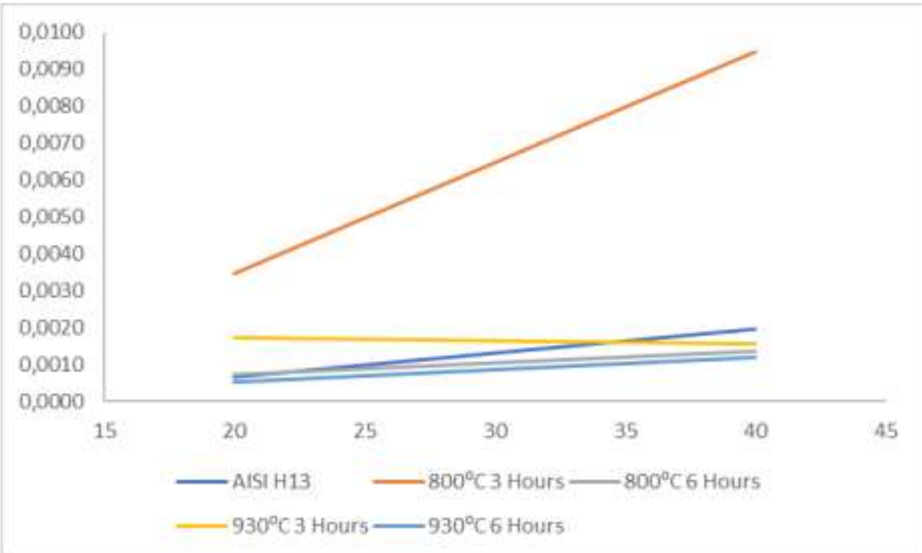

Figure 6.14. Specific wear values in dry environment conditions.

Figure 6.15 contains the results of SEM analysis after dry wear. These results show that the dominant wear mechanism in all materials and loads is abrasive wear. However, the 930ºC 3-hour cemented sample (Figure 6.10 g and h) has an oxidative wear mechanism as well as abrasive wear mechanism at 20N and 40N loads. This explains the reason for the increased wear resistance. Considering the AISI H13 steel.

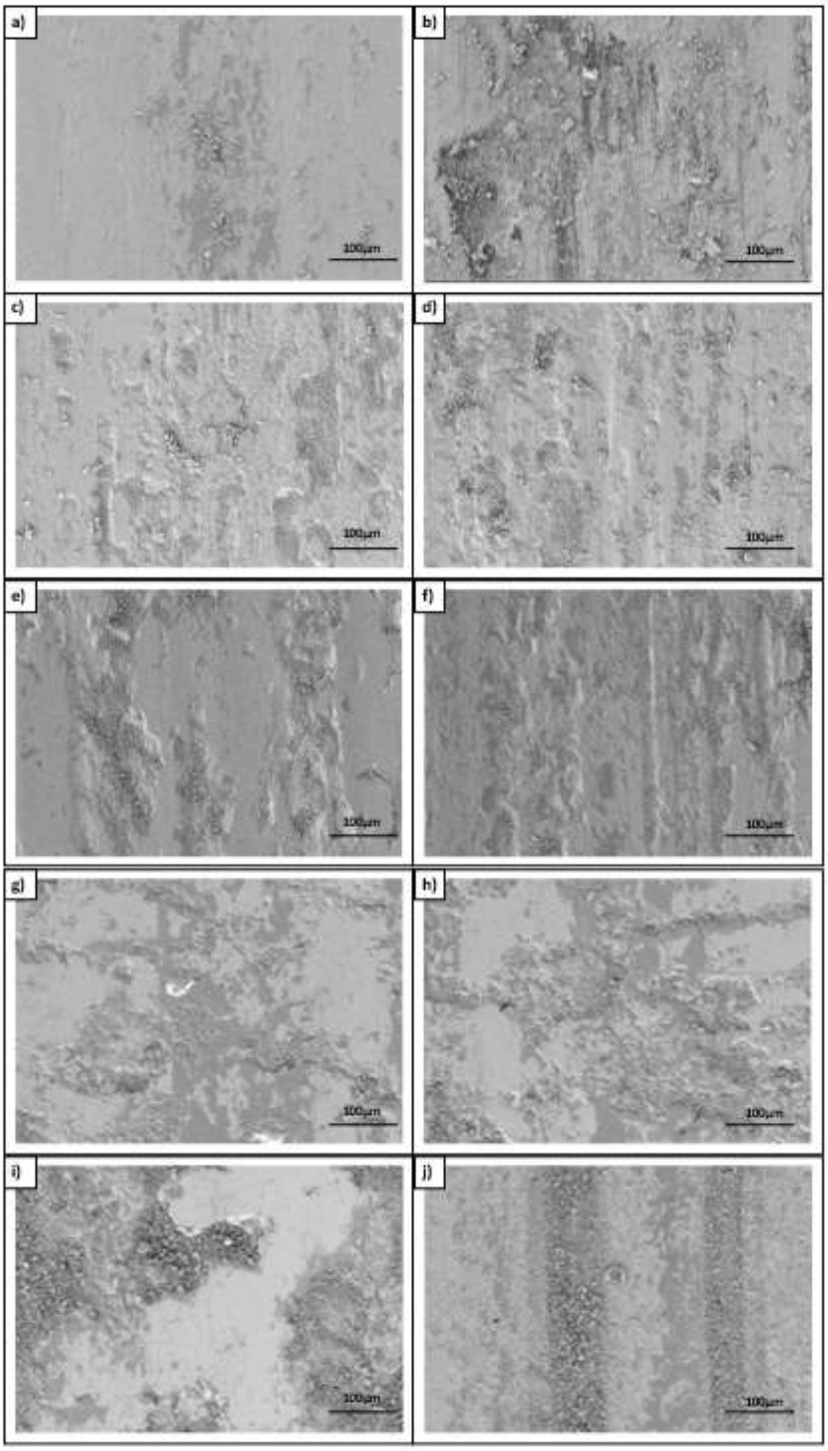

Figure 6.15. SEM analysis at 500X magnification after wear a) AISI H13 20N b) AISI H13 40N c) 800 ºC 3 hours cementation 20N d) 800 ºC 3 hour cementation 40N e) 800ºC 6 hours cementation 20N f) 8000ºC 6 hours cementation 40N g) 930ºC 3 hours cementation 20N h) 930ºC 3 hours cementation 40N i) 930ºC 6 hours cementation 20N j) 930ºC 6 hours cementation 40N.

6.4. CORROSIVE WEAR

When corrosive wear results are evaluated, it is seen that the results are different in dry wear. This is because in the cementation process, the rate of precipitation carbons increases and dry wear can be inferred that these precipitation carbons increase the friction coefficient and reduce corrosion resistance. Here, unlike the dry environment, it is thought that thespecific wear of the sample, which was semented for 6 hours at 930 ºC, was due to the increased specific wear, therefore the highest rate of precipitation carbides, and the specific wear in the sample treated for 6 hours at 800ºC was thought to be due to the fact that this sample was of a homogeneous microstructure.

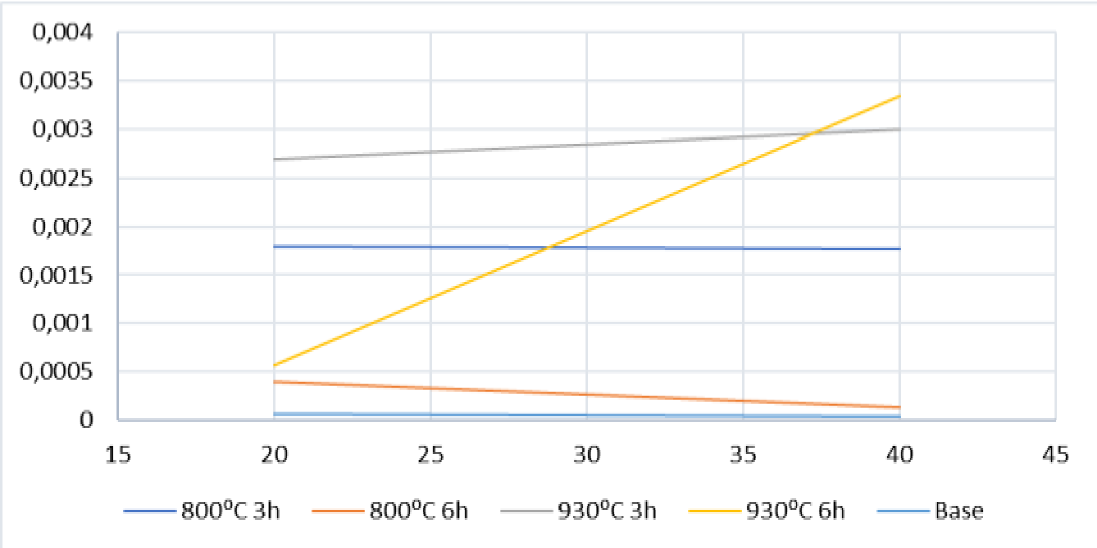

Figure 6.16. Specific wear values in corrosive ambient conditions.

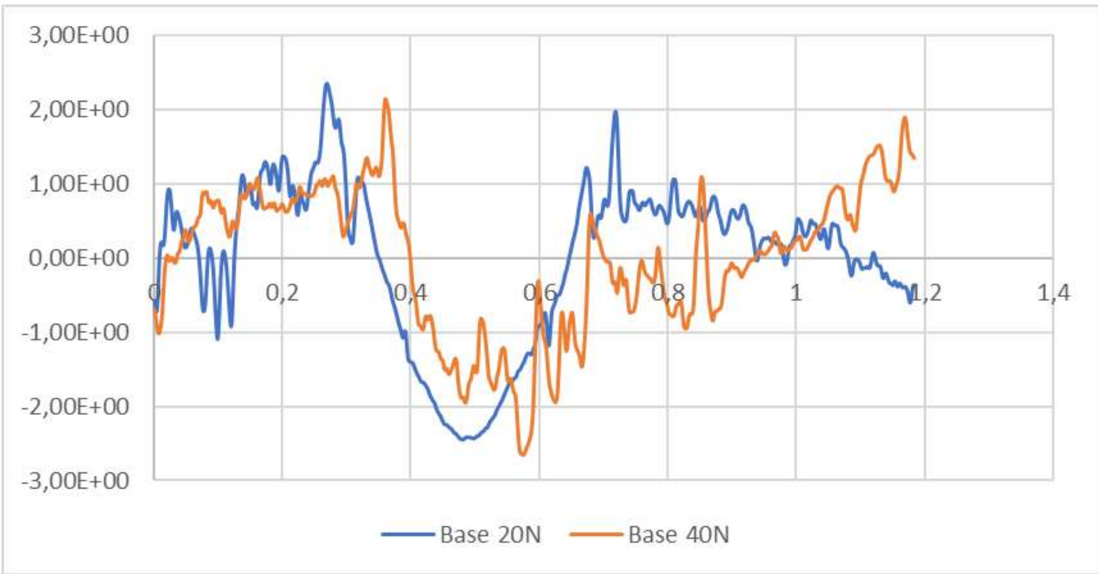

Figure 6.17. AISI H13 steel as a result of surface spectrometer of wear surface in corrosive environment.

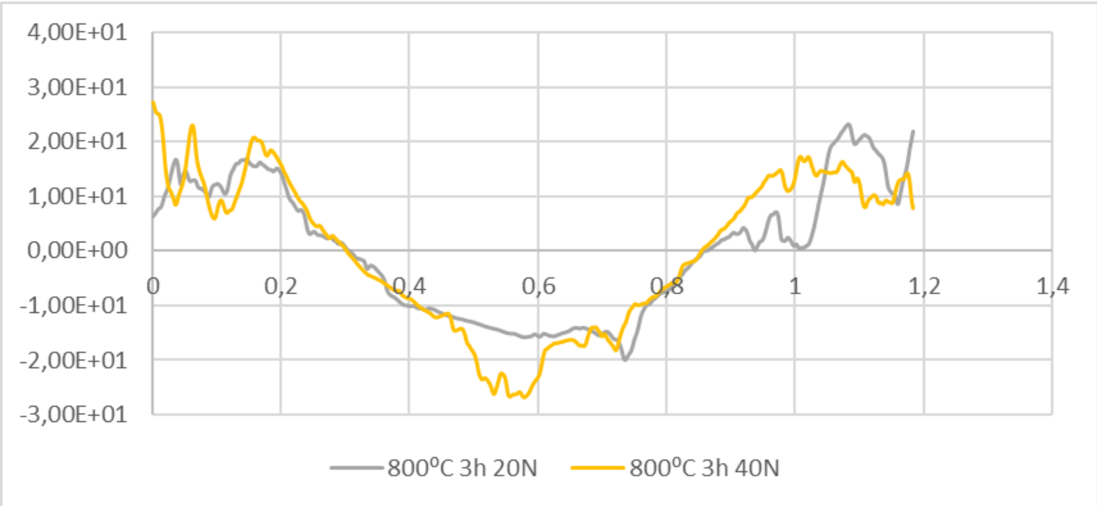

Figure 6.18. AISI H13 800 ºC 3 hours cemented sample as a result of surface spectrometer of corrosive ambient wear surface.

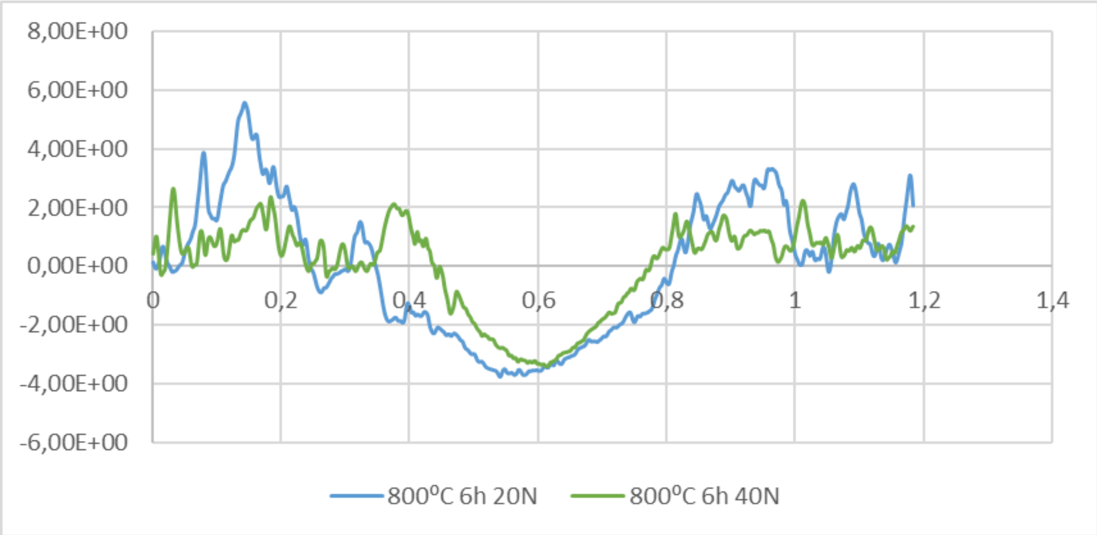

Figure 6.19. ASI H13 800 ºC 6 hours cemented sample as a result of surface spectrometer of corrosive ambient wear surface.

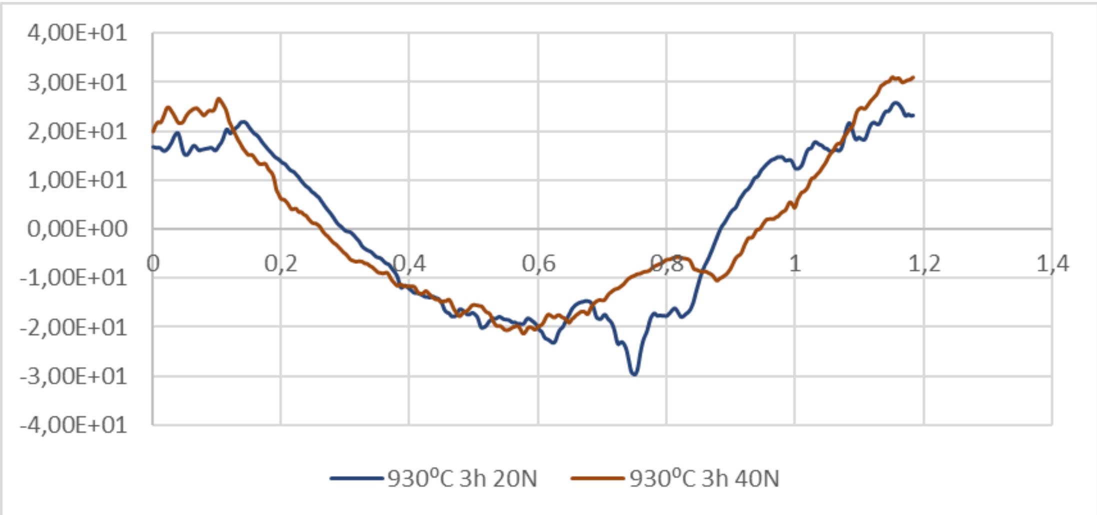

Figure 6.20. AISI H13 930 ºC 3 hours cemented sample as a result of surface spectrometer of corrosive ambient wear surface.

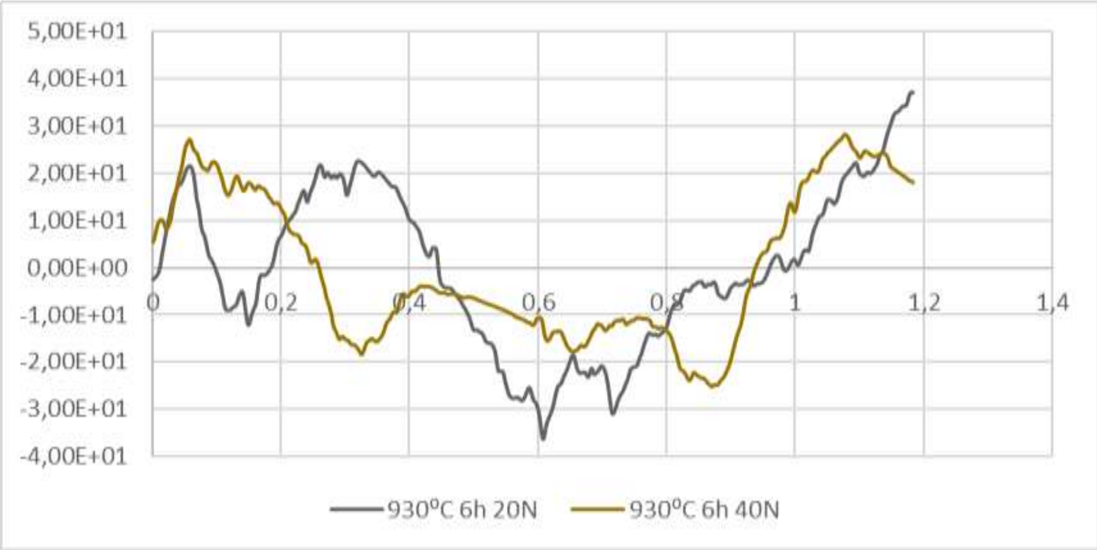

Figure 6.21. ASI H13 930 ºC 6 hours cemented sample as a result of surface spectrometer of corrosive ambient wear surface.

PART 7

RESULTS

As a result, when the abrasion and hardness results of AISI H13 steel are evaluated after the cementation process;

1. In the samples thatwere semented for 930 ºC 3 hours, the hardness reached the highest value and the average hardness value was around 1011HV in the sample that was cemented for 6 hours at 930ºC immediately afterwards.
2. 930ºC 3 hours cementation was performed, which again gave the best results in abrasion tests performed in dry environment conditions, and showed that the optimum values of the cementation process were 3 hours at 930ºC.
3. In the corrosive environment, it is understood that unlike the dry environment, the cementation process negatively affects the corrosion resistance decrease due to the presence of precipitated carbides and as a result, corrosive environment wear resistance.

As it can be understood from here, it is understood that cementation of AISI H13 steel at a temperature above 900ºC must be performed in order for the cementation process to be successful. However, long cementing means that there are more sediment carbides on the material surface. This directly affects the results of wear in a corrosive environment. It is understood that sediment carbides create weak regions in the corrosive environment, causing decreased wear resistance.

REFERENCES

1. Öner, E., “Termoreaktif difüzyon (TRD) yöntemiyle krom karbür ve vanadyum karbür kaplaması AISI D3 seri soğuk iş takım çeliğinin mikroyapı ve aşınma özelliklerinin incelenmesi”, Yüksek Lisans Tezi, ***Bartın Üniversitesi Fen Bilimleri Enstitüsü***, Bartın (2012).

2. Arslan, Y., “Kriyojenik işlemin AISI D3 soğuk iş takım çeliğinin performansına etkilerinin incelenmesi”, Yüksek Lisans Tezi, ***Gazi Üniversitesi Fen Bilimleri Enstitüsü,*** Ankara (2014).

3. Sinoplu, Ö., “Termo-reaktif difüzyon (trd) yöntemiyle titanyum karbür kaplanan aısı D3 seri soğuk iş takım çeliğinin mikroyapı ve aşınma özelliklerinin incelenmesi”, Yüksek Lisans Tezi, ***Bartın Üniversitesi Fen Bilimleri Enstitüsü,*** Bartın (2012).

4. Arslan, K. F., “Soğuk iş takım çeliklerinde sıfıraltı işlem derecesinin mekanik özelliklere etkisi”, Yüksek Lisans Tezi, ***Sakarya Üniversitesi Fen Bilimleri Enstitüsü,*** Sakarya (2010).

5. Brezinová, J., Viňáš, J., Guzanová, A., Živčák, J., Brezina, J., Sailer, H., Vojtko, M., Džupon, M., Volkov, A., and Kolařík, L., “Selected Properties of Hardfacing Layers Created by PTA Technology”, ***Metals,*** 11 (1):134 (2021).

6. Abakay, E., “Termo-reaktif difüzyon (TRD) yöntemi ile çeliklerin Nb-Al-N kaplanması, Yüksek Lisans Tezi, ***Sakarya Üniversitesi Fen Bilimleri Enstitüsü,*** Sakarya (2013).

7. Pazarlıoğlu., S. S., “Çeliklerin niobyum borür kaplanması ve özellikleri", Master’s Thesis, ***Sakarya Üniversitesi Fen Bilimleri Enstitüsü,*** Sakarya (2006).

8. Er, A. O., OOrhan, S., Camuşçu, N. and Aslan, E., “Sertleştirilmiş 1.2738 plastik kalıp çeliklerinin yüksek hızlarda işlenmesinde titreşimin işleme etkilerinin deneysel olarak incelenmesi”, ***Ulusal Talaşlı İmalat Sempozyumu, UTİS,*** Ankara (2012).

9. Yılmaz, H., Yazır, B., Yıldız, S., Davut, K., and Şimşir, C., “Determination of factors ınfluencing distortion of carburized quenching of steel shafts using DoE with computer simulations”, ***Department of Metallurgical and Materials Engineering, Conference / Seminar*** (2016).

10. Feistle, M., Koslow, I., Krinninger, M., Golle, R., and Volk, W., “Reduction of burr formation for conventional shear cutting of boron-alloyed sheets through focused heat treatment”, ***Procedia CIRP,*** 63:493-498 (2017).

11. Yuan, J., Kang, J., Rong, Y., and Sisson, R. D., “FEM modeling of induction hardening processes in steel”, ***Journal Of Materials Engineering And Performance,*** 12(5): 589-596 (2003).

12. Ratajski, J., Olik, R., Suszko, T., Dobrodziej, J., and Michalski, J., “Design, control and in situ visualization of gas nitriding processes”, ***Sensors,*** 10 (1): 218-240 (2010).

13. Bhushan, B., “Introduction to tribology”, ***John Wiley & Sons*** (2013).

14. Peters, G. A. and Peters, B. J., “Automotive Vehicle Safety”, ***CRC Press,*** Florida (2002).

15. Song, Y., Xing, Z., Wang, H., He, P., and Xu, B., “Very high cycle bending fatigue behaviors of FV520B steel under fretting wear”, ***Journal Of Materials Research***, 31 (12): 1748-1754 (2016).

16. Kato, K. and Adachi, K., “Modern tribology handbook”, ***Wear Mecanisms***, 2 (2001).

17. Zum Gahr, K.-H., “Microstructure and Wear of Materials”, ***Elsevier*** (1987).

18. Friedrich, H. and Schumann, S., “Research for a “new age of magnesium” in the automotive industry”, ***Journal Of Materials Processing Technology***, 117 (3): 276–281 (2001).

19. Tabonah, T. M. K., Akkaş, M., and Islak, S., “Microstructure, wear and corrosion properties of NiB-TiC composite materials produced by powder metallurgy method”, ***Science Of Sintering***, 51(3) (2019).

RESUME

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