THEORETICAL AND EXPERIMENTAL INVESTIGATION OF THE PUNCHING PROCESS OF DP600 AUTOMOTIVE SHEET STEEL WITH DIFFERENT PUNCH TIPS

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"I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well."

MAAMAR MIFTAH RAHMAH

ABSTRACT

Master Thesis

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF THE PUNCHING PROCESS OF DP600 AUTOMOTIVE SHEET STEEL WITH DIFFERENT PUNCH TIPS

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Dual-Phase (DP) steels, part of the Advanced High Strength Steels (AHSS) group, are preferred by car manufactures due to building demand for the body in white by using materials having excellent strength to weight ratio. During the automobile body producing a lot of metalworking process are used also very much punching-cutting also take place extensively. Important of this, all metalworking process must be optimized, understood very well to manage all well doing requirements. Sheet metal cutting operations such as blanking, fine blanking, trimming and punching aim to separate a certain amount of the material from the remaining sheet by using a controlled shearing and fracture at the contour of cut. There are many factors, which has huge effects on all properties of the worked materials during punching such as clearance, burr height, burr location, cut surface conditions, punch properties, materials properties and so.

For doing well on manufacturing, understanding, and optimization of punching of dual phase steel are also very important with more other factors such as formability weld ability, wearing, cost, etc.

In this thesis, experimental and theoretical analysis using punches with different dies, for work materials under normal conditions are investigated by using automotive DP 600 sheet steel. Automotive DP600 sheet steel is one of the widely used steels in lots of industrial area particularly in automotive, has a big effect in, therefore selected for this study. This study comprised that punching operation by using different punch tips, failure analysis and, evaluation of punch shapes in terms of shearing and product quality, which subjected to punching. In the experiment, a simplified simulation model has been created using a digital-analog converter used to transmit the amplified signal to a computer. Punching experiments were carried out by using four different punched tips. In addition to that, simulations of the punching process by using deform software were also performed.

It is observed that experimental and simulations results have been good intersections to each other. This is showing the use of the simulation software on punching of dual phase steel, which can prove useful gain in time and cost saving. Punch shape results also give detailed information on the punching process and its effects.

Keywords : Punching, dual-phase steels, DP600, pressing punch tips, failure analysis of sheared surface and part,

Science Code : 91416

ÖZET

Yüksek Lisans Tezi

FARKLI TİPTE ZIMBA KULLANILARAK DP600 OTOMOTİV SAC ÇELİĞİNİN PRESTE DELME İŞLEMİNİN, TEORİK VE DENEYSEL İNCELENMESİ

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Gelişmiş Yüksek Mukavemetli Çelikler (AHSS) grubunun bir parçası olan Çift Fazlı (DP) çelikler, mukavemet-ağırlık oranı mükemmel malzemeler kullanılarak hafif gövde yapım talebi nedeniyle otomobil üreticileri tarafından tercih edilmektedir. Otomobil gövdesi üretimi sırasında çok sayıda metal işleme işlemi kullanılır, ayrıca çok fazla delme-kesme de yaygın olarak gerçekleşir. Önemli olan, tüm iyi iş gereksinimlerini yönetmek için tüm metal işleme sürecinin optimize edilmesi ve çok iyi anlaşılması gerekir. Körlenme, ince kesme, kırpma, delme gibi sac kesme işlemleri, kesme konturunda kontrollü bir kesme ve kırma kullanarak kalan sacdan belirli bir miktar malzemeyi ayırmayı amaçlamaktadır. Boşluk, çapak yüksekliği, çapak konumu, kesilmiş yüzey koşulları, zımba özellikleri, malzeme özellikleri gibi delme sırasında işlenen malzemelerin tüm özellikleri üzerinde büyük etkileri olan birçok faktör vardır. İmalatta başarılı olmak için, çift fazlı çeliğin zımba ile delinmesi ve optimizasyonu, Bu tezde, normal şartlar altında iş malzemeleri için farklı kalıplara sahip zımbalar kullanılarak deneysel ve teorik analizler, otomotiv DP 600 çelik sac ve farklı zımba ucu tipleri kullanılarak incelenmiştir. Otomotiv DP600 çelik sac, özellikle otomotiv başta olmak üzere birçok endüstriyel alanda yaygın olarak kullanılan çeliklerden biridir ve büyük etkiye sahiptir, bu nedenle bu çalışma için seçilmiştir. Bu çalışma, farklı zımba uçları kullanılarak zımbalama işlemleri, hata analizi ve kesilen yüzeyin karakterizasyonu ve zımbaya maruz kalan parça ve malzemelerle ilgili tüm koşulların analizini içermektedir. Deneyde, yükseltilmiş sinyali bir bilgisayara iletmek için kullanılan bir dijital-analog dönüştürücü kullanılarak basitleştirilmiş bir simülasyon modeli oluşturuldu. Dört farklı zımba tipi kullanılarak zımba ile delme deneyleri yapılmıştır. İlaveten, Deform yazılımı kullanılarak delme işlemi simülasyonları gerçekleştirildi.

Sonuç olarak, deneysel ve simülasyon sonuçlarının birbiriyle iyi kesiştiği görülmüştür. Bu, simülasyon yazılımının Çift fazlı çeliğin zımba ile delinmesinde kullanılmasının zaman ve maliyet tasarrufu açısından faydalı bir kazanç sağlayabileceğini göstermektedir. Hasar analizi sonuçları da punch ile delme işlemi ve etkileri üzerine oldukça detaylı bilgiler vermektedir.

Anahtar Kelimeler: Preste delme, Çift-Fazlı çelik, DP600, Pres zımbası kesilmiş yüzey ve parçaların hasar analizi.

Bilim Kodu **:** 91416

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SYMBOLS AND ABBREVIATIONS INDEX

SYMBOLS

ε_f	:	Strain of ferrite
ε_m	:	Strain of martensite
μm	:	Micrometer

ABBREVIATIONS

FEM	:	Finite Element Method
AHSS	:	Advanced High Strength Steel
HSS	:	High Strength Steel
TRIP	:	Transformation Induced Plasticity
DP	:	Dual Phase Steel
UTS	:	Ultimate Tensile Strength
YS	:	Yield Strength
MPa	:	Mega Pascal, the unit for tensile strength
LBG	:	Liquid Petroleum Gas
HSLA	:	High Strength Low Alloy
HF	:	Hot Forming
M-A	:	Martensite-Austenite
CTT	:	Continuous Cooling Transformation Diagram
BIW	:	Body in White
CP	:	Complex Phase
Mart	:	Martensitic
TWIP	:	Twin Induced Plasticity

FEM	:	Finite Element Method
IF	:	Interstitial Free
BH	:	Bake Hardened
HSLA	:	High Strength Low Alloy
HF	:	Hot Shaping
LPG	:	Liquid Petroleum Gas
CTT	:	Continuous Cooling Transformation
FEM	:	Finite Element Method
CNC	:	Computer Numerical Controlled

PART 1

INTRODUCTION

Recently, AHSS including DP steels gained high significance in automotive industry. The structural parts of the vehicles are composed using these steels to keep safety of passengers. The DP steels are considered one of the most prominent AHSS and offers a great compromise between sheet metal formability (low initial production stress) and improved mechanical properties (high final tensile strength) thanks to the ferritin-martensitic structure usually obtained through a continuous annealing process. In the previous years, DP steel, TRIP and their galvanized products are commonly used to industrialize and produce the automotive parts such as bumper beams, lists and bumper reinforcements. TRIP steel and DP steel together provide a great possibility of higher strength and formability combination [1]. The high and increased competition of car industry led to variety of models and shorter model cycles. In addition, the competition led to a very intense development to decrease cost and increase productivity. Moreover, the development of car manufacturing is affected by customer demands such as lower consumption and more comfort in addition to some legal requirements such as decrease the harmful emissions, environmental requirements, and safety regulation [2].

AHSS sheets helped in manufacturing the structural elements with less thickness and therefore, they helped to produce lighter vehicles with the compromise to decrease consumption of fuel and emissions of greenhouse gases. The structural automotive elements manufactured from metallic sheets are commonly formed using punch-die tooling to get the required geometry part. In the industrial sheet, metal forming process of traditional steel grades, confined necking normally manages the fracture of blank.

The application of lightweight design principles is considered one of the most significant trends in meeting these multiple requirements [3]. It is necessary to mention the increasing applications of high strength steel between the recent material developments. The last few decades witnessed the development of numerous new grades of high-strength steel. During the past 30 years, many research and papers were mentioned the potential applications of DP steels as shown in Figure 1.1.

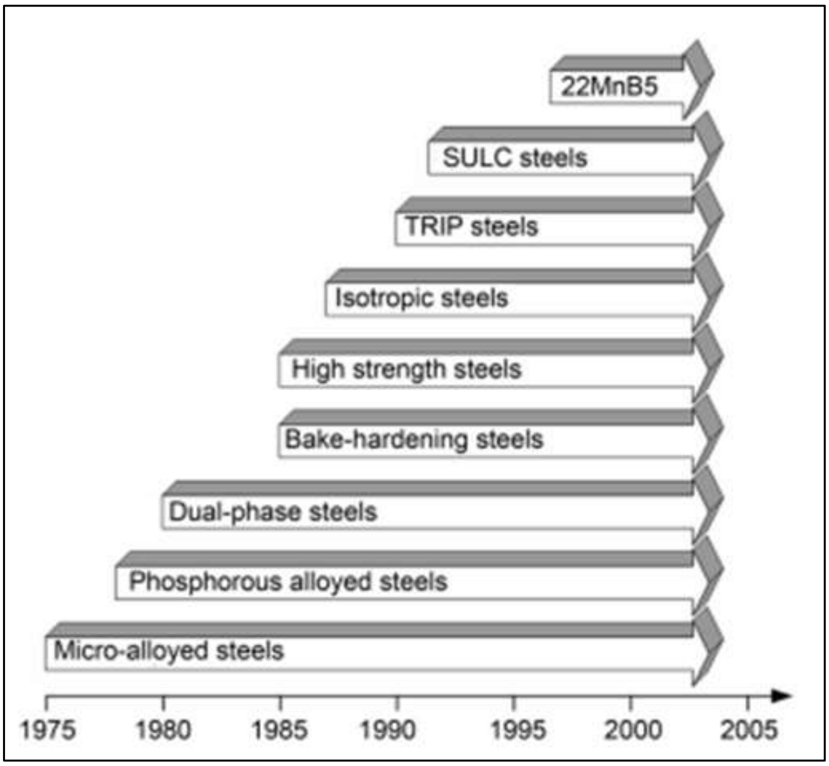


Figure 1.1. Trends of steel development through the last 30 years [4].

Figure 2.1 shows the advantages of DP steels that illustrates the relationship between yield and ultimate tensile strength and elongation of different steels. As shown, that TRIP and DP steels presents a wide range of ductility and strength. The maximum acceptable deformation of car crash does not exceed 10% strain [5]. Therefore, the energy absorption of the automotive body at 10% strain is a significant factor. As shown in Figure 1.2, DP steels have greater energy absorption at 10% strain if compared with TRIP steels with the same strength. Therefore, DP steels can improve the cars safety in case of car accidents.

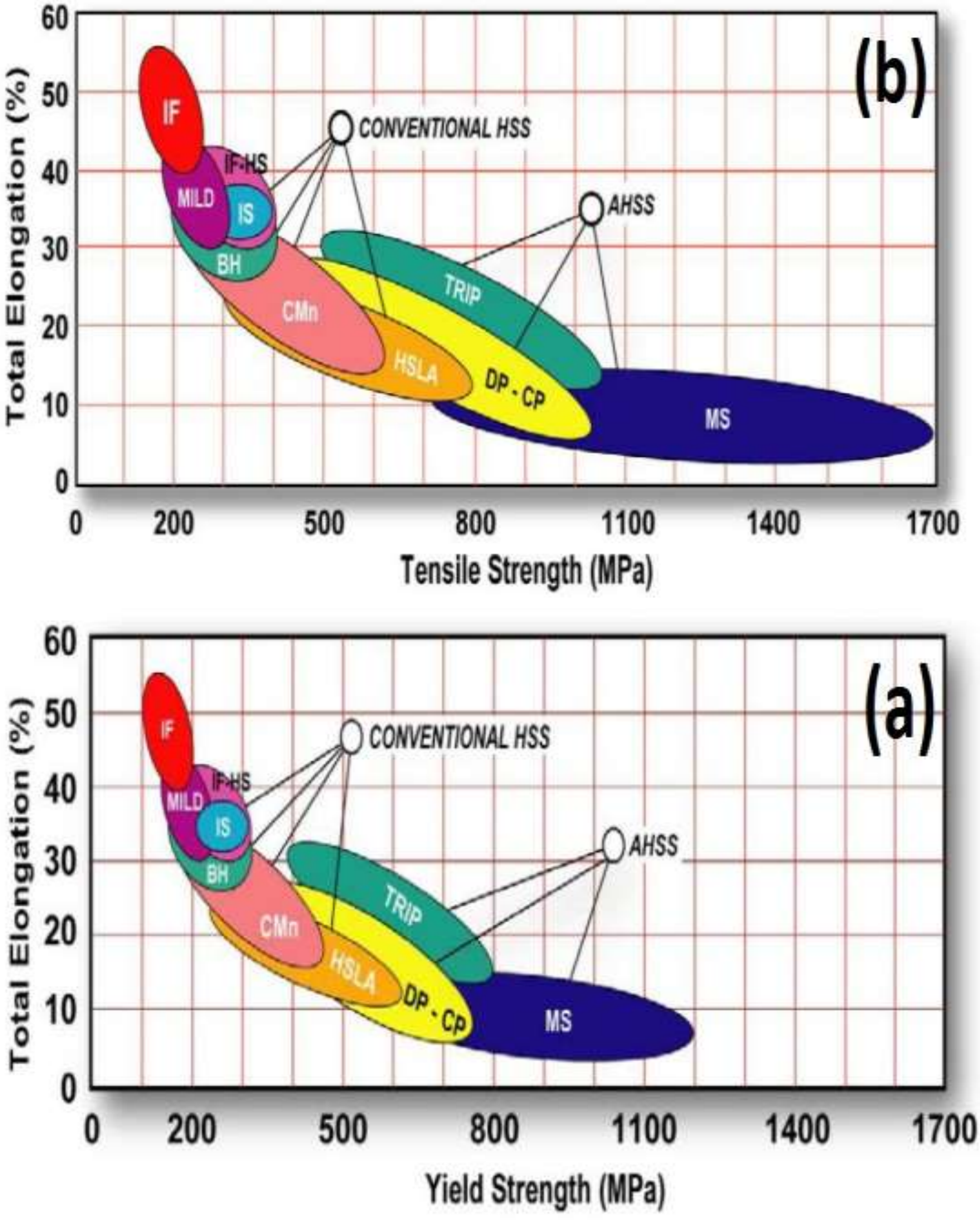


Figure 1.2. The relationship among the total elongation of steels and (a) yield strength and (b) definitive tensile strength. HSS: high strength steel; AHSS; IF; BH; HSL; TRIP: trans [6].

Due to the quality, formability, and fetched, DP steels is considered one kind of progressed high quality steel (AHSS) and can fulfill the requirements of car industry.

The steel is enabled to have both high quality and great formability due to its extraordinary microstructural features and difficult martensite implanted in a delicate ferrite framework [7].

The main obvious of DP steel was submitted in the United States in 1968. However, the applications and main points for this review were completely detected by Hayami and Furukawa where they methodically and completely portrayed the microstructural highlights, formability, mechanical properties and chemical composition. Since then, DP steels are progressively used due to its combination between formability and quality [8].

1.1. BACKGROUND INFORMATION

The term HSS is a variable concept. Currently, the surrender quality of HSSs is higher than 550MPa. Steels classifications concurring to their surrender quality gives a particular comparison between different types of steels [9]. The abdicate quality of HSSs is less than 550 MPa. This gather of steel combines BH (Hard enable) steels, CM (Carbon Magnetized) steels, IS (Isotropic steels), IF-HS (high Quality Interstitial Free) steels, and HSLA (high strength low alloy) steels (World Auto). The last few years witnessed the expanding in use progressed high quality steels (AHSS) of steel white automotive body applications. In future, it is expected that DP steels may cover 70-80% of AHSS applications in cars as shown in Figure 1.3.

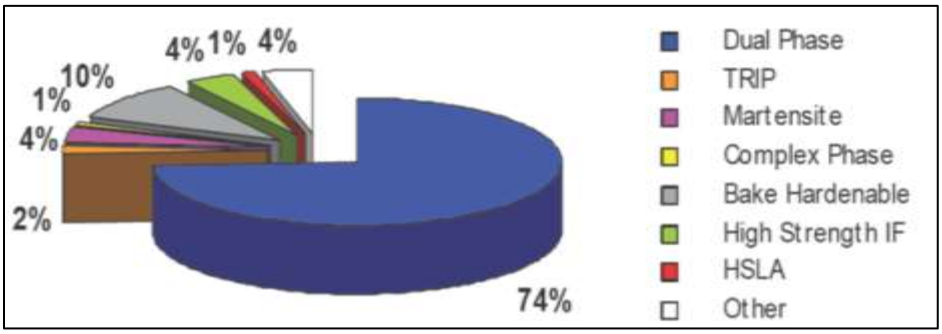


Figure 1.3. ULSAB-AVC with important claims of enhancement performance with AHSS [10].

DP steel microstructure consists of an extremely difficult martensite particles scattered in a pliable and delicate framework [11]. It must be mentioned that a well-balanced volume ratio between the volume divisions of martensite and ferrite is the primary dynamic and significant figure influencing the mechanical features of DP steels. The other familiar elements effecting the mechanical execution to include the morphology of martensite islands, the carbon substance in martensite, and ferritin misshaping status, etc. DP600 double-phase steels are considered of the steel grades that particularly used in car industry within the concept of progressed quality steel.

Chan et al [12] approving to the work of DP600 steels have increased strength and high uniform elongation. The increased strength and extended uniform and total elongation of these steels are high profitable in terms of quality and strength amid the collision of vehicles [13]. DP steels have great properties in terms of ductility and quality. These vital features are owed to the ferrite phase incorporating the tough and difficult martensite particles and martensite molecules. Stages of DP incorporate well properties including difficult phase islands (martensite) inserted in matrix phase (ferrite), very high work hardening coefficient, heater solidifying [14].

In past, it has clarified that decreasing the weight of normal car from 1750 kg to 1500 kg can increase the fuel consumption up to 2 km/l. DP steels with their difficult phase islands (martensite) that inserted in a matrix phase (ferrite) consist one of the kind properties such as feasible yield-to-tensile stress proportion. Nevertheless, the retained austenite in TRIP steels increasingly changes to martensite with increasing the strain, thus increasing the ratio of work hardening at higher strain levels as illustrated in

Figure 1.4. The behavior of stress-strain for HSLA, DP and TRIP steels are almost similar yield strength. The DP steels show greater initial work hardening, greater ultimate tensile strength and lower YS/TS rate than the similar yield strength of HSLA.

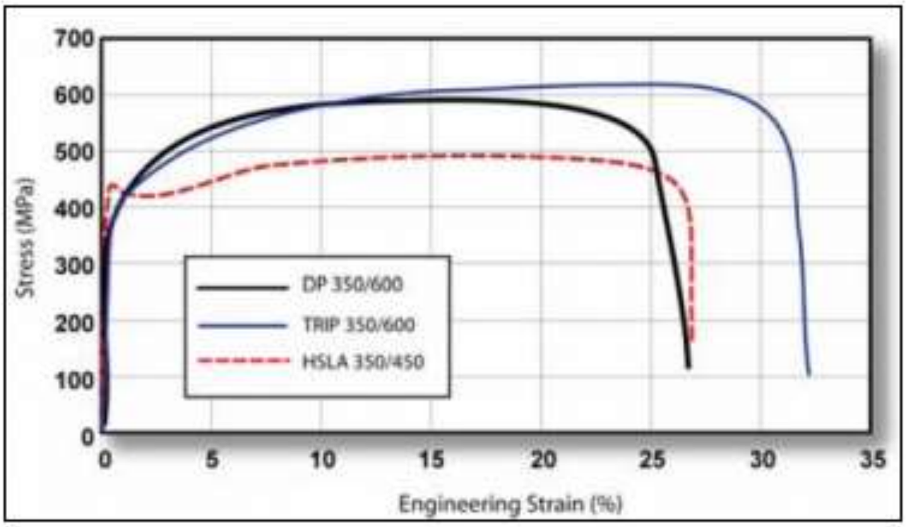


Figure 1.4. Comparison of different AHSS [15].

In addition, DP and other AHSS have a bake hardening impact that is a significant advantage as compared with traditional steels. The bake hardening effect is the increase in the strength of yield resulting from the high temperature aging (generated by the curing temperature of paint bake ovens) after restraining (created by the work hardening because of the deformation through the stamping or other manufacturing process). The thermal histories of the steels and particular chemistry determine the extent of the bake hardening impact in AHSS [16, 17].

The work hardening ratios of TRIP steels are significantly higher than for traditional HSS, offering important stretch forming and unique cup drawing benefits. This is significantly beneficial when designers benefit of the hard work hardening ratio (and increased bake hardening impact) to design a part using the designed mechanical properties. The association between parts of cars are both welded and detachable. Boring practical gaps for the detachable-screw association is provided by punching with the punch [18].

Punching process are considered of the most used punching forms for level sheet items. For the most part talking, shaping forms are forms that cause a significant shape changes in metal parts that are huge rather than the metal sheet. The work of the shaping forms is inside the frame of applying efficient constrain of the metal to need the specified shape [19].

The blanking process steps using punch-die tool start from the movement of translation, blanking punch into the die blanking tool that splits the metal as shown in Figure 1.5. The punch touches the sheet metal and start causing elastic deformation. Then, the plastic deformation phase is taken and leaving the metal sheets with permanent camber. The top edge of the metal sheet is then bended and pulled down followed by shearing that leaves the smooth and visible area on the cut surface (shear zone). Cracks are formed if the shear strength is passed. In general, these run from the edges of the blanking die tool and go over the metal sheet.

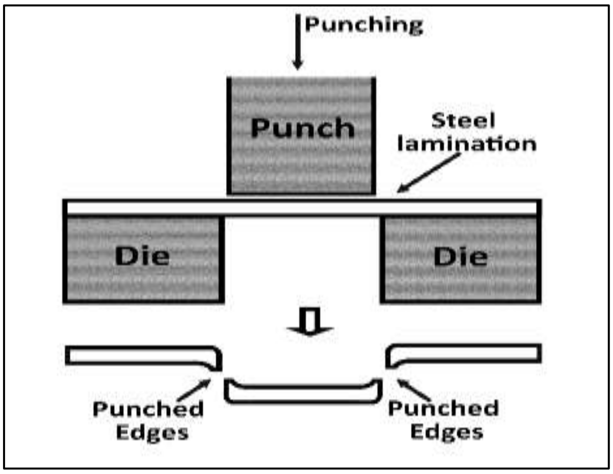


Figure 1.5. Diagram illustration of designing the sheet metal by punching, signifying the formation of burr near the punched edges [20].

The stapler apply the material to accumulate whereas the force of driving for the sinking press head continues. The material in the demanded shape is pushed to the mold space. At this phase, the event of real cutting happens. The material breakage because of the continuity of punching pressure in the mouths of the die and punch cutter. Breaks extend to each other if the cutting conditions and normal. When this occurs, the break is completed, and the material is cut as required from the strip of material. It is not possible to cut the parts (molded) exactly between the punch and female [21].

The piece aimed to be cut from the strip material between the punch and the female die presents great cutting resistance between the two cutting edges. Simultaneously, the staple somewhat sinks to the material and cuts until the material exceeds to the flow limit [22]. The part is broken when the material exceeds the flow limit. It is seen that the tensile stress happens on the lower surface of the molded part with the higher surface of the strip material, and the compression stress happens on the punching surface of molded part. When a circular hole is implemented to the metal sheet, the external size of piece removed from the sheet will be bigger than the size of hole because of the sheared edges geometry as shown in Figure 1.6.

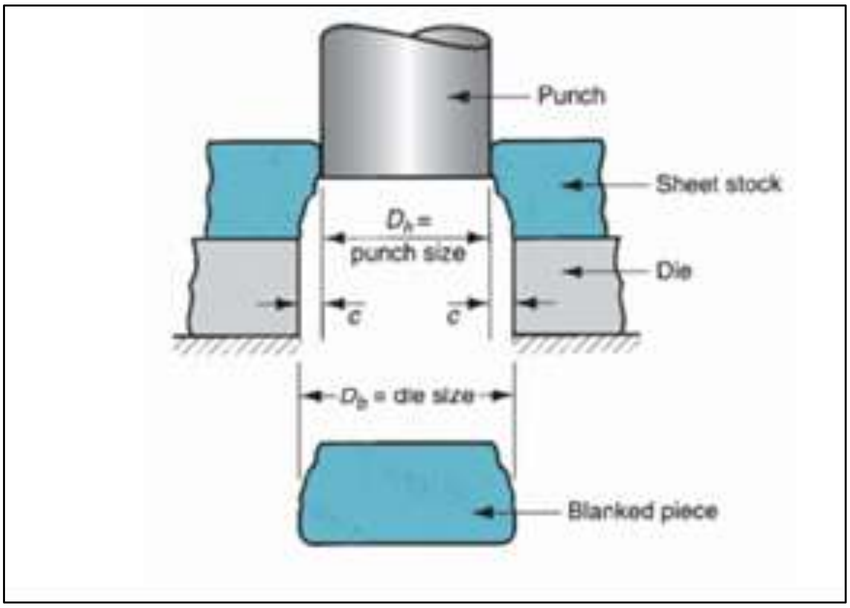


Figure 1.6. View of the workpiece after cutting.

Therefore, the die dimensions and punch of around plate workpiece with diameter of DP can be represented in the following equation [23]:

$$\text{Punch diameter of the sheet workpiece} = \text{Db} - 2\text{c} \tag{1.1}$$

$$\text{Die diameter of the sheet workpiece} = \text{Db} \tag{1.2}$$

As shown above, the application of punching operations and its modeling afterwards are conducted by modeling of cost and broad work in addition to the experimental work as in other shaping processes. The literature showed that the use of different types of staples and punching of DP steels with staples have not been studied efficiently. Also, cost savings are sought after informing operations which motivated the industrial researchers to search about alternatives to conventional drawings and stamping.

It is used recent years due to its potential to increase the sheet materials formability already used. Electrohydraulic forming provides the advantages to require less equipment to operate, fewer forming phases, and increased formability of typical materials that are already used in the industry. Currently, these advantages are attractive in automotive research.

1.2. THE OBJECTIVE OF STUDY

Steels are considered of the most scientist's materials that help development in many engineering fields including energy, infrastructure, and transportation. AHSS are among the developments resulted from the breakthroughs in these fields. The pronounced demand and interest in AHSS by scientific and researchers are due to its importance in fuel efficiency and crash resistance materials. The earliest known types of AHSS are the DP steels. There are not any research and publications which fully understand the material behavior of DP steels until now. Many scientific questions raised from the complex structure of DP steels. In this chapter, we will focus on the influence of punch of DP steels and the influence of distinctive strength. Punching operations applications and their modeling of limited elements as the case of other shaping forms may provide extremely genuine focal points to take a toll and comprehensive work in addition to test work. It is clarified that punching of DP steels with typical sorts of materials are not reachable and mimics will be applied for the first time. Therefore, the aim of this study is examining the punching handle of DP600 sheet steel used inside the car industry by using both tests and limited components strategies [25].

Punching operations will be implemented with distinctive sorts of punch and the influence of changing the stable on punching operations will be reviewed in next chapter in addition to the experimental and theoretical studies of punching of DP600 steel sheet metal. It begins by interviewing DP steels their features, problems, and manufacturing approaches. The following parts illustrate the process of forming metals. Section four provides a simulation about the forming operations by FEM, the punching process in car industry and the punching process of sheet metals. Finally, the experimental section deals with results to simulate the FEM process of DP600 steel and some mechanical tests performed on metal which will be utilized in the experimental part of this study.

PART 2

ADVANCED HIGH STRENGTH STEEL (AHSS)

Car manufactures around the world search for unused materials and constructing capabilities to fulfill necessities which as often as possible conflict. Consequently, helped applications need materials which characterize by high strength and quality, commonly fulfill manufactured needs that obviously thickness. Nevertheless, when the component thickness is diminished, the fuel economy and spread are distinctly affected. Plans of unused vehicles with difficult geometries are sophisticatedly satisfying but upsetting to generate a compromised interface motivate by thickness diminish to recognize mass diminishment targets. The steel industry in this world will continue to develop and forming cutting edge grades of steels which characterize by ever-expanding quality and formability competences, ceaselessly reconsidering this arranged texture to address these restraining needs [26].

AHSS are planning materials that collect between inconceivable formability, higher quality (execution) and inconceivable imperativeness absorption (crashworthiness). In all over the world, offering the basic needs and increased concerns about common pollution and global warming, the coherent society and associated considerations are increasing. Changing the quality, properties, and capacity of materials which most of them are metals, decreases cross range of texture, decreases the weight of parcel resulting to decrease the use of fuel. This made believable to decrease the spread of gas. Advanced high-quality steel is considered the culminating course of action for the typical prerequisites of present cars [27].

During the eighties of the last century, car industry faced many challenges to enhance security, decrease the weight and use of fuel. The levels of AHSS essentially contribute to security; deplete gas contamination, natural arrangement, fuel viability, strength, reasonability, great formability, and quality requisites at generally was taken a toll [28].

AHSS is reliable with steelmakers and can be used to provide extraordinarily high quality and other beneficial mechanical properties and capacity protection. AHSS combines between quality and ductility by arrangement support, phase transformation, and satisfy a strength-to-weight ratio for light applications within the automotive industry [29, 30]. The steels are classified by the content and use of carbon [31]. Carbon steels (0 – 0, 30 wt. % C) are the primary important due to the keenness of structure for the car vehicle as they structure the Body in White (BIW). The highlights of plain carbon steels depend on substance of carbon and their microstructure. The most beneficial influence of these alloying elements is increasing quality and sturdiness in growth to the fabric hardenability. The firmness does not affect [32].

Due to the quality of homogenous microstructure and low carbon substance of the plain carbon steels in most of their parts, they provide great weldability and formability, and both display distinct centrality inside the automotive industry. Overall, increasing strength is necessary inside the car industry for implementation. It is possible to increase the cold working quality. However, the chemical composition of the steel makes it constrained in most cases. The wide level of alloy industry will increase the loss and effects positively on weld ability. HSLA steels have been created to enhance the quality and durability of steels with high weld ability [33].

Generally, low alloy steels include both manganese and silicon and may show high quality and great formability, on the likelihood that they are, to start with, warm protected to form a ferrite network with martensite islands [34].

AHSS collects between both quality and ductility by changing the phase fortifying arrangement and finish a strength-to-weight ratio in light application inside the automotive industry.

2.1. CLASSIFICATION OF AHSS

AHSS characterizes by too much quality and ductility if compared with routing high quality strength (HSS). The relationship with strength ductility is one of the most critical and profitable highlights of high-quality steel. There are limited types of progressed high-quality steels (AHSS) that can be classified agreeing to the handling and mechanical highlights of the material. Currently, the most frequently used types include FB, MS, TRIP, and martensite (MART) twinning-induced plasticity (TWIP) [35].

Among the features related to the equipped 590R, there are improved permeability together with high strength fulfill a wide range of applications in automotive industry. This new type of steel was developed depending on a stable wieldable alloy with low level of carbon and alloying components [36].

High-definition way and sorts of AHSSs are families of steels that are more grounded and characterize by higher ductility and formability than customary high-quality steels (HSSs) [37].

It is possible to distinguish between the AHSS family and the quality levels that can be commonly characterized by item abdicate quality larger than 300 MPa and extreme malleable larger than 600 MPa. Economy of fuel is one of the key calculations and therefore, a weight reduces in the automotive industry [38].

Light cars have been manufactured with high-advanced quality using high-level steels including multiphase steels. Other categories of AHSS have been created and all of which consist a microstructure comprising two or more diverse phases, of which (at slightest) one comprises hardness and quality to the materials while the others offer more formability as shown in Table 2.1.

Table 2.1. Advanced high strength steels [39].

AHSS	Microstructure Composition
DP	Ferrite, martensite
TRIP	Ferrite, bainite, retained austenite
CP	Martensite, pearlite, retained austenite
FB	Ferrite, bainite
MS	Martensite, bainite, ferrite
Q&P	Martensite, ferrite, retained austenite

Since TWIP and HF steels have been seemed to consist advanced quality and penetrability, they collected beneath heading AHSS [33]. Overall, they do not include complex microstructural composition that sets AHSS separated from HSLA steels. Generally, while the chemical composition of TWIP steels consists a high substance of manganese (17 - 24 %), it does not classify them as carbon-steels. Progressed high Quality Steels are not classified in accordance with the microstructural composition highlight but in accordance with the application, they can be classified according to the mechanical properties, thickness of the material and the chemical composition. In Europe, the key standards of AHSS are called the Euro norm [34].

2.2. DP STEELS

The term DP steels denotes to a type of high strength steels that consists of two phases; usually a ferrite matrix and a second stage dispersed of martensite, austenite retained and / or a pantie. DP steels were developed during the 1970s. The motivation behind the development of this material is the need to create high strength steels without increasing cost or decreasing the formability. Particularly, car industry needed steel grades characterize by high tensile elongation to guarantee the formability, high tensile strength to create crush and fatigue resistance, low alloy content to guarantee weld ability without manipulating the cost of production. Later, the need to DP steel is increased gradually due to its combination between high strength and good formability and therefore decrease vehicles weight and other products show economic and environmental benefits it consists of a martensite and ferrite. It consists (10 - 25 %) hard martensite phase in a pure ferrite lattice and, in a several cases, little increases of hold austenite, bainite and/or pearlite [40].

Currently, it includes up to 80%. It consists of a great formability and ductility at high quality steel. Advantages such as weight diminishment (use of gas) are achieved during the service when using DP steel. Due to the absolute mechanical properties of DP steel, it ended up an appealing fabric in the applications inside the development of body in automobiles. Many parts of cars including rails, columns, boards and bumpers made with the traditional steel high quality low alloyed steel (HSLA) have been changed gradually by DP steel [41,42].

As we mentioned earlier, the main use of DP grades is in car industry. The use of DP grades is wide and different where they are used in different and wide components of the car such as wheel discs, brake components, bumper and door reinforcements, A, B, and C pillars, windshield frames, steering couplings, rims, door, and hood outer and inner panels as shown in Table 2.2. Moreover, DP steels gained great significance in farm equipment industry, heavy construction units and machine building.

Table 2.2. Range of automotive elements construct from DP steels (from different Manufacturers) [43].

Producer	**Component**
General Motors	Wheel discs and rims, bumper reinforcements, face bars, jack posts, water pump pulleys, Steering coupling reinforcements
Hoesch-Estel	Wheel discs
Inland Steel	Plate brake backing (grinding), Panel for doors, deck (boot) lids, centre pillars, windshield frames, wheelhouses
Jones and Laughlin	Bumper face bars, bumper reinforcements, rear suspension, wheels, alternator fan blades, steering column reinforcements
Kawasaki	Stylized wheel discs, door and hood panels and fenders
Nippon Steel	Bumper stay/facing door impact bars, frame sections
NKK	Outer and inner panels, door, beam and bumper reinforcements
Sumitomo Metal Industries Ltd	Outer body panels
Toksid-Accial	Stylised wheel discs
US Steel	Parts in cars, trucks, buses, farm equipment, industrial handling units, heavy construction units

2.2.1. General Characteristics of DP600 Sheet

DP600 dual-phase steel enjoys by great weld ability and formability and it is suitable for car security elements such as situate racks. This steel is subject to special heat treatment, generating mainly structure with two phases. Ferrite, which conveys unique forming properties, signifies one phase while martensite that represent the strength is the other phase. As other grades of HSS, the great percentage of DP600 production is used to manufacturing the components of cars. The major producers of steel such as SSAB, Mittal, Arcelor and Tata Steel, DP600 can be found in (Figure 2.1):

- Longitudinal and cross sections
- Safety precarious and crash structure elements
- Fasteners
- Beams of doors
- Suspension components
- Chassis elements of vehicles
- Wheel discs
- Seat tracks
- Bumper reinforcements
- A and B pillar reinforcements

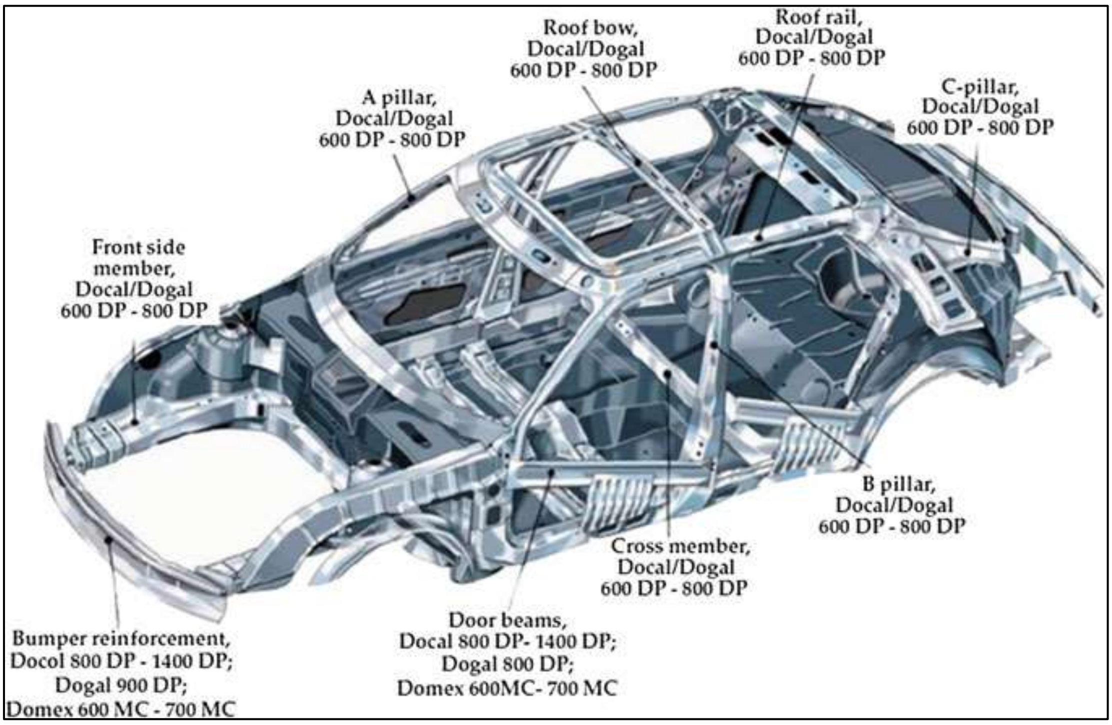


Figure 2.1. Application of DP type Docol steels in a modern passenger car's body in white unit [44].

In addition, DP600 steel is used in other applications than automotive industry such as:

- Precision tubes
- LPG cylinders
- Seats of Trains
- Yellow goods (construction materials and earth movement equipment, forklift vehicles and mining equipment).

2.3. THEORY OF DP STEEL PRODUCTION

The structure of most DP steels before the heat treatment or rolling comprises of grain boundary iron carbides, pearlite, and ferrite [45]. The cooling process is still the same despite the production process whether cold or hot rolling, continuous or batch annealing.

DP steels are heated inside the intercortical temperature range that is in the field α+γ of the Fe-C phase scheme is illustrated in Figure 2.2. Consequently, through quick cooling, austenite transformation to martensite when the temperature accesses the Ms temperature. As shown in Figure 2.3, the black curve signifies the distinctive cooling path of C-Mn DP steels.

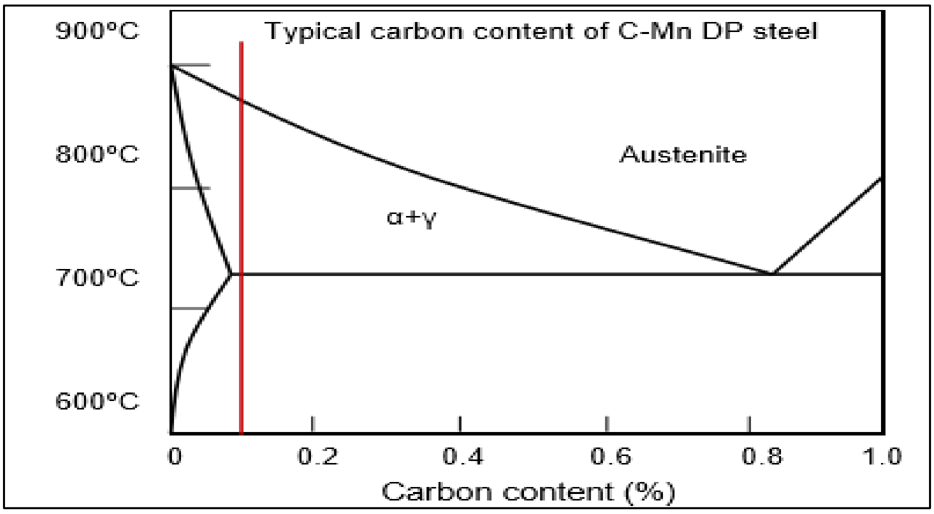


Figure 2.2. A portion of the Iron-Carbon stage scheme [46].

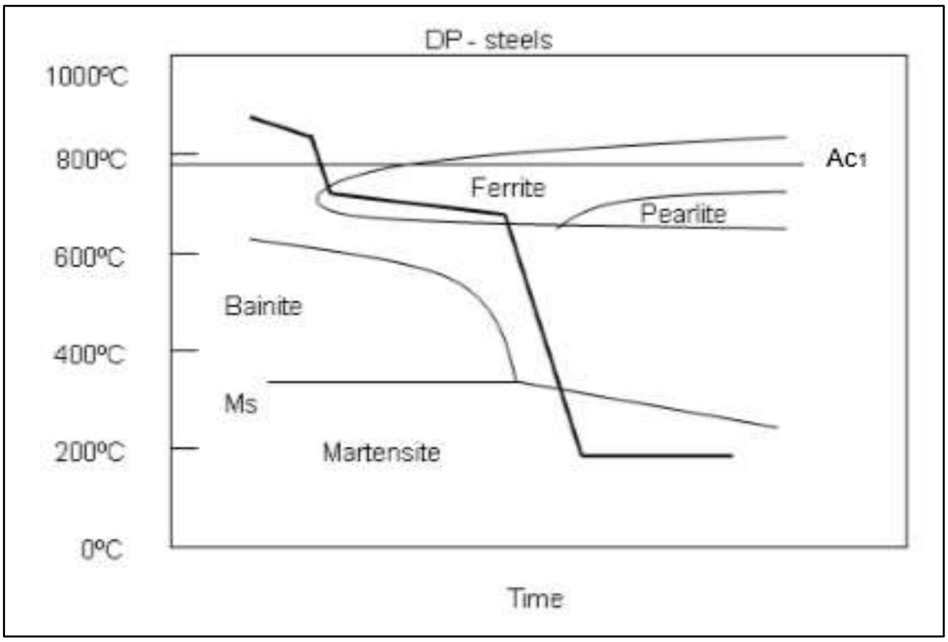


Figure 2.3. CTT diagram of DP steel [47].

It must be mentioned that Ac1 represents the austenite transformation start temperature on heating and Ms represents the martensitic transformation start temperature.

The whole theories associate with the production of DP steels pass by three common phases as follows:

- Heating over the lower intercortical temperature and holding for a short period**.** This defines the volume fraction of austenite.
- Cooling lower the martensite starts temperature (Ms) that promotes the transformation of the austenite to martensite. The cooling ratio should be adequately quick to increase the concentration of carbon in the austenite and thus increase its strength.
- After cooling from the intercortical annealing temperature, some processes also consist, an averaging phase lower the martensite start temperature to enhance the ductility and durability of the steel at the overhead of tensile strength.

During the production process, many parameters control the volume fraction and composition of the austenite and ferrite such as cooling ratio, annealing temperature and soaking time [47].

For C-Mn DP steels, the existence of Si in the ferrite stimulates migration of carbon from the ferrite to the austenite whereas Mn diffuses differently to the austenite and increases its strength [48, 49]. To determine temperature of transformation as a function of the chemical composition of DP steels, many empirical equations have been developed as follows [50]:

$$Ac1 = 723 - 10.7Mn - 16.9Ni + 29.1Si + 16.9Cr$$
$$Ms = 539 - 423C - 30.4Mn - 17.7Ni - 12.1Cr - 7.5Mo$$

The microstructure of DP steel usually includes two stages, body centered cubic (bcc) ferrite and body center Tetragonal martensite as shown in Figure 2.4 (a) whereas (b) the ferrite in HAZ and Micro-component Martensite are thinner than either of FZ and BM because of the incomplete austenitization in HAZ and form the grain of austenite. Therefore, the lath Martensite is supposed to form, incudes very thin lath or retained austenite between laths and there may be some lower bainite as shown in Figure 2.4 (c). The microstructure of DP steels differs expressively with the absolute strength. Moreover, the substructure of martensite transformation within DP steels that plays a significant role in the mechanical behavior may differ from a lath martensite substructure distinctive with low-carbon martensite as shown in Figure 2.5.A, to within twinned substructures distinctive to the high carbon martensite as shown in Figure 2.5.B.

This change in shape reflects the effect of annealing temperature between critical and chemical composition on the carbon content in the austenite phase, which in turn affects the temperature of MS [51].

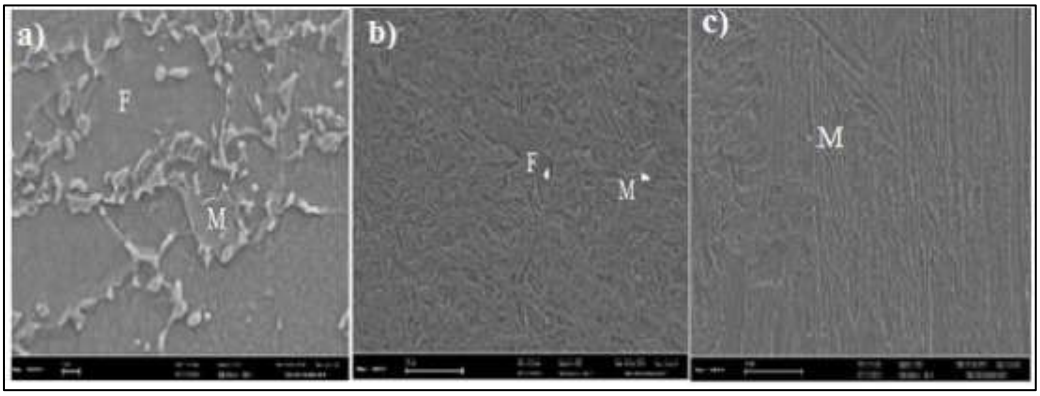


Figure 2.4. The microstructure of DP600 a) BM, b) HAZ and c) FZ [52].

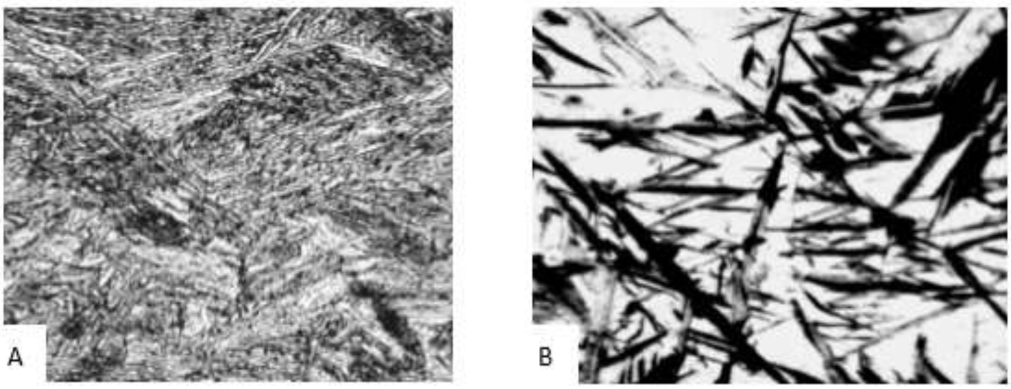


Figure 2.5. a) Lath martensite, b) Twinned martensite [53].

2.4. CLASSIFICATION OF DP STEELS

There are many types of DP steels according to the ultimate tensile strength such as DP 1000, DP 600 and so on. The tensile strength of DP steels is greater than 1000 MPa for DP 1000 and 600 MPa for DP 600 compared with conventional high strength steels in the range between 400 and 440 MPa. Nevertheless, the production strength of them is considered very well and they are good selection in the production of lightweight vehicles [54, 55]. Therefore, more thin DP sheets can be used which decrease the weight of cars without losing their strength. As well as they characterize by higher or similar absorption of energy accident.

Manufacturers agree that design parts of car using AHSS steels provide the chance to decrease the cost of industry and decoration of vehicles.

Presently, DP and TRIP steels are well created as the case with AHSS. Generally, it is reported that the percentage of weight decrease is about 30-40% for 1300-1500 MPa steels. These advantages are existed in DP 600 steel and currently preferred. In addition, it is important that the thermal properties of automobiles and other products such as formation and welding be obtained. When the temperature is decreased, the mechanical properties of DP cold-forming steels rapidly change which cause the loss of load bearing capacity of DP-shaped cold steels [56].

Consequently, designing DP-shaped steel structures need well knowledge and considerate to the thermal properties of the mechanical characteristics with increased temperatures. Therefore, it is important to understand the thermal properties related to the yield strength and DP 600 elastic module with high temperatures. So, experimental study has been conducted to study the mechanical properties of DP 600. Tensile tests have been conducted by the using a fixed state test approach of temperatures in the range 20C°. Many types of DP steels are shown in Table 2.3. Also, the mechanical properties of DP 600 Steel at different temperature are shown in Table 2.4.

Table 2.3. Reviews the product property requirements of numerous categories of DP steels in accordance with ArcelorMittal criterea 20×80 mm ISO tensile specimens (thickness: less than 3mm) [57].

Steed grade	Yield Strength (YS) [MPa]	Ultimate Strength (UTS) [MPa]	Total Elongation [%]	Direction
DP 450	280-340	450-530	% 27	Transversal.
DP 500	300-380	500-600	% 25	Longitudinal.
DP 6000	330-410	600-700	% 21	Longitudinal.
DP780 Y450	450-550	780-900	% 15	Longitudinal.
DP780 Y500	500-600	780-900	% 13	Longitudinal.
DP980 Y700	700-850	980-1100	% 8	Longitudinal.
DP 1180	900-1100	1180	% 5	Longitudinal.

Table 2.4. Mechanical properties of DP 600 Steel at different temperature [57].

Temp.	**E. Modulus**	**Yield strength**	**Ultimate strength**	**Total Strain**
	E	RP 0.2	Rm	A
°C	MPa	MPa	MPa	%
20	201.40	431	671	22.9
200	200.94	413	630	18.3
400	198.80	378	619	22.9
600	97.38	168	224	28.8
700	54.38	84	110	41.1
800	26.63	38	46	80.8

2.5. MECHANICAL PROPERTIES

DP steels are characterized by high work hardening ratio, superior formability and good ductility if compared with other HSLA steels. They provide enhanced combination of ductility and strength. They characterize by high strain hardening capacity. This gives DP good steels capacity to redistribute strain, and therefore ductility. The mechanical properties of the finished part are overcome the mechanical properties of the initial blank due to the strain hardening.

These types of steels are suitable to be used in reinforcement and structural parts because of the high mechanical strength of the finished parts that cause outstanding fatigue strength and good energy absorption capacity. Strong BH impact and strain hardening give these types of steels outstanding properties for decreased skin and structural part weight. The excellent properties for DP steels in car industry are continuous to give high YS to tensile strength rate, decrease cost and outstanding surface finishing due to the removal of the yield point elongation [58, 59].

The tensile strength and of total elongation ferrite–martensite DP steels compared with low alloy steels strengthened by solid solution and participation hardening are shown in Figure 2.6 [60]. As shown in the figure that DP steels with total elongation and tensile strength in the range 10–35% and 250–1000 MPa, respectively are superior on other types of steels in terms of ductility and strength. Entering DP steels in many parts of the car such as wheel discs, pulleys, springs wheels and bumpers have resulted in decreasing the weight of the car up to 30% and increased the life of these components.

DP steels show crashworthiness advantages because they have excellent post-uniform elongation. Consequently, DP steels are used in the crash-sensitive parts in the rear and front rails of the cars [61].

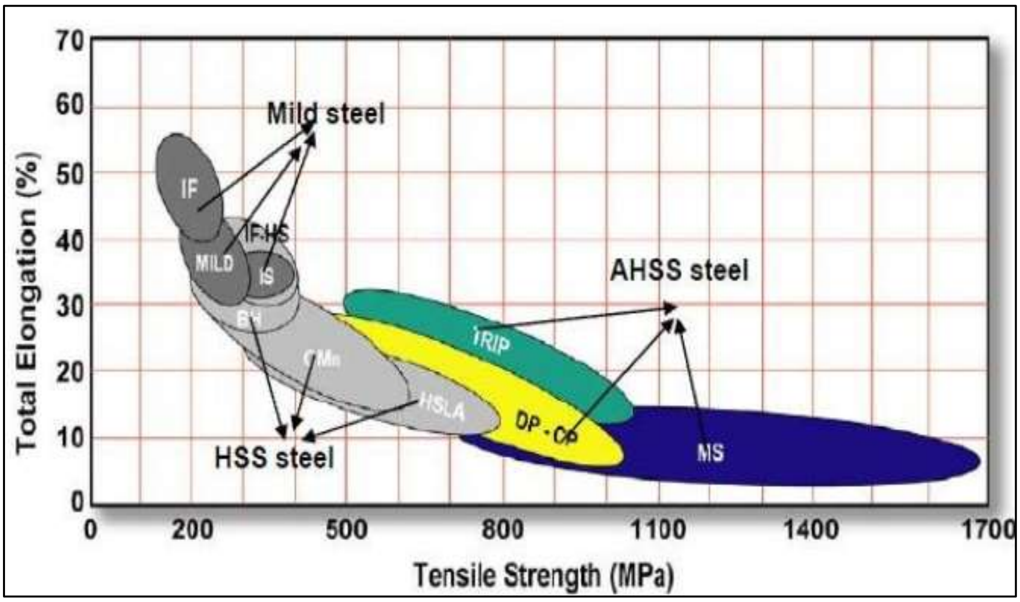


Figure 2.6. Strength-formability relationships for mild, conventional HSS and three generations of AHSS [62].

The total impact of tempering any dual-phase steel is to result in a lower strength combination of ductility. It is suggested that the DP steel ductility is necessarily determined by the primary structure and ferrite percentage in the structure is the main element controlling the DP steels ductility; the larger the amount of ferrite the larger is the ductility [63].

The strength of the martensite determines the strength of the DP steels. Therefore, softening the martensite by tempering decreases the DP steel strength, but not essentially increase its ductility. Overall, the special microstructure of DP steels provides an outstanding candidate to the structural component of the car body. In general, DP steels are always used in car body in spaces maintain surviving of passengers in crash events. Moreover, these types of steels are used for decreasing the weight of cars.

2.6. MICROSTRUCTURE AND ITS IMPORTANCE OF DP STEEL

The microstructure of DP steel includes two main components composed of martensite-austenite (M–A) elements or soft ferrite matrix and 10–40% of hard martensite. Figure 2.7 shows the 3D RVE models used for DP steels with their microstructural components. The highest tensile strength can be achieved by using this type of microstructure where the tensile strength at this type of steel is in the range of 500–1200 MPA. DP steels are usually called partial martensitic when the fraction of volume for martensite surpasses 20%. The ferrite-bainite steels have been generated in order to modify the mechanical properties. It is revealed that bainite instead of martensite improves the formability with little decrease in the strength and advancement [41]. Many researches have been implemented on the influence of the martensite fraction, size of the area, spreading, the influence of the ferrite fraction and the size of grain on the mechanical performance of the DP steels [64, 65].

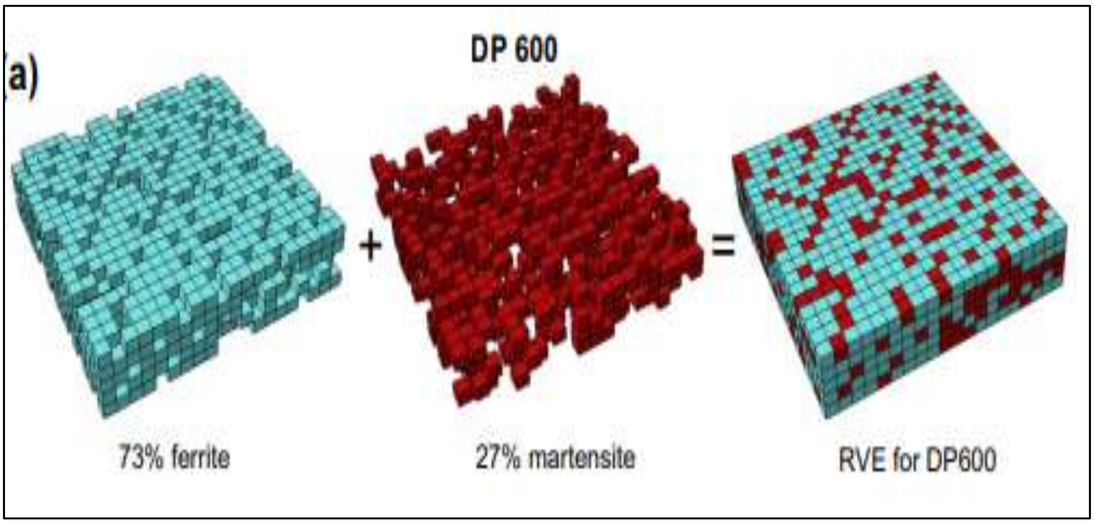


Figure 2.7. 3D RVE models used for DP steels with their structural components DP600 [66].

The structure of DP steels provides many benefits over the traditional types of high strength steels and these benefits can be summarized as follows:

- The DP steel microstructure strength can be regulated by the ductility and amount of martensite by the spread and size of this stage.
- DP steels do not show yield point elongation.
- DP steels possess low UTS/YS rate (around 0.5) and high strain hardening features (high n value), particularly in the beginning of plastic deformation.
- DP steels can be strengthened through the dynamic or static strain ageing (BH effect).

- It is proven that grades include low number of carbons shows great resistance to fatigue crack spread at growth ratios near to the fatigue threshold intensity range ΔK_{th}.

The impact of carbon and alloying elements are very significant to the development of DP steels as summarized in Table 2.5.

Table 2.5. Effect of alloying elements in DP steels.

Alloying Element	Effect and Reason of Adding
C (0.06-0.15%)	Austenite stabilizer Strenghthens martensite Determines the phase distribution
Mn (1,5-2.5%)	Austenite stabilizer Solid solution strengtheners of ferrite Retards ferrite formation
Si	Promotes ferrite transformation
Cr, Mo (up to 0.4%)	Austenite stabilizers Retards pearlite and binate formation
V (up to .06)	Austenite stabilizer Precipitation strengtheners Refines microstructure
Nb (up to 0.4%)	Austenite stabilizer Reduces Ms temperature Refines microstructure and promotes ferrite transformation from non-recrystallized austenite

The percentage 1.5-3% Mn leads to strength the ferrite and stabilizes the austenite stages. It is though that pearlite or bainite formation is delayed by the molybdenum and chrome. The Si stimulates ferrite transformation. The microstructure is refined, and precipitation is strengthened by the V and Nb elements. Furthermore, the distribution of martensite influences the mechanical behavior of DP steels [67,68]. The most used DP steels include 20-30% bainite or martensite spread in topological continuous soft stage as shown in Figure 2.8.

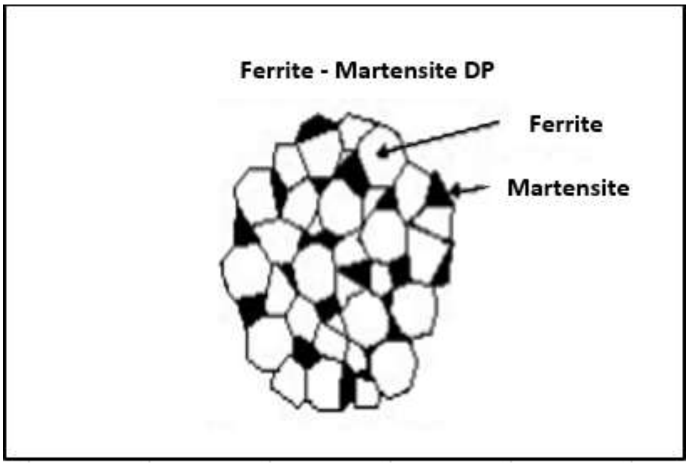


Figure 2.8. Diagram representation of the microstructure of DP steels [69].

The martensite regions appear as isolated areas within the result of ferrite matrix in a better combination of strength and that of the ductility than that of the martensite regions that form a chainlike network structure adjacent to the ferrite. The regions of refinement of martensite and ferrite simultaneously enhances the strength and ductility. Phase transformations, mechanical properties and final microstructure of DP steels are usually controlled by its principle alloying factor and carbon. As well as it helps in the stability of austenite that leads in the formation of martensite upon cooling [70].

PART 3

THE INVESTIGATIONS SHEARING AND FORMING OF HIGH-STRENGTH DUAL PHASE STEEL

In general, it is always seen that car industry as the main manufacturing process behind sheet metal forming and shearing. Thus, the requirements to develop the automotive industry play a significant role in the development of sheet metal forming and shearing. Car industry faces many paradoxical requirements such as less harmful emission and less consumption with better performance and more comfort and safety. It is complex to achieve all these requirements concurrently with conventional materials and manufacturing process. Fulfilling all these paradoxical requirements is always considered the main driving forces in car industry and therefore in the materials development and processes in addition to the formation of sheet metal.

Recently, we can notice the significant development in the application of high-strength steel. One of the best examples in this regard is the application of DP steels [71]. Nevertheless, these types of steels always configure problems in forming and manufacturing process. One of the problems associate with the formability is the spring return that happens after forming the sheet metal.

The deformation such as the straightening and bending over the tool radius pass through the draw bead, etc. Another issue is that behavior of hardening has an important difference forward and reverse loading because of the familiar Bausch Inger impact that inevitably happens through similar forming cases such as the reverse loading conditions.

The challenges associate with the formation of AHSS can be summarized as follows:

- As a result of the complex manufacturing process and multi-phase structure:

1) Determination the properties of materials accurately need new testing approaches.
2) Batch-to-batch variation is common.

- As a result of the low formability and high strength:

1) Initial fractures are noticed in numerous forming operations needing examining of fracture.
2) Greater press capacities are necessary for blanking or forming.
3) Tools wear out rapidly. Lubricants, tool materials and coatings need careful choice.
4) Larger spring back (which lead to dimensional imprecision) is a significant issue needing other development.

The mechanical properties of the sheet material (such as stress-strain curve or flow stress) during the sheet forming process highly effect the product quality and metal flow as shown in Figure 3.1. So, the accuracy to determine the flow stress is very important in process simulation across FEM [72].

In addition to the importance changes in formability with increasing strength, the increased spring back arising through the forming of high-strength steels is considered one of the main technological problems in design and manufacture sheet metal elements with the demanded shape and dimensional precision.

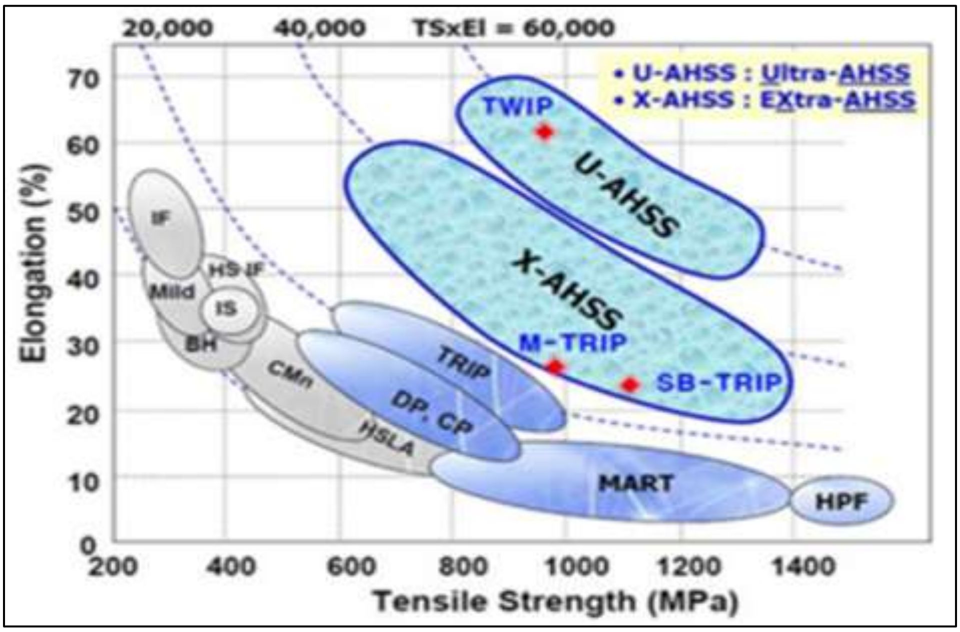


Figure 3.1. Elongation versus tensile strength of the traditional and AHSS [73].

In recent years, the spring back after forming is predicted by the using finite element simulation. The reliable simulation determines the accurate dimension and shape of tools and therefore those related to the deformed parts. The phenomenon of spring back is highly associated with many material and physical properties. Continuum mechanics points that the yield strength and Young's modulus mainly its changes through cyclic loading are the most significant mechanical properties, but several experiments refer also to the microstructure significance.

3.1. METAL SHEARING PROCESSES OF DP STEEL

Operations of sheet metal cutting including trimming, fine blanking, punching and blanking aim to isolate many amounts of the material from the residual sheet by using the controlled fracture and shearing at the cut contour. The ratio of fractured and sheared areas determines the properties of resulting cutting surface [74].

The properties of cutting surface are defined by the material properties and process parameters including clearance, die radii, sheet thickness and punch. It is known that blank edge geometrical and microstructural characteristics of cutting may give very significant impact to the following stamping operations and it is more for sheet materials which characterize by low formability and high strength. For instance, it is well recognized that AHSS is very sensitive to edge cracking and therefore the characteristics of the sheared edge need to be better featured and their impact on stamping formability needs to be studied. Steels industries in many countries in this world developed special case studies and guidelines of applications [75].

DP steels is considered one of the advanced high strength steels which characterized by its unique features comprising fine-grained martensite particles embedded inside a ferrite matrix, produced during the thermo-mechanical processing that result in mutual strength and ductility with low cost. The stamping operations of car body consists of many manufacturing cutting processes including trimming, piercing and blanking.

In production circumstances most of these operations use mechanical shearing to break apart sheets beside a designed cutting line at a high cutting ratio or effectiveness, whereas in a preparation or for forming sample parts laser cutting is frequently used, because of its benefits of high geometrical flexibility, decreased lead time and tooling cost [76].

The literature includes large number of studies on trimming, blanking and piercing. This set of materials is generally identical. It is not uniform microscopically in terms of its DP microstructure (with martensite elements at the scale of a limited microns or less), and by fluctuating the volume fraction of martensite stage, different strengths can be gotten with better formability than that in normal high strength steels of related strength. Nevertheless, few studies and researches addressed cutting AHSS especially the edge features and its association with edge cracking of DP steels. The previous literature of current interest consists flanging of AHSS by [77] which refer if micro-cracks proliferate mostly with the stage interfaces in DP steels, the edge-stretch-formability is poor whereas if cracking is through the ferrite and martensite stages, the formability is high. Hardness difference is the prevailing elements influencing the crack path and formability of stretch-flange. Furthermore, the formability is also affected by the volume fraction of phases. In terms of the single-phase martensite steel, a high edge strain incline is in the interest to the high flanging formability. Understanding the mechanism responsible on edge cracking of AHSS needs knowledge of the edge morphological properties and associated fractures mechanisms to give a qualitative explanation of the pre-strain supply at the sheared edge from cutting operations [78].

PART 4

SIMULATION OF FORMING OPERATION BY FEM

In general, automobile industry faces many obstacles worldwide such as high competition, strict governmental regulations about environmental protection. Automakers follow a strategy to fulfill these challenges and this strategy is called 3R strategy:

- Reduce necessary time of marketing.
- Reduce the development cost to gain competitiveness.
- Reduce the weight of vehicle to enhance the consumption of fuel.

The solution to accomplish the previous goals are basically depend on implementing new technologies through design of process and development of product. The most important element of this effort is focused on reducing the tooling costs and leading time associated with automotive body panels, even during the increased technological problems including using aluminum alloys, high-strength steels and requirements of high geometrical precision of the stamped parts [79].

To deal with difficulties caused by these directions which beyond the previous experience, many numerical approaches have been developed and occupied great importance to simulate the sheet forming and replace the physical tryout of stamping by a computer tryout. The use of finite element analysis provides many benefits in the tooling design of sheet metal forming processes because it is more cost-effective than trial and error processes [80].

Recently, using software of simulation in metal forming processes has been widely increased. The rapid development of computer hardware and low-cost along with the quick development of software technology allowed many manufacturing operations to be implemented effectively in terms of cost which was impractical few years ago. Using sheet metal forming simulation, it is possible to decrease both the development costs of new stamp and production lead-time. FEM is employed by many analysis software where the geometry of the element to be deformed is separated to basic regular shapes called “elements”. There is a wide range of components existing of different complexity or degrees of freedom which can model several deformation modes (and fields of temperature or electromagnetic) [81].

The main goal for the industrial application of FEM simulation of stamping process is to substitute the physical experiment with computer experiment to decrease time, cost, and enhance quality in the cycle of die design/industrial. The process of formulation simulation provides high rationalization reserve for instance; it enhances the tool and element and therefore improvement of process reliability. The current used program system should be extended in many directions to fulfill the increasing practical needs. The simulation of metal formation process is used to expect tool forces, distribution of temperature, potential sources of failure and defect, stresses, strain and metal flow. Also, in many cases, it is possible to expect the properties and microstructure of the product in addition to elastic recovery and residual stresses. The simulation allowed the decrease of physical testing and costly problems by allowing the upfront method application [82].

4.1. PUNCHING PROCESS OF SHEET METALS

The most widely used manufacturing sheet metal forming process is punching. It helps on using the elements by the use of reasonably few numbers of passes. Other forming processes including bending, stamping, hydroforming and edge rounding generally follow the punching process. Therefore, the performance of these following operations is associated with the punching operation and the history of strain in the punched areas [83]. So, it is significant to characterize and determine the growth and behavior of damage caused by the punching to take into consideration these phenomena in the overall formability analysis of the industrial cycle. Understand the mechanism of damages involved through the shearing can decrease the damages across good management of complete set of forming process factors. The punching process is implemented by a tool punches the metal sheet, eliminate undesirable material, generates a hole or other demanded geometry feature.

Through the punching process, material fractures inside the clearance (space between die and tool) area, generates sheared edge, which consists four areas (rollover, burnish, fracture and burr areas) in the thickness direction of metal sheet as shown at the circled area in Figure 4.1.

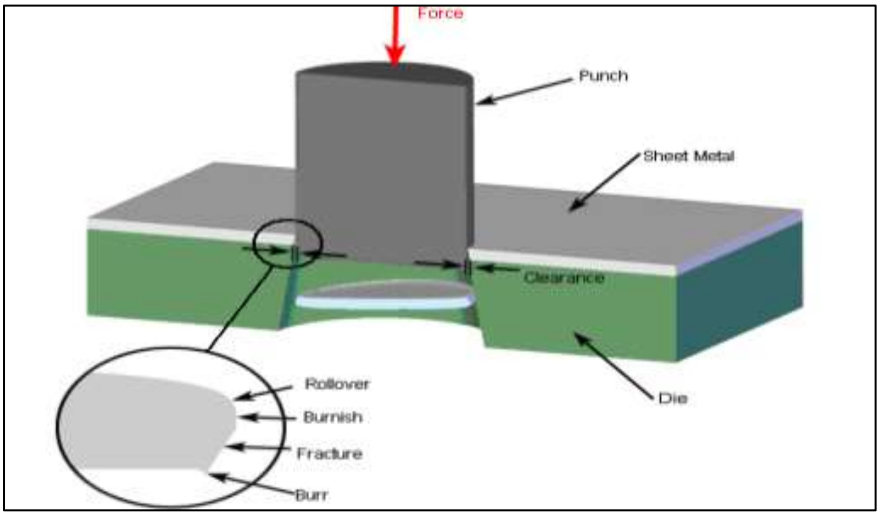


Figure 4.1. Process of hole punching [84].

The punching process needs sheet metal stock, punch, die and punch press. The sheet metal stock is located between the die and punch inside the punch press. The die located under the sheet, has a cutout in the shape of the preferred feature. Beyond the sheet, the punch is hold by the press that is a tool in the shape of the demanded feature. In general, dies and punches of typical shapes are used but custom tolling are made to punch composite shapes. These tools whether custom or standard are usually made from carbide or tool steel. The punch press pushes the punch downward with high speed through the sheet and to the die lower.

The clearance between the punch and edge is small which cause the material to rapidly bend and fracture. The slug that is punched out of the sheet drops easily through the tapered opening in the die. This operation was implemented by a manual punch press but currently, CNC punch presses is typically used. A CNC punch press can offer about 600 punches each minute and can be powered electrically, pneumatically, or hydraulically. Moreover, several CNC punch presses use a turret which can hold up to 100 different punches that rotated to be positioned when needed.

4.2. PUNCHING IN THE AUTOMOTIVE INDUSTRY

Holes are included in many parts of the car. These holes are created by using many methods such as ultrasonic cutting, drilling, water jet cutting, magnetic field cutting, laser cutting, punching and plasma cutting. All the previous ways are used to make holes [85]. Steel blanking became one of the prominent methods in steel industry due to its ability on making greatly specialized parts which decrease cost and waste. The goal behind the use of steel blanking is using what is punched instead of using what is left after going across the die. The punched piece in steel blanking is the part. Steel blanking is an industrial process where a flat, geometric shape (or "blank") is generated by feeding a sheet metal coil to a press and die. In this operation, the blank is punched from large metal sheet as clarified in Figure 4.2.

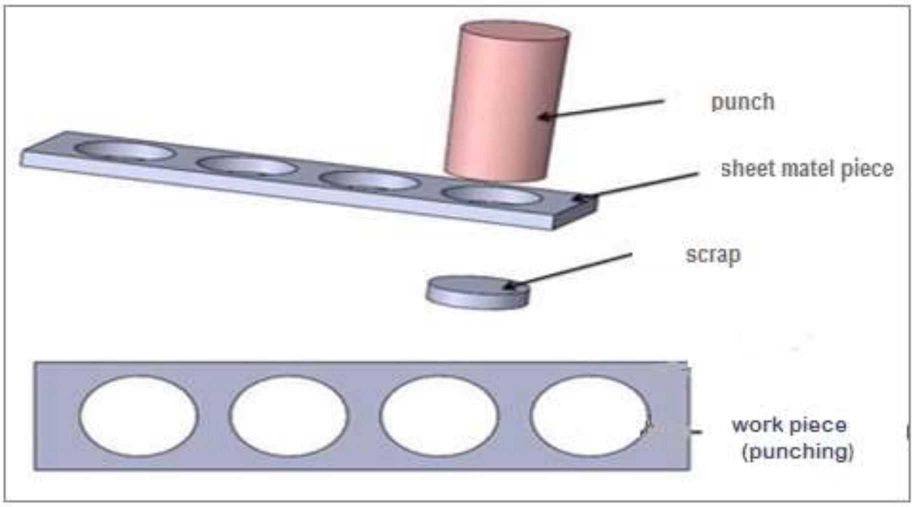


Figure 4.2. Punching sheet metal cutting operation (piercing) [86].

Typically, the press blanking machines could process material up to 250 inches (6.35mm) thick and 72 inches (1828mm) wide from coils up to 80,000 lbs. normally, single operation is used to blank multiple sheets and the blanked elements will need secondary finishing smoothing out burrs beside the bottom edge. Other similar operations include piercing and punching. Both operations work on removing the materials from metal sheet, but the result differs from the steel blanking.

Punching is also a material removal process but rather than the final product being the punched-out material, like in blanking, metal is removed so that the sheet metal itself is the final product. An easy way to differentiate is to think of a piece of paper that you punch a hole through. Blanking uses the circular piece as the final product while punching uses the piece of paper with the hole in it as the final product as given in Figure 4.3.

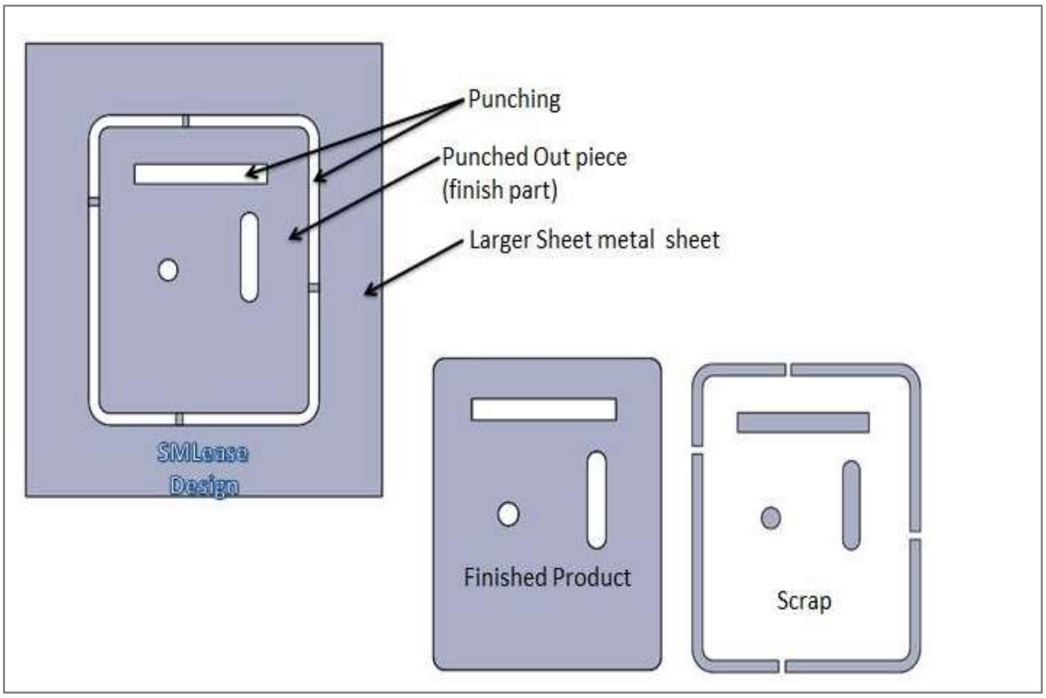


Figure 4.3. Sheet metal cutting using punching operation [87].

Steel blanking generates chip metal parts which are customized to satisfy needs of customers. The material in the blanking process is constantly entered to the machine that leads topless setup and management of parts. This operation helps you to perform more with less effort. This operation is highly decreased the waste because the tools are normally designed to nest parts close to each other as can as possible. Moreover, the cost of shipping is decreased by only sending the net weight and leave the rest behind [88].

The punching process is considered cheaper and more productive than other types of processes. Therefore the punching is used to hole the sheet metal. In sheet metal stamping process in appliance and automotive industries, the work piece blanks are arranged primarily by mechanical shearing with high production speed [89].

The punches and dies produced by a company are typically for the two basic sheet metal cutting processes: punching and blanking. Blanking is a cutting process through which a part is cut from a sheet metal stock such that the cut does not touch any edge of the sheet metal stock. The cut part from the sheet metal stock is named a blank. There is only a small difference between the punching and blanking operations despite the quite similarity between each of them. In punching process, the part that is cutout (called a slug) is scrapped; in blanking, the part cut from the original sheet metal stock is the usable part [90].

The cutting and production of large metal sheets in automotive industry are usually face many challenges. The cutting process may include many challenges despite its simplicity for the first glance. On unpleasant surprise associate with sheet cutting is the slug pulling. The motivation to produce more products in short time by blanking or punching sometimes lead to slug pulling [91].

CNC punching machine is used to develop the manufacturing punching technology. CNC machine helps to produce holes in sheets by using the automated mechanical operations. To perform the manufacture punching technique, compression force is applied on the punch aim to exert the pressure and can be entered into the sheet. This operation generates initial deformation to be formed material followed by shear stress that allow the material to be cutout and fractured. The cut piece that results from this punching is expelled [92]. The manufactural punching technique allow quick, accurate and efficient processes to form the metal parts from many manufactural sectors. Unlike the conventional equipment which work with manual controls by levers or hand wheel, CNC machine works by set of commands programmed in data storage medium [93].

Generally, press blanking line is designed to satisfy high quality needs of the fabrication and automotive manufactures. This comprises providers of “surface-exposed” panels and other supplementary sectors. Blanking material uses rapidly increases and enters in many industries. The reason behind this is the ability to blank and adopt with the final shape of the part that fulfills many types of industries.

PART 5

MATERIALS AND METHODS

5.1. MATERIAL

The material that was used in this study is AHSS sheet material (DP600) steel with 1.5 mm thickness. Low carbon steel with comparatively high level of manganese and some Cr and Si to simplify the formation of the DP microstructure and to provide the aimed properties as shown in Table 5.1 characterizes the chemical structure of the material.

Table 5.1. The chemical structure of the studied DP steel- in weight-%.

Material	C	Si	Mn	P	Cr	Ni	Mo	Cu	Ti	V
DP600	0.123	0.265	1.763	0.02	0.22	0.033	0.05	0.015	0.003	0.005

The results of microscopic imaging are shown in Figure 5.1 showed that the primary structures included of 30% martensite and 70% ferrite. The average grain size of ferrite is 7 μm.

Figure 5.1. Image of the investigated base material.

To characterize the material properties, the tensile test results of the material have been used in DEFORM. The engineering stress-strain curve processed in the test is used to calculate the true stress-strain curve. Figure 5.2 shows the tensile results tests of the used materials.

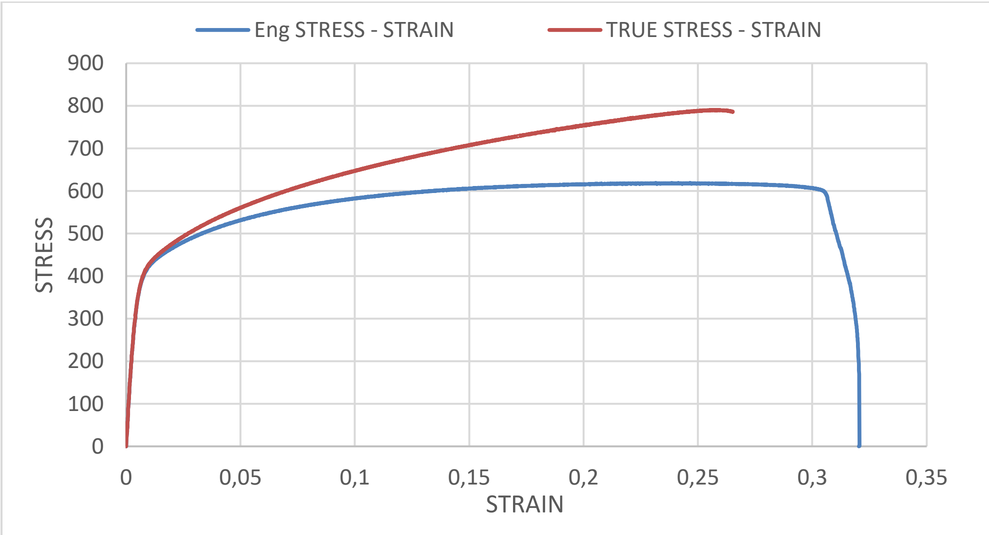


Figure 5.2. Tensile test results for DP600.

5.2. PUNCHING TEST AND EQUIPMENTS

Figure 5.3 shows the punching geometry. The experiments included four types of punches with different tip forms. The diameter of each punch is 20 mm. Punches Tip forms were given as flat-ended (0°), angled (4°), concave formed (R1), and angled (16°), which cut using wire EDM.

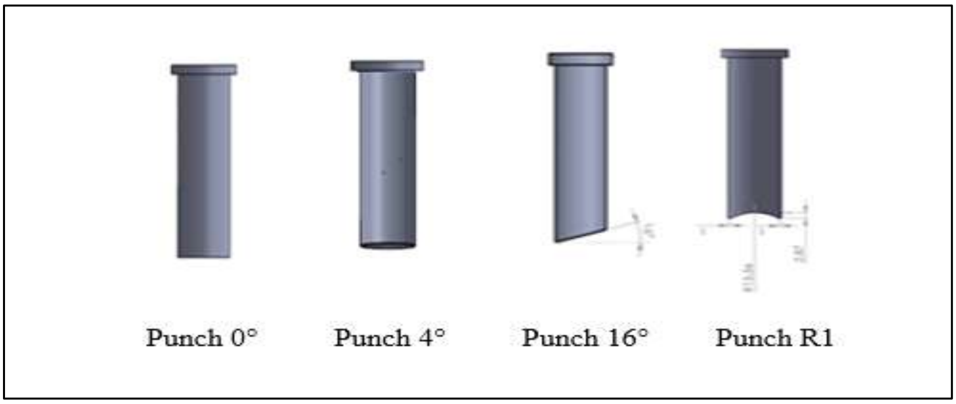


Figure 5.3. Type of punches used in the experiments.

In the punching/piercing tests, a hydraulic press with vertical speed has been used. Punching experiments have been implemented using DP600 sheet, a commonly used steel grade in the automotive manufacturing, with a nominal thickness of 1.5 mm that was chosen for this study. DP600 combines comparatively high strength because of the existence of martensite islands with good ductility because of the ferrite matrix. Figure 5.4 shows the experimental setup of punching determination. Punching force measurements were carried out using a load cell that has 240 KN capacity it is attached to the top side of the die to measure loads during experiments and 10000 data/sec data reading speed. The reading speed of data was adjusted as the 2000 data/sec.

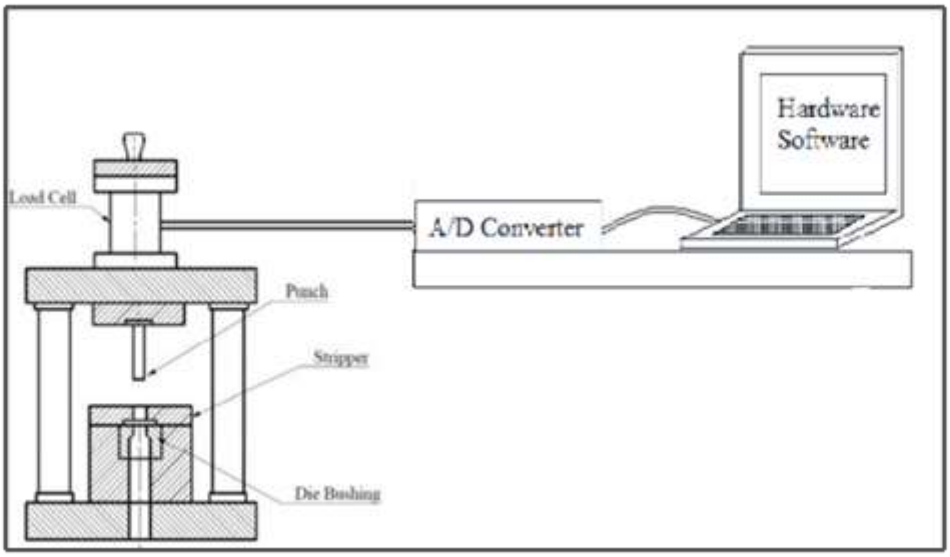


Figure 5.1. Schematic overview of the experimental set-up.

The results of the experiments were transformed to the digital media using data card, amplifier, and load cell and computer software as clarified in Figure 5.5. The amplified signals were transferred to the computer using analog to digital converter. The test set-up was adjusted before testing, and the shearing forces conforming to the changes in the voltages created by the load cell have been determined.

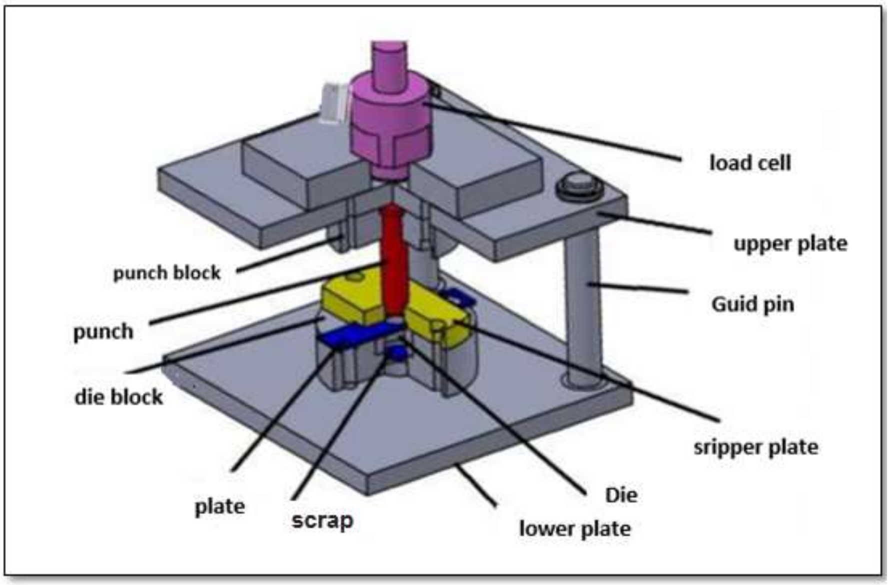


Figure 5.2. Assembly of die and load cell.

5.3. EXPERIMENTAL AND SIMULATION INVESTIGATION ON PUNCHING OF DP600

The manufacturing industry increasingly uses the punching process. The punching is between the most significant sheet metal in manufacturing process in mass production of metal components and parts. The process has high influence on many industries including the automotive industry [94].

Recently, the technological aspects of the punching process are greatly understood particularly in punching tools. Manufactural sheet punching and blanking are commonly used processes in many applications such as electronics, communication, automotive and other manufactural applications. The blanking process is implemented by separating a blank from the sheet to be used in additional manufacturing phases. The punching process is carried out by producing holes of different sizes and forms in a blank of sheet metal. Both cases work by applying a punch tool to shear piece separate from a sheet. The two process (punching and blanking) are implemented by applying punching tools in different types of presses [95].

The most common types of presses used with punch tools are hydraulic, eccentric and turret punch presses.

Punching process is very important because of commonly used in any kind of sheet metal part production. Punching, affect the mechanic performance of sheet parts and affect the punching press machine parts like hydraulic parts, punch and die. To investigate the punching process comprehensively, finite element method (FEM) commonly used. In this study DEFORM, a FEA software was used to analysis punching process. DEFORM is a simulation system based on a FEM used to analyze many heat treatments and forming process utilized by metal forming and associated industries. The DEFORM system resolves time-dependent non-linear problems by creating a sequence of FEM solutions at discrete time increments. In each time increment, the speeds, temperatures, and other key variables of each node in the finite element mesh are determined depending on boundary circumstances, thermos mechanical characteristics of the work piece materials, and possible solutions at previous steps.

These basic values are used to derive other state variables and they are updated for each time increment. Since blanking and punching are extensive industrial operations, enhancement processes and tools are important for the effectiveness and production economy. Flat type punching tools are considered most common types used in sheet metal blanking and punching processes. Geometrically, they are simple and easy to sharpen. However, the cutting forces for punching and blanking are relatively large and thus the cutting process is often noisy [96].

To decrease both noise level and cutting forces, flat-ended, and even the angled or concave shearing has been used in the punches. The main purpose to use these geometries is to reduce the cutting force for thicker sheets. Nevertheless, for a real simulation of the blanking process, the accurate modelling of the flow behavior as a function of strain rate, temperature, strain and damage behavior under many stress states is necessary. So, stack compression tests have been implemented for the AHSS cold rolled steel sheet dp600 at normal temperatures to handle large deformation and high strain ratios in the blanking process. Furthermore, standard tensile tests have been implemented [97].

PART 6

RESULTS AND DISCUSSION

AHSS has been used for the analyses and experiments cold-rolled steel sheet DP600 at normal temperatures to handle large deformations and high strain ratios in the blanking process. Furthermore, standard tensile tests have been performed.

6.1. EXPERIMENTAL RESULTS

Punching experiments have been performed using four types of punches with a constant clearance value of 0.07mm. The results were revealed that the punch tip form considerably affects the rolling speed and punching force as clarified in Figure 6.1. The perceived punching forces through the experiments were minimal when an angled punch (16°) is used. Higher punching forces have been measured with the angled (4°) compared to the concave tip. The highest punching forces have been measured using flat punch.

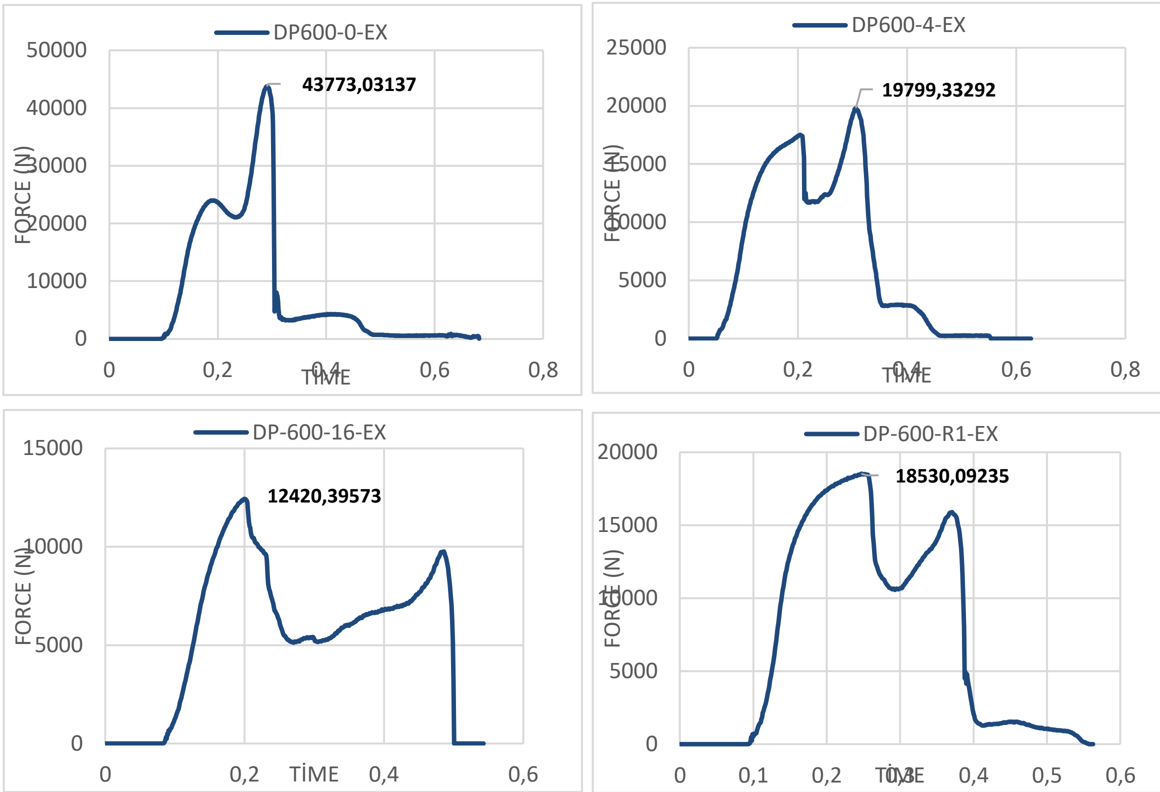


Figure 6.1. DP600 experiment results.

When flat-ended punch is used, the maximum shear force was 43773 N. Nevertheless, when the punches were used, the shearing force were 19799, 18530, 12420 N respectively as clarified in Figure 6.2. As well as we note from the results that inclined shear punch decrease the punch force by more than 50% of the flat punch, which must be taken into consideration when the loading capacity of the punching equipment is limited and to spread the beneficial life of the punch and increase the ratios of production between the punch edge. The mean reason of decreasing in punching force with different tip thought that the nature of relation between contact area and stress. With the increasing of punch tip inclination, the contact area between punch and material will decrease. Crack formation and propagation will occur in the region where the stress reaches, the rupture stress value from the yield stress value of the material. That mean with in ongoing strokes, stress will be constant hence the force value will change according to punch tip angle. The punching tests performed, confirm this theory. Especially, the decrease in force values can be understood more clearly with the increase of the punch tip angle in the picture. With the P2 punch, the flute at the tip of the punch creates twin two tips with an angle. But this angle decreases in the middle of the punch and becomes 0 degrees and also twin tip cause more contact area than P2 punch during punching process. Hence it is considered force value higher than the P4 punch.

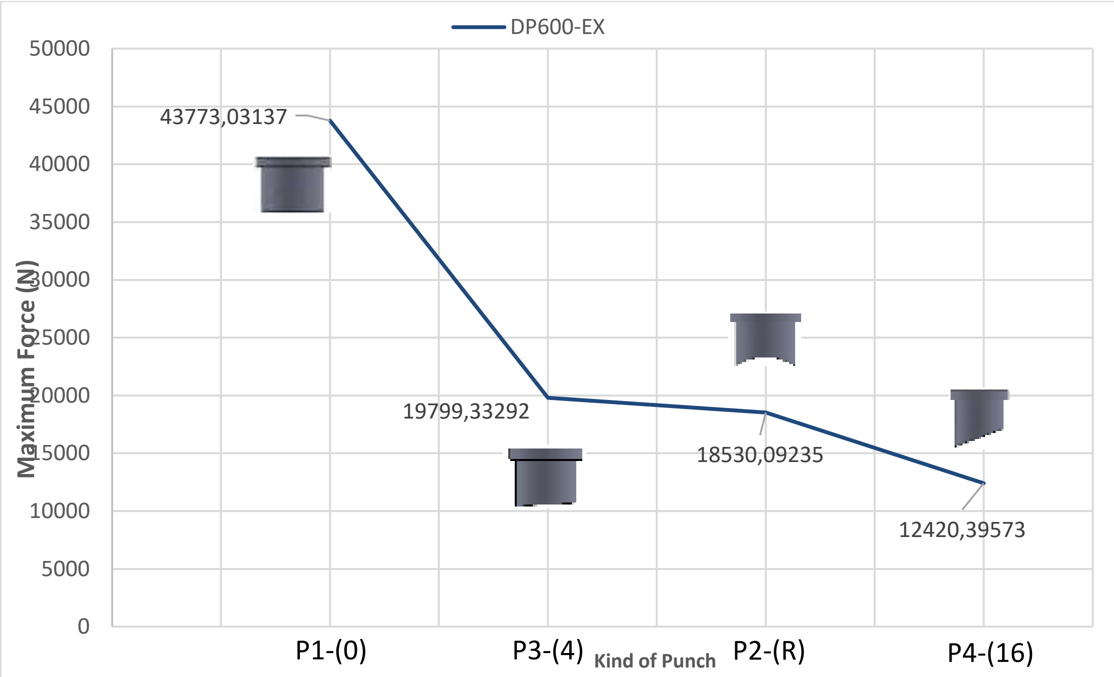


Figure 6.2. DP600 experiment all results.

When using a punch 0, the shearing force was great if compared of using punches R1, 16°, and 4° as clarified in Figure 6.3.

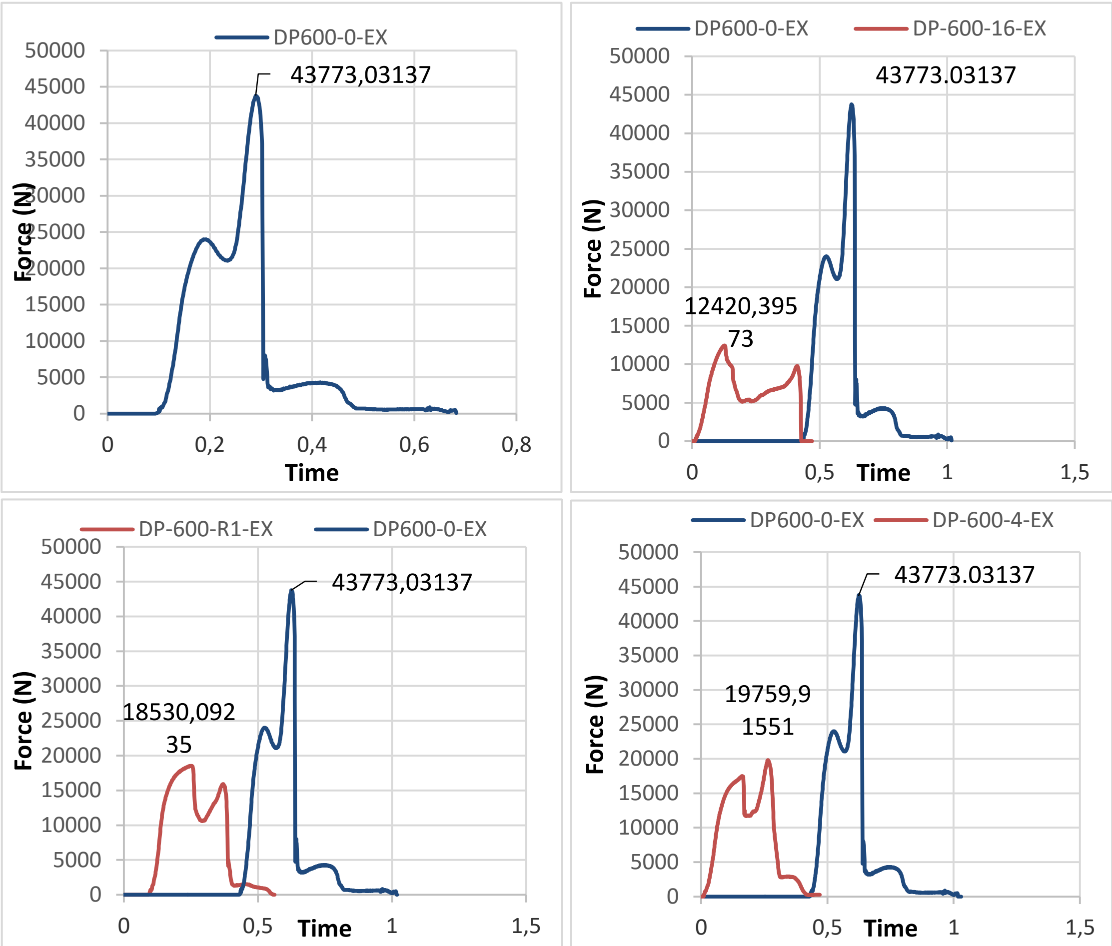


Figure 6.3. Comparison between punch 0 and others punches for DP600 experiment conducted.

Regarding this issue, used AHSS steels to investigate the effects of different punch geometries on punch force and cutting surface, as well as the wear properties of the punches. As a result of the studies, 50% less punch forces were obtained from the 6º inclined punch compared to the forces obtained from the conventional punch. In addition, it has been observed that the least abrasions are in the punches with angle [98]. Also, it was observed that punching with inclined punches achieved 60% improvement compared to conventional punches. In addition, it was observed that optimum cutting conditions for AHSS steels were obtained in punches with an angle of 3-6 degrees and 17% clearance values.

6.2. DP600 ANALYSIS (DEFORM SIMULATION) RESULTS

Deform software has been used to implement the analysis. To confirm the consistency with the experimental studies, 3D models have been used. Analysis results were gotten by using 3D models for shearing of DP600 sheet material with four different punches angled flat (0), angled (4°), curved (R1), and angled (16°) punches as shown in Figure 6.4.

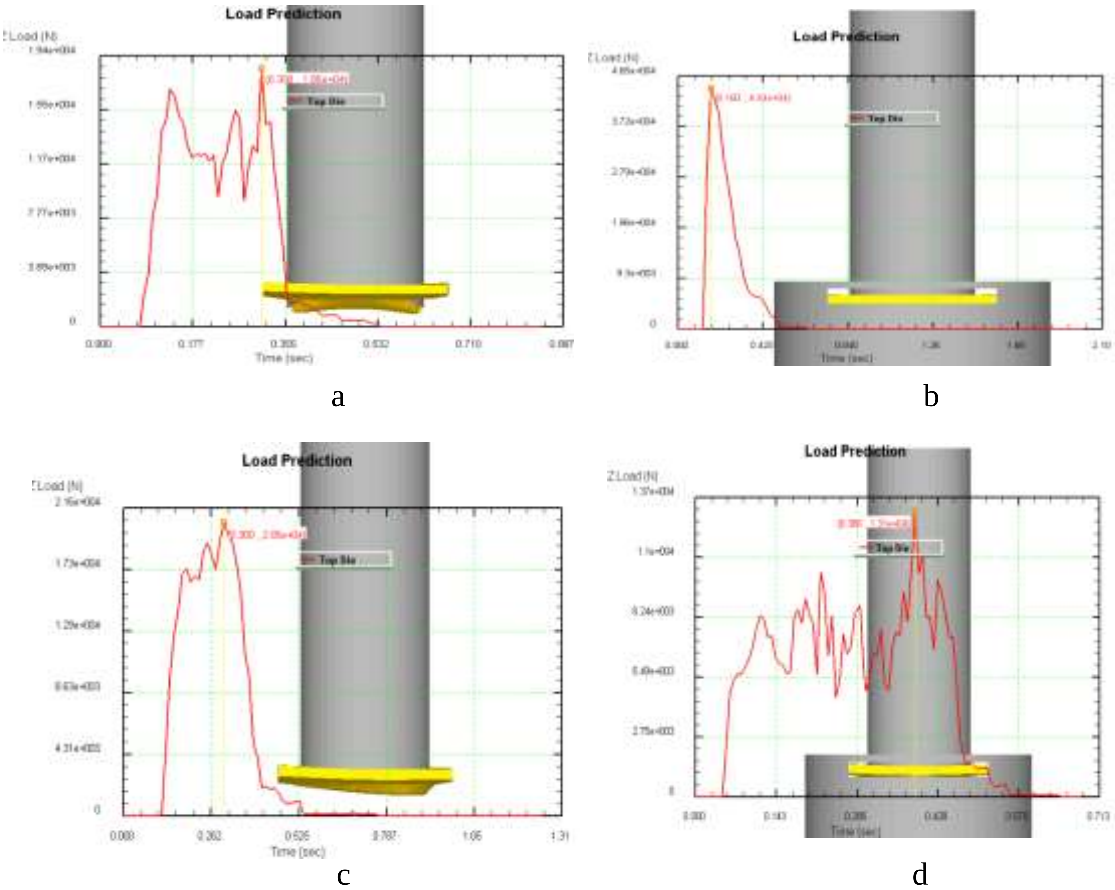


Figure 6.4. Analysis results obtained using 3D models for shearing of DP600 sheet material a) Flat punch (0), b) Curved punch (R1), c) Angled punch (4°), d) Angled punch (16°).

When the theoretical experiments have been implemented by using Deform Program, the results were very similar to the practical results as clarified in Figure 6.5. There was very good connection between the practical and theoretical results. In any way, the analytical values were larger than the experimental ones, but they represent good approximations of the reality. It is known that this correspondence is valid only for the current tested material.

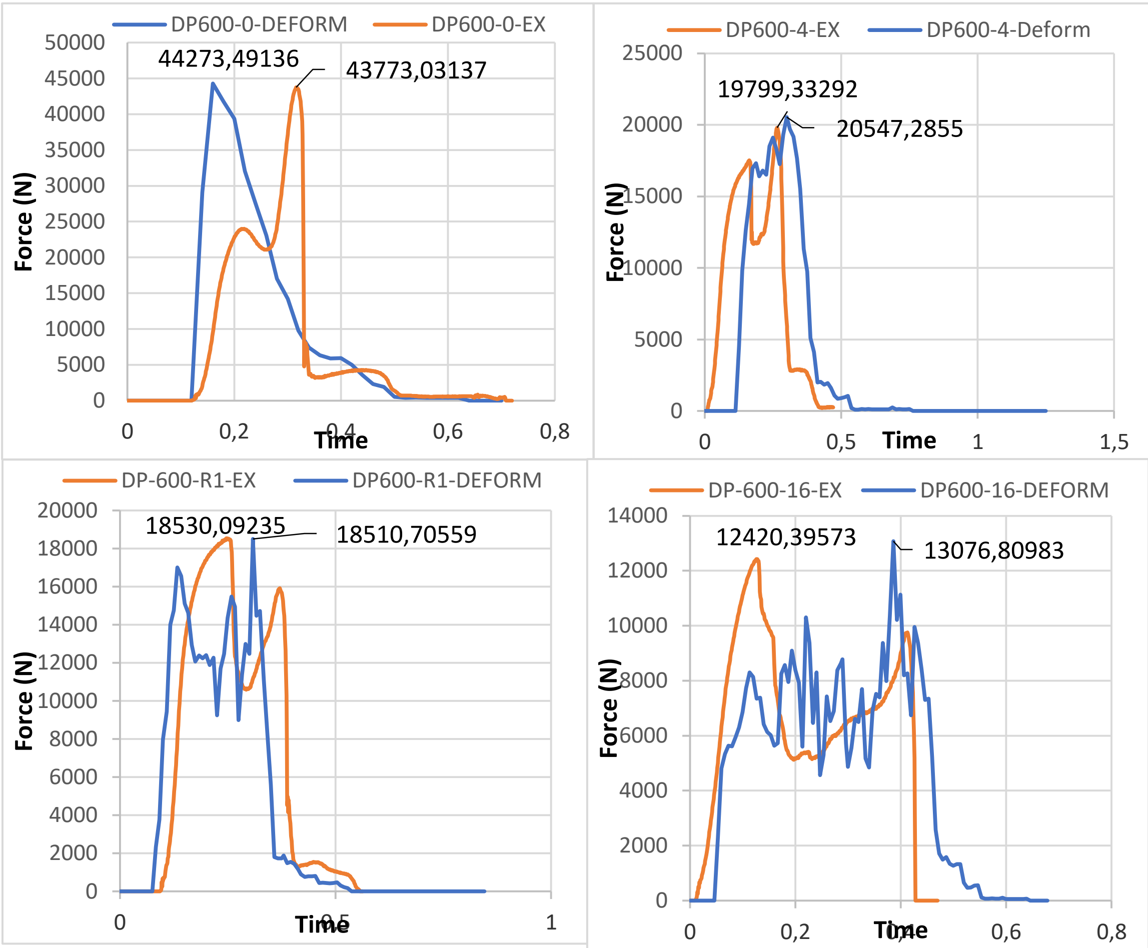


Figure 6.5. Results obtained from deform simulation and experiments for different punch shapes.

Four types of different punch angles with DP steel (DP600) were used to implement the punching experiments. The punching tests were implemented using a hydraulic press with vertical speed control. Higher blanking forces were measured with the concave tip shaped punch compared to the angled one. The highest punching forces were measured when the flat-ended punch is used. As well as it is observed that lowest punching forces was gotten when using an angled punch (16°). The results of flat-ended punch were chosen for the comparison of the punching force in the same thickness DP steel. The obtained results in this type of punch were clearer than the other types of punch because the large cutting region exposed to Blanking/piercing processes. When a comparison is made between the obtained results from the experiment with those obtained from Deform Program, it is found that the results were highly similar. The shearing force obtained from the Deform Program is 44273 KN and the experiment result is 43773 KN for the punch 0. Likewise, the results were obtained as 20547 KN and 19799 KN for punch (4°), 18530 KN, and 18510 KN for R1 13076 KN, and 12420 KN for punch 16°. The first values denote to the Deform results and the second values experimental ones. This study has established that shearing forces are decreased by up to 80 % when different punch angles were used. Therefore, the difference between the forces of the flat end punch and the angled punch (16°) is as noticeable as large as 30696 KN. Figure 6.6 shows a comparison between shearing forces obtained from the Deform Program and the experimental results for all used punches.

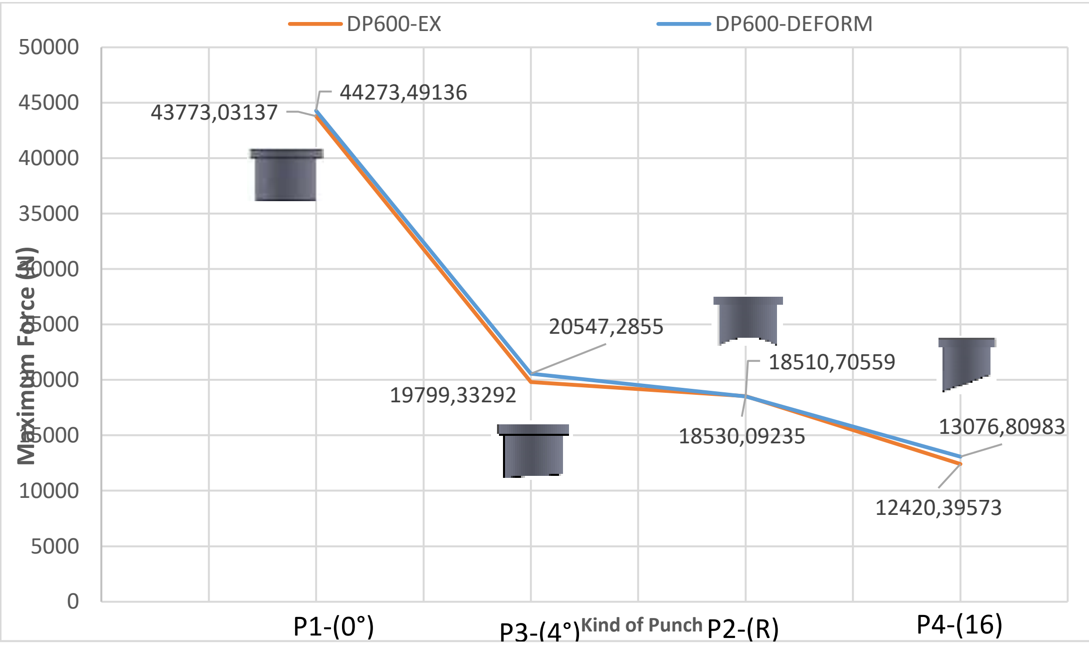


Figure 6.6. Comparison of the shearing forces obtained from experiments and analyzes for DP600.

6.3. EVALUATION OF THE SHAPES OF THE PUNCHES IN TERMS OF SHEARING FORCE AND PRODUCT QUALITY

After force study comprehensively, the most important point in punching operation is cutting surface properties. Cutting surface properties affect the mechanical performance of punched part. Cutting surface is consist of four different regions. To mechanical properties fracture zone is very important. Generally, in service life of parts fracture initiate fracture zone and propagate through rollover zone and part body. In Figure 6.7. Cutting surface measurements of P-(0°) punched parts was shown.

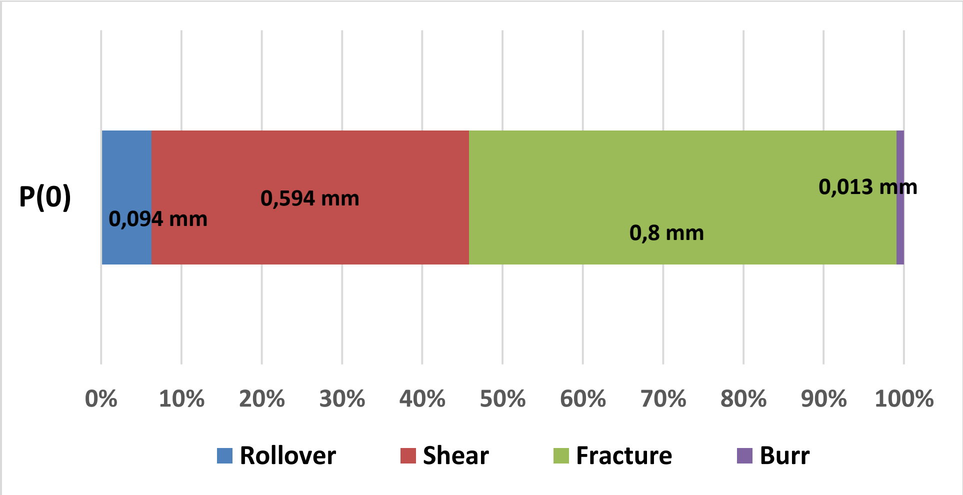


Figure 6.7. Measurements of different region zones in P-(0°) punched parts of cutting surface.

A uniform cutting surface was obtained in punching experiments with P-(0°). This means, rollover, shear fracture and burr zone are almost uniform in size along all the cut surfaces. This may make it easier to predict the mechanical performance of the part. However, it has been observed that the cutting surfaces that were created by other punches are not uniform. This situation can make it difficult to predict its mechanical properties. For this reason, performing gap expansion tests on the parts punched with punches with tip geometries at different angles may be good in terms of what kind of mechanical performance will be displayed. Holes expansion tests can be useful for determining the effects of a complex cutting surface on the mechanical performance of parts. The cutting surface features and gap images formed in the parts as a result of punching processes with different punches are shown in Figure 6.8.

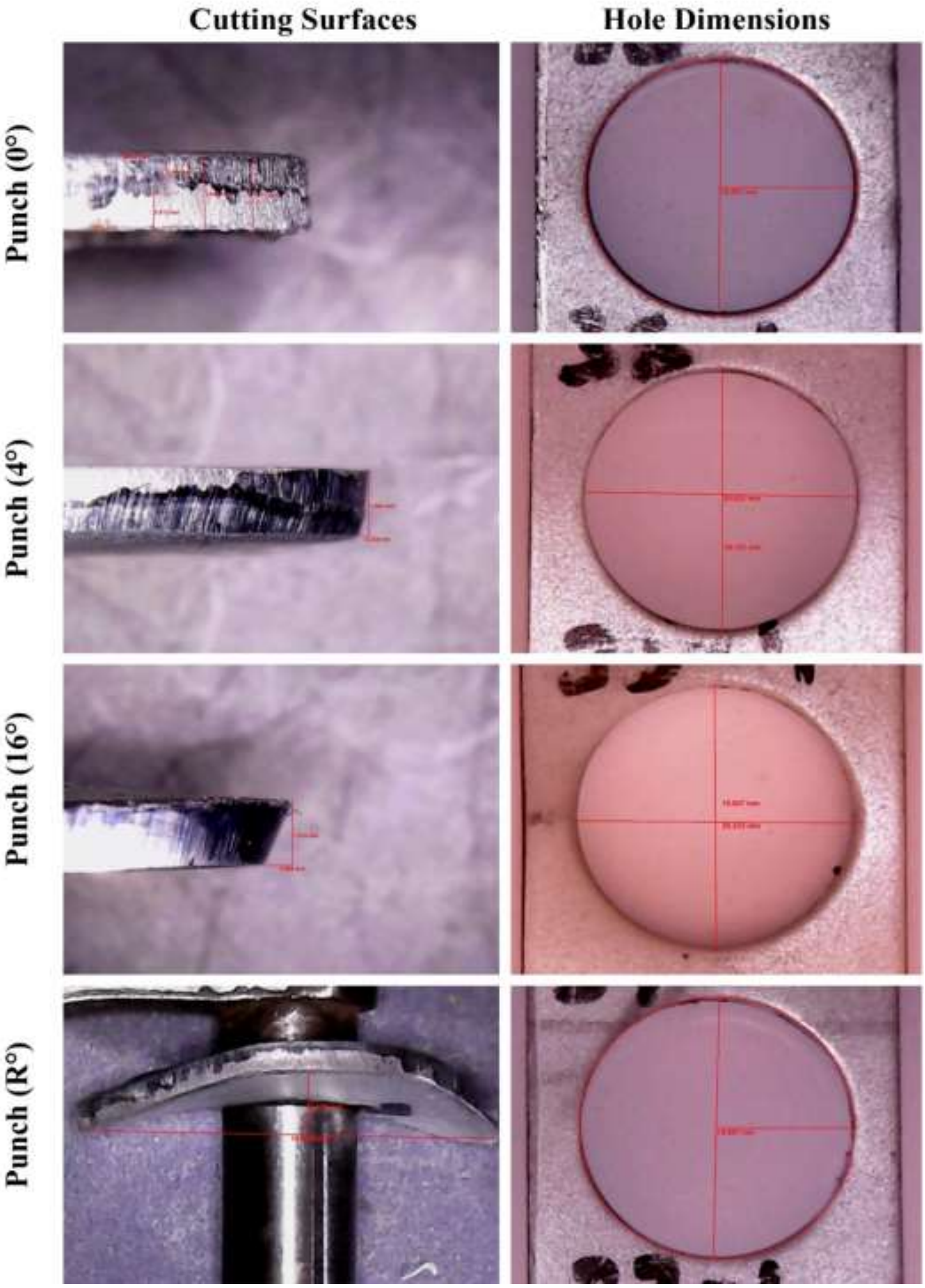
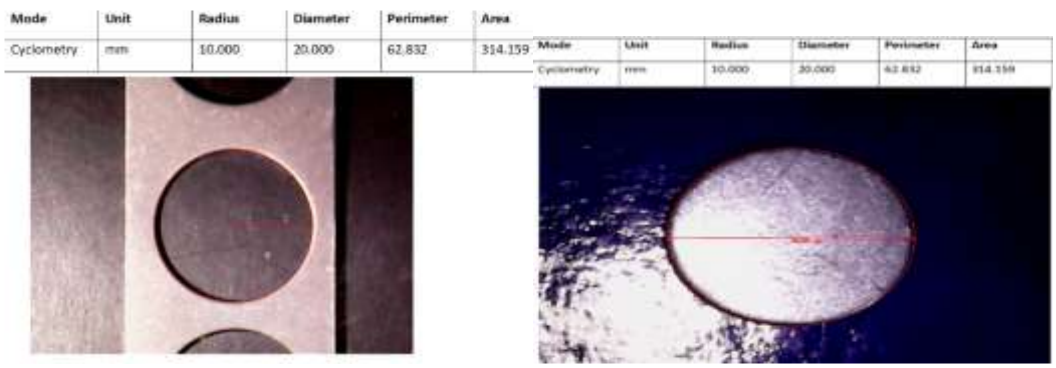


Figure 6.8. Cutting surfaces of punched parts with different punches and holes.

With the increase of the inclination in the punches, bending occurs in the parts during cutting. Therefore, this can affect the cutting surface properties. The angular difference that occurs on the cutting surfaces, especially in the punching operations with (4°) and (16°), can be seen in Figure 5.13. In addition, in stereo microscopic examinations, burr formation was observed in punching processes with (0°) punch, while it was observed that burr formation occurred very rarely in other punches with different geometries. It is thought that this situation may be caused by the inclined punches creating bending moments in the part. In their studies on this subject, they used punches with different geometries in punching work with AHSS steels [99]. In the studies, it has been observed that the best and uniform cutting surface properties are obtained from the punching operations with a conical tip punch with a curved surface. They stated that this may be caused by the inclined surface of the punch changing the cutting mode by creating a bending on material. In addition to these, it was understood from the study that the samples should be checked with gap expansion tests.

It can be noticed from the punching process that the distortions of meshes are limited to a small region near the punch–die clearance. Punching processes by the use of a punch with a flat angle occur concurrently in one shot beside the shearing line, whereas the process is non-instantaneous when the punch is angled and takes a time. The penetration depth amounts necessary to pierce the sheet metal increases with the punch angle used. When using a punch angle, the demanded depth of penetration is increased for the punch out of the process to be fully completed. The experimental study for all types of punches showed that the punch (0°) is the larger one needs shearing force, and this is not required. However, in terms of product quality, the product was not deformed because the diagonals were constant and not deformed. Figure 6.9 shows the impact of punch (0°) on the product in terms of deformation in the diameter for both blanking and piercing.



a b

Figure 6.9. a) The effect of the punch 0 on the product piercing, b) The effect of the punch 0° on the product blanking.

In contrast, when the punch 16° was used, the shearing force was less, and this represents a positive result. Nevertheless, the product was deformed, and diameters were irregular with both piercing and blanking. This does not motivate the use of this type of punching unless the diameters accuracy is not significant in the product. When the punch (R1) is used, it is found that the shearing force was a bit larger than the punch 16°. Nevertheless, the deformation occurred in the blanking only and piercing was not deformed. Punch 0° must be used to know if the product was piercing. In terms of punch 4°, the shearing force was somewhat larger than the shearing force for the punch (R1), and there was a little deformation occurred to the product

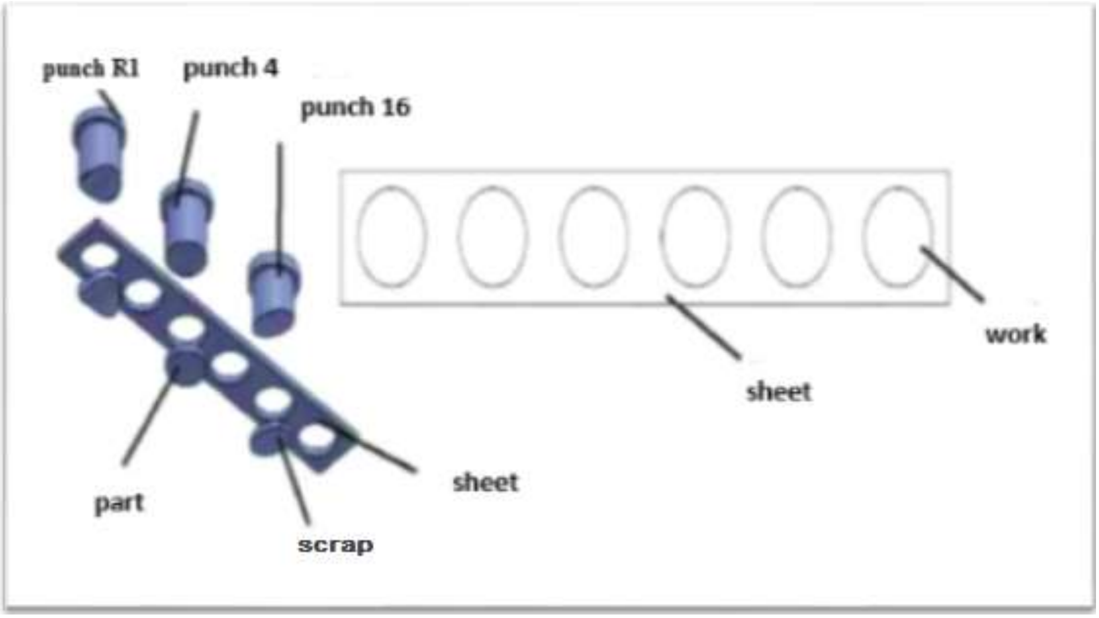


Figure 6.10. Different punch and scrap for piercing and blanking .

It is found that punch angle has an important impact on cutting force. Despite that decreasing cutting force by the use of angles punches is cost efficient approach and practical, it causes deformation in the perforated part. The area of deformation is increased if the punching angle increases. Relating with this issue some measurements were done for punched hole. The results have showed in Figure 6.10. The red line in the graphic represents the nominal diameter of 20 mm. It has been observed that the holes diameters are lower than the punch diameter in the measurements of the holes resulting from the punching process with P-(0°) and P-(R1) punches.

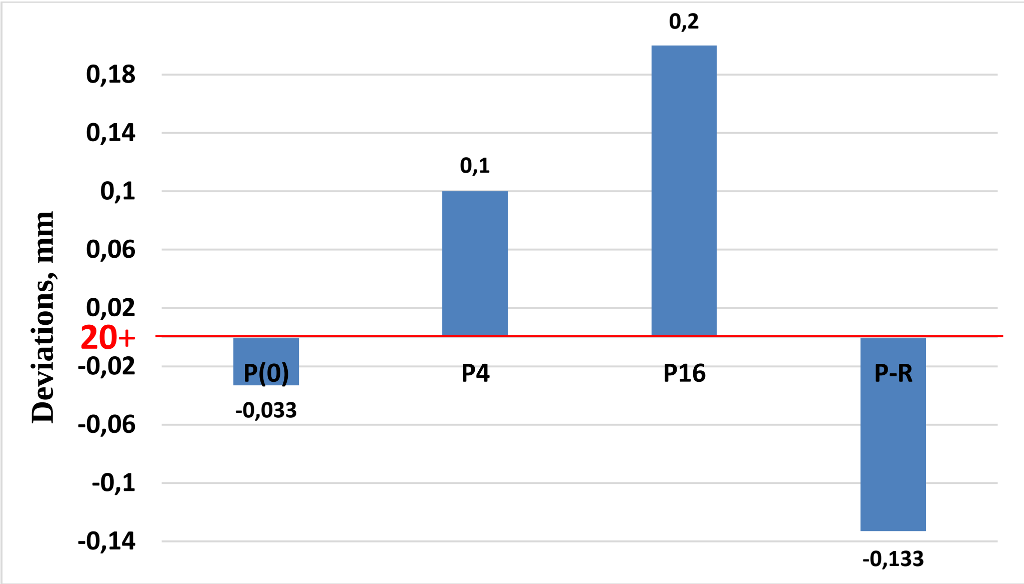


Figure 6.11. Measurement deviations of holes punches by different punches.

As can be seen in Figure 6.11, it was observed that the diameters of holes that are created by P-(0) and P-(R) punches were below the nominal punch diameter size. Diameters of holes that are created by P4 and P16 punches with angles, values above the nominal size were measured. Dimensional measurements vary between ±0.2 mm and this means the beveled and different geometry can affect the accuracy of holes diameters for DP600. Relatively this issue Jia et al, they investigate deviations of hole, punched by 3º, 7º and 14º angled punches [99]. They used AHSS steel for this study. They observed deviations in measurements and consequence of their study, they have stated that deviations related to spring-back phenomena.

With the studies carried out, it has been observed that the beveled punches have a positive effect as a force reducer. Significant amounts of punching force could be reduced compared to the flat end punch. With the P16 punch 70%, with the P4 punch 57%, with the PR punch it was achieved 54% reduction in punching force carried out Also force values that are obtained from experimental studies are verified by the finite element analysis that were carried out. Thus, it was understood that the data obtained from the experiments, the errors that occurred during the experiments or the die, punch and material defects did not occur. In addition, similar results were observed in similar studies with different punch geometries and AHSS steels in the literature. As a result of the experiments, a 90% decrease in the force values was observed compared to the flat tip punch. The reduction of forces has a significant effect on die and punch wear as well as a positive effect on the life of the punching press machine. Likewise, this situation has been expressed in many studies on the subject [100].

However, the reduction of the forces is also extremely important to have the same positive effect on the manufactured part. As can be seen in all the studies, the punches used for force reduction also affect the dimensional stability and the cutting surface properties, which have a very important effect on the mechanical performance of the part. Also, dimensional differences increased with the increase of the punch angle and non-uniform cutting surface features were observed. It is also very important to examine the effects of these effects on mechanical performance and to determine the punch that will provide optimum performance. In the continuation of this study, it may be recommended to perform extra holes expansion tests for different punches to determine the mechanical performance of the part.

PART 7

CONCLUSION

Punching is considered one of the main sheet metals forming processes. Therefore, its simulation must witness a great attention. From the analysis of the punching process that used in the experiments a set of punches which shaped by using the use of EDM wire as a flat, concave, 4°, and 16 ° angle end, using FEM simulations and comparison with experimental tests, DP steel DP600 have been used in the experiments. The main goal of this study is identifying the form of punch in which best part quality and the lowest cutting force will be gotten. The following conclusions are derived from the results of this study:

- The minimal cutting forces were perceived through the experiments when the angled punch (16°) was used which 12420 N whereas the highest value of this force was perceived when using a flat-ended punch (0°) was 43773 N.
- It was perceived that the highest cutting force was perceived when using a flat punch (0°) the blank and the falling part are gotten in a suitable form and dimensional accuracy. It is confirmed that punch 0° can be used for perforating and blanking operations.
- The results specify that shearing forces can be decreased by 80 % when using a 16° punch angle. The punch clearance was perceived not to have as an important impact as the punch angle did on the shearing force.
- Although the reduction of shearing forces using angled punches is a practical and cost-effective approach, it deformed the punched part.
- Depending on the side profile form of the falling part, punch 0° can only be used in the blanking process to accomplish the demanded part shape and dimensional accuracy. Nevertheless, the punches named 0°, 4°, R1, and 16° can be used for the punching process.

It is concluded from the numerical results that clearance between the punch and the die will affect the precision of the shape and dimensions intensely. It can be expected that numerical simulation can be useful to determine the parameters of process that can enhance the quality of the blanked work piece.

FEM simulations provide an efficient means not only to cost savings and speedup of the industrial production process but also to expect the quality of the cut profile of the blanked products with satisfactory accuracy.

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RESUME

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