THE EFFECT OF PUNCH SHEAR ANGLE ON SHEAR FORCE DURING THE PIERCING PROCESS

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I certify that in my opinion the thesis submitted by HASHIM ALASHARIF titled "THE EFFECT OF PUNCH SHEAR ANGLE ON SHEAR FORCE DURING THE PIERCING PROCESS " is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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ABSTRACT

M. Sc. Thesis

THE EFFECT OF PUNCH SHEAR ANGLE ON SHEAR FORCE DURING THE PIERCING PROCESS

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Sheet metal fabrication processes widely use punching, stamping, cutting and bending of sheet metal parts, and various processes and their combinations are widely used for sheet metal parts. Punching and broaching are two major operations that depend on the shearing processes by which the incoming sheet metal is cut and transformed into the desired shape. This study investigates the perforation at three different angles (0°, 3°, 6°) for their effect on the perforating process of two samples Al(1050)-1, Al(1050)-2 and two samples of steel St (AISI304L)-2, St(AISI304L) - 1 Tested in this experiment, the test was carried out in perforation tests conducted in the laboratory in the Faculty of Mechanical Engineering, in the stationary test lab. At Karabuk University, Turkey, under room temperature (25°C), at a speed of 15 mm/min, with Zwick Roell type Z600.

This study aims to know the effect of the shear angle on the shear resistance during the drilling process, and reached the following results in steel St (AISI304L) -1, initially the angle was 0 degrees, and the maximum shear strength was, but when changing the angle 3 degrees to 6 degrees, The strength is gradually decreasing, which means that as the shear angle increases, the shear force decreases during the drilling process in the steel sample. For aluminum Al (1050)-1, the maximum strength of aluminum was at the angle 0°, when changing the angle from 3° to 6° the strength began to decrease

Key Words : Shear Angle, Aluminum (Al), Stainless Steel (St), Piercing, Punching.
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ÖZET

Yüksek Lisans Tezi

İSKELE SÜRECİNDE ZIMBA MAKAS AÇISININ MAKAS KUVVETİ ÜZERİNDEKİ ETKİSİ

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Sac metal imalat prosesleri, sac metal parçaların delinmesi, damgalanması, kesilmesi ve bükülmesini yaygın olarak kullanır ve çeşitli prosesler ve bunların kombinasyonları sac metal parçalar için yaygın olarak kullanılır. Delme ve broşlama, gelen sacın kesildiği ve istenen şekle dönüştürüldüğü kesme işlemlerine bağlı olan iki ana işlemdir. Bu çalışmada, Al(1050)-1, Al(1050)-2 ve AISI304L-1, AISI304L-2 çelik numunelerinin perforasyon işlemi üzerindeki etkilerini üç farklı açıda (0°, 3°, 6°) araştırmaktadır. Bu deneyde test edilen test, Makine Mühendisliği Fakültesi laboratuvarında, sabit test laboratuvarında yapılan perforasyon testlerinde gerçekleştirilmiştir. Karabük Üniversitesi, Türkiye'de, oda sıcaklığında (25°C), 15 mm/dk hızda, Zwick Roell tip Z600 ile.

Bu çalışma, delme işlemi sırasında kesme açısının kesme direnci üzerindeki etkisini bilmeyi amaçlamaktadır ve çelik St (AISI304L) -1'de aşağıdaki sonuçlara ulaşılmıştır, başlangıçta açı 0 dereceydi ve maksimum kesme dayanımı idi, ancak açıyı 3 dereceden 6 dereceye değiştirmek, Mukavemet giderek azalır, yani kesme açısı arttıkça çelik numunede delme işlemi sırasında kesme kuvveti azalır. Alüminyum Al (1050)-1 için, alüminyumun maksimum mukavemeti 0° açısındaydı, açı 3°'den 6°'ye değiştirilirken mukavemet azalmaya başladı.

Anahtar Kelimeler : Kesme açısı, Alüminyum (Al), Paslanmaz Çelik, Delme ve Delme.

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

V_p : Punch velocity

d_p : Punch diameter

r_p : Punch corner radius

d_p : Blank holder diameter

f_b : Blank holder force

d_d : Die diameter

r_d : Die corner radius

t : Sheet corner radius

Cr : Chromium

Fe : Iron

Mo : Molybdenum

Al : Aluminum

Cu : Copper

Ni : Nickel

Co : Carbon monoxide

Mg : Magnesium

Zn : Zink

σ : normal gerilme

ABBREVIATIONS

AISI : American Iron and Steel Institute (Amerika Demir ve Çelik Enstitüsü)

ASTM : American Society for Testing and Materials (Amerika Deneme ve Malzeme Topluluğu)

PART 1

INTRODUCTION

In the automotive sector, aluminum and steel have recently become quite important. The structural parts of vehicles consist of using this steel to protect occupants' safety. Steel is one of the most widely noticed steels that offers an excellent compromise between sheet formability and mechanical characteristics (high final tensile strength) Different models and shorter model cycles were driven by the high and growing rivalry from the automotive industry. Furthermore, there has been a very strong development of rivalry to cut costs and boost production.

Aluminum and steel layers contributed to the development of less thick structural sections, hence helping to build lighter automobiles with a decreased fuel and greenhouse gas emissions compromise. The structural features of sheet metal cars are usually manufactured by punching instruments to get the necessary engineering component. In industrial sheets, constrained punching frequently break the vacuum through the metal forming process of traditional steel grades [1].

Furthermore, customer needs like lower consumption and increased comfort as well as some regulatory requirements like the reduction of hazardous emissions, environmental requirements and safety rules influence the growth of automotive production.

In industrial work, sheet forming with cutting and punching dies is widely used. The mechanical properties of sheet metal affect the processing of bleaching and perforation plates. High-resistance sheet metal is used to make durable, high-quality items. The use of high-resistance sheet metal has a negative impact on the mechanical processes involved. The state-of-the-art machining technology necessary for such metals has been further researched. Changes in punch and shape are one of the regularly utilized strategies for reducing cuts. In the investigation, the usage of wave-formed tools showed reduction of punching force and increased quality.

When shaping materials, the shear angle is critical. The smaller the shear angle, the higher the pressure, processing strength and power requirements. In tool engineering there is nothing to define what the shear angle will become, the shear angle can be specified preceded by the span thickness, even if the slice is not limited to a certain extent. To understand the development of the chips, it is necessary to determine the shear angle. The shear angle can be estimated assuming that it is oriented so that the work on shaping the slide is minimal. To do this, the cutting force is written in terms of pressure on the shear plane, tool chip friction, shear angle, and cutting geometry parameters. Assuming that the tool chip friction and pressure in the shear plane do not change with the shear angle, the shear angle for the minimum cutting force is determined as the friction angle, where the average friction coefficient in the contact of the tool and the chip. Although the stress stiffness or the ability of the slide to transfer deformation forces from the tool to the shear plane is ignored [2].

The sheet metal shearing process uses two tools, a die and a punch, to apply shear stress to a sheet of metal of a specified thickness and length. Shearing occurs due to severe plasticity deformation and then fracture occurs which develops in the thickness of the plate. The clearance between the die and hole is an important variable that limits the shape of the shear edge of the hole and the blank. Generally, the clearance is between 2% - 8% of the thickness of the metal plate [1].

The piercing process is a mass production procedure that is performed extremely quickly. All investigations are concerned with reducing the forces needed to cut metal sheets in order to keep the cutting instrument in good time. The design for the tool is considered an important variable and affects cutting force [1].

1.1. ABOUT THIS STUDY

Sheet metal cutting processes are the most preferred metalworking process in today's industry due to their ability to increase work capacity and produce quality products in continuous, fast, and standard sizes. The rapid growth of technology industries such as automotive and white goods caused a significant increase in sheet metal operations. Especially in the automotive industry, piercing has become the most common manufacturing process. Therefore, it has become important to be able to perform more cutting operations with less force and the load on the punches and dies used in piercing processes in continuous and rapid production. On the other hand, aluminum and steel have become very important in the automotive industry in the last 20 years. Considering factors such as structural parts of vehicles and ensuring the safety of passengers, steel and aluminum sheet materials are frequently preferred for material selection. Therefore, it is very important to provide more production with less effort on these products and also to increase the life of the tools used during the piercing process.

In this study, the effect of the punch angle, which is widely preferred in cutting processes in engineering fields and used in piercing processes, on the shear forces created during piercing processes was experimentally investigated. AISI 304L stainless steel and Al-1050 aluminum alloy sheet plates were preferred for the experimental piercing procedures. In addition, in this experimental research, a tensile test was performed to determine the mechanical properties of AISI 304L and Al-1050 materials, and a chemical composition analysis was carried out to determine their chemical properties. After the researches, the data obtained were compared with each other and many mechanical results were determined.

PART 2

LITERATURE REVIEW

Tool materials usually lose their usefulness by breakage, obsolescence, or wear. Updates in technology and processes cause many machines to go obsolete. Breakage is when the material undergoes an accident and is no longer in a working condition. Wear is slightly different and usually makes the material lose its usefulness over a given duration of time due to constant use. Generally, wear is a harmful phenomenon. There are however certain situations when wear contributes to practical utilities. Certain processes like writing with a pencil, production of new work surfaces, and sharpening of blunt tool edges like blades, scissor edges, knives, etc. benefit from wear [3].

2.1. DUCTILE WEAR

In 1953 published the effect of wear on the steel sheet blanking process. His work comprised of studying the edge wear and punch and die face flank [4]. Faura and Lopez (1997) used a similar approach in understanding the process of tool wear [5]. Extensive research was later done in Japan by Matsuno et al. (1984) to study crater wear, crater slope wears in blanking, and effects of work material restriction, clearance, and finish of cutting edge were recapitulated [4].

Rabinowicz describes wearing as the removal of metal from solid surfaces as a consequence of mechanical action. Burwell (1958) categorized wear into four major categories: abrasive, adhesive, corrosive, and surface fatigue wear. Depending on how many hard particles are entrapped on the surface of a soft material the amount of abrasive wear can vary. These hollowed-out groove particles can form debris and get stuck between other surfaces causing further wear. The abrasive costume can be abridged and even eliminated by decreasing the probability of hard particles getting stuck between rubbing surfaces by surface cleaning and the use of pure metals. Corrosive wear is caused by the sliding of surfaces leading to the top layer being removed which can lead to the corrosion of either surface. When these surfaces slide over each other, the layer is removed, and the mechanism continues till the material is rendered useless. The effect of corrosive wear can be substantially reduced by making sure the materials in contact do not react chemically with each other or with the lubricant being used for friction reduction or temperature control. Surface fatigue wear occurs due to the continuous loading and unloading action (sliding or rolling) of the materials. This type of motion induces cracks in the surface that lead to eventual falling out of fragments leaving pits in the material [7, 8].

Surface fatigue wear can occur when brittle materials are strained beyond their elastic strength. Fatigue wear is reduced by the other three wear mechanisms as those wear mechanisms keep removing the surface material before it has a chance to become fatigued by the constant stressing and unstressing multiple times. Adhesive wear is a unique form of wear. It occurs when one of the bodies' particles comes off and adheres to the other materials' surface during sliding. This particle can stay adhered to the new material or get dislodged as abrasion causing debris [9].

The theory states that this article can also be transferred back to the original surface. Unlike the earlier discussed wear mechanisms reduction of adhesive wear in tools is a relatively tough and tricky problem. Since adhesion occurs during sliding between the atoms of the two surfaces, sometimes the atoms of one surface stay adhered to the foreign surface even after the bodies have parted. These atoms on the surface of the materials cause scratching and itching. This is one of the reasons why on first glance these scratches are mistaken for abrasive wear without understanding that the actual cause is adhesive wear. Adhesive wear occurs at a slow rate and it is almost impossible to eliminate it completely [9].

2.2. ARCHARD'S WEAR MODEL

Adhesive wear has been observed in extremely soft material surfaces as well, this leads to the conclusion that that in certain cases, the adhesive wear rate can be independent of the surface roughness of the interacting materials. Archard's wear model is currently the most widely accepted plausible model of the sliding process. According to Archard, the probability of an adhesive wear particle being formed every time two asperities form a contact junction is constant, k. His fundamental law of adhesive wear states that the volume of transferred fragments formed in sliding through a given distance [10].

Lots of researchers during the 1950s tried to determine the type of wear associated with the failed sliding material. It is a complex process to determine the cause of the failure by the method of inspection. This is because most failures are caused by more than just one type of wear. Sprague and Dundy (1959), Kaufman and Walp (1953), and Bugbee (1958) have also observed cases of adhesive and abrasive wear, abrasive and corrosive wear acting together [11].

2.3. CRACK MECHANICS THEORY

Crack nucleation occurs when a substantial number of dislocations piles up in a particular location to cause the crystal planes to separate causing propagation of cracks. Crack nucleation methods can vary depending on the type of material being studied. Three categories for separating materials are: brittle, semi-brittle, or ductile. The behavior of dislocations in crack nucleation is governed by their brittleness. In extremely brittle metals, the displacements are basically immobile, whereas, in metal ductile displacements have an advanced degree of autonomy to transfer around. The nucleation of a crack in metals usually involves the rupture of interatomic bonds. Crack propagation can also start from any cavities, foreign particles, and inclusions. Plastic deformation plays an important role in ductile materials. The term ductility means a material's ability and capacity to endure plastic distortion without fracturing. The important feature which impacts the plastic deformability of materials is the flexibility of slip planes. Dislocation assemblies can function between multiple slip planes and even cross from one plane to another. When these dislocation assemblies pile against a barrier, the material cracks. These cracks are called Zener--Stroh cracks (1948). Upon multiple stressing and un-stressing, the dislocations are relaxed by the method of crack nucleation. If the dislocations move away from the barrier then the crack will not nucleate. Cracks also propagate at interacting metal boundaries representing that those areas were highly stressed. The nucleation and development of cavities is of great standing in defining the breakage features of ductile metals. Metals are considered by portable displacement associations and usually display a ductile crack. Various replicas have been future for void advance [12, 13, 32].

During blanking and punching when the punch shears against the workpiece the strain rate and the temperature have opposing special effects on ductility. Rankine, Tresca, and von Mises have given their own flow yield and fracture criteria equations [14].

2.4. BURR FORMATION AND PROCESS PARAMETERS

Crack The process parameters in punching have been widely studied by Hambli et al (2003). Hambli applied neural networks and the design of experiments in the investigation of the effects of clearance and tool geometry and proposed mathematical association unfolding the crack zone distance, the crack angle, and the shear force. In addition to the above mentioned, the effect of optimum clearance has also been discussed by Hambli et al. (2003) on AISI 304 sheet, and Fang et al. (2002) on aluminum alloy 2024 [15, 33].

Farzin et al. (2006) considered a new parameter “Die to Punch corner ratio” with various damage models. Maiti et al. (2000) studied the blanking load by numerical method. It has been proved that the reduction in the tool clearance, an increase of friction coefficient will result in the increase of blanking load. Fracture and burr formation is numerically analyzed in Hambli et al. (2003) and Taupin et al. (1996). Klaasen et al. (2006) focused on the surface destruction process in metal tools in the piercing of sheet metals. They found that metals opposition to cement wear and origin-circulation of weariness cracks could switch surface destruction opposition [16, 33].

Thipprakmas et al. (2005) compared both the FEM and experimental results and predicted the formation of defects on the blanked surfaces, such as shear surfaces, tearing shear surfaces, and cracks in the fine blanking process [17]. Hatanaka et al. (2003) proposed a simulation method to investigate the formation of rollover and the burnished surface and crack initiation and propagation. It is reported that the burnish length slowly increases at the beginning of punch penetration and then increases approximately in proportion to the punch penetration depth when punching displacement beyond 0.2 [19]. Taupin et al. (1996) and Farzin et al. (2006) also performed the process of matching fracture formation. Although the study of punch roughness has not been reported in literature roughness and friction at the interface has been investigated in sheet drawing and stamping [18].

Harr (1966) studied the friction model in sheet metal forming in his thesis. The outcome of irregularity on resistance in the edge lubrication command is long-established with trials that the resistance increases with surface irregularity. Lee (2002) has measured friction coefficients under an extensive variety of tri-biological circumstances on numerous steel sheets. The consequence of die irregularity on the resistance coefficient has been examined. It shows Friction coefficient could be as low as 0.02 between 0.5 and 1 μm on the surface. The friction coefficient increases and it could be up to 0.2 to 0.3 for an ultra-smooth surface [20].

2.5. EFFECT OF PUNCH-DIE CLEARANCE

In common, as the clearance amongst punch and die increases, the roll ended zone, crack zone, breakage angle, and accent increase although the shear region decreases. Inadequate clearance yields subordinate shear i.e., the fractures creating at the punch and die do not encounter; hence a circle of substantial is additionally stressed to its shear boundary, spending more vitality [19].

Excessive consent causes huge plastic distortion, large inflection, and high breakage angle. Moreover, tool life is dropped by unsuitable clearance. There are revisions that have studied the result of hit-die permission on part brink excellence and punch life, most of them are mentioned in figure 2.1 [19].

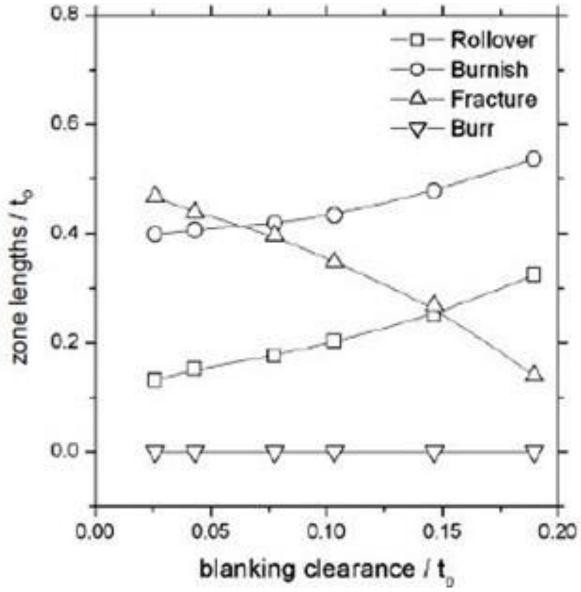

Figure 2.1. Effect of blanking clearance on part edge as predicted with finite element simulations on 0.58mm [19].

Bell in 2006 conducted a study in which 1400 MPa rating sheet metals, 1mm thick was piercing with PM 4% V, 60 HRC punch at 3 changed clearances, 6, 10, and 14% of sheet thickness. Punch wear was dignified after 200 thousand hits. It was originated that lesser permission caused annoying although advanced clearance instigated high twisting stresses angle in the spiteful brink growing the hazards of brink chipping [20]. There is a prime clearance amongst the two which will have minor wear on the instrument shown in figure 2.2.

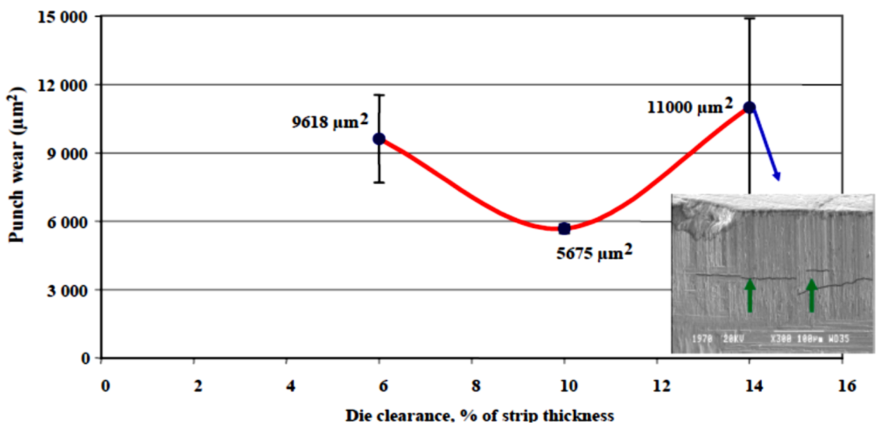

Figure 2.2. Effect of blanking clearance on part edge as predicted with finite element simulations on 0.58mm [21].

Högman in 2004 studied the influence of punch-die clearance on the punch life in a rectangular part. Experiments were conducted on 1mm thick Docol 800DP sheet material. Two radii were used in the punch for the corner of the rectangle for the experiments, 0.2mm and 0.5mm. A constant punch-die clearance of 10% is maintained in the case of 0.2mm radii. A punch-die clearance of 10% is maintained along the straight edge but increases to a maximum value of 20% in the corner in the case of 0.5mm punch corner radius as shown in Figure 2.5. The tool material used was Vanadis 4 with a hardness of 60 HRC. The punch with a punch-die clearance of 10% at the corner of the rectangle lasted 45000 strokes before chipping [34]. The punch with a punch-die clearance of 20% at the corner of the rectangle lasted 200000 strokes without chipping [20]. Figure 2.3 shows the worn tools with the different corner radii on the rectangular punch.

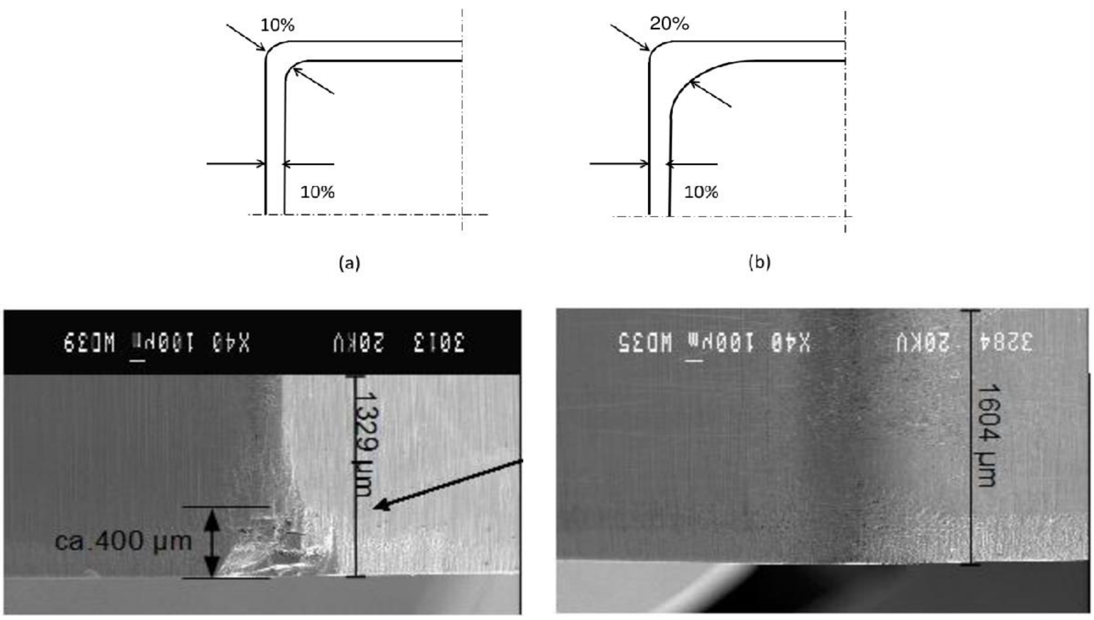

Figure 2.3. Effect Influence of punch-die clearance on shear edge length for different blanking velocities wear [21].

All the studies have shown consistently similar results for the effect of punch-die clearance on blanked edge quality and punch wear. It should be noted that all studies except Hogman are conducted for blanking of round parts, maybe because of the simplicity involved. Hence, the effect of sheet material and thickness, punch-die clearance, and blanking velocity on blanked edge quality and punch wear are studied. The effect of the geometry of the pierced shape on punch wear is not studied. From many challenges when using balancing/piercing mechanic metallic sheet the significant one is the control of shearing force which is required for thick stock and high strength. When the shearing force increases then the expected performance of machine requirements increases and the wear on the punch tool and die. The clearance increases the precision and quality of the blanking/piercing operations. It also affects the shearing force. The most common using technique for reducing the shearing force is the employment of punch shear angle. The given data is about the steel used in the manufacturing industry to explain the effects of clearance and punch shear angle, DC01 these are the different punch shear angles used named 0°,2°,4°,8° and16°. Different six materials with different rates of clearance (0.4%,0.5%,0.6%0.7%,0.8%, and 0.9%) were used in the study and for changing the clearance modular materials on the die are used. The experimental results were changed to a model named a fuzzy logic model for getting the extrapolated results of intermediate values of the results of the experiment. The results of both the fussy logic model and the experimental result are mostly similar to each other. These results showed the by using the fuzzy logic the developed model is used to find out the different shear angles and clearance values [21].

The technique of blanking and piercing die is used at the industrial level for making the sheet metal. The metals with different mechanical properties are used different conditions for clearance and piercing dies. Higher-strength sheet metals are used for increasing the quality of the product and produced durable products. On the other hand, the use of strengthening sheets also affected the mechanical process involved in it. The art of this technology has been under process for taking the mechanical effect down. The best one and the common method among all ones are the changes in the punch and the other one is the geometry of the die. In the study, the use of wave-formed tools the reduction of shear force and the increase in the quality result observed [25].

The experimental study of Mackencen et al. [24] studied the effects of the punch angle that affects the die and blanking/ piercing force. A test setup has been used which enables us for measuring the orthogonal force used during blanking/piercing. The result of the experiment shows that the increase in the angle of punch and die decreases the blanking/piercing force and this experiment also explains that the effects of punch angle are more than the die angle. The experimental studies of the last decades explain that the clearance and the punch angle are the most prominent part of the production. The reduction of blanking and punching force is due to the punching angle increases. The negative effect of balancing and piercing force is due to clearance. By increase clearance value the quality of products decreases Choi et al. [26, 35].

Studied the effect of clearance and the inclined angle of the die on the sheared edge, the characteristics of the trimmed DP980. Due to the large bending moment, the trimmed load decrease with the increase in the clearance, which gives a pathway to the hydrostatic tensile stress in the circle of the sheared zone. Above 15.6% the trimming clearance creates the occurrence of tensile type burr. The negative trimmed angle increases the edge quality. The negativity of the trimming angle also decreases the trimming load. Lo, et al. shearing parameters are the punch angle, clearance, number of shearing strokes, and the cutting-edge materials [36]. The study of clearance effect, tool wear, and metal shear thickness on the blanking force. Lin et al. [27] to determine the relationship between the clearance and punching life a neural network system is used. Gram and Waggoner explain the relationship which metal being processed and blanking and piercing force. Results explain that the hardening of the punch and the die increases the life of tools when the high-strength sheet metals are used [27].

Researchers explain the effects of clearance of cutting at different angles such as the longitudinal, transpersonal, and diagonal orientation of the trimmed line related to the rolling direction on broadly used aluminum alloys. 6111-T4. They found that for the entire sheet in orientation, the cutting clearance increases in this result a substantial reduction in the stretch ability of the material along the sheared surface [27].

As the result of this experiment who the stretch ability affected by the cutting angle, higher elongation observed under the cutting angle of 10% and 20% for 10% clearance which is broadly used, with an identical clearance compared with orthogonal cutting. For improving the mechanical properties of sheet metal parts, the shapes of die and punches are very important by this the surface quality and dimensional accuracy also increases [28]. Qazi Sheikh explains the parameter's effect on the process of blanking/ piercing. The optimization method with experimental design also described by them the methods are FEM analysis and Simulation. Armunanto et al. [29] explains the relationship of the punch, clearance, and dies circularity and circularity of the product of the punching process. Jaafar et al, developed an eccentricity model in the ultra-high steel sheet cutting process. The eccentricity between die and punch is provided by a moving die in their model. On sheared edge the distance of the burnished surface increases [30, 31].

PART 3

SHEET METAL OPERATIONS

3.1. METALWORKING

In metalworking, an initially simple part (a metal billet or a blank sheet) is plastically deformed between tools or dies to achieve the desired final configuration. Metal forming processes are generally classified into two main categories [37];

a. Bulk or massive forming operations
b. Sheet metal forming processes

In both types of processes, the surfaces of the deforming metal and the tools are in contact, and the friction between them can have a major impact on the material flow. In bulk-forming, the input material is in the form of billet, bar or plate, and the surface-to-volume ratio in the formed part increases significantly under the influence of compression loading. On the other hand, in sheet metal forming, a piece of sheet metal is plastically deformed into a three-dimensional shape by tensile loads, often without significant changes in sheet thickness or surface characteristics. Processes that fall under the bulk-forming category have the following distinguishing features [37];

a. The deformed material or workpiece undergoes large plastic (permanent) deformation, resulting in a significant change in shape or cross-section.
b. The plastic deformation part of the workpiece is generally much larger than the elastic deformation part; therefore, elastic recovery after deformation is negligible.

The various forming processes discussed above are associated with a wide variety of forming machines or equipment, including [37];

a. Rolling mills for sheet, strip, and shapes
b. Profile rolling machines from the strip
c. Ring rolling machines
d. Thread rolling and surface rolling machines
e. Magnetic and explosive forming machines
f. Draw benches for the tube and rod; wire and rod drawing machines
g. Machines (presses) for pressing type operations

Among those listed above, pressing machines are the most widely used and are applied to both casting and sheet forming processes. However, in this section, sheet metal processes through presses are discussed.

3.2. MECHANISM OF CUTTING IN SHEET METAL MATERIALS

The cutting (shearing) has an important place in forming sheet metal parts. This process is involved in the shaping of many sheet metal parts at least once, or multiple cutting processes may be used in the manufacturing process. In order to be competitive in the global market, the shape and dimensions of the manufactured parts must be in the desired dimensions. It is not enough to temporarily protect the quality of the part during the production process, but to maintain it without deterioration is an important task. Cutting is the process of shear between two different press pieces according to a predetermined cutting line. The quality of the final piece to be obtained is affected by many production parameters such as the material being shear, the material of the cutting punches, and the cutting speed [38].

Measurement accuracy is ensured in the parts obtained by mass production and material consumption can be minimized. Because there is no chip removal process in the production with cutting dies. In addition, the precision of the produced parts depends on the elements called punch and die. It requires delicate workmanship when manufacturing punches and molds. During mass production, the molds ensure the identity of the parts. For this reason, the precision that should be sought in the parts produced by cutting with molds compared to the production made by machining has become a feature of the cutting die [38].

3.2.1. Cutting Theory in Dies and Punches

Cutting occurs when the forces act on the material in the shearing and punching molds without machining from the sheets or strip sheets of the desired profile and dimensions. If the cut piece is to be used directly as a workpiece in the cutting of materials with a punch, it is called a cutting die. If the cut piece is the scrap piece to be discarded, the die is called the punching die. However, in both, the operation is a shearing operation. During the shearing of the material with a punch, the cutting process consists of three stages [38].

a. Plastic Deformation
b. Shear
c. Fracture

3.2.1.1. Plastic Deformation

After the punch contacts the sheet metal material, the movement of the punch towards the workpiece forces the material into the die. After the elastic limit of the material is exceeded, plastic deformation begins. With the combination of Elastic-Plastic deformation, a lower strain occurs on the cut piece and an upper strain occurs on the sheet metal material [38].

3.2.1.2. Shear

The sheet metal strip material is pushed into the die with a punch. The material is forced to curl at the shearing edge of the punch and die. And so the material begins to be shear at the cutting edge of the punch. At the same time, the cut piece is pushed into the mold cavity. The material resists breaking at the cutting edge of the die and is sheared between the cutting edge of the die. The cutting operation is completed when the resistance of the material cannot withstand the cutting force. A bright cutting and radius band of approximately one-third (1/3) of the sheet thickness is formed on the lower and upper edges of the sheet metal material [38].

3.2.1.3. Fracture

Due to the gap between the cutting edges of the die and the punch, a resistive force occurs in the material and this resistive force takes place in a fracture phase. If the pressing force of the punch continues after the shearing phase, the part is separated from the sheet metal material according to the shape of the punch and the profile of the die. In this step, a rough conical fracture surface is formed and the cutting process is completed as soon as it can no longer resist shearing [38].

The mechanical events that occur during the cutting process of the material are illustrated in Figure 3.1.

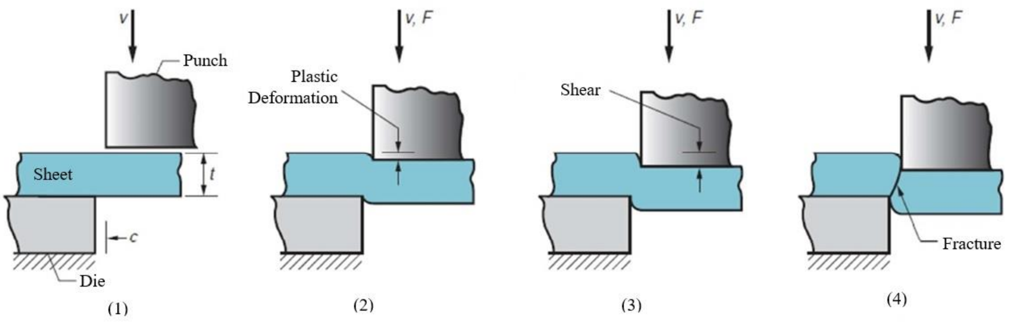

Figure 3.1. The mechanical steps during the cutting process of the material [38].

3.2.1.4. Stresses of During the Cutting Process in the Material

The part to be cut from sheet metal material between the matrix and the punch shows the greatest cutting resistance between the two cutting edges. At the same time, the punch sinks into the material and cuts until it reaches the yield strength limit of the material. After the maximum shear strength is exceeded, the material loses its shear resistance and begins to yield. When the yield limit is exceeded, the part breaks. It is known that tensile stress occurs on the upper surface of the strip material and the lower surface of the cut piece, and compressive stress occurs on the punch contact surface of the cut piece [38].

The stresses that occur in the cut material are important for the determination of the shear force. During cutting, compression stresses occur on the lower surface of the cut material that contacts the die hole, and both shear and compression stresses occur on the upper surface that contacts the periphery of the punch [38].

3.2.2. Cutting Clearance

The clearance, or the clearance between the punch and the sidewall of the die, affects the operating reliability of cutting and circular cutting equipment, the characteristics of the cut edges, and the life of the punch and die. Published recommendations for openings vary widely, with most recommending a clearance per edge of between 3% and 12.5% of the stock thickness for steel. The creation of the cavity to be used for particular punching (circular cutting) or cutting operation is affected by the required properties of the cutting edge of the hole or cavity and by the thickness and properties of the work metal. Larger clearances increase tool life. The optimum clearance can be defined as the largest gap that will create a hole or cavity with the required characteristics of the cutting edge in a given material and thickness [39].

There must be some space between the punches and the die for cutting or punching to occur. The one-sided size difference between the female die and the punch is called the cutting clearance. The one-sided shear clearance is found according to the thickness, type, and tensile strength of the sheared sheet material [38].

The clearance between the punch and the die initiates the ideal fracture crack at the cutting edge of the punch and also in the die. The cracks progress until they meet each other. The punch should deform the material up to 1/3 of the sheet thickness without tearing. This rate, also known as the punch penetration rate, can vary between 20% and 50% of the sheet material thickness, depending on the material and the cutting clearance. After the punch deforms, tears occur in the microstructure of the material. The shape of the cutting surface with the effect of these tear lines and compressive stresses depends on the material and the cutting clearance. In Figure 3.2, the punch opening in the punching process is shown with C. [38].

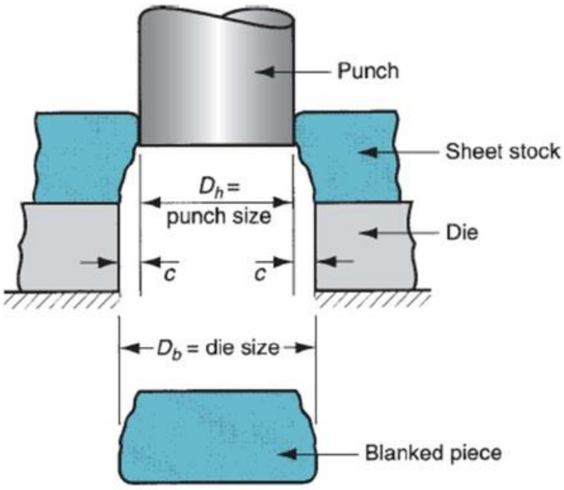

Figure 3.2. The punch clearance in piercing process [38].

The cutting clearance should be equal on all sides along the cutting edges. In this way, the radial forces that occur during cutting remain in balance. Otherwise, unwanted burrs are formed, and die life is shortened. In the cutting operations made in dies with less cutting clearance, the punch and die are subjected to more stress than the stresses that would occur under normal conditions. The plastic yield time is reduced, a small diameter is formed and the cutting width is narrowed. However, in the punch and die, a small break line develops. Due to the fusion of the fracture line and the sudden increase of the second fracture line, the material is forced to fracture. When there is not enough space between the punch and the die, high stresses arise in the cutting process and at the same time, burrs increase. In this case, abrasions and high stresses occur on the cutting edges of the die and punch. In cutting or punching processes with the blunt punch and die with a large cutting clearance, the strip material is not forced to be cut, but first to bend and then to fracture [39].

In the design of the die and punches, the cutting gap is determined by considering the type, quality, and thickness of the material being cut, the dimensions and shape of the punches, and the precision of the designed die. The cutting gap between the punch and the die affects the quality of the manufactured part [39].

It is important to choose the cutting clearance and transfer it to the punch and die [19]. If holes of certain diameters are to be drilled on the material, the cutting clearance is given to the female mold. That is, the die is made as large as the cutting gap from the main gauge. Here, the stapler does the cutting. Therefore, the size of the piece is determined by the punch size [13-17]. If parts of certain sizes are to be produced from the material, the cutting clearance is given to the punch. That is, the punch is made as small as the cutting clearance. Here, the die performs the cutting process. Therefore, the size of the piece is determined by the size of the die [38].

3.2.2.1. Calculation of Cutting Clearance

The calculation of the cutting clearance is made according to the sheet material thickness. The calculation of the cutting clearance for sheets up to 3 mm thick and for sheets thicker than 3 mm is shown below [38].

The thickness of the sheet metal of up to 3 mm;

$$C = \mu . t . \sqrt{\tau_k / 10} \quad (3.1)$$

Sheet metal plates with a thickness of more than 3 mm

$$C = (1{,}5 . \mu . t - 0{,}015) . \sqrt{\tau_k / 10} \quad (3.2)$$

it is calculated as [13, 19]. The parameters in these equations express the following;

C : One-sided cutting clearance, mm
μ : Coefficient, (0,005-0,035)
τ_k : Shear stress, N/mm^2
t : Sheet metal thickness, mm

The coefficient μ used in the equations can be selected between 0.005 and 0.035. A value of 0.005 of the μ coefficient can be used for a clean cutting surface, while higher values up to 0.035 can be preferred for low cutting force and work requirement. A value preference can be made for this coefficient according to the conditions expected from the cutoff. In cases where the cutting surface is not so important, the μ coefficient can be taken as 0.03-0.04 for low cutting force and work conditions. For cutting dies to be made of hard metal, the μ value can be selected between 0.015 and 0.018 [38].

3.2.3. Shear Force

In order to be able to select the required press bench for the part to be produced and to determine the dimensions of some parts of the die, the cutting force must be calculated. The force required to cut the part is called the shear force. In other words, the shear force can be defined as the resistance of the part against the separation of the strip material at the time of cutting. Shear force, depends on the type of material to be cut, the total length of the material to be cut, and the thickness of the material to be cut. If the die-cutting surface and the punch tip are sharpened flat, the highest cutting force is obtained, and the shear force can be reduced by giving a certain angle to the punch tip [39]. The shear force,

$$F = c.t.\tau_s \tag{3.3}$$

can be calculated by the equation. The parameters in these equations express the following; [T – 0]

F : Shear force, N
c : Perimeter of edges to be cut, mm
t : Sheet metal thickness, mm
τ_s : Shear stress, N/mm^2

In the calculation of the shear force in the cutting dies, the perimeter of the cut piece, the thickness of the sheet material, and the cutting resistance must be known in advance. In addition, the press safety factor (PSF) should be considered. Generally, a press safety factor of 1.5~4 is recommended [39]. Safe cutting force,

$$F_{sf} = F.(PSF) \tag{3.4}$$

The parameters in these equations express the following;

F_{sf} : Safe shear force, N

F : Shear force, N

PSF : Press safety factor

3.3. TYPES OF SHEET METAL OPERATIONS

Metal forming processes are processes that cause significant shape changes in metal parts. Forming processes applications occur with the application of sufficient tension for the metal to take the desired shape. Sheet metal forming operations require in-plane tensile forces and lower forces than mass forming. The basic mechanical condition for determining these forces is the tensile strength of the material.

In sheet metal forming applications, the tensile strength of the material is very important, especially in deciding which forming process is appropriate. The microstructures of sheet metal sheets generally show anisotropic properties. Therefore, in sheet metal, material properties change with direction and direction. In sheet metal forming processes, the majority of defects that occur while forming are caused by thinning or tearing the sheet metal. When deciding on the most suitable direction for shape operations, strain analysis should be done [40].

Today, many sheet metal forming processes are carried out in machines called presses. Some intermediate elements are needed to process sheet metal sheets with presses. Intermediate elements used to carry out these operations are called punches and molds. In addition, the name sheet press mold is also used. The processes applied in sheet metal sheets by means of presses are divided into 3 main categories as cutting, bending, and deep drawing. Cutting; It is used for cutting large sheet material into small pieces, circumferential cutting of the part, and drilling holes. Bending and deep drawing processes, on the other hand, provide the desired shape of the sheet metal part.

3.3.1. Cutting in Sheet Metals

The process of cutting sheet metal can be compared to cutting sheet metal with scissors between two sharp edges. The cutting action is carried out in four stages, with the moving edge moving towards the fixed edge. First, the punch presses against the surface to be cut and causes plastic deformation on the surface of the sheet. The punch continues its downward movement and enters the sheet metal and separates the metal into two parts. The thickness through which the punch enters the sheet is generally preferred to be one-third of the sheet metal thickness. The punch continues to move into the sheet, and cutting occurs between the two cutting edges. During this process, as in other sheet metal forming processes, one of the most important considerations is the clearance between the punch and the die. If the clearance between the punch and the die is at suitable values, the two fracture lines are compatible with each other and a clean cut is obtained. The basic cutting process is shown in Figure 3.3

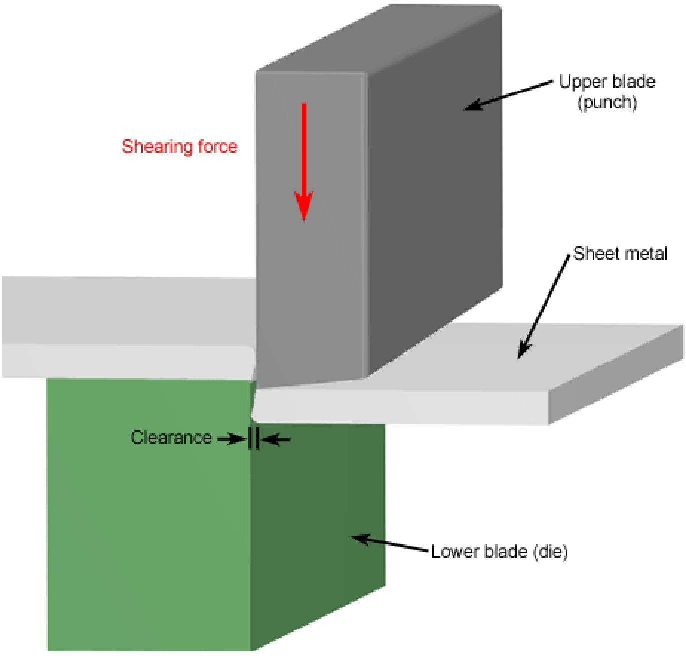

Figure 3.3. The basic cutting process [38].

In the sheet metal cutting process, the gap between the punch and the die, sheet thickness, material type, material strength and cutting length are the main cutting parameters [40].

3.3.2. Circular Cutting in Sheet Metals

The circular cutting process in sheet metal sheets is the general definition of the process of creating holes on the sheet with punches and dies placed in the sheet metal press machine. There are 2 basic applications in the circular cutting of sheet metal, these are blanking and piercing processes, respectively. The main difference between these two processes is whether the sheet metal to be cut circularly will be used or not. In the blanking process, the perforated sheet metal is not used, and the ejected circular piece is the workpiece. In the piercing process, on the other hand, the circular piece is removed while the pierced sheet metal workpiece is not used. Figure 3.4 shows the pieces obtained after blanking and piercing [41]

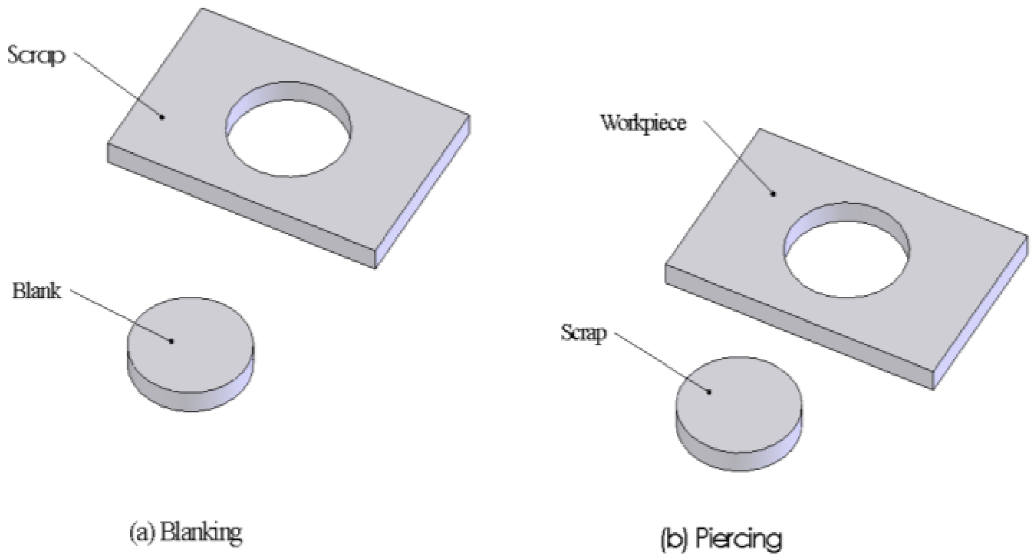

Figure 3.4. Blanking and piercing useful workpiece [38].

Since the piercing process is used in this study, information about the piercing process will be given. Detailed information about the piercing process will be given in the next sections.

3.3.3. Bending Process in Sheet Metals

Sheet metal bending is plastic deformation around a linear axis with little or no change in surface area. The bending process is carried out with bending tools called punches and molds in press machines. The punch and die must have proper alignment and clearance. It is defined as bending around a straight axis as shown in Figure 3.5a. During bending, compression occurs in the region below the neutral axis, and the tension occurs in the region above the neutral axis. These strain states can be seen in Figure 3.5b [2].

The smallest bending diameter, the degree of ductility of the material and the thickness of the sheet metal are the determining factors of the bending process for the sheet metal to be bent. The smallest bending diameter of these parameters expresses the capacity of the sheet material to be bent without breaking.

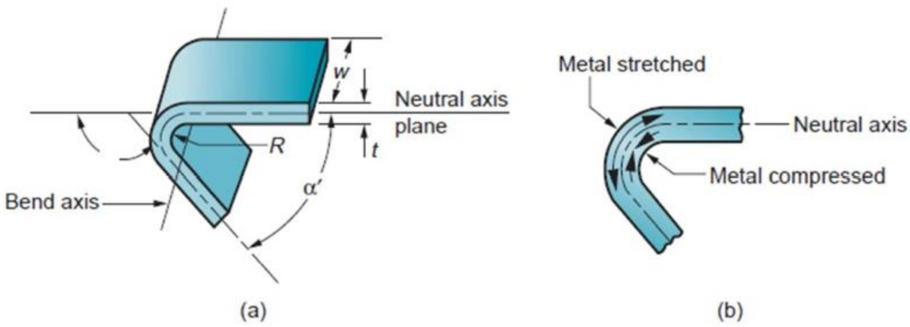

Figure 3.5. The final state of the workpieces after the V bending process [39].

The types of the bending process can be listed as V bending, free bending, edge bending, double-action bending, crush bending, twist bending and U bending. However, V bending and edge bending are the most commonly used bending methods in today's industry.

3.4. PIERCING PROCESS

Punching in sheet metal sheets is the general definition of the process of creating holes in sheet metal with punches and dies placed in the press machine. There are 2 basic applications in punching sheet metal, these are the blanking and piercing processes, respectively. Sheet metal forming using blanking and piercing dies is used on a large scale in the manufacturing industry. The mechanical properties of sheet metal affect the conditions in which cutting and punching dies are processed. Higher-strength sheets are widely used to ensure the production of durable and quality products [1, 2].

However, the use of high-strength sheet metal negatively affects the associated mechanical processing. Research is ongoing to develop the latest technology for the processing required for such metals. [40]

These two processes are basically based on the same logic, but in this study, basic information about it will be given, since studies are carried out on the piercing process.

Piercing is generally the fastest method of punching in steel sheets or strips and is often the most economical for medium to high production. Punched holes can be of almost any size and shape. The accuracy of conventional tool steel or carbide dies provides punched holes with a satisfactory degree of quality and accuracy for a wide variety of applications [32].

Sheet metal piercing is a cost-effective process as it can produce parts at much higher production rates than is possible with other traditional methods. Many parts that are designed to be subjected to other metal manufacturing processes, such as casting, die casting, forging, or machining, can be designed for piercing just as easily. The quality, accuracy, function, wear life, and appearance of parts can be greatly improved by being properly designed for drilling. Sheet metal piercing allows parts to be made from a harder material than other processes allow. In addition, strain hardening results in the part gaining superior mechanical properties [39].

Sheet metal piercing is mainly used for steel, brass, copper, aluminum, zinc, nickel, titanium, etc. It is a metal forming process in which sheet metal formed from metals is shaped into predetermined pieces in a punch press. Piercing in sheet metal is based on the application of force to the material by punches and die tools placed in the press machine, as in other sheet metal forming processes. The difference in the die used in the piercing process is that there is a hole in the die where the punch can enter. The piercing process for sheet metal begins with the insertion of sheet metal into a still die. When the sheet metal plates are placed on the die and the punch connected to the press head is given the first movement, the punch comes into contact with the material and exerts a pressure effect on the material. Plastic deformation occurs when the yield strength limit of the material is exceeded. While the driving force of the press head continues, the punch forces the material to break at the point of contact. In the meantime, a pile-up effect is observed in the microstructure of the sheet metal. With the applied force, the material in the desired shape is pushed into the mold cavity. In the meantime, the yield strength on the sheet metal surface is exceeded. The continuation of the punch pressure causes ruptures in the microstructure of the material at the die and punch cutting edges. These are the points where the greatest stress concentrations occur. Under normal shear conditions, the grain rupture extends towards each other and they meet. When this happens, shearing is completed and sheet metal is cut from the material strip as desired [42].

Parts cut from sheet metal materials cannot be cut exactly between the female die and the punch. The piece to be cut from the strip material between the female die and the punch shows the maximum cutting resistance between the two cutting edges. At the same time, the punch penetrates the material a little and cuts until the material reaches the yield limit. After the maximum resistance, the material loses its strength, and yield strain begins. The part that exceeds the yield strength limit is subject to rupture. It is seen that tensile stress occurs on the upper surface of the strip material and the lower surface of the cut piece, and compressive stress occurs on the punch contact surface of the punched part. When a circular hole is to be drilled in sheet metal, the outer dimension of the part removed from the sheet metal will be larger than the hole size due to the geometry of the cut edges. In addition, after the piercing process, the piece cut from the sheet metal will be scrap, while the remaining sheet metal will be used as a workpiece [42].

The simple application of the piercing is shown in Figure 3.6

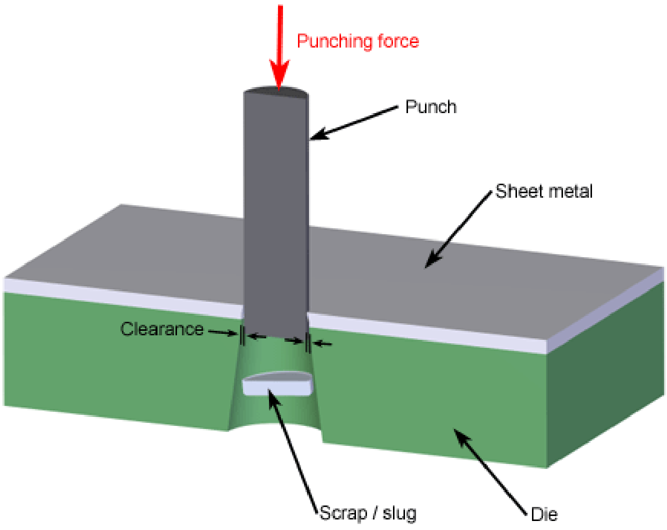

Figure 3.6. The simple application of the piercing process [39].

Recent studies have shown that the punch angle used to pierce sheet metal is the most important factor affecting cutting force and part quality. These studies show that the punch angle significantly reduces the required cutting/punching force. In addition, the clearance negatively affects the blanking/piercing force. In addition, increasing void values decrease the quality of the product [39].

PART 4

EXPERIMENTAL STUDIES

4.1. OVERVIEW

In this thesis, piercing processes on AISI 304L and Al-1050 sheet metal sheets, which are frequently preferred in the industry, were investigated experimentally. AISI 304L and Al-1050 sheet metal plates were provided for the test samples to be used in the piercing process of sheet metal sheets. In this experimental study, test samples were prepared in the light of literature research for the mechanical effects that test pieces may be exposed to after piercing. In this research, firstly, the chemical and mechanical properties of AISI 304L and Al-1050 sheet metal sheets to be used were determined. Detailed information about the chemical and mechanical properties of the samples to be used in the experimental studies and the general properties of the samples are given in the following sections, respectively.

The main goal of this study is to examine the mechanical effects that occur in the cutting areas of the sheet metal after the piercing process. After the examinations, experimental data tables were obtained. Finally, graphs were created with the obtained tables and many mathematical results were reached in the light of the graphs created and the formulas used in the tensile test.

4.2. MECHANICAL PROPERTIES OF AISI 304L AND Al-1050

Before the piercing process, 4 samples, two from each of the AISI 304L and Al-1050 sheet plates, were prepared in order to determine the mechanical properties of the test pieces to be used during the process, to see the tensile diagrams in the computer environment, and to make strain hardening calculations. The samples prepared for the tensile test were tested in accordance with DIN EN ISO 6892-1 standard. In order to better understand the tensile tests performed before the properties of the prepared samples, the theoretical part of the tensile test will be mentioned.

4.2.1. Tensile Test Theoretical Background

In the periods when technological systems were not developed, in order to draw the engineering stress-strain curve, it was necessary to scale the load-strain diagram by dividing the load by the initial cross-sectional area, $A_0 = \omega_0 . t_0$ and the extension by l_0. With this method, a curve was obtained that did not depend on the initial dimensions of the sample, but this curve was still not a curve expressing a standard material property. During the tensile test, the cross-sectional area will decrease so that the actual stress on the test piece is greater than the engineering stress. The engineering stress-strain curve is still used today and various properties are derived from this curve. Figure 4.1 shows the engineering stress-strain curve calculated from the load [43].

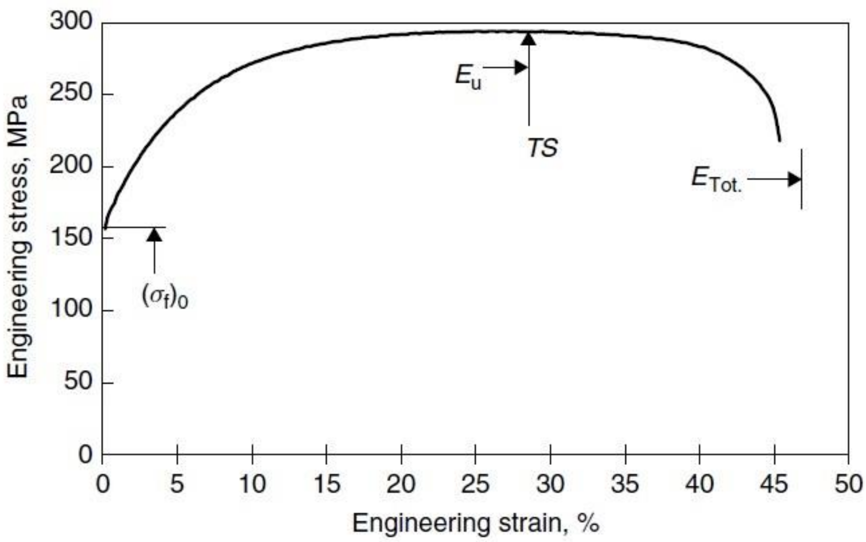

Figure 4.1. Generalized engineering stress-strain diagram [43].

The basic strength formulas used to calculate this curve are given below, respectively. Engineering stress equation is

$$\sigma_{eng} = \frac{P}{A_0} \tag{4.1}$$

Engineering strain equation is

$$e_{eng} = \frac{\Delta l}{l_0}\, x\ 100\% \tag{4.2}$$

Initial yield stress equation is

$$(\sigma_f)_0 = \frac{P_y}{A_0} \tag{4.3}$$

The maximum engineering stress or ultimate tensile stress or tensile strength;

$$TS = \frac{P_{max}}{A_0} \tag{4.4}$$

Young's modulus;

$$E = \frac{(\sigma_f)_0}{e_y} \tag{4.5}$$

Using the plastic deformation of metals and metal alloys to occur without appreciable change in volume, the actual stress between initial yield and maximum load can be determined from the load-elongation diagram. Since the volume of the sample is constant, the product of the initial cross-sectional area and length will be equal to the product of the post-yield cross-sectional area and its length. If the gauge length increases by a very small amount, dl, during the deformation of the test piece, the corresponding strain, ie unit strain, becomes the amount of elongation per unit yield length. For very small strains, strain growth is very similar to engineering strain, but for larger strains there is a significant difference. As in the tensile test, if the tensile process continues evenly in one direction, the strain increase can be calculated to give the true stress. If we write the engineering stress equation in the true stress equation, the new equation will be as follows [43];

$$\sigma = \frac{P}{A} = \frac{P.A_0}{A_0.A} = \sigma_{eng}\frac{l}{l_0} = \sigma_{eng}\left(1 + \frac{e_{eng}}{100}\right) \tag{4.6}$$

in addition

$$\varepsilon = \ln\left(1 + \frac{e_{eng}}{100}\right) \tag{4.7}$$

Figure 4.2 shows the actual stress-strain curve calculated from the load-strain diagram.

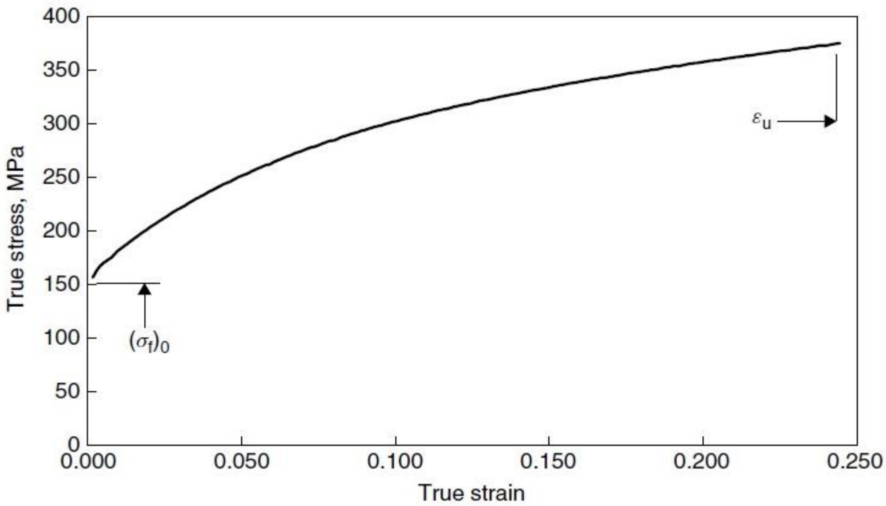

Figure 4.2. Generalized true stress-strain diagram [43].

The true stress-strain curve is continuous although it occurs at a decreasing rate with deformation, but it can be seen that the curve does not reach its maximum as strain hardening. Once necking begins, the gauge length deformation is no longer uniform. The curve in Figure 4.2 cannot be calculated beyond a stress corresponding to the maximum load. This strain at maximum load is called maximum uniform strain. Many examples of soft, annealed sheet metal will show the properties of this diagram if the actual stress and strain are plotted on logarithmic scales as in Figure 4.3 [43].

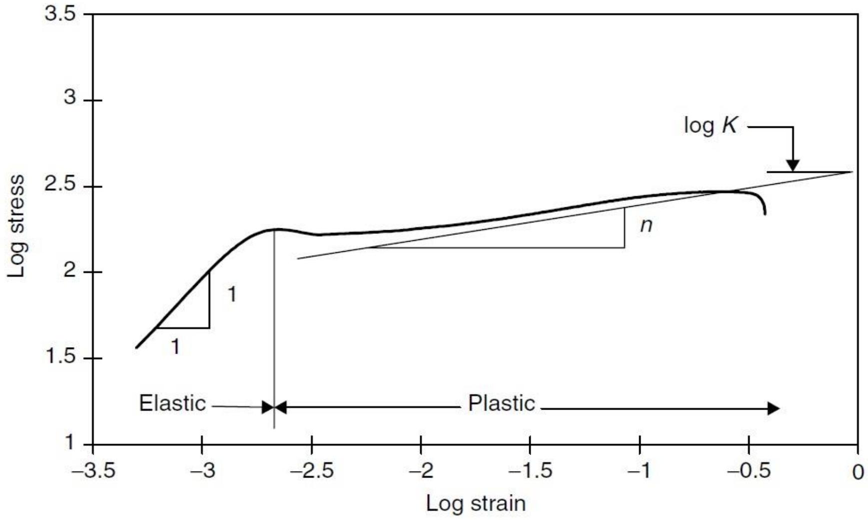

Figure 4.3. Generalized logrithmic true stress-strain diagram [43].

The maximum uniform strain equation mentioned here is as follows;

$$\varepsilon_u = \ln\left(1 + \frac{E_u}{100}\right) \tag{4.8}$$

At low strains in the elastic range, the curve is approximately linear with a slope. This corresponds to an equation for the elastic state [43];

$$\sigma = E.\varepsilon \quad \text{or} \quad \log\sigma = logE + log\varepsilon \tag{4.9}$$

Also, at higher strains, the equation for the logarithmic curve

$$\sigma = K.\varepsilon^n \tag{4.10a}$$

Or

$$log\sigma = logK + n.log\varepsilon \tag{4.10b}$$

In this section, all the formulas used in the tensile test calculations are given respectively. These formulas will be decisive in determining the tensile properties of the samples.

4.2.2. Measurements of Test Samples

The dimensions of the prepared samples are given in Table 4.1. In addition, the final state of the samples as a result of the tensile test is shown in Figure 4.4 and Figure 4.5, respectively.

Table 4.1. Dimensions of AISI 304L and Al-1050 samples.

	Length (mm)	**Width (mm)**	**Thickness (mm)**
AISI 304L - 1	345	29,95	2
AISI 304L - 2	345	29,95	1,95
Al-1050 - 1	345	29,90	2,05
Al-1050 - 2	345	29,95	2,05

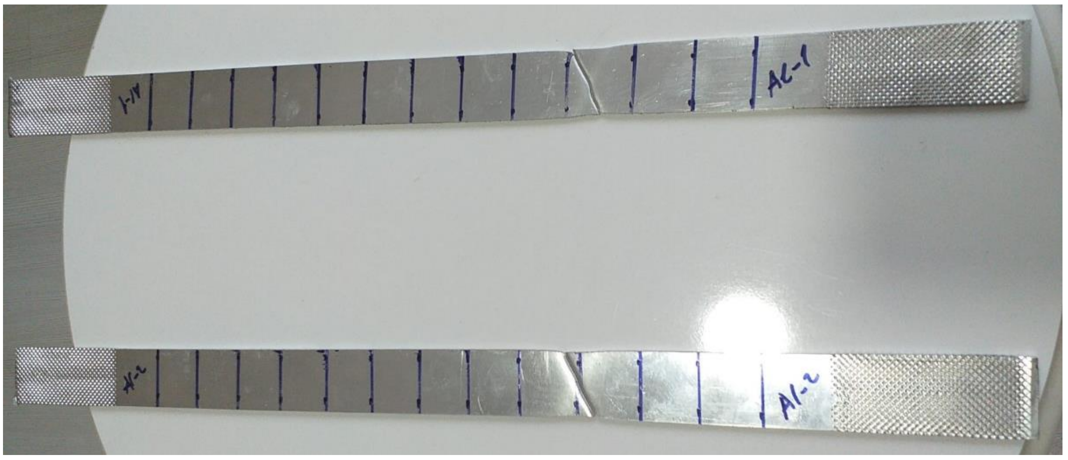

Figure 4.4. Al-1050 tensile test samples.

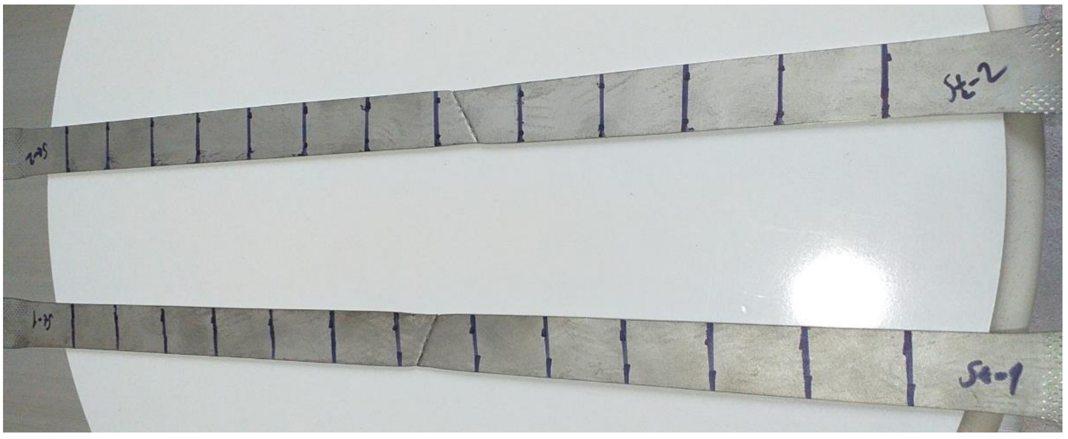

Figure 4.5. AISI 304L tensile test samples.

The tensile test results on AISI 304L and Al-1050 samples were transferred to the computer as Excel data and the graphs of the data were created. With the Engineering Stress-Strain data obtained as a result of the tensile test, the True Stress-Strain values were found by using the mathematical operation feature of the Excel program, and their graphics were created. Equation 4.6 and Equation 4.7 are used for True Stress-Strain values. Logarithm True Stress-Strain values were found by using the mathematical operation feature of the Excel program to the true stress-strain values obtained and their graphs were drawn. Equation 4.10b is used in the process for Logarithm True Stress-Strain values.

The Engineering Strength Curves, the True Stress-Strain Curves, and Logarithm Stress-Strain Curves of the AISI 304L and Al-1050 samples will be shown, respectively. In addition, as a result of the operations performed with Excel, the Log K curves of AISI 304L and Al-1050 samples were obtained. The mathematical equations to be used and the curve equations obtained are given in the following headings, respectively.

4.2.3. AISI 304L - 1 Tensile Test Diagrams

Engineering Stress-Strain, True Stress-Strain, and Logarithm True Stress-Strain graphs were created from the data obtained as a result of the tensile test performed on the AISI 304L-1 sample. Figure 4.6 shows the Engineering Stress-Strain curve, Figure 4.7 the Actual Stress-Strain curve, and Figure 4.8 the Logarithm True Stress-Strain curve.

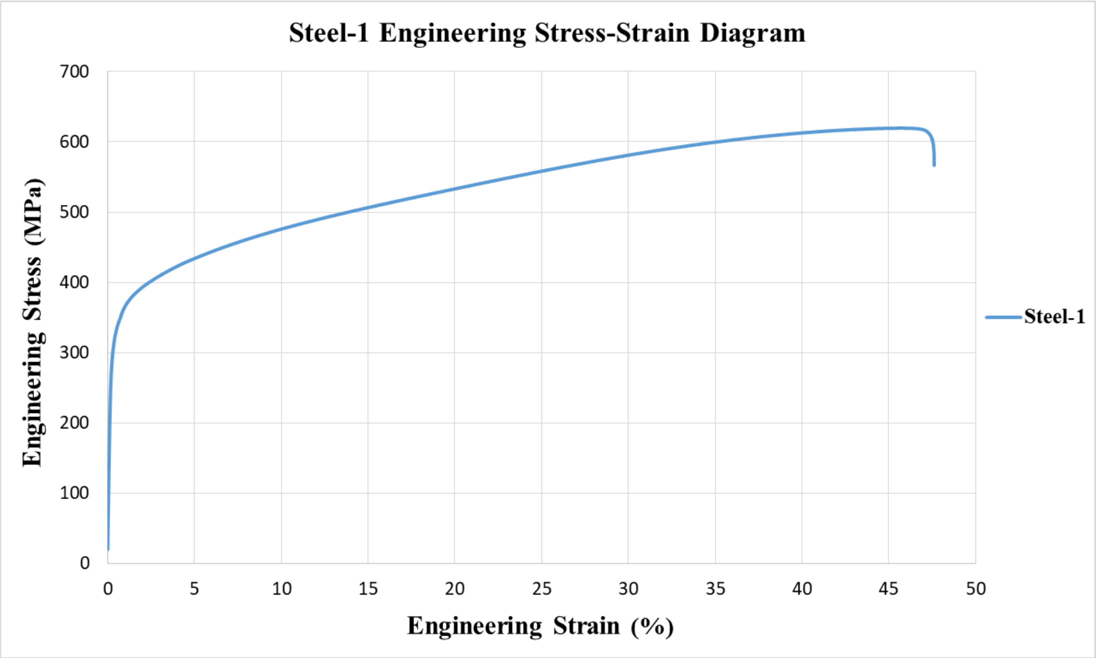

Figure 4.6. AISI 304L – 1 Engineering Stress-Strain Diagram.

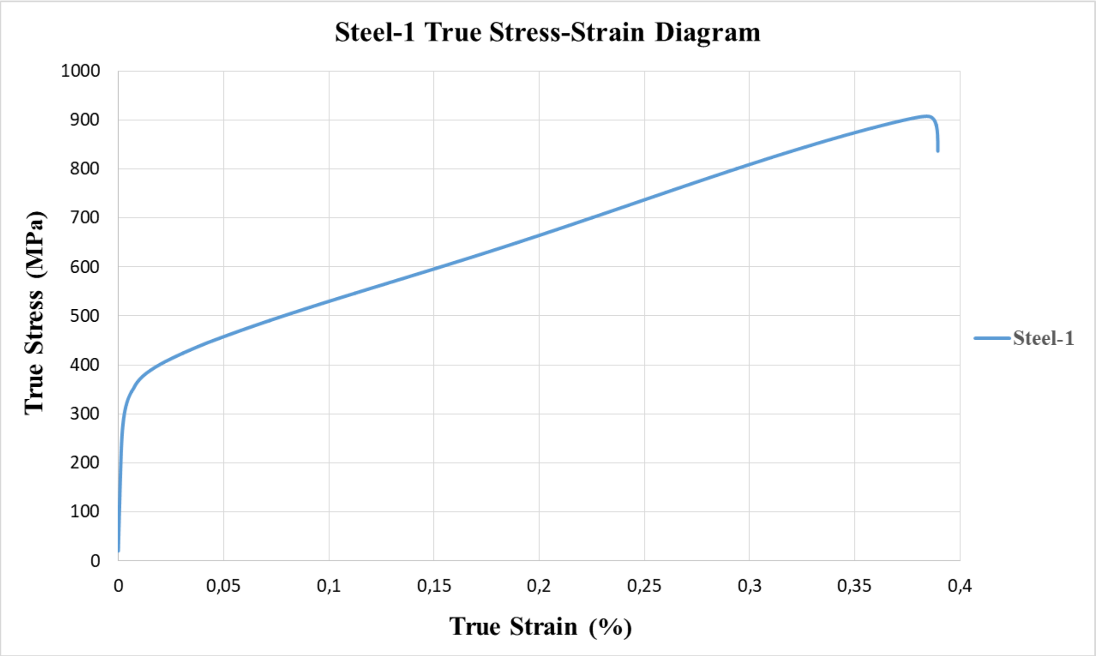

Figure 4.7. AISI 304L – 1 True Stress-Strain Diagram.

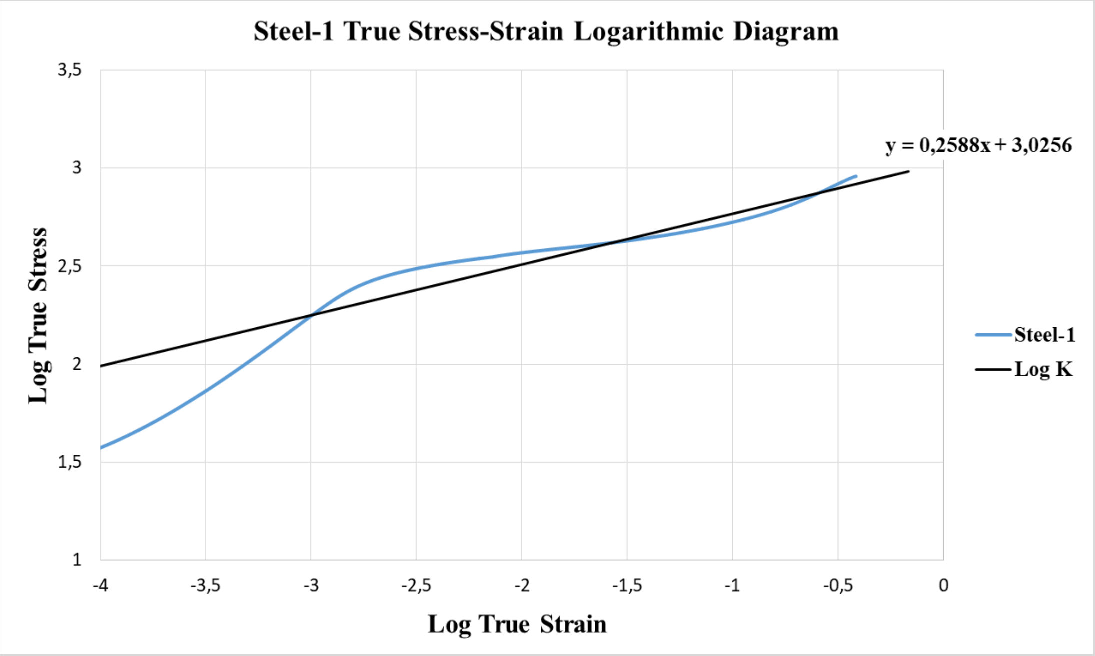

Figure 4.8. AISI 304L – 1 Logarithmic True Stress-Strain Diagram.

Linear equation:

y = 0.2588x + 3.0256

$x = 0 \;\; => \;\; y = logK$

$y = logK = 3.0256$

$10^{log\,K} = \; 10^{3.0256}$

$K = 1060.7182 \; MPa$

4.2.4. AISI 304L - 2 Tensile Test Diagrams

Engineering Stress-Strain, True Stress-Strain, and Logarithm True Stress-Strain graphs were created from the data obtained as a result of the tensile test performed on the AISI 304L-2 sample. Figure 4.3 shows the Engineering Stress-Strain curve, Figure 4.4 the Actual Stress-Strain curve, and Figure 4.5 the Logarithm True Stress-Strain curve.

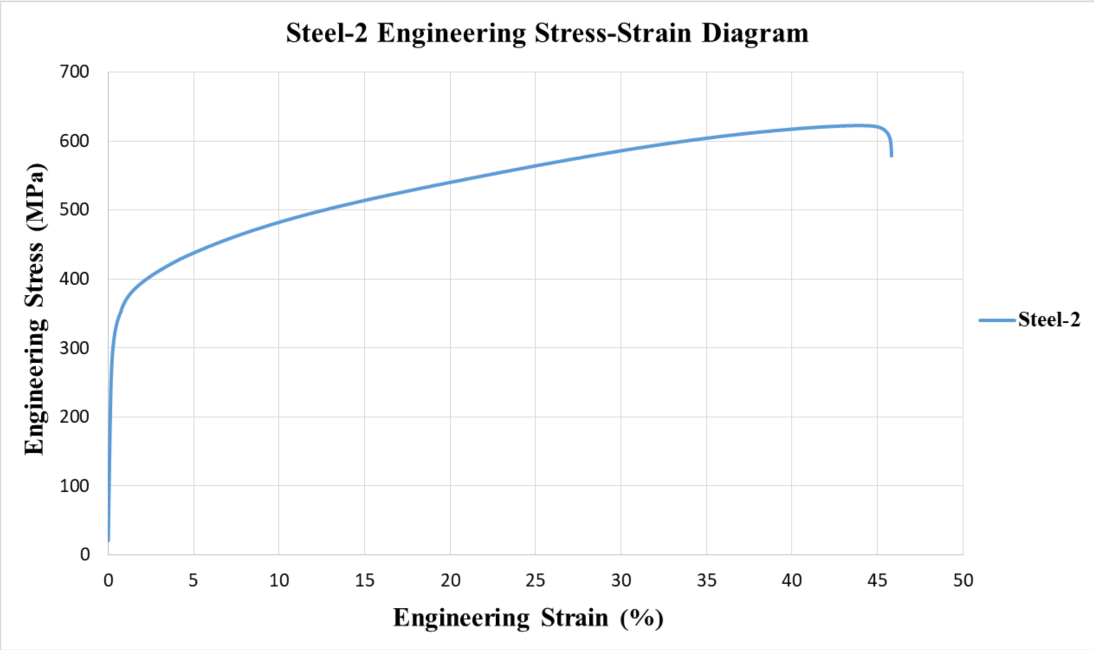

Figure 4.9. AISI 304L – 2 Engineering Stress-Strain Diagram.

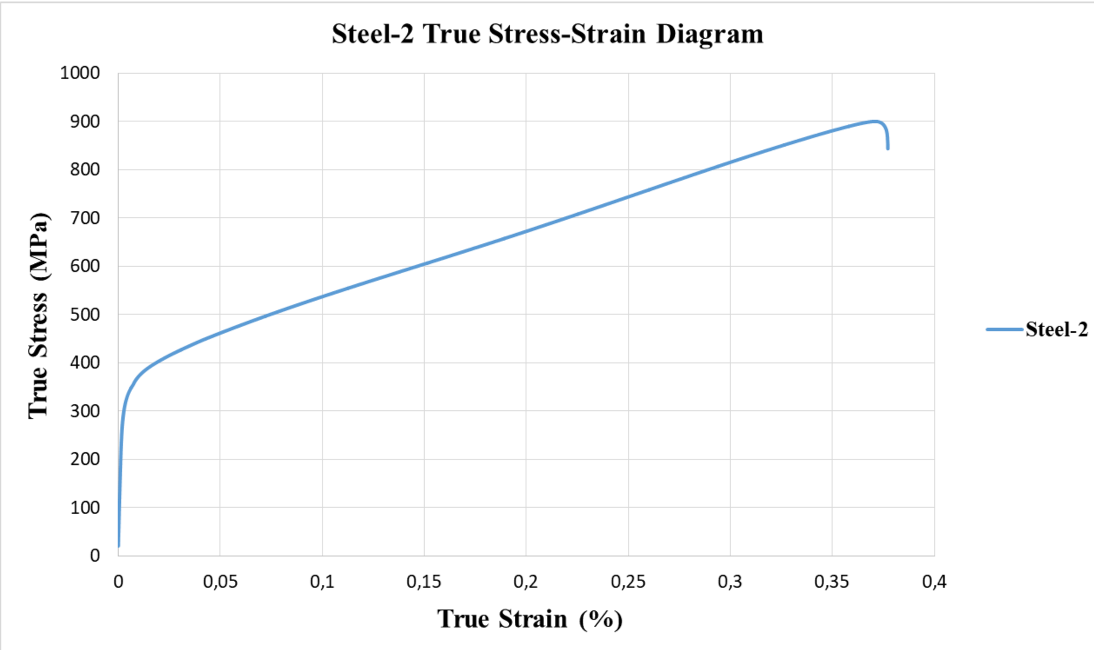

Figure 4.10. AISI 304L – 2 True Stress-Strain Diagram.

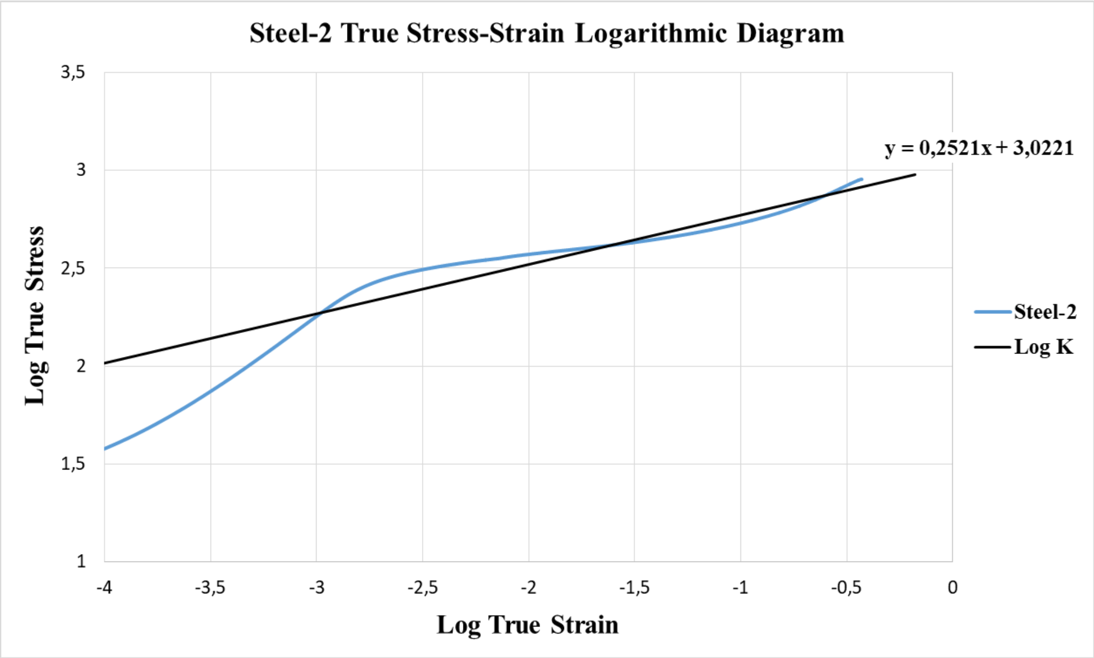

Figure 4.11. AISI 304L – 2 LogarithmicTrue Stress-Strain Diagram.

Linear equation:

y = 0.2521x + 3.0221

$x = 0 \;\; => \;\; y = logK$

$y = logK = 3.0221$

$10^{log\,K} = 10^{3.0221}$

$K = 1052.2041\ MPa$

4.2.5. Al-1050 - 1 Tensile Test Diagrams

Engineering Stress-Strain, True Stress-Strain and Logarithm True Stress-Strain graphs were created from the data obtained as a result of the tensile test performed on the Al-1050-1 sample. Figure 5.3 shows the Engineering Stress-Strain curve, Figure 5.4 the Actual Stress-Strain curve, and Figure 5.5 the Logarithm True Stress-Strain curve.

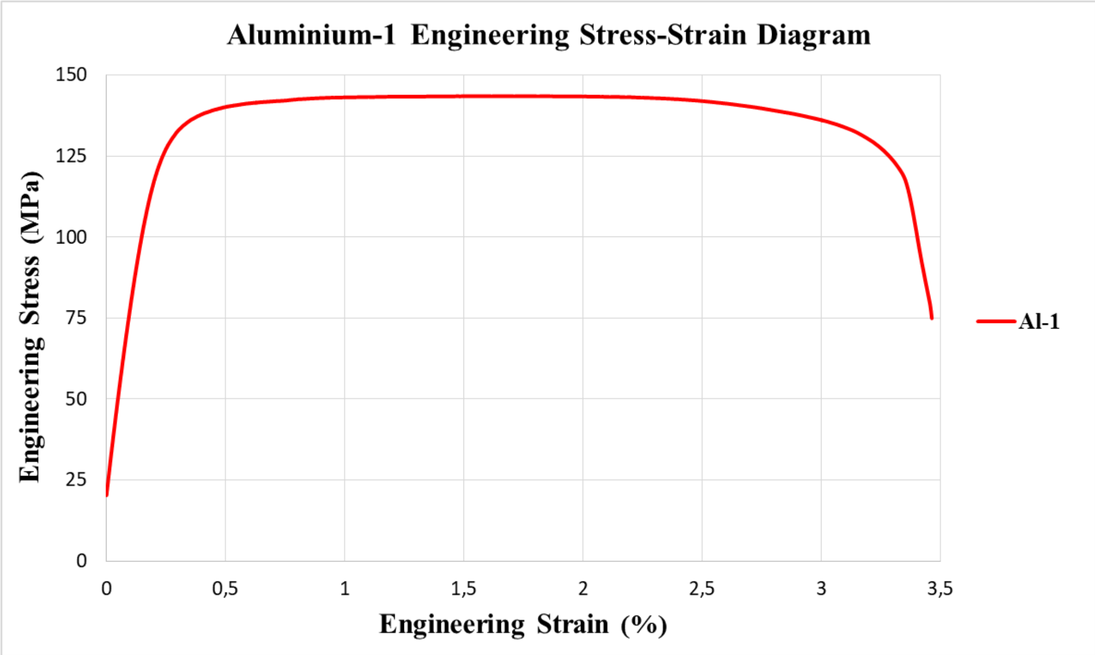

Figure 4.12. Al-1050 – 1 Engineering Stress-Strain Diagram.

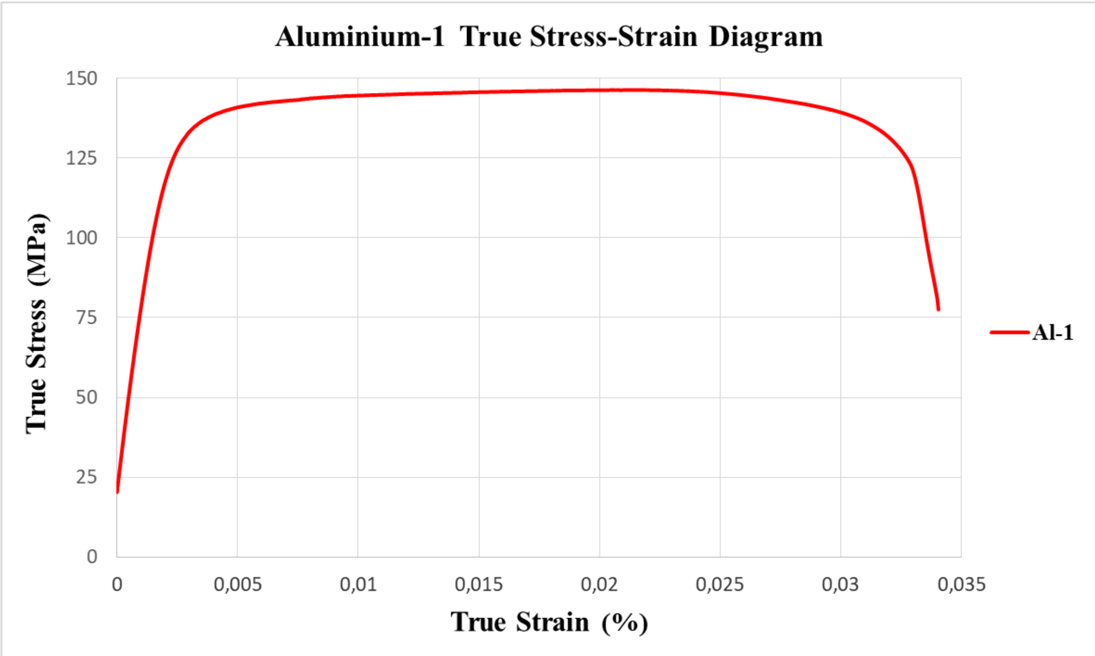

Figure 4.13. Al-1050 – 1 True Stress-Strain Diagram.

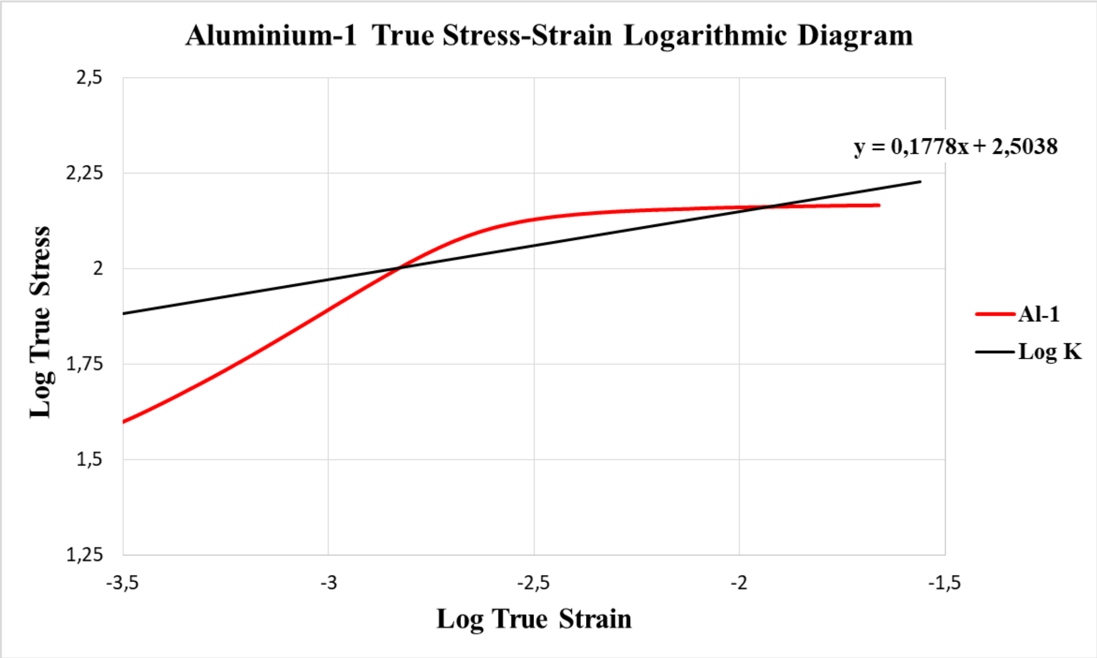

Figure 4.14. Al-1050 – 1 Logarithmic True Stress-Strain Diagram.

Linear equation:

y = 0.1778x + 2.5038

$x = 0 \;\; => \;\; y = logK$

$y = logK = 2.5038$

$10^{log\,K} = 10^{2.5038}$

$K = 319.0068\,MPa$

4.2.6. Al-1050 - 2 Tensile Test Diagrams

Engineering Stress-Strain, True Stress-Strain and Logarithm True Stress-Strain graphs were created from the data obtained as a result of the tensile test performed on the Al-1050-2 sample. Figure 5.3 shows the Engineering Stress-Strain curve, Figure 5.4 the Actual Stress-Strain curve, and Figure 5.5 the Logarithm True Stress-Strain curve.

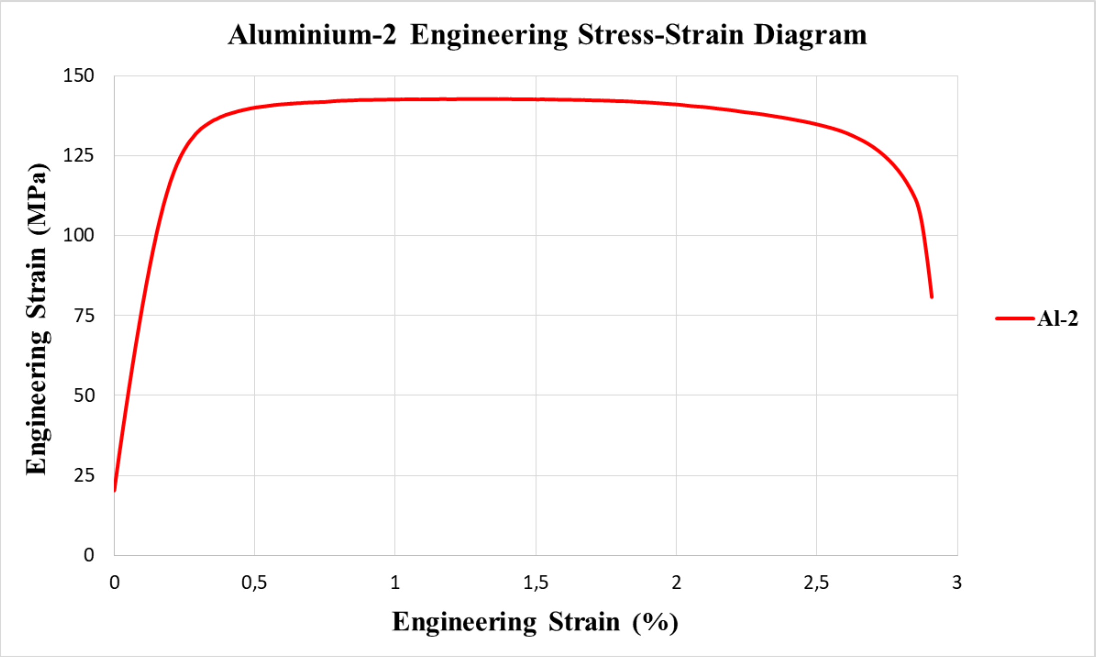

Figure 4.15. Al-1050 – 2 Engineering Stress-Strain Diagram.

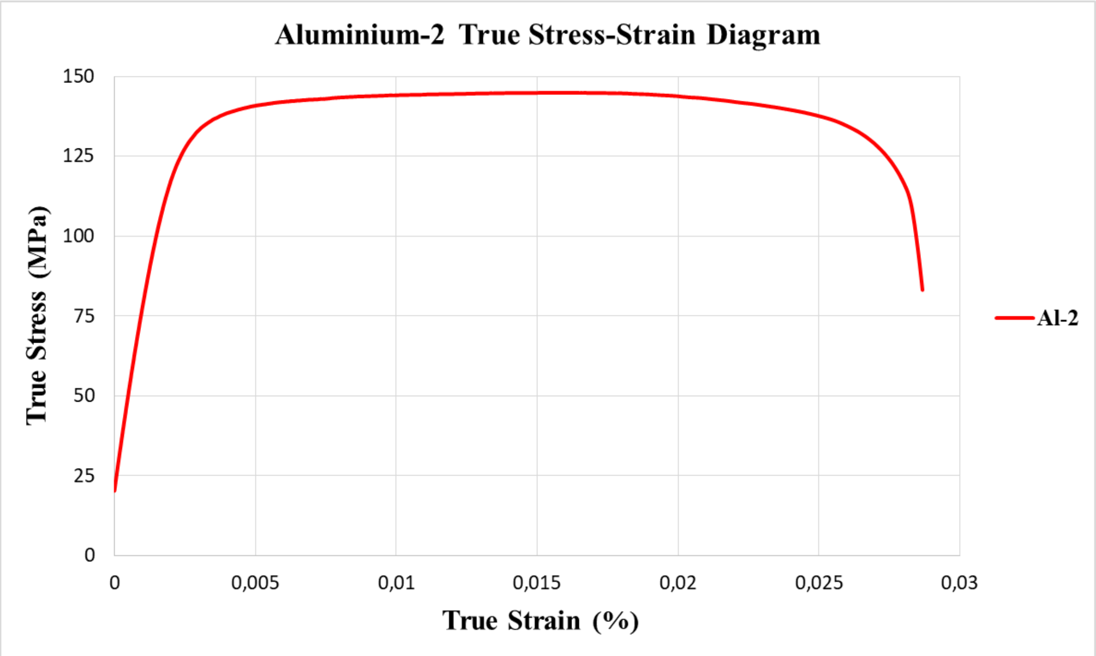

Figure 4.16. Al-1050 – 2 True Stress-Strain Diagram.

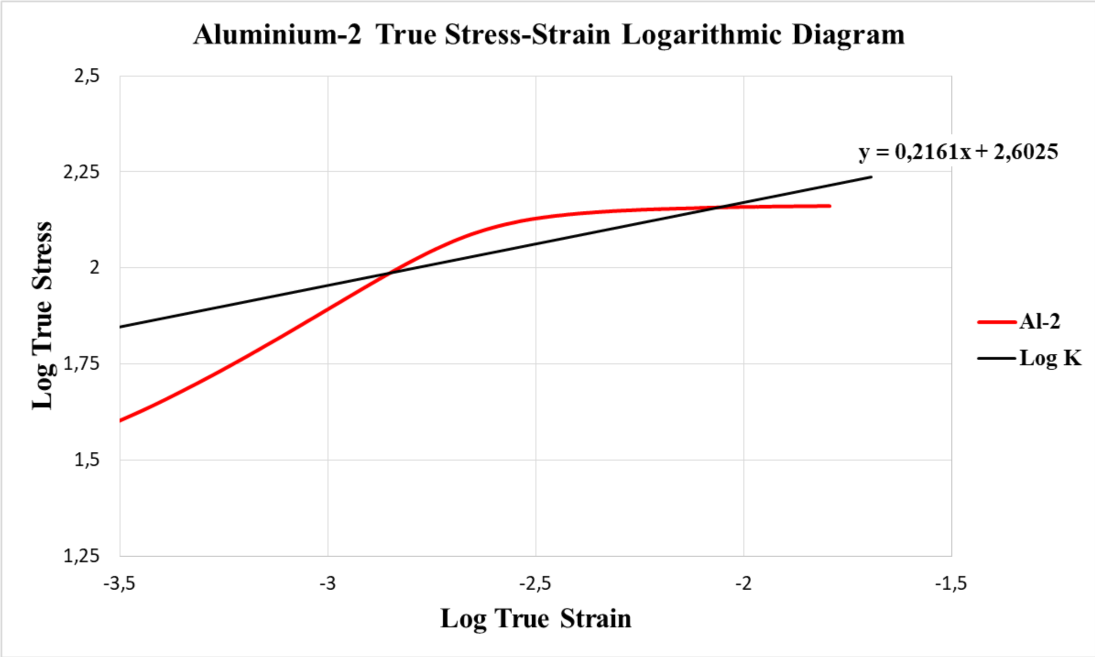

Figure 4.17. Al-1050 – 2 Logarithmic Stress-Strain Diagram.

Linear equation:

y = 0,2161x + 2,6025

$x = 0 \;\; => \;\; y = logK$

$y = logK = 2{,}6025$

$10^{log\,K} = 10^{2{,}6025}$

$K = 400{,}4054\; MPa$

The mechanical properties obtained from the tensile tests are given in Table 5.2.

Table 4.2. Mechanical properties of AISI 304L and Al-1050 samples.

Specimen designation	**$R_{p0.2}$ (MPa)**	**R_{max} (MPa)**	**m_E (GPa)**	**A_{80} (%)**	**K (MPa)**
AISI 304L - 1	318,1392	619,3653	161,5324	47,27275	1060,7182
AISI 304L - 2	321,3106	622,4572	165,6703	45,48971	1052,2041
Al-1050 - 1	138,4191	143,5176	51,82521	3,36823	319,0068
Al-1050 - 2	138,4215	142,7736	51,38906	2,800744	400,4054

4.3. CHEMICAL PROPERTIES OF SAMPLES

Metal analysis spectrometry, which is used in the chemical industry today, is an effective method that provides the determination of the chemical structure of metal elements. The purpose of metal analysis spectrometry is to detect metal elements both proportionally and in terms of microstructure. Chemical analysis with metal analysis spectrometry utilizes the sparking process, which involves applying an electrical charge to the sample and evaporating low levels of material. It is an ideal method for harder metals and other chemical analysis methods that may be resistant to sparks. The spectrometer is widely used in the chemical industry and sub-branches related to the chemical industry. Metal analysis spectrometry is seen as an ideal choice for applications that require complete disintegration of solid materials, especially in engineering applications. Therefore, metal analysis spectrometry was used for the chemical analysis in this study. In addition, the sample surface should be clean and bright in order to perform chemical analysis more efficiently and to obtain clearer results. For this purpose, the surfaces of the sample samples were sanded and polished for the chemical test. An example of the polishing machine used is given in Figure 4.

Figure 4.18. Polishing machines.

Chemical analysis data for AISI 304L and Al-1050 samples are given in Table 4.3 and Table 4.4, respectively.

Table 4.3. Chemical properties of AISI 304L.

Material	Chemical Compositions							
	C	CR	Mn	NI	P	S	Si	Fe
AISI 304L	0.017	18.115	1.743	8.070	0.033	0.004	0.415	Rest.

Table 4.4. Chemical properties of Al-1050.

Material	Chemical Compositions							
	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
Al-1050	0.097	0.257	0.001	0.005	0.003	0.006	0.016	Rest.

4.4. PREPARATION OF EXPERIMENT SAMPLES

In this study, experimental studies will be carried out on AISI 304L and Al-1050 sheet metals. Before starting the experimental studies, the mechanical and chemical properties of AISI 304L and Al-1050 sheet metal sheets to be used were determined. After the determination of the mechanical and chemical properties, the preparation of the test samples was started. For the piercing process, 1000x30x2 mm sheet metal strips were prepared. The prepared sheet metal strip samples are shown in Figure 4.

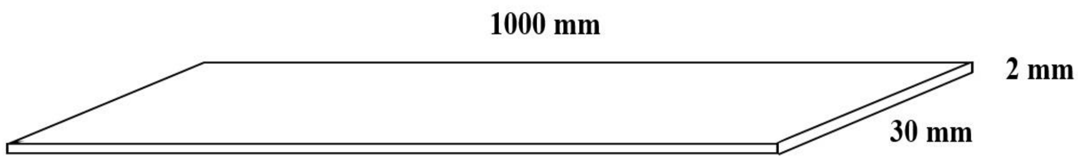

Figure 4.19. The piercing process samples measurements.

4.5. SHEET METAL PIERCING PROCESS

4.5.1. Press Machine

Modern sheet metal piercing is conducted by utilizing weighty, such as Zwick Roell type Z600 press machine, to make holes and indents in a piece of sheet metal. The pierced sheet metal is like a sandwiched located between the punch and a die. The piercing force declines downward and in the direction of the die. This results in the sheet metal below the piercing being cut away from the other surrounding material. It is suggested to collect the cut metal pieces inside a container for reuse or recycling. The piercing press is created to make specimens via punching, utilizing hollow dies of several different sizes and lineations. Different numbers of dies can be obtained by commutable socket punches with many different profiles and sizes depending on the standards and demands. Dies are synthetic from steel with hand-finished shearing edges and associated with an ejector for simple and faster removal of the specimen after cutting or punching. In this study, the hole piercing trials were conducted via a servohydraulic test system the Zwick Roell type Z600 machine displayed in Figure 4.8.

Figure 4.20. Press machine used in piercing process.

The machine is hydraulically actuated and applied affected by ±37,10 kN for steel and ± 8,80 kN for Aluminum and has a displacement area of 50 mm and a frequency of 50 Hz. Created and designed to apply tensile and compression probes as well as dynamic probes. Correlations between the forces and punch displacement of each punch were generated on two different materials. The device is designed for rapid preparation of manual and automatic patterns and is distinguished by its ability to repeat tests with accurate results and save time. The Zwick Roell of the Z600 features accuracy and data integrity that cannot be obtained with other servo hydraulic test systems. Enhanced control, data processing features, and an expanded power architecture in the Z600 controller ensure samples and research data protection and integrity.

4.5.2. Piercing Dies and Punches

As mentioned in the previous sections, changing the cutting angle of a punch helps improve the tool life used in piercing. In other words, correctly selected cutting angle or punch geometry are very important parameters for prolonging the life of the press machine and the tools used for piercing, and a higher quality of the end product obtained after the process. It is very important to increase the life of the punch and die tools in the piercing process, because during the piercing process, the tools can be exposed to high abrasive effects, especially in the contact areas, and cause serious deformations on the tool surface. Therefore, considering the high number of operations, this may cause effects that may reduce the production quality, and the constant replacement of tools means an increase in production costs. These are undesirable situations during production. As a result, choosing the right shear angle for the punches used during the piercing process increases the production efficiency and quality of the sheet metal strips.

In this study, the effects of the change of the punch angle on sheet materials and punches are investigated by choosing the punch tip angle of 0°, 3° and 6° for the piercing process to be applied for AISI 304L and Al-1050 sheet metal strips. Staples used in experimental studies are countersunk piercing punches. In addition, piercing patterns produced for standard piercing were used in the experiments. Staples used in experimental studies are shown in Figure 4.9 and piercing patterns are shown in 4.10. In addition, the technical drawings of the punches are shown in Figure 4.11.

Figure 4.21. Special production punches used in piercing process.

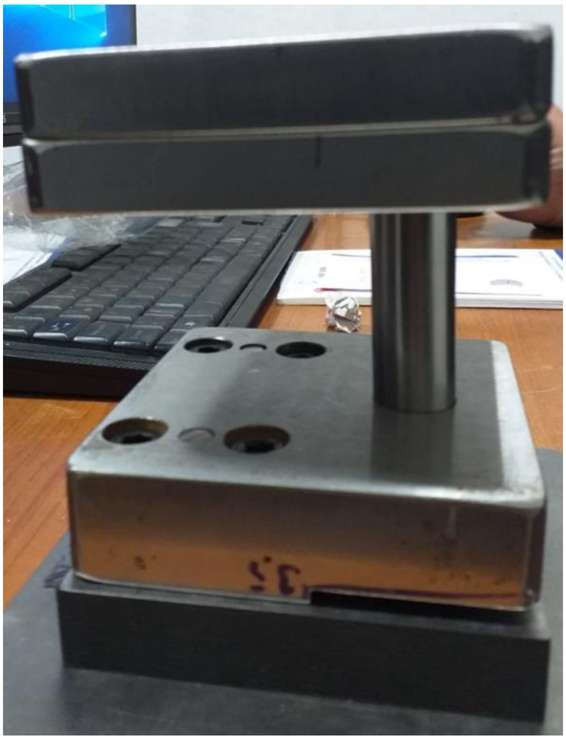

Figure 4.22. Delme işleminde kullanılan kalıp tertibatı.

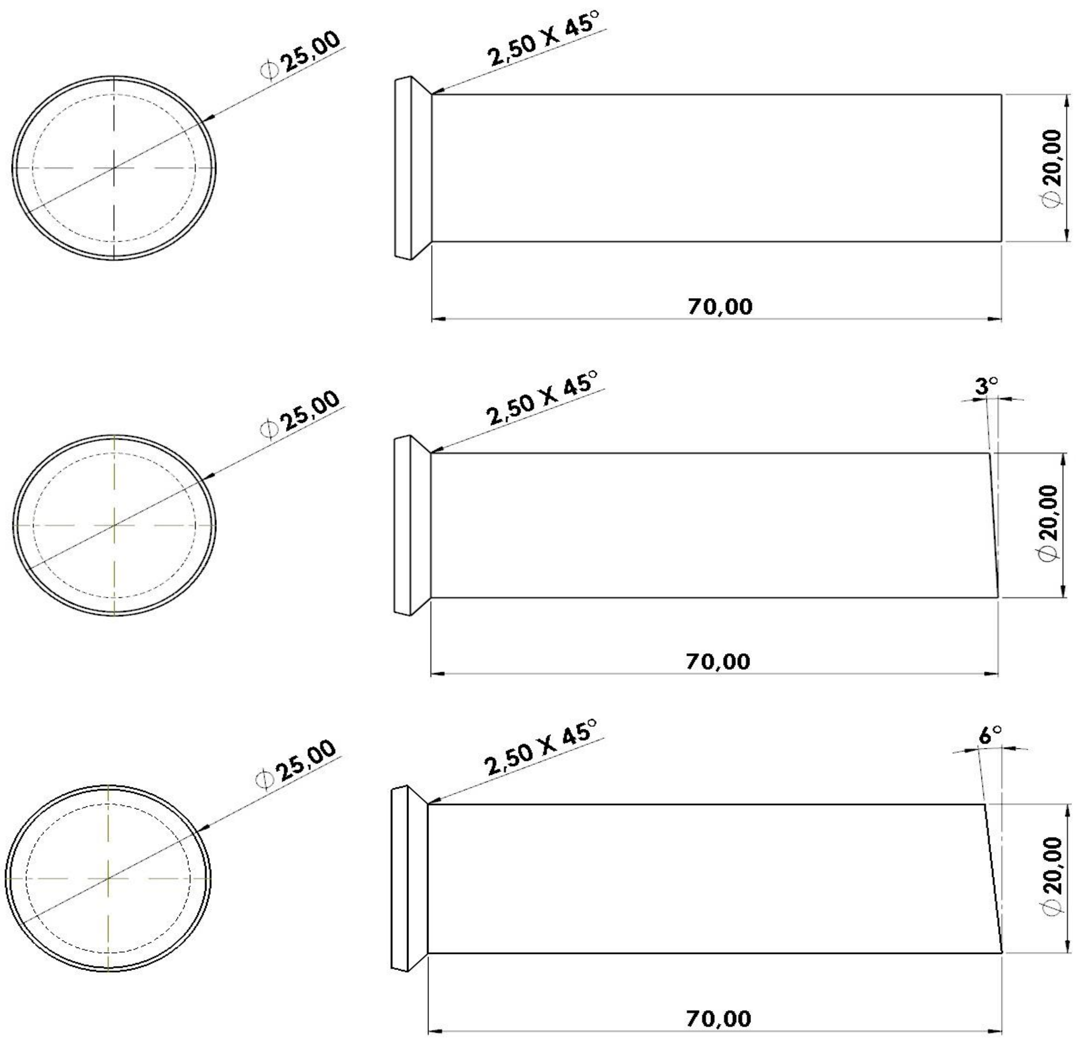

Figure 4.23. Technical drawings of piercing staples.

4.5.3. Applying Piercing to Sheet Metal Strips

Piercing tests were performed in the static test laboratory of the Faculty of Mechanical Engineering of Karabuk University at room temperature (25˚C). Piercings were performed by repeating each test twice to reduce experimental errors, to show that the experimental data obtained was not accidental, and to ensure that the experimental studies were performed in a standard way. This helps to avoid drawing conclusions without sufficient data. Many factors affect the number of repetitions, such as the availability of material resources. Vertical speed control in conjunction with the hydraulic press mentioned in the previous sections was used for drilling tests. During sheet punching, the material was removed at high speed from the AISI 304L or Al1050 sheet strip, using a sufficient shear force in the cutting process, and the material sheets were quickly exposed to shear force. Then the parts were cut in order. As a result of the processes, the cut sheet metal strips and scraps were separated from the mold (the part under the sheet that includes cutting the shape with the desired feature).

Paper punches function as a punch for paper. Typically, the punch clamps the paper against the metal plate backing and eventually turns into a round opening. Scrap from the piercing process is usually collected in the piercing tool.

The same approach is applied in the piercing process. The sheet metal strip is placed between the piercing die and its punch, and then the punch is plunged into the die by moving it downwards. The edges of the punch move past each other, corresponding to the hole of the piercing die, and the sheet metal is cut. In this application, the piercing process takes place in many stages. When the punch contacts the sheet, the sheet is deformed and then it is under the effect of shear force. As a result of this effect, the tension in the sheet material becomes very high and the material is sheared with the increase of the deformation in the microstructure. When the punch moves upwards again, it can pull the plate and thus the scraper separates the plate from the staple and the piercing process is completed.

4.5.4. Calculation of Total Shear Force

Spring elements are used between fixed and movable dies to adjust the plunge distance of the punch during the punching process and to ensure a more stable and controlled application of the cutting force. The formwork system prepared for the drilling process is shown in Figure 5. Although it is thought to be a disadvantageous situation for the cutting force at first glance, die springs ensure that the force applied to the sheet metal strip is distributed evenly during the cutting operations. Cutting operations are carried out by pressing machines in standard sizes and by eliminating the imbalance of punches. The springs used between the molds are red heavy load springs. Therefore, the die springs create a counterforce in the punching process, causing the press machine to apply more force. For this reason, it is necessary to subtract the spring forces from the cutting forces obtained after drilling. Spring forces can be calculated with the following equation;

$$F_{spring} = k.x \tag{4.11}$$

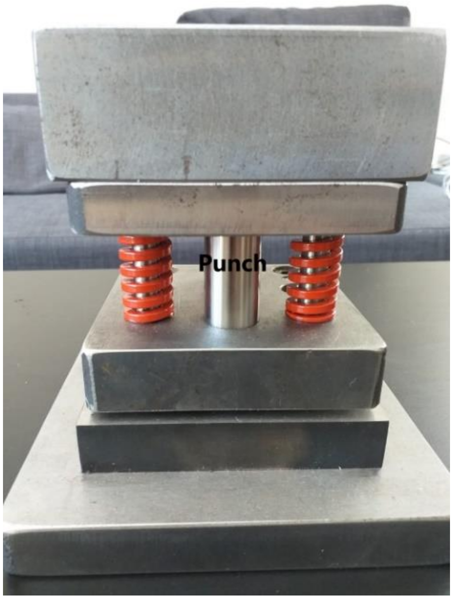

Figure 4.24. Experiment equipment prepared for piercing process.

Here F_{spring} is the spring force, k is the spring coefficient and x is the amount of deformation. In the spring force calculations used in the literature, there is a minus (-) sign in front of the $k.x$ expression. This is because springs always create a reaction force in the opposite direction. However, it is not included in the formulation in order to be able to express the force analysis performed here. Force analysis will be explained accordingly. Another way to calculate the spring force is the linear equation line. As it is known, the slope of the linear line of the force-deformation graph gives the coefficient k, while the vertical movement of the punch during the piercing process gives the x deformation amount. In this study, the Excel program was used to calculate the spring force, as in other calculations. One example will be shown regarding the calculation of the spring coefficient k, and the other calculated spring coefficients and the spring forces obtained after the piercing process will be shown as table data in the experimental results section.

In calculating the sample spring coefficient to be made, the data obtained for the piercing process applied to the AISI 304L sheet strip with a 0-degree punch was used. The graph of the pressing force-deformation amount obtained after the piercing process applied to the AISI 304L sheet metal strip is given in Figure 4. As can be seen in this figure, spring compression occurs at the end of the applied press force. The curve shown in the red area in Figure 4 is the slope curve to be calculated. A closer view of this curve is given in Figure 4.

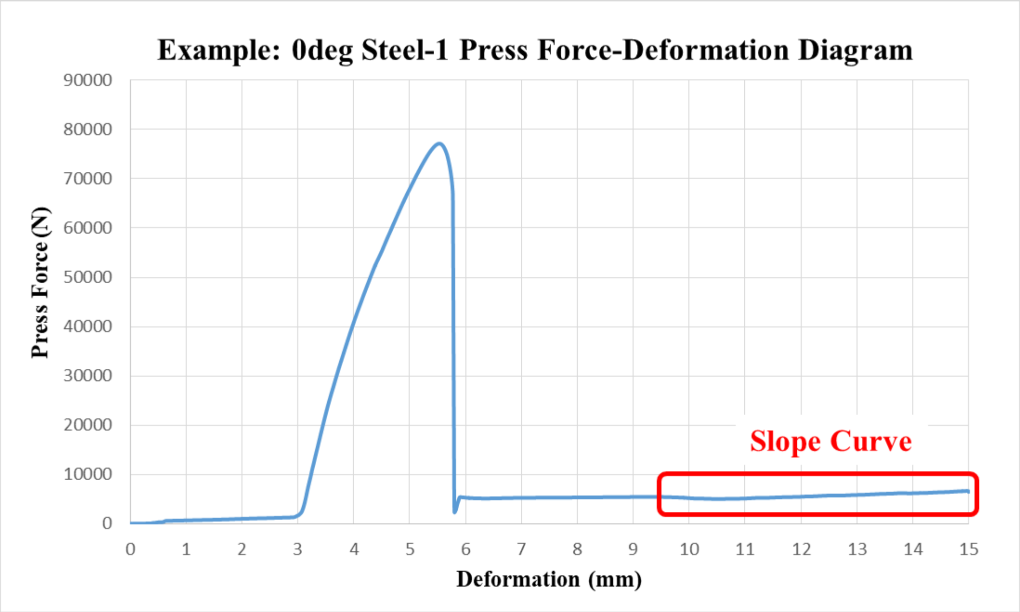

Figure 4.25. Slope curve in piercing process.

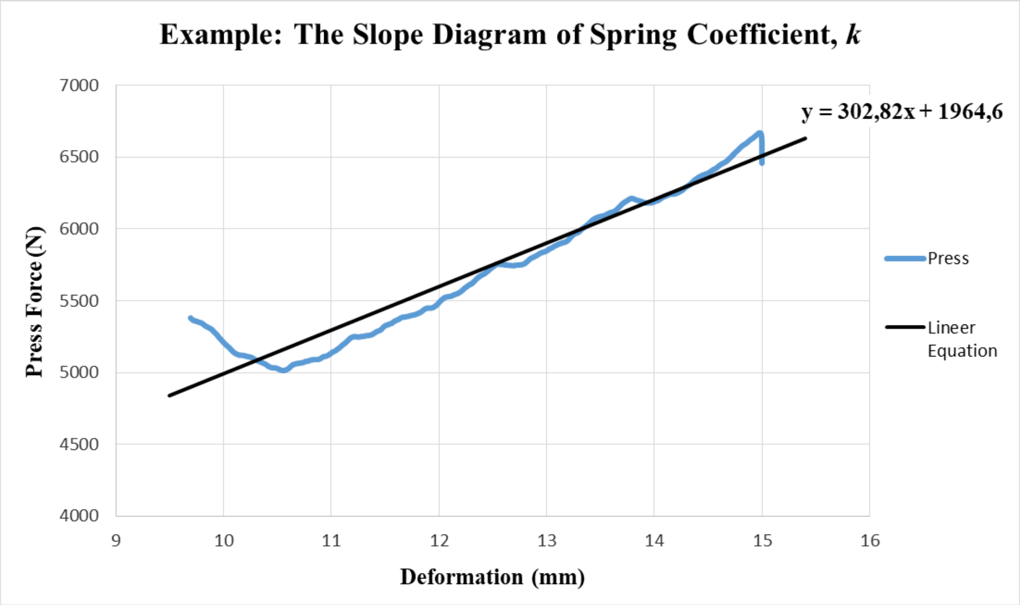

Figure 4.26. Slope curve and linear equation diagram in piercing process.

The curve shown here in blue is the press force-deformation curve. The black curve is the linear equality curve. Here, the convergence is made with the linear equation curve. In this way, it allows us to calculate the slope of the applied force and deformation amount with a very small margin of error. Also, as it is known, the coefficient of the x-axis in the equation of the linear equation curve gives the slope of the linear line. Therefore, the slope of the linear equality curve drawn in the example graph is as follows,

Lineer equation;

$y = 302{,}82\,x + 1964{,}6$
$m = 302{,}82$

The m used in these operations represents the slope. As explained earlier in this section, the slope of this linear equation is equal to the spring coefficient k that we want to find. Therefore;

$m = k$
$k = 302{,}82 \quad N/mm$

Here, these operations are performed to exemplify finding the slope and spring coefficient. With this method, all k values were calculated and spring forces were calculated by using Equation 4.11 in Excel program. Finding the spring force is an important element that should not be neglected in order to find the total shear force. Die springs create a counterforce in the piercing process, causing the press machine to apply more force, and therefore the force applied by the press machine after the piercing process also includes the force value applied for the compression of the spring. This situation is expressed in equation 4.12

$$F_{press} = F_{shear} + F_{spring} \tag{5.12}$$

In this equation, F_{press} refers to the maximum force applied by the press machine during the piercing process, F_{shear} refers to the shear force required for piercing, and

F_{spring} refers to the spring force required to compress the springs used in the piercing patterns. As can be seen in this equation, in order to obtain the total force, the spring force must be subtracted from the maximum force applied by the press machine. This situation is given in equation 4.13

$$F_{total} = F_{shear} = F_{press} - F_{spring} \tag{5.13}$$

Here, F_{total} is equal to the shear force applied to the sheet metal during the piercing process. As mentioned, all calculations were made mathematically in the Excel program and plotted as graphs of the total force-deformation amount applied to the sheet metal. All calculations and graphics will be given in the experimental results section.

PART 5

EXPERIMENTAL RESULTS

5.1. OVERVIEW

In this study, the piercing process was applied to AISI 304L and Al-1050 sheet metal strips with 0°, 3°, and 6° angled punches. Due to the advantageous situations created during the piercing process, 3 springs were used between the molds. The springs used between the molds are heavy load springs in red color. Die springs create counterforce in the piercing process and cause the press machine to apply more force. Therefore, in order to find the total force, the spring forces must be subtracted from the press force obtained during the test and the total force must be obtained in this way.

As mentioned before, due to the different mechanical effects during the experimental applications, the Excel program was used in the calculation of the spring force in this study, as in the other calculations. The calculation of the spring coefficient k was shown in the previous section. In this section, the values of the spring coefficients, the maximum spring forces, the spring force values at the maximum load, the total force occurring during the piercing process of AISI 304L and Al-1050 sheet metal plates, and the obtained graphic results will be given.

5.2. TOTAL SHEAR FORCE RESULTS

In this section, the total force values obtained after the experimental studies will be given. In order to find the total force, the following operations were carried out respectively;

a. Calculating the spring coefficient (k)
b. Calculation of spring forces

c. Subtracting the spring forces from the force values applied by the press machine

The results of the experimental study will also be given in this order. The k values obtained as a result of the calculations are given in Table 5.1.

Table 5.1. Calculated k values.

Material	**Punch Degree**	***k***
Al-1050 - 1	0˚	306,70
	3˚	332,68
	6˚	308,80
Al-1050 - 2	0˚	308,87
	3˚	351,51
	6˚	309,05
AISI 304L - 1	0˚	302,82
	3˚	366,87
	6˚	309,70
AISI 304L - 2	0˚	304,00
	3˚	413,98
	6˚	384,94

Equation 4.11 formula was formulated in Excel program and the obtained k values were written in this formulation and the spring forces were found. The spring coefficients found were applied to all deformation values and the maximum spring force values obtained were tabulated since the spring forces were found. The maximum amount of deformation during the piercing process is 15 mm. As expected, the spring force will reach its maximum value at the maximum deformation amount of 15 mm. The maximum spring forces, which are the second step of the calculation, are given in Table 5.2.

Table 5.2. Maximum spring forces.

Material	Punch Degree	Maximum Deformation (mm)	*k* (N/mm)	Maximum Spring Force (N)
Al-1050 - 1	0˚	15	306,70	4600,50
	3˚	15	332,68	4990,20
	6˚	15	308,80	4632,00
Al-1050 - 2	0˚	15	308,87	4633,04
	3˚	15	351,51	5272,65
	6˚	15	309,05	4635,75
AISI 304L - 1	0˚	15	302,82	4542,30
	3˚	15	366,87	5503,05
	6˚	15	309,70	4645,50
AISI 304L - 2	0˚	15	304,00	4560,00
	3˚	15	413,98	6209,70
	6˚	15	384,94	5774,09

As it is known, in order for the graphic values to be completely accurate, the spring forces must be found in all deformation values and subtracted from the press force. However, since the obtained press force values are too high to make a table, it was deemed appropriate to make the table for the total force for the maximum total force data from the total shear forces found. In addition, the spring forces at the maximum total force value will be given as data instead of the maximum spring forces in the table. As a result of the calculations, the maximum total force values applied to the AISI 304L and Al-1050 sheet strip samples are given in Table 5.3. In this table, the press force represents the force applied by the press machine during the piercing process, the spring force represents the force applied by all the springs and the total force represents the shear force applied to the specimens during the piercing process.

Table 5.3. Maximum total forces.

Material	Punch Degree	Press Force (kN)	Spring Force (kN)	Maximum Total Force (kN)
Al-1050 - 1	0°	12,5919	1,0549	11,5370
	3°	6,3222	1,2657	5,0565
	6°	5,8996	1,3462	4,5534
Al-1050 - 2	0°	12,5712	1,0067	11,5645
	3°	6,4461	1,1958	5,2503
	6°	6,7162	2,1044	4,6117
AISI 304L - 1	0°	77,1439	1,6736	75,4703
	3°	31,2647	1,7268	29,5378
	6°	28,1006	1,8905	26,2101
AISI 304L - 2	0°	79,3429	1,8839	77,4591
	3°	31,1912	1,7736	29,4176
	6°	27,6656	1,7568	25,9088

In this table, the total force applied to the AISI 304L samples is more than 6 times greater than the total force applied to the Al-1050 samples. Therefore, it has been observed once again that AISI 304L sheet metal samples have better mechanical properties compared to Al-1050 sheet metal sheets during the piercing process. In addition, as can be seen from the calculations, all spring force values during the piercing process are very close to each other and the error rate is very low. This is proof that the spring forces are correct and the margins of error can be ignored. Considering the total force values, which is another factor, as the punch angle increases, there is a high decrease in the press force and therefore the total force values. In order to analyze this situation in more detail, the graphic results of Al-1050 - 1, Al-1050 - 2, AISI 304L-1 and AISI 304L - 2 samples will be examined in the next headings, respectively.

5.2.1. Piercing Results of Al-1050 - 1

In this section, the results of 0°, 3° and 6° punch angles of the Al-1050 – 1 sample will be given. The total force graphs obtained for 0°, 3° and 6° punch tip angles as a result of the experimental studies are shown in Figure 5.1, Figure 5.2 and Figure 5.3, respectively. In addition, the comparison diagram of the data is given in Figure 5.4.

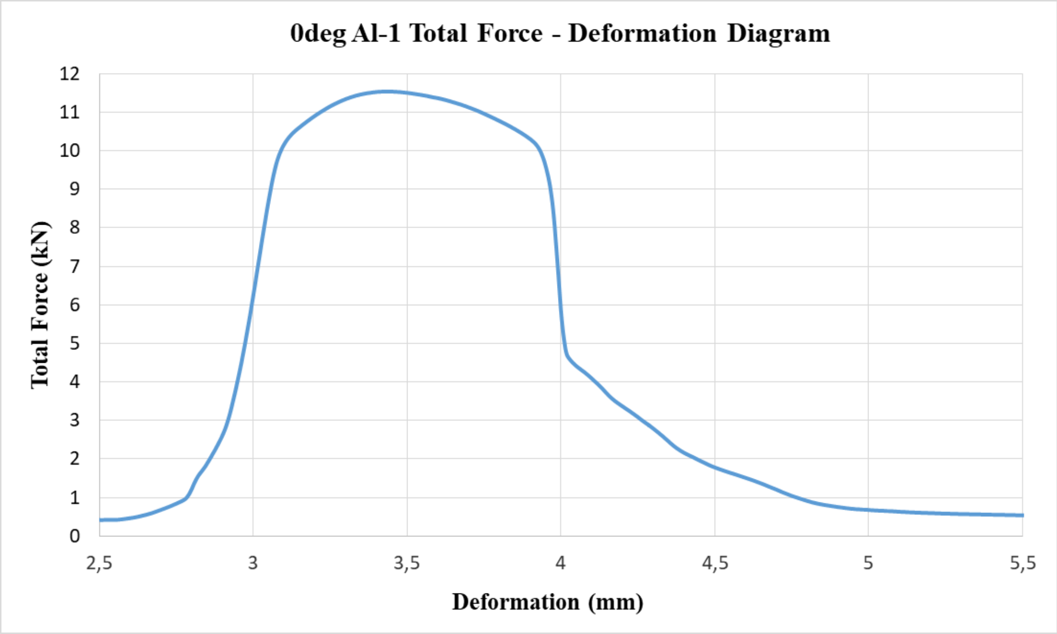

Figure 5.1. 0-degree punch Total Force-Deformation Diagram of Al-1050 – 1.

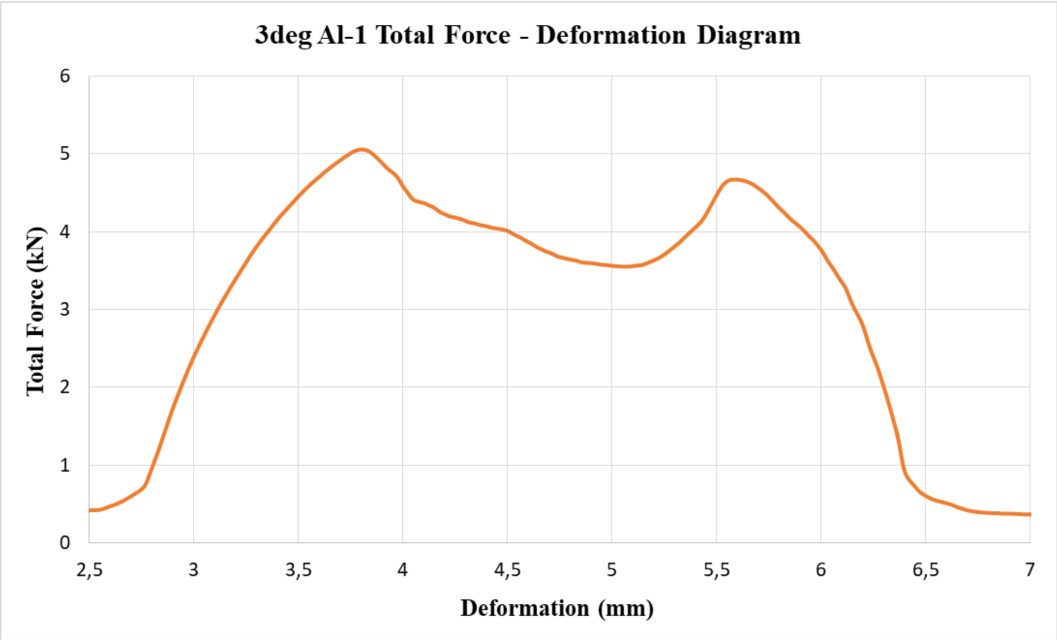

Figure 5.2. 3-degree punch Total Force-Deformation Diagram of Al-1050 – 1.

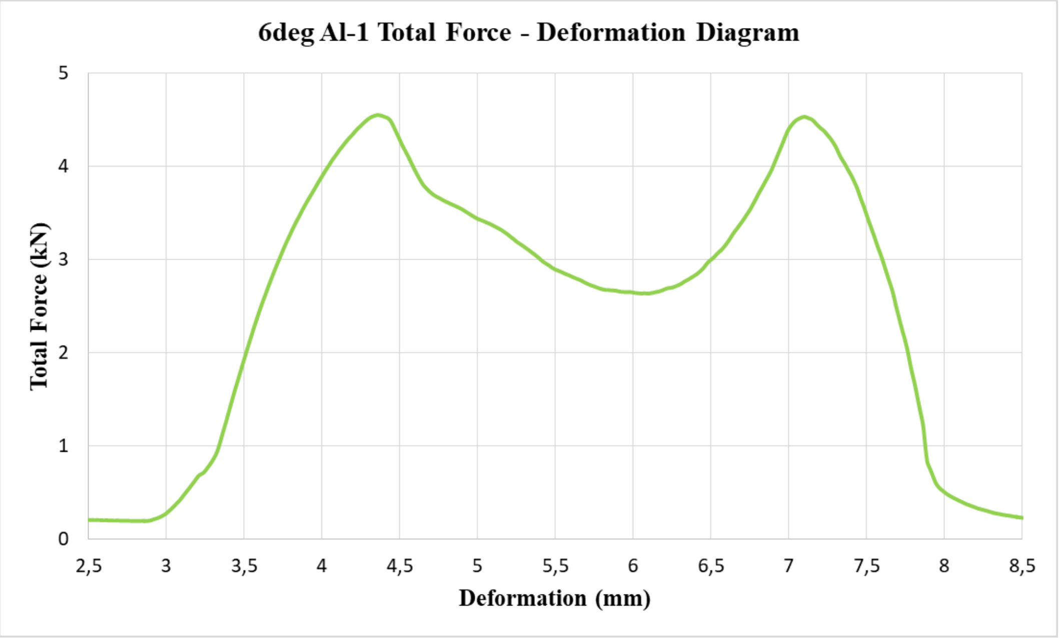

Figure 5.3. 6-degree punch Total Force-Deformation Diagram of Al-1050 – 1.

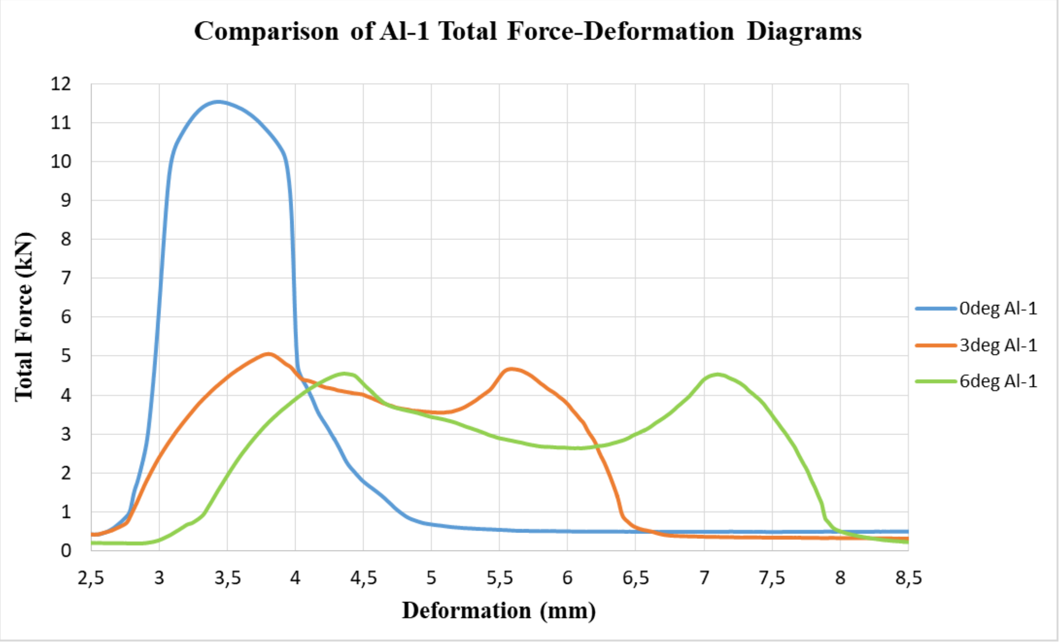

Figure 5.4. Comparison of Al-1050 – 1 Total Force-Strain Diagram.

As it is known, the first issue to be considered in the piercing process is the shear force applied by the punch and the amount of deformation. As can be seen from the comparison diagram of the Al-1050-1 samples, the piercing process using an unangled punch takes place all at once along the cutting line, while the piercing is not instantaneous when the punch is angled and takes a certain time. In angled punches, the force first reaches its highest levels and then starts to decrease partially. Towards the end of the piercing process, the cutting force applied to the sheet metal increases again. After this increase, the force value decreases completely. In the light of the data obtained, while the angle of the punch tip is increased, the depth of penetration required to pierce the metal part increases as the duration of the piercing process will be longer. Therefore, it can be said that the increase in the angle of the punch tip during the piercing process caused a decrease in the total force and an increase in the amount of deformation during the piercing process.

5.2.2. Piercing Results of Al-1050 - 2

In this section, the results of 0°, 3° and 6° punch angles of the Al-1050 – 2 sample will be given. The total force graphs obtained for 0°, 3° and 6° punch tip angles as a result of the experimental studies are shown in Figure 6.1, Figure 6.2 and Figure 6.3, respectively. In addition, the comparison diagram of the data is given in Figure 6.4.

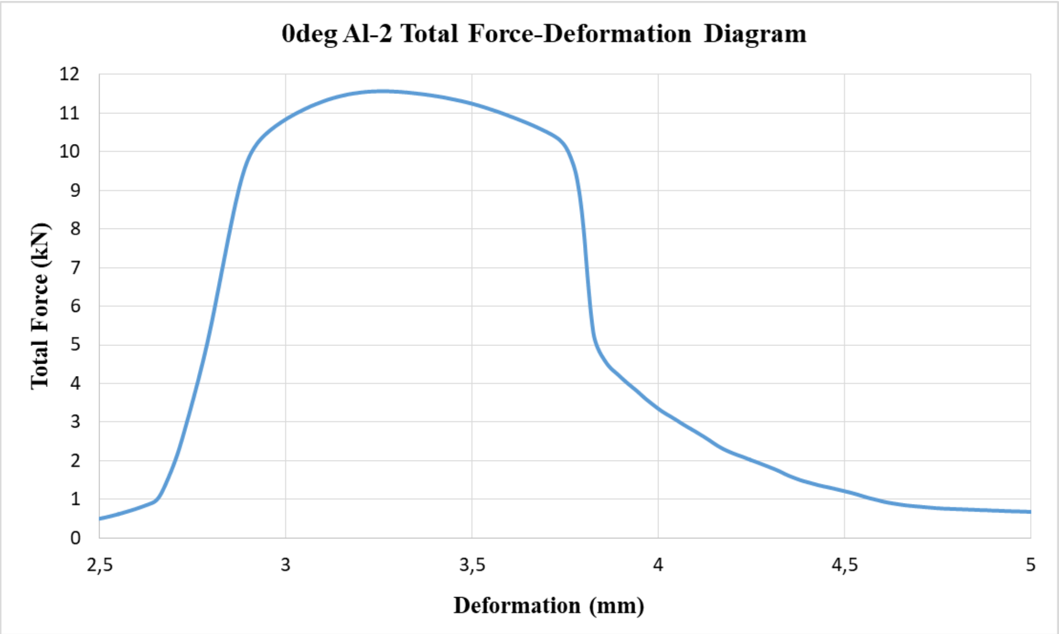

Figure 5.5. 0-degree punch Total Force-Deformation Diagram of Al-1050 – 2.

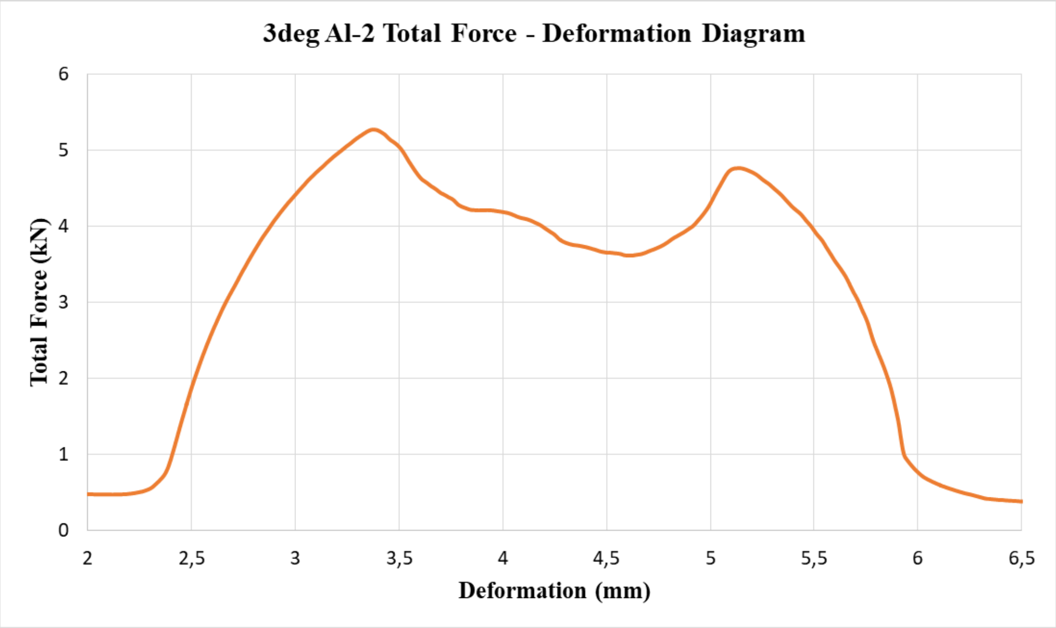

Figure 5.6. 3-degree punch Total Force-Deformation Diagram of Al-1050 – 2.

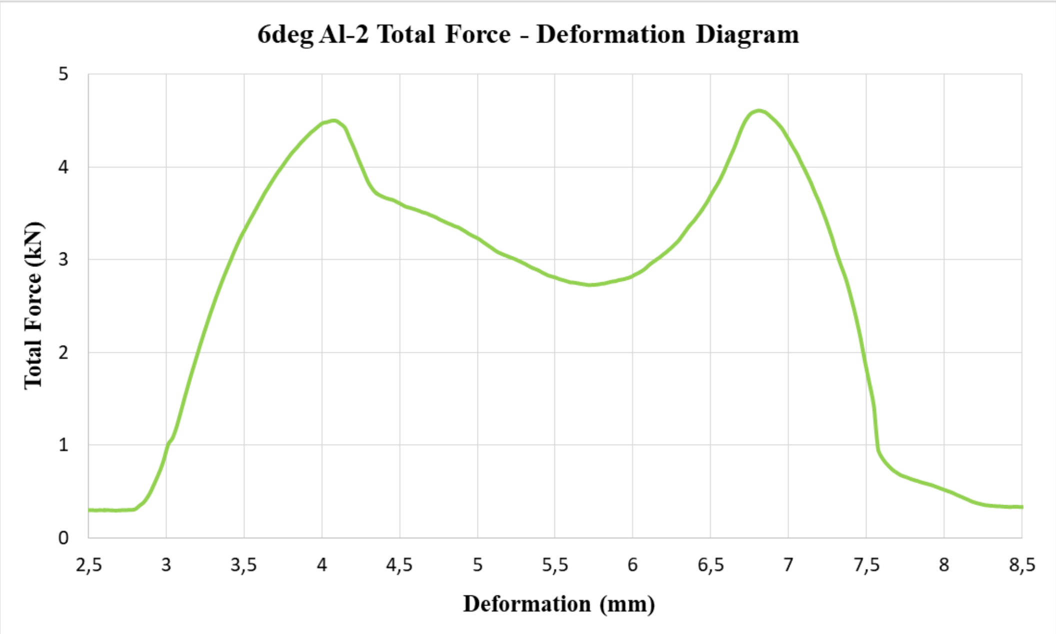

Figure 5.7. 6-degree punch Total Force-Deformation Diagram of Al-1050 – 2.

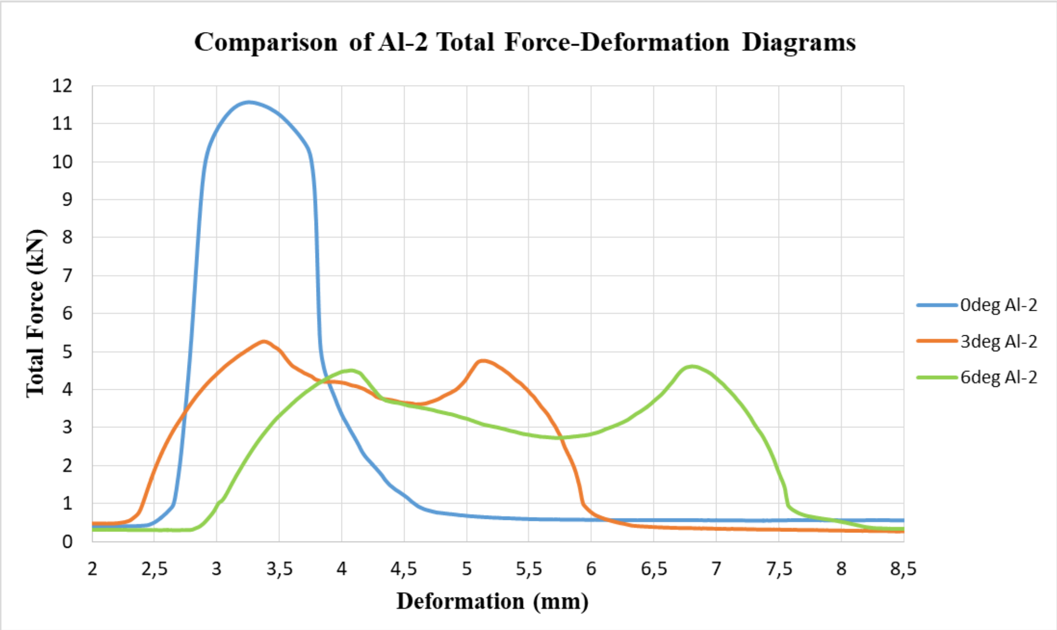

Figure 5.8. Comparison of Al-1050 – 2 Total Force-Strain Diagram.

As can be seen from the comparison diagram of the Al-1050 – 2 samples, the change of the punch tip angle again showed the same effects. Piercing using a non-angle punch is instantaneous at one time along the cutting line, while when the punch is angled, the piercing is not instantaneous and spreads over a certain period of time. In angled punches, the force first reaches the highest levels and then starts to decrease partially during the process. Towards the end of the piercing process, the cutting force applied to the sheet metal increases again. After this increase, the force value decreases completely. As the punch tip angle is increased, the penetration depth required to pierce the metal piece increases as the piercing process will take longer. Therefore, for this study, the increase in the angle of the punch tip during the piercing process caused a decrease in the total force and an increase in the amount of deformation during the piercing process.

5.2.3. Piercing Results Of AISI 304L - 1

In this section, results of 0°, 3° and 6° punch tip angles of AISI 304L - 1 sample will be given. The total force graphs obtained for 0°, 3° and 6° punch tip angles as a result of the experimental studies are shown in Figure 6.1, Figure 6.2 and Figure 6.3, respectively. In addition, the comparison diagram of the data is given in Figure 6.4.

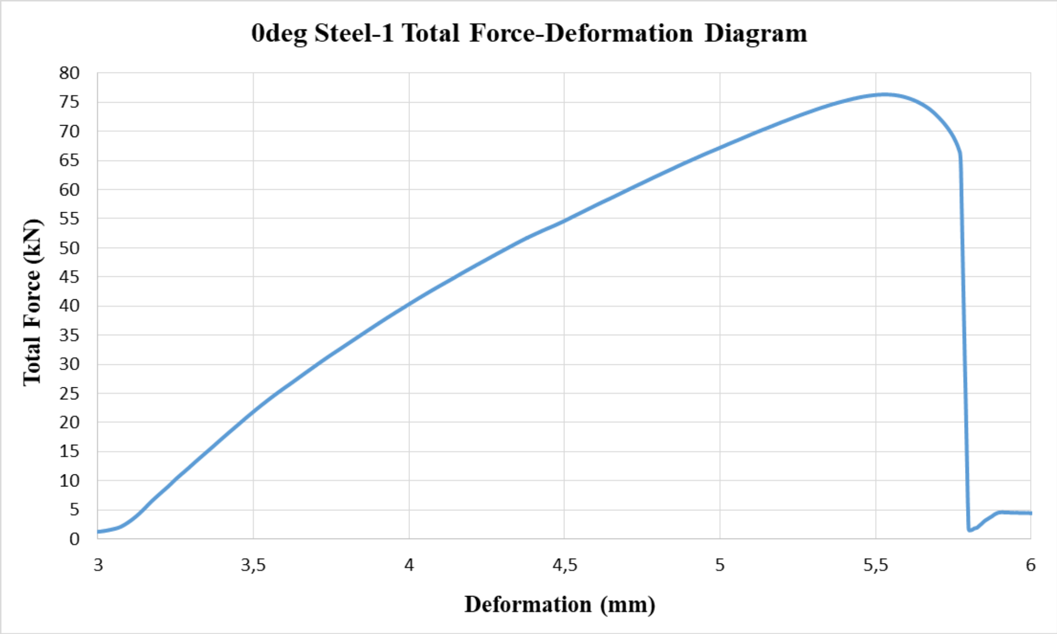

Figure 5.9. 0-degree punch Total Force-Deformation Diagram of AISI 304L – 1.

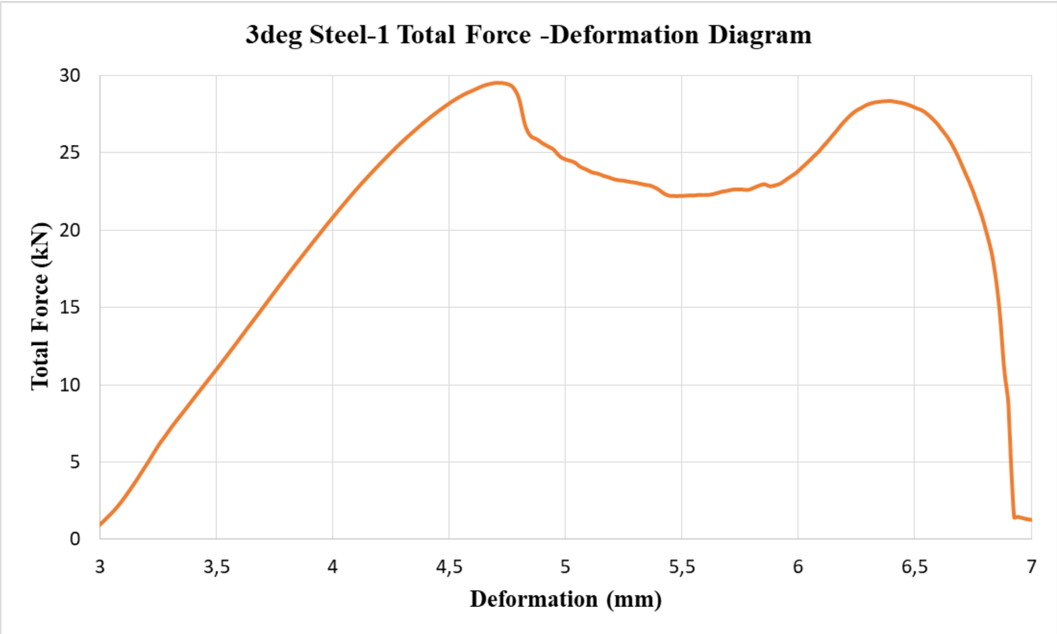

Figure 5.10. 3-degree punch Total Force-Deformation Diagram of AISI 304L – 1.

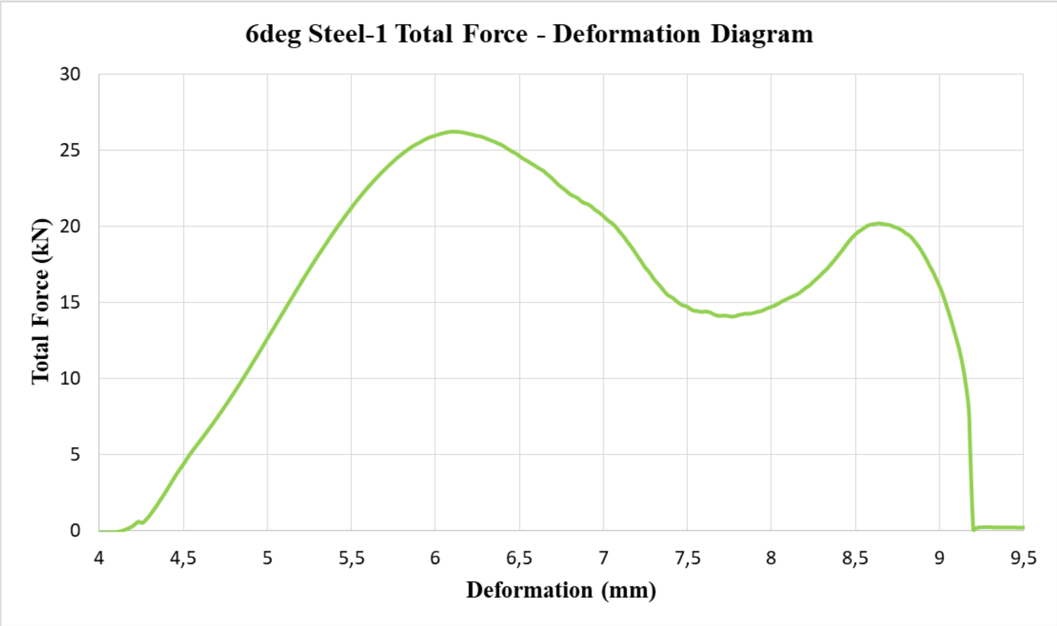

Figure 5.11. 6-degree punch Total Force-Deformation Diagram of AISI 304L – 1.

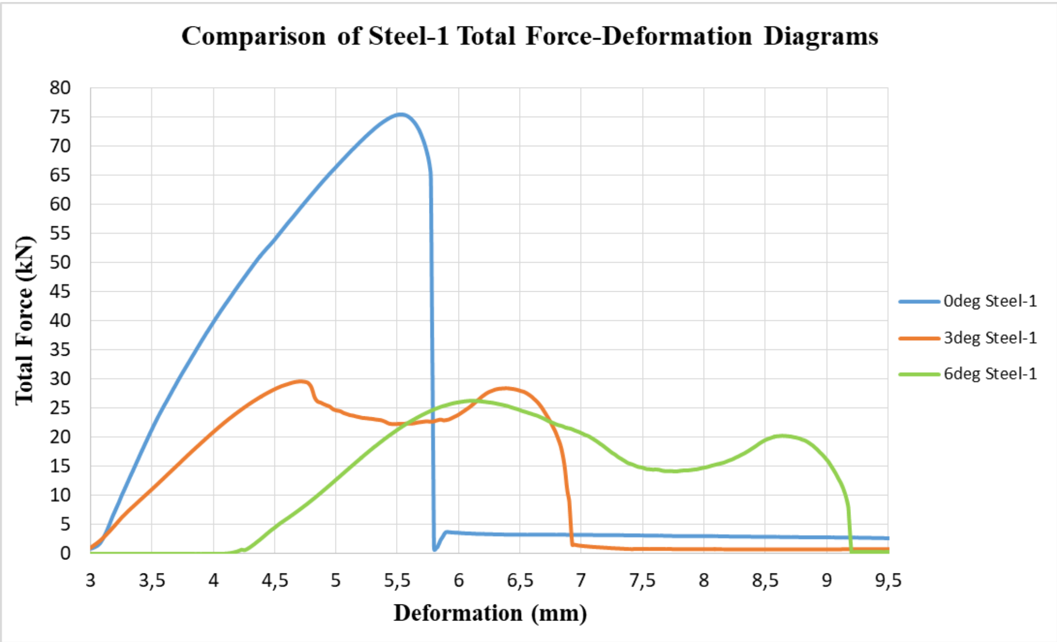

Figure 5.12. Comparison of AISI 304L -1 Total Force-Strain Diagram.

As can be seen from the comparison diagram of the AISI 304L-1 samples shown graphically, the change of the punch tip angle again showed the same effects with the Al-1050 samples. Piercing using a non-angle punch is instantaneous along the cutting line, while when the punch is angled, the piercing is not instantaneous and takes a certain amount of time. In angled punches, the force first reaches its highest levels and then starts to decrease partially. Towards the end of the piercing process, the cutting force applied to the sheet metal increases again. After this increase, the force value decreases completely. As the punch tip angle is increased, the penetration depth required to pierce the metal piece increases as the piercing process will take longer. Therefore, for this study, the increase in the angle of the punch tip during the piercing process caused a decrease in the total force and an increase in the amount of deformation during the piercing process.

5.2.4. Piercing Results Of AISI 304L - 2

In this section, results of 0°, 3° and 6° punch tip angles of AISI 304L - 1 sample will be given. The total force graphs obtained for 0°, 3° and 6° punch tip angles as a result of the experimental studies are shown in Figure 6.1, Figure 6.2 and Figure 6.3, respectively. In addition, the comparison diagram of the data is given in Figure 6.4.

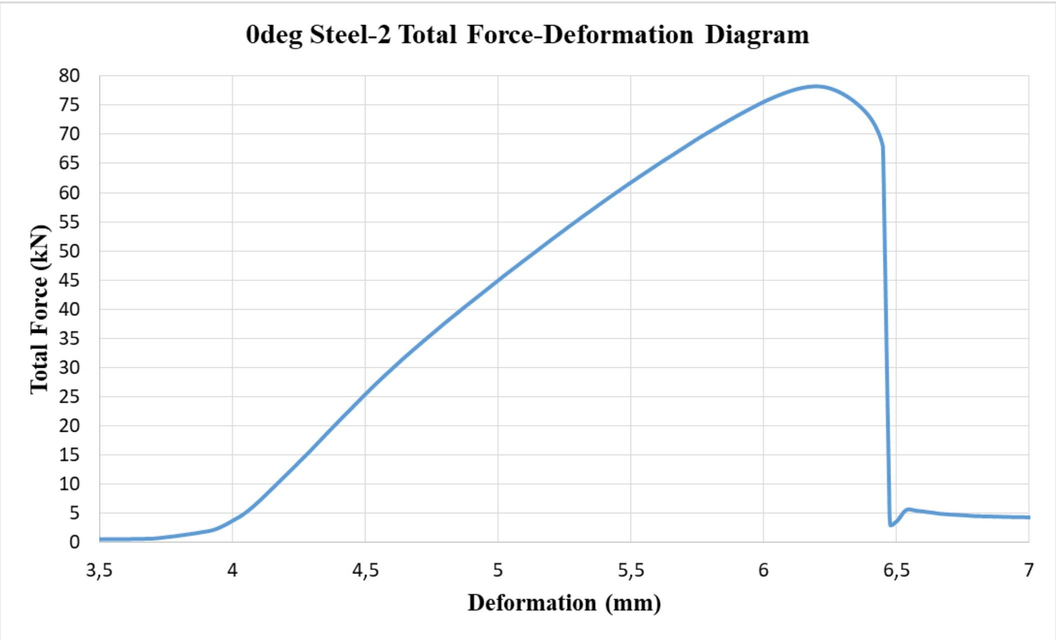

Figure 5.13. 6-degree punch Total Force-Deformation Diagram of AISI 304L – 2.

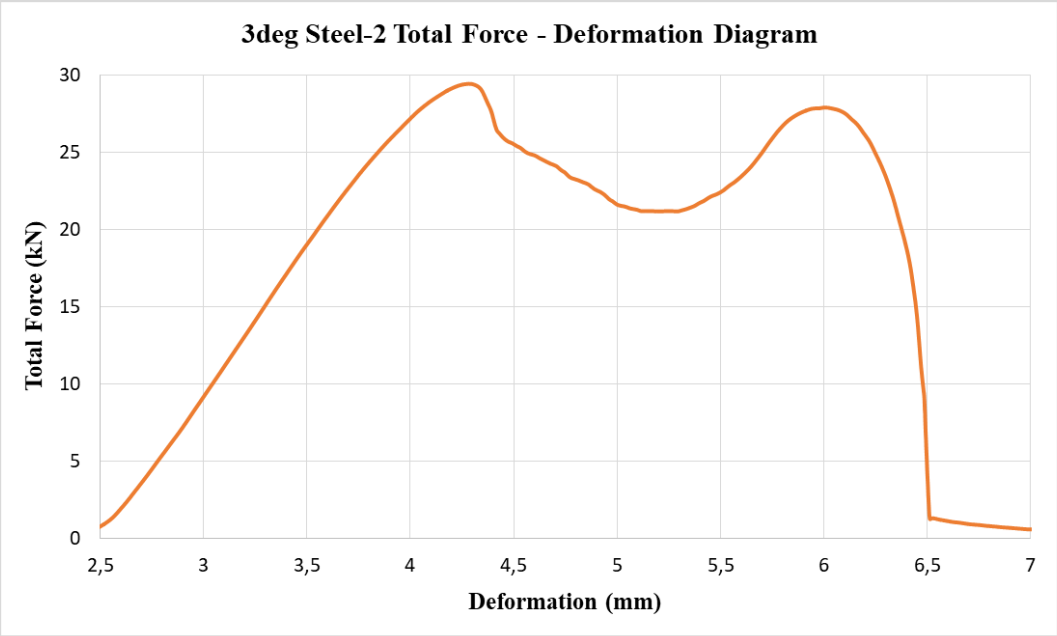

Figure 5.14. 6-degree punch Total Force-Deformation Diagram of AISI 304L – 2.

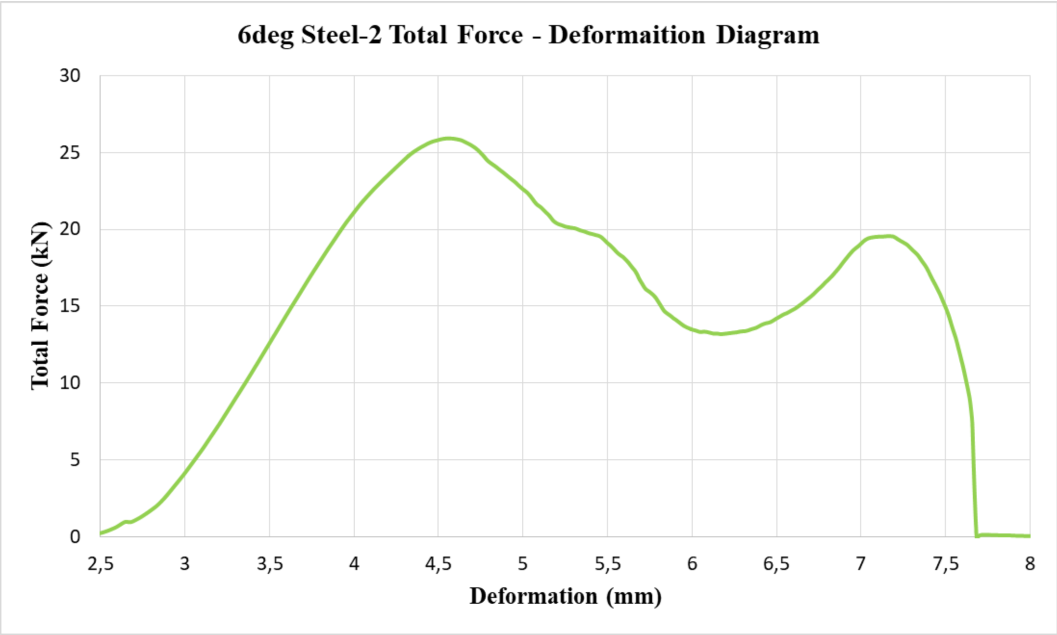

Figure 5.15. 6-degree punch Total Force-Deformation Diagram of AISI 304L – 2.

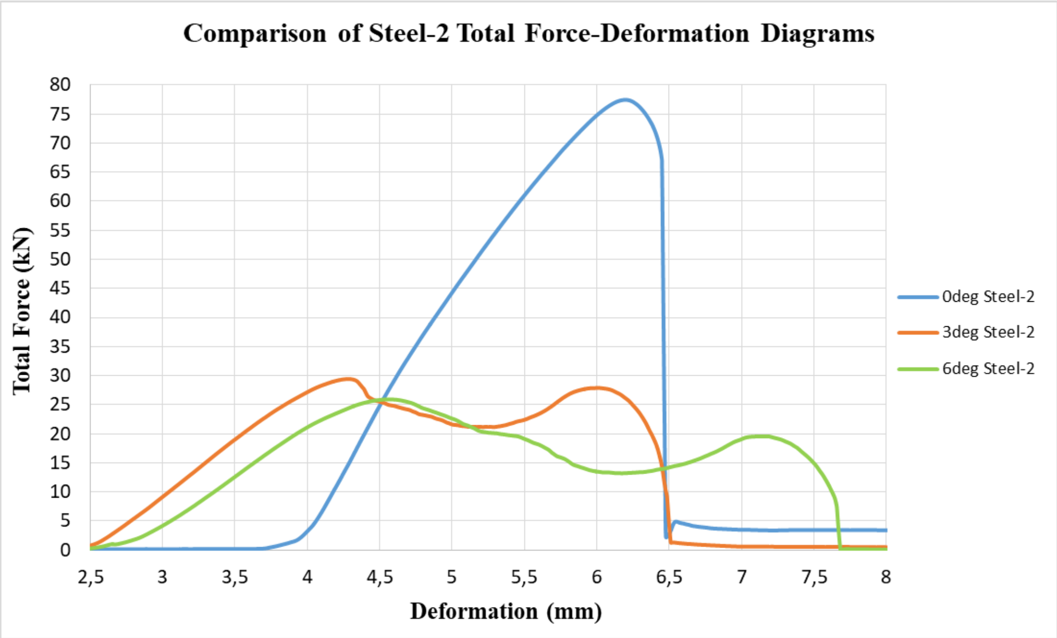

Figure 5.16. Comparison of AISI 304L -1 Total Force-Strain Diagram.

As can be seen from the comparison diagram of the AISI 304L-2 samples shown graphically, the change of the punch tip angle again showed the same effects with the Al-1050 samples. As in other experimental studies, piercing using an angle punch is instantaneous at one time along the cutting line, while piercing is not instantaneous when the punch is angled and takes a certain amount of time. In angled punches, the force first reaches the highest levels and then starts to decrease partially during the process. Towards the end of the piercing process, the cutting force applied to the sheet metal increases again. After this increase, the force value decreases completely. However, in this experimental study, angled punch ends started to deform later than non-angle punch ends. Apart from this situation, this experimental study, as in other piercing processes, increased the angle of the punch tip, causing a decrease in the total force and an increase in the amount of deformation during the piercing process.

PART 6

RESULTS

6.1. SUMMARY OF THE STUDY

In this study, the effect of the punch angle, which is widely preferred in cutting processes in engineering fields and used in piercing processes, on the shear forces created during piercing processes was experimentally investigated. AISI 304L stainless steel and Al-1050 aluminum alloy sheet plates were preferred for the experimental piercing procedures. In this study, many literatures have been researched to be an example of experimental applications and the information obtained from this literature has been added to the topics in the thesis. The study first started with the definition of the mechanical properties of AISI 304L and Al-1050 sheet metal materials. For this, firstly, two tensile test specimens were prepared from AISI 304L and Al-1050 sheet metal plates. AISI 304L and Al-1050 samples are named as AISI 304L -1, AISI 304L -2, Al-1050 -1 and Al-1050 -2. The dimensions of these samples are 345x29.95x2 mm, 345x29.95x1.95 mm, 345x29.90x2.05 mm and 345x29.95x2.05 mm, respectively. The dimensions of the prepared samples were prepared as close to each other as possible and the mechanical effects were tried to be observed. Tensile test was applied to specially prepared samples and the data obtained as a result of the tensile test were recorded as Excel tables. The obtained data were then calculated using the Engineering Stress-Strain, True Stress-Strain and Logarithmic True Stress-Strain formulas. Tensile test formulas were used in the calculations and the formulas used were given theoretically. In addition, as a result of the tensile test calculations, the data were converted to Excel graphics. Log K value was found with the help of the Logarithmic True Stress-Strain curve from the generated graphics. As a result of the tensile tests, the K value of the AISI 304L -1 sample was found to be 1060.72 MPa, while the K value of the AISI 304L -2 sample was found to be 1052.20 MPa. On the other hand, the K value of the Al-1050 -1 sample was found to be 319.01 MPa, while the K value of the Al-1050 -2 sample was found to be 400.41 MPa.

After determining the mechanical properties of AISI 304L and Al-1050 sheet plates to be used in the study, chemical analysis was performed on the sample taken from the material with a metal analysis spectrometer in order to determine the chemical structure of the materials. The chemical structures of AISI 304L and Al-1050 materials obtained as a result of the chemical analysis are given in the table. Since the basic properties of the materials were completely determined, piercing processes were started after chemical analysis.

The preparatory phase of the piercing process was the preparation of the pressing machine and the piercing experiment setup. It was deemed appropriate to use the Zwick Roell type Z600 press machine in the experimental studies to be carried out. Piercing staples constitute the main point of the study in experimental studies. Specially produced staples with a punch tip angle of 0°, 3°, and 6° are provided for the piercing process. During the preparation of the piercing patterns, which is another element of the experimental setup, attention was paid to the preparation of the molds in accordance with high force values. For this, 3 red-colored heavy load springs were used between the punch and the die. The prepared experimental setups were mounted and the piercing process was started. For the piercing process, 1000x30x2 mm samples from sheet materials were preferred. The piercing process was applied to each sheet metal twice because of the possibility of experimental errors. The force and deformation data obtained as a result of the piercing processes were recorded and transferred to the Excel program and calculations were started. Since 3 heavy-load springs are used between the dies during the piercing process, it is not necessary to subtract the spring forces from the force applied by the press machine in order to calculate the shear forces. Therefore, in the phase of finding the total forces, first the spring coefficient and then the spring forces are found. Then, the total force values were found by subtracting the force values applied by the press machine. All the total force values found were converted into tables and graphs with the Excel program. The maximum shear forces and other parameters obtained with the Excel program are shown in Table 6.1. In addition, images after piercing applied to Al-1050 sheet metal are shown in Figure 6.1 as an example.

Table 6.1. Maximum shear force.

Material	Punch Degree	Press Force (kN)	Maximum Total Force (kN)
Al-1050 - 1	0˚	12,5919	11,5370
	3˚	6,3222	5,0565
	6˚	5,8996	4,5534
Al-1050 - 2	0˚	12,5712	11,5645
	3˚	6,4461	5,2503
	6˚	6,7162	4,6117
AISI 304L - 1	0˚	77,1439	75,4703
	3˚	31,2647	29,5378
	6˚	28,1006	26,2101
AISI 304L - 2	0˚	79,3429	77,4591
	3˚	31,1912	29,4176
	6˚	27,6656	25,9088

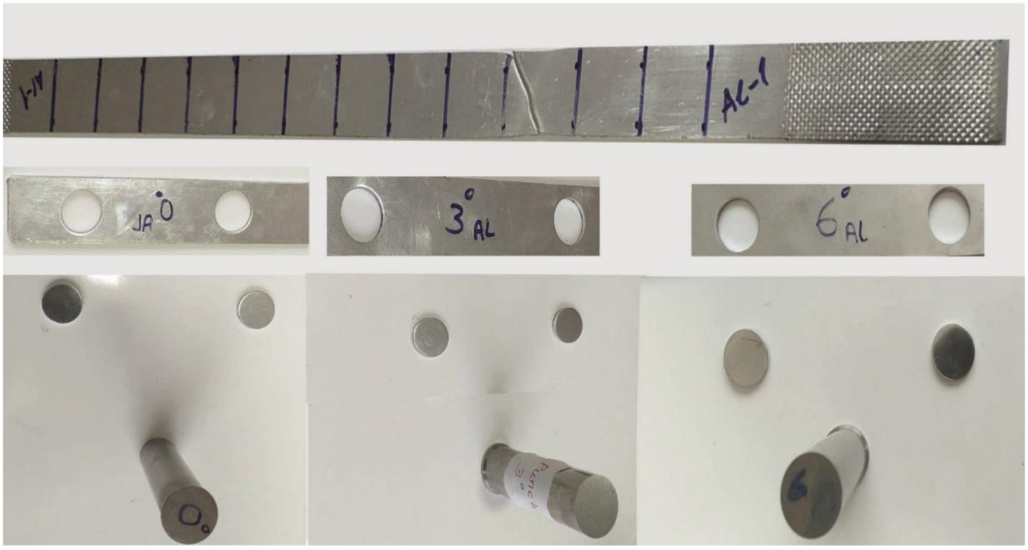

Figure 6.1. Al-1050 - 1 samples after piercing processes.

6.2. CONCLUSIONS

In this study, an experimental investigation of the piercing process, which is frequently used in sheet metal cutting processes in the automotive and many other engineering industries, has been carried out according to the punch angles of the fringed. In the light of the tensile test and the data obtained, it has been proven that the increase in the angle of the punch tip used during the piercing process causes a decrease in the applied shear force. In addition, it should be emphasized that the increase in the angle of the punch tip may increase the life of the punch and die used in continuous production in the piercing process. The results obtained as a result of the experimental studies are given below, respectively.

When the force values applied to the Al-1050 sheet metal plates are examined according to the angle of the punch tip, the 0-deg punch, which is the non-angle punch, was applied to both aluminum samples with approximately the same maximum force, and these force values were 11.5370 kN in the first sample and 11.5645 kN in the second sample. Angled staples caused serious reductions in the forces applied during the piercing process. At this point, the 0-deg force values should be compared to the force values of the 3-deg and 6-deg punches and the amount of reduction in forces should be checked. When the force values of the 0-deg punch applied to the Al-1050 sheet samples were proportionally proportioned with the 3-deg, the force decreased by 56.17% in the first sample, while the applied force decreased by 54.60% in the second sample. In another piercing process applied to Al-1050 sheet metal samples, when the force values of the 0-deg punch were proportionally proportioned with the 6-deg force values, a 60.53% reduction in force was observed in the first sample, while a decrease in the applied force of 60.12% was observed in the second sample. Therefore, in the light of these data obtained, it has been shown that the increase in the angle of the punch tip causes the force reduction in the piercing process.

When the maximum force values applied to AISI 304L samples, which is another test material, are examined according to the angle of the punch tip, the 0-deg punch, which is an unangle punch, has approximately the same maximum force applied to both samples and these values are 75.4703 and 77.4591. When the force values of the 0-

deg punch applied to the AISI 304L sheet samples are proportionally proportioned with the 3-deg, the force decreased by 60.86% in the first sample, while the applied force decreased by 62.02% in the second sample. In another piercing process applied to AISI 304L sheet metal samples, when the force values of the 0-deg punch were proportionally proportional to the 6-deg force values, a 65.27% force reduction was observed in the first sample, while a 66.55% decrease in the applied force was observed in the second sample. Again, in the light of these data obtained here, it has been shown that the increase in the angle of the punch tip causes the force reduction in the piercing process.

The first result from the percentage comparisons is that the 6-deg angled punch provides a minimum 60% gain in shear strength compared to other punches. Therefore, it was concluded that the optimum punch tip angle is 6-deg. Since the piercing process is a cutting process that requires surface contact, besides the amount of force and deformation, other factors to be considered for this process are the production of standard parts and the long-term use of the tools used in the piercing process. Standard production was carried out in the piercing process. When the effects of the experimental setup are examined, the positive effects of the punch tip angle are seen. Especially due to the decrease in the load on the punch tip, the amount of force that the punch tip and punch surface are exposed to decreases in direct proportion to the amount of force. Therefore, in continuous production, it can be interpreted that increasing the angle of the punch tip decreases the applied force value and prolongs the life of the test tools used in the piercing process.

6.3. SUGGESTION

In the light of the experience gained as a result of this study, the recommendations are as follows;

a. Determining all the force losses in the experimental setups can minimize the error rates in the shear force values to be obtained as a result of the study, shear force results closer to reality are obtained.

b. In order to calculate the lifetime of the test instruments used in the piercing process, applications are made continuously and in longer time parameters, providing clearer data.

c. In order to see the mechanical effects of the angle of the punch tip on the samples in more detail and to reach a precise judgment, studies can be made with higher angle punches in the piercing process.

d. In order to see the effect of the angle of the punch tip on the life of the punch in the piercing process and to reach a definite judgment, studies can be made with higher angle punches.

e. In the piercing process, the microstructure of the deformations of the punch tips can be examined in order to see the effect of the punch tip angle on the punch life and to reach a precise judgment.

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RESUME

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