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Optimization of a Hot Stamping Production Line in the Automotive Industry

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Abstract

Due to increasing demands from various organizations and strict legislation governing passive automotive safety, as well as efforts to reduce vehicle emissions and, in the case of electric vehicles, increase battery range, the use of high and ultra-high strength components in both the car body and closures has grown massively over the last two decades. Regarding metallic materials, aluminium alloys and different steel grades are the most common in car body components and reinforcement beams. Simultaneous forming and quenching is a current manufacturing process, referred to as hot stamping or press hardening, for low weight and ultra high strength components.

This dissertation, carried out in a business environment at Sodecia Automotive Saarlouis (Germany), was developed as part of the master's degree in Mechanical Engineering - Manufacturing. It aims to study and optimize a hot stamping production line in the automotive industry.

The work objectives proposed by the company were the cycle time and material utilization reduction along the production. These objectives were accomplished by the development of two projects: Project 1 consists in the optimization of the hot stamping robot's movement and the reduction of the cycle time; Project 2 proposal is to change the blanking process, prior to hot stamping, resulting in the optimization of the material utilization and reduction of the steel consumption.

Keywords: Hot stamping, cycle time, material utilization

Resumo

Devido às exigências continuamente maiores de diferentes organizações e à legislação severa sobre segurança automóvel passiva e ao esforço para reduzir as emissões dos veículos e, no caso dos veículos elétricos aumentar a autonomia de alcance, a utilização de componentes de alta e ultra alta resistência na carroçaria aumentou drasticamente durante as últimas duas décadas. Relativamente aos materiais metálicos, as ligas de alumínio e diferentes qualidades de aço são os materiais mais comuns nos componentes da carroçaria de automóveis e nas vigas de reforço. A conformação a quente e têmpera simultânea é um processo de fabrico atual, referido como estampagem a quente para componentes de baixo peso e ultra alta resistência. Quando comparado com a estampagem a frio, este processo tem ainda como vantagem a possibilidade de obter peças com geometrias mais complexas, forças de prensagem menores, menor retorno elástico e redução do desgaste das ferramentas.

Esta dissertação, realizada em ambiente empresarial na Sodecia Automotive Saarlouis (Alemanha), foi desenvolvida como parte do mestrado em engenharia mecânica, especialização em materiais e processos tecnológicos. O seu objetivo é estudar e otimizar uma linha de produção de estampagem a quente na indústria automóvel.

Os objetivos de trabalho propostos pela empresa foram a redução do tempo de ciclo e a redução da quantidade de material utilizado ao longo da produção. Estes objetivos foram alcançados através do desenvolvimento de dois projetos: No projeto 1 foi realizada uma otimização do movimento do robô presente na linha de estampagem a quente, o que possibilita a redução do número de passos do robô, eliminando este gargalo da linha de produção e redução do tempo de ciclo da produção. O projeto 2 propõe a alteração do processo de corte que antecede a estampagem a quente, permitindo um melhor aproveitamento da chapa de aço. A substituição do corte laser 2D por um corte mecânico a frio, por meio de uma ferramenta de corte e prensa com alimentação automática, permite uma redução do material necessário para o mesmo número de peças produzidas.

Keywords: Estampagem a quente, tempo de ciclo, utilização de material

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To my grandfather, to whom i promised the completion of this degree and, unfortunately, is no longer present to see it happen. The fulfillment of that commitment was my motivation to finish my studies and this Dissertation is dedicated to you.

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Rodrigo Namora

"Wisdom is not a product of schooling but of the lifelong attempt to acquire it."

Albert Einstein

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Abbreviations

AHSS	Advanced High-strength steel
BH	Bake Hardenable
BMW	Bayerische Motoren Werke
CAE	Computer Assisted Engineering
CCT	Continuous Cooling Transformation
CMn	Carbon-Manganese steels
CP	Complex Phase
DP	Dual Phase
EP	Extreme Pressure
FCA	Fiat-Chrysler Automotive
FE	Finite Element
GM	Generous Motors
HAZ	Heat-affected Zone
HRC	Hardness Rockwell B
HS-IF	High-Strength Interstitial Free
HSLA	High-Strength Low-Alloy
HSLA	High-Strength Low-Alloy
HSS	High-Strength steel
JD	Julian Date
LASER	Light Amplification by Stimulated Emission of Radiation
MART	Martensitic steels
MUD	Material Utilization Development
OEM	Original Equipment Manufacturer
PHS	Press Hardened Steels
PHS	Press Hot Stamping
PSA	Peugeot Citroën Automotive
R1	Robot 1
R2	Robot 2
R3	Robot 3
SEM	Scanning Electron Microscope
TRIP	Transformation Induced Plasticity
USA	United States of America
VW	Volkswagen

Chapter 1

Introduction

1.1 Motivation

Due to continuously higher demands from different organizations and severe legislation on passive automotive safety and the effort to reduce vehicle emissions and, in the case of electric vehicles increase driving range, the use of high and ultra high strength components in both car body and closures have increased drastically during the last two decades. Regarding metallic materials, aluminium alloys and different steel grades are the most common in car body components and reinforcement beams. Simultaneous forming and quenching is a current manufacturing process, referred to as hot stamping or press hardening, for low weight and ultra high strength components.

The price of steel represents the largest portion in the production costs of the components. Thus, it is of high interest that the amount of material used and the waste inherent to the production be as small as possible for economic and environmental reasons.

Another big contribute to the economic balance are the hourly costs on the equipment. The machines used in this industry are expensive, so productivity must be optimized as much as possible to reduce the number of working hours and thus reduce production costs.

1.2 Objectives

The internship carried out at Sodecia Automotive Saarlouis, Sodecia's unit in Germany, had as main objective to study and implement improvements in the production process by hot stamping of components for the automotive industry.

The production by this type of manufacturing process, continues to increase in applicability and evolving. Given the recent acquisition of the unit by Sodecia Group, there are still many opportunities for improvement and transition for the company's standards.

Based on the knowledge acquired during the Mechanical Engineering degree and the Masters in Materials and Technological Processes and using a bibliographical research, it is intended to solve concrete problems in the company's production and, at the same time, to acquire new knowledge and experience. It is therefore supposed to be a bilateral experience of knowledge sharing, between the company and the trainee. During the internship the following improvements in the production line were proposed:

- Reducing cycle times;
- Reducing the material waste.

1.3 Structure of the Thesis

Chapter 1 introduces the motivation for the developed work, the proposed objectives and the structure of the current thesis.

Chapter 2 covers steels metallurgy and microstructure, with a focus on boron-alloyed steels, which are widely used in the automotive industry, the historic context of the hot stamping process, its fundamentals and the related manufacturing processes. It also covers the literature review done to base the implementations of the proposed changes developed in the case studies.

In Chapter 3 is made an introduction of Sodecia, the company where the internship took place, and the methodology and materials used to carry out the developed projects and case studies. It hands a brief description of those projects and some analysis tools that were of use.

Chapter 4 discusses the case studies and optimization projects developed during the internship, aiming to achieve the proposed goals.

At last, Chapter 5 provides the overall conclusions on the work done and proposed future works related to the projects presented in this Thesis.

Chapter 2

Literature Review and Theoretical Fundamentals

2.1 Hot Stamping Fundamentals

2.1.1 Introduction

The automotive industry has increased its use of Ultra High-Strength Steel (UHSS) in recent years as manufacturers seek to improve crash safety and reduce weight. Hot stamping is increasingly being used to manufacture UHSS components such as B-pillars, side impact reinforcement beams, and bumpers.

Hot stamping involves heating blanks made of a special boron-alloyed steel to its austenitization temperature (approximately 900 °C) in a furnace, forming them in an internally cooled die set, and quenching them under pressure at a minimum cooling rate of 27 °C per second. This minimum cooling rate ensures that the part develops a martensitic microstructure, which confers on it a strength of approximately 1500 MPa.

In this section is made an introduction of the steel grades utilized in the automotive industry, a historic context of the hot stamping process, the heat treatment and metallurgical transformation on boron-alloyed steels, coatings, hot stamping types and process as well as pre and post hot stamping processes necessary for the manufacture of this automotive components.

All of this aspects were useful to better understand the production of the company and evaluate possible optimization opportunities to implement.

2.1.2 Classification of Automotive Steels

Higher strength steels such as High-Strength and Ultra High-Strength, may aid in weight reduction through down-gaging (i.e., using thinner sheets), while maintaining or improving crash performance [10]. However, there are a number of drawbacks to using thinner, stronger sheets:

(1) as strength increases, formability decreases (see Fig, 2.1), making it more difficult to design a component without splits in the press;

(2) as the sheet's strength increases, it tends to springback more, making it more difficult to manufacture the part within the tolerances;

(3) die wear issues are more prevalent with high strength steels, as the forming/cutting forces/stresses and contact pressures are significantly higher [11].

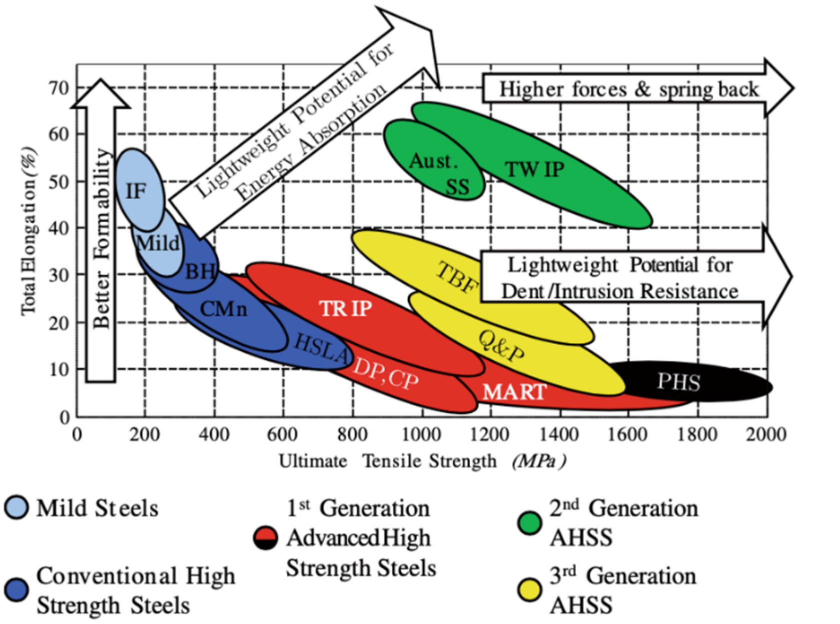


Figure 2.1: "Banana Curve" shows that higher strength steels have lightweight potential, but limited formability and hard to control springback [10]

Mild Steels

Mild steels are usually composed entirely of ferrite. These steels typically have a tensile strength of less than 280 MPa. Their primary advantage is their adaptability to complex geometries. Mild steels were the dominant material in automobile bodies until the 1990s [2], but their use is now confined to (1) stiffness-related components (i.e., floor panels that do not bear crash loads) and (2) cosmetic components with intricate bending and drawing (outer panels).

High-Strength Steels (HSS)

Conventional high-strength steels (HSS) acquire increased strength levels through a process called "solid-solution hardening." Although there are further varieties, the automotive sector generally uses four classes of HSS. These steels are identified by their yield strength:

-Bake Hardenable (BH): 450-480 MPa tensile strength;

-Carbon-Manganese steels (CMn): 310-540 MPa tensile strength;

-High-Strength Low-Alloy (HSLA): 340-1000 MPa tensile strength;

-High-Strength Interstitial Free (HS-IF): 340-500 MPa tensile strength.

Advanced High-Strength Steels (AHSS)

The microstructure of Advanced High-Strength Steels (AHSS) is martensitic with at least one additional phase. Five different types of AHSS are employed in the automotive sector. Typically, AHSS classes are denoted by their tensile strength level. A comparison of engineering stress–strain curves of mild steels with conventional HSS and first-generation AHSS is given in Fig. 2.2.

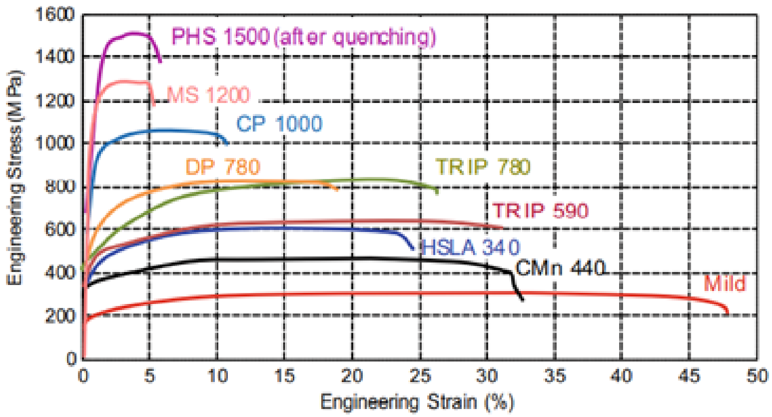


Figure 2.2: Engineering stress-strain comparison of several AHSS, HSS and mild steels. [10]

(1) Dual Phase (DP) steels have ferrite in addition to a martensite content of 5–50 vol.%; consequently, they are referred to as "dual phase." The amount of martensite in the steel determines its strength. At equivalent strength levels, DP steels often have more formability than HSLA steels. These grades range in tensile strength from 450 MPa to 1400 MPa. DP is the most prevalent AHSS type in the automotive industry at the moment. [11, 40, 43, 54].

(2) Complex Phase (CP) steels normally have higher formability than Dual Phase (DP) steels and contain bainite in addition to martensite and ferrite. Additionally, some preserved austenite may be present. Titanium, Vanadium, and/or Niobium microalloying is added to assure grain refinement. These grades are commercially available in tensile strengths ranging from 600 to 1200 MPa. At the same strength level, CP steels have a greater hole expansion ratio than DP steels. [42, 7, 40].

(3) Transformation Induced Plasticity (TRIP) steels contain 10–15% retained austenite phase. When deformed, retained austenite changes into the strong martensite phase, which aids in strain distribution and enhances elongation. This is referred to as the TRIP effect. These steels have-higher formability than CP, DP, or HSLA. Currently, TRIP steels are available with tensile strengths ranging from 590 to 1,180 MPa. These steels are occasionally referred to as "Retained Austenite" steels. [18, 40, 43].

(4) Martensitic (MART) Steels are predominantly martensitic in composition, with trace phases of ferrite and bainite. Martensitic steels are the toughest yet least formable kind of steel. Their strengths can be increased or decreased by alloying with carbon (C), manganese (Mn), chromium

(Cr), molybdenum (Mo), or boron (B). These steels are available in tensile strengths ranging from 900 to 1,900 MPa. Although lower strength versions could be stamped, these steels are typically roll formed [40, 6].

(5) Press Hardened Steels (PHS) (alternatively referred to as hot-formed steel or hot stamped steel) are considered as first-generation AHSS. This steel grade is the more relevant and the focus of the current study [10].

Ultra High-Strength Components in Car Body

The components in the car body that are commonly made of Ultra High Strength Steels are shown in Fig. 2.3.

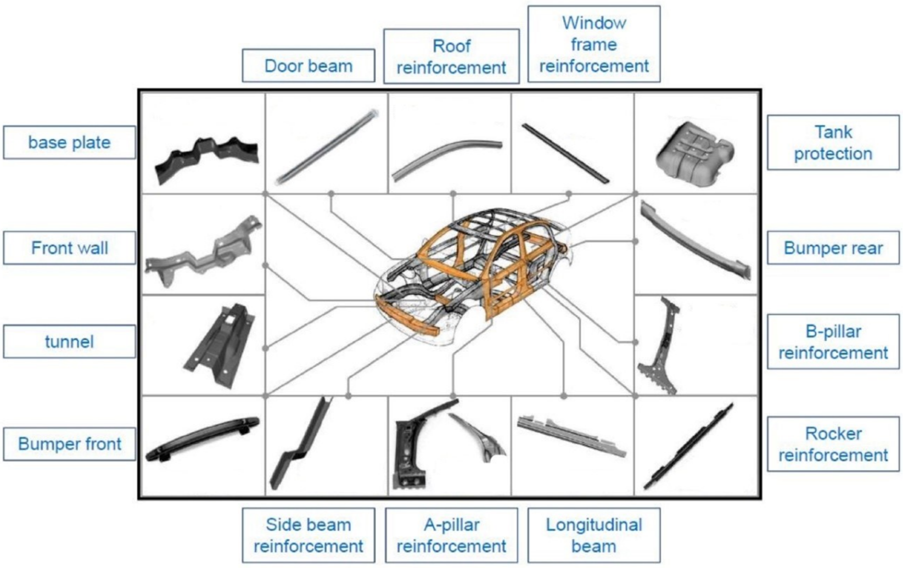


Figure 2.3: Components in the car body that are commonly made of ultra high strength steels [15]

2.1.3 Historic Context

Hot stamping can be traced back to Japan in the thirteen-fourteenth centuries where the basis of this process was used to obtain traditional swords. The first patent for press hardening dates back to 1914 in Switzerland, and that process was used to obtain agricultural products since 1930s. The difference between that process and the process known today resides in the fact that nowadays the quenching is done in a press die to reduce distortion. The first patent of press hardening process, commonly used today, was issued in 1977, Sweden. The hot stamping rights were sold to Plannja AB in 1982. The first automotive application occurred in 1984, when Saab began purchasing hot stamped side impact door beams for the Saab 9000. Jaguar began using hot stamped door beams in its XJ model in 1986 [19, 49, 24, 23, 9]. Plannja AB was the sole manufacturer of hot stamped items until 1995. However, as the patent expired in that year, competition intensified, and other companies began investing in hot stamping. [19, 9]. In 1998, the French steel supplier Usinor (later merged to Arcelor and now ArcelorMittal) developed the aluminum-silicon-coated 22MnB5 steel, USIBOR 1500 ® [55, 30].

The coating on the steel allowed to significantly reduce the scaling on the material surface. Beginning with 2010, most carmakers—including but not limited to: Alfa Romeo, Audi, Bentley, BMW, Chevrolet, Chrysler, Citroën, Dodge, Fiat, Ford, Honda, Jaguar, Jeep, Land Rover, Mazda, Mercedes, Nissan, Opel, Peugeot, Porsche, Renault, RollsRoyce, Saab, Seat, Škoda, Toyota, Volkswagen, Volvo—had already started using hot stamped components in bodies-in-white or hang-on parts[10].

As the technology advanced, hot stamping was not only used to reduce the weight of components, but new applications were discovered. The first was to make the pillars slimmer to increase visibility. Since 2012, several vehicles have surpassed 20% (by mass) barrier of hot formed body components. The first one was Volvo V40 (SOP 2012) with 20% hot stamped parts by mass [25].

As hot stamped components gained more applications in the auto body industry, more vehicle manufacturers embraced the technology. Figure 2.4 shows the increasing demand of hot stamping industry. Note that, initially the technology was only used for simple parts, such as side impact door beams. With improvements in the technology, it has been used for transmission tunnels and subplates using tailored technologies. [25, 34]

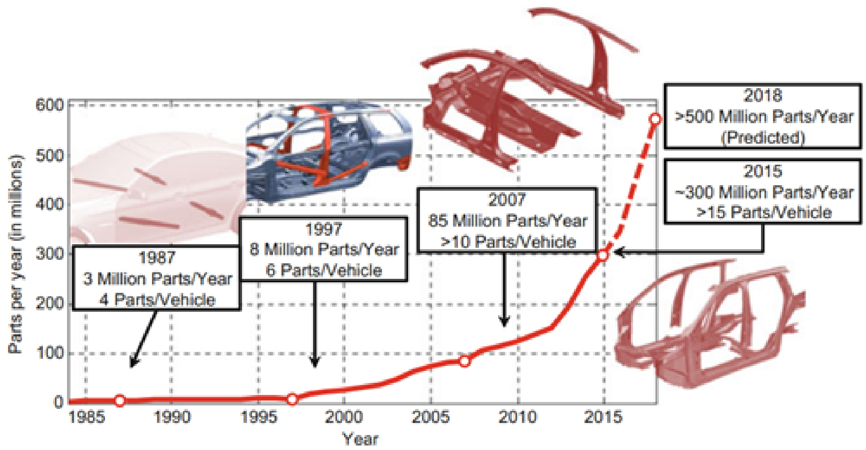


Figure 2.4: Since its inception, both the complexity and production volume of hot stamped parts have been increasing [10]

2.1.4 Heat Treatment

For hot stamping boron steels, the material is first heated to the austenitization temperature, above the Ac3 line, which in this case is around 900°. The metal sheet is maintained at that temperature for 5 to 10 minutes, depending on the thickness, to assure a homogeneous austenitic microstructure.

22MnB5, the comonly used steel for hot stamping, has 0,2 to 0,25% of carbon, making it a hypo-eutectoid steel. The intersection of the vertical line on Fig. 2.5, corresponding to the carbon percentage, with the Ac3 line, provides the temperature when the transformation from Perlite and Ferrite to Austenite occurs (ate approximately 870°C). As a safety factor, to assure the entire microstructure transformation, a temperature close to 920°C should be used (870+50°C).

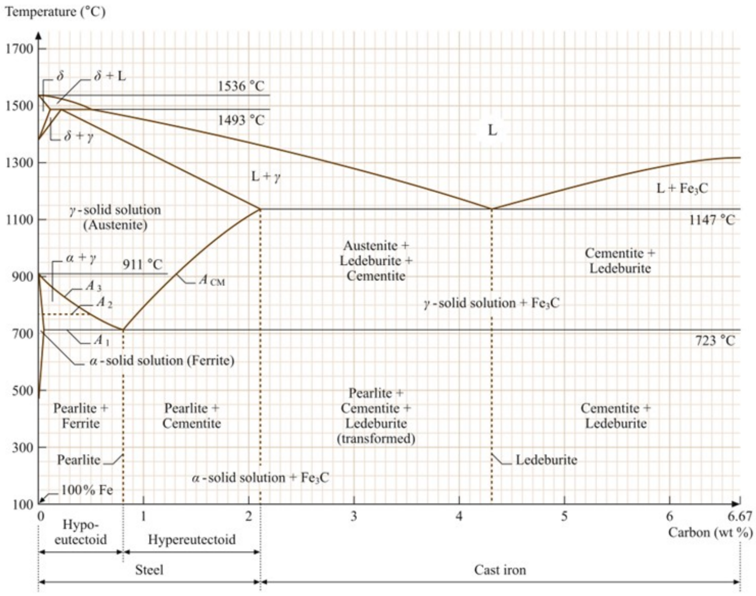


Figure 2.5: Fe-C phase diagram [10]

As shown in Fig. 2.6, during cooling, austenite transforms to ferrite and pearlite if cooled slowly, bainite forms at a moderate cooling rate and at high cooling rate martensite forms.

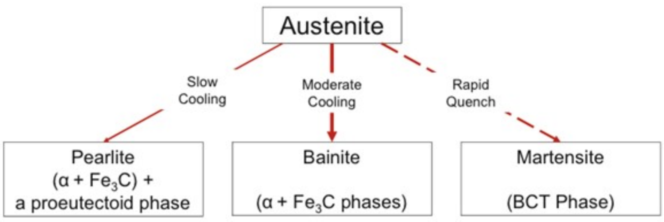


Figure 2.6: Possible austenitic transformations: solid lines ilustrate transformation with diffusion, dashed line shows diffusionless transformation [10]

Therefore, after entering the austenitic regime, cooling at a sufficiently high rate must be followed so that a martensitic microstructure is formed. That is the intended end phase because martensite is the hardest form of steel. After the rapid cooling and after entering the martensitic domain (around 350°C) the further cooling can be done in air, as the martensitic structure will not suffer any phase transformation. As shown in Fig. 2.7, the final microstructure can be predicted using the CCT curves, from where its gathered that the cooling speed must be greater than 25°C to obtain a 100% martensitic microstructure.

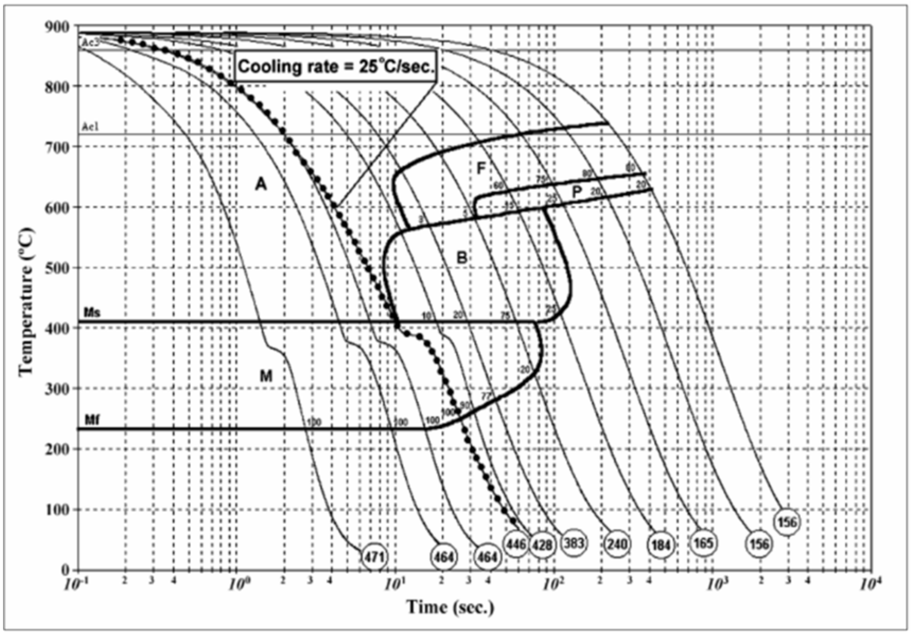


Figure 2.7: CCT diagram for 22MnB5 steel [15]

Table 2.1 presents the very notable mechanical properties differences for the steel in question, before and after the heat treatment.

Table 2.1: Mechanical properties of 22MnB5 steel before and after hot stamping [15]

	Before Press Hardening	**After Press Hardening**
Yield Strength [MPa]	350-550	1100
Tensile Strength [MPa]	500-700	1500
Elongation [%]	>15	6
Hardness [HV]	180-220	400-520

2.1.5 Coatings

During austenitization the steel sheets, commonly referred to as blanks, reach high temperatures, so a protection against scaling is necessary. An Aluminium-Silicium coating is standardly used on 22MnB5 steel. To prevent scaling, 60 µm of the coating is applied to each side of the blank. It provides a good corrosion resistance, higher process stability, its weldable and paintable, reduces the risk of decarburization and no surface cleaning is necessary. Plastic forming at high temperature allows highly complex geometries to be obtained due to the high hot-formability of this material. This is due to the fact that the austenitic phase is very malleable. A further analyzes on the coatings and its influence on the microstructure of the steel is given in Appendix A.2.

2.1.6 Hot Stamping Types

Hot stamping, also referred to as press hardening or hot press forming, is a relatively new process which allows ultra high-strenght steels (typically 22MnB5) to be formed into complex shapes.

There are two types of hot stamping:

-Indirect Process: the blank is formed, trimmed and pierced in cold condition. Afterwards it is heated and quenched in a die to get the strength properties (Fig. 2.8).

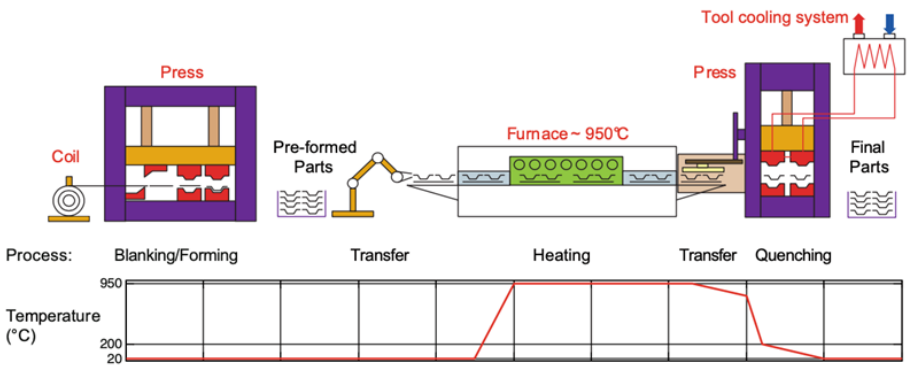


Figure 2.8: Indirect hot stamping process [10]

-Direct Process: the unformed blank is heated in a furnace, hot formed and quenched in a die to achieve the required properties (Fig. 2.9).

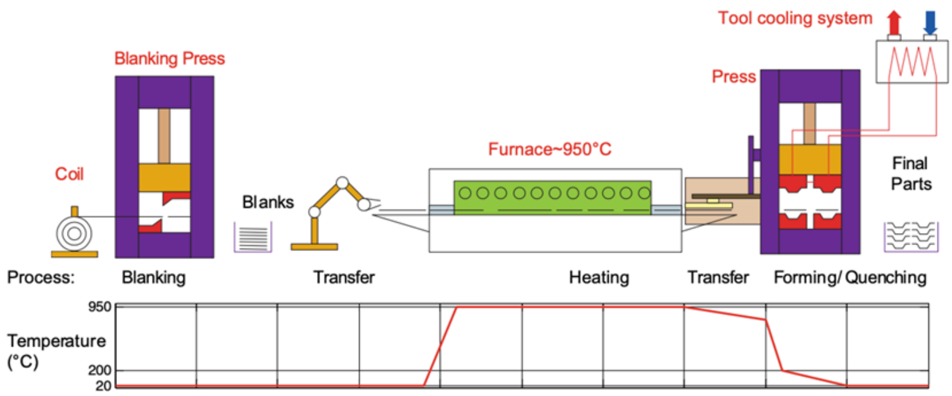


Figure 2.9: Direct hot stamping process [10]

2.1.7 Hot Stamping Process

Hot stamping requires a special production line, typically composed of (1) furnace/heating system, (2) a material handling system, (3) a press, and (4) an exit line. Trimming/piercing systems can also be included in the definition of a hot stamping line but will be discussed in the following sub chapters 2.1.8 and 2.1.9 as a pre and post process of the hot stamping line.

Figure 2.10 presents the graph of the temperature evolution in function of the time [s] along each step of the hot stamping process.

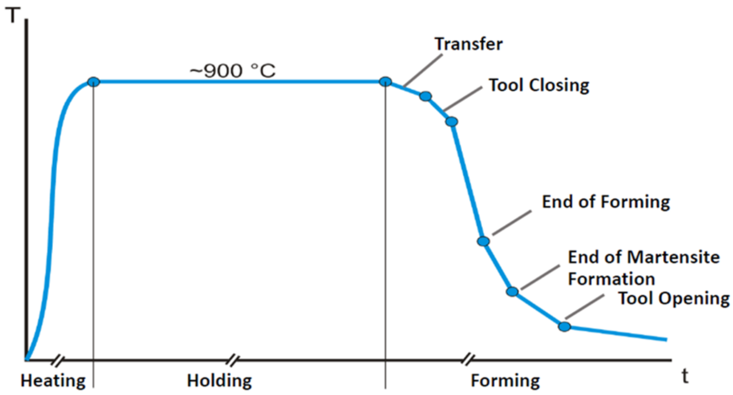


Figure 2.10: Temperature evolution along each step of the hot stamping process [15]

Transfer Time as Function of the Thickness

During the transfer of the heated part from the oven to the press there is a cooling down due to heat transfer by convection and radiation. With the decreasing of the thickness the transfer time is very critical as shown in Figure 2.11.

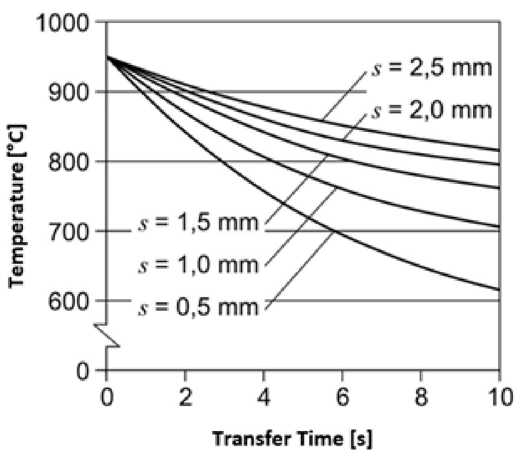


Figure 2.11: Temperature decrease as function of the transfer time for different steel sheet thicknesses [15]

Thermal Expansion

Thermal expansion has to be considered during the tool construction phase, it is a complex process with several variables. Robust robot automation from oven to press is necessary, as well as complex tolerance analysis and experiente hot stamping tool maker.

Equipment

A scheme of the hot stamping line is presented in Fig. 2.12 and a photo of the same hot stamping line present in the factory in Fig. 2.13.

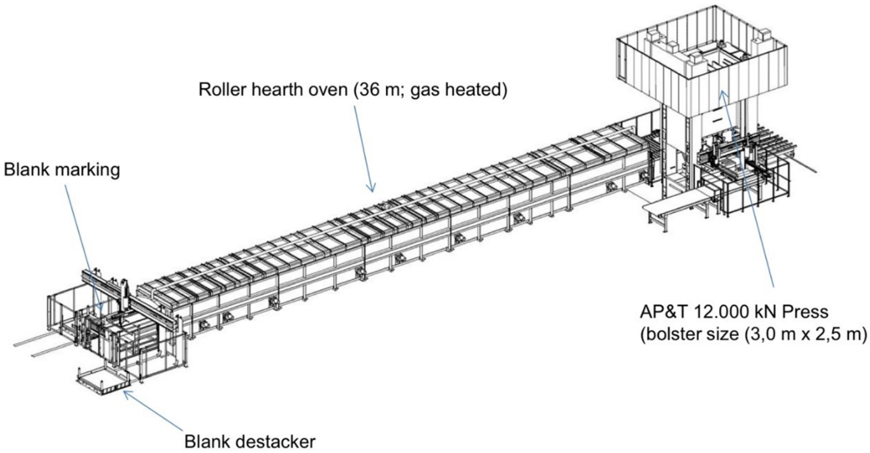


Figure 2.12: Scheme of the hot stamping line [15]

Figure 2.13: Photo of the hot stamping line present in the company's factory [15]

2.1.8 Pre-Stamping Process - Mechanical Blanking

Before the hot stamping process itself, the metal from the coil goes through a pre-forming process where the planar blank is formed, trimmed and pierced in cold condition. One of the processes available to transform the blank into the desired 2D part is mechanical blanking. Using a single or series of dies to create the desired shape or profile. The force that is applied to the blank modifies and changes its geometry, which creates stress that make the workpiece suitable for shaping. The basis of this process is the surpassing of the plastic limit of the material inducing its rupture to provide a separation of an outline of the metal sheet and obtain a desired shape. This operation is conducted in a press with a cutting tool whose fundamental elements are the punch and the die [28]. The dies in die stamping are specialized tools that have been customized to create a specific design, which can be very simple common items or more complex components. Dies can be designed to perform a single function or be part of a series of functions that happen in stages. This operation is obtained by the plastic deformation of the metal. The principle of the cut is shown on Fig. 2.14.

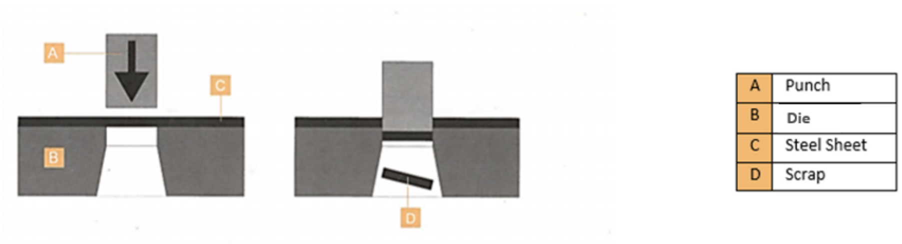


Figure 2.14: Cutting principle (re-created after [28])

Mechanics of the Cut - Process Explanation

The die is fix and the punch is the moving part. This operation can be summarized in three stages:

1- deformation: Before initiating the cut, the punch is lean against the metal sheet, supported in the die, and the material is forced to leave through the die hole. The metal undergoes elastic deformation followed by plastic deformation on both sides of the metal sheet, compressed between the punch and the die;

2- cutting: The punch continues its downward movement inducing a strong shear stress on the material, originating a shear zone;

3- rupture: After a certain point, the punch movement causes the material's rupture and part of the material is separated.

Dimensional Precision

The conventional cutting process its rarely considered high precision. The precision obtained are of the order of 0.1mm. This parameter is directly related with:

-type of tool used;
-tool guidance and good working of the press;
-wearing of the tool;
-clearance: the reduction of the clearance improves the precision (above 15% of radial clearance the precision decreases drastically);
-distance between the part and the sheet limit.

Depending on the dimensional tolerances and superficial quality requirements on the part's project, it might be necessary to apply some rectification operations after the blanking to obtain a better border finish.

2.1.8.1 Cutting Tool

Due to the plasticity and elasticity of the material, the cutting process might originate some defects, wrinkles and burrs on the part's borders. To minimize these defects is important to project correctly the cutting tool and steps, include a blank holder and define the appropriate clearances between the punch and the matrix. The project and conception of the tool must consider the dimension of the production, the material that is going to be stamped and its thickness, the quality (precision and appearance), the type of feeder of the press and the contour of the part. There are three types of cutting tool: (1) Compound dies, (2) Transfer dies and (3) Progressive dies.

(1) Compound Dies

This type of tool is characterized by forming the part in one single downward movement, combining several operations such as cutting, punching, and stamping. The fact that all the operations are applied at once and is done without the moving of the sheet, allows for maintaining a good repeatability of the relative dimensions. On Fig. 2.15, is presented a scheme of a compound die.

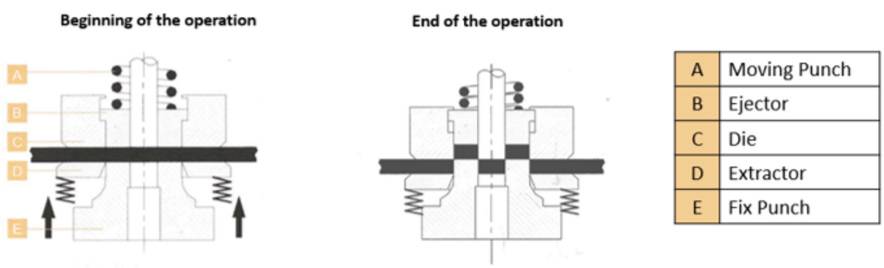


Figure 2.15: Scheme of the cutting tool: beginning and end of the operation (re-created after [28])

(2) Transfer Dies

Transfer dies (Fig. 2.16) use the same concept as line dies but have multiple dies that are timed together with an evenly spaced pitch, distance between dies, on a single press. Parts move between presses on side by side mounted rails. When one cycle is completed, the workpiece is transferred to the next die by an automatic transfer or robots equipped with mechanical grips or pneumatic suctions cups.

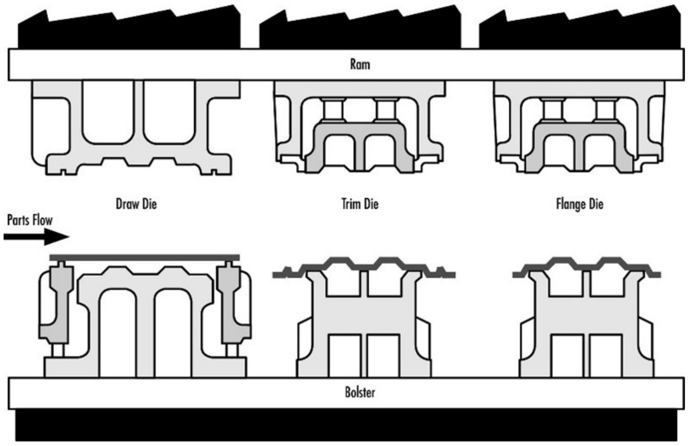


Figure 2.16: Scheme of a transfer die line [41]

(3) Progressive Dies

When the parts require several cutting operations, as shown on Fig. 2.17, this is usually the process applied. The part is obtained by a sequence of cutting operations done while the coiled metal sheet is pushed through the tool. Between each tool descent, the metal sheet moves forward a determined distance and that distance, referred to as pitch. The production costs of this type of tool is quite significant, consequently should only be used for medium to big productions. The feeding of the material is done by an automatic uncoiler. However, that mechanism is not enough to assure the precision and its replicability. Therefore, the positioning of the sheet should be done by centering pilots and/or the feed knife. The centering pilots allow a rigorous centering of the plate and are included in the moving part of the tool. On the movement down, the pilots fit in the holes or tears previously made in the sheet. This centering elements have a few hundredths of a millimeter less of diameter than the hole to allow an auto-centering of the plate to the tool. They should also have a bigger salience then the punch so that the sheet gets positioned before the cutting operation. The holes where the pilots fit might be functional elements of the part or exclusively made for the purpose of centering the sheet.

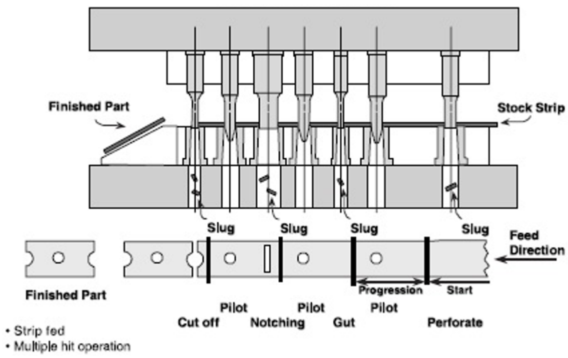


Figure 2.17: Scheme of a line using progressive dies [51]

Defining the Clearances

The clearance between the punch and the matrix is an important parameter to define in the cold stamping cut process because it influences directly the quality of the product and the life of the tool. If it is too small, it increases the wearing of the tool and, if excessively big, a poor quality of the product because it produces a rupture angle and burrs overly demarcated. Figure 2.18 presents an estimation of the clearance between punch and die as a function of material and sheet thickness.

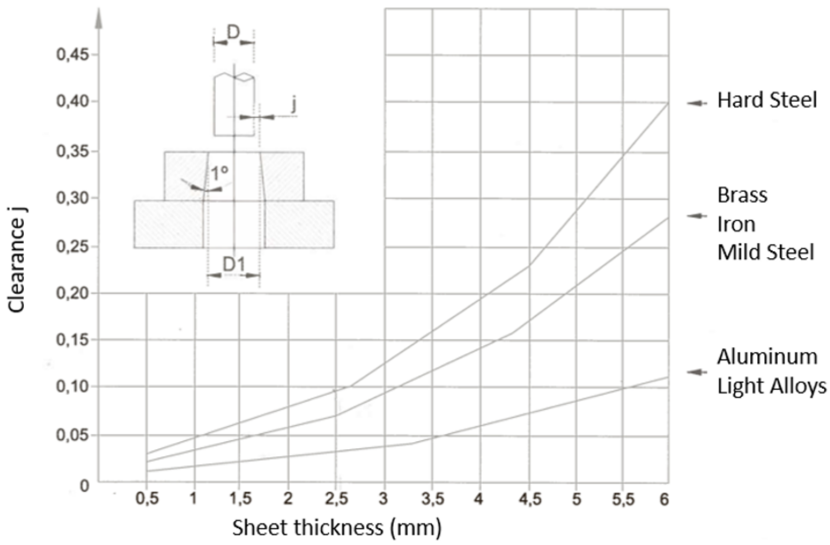


Figure 2.18: Determination of the clearance between punch and die regarding the material and sheet thickness [28]

Defining Strength and Energy

It is important to determine the shear force to find the adequate press and to determine the tools distribution on the press. Shear Force (F_c) is obtain by Equation 2.1.

$$F_c = L \cdot e \cdot R_c \tag{2.1}$$

F_c [N] - shear force

L [mm] - perimeter of the trimmed part

e [mm] - thickness

R_c [MPa] - shear stress

Table 2.2: Values of shear stress (R_c) for steels with 0,2%C

	Materials	R_c (MPa)
Steel	0,2 %C	
	Annealed	310
	Cold rolled	390

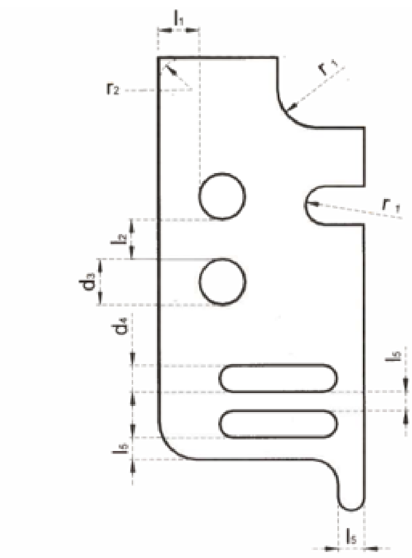
The shear stress (R_c) is a mechanical property that depends on the material but is usually calculated using the Equation 2.2.

$$R_c = 0,8 \cdot \sigma_r \tag{2.2}$$

Table 2.2 presents the values of shear stress (R_c) for steels with 0,2% of Carbon, as is the case of 22MnB5 steel.

Part Geometry

The parts produced by this type of process have some restrictions varying on the part's geometry. The image illustrates the recommended restrictive values for each geometry. The no compliance to these values might result in the diminish of the cutting quality.



r1	4 mm or 2e (*)		
r2	2e minimum		
l1 or l2	e < 1,5 mm	1,5 < e < 3 mm	
	General case	Ferrous	Nonferrous
	≥ 1,6 mm	3 mm or 1,5e	2,5e
d3	2,5 mm minimum or 1 x thickness (3 mm minimum for stainless alloys)		
d4 or l5	e < 0,8 mm	3 mm or 1,5e	3 < e <10 mm
	1,5 mm	2e	2,5e

Figure 2.19: Recommended sizing for mechanically cut parts (re-created after [28])

2.1.9 Laser Cutting

Laser is an acronym for light amplification by stimulated emission of radiation. It is used as pre process of hot stamping for blanking and as a pos process as well. Figure 2.20 shows the laser cut operation.

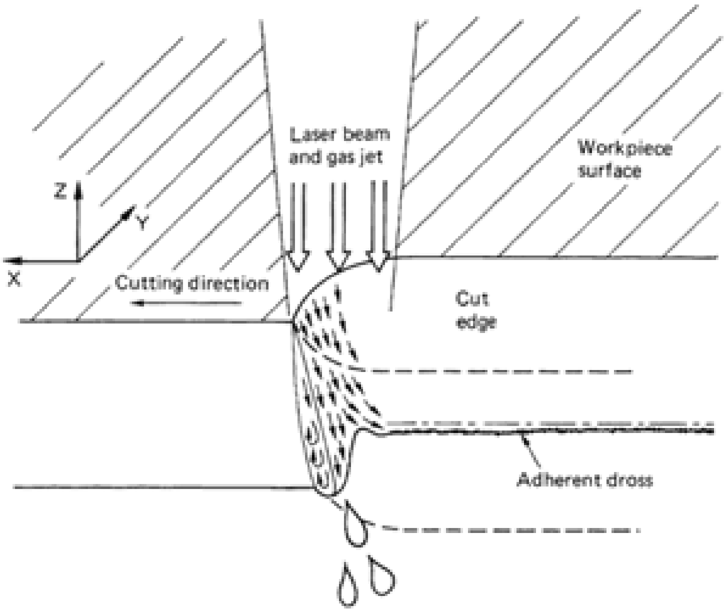


Figure 2.20: Laser cut operation [14]

2D Laser

Laser cutters for fabrications of 2D parts have been long available. This process is mainly used in small batch production as a pre-process to form the blanks for hot stamping. While external force-induced high tensile stress can be avoided through proper design, residual tensile stress caused by welding and trimming requires attention. Particularly, the residual tensile stress caused by mechanical trimming is close to the material's yield stress. As a result, laser cutting is frequently used to eliminate excessive residual tensile stress in trimmed or pierced sections. [10].

3D laser

Currently laser cutting is the most commonly used method for cutting purposes. It is applied after the parts are hot formed to obtain the final shape with the required dimensional tolerances. The advantage of using the laser is that there is no limitation on the shape of the parts to be trimmed. The disadvantages are relatively long cycle times and high capital investment and maintenance cost [27, 20]. Laser cut components, on the other hand, may have a higher fatigue strength and failure strain. The latter is critical for crashworthiness. [16, 27]. In principle, when laser is absorbed by a surface, the surface is heated by radiation. When excessive heat is focused on a very small area (i.e., high power density), laser can be used for cutting purposes. Depending on the material type and thickness, cutting could be achieved by evaporation or melting. In the case of hot stamped steel, laser melts the material in the kerf (the width of the cutting groove). Molten steel is removed by reactive gas [36, 10]. A minimum of three laser cells is required per each hot stamping line.

Figure 2.21: 3D laser cells present in Sodecia's factory

2.2 CAE Validation of a Hot Stamping process

Tool design based on computer models is nothing new for the stamping industry. Although mostly the same software packages are used for cold and hot stamping simulations, simulation of hot stamping differs significantly as it is not only a mechanical simulation. Hot stamping is a multi-physics problem with heat transfer, metallurgical transformations and even fluid dynamics in the cooling channels (Fig. 2.22).

Simulation of hot forming process can be divided into at least four stages, as shown in Fig. 2.23. The gravity stage is implicitly modelled and contains simply the mechanical field. Mechanical and thermal fields are used in the holding and forming stages. Forming must be completed with the blank in an austenitic phase and no phase change is desired. The quenching stage is a combination of heat and metallurgical fields [10].

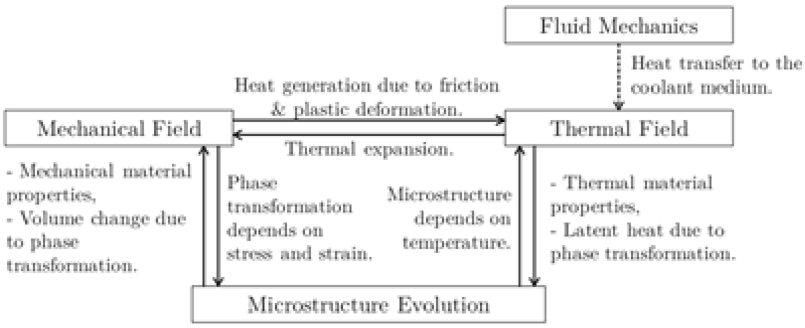


Figure 2.22: Different fields involves in the hot stamping simulation [57, 39]

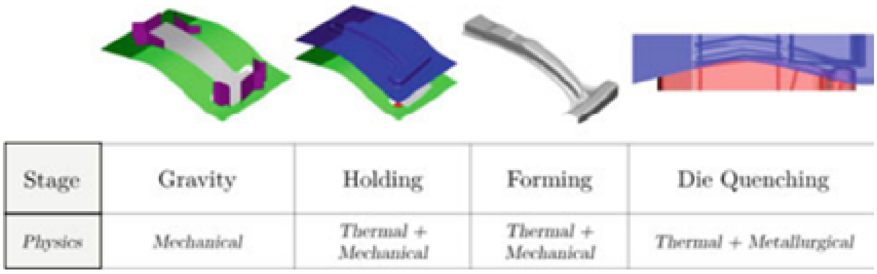


Figure 2.23: Stages of the hot stamping CAE validation [17]

2.2.1 Inputs to the simulation

The necessary inputs to the simulation can be divided into two groups: Properties of the blank and properties of the tool.

Properties of the blank

-Flow stress: this material property is necessary for the forming stage because at high temperatures (>500ºC) the strain rate has significant effect on the flow stress.

-Thermal properties: heat capacity, thermal conductivity (k) and coefficient of thermal expansion (Fig. 2.24).

The coefficient of thermal expansion (α) for 22MnB5 is constant and approximately given by Equation 2.3:

$$\alpha = 1,3x10^{-5}\ \frac{1}{°C} \tag{2.3}$$

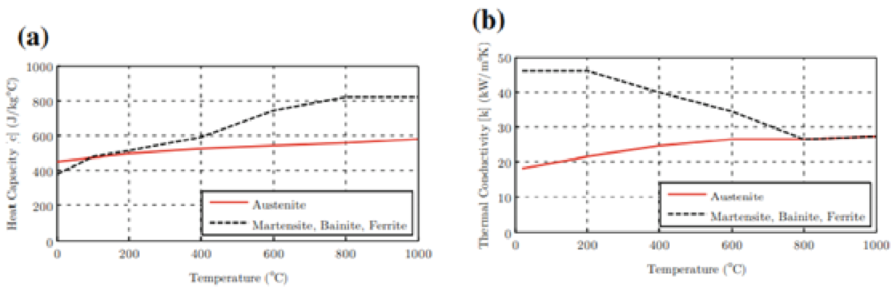


Figure 2.24: Variation of heat capacity (a) and thermal conductance (b) in function of temperature [22]

-Elastic properties (Fig. 2.25)

The phase transformation is an important aspect to consider in the hot stamping simulation. Contrarily to the cold stamping process, press hardening is a heat treatment process. Therefore,

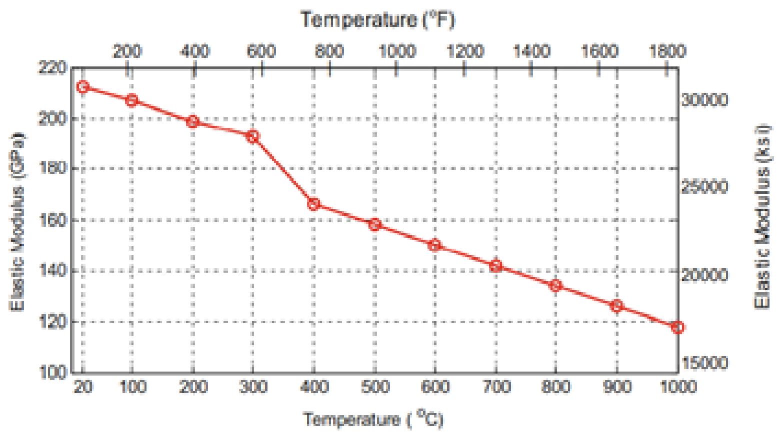


Figure 2.25: Graph of the Elastic modulus in function of the temperature [46]

the phase transformation has to be taken into consideration. The beginning of the press hardening process consists in the heating of the blank over its austenitizing temperature and left to soak for some time to assure the complete transformation of the that microstructure. In the simulation it is convenient to start with the assumption that 100% of the microstructure is austenite.

Properties of the Tools

To simulate the blank's heat loss and the tools' heating, the tools must be characterized as thermally conductive. Due to the requirement for a heat capacity, the tools must have mass, which only solid components possess. If shell elements are to be employed, a fictitious "thermal thickness" can be added, as shown in Fig. 2.27. Below the thermal thickness, it is assumed that free convection with air would occur, simulating the thermal conductivity of the real tool mass. Thus, the tools possessed a realistic heat capacitance and conductance, allowing for non-isothermal simulations [10].

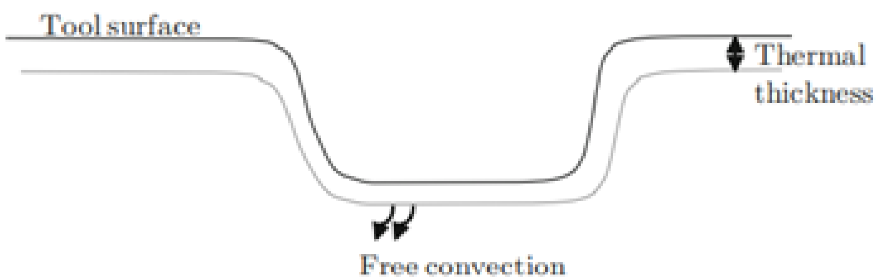


Figure 2.26: Laser cut surface [22]

If a cyclic cooling simulation cannot be performed, the initial temperatures of the tools might be considered uniform and equal to 75 °C for mass production conditions [8]. The values for thermal conductivity (Eq. 2.4) and specific heat (Eq. 2.5) can be entered as constants. For H13 tool steel, these values would be [22]:

$$k = 31 \left[\frac{W}{m^2 \cdot {}^\circ C} \right] \tag{2.4}$$

$$C = 650 \left[\frac{J}{Kg \cdot {}^\circ C} \right] \tag{2.5}$$

-Friction

Friction is also an important parameter and one of the most influential inputs to the simulation. It is a function of pressure level, relative sliding velocity, interface temperature and surface roughness of tool and the blank coating. In hot stamping, presence and type of the blank coating, tool material and coating, interface temperature and contact pressure are known to have effect on friction coefficient [13, 5, 3, 33, 29, 4, 56].

-Thermal Contact Conductance

Heat extracted from the blank can be calculated using the "thermal contact conductance", time elapsed (t), surface area in contact (A), and the temperature gradient (ΔT). Thermal contact conductance is known to be a function of the gap between the blank and tool when they are not in contact and of the interface pressure when they are in contact. The coefficient increases with the increasing pressure, until the pressure exceeds a threshold value [47]. Several articles in the literature, including [8, 31, 32, 38], indicate that, for Al/Si coated 22MnB5 material, the thermal contact conductance can be used as in Fig. 2.27. Merklein et al., found that the threshold value is 30 MPa (4.4 ksi), after which the thermal contact conductance does not increase anymore [32, 10].

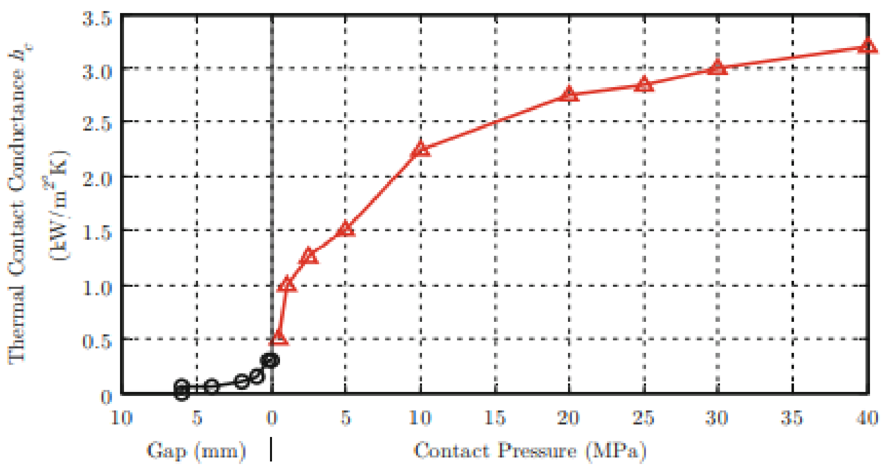


Figure 2.27: Thermal contact conductance input to simulation, as a function of pressure and gap [22, 8, 32]

2.3 2D Laser vs. Mechanical Cut

Durability requirements for safety-critical UHSS structures used in automotive applications are significantly influenced by the conditions of the cut-edges produced during component manufacture. Due to the cut-edge properties of these high performance steels, they are more susceptible to fatigue cracks. The automotive sector's deployment of HSS grades is critical commercially, since it enables improved strength in vehicle chassis components while also saving up to 30% in weight. However, fatigue concerns prevent the widespread usage of such high performance steels in demanding structural applications.

The vast majority of steel components used in vehicle structures are made primarily through the mechanical blanking operation. The clearance between the punch and die is the primary determinant of the surface roughness characteristics, residual stresses, and work hardening exponents of mechanical cut-edges. If the clearance is adjusted right, the shearing cracks formed at the top and bottom shear edges will meet to form an optimal mechanical surface [12].

The cut-edge characteristics of automobile structures created during the mechanical blanking and laser cutting procedures have a major impact on their fatigue life performance. By modifying critical cutting process parameters, mechanical blanking clearance, and the relation between power and traverse cutting speed during the laser cutting process, it is possible to achieve optimal fatigue lifetimes.

Optimal fatigue lives are attained by minimizing the cut-edge surface damage and by controlling the near edge microstructural deformations during each cutting process. It is the critical significance of fatigue which is the limiting factor towards being able to effectively downgauge steel grades used as automotive chassis [37, 48].

With its great flexibility and capacity to cut sheet components with complex geometries with high precision, laser cutting is a viable alternative to mechanical blanking. The observed changes to the cut-edge surface during CO2 laser cutting are a result of material deformations caused by the laser beam during the cutting process [35]. These changes have a substantial effect on the fatigue properties of components. However, additional impacts of the treatment on the material must be considered. The interaction of the laser beam with the material results in localized heating and cooling, as well as the formation of a heat-affected zone (HAZ) whose properties are determined by the laser power and transverse cutting speed parameters [12].

The laser cut surface, as shown on Fig. 2.28, can be divided in three zones through the thickness of the cutting kerf: IN, MID, OUT, corresponding to the laser pulse entrance, center, and exit region. The corresponding SEM micrographs extracted from cut samples demonstrate the extension of the HAZ, denoted by a dark area.

Blanking Quality

Blanking establishes the dimensions of any part features utilized to locate the hot steel in the hot-stamping die. The dimensions of the blank must be exact enough to avoid interfering with the features of the hot-stamp die (such as peripheral guides, etc.). During blanking, any hole features

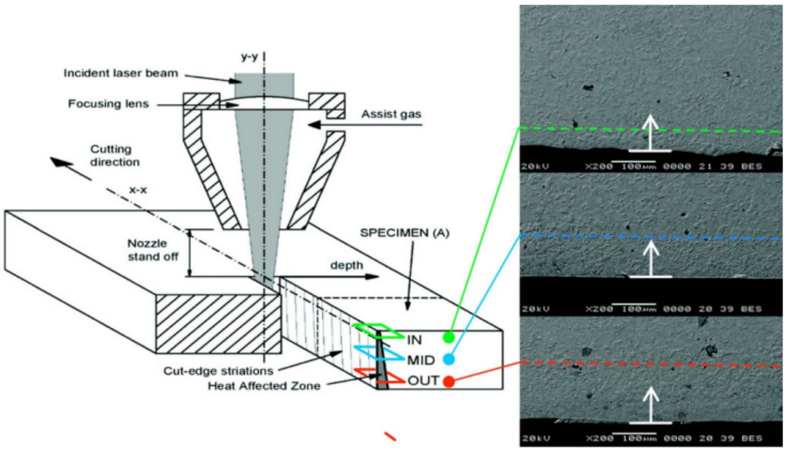


Figure 2.28: Laser cut surface [37]

that are incorporated into the blank and carried over to the final product are also set. The two primary considerations about blanking quality are as follows:

(1) Wear of the cutting tools creates excessive burrs in blanks. Keeping sharp and well-maintained cutting tools and punches will guarantee that the blanks do not develop excessive burrs, which can obstruct the hot-stamping process. Additionally, it will guarantee that any holes that extend through to the hot-stamp tool and finished component have the correct size (as pins wear, the hole diameter in the metal shrinks).

(2) Pitch from the raw material input is inconsistent. Maintaining consistent pitch ensures that blanks fits properly between peripheral guides and that hole dimensions are always in the same relative position to one another and to trim lines. The final shape of the blank can be controlled by creating a simple jig that captures the blank trim. This assures consistent pitch throughout the blank stamping process and that the blank is suitable for the subsequent production procedure. [10].

2.4 Mechanical Cut: Tool Life

A progressive die is expensive, and because it is usually set up in an automatic press with scrap cutter, feeder, straightener and uncoiler, the total cost of the auxiliar equipment is also high. Therefore, it is important to predict the tool life and analyze the size of the batch to validate or not the investment to apply this process into the production. It is then important to understand wear factors that influence tool life.

Wear patterns

Wear patterns include flank, tip edge and face wear. Flank wear can be characterized by length (l in Fig. 2.30) or area. Flank wear is crucial since it dictates the amount of length lost during regrinding. It is caused by adhesion and abrasion and grows in proportion to the number of

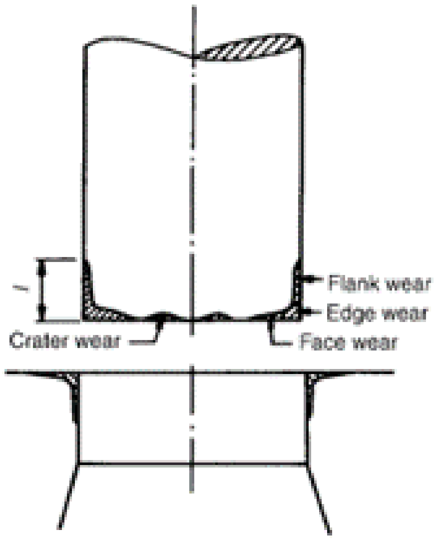


Figure 2.29: Wear of shearing punch and die [44]

strokes—more significantly when the clearance is too small. The wear length rises asymptotically up to the maximum penetration given by the punch. A semi quantitative assessment is possible by inspecting the flank for scoring and pickup.

Even though it is difficult to distinguish from flank wear (Fig. 2.30), tip edge wear is important since it dictates burr height. This, too, increases with the number of parts and is at a minimum at some fairly generous clearance (12%). Excessive clearance (17%) leads to a large burr also, but only because the part is finally separated by tensile fracture, and not because of wear. Face wear is mostly abrasive in origin and as such increases linearly with the number of parts [1].

Wear Control

Because friction has little or no effect on the shearing (blanking, punching) operation, the primary function of lubrication is to reduce die wear. Adhesive, abrasive, fatigue, and chemical wear mechanisms all contribute to the deterioration of the punch and die profile, resulting in an increase in clearance and the formation of a burr on the sheared portion. Wear is minimized by selecting the suitable die materials and lubricants. Die materials must be tough while maintaining enough ductility and low adhesion. Die surface coatings are critical. Lubricants are almost always formulated to decrease adhesive and abrasive wear by forming boundary and extreme-pressure (EP) layers. Due to the fact that lubrication has no direct effect on the shearing process, it is more relevant to evaluate the many aspects affecting wear control and die life [1]. Fig. 2.30 summarizes the general elements affecting tool life in cold work applications.

In general, the tool material and/or surface treatment should be selected based on the most likely failure mechanisms. Cold working dies may sustain damage from wear, galling, indentation, chipping, and cracking as a result of the following:

-Abrasive or adhesive wear that results in continuous or discontinuous material loss, depending on the sheet material, application, and process conditions.

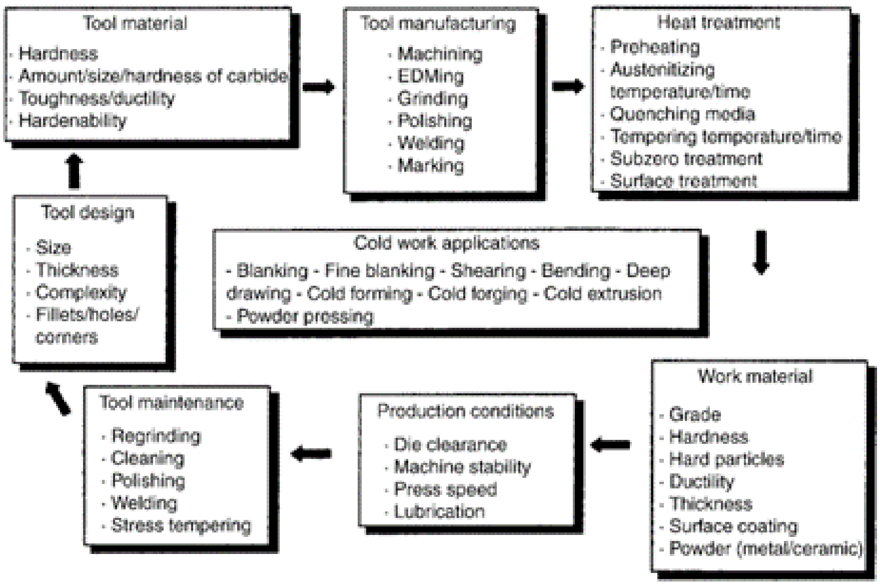


Figure 2.30: Factors influencing tool life in cold work applications [26]

-Galling severity is dependent on the smoothness of the tool's surface, the chemical composition of the tool and sheet material, and the type, size, and distribution of hard phases in the tool material. Coating the surface may help to lessen or eliminate galling.

-Plastic deformation occurs when the working stresses exceed the tool material's compressive yield strength.

-Chipping as a result of process stresses and the tool material's fatigue resistance.

-Cracking caused by process stresses, the length, and geometric configuration of an existing crack results in a stress intensity greater than the material's fracture toughness [1].

Blanking may reveal all of the failure mechanisms. Plastic deformation, chipping, and cracking damage is frequently uncontrollable and should be prevented at all costs to avoid costly production interruptions. Wear and galling are more predictable modes of failure that may be controlled through scheduled die set maintenance [44].

Shear Blade Tool Steels

The composition and thickness of the material being sheared are the most important factors in the selection of a blade material. Tool steels vary in toughness and wear resistance, and the metals being sheared vary in hardness and resistance to shearing. For shearing material of greater thickness and higher hardness, it may be necessary to decrease blade hardness, or change to a less wear-resistant blade material or to a shock resistant tool steel having a hard case over a tough core, to obtain the toughness needed to resist edge chipping. The rate at which a blade wears in cold shearing depends chiefly on its carbon content and hardness. In shearing metals such as high-strength low-alloy steels, hardness of D2 blades must be kept below 58 HRC to prevent breakage

[1].

Shear Blade Life

Available data report blade life in terms of number of cuts, linear footage (in slitting), tonnage, or time between redressings. The service data in Table 2.3 encompass all of these variables. The number of cuts per edge before regrinding is the most common basis of evaluation [1].

Table 2.3: Service data for shear blades [44]

Type of shear	Material sheared	Thickness of material sheared		Blade steel	Blade hardness, HRC	Blade service before regrinding
		mm	in.			
Cold shearing of steel						
Sheet metal	Low-carbon steel	5	Up to $^3/_{16}$	W2	58 to 60	30,000 cuts
Sheet metal	Low-carbon steel	5	Up to $^3/_{16}$	A2	58 to 60	55,000 cuts
Sheet metal	Low-carbon steel	5	Up to $^3/_{16}$	D2	58 to 60	100,000 cuts
Bar shear	1025 & 1040 steel	25	1	W2	58 to 60	20,000 cuts
Bar shear	1025 & 1040 steel	25	1	L6	...	40,000 cuts
Bar shear	1025 & 1040 steel	25	1	S5	...	100,000 cuts
Sheet and strip	1010 steel	5	Up to $^3/_{16}$	D2	58 to 60	150,000 cuts
Sheet and strip	Stainless steel	12	0.478	D2	58 to 60	65,000 cuts
Sheet	2 to 5% silicon steel	0.8	0.032	D2	58 to 60	45,000 cuts
Slitter	Carbon, silicon and galvanized steels	0.16 to 4	0.005 to 0.160	D2	58 to 60	1 week(a)
Slitter	Stainless steel	0.8 to 1.5	0.030 to 0.060	D2	58 to 60	15,000 ft
Blade 1.5 m by 100 mm by 25 mm (60 by 4 by 1 in.)	Stainless and silicon steels	2 to 2.5	0.080 to 0.100	D2	60 to 62	2 weeks(b)

2.5 Summary

The current chapter gives an introduction on the hot stamping process and its historic context. The introduction of Press Hardened Steels, which are included in the Advanced High-strength steels (AHSS) class, allow for the attainment of thinner and lighter but yet hard components for vehicles. That it possible due to the manipulation of a microstructure transformation in the steel, by the heating of the metal and sequentially pressing and quenching the steel sheet in a die set. Since the pressing is done at high temperatures, this process allow for more complex shapes to be obtained, compared to cold stamping. The blanking of the steel sheets, either by mechanical or 2D laser cut, is a manufacturing process that precedes the hot stamping but that is usually included in the process line. The same applies to 3D laser cut, which is done after the hot stamping, and allow for the obtaining of complex cut geometries with tight dimensional tolerances.

The second part of this Chapter presents a bibliographic research on topics useful to base and validate the implementation of the proposed optimizations further discussed on Chapter 4. Computer assisted engineering (CAE) validation of a hot stamping process introduces the necessary inputs to the FE simulation of the hot stamping of a component. This procedure saves time and money because it gives a preview of the real life behaviour the parts undergo during the process by solving a multiphysics problem based on computer models. It is also done a comparison between the 2D laser and mechanical cut and the quality obtained on both, to proof it is possible to change the current blanking process. The last topic addresses the tool life when using a mechanical cut, to further study the economic viability of implementing this process.

Chapter 3

Methodology and Materials - Company Case Studies

3.1 Introduction

In this chapter is made an introduction of Sodecia, the company where the internship took place, and the methodology and materials used to carry out the developed projects and case studies. It hands a brief description of those projects and some analysis tools that will be of use.

3.2 Case Study - Sodecia

Sodecia began as a privately held company in Portugal in 1980, but it was not until 1997 that it achieved international prominence with the establishment of Sodecia Brazil, in São Paulo. The first technological center opened in 2005 in Porto, and the group continued to acquire smaller companies and build new plants in both Portugal and Brazil. The group expanded into new markets, including Argentina (2006), Germany (2009), Canada and the United States of America (2010), India and China (2011), and South Africa (2013), establishing itself as a serious and respected corporate company in the sector. Today, the group operates in 32 different locations, Fig. 3.1, across 16 countries in Africa, Asia, Europe, North and South America employing 7086 professionals worldwide.

Sodecia is a leading Tier 1 supplier of the largest auto OEM's companies, such as BMW, Jaguar, Land Rover, Ford, FCA, VW, Volvo, Seat, Skoda, Renault Nissan Mitsubushi, PSA, GM, Honda, Daimler, developing new products and ideas for the future. With its headquarters in Porto, Portugal, Sodecia has grown into a global industrial corporation that operates as a full supplier of Safety Interiors, Powertrain, and Body in White. It operates three technological centers that provide comprehensive collaborative engineering services: Porto, Portugal; Hannover, Germany; and Detroit, Michigan, USA.

Figure 3.1: Sodecia units locations around the world [52]

3.2.1 Sodecia Automotive Saarlouis

This unit is the latest acquisition by the group Sodecia and is its second factory located in Germany, a central location for European distribution. It is focused in the production of body in white components, Fig. 3.2, for the automotive industry, obtained by hot stamping. The factory's building has three main sectors: prototyping and 2D laser, hot stamping and 3D laser, welding and storage. On the prototyping area there are ovens, cold stamping presses and one 2D laser. The second warehouse has three hot stamping lines, each of them composed by one conveyor, two robots and one press. On the same sector, there are also nine 3D laser cells, three for each hot stamping line, and two extra ones, currently used only for rectifying some defects that occur sporadically. The last warehouse of the building is used for the welding process and for storage of the ready to ship components. In terms of departments, there is engineering, production, quality, maintenance, logistics, IT, Human Resources and Finance. The units counts with the help of approximately two hundred (200) workers.

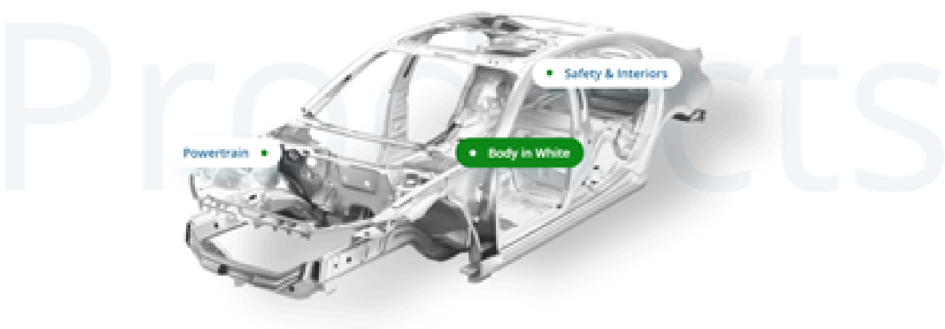


Figure 3.2: Solutions for cars provided by Sodecia [52]

3.3 Methodology

The beginning of the internship required a period of familiarization with the company. In an initial phase, safety training was carried out, not only on personal protective equipment, but also on mandatory rules of circulation and behavior in the various parts of the facilities. In addition, guidelines were given on how to proceed in case of personal accident, fire, or need for evacuation. The insistence on the fulfillment of these rules showed the company's concern for workers' safety. In a second phase, a visit was made to the facilities and to the various departments in which the company is subdivided to coordinate operations. Training was also given on the operation of each piece of equipment and the production line. After this training, a meeting and a more in depth tour in the factory was done with the company's plant manager to better understand the production and to expose the intended objectives for the internship.

The first part of the work consisted in the observation of the production of several parts, searching for data and studies already done in the company and collecting missing data, namely cycle times broken down for each production step and for each component (2D laser, robots, oven, pressing and quenching, rework, 3D laser and welding). This was followed by a study of the entire hot stamping process, including laser cutting, and the literature review in order to come up with some measures and alternatives to achieve cycle time and material waste reductions.

The cycle times data breakdown flagged the production of a component with a bottle neck in a stage of the line different then the remaining products. That became the first case study and the subject further analysed in Project 1 for reducing the cycle time.

Through the literature review, the opportunity arose to change the blanking process, replacing 2D laser cutting with a mechanical cut. This is the proposal that Project 2 is based on and will be analyzed and discussed in Chapter 4.

3.4 Materials

Since no specific components were detailed to develop the optimization, a survey of all the parts, their dimensions and analysis of the profiles was made. The parts were organized in a Microsoft Excel file by importance and the Pareto analysis was made to obtain the ABC curve (Fig. 3.3). This method of stock organization aims to determine which products are most important to a company. Through this analysis it was possible to select the 20% items in production that represent 80% of the company's revenue and focus the analysis on these products. The optimization of these items would have the biggest impact. From there were defined some parts that would serve as a case study to present to the board and demonstrate the impact of the process change discussed in Project 2.

AutoForm's software solutions form a comprehensive platform for the engineering, evaluation and improvement of the sheet metal forming and Body in White (BiW) assembly processes. It was through the use of this software that the hot stamping simulation was carried out in Project 1, to validate a change made in the part layout. This change on the part was conducted to enable the robot's grip position change, optimize its movement and reduce cycle time. It was also used to approach the optimization of the blank in Project 2 to reduce material waste and nest the parts. Therefore, this software was a very valuable tool.

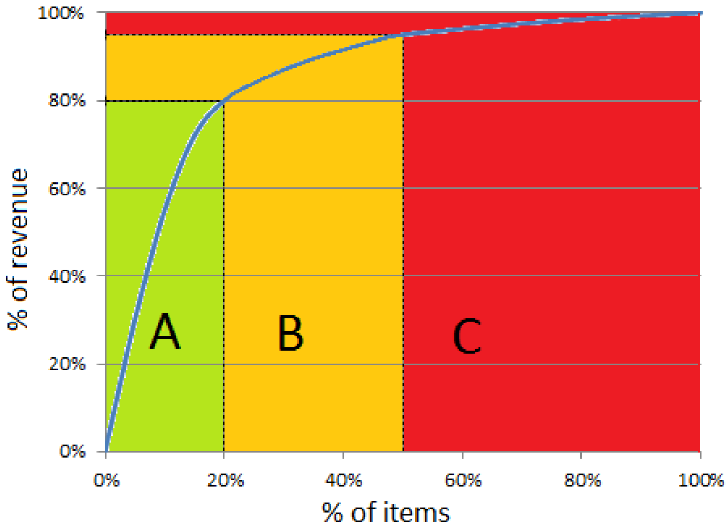


Figure 3.3: Pareto analysis - ABC curve [21]

Chapter 4

Optimization Studies - Results and Discussion

This chapter discusses the two projects developed along the intership in Sodecia Automotive Saarlouis. The projects focus on the production of two different components: the first one (Project 1) aims to reduce the cycle time and the second (Project 2) to reduce the material utilization.
On both it is firstly given a motivation for its development, followed by the presentation of the component, the current production steps and processes involved. For each of them it is also presented the reached solution to optimize the production and the impacts that its implementation carries.

4.1 Case Study 1 - Cycle Time Reduction

4.1.1 Motivation

The cycle time in high volume productions, such as the one where the intership took place, have a big impact on the company's productivity. In fact, even the smallest reduction of a few seconds per part manufactured, represent a big saving in the overall costs. In this type of industry, the hourly-cost of the machinery is extremely high and a cycle time reduction impact not only that cost reduction but also impact the number of shifts (men-power) needed. That, for itself, would be a good enough motivation, to which is added the possibility of accepting new orders, if a big enough reduction is obtained, that are currently being declined because the factory is working at its maximum production capability.

While analyzing the production of different components, the part assessed in this project stood out due to the fact that the bottle neck was not the pressing and quenching of the parts. Therefore, all the steps where timed to understand what was holding the production on the press, which is the most expensive machine per hour in the production. Project 1 presents the studies made to overcome this problem and reduce the cycle time for this part's production.

4.1.2 Case 1- Part A

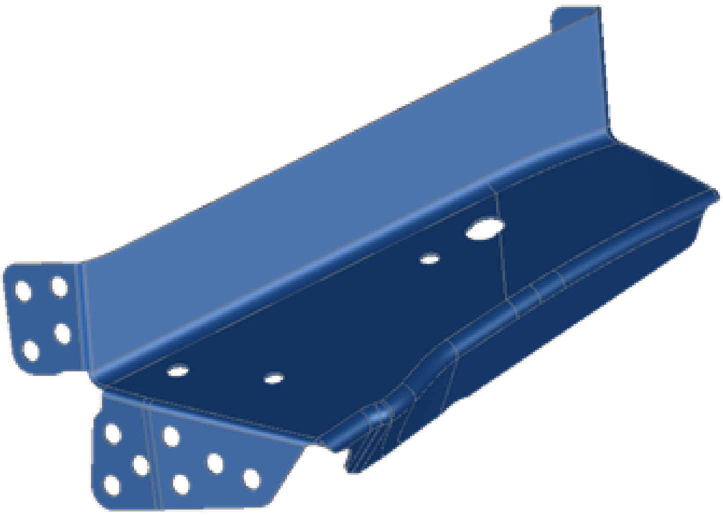


Figure 4.1: 3D of part A, in assessment in Project 1

Each part, as shown on Fig. 4.2, produces two parts, one right and one left, as the one on Fig. 4.1. The separation of the blank into the two parts and the holes are made after the hot stamping process, using a 3D laser equipment.

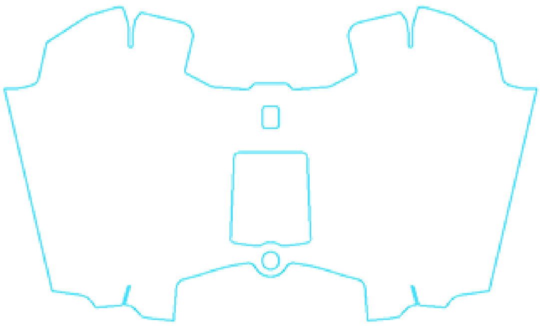


Figure 4.2: 2D of the part's blank to be hot stamped

4.1.3 Current Production Procedure

The production starts with the 2D laser cut of the part from the rectangular blanks. After that, the part's blank is stacked and moved to the hot stamping feeder from where robot 1 (R1) picks one blank at time, using a suction cups grip, engraves it on both sides and transports it to the conveyor. Those parts are heated from room temperature to around 950ºC, when the material reaches the austenitic phase. The part is kept at that temperature for approximately 5 min to assure a complete microstructure transformation. The parts are then moved by robot 2 (R2) from the conveyor to the press where the blank is pressed and quenched. This movement needs to be very quick because there is a big amount of heat transfer from the part to the environment by radiation and convection. That is critical because the formability decreases greatly when the part decreases its temperature and outers the austenitic phase. Besides the decrease on formability, the intended martensitic microstructure may not be obtained if this transfer step is not fast enough. After quenching, robot 3 (R3) picks the stamped part, using a clamps grip, instead of suction cups, and moves it from the press die to the last conveyor. In the end of the conveyor, an operator stacks the parts in a container which is then transported to the following process. The last step of the production is the 3D cut, using an automatic laser machine. The processes involved in the manufacturing of this part are summed on Fig. 4.3 .

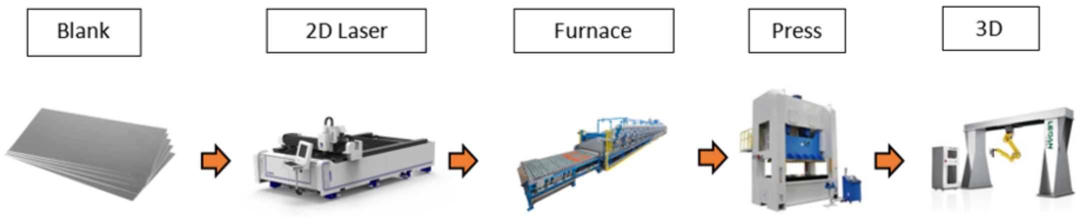


Figure 4.3: Process sequence to obtain the final part (re-created after [15])

On Figure 4.4 is presented the plant of the hot stamping line used to produce the current part, including the robots used to operate the parts in the intermediate steps.

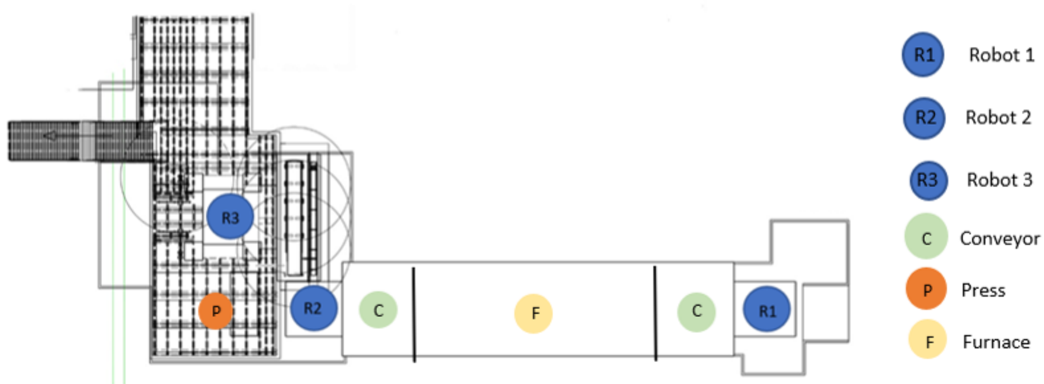


Figure 4.4: Hot Stamping plant (re-created after [15])

On Figure 4.5 is presented a sketch of Robot 1 and the suction cups grip used to pick the blank, engrave the parts and move it to to conveyor for the heat treatment. Robots R2 and R3 have the same fixtures as the one presented but different grips. Due to the high temperatures of the blanks before and after the quenching, it is not possible to use suction cups as a grip.

Figure 4.5: Robot (R1) and suction cups grip [53]

While analyzing the production line, it was notable that the press was "waiting" for the arrival of new blanks, therefore not working at its maximum capability. In fact, after quenching a part, the press stayed open for unnecessary time. To find the reason behinde, the previous stages were studied and timed. Firstly, the heat treatment in the furnace was reviewed to assess if a reduction was possible. However, it was concluded that, for the thickness of the blank, the heat treatment time was set to the minimum required time for the formation of a martensitic microstructure. Therefore, the bottle neck of the process had to be the movement of robot 1. Regarding the R1, before transporting the blank to the conveyor, it needs to undergo an engraving step on both parts (left and right side of the blank). The parameter of the robot showed that the velocity was set to its maximum capability (100%). The sequence of this process was scrutinized to find a solution for reducing the cycle time. In this production the bottle neck should be either be the heat treatment in the furnace or the pressing and quenching, assuming they are optimized for obtaining the final desired properties. Those steps are summarized on Fig. 4.6.

1- The robot picks the part from the stack, applying the suction cups in the middle of the part.

2- Robot moves the blank to the support table.

3- Location of the suction cups is changed from the middle to the left side.

4- Part is moved to the center of the engraving area.

5- Right side of the part is marked.

6- Part is moved to the center of the engraving area.

7- Robot moves the part to the support table.

8- Location of the suction cups is changed from the left to the right side.

9- Part is moved to the center of the engraving area.

10- Left side of the part is marked.

11- Part is moved to the center of the engraving area.

12- Part is transported to the conveyor for heat treatment in the furnace.

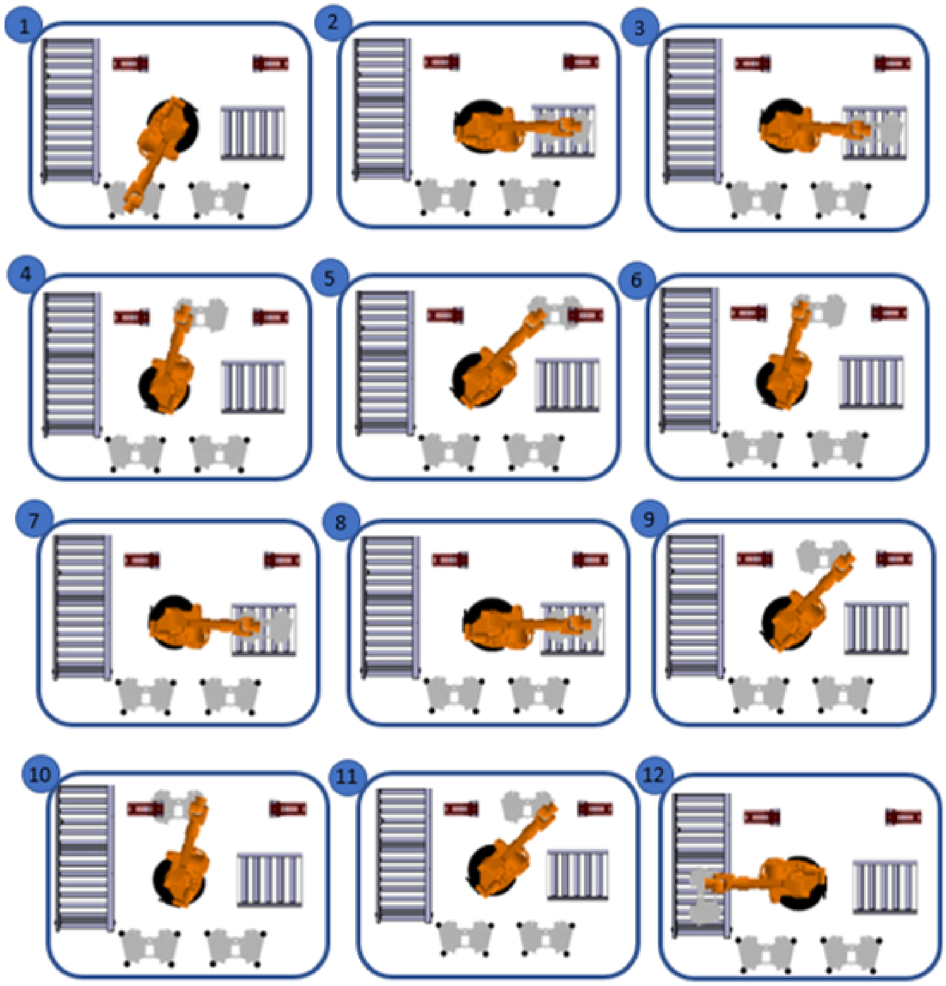


Figure 4.6: Current 12 steps of the robot R1

In this process the engraving of the Julian Date (JD) is done in every part manufactured. There is a part JD and a Sodecia PHS JD, both marked on the part at this stage. This marks allows for traceability of the parts: the steel coil where it originated from, the Hot Stamping Press (PHS) and batch it traces back to. Among other reasons, this is helpfull to unveil possible factors behind quality issues of the final part, such as problems with the supplying coil or the hot stamping parameters of a batch. On Fig. 4.7 there is an example of an engraving number of this part and the location of this engraving on the part e given in Fig. 4.8.

Figure 4.7: Traceability engravings on the parts

4.1.4 Optimization Proposal

An immediate solution would be to cut steps 2, 3, 7, 8 and 9 and program the robot to do the marking on the two sides sequentially, without having to change the positioning of the suction cups on the part. That would mean changing the position of the suction cups to the middle of the part, as shown on Fig. 4.8.

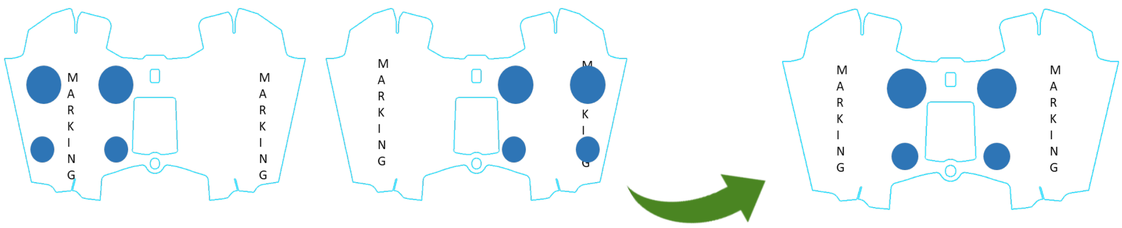


Figure 4.8: Grip position change

However, the problem with this solution is that the connections of the suction cups collide with the engraving machine, damaging the equipment, not marking the parts and provoking the fall of the part. Fig. 4.9 shows the 3D of the engraving device and the connectors of the suction cups.

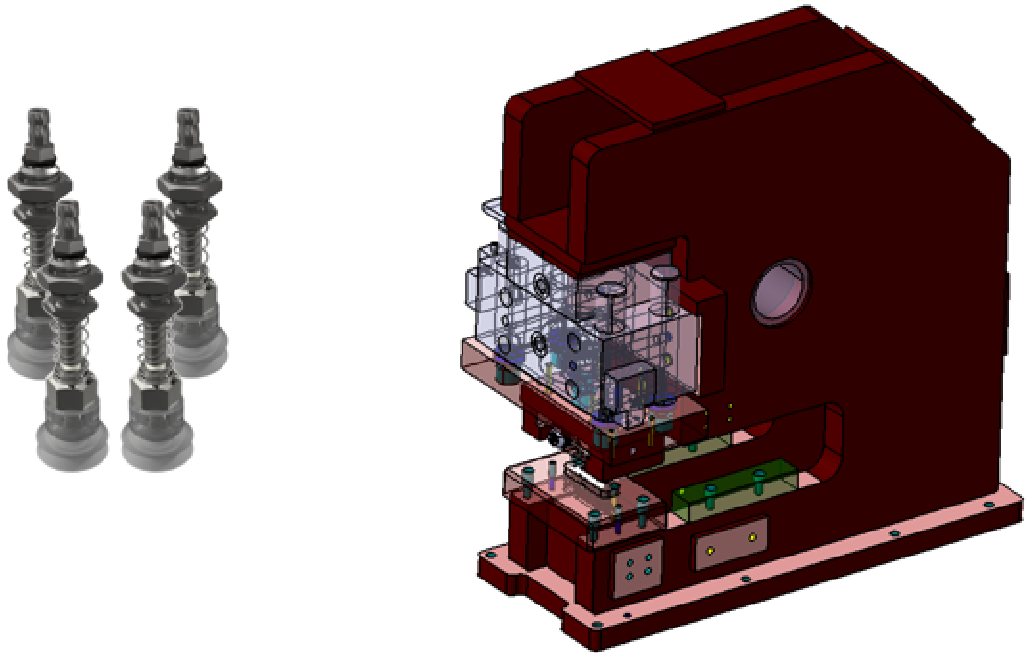


Figure 4.9: 3D of the connectors from the suction cups and the engraving machine

To solve that problem but still be able to mark the two sides consecutively, a reduction of the center hole was studied. Since it is not part of the functional final part, it can be considered. The proposed change is shown on figure 4.10.

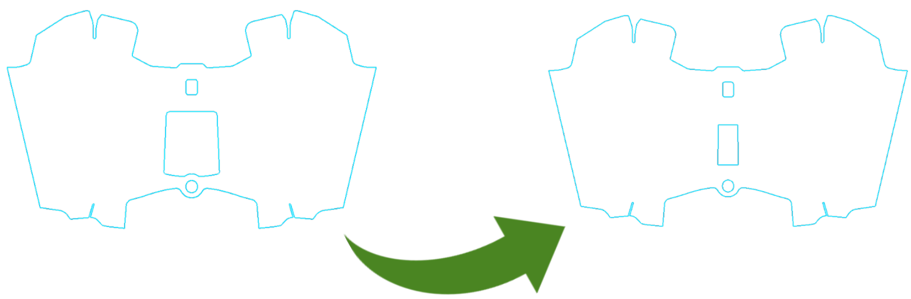


Figure 4.10: Proposed reduction of the blank's center hole

It would be necessary to move the suction cups 21 mm to the center on both sides in order to prevent the collision with the marking device. The reduction made was of 29.61 mm on both right and left side, 21.46 mm on the top and 15.66 mm on the bottom (Fig. 4.11).

The reduction of the center hole allows for the suction cups to be placed closer to each other and further from the marking areas. This abolishes the crush of the connections of the suction cups with the engraving machine.

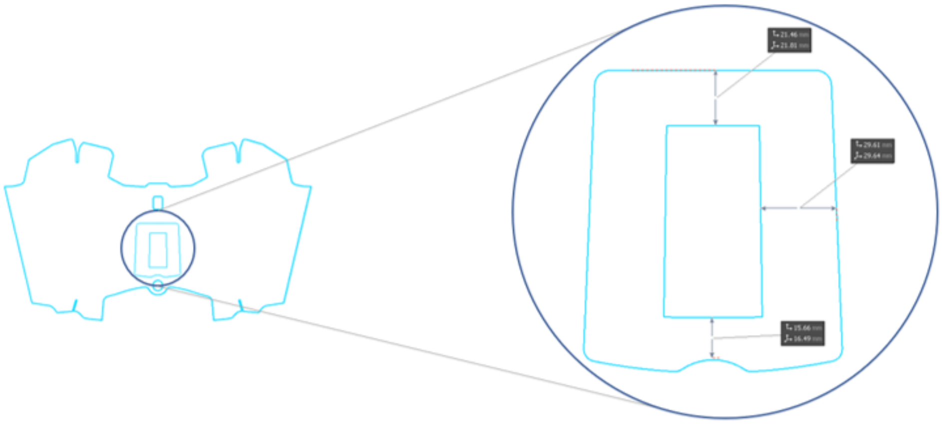


Figure 4.11: Dimensional reduction of the part's center hole

The outer line on 4.11 represents the previous hole dimension and the inner line the proposed new hole.

After granting there is no collision, an assessment has to be made regarding the location of the blank in the existing die. In fact, due to the high cost of the dies it wouldn't be executable to make any change on it. Therefore, the new part design must be compatible with the existing die, more specifically to the punch. Using Autoform, and considering the locating pins used for centering and positioning on the die, it was assured there were no conflicts. The existing centering positioner, in the middle of the two pins (Fig. 4.12), did not allow for the complete removal of the center hole, as initially was thought to be a possible solution. The hole in the proposal is the maximum reduction possible to allow the proper assembly in the die (Fig. 4.13).

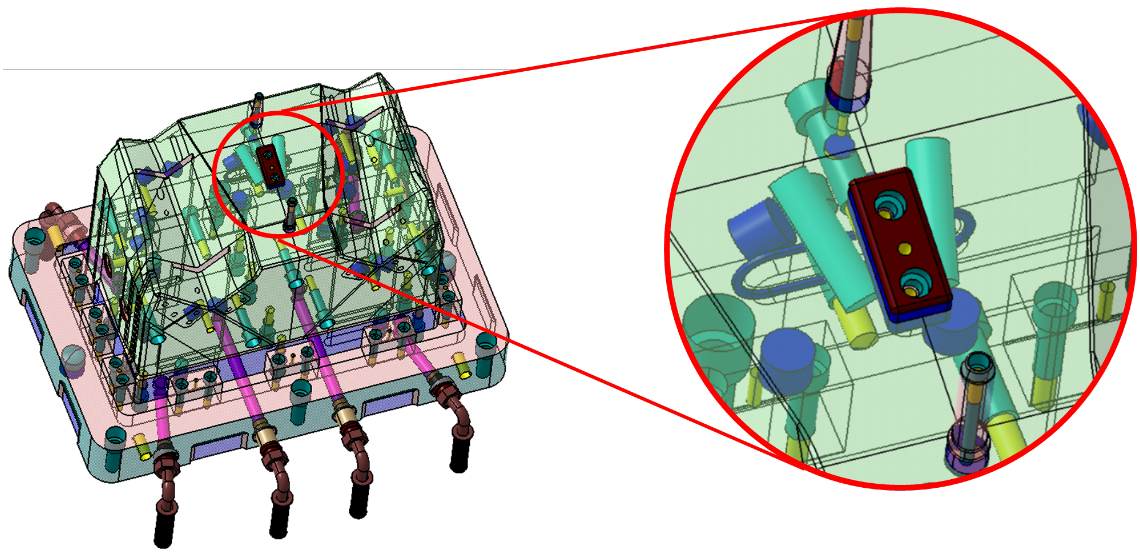


Figure 4.12: Service data for shear blades

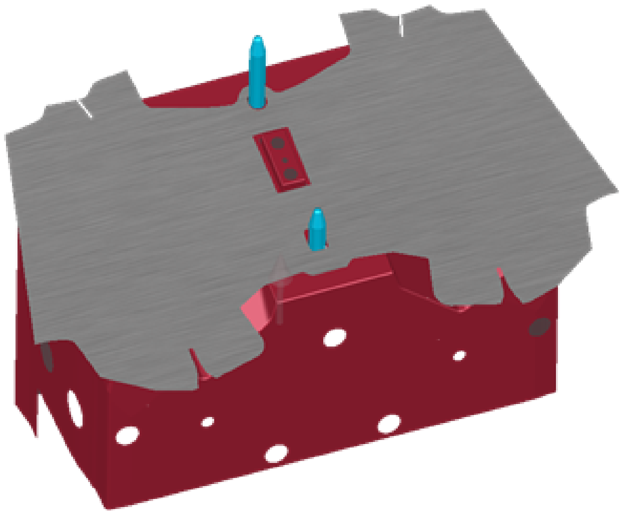


Figure 4.13: Assembly of the blank on the die

4.1.5 Simulation and Validation

Since the blank shape was changed, it should go through an analysis to predict its behavior while undergoing the hot stamping process. Finite element (FE) simulation of the hot stamping process is useful to predict final item properties such as thickness, temperature, and hardness distribution.

During hot stamping, mechanical deformation, heat transfer, and microstructure evolution all occur simultaneously. As a result, FE simulation of the process is difficult. To represent what happens during hot stamping, most researchers employ a combination of multiple FE codes. Making appropriate assumptions while ignoring the impact of some of the less significant parameters can significantly shorten the time required to produce reasonably accurate results when using FE simulation. However, some parameters must be provided as input to the FE codes.

Essential material parameters: such as emissivity and flow stress as a function of temperature, strain, and strain rate are used as input. Young's modulus, Poisson's ration, thermal conductivity, specific heat capacity, and coefficient of thermal expansion are also required, all of which must be calculated as a function of temperature.

Essential process parameters: such as final austenitization temperature, blank transfer time, blank temperature as forming begins, die stroke versus time, contact heat transfer coefficient between blank and tool as a function of pressure and distance between tool and die surface, coefficient of friction as a function of pressure; initial tool temperature for non-isothermal simulation; temperature of the cooling medium needed to cool dies; blank holder force, closing pressure of the tools; time required for quenching and air cooling.

The software used in the feasibility study was Autoform, available in Sodecia Automotive Saarlouis. In this software the material parameters for the steel 22MnB5 are available in the library and are presented in Appendix A.1.

The formability simulation results are presented on Fig. 4.14.

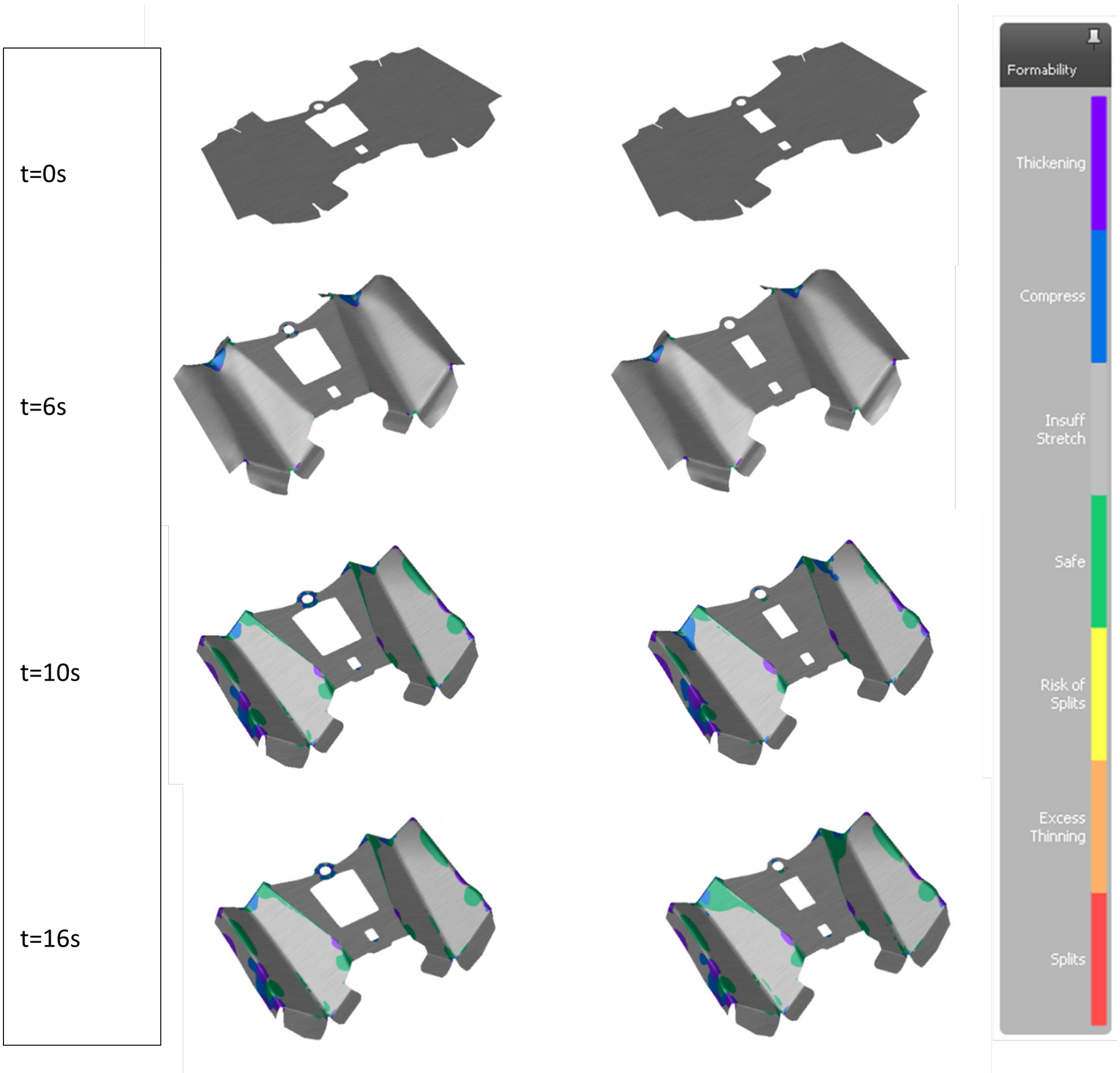


Figure 4.14: Formability simulation of the proposed blank layout: left - current solution; right - proposal

On the left side of Fig 4.14, is presented the formability simulation of the current blank and on the right side the proposed blank change simulation. The represented images were taken at the exact same time set of the simulation (t=0s, t=6s, t=10s and t=16s). Until t=10s occurs the downward movement of the punch. From there on and until t=16s, occurs the quenching and upper movement of the punch.

After analyzing the simulation results, it is visible that there is no risk of splits or excess thinning and that the proposal is feasible. The formability results are very similar on both blanks. The main difference between the proposal and the current blank layout is the decrease of thickening and compression on the top hole. This hole, although not part of the functional final piece, has the purpose of centering the part in the die and as a locator in the 3D laser trimming process. It might as well be an improvement in better positioning of the part in the 3D locators because it has less distortion. The reduction of the thickening is a result of the increase of material on the proximity's of the hole. It is important to emphasize that this proposal does not affect the material waste, which stays the same as the previous layout.

4.1.6 Improvements

With this new blank layout, it possible to reduce the robot steps from 12 to 7. The proposed routine for the robot is presented on Fig. 4.15.

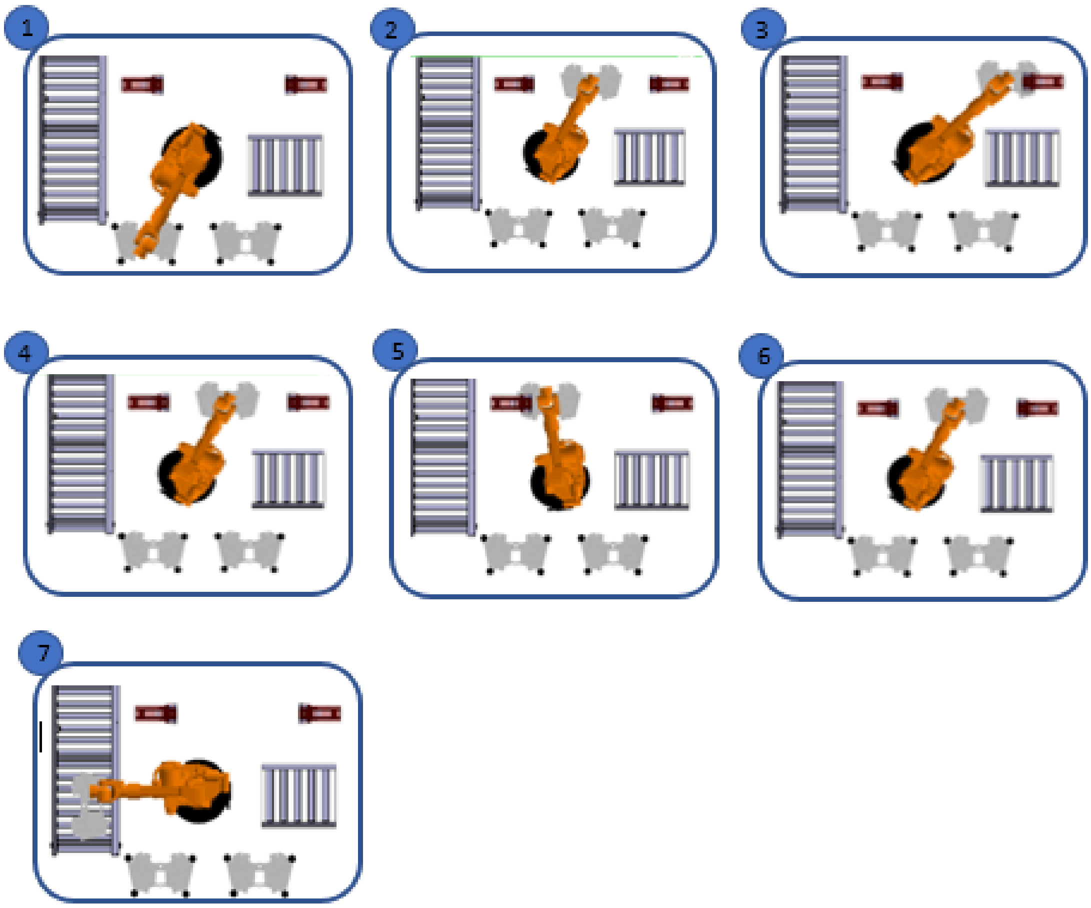


Figure 4.15: Necessary steps of robot R1 with the proposal

1- The robot picks the part from the stack, applying the suction cups in the middle of the part.
2- Part is moved to the center of the engraving area.
3- Right side of the part is marked.
4- Part is moved to the center of the engraving area.
5- Left side of the part is marked.
6- Part is moved to the center of the engraving area.
7- Part is transported to the conveyor for heat treatment in the furnace.

Regarding the 2D laser, it was decreased in 5% the cycle time, due to the perimeter reduction of the center hole (Fig. 4.16).

The routine of the robot R1 optimization translates in a reduction of 28s in the robot movement, which represents a decrease of 42% of the robot (R1) previous cycle time (Fig. 4.17).

This optimization reflects in a decrease of 21% in the cycle time of the hot stamping line (this percentage does not take into account the reduction of the cycle time of the 2D laser). In Total is possible to reduce 87 hours per year in the production of this component by implementing this changes. Table 4.1 presents the discriminated hours saved in each production process.

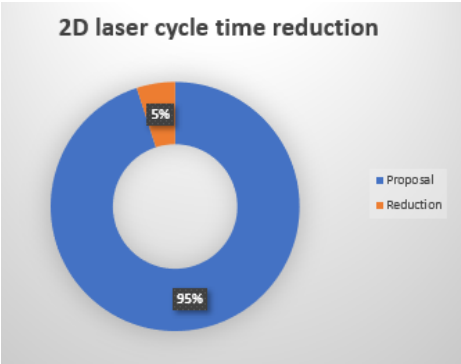


Figure 4.16: 2D laser cycle time reduction

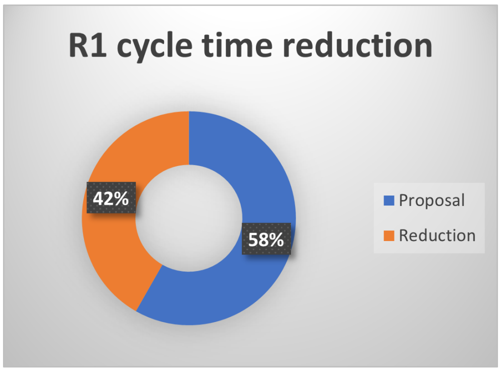


Figure 4.17: Robot R1 cycle time reduction

This cycle time reduction represents an increase on productivity which means that, in the same time-frame, there are produced more parts. Since there is a fixed number of parts produced per year of the component, this reduction does not lead to an increase of the total parts produced but a reduction of the cost per part. The hot stamping equipment has a high hourly cost and a reduction of the hours needed to manufacturing a product reduce considerably the costs per part. Besides that, there is also a saving in reducing the number of shifts/workers needed for the production of a part series. The cycle time reduction is also important because, if a significant number of hours is reduced, it allows for new orders of other components to be accepted by the company.

Table 4.1: Number of hours reduced in per year

Process	Current [h]	Proposal [h]	Saved Hours per Year
2D Laser	191	181	10
Hot Stamping Line	367	290	77
		Total	**87**

4.2 Case Study 2 - Material Waste Reduction

4.2.1 Motivation

Material utilization is a critical concern in today's automobile industry. With the price of steel and aluminum continuing to rise and the automobile industry incorporating an increasing amount of high-strength steels and lightweight materials, manufacturers are constantly looking for ways to optimize their material usage. Material utilization has the greatest impact on a low-end car model, but even in smaller productions such as high-end car models, significant cost savings can be achieved with every millimeter which is saved in blank size and each scrap area avoided. The focus of this study is optimizing the production process of one automotive part, obtained by hot stamping. This optimization consists in reducing steel waste, also commonly referred to as scrap. The part has tight tolerances, imposed by the costumer, and that is hard to maintain in a hot stamping line. In fact, there are several variables during the process of hot stamping that can collide with very restrictive dimensional quality parameters. The dilatation of the material, for instances, and a homogeneous temperature of the molding tool are hard the keep constant and can affect the final dimensional and mechanical properties of the parts in the same lot of production. Besides that, is also important to have a blank material utilization percentage as high as possible to reduce steel waste of the process. The relevance of this approach relies on the fact that the material cost is normally the biggest component in the cost's breakdown assessment of a hot stamping production, as visible in Fig. 4.18.

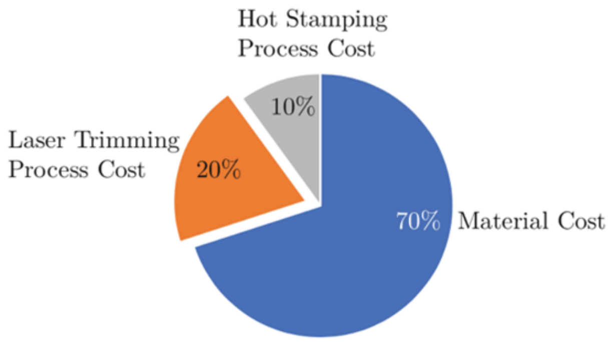


Figure 4.18: Aproximate cost breakdown of the most common process: direct hot stamping of ALSi-coated 22MnB5 followed by laser trimming [10]

4.2.2 Case 2 - Part B

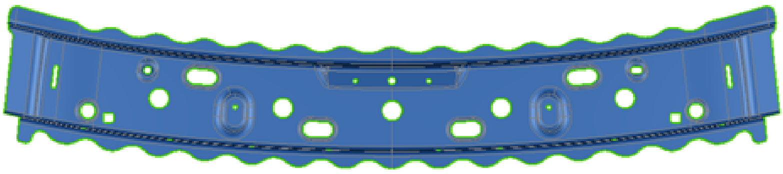


Figure 4.19: Part B, in assessment in Project 2

4.2.3 Current Production Steps

For the current part (B), the 2D laser blank cut is insourced, arriving to the factory stacks of big rectangular blanks. The cost paid include the transport and two cuts: slitter and shearing. The “mother” coil is the primary material from the steel suppliers. The slitter cut consists in cutting this coil into two or more smaller width coils. For that, the coil is uncoiled and slitted into smaller and standard width steel sheets which are then again coiled. The supplier receives all the orders from the costumers and try to group them in the most optimized way in the “mother” coils, in order to obtain the most usage out of it. On Appendix A.1 are presented the standard width dimensions from which the clients can order. Anything outside the standard width has to be consulted with the supplier, and the price is normally higher for tailored dimensions. The customer’s sales department has to consider whether it is worthwhile placing an order with a slightly larger width than needed, but within the standard sizes, or ordering a tailored one. The shearing cut follows the slitter and is done to obtain rectangular blanks, which are then ready for the 2D laser cut into the desired contour of the parts to hot stamp. The complete production line is summarized on Fig. 4.20, for the outsourced steps and on Fig. 4.21 the insourced production steps.

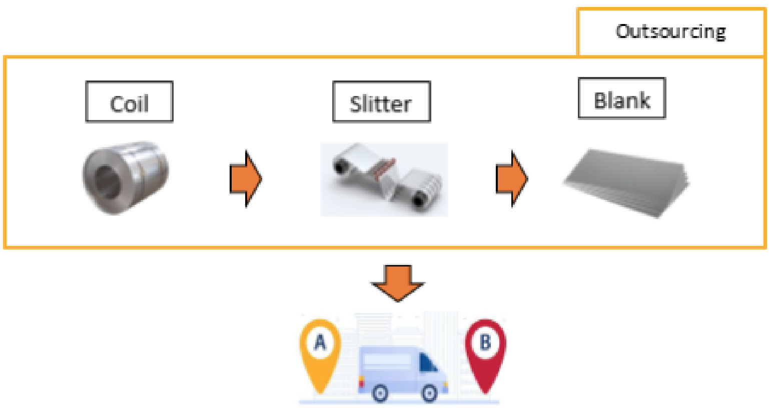


Figure 4.20: Current outsourced production for the part in assessment (re-created after [15])

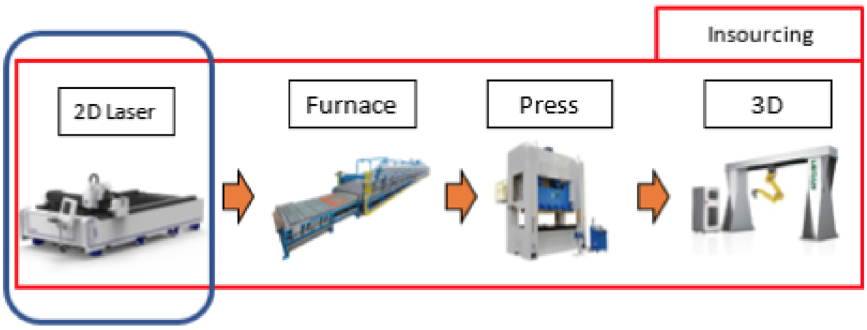


Figure 4.21: Current insourced production processes for the part in assessment (re-created after [15])

As shown on Fig. 4.22, the rectangular part is cut into the blank shape ready for hot stamping using a 2D laser.

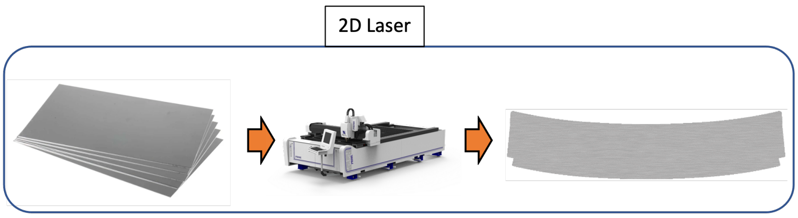


Figure 4.22: 2D laser process

The steel used for this component is the 22MnB5 with a coating of AS150, used to prevent scaling of the material when it undergoes the heat treatment. The part layout and thickness is presented on Fig. 4.23.

Material	22MnB5 + AS150
Thickness [mm]	1,2

Figure 4.23: Blank layout, material and thickness

The 2D laser is commonly used as a blanking process for high end car manufacturers, where the production quantity is not very high. It allows for good quality and tight dimensional tolerances. However, the cycle time is quite long and does not have the best material utilization, when compared to other processes.

The cut disposition of the profiled parts, using the 2D laser on the rectangular initial blank, is presented on Fig. 4.24.

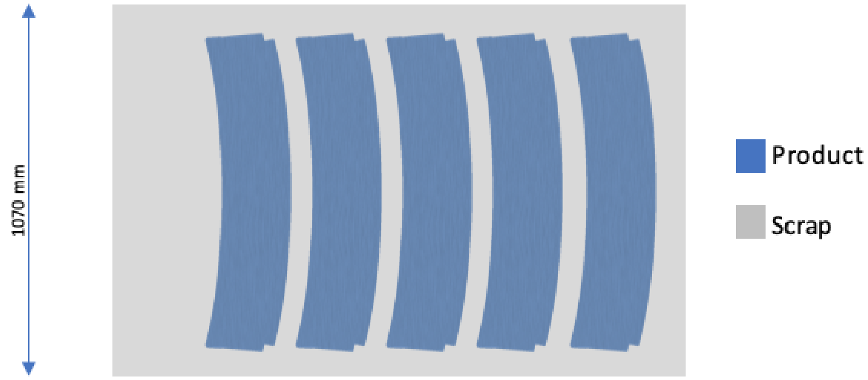


Figure 4.24: 2D laser cut - blank dimension and part nesting

The Material Utilization Development (MUD) is the percentage of the material from the rectangular blank that compose the product. All the remaining, whether it comes from the 2D or 3D laser cut, is considered material waste or informally "scrap". The scrap can be sold, but at a much cheaper price than the raw material where it originated from. On Fig. 4.25 is presented an example of the stacking of material waste from the 2D laser cut.

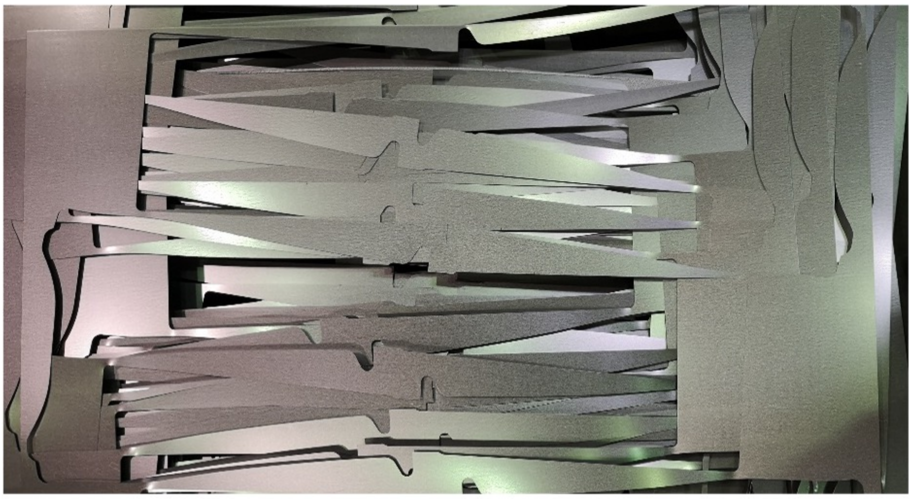


Figure 4.25: Example of steel wast from the 2D laser cut

In this case, the product weights 1,698 Kg and for each blank are produced 5 products, which results in a total product weigh per blank of 8,490 Kg. Dividing this value by the blank weight of 13,043 Kg, is obtained the material utilization of this component of 65%. The compilation of this information is presented on Table 4.2.

Table 4.2: Material utilization of the component (MUD)

Product Weight	1,698 Kg
Blank Weight	13,043 Kg
Parts per blank	5
Product Weight per blank	8,490 Kg
MUD	**65%**

4.2.4 Optimization Proposal

Using the planning and bidding functionality of the simulation software Autoform it is possible to test different dispositions of the product on the blank and optimize the material utilization. The software allows for Process Planning, Strips Layout, Material Utilization, Tool Cost -Estimation, Part Cost Estimation analysis. When using the laser for blanking, it is necessary to leave at least 6 mm between the products and to the borders of the steel plate. Besides that, as it is a standard rectangular blank for all the parts, there is a big part of the ends of the blank that is not utilized because is not enough to add one more product. The proposal is to replace the 2D laser with a mechanical cut in a press. With this alternative process, instead of rectangular blanks is used an automatic feeder that uncoils the steel from the coil. Using a knife and the press die, the cutting process has a much higher productivity. In the mechanical blanking there should also be a gap between the product to trim and side border of the coil 2,5 times the thickness of the steel sheet. However, by making a slight change on the sides of this part, it is not necessary to shear the sides of the part because they will coincide with the borders of the metal sheet. This change also allows for a simpler knife profile, reducing its cost, and a reduction of 20mm of coil width. The order to the supplier can pass from the standard width of 1070mm to 1050mm. The proposed change is shown on Fig. 4.26.

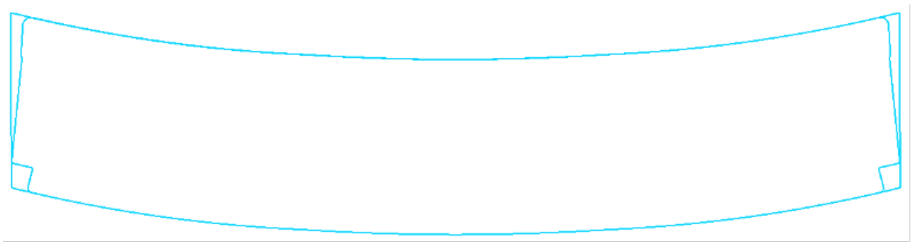


Figure 4.26: Proposed change on the layout of the part profile

Knowing the perimeter of part B, it is possible to calculate the necessary force the press has to apply to cut the metal sheet. Table 4.3 has the capability of the press and table 4.4 the requirements for the product in discussion.

Table 4.3: Press capabilities

Press	**Tonnage [KN]**		6300
	Feeder type		Coil (slitter)
	Blank thickness [mm]	**Min.**	0,55
		Max.	4,25
	Width [mm]	**Min.**	200
		Max.	2000

Table 4.4: Perimeter, press necessary force and coil width for product B

Product B	**Perimeter [mm]**	2516
	Force [KN] (*)	1449
	Coil width [mm]	1050

(*) Value calculated resorting to equation 1.1

After analyzing the data from the table, is possible to conclude that the part can be cut using the available press. The proposed cut disposition of the blanks on the steel coil is presented on Fig. 4.27. It it represented only five components on the steel coil but in fact all the entire length of the coil is utilized to produce parts. The only scrap provenience from this cut is the small grey part on the left and an equivalent amount on the end of the production.

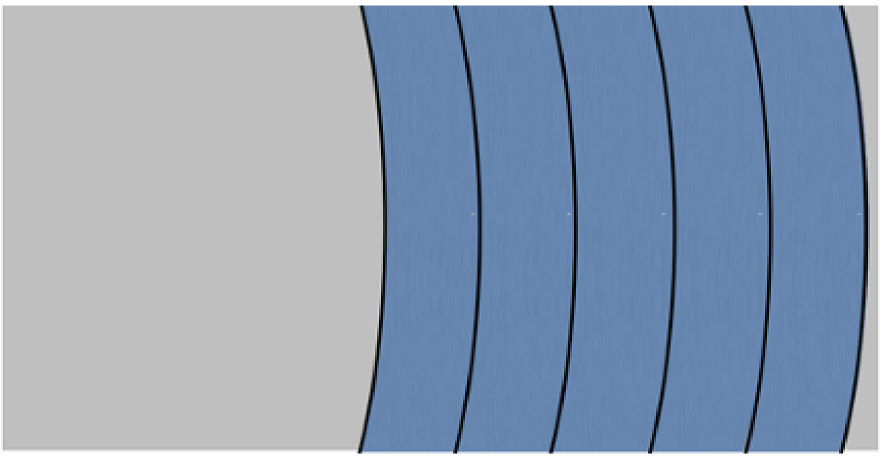


Figure 4.27: Proposed disposition of the parts on the blank

4.2.5 Improvements

By changing the 2D production process and optimizing the blank layout, the material utilization for this part increased in 17,7%, This reflects in a total save of 16,7 tons of steel per year in relation to the current procedure. Since the production is planned for five more years, it would mean a total saving of 83,5 tons worth of steel in this component production life. Although not the focus of this projects, it can also be referred that the cycle time was reduced in 91%. Fig. 4.28 shows the improvement when comparing the proposal with the current production.

CURRENT

Product Weight	1,698 Kg
Width	1070 mm
Pitch	259,4 mm
Thickness	1,2 mm
Blank Weight	2,609 Kg
MUD	65%
Blank Weight (y)	78,8 Ton

PROPOSAL

Product Weight	1,698 Kg
Width	1050 mm
Pitch	208 mm
Thickness	1,2 mm
Blank Weight	2,053 Kg
MUD	82,7%
Blank Weight (y)	62,1 Ton

Figure 4.28: Comparison of the material utilization and necessary steel on the current and on the proposal production

4.3 Summary

The present chapter describes the proposed implementations to reduce the material utilization and the cycle time.

Project 1 focus on the cycle time reduction of robot R1, which is responsible for transporting the parts from the stack to the engraving device and from there to the conveyor where it undergoes the heat treatment. With this cycle time reduction, this step of the production process is no longer the bottle neck, and the total cycle time of the line was reduced. To obtain this improvement was necessary to reshape the part's blank in other to change the grip position and reduce the steps of the robot. Since the shape was redone, it was also necessary to conduct a CAE validation of the hot stamping process to assure the final desired properties were still obtained.

Project 2 suggestion of changing the blanking process from a 2D laser to a mechanical cut enables a considerate reduction on the material utilization due to a better blank disposition optimization. This significantly lowers the cost per part.

On both projects the proposed goal was obtained.

Chapter 5

Conclusions and Future Work

5.1 Conclusions

The implementation of Case Study 1 (Cycle Time Reduction) reflects in the cycle time reduction of 5% in the 2D laser, 42% in the Robot 1. The optimization of the robot movement leads to a 21% reduction of time needed in the hot stamping line, when compared to the current procedure. There is a total reduction of 87 hours per year in the production of this component with the implementation of this proposal. Other than the cycle time reduction , measures alike the one introduced in project 1 can have a big effect towards achieving this goal. Therefore, more than the impact the project inflicts in the production of this specific component, it can be used as an encouragement for searching and developing actions alike this case study on other parts.

The implementation of Case Study 2 (Material Waste Reduction) reflects in a 17,7% reduction of the steels waste. when compared to the current procedure The mechanical cutting is a good alternative blanking process to 2D laser cutting. Although the edge quality and dimensional accuracy is lower, this can be rectified after hot stamping, in the 3D laser.

Most components produced in the factory require tight dimensional tolerances and the hot stamping process alone cannot meet these requirements. Therefore, it is almost always necessary to apply a 3D laser cut after stamping, not only to obtain certain geometries, not possible to obtain in the pressing process, but also to obtain such dimensional tolerances. Since the part profile is always cut in the 3D laser, the lower quality of the part's boundaries obtained by applying the mechanical cut by virtue of the 2D laser cut, is not problematic. It is therefore preferable to opt for this process because it is cheaper, faster (better cycle times) and allows for better material utilization and thus reduced steel waste.

This study is of great value to the company because provides information of the downsides and advantages of the process change, the possible wear problems of the tools and its life expectancy in regards to numbers of cuts and needed maintenance. This process change has great impact on the production cost and can be applied no only to the current in production components but also to future new orders. For confidentiality reasons the economic impacts, although studied, have not been addressed in this dissertation.

5.2 Future Work

Due to logistics of the planned production it was not possible to carryout the tryouts and assess the results of the proposed alterations, during the duration of the internship. That should be the first further measure to put in motion in the current year, analyze the results and get the client's approval on the process change and parts quality.

The blanking process change from 2D laser to mechanical cut appears to be a good measure to implement into the in question production. It allows for a significant reduction in the cycle time (in each minute there is a productivity increase from 1 to 25 produced parts), lower hourly cost of the machine, less energy consumption and better material utilization (in most cases). However, that material utilization reduction is not linear for all the components in the production. For instance, parts with a length higher than than the maximum width of coil supported by the press available for the mechanical cut experience a MUD loss when compared to the 2D laser, as is the case on Fig. 5.1 . Part C, shown on Fig. 5.2 has a bigger length (2055 mm) then the steel sheet maximum width (2000mm) and has to be rotated to fit in.

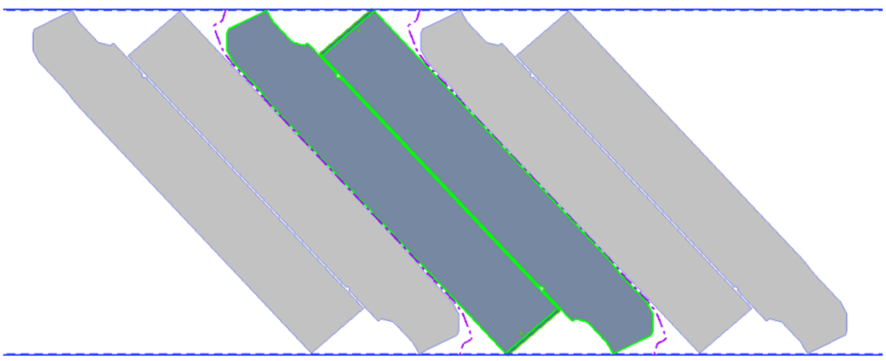


Figure 5.1: Part disposition on the blank, with the necessary rotation to fit in the steel sheet

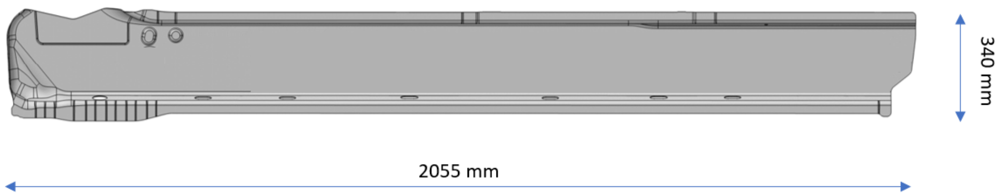


Figure 5.2: Part C dimensions

However, even with the decrease in the MUD, which means extra cost with steel, it might be worth it if the blanking of the part is outsourced. That is justified because when the cut is outsourced, the scrap inherent to its cut can not be sold by the company (Sodecia) because is not its property. That scrap value belonging to the outsourced company combined with the extra scrap from the MUD increment gained by cutting the parts in-house plus the difference from cut prices (in-house price/part is lower than the outsourced one) might be worth the change. A balance of the cost when changing the outsourced 2D laser to in-source mechanical cut is given in Table 5.1.

Table 5.1: Balance of the cost when changing from an outsourced 2D laser cut to an in-house mechanical cut

2D laser outsourced → Mechanical cut in-house
− Tool Price (divided by all the parts in that production lifetime)
+ Value of the scrap
+ Transport
(− Difference from steel price and sold scrap value due to the MUD increasement) ↳ Only applicable when the MUD is worst than the current one
+ Value paid to the outsourced company for the cut

Beside this cost balance, it has also to be taken into account that not all parts can be mechanically cut by this process and that complex shapes with the necessity of multiple and complex shaped knifes may require and investment whose cost is not viable or/and require a pitch higher than the press maximum capability. The press's table size has to be bigger than the pitch of the cutting sequence, otherwise it is not possible to produce functional parts. In Fig. 5.3 there is an example of a disposition of part C on the blank that gives a better MUD than the one presented in Fig. 5.1. However the required pitch is (2062 mm) and the maximum admissible is 2000 mm to fit on the table.

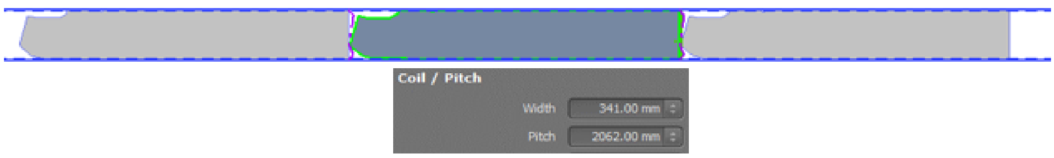


Figure 5.3: Part disposition on the blank, with the necessary rotation to fit in the steel sheet

It is also important to analyze the profile of the component to check if there are any critical areas, such is the case of the part discussed on project 1. The sections in Fig. 5.4 marked with a red circumference would be critical if mechanically cut. That was the reason why it was not also propose a blanking process change for that component, maintaining the 2D laser cut.

Another topic worth the attention when making this process change is the planning of the cutting sequence. The knifes should be grouped so that on every downward movement of each set, the sheet stays as static as possible to avoid quality and dimensional defects. In Fig. 5.5 is presented a developed cutting plan for part C with three groups of knifes.

Once almost all of the parts have a rectification done on all the contour after hot stamping, by 3D laser, the possibly poorer surface quality from the process change wouldn't be an issue. Also, some of the final clients (car brands) contacted have shown acceptance in that process change.

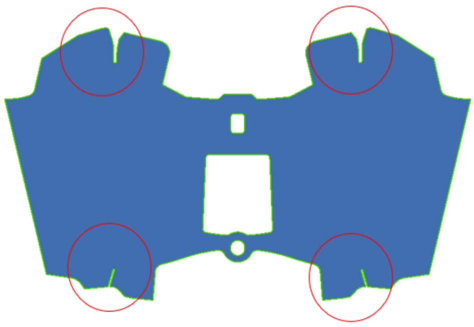


Figure 5.4: Critical areas to mechanically cut the part from project 1

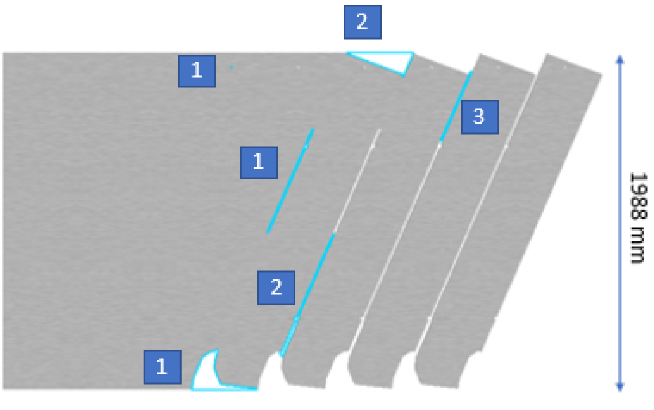


Figure 5.5: Cutting plan and knifes sets for part C

On Appendix A.3 is presented an excel sheet with an initial study of 26 other components to assess more candidates to replicate the same process change, as the one proposed on Project 2. This parts should be further studied to validate the worthiness of this implementation, namely asking for tool quotation and including these values in the balance sheet.

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Appendix A

Appendix

A.1 Boron steel 22MnB5 – Specifications

Suppliers and commercial designations of Boron Steels

-ARCELOR (ArcelorMittal) $\rightarrow USIBOR1500P$

-SSAB $\rightarrow DOCOLBORON02/20MnB5$

-RUUKKI $\rightarrow RacoldB24/RaexB24$

-SALZGITTER FLACHSTAHL $\rightarrow 22MnB5$

-USIMINAS $\rightarrow 22MnB5$

Chemical compositions

Table A.1: Chemical composition of each supplier's Boron steels

	Usibor 1500	Docol Boron 02	Racold B24 Raex B24	SALZGITTER 22MnB5	USIMINAS 22MnB5
C %	< 0,25	0,20-0,25	0,20-0,255	0,22-0,25	0,19-0,25
Si %	< 0,35	0,20-0,35	< 0,40	0,20-0,30	< 0,40
Mn %	< 1,40	1,00-1,30	< 1,43	1,20-1,40	1,10-1,40
P %	--	< 0,030	< 0,025	< 0,020	< 0,025
S %	--	< 0,010	< 0,015	< 0,005	< 0,015
Cr %	< 0,30	0,14-0,26	0,18-0,44	0,11-0,20	0,15-0,35
B %	< 0,0050	< 0,0050	< 0,0050	0,002-0,0035	< 0,0050

Analyzed material - ARCELORMITTAL 22MnB5

Chemical composition

Table A.2: Chemical composition of ARCELORMITTAL 22MnB5

	C	Si	Mn	Cr	Mo	P	S	Ti	Al	B
% Weight	0,24	0,15	1,10	0,15	0,35	0,025	0,008	0,020	0,020	0,005

Supplying mechanical properties

Table A.3: Supplying mechanical properties of ARCELORMITTAL 22MnB5

Yield strength (Rp0,2) [MPa]	Tensile strength (Rm) [MPa]	Elongation [%]
400	600	-20

Supplying Thicknesses and Widths

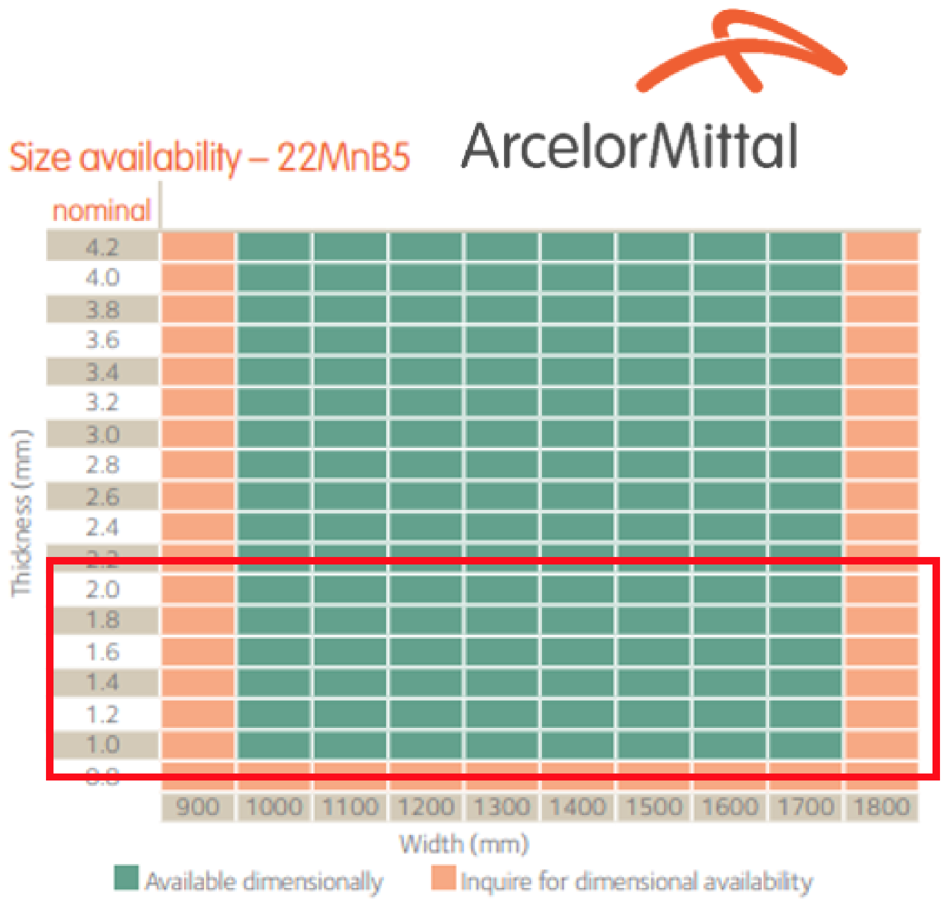


Figure A.1: Supplied Thicknesses and Widths from ArcelorMittal

Percentage of coating constituents

Table A.4: Percentage of coating constituents - ARCELORMITTAL 22MnB5

	Al [%]	Si [%]
Minimum	85%	5%
Maximum	95%	11%

Amount of Boron Steel Coating

Following EN 10327 norm, measure in three points of the sheet:

>150 g/m2 on both upper and lower surfaces (AS150)

Table A.5: Amount of Boron Steel Coating - ARCELORMITTAL 22MnB5

	Thickness [g/m^2]
Minimum	70
Maximum	90

Supplying tolerances

Table A.6: Supplying tolerances of the "mother" coil

Dimension Range	Minimum [mm]	Maximum [mm]
601-1199	0	5
1200-1500	0	6
>1500	0	7

Supplying coil tolerances

Table A.7: Supplying coil tolerances

Thickness [mm]	Coil width			
	<125	>125 & <250	>250 & <400	>400 & <600
< 0,6	0/+0,2	0/+0,2	0/+0,3	0/+0,5
>0,6 & < 1,0	0/+0,2	0/+0,3	0/+0,4	0/+0,6
>1,0 & < 2,0	0/+0,3	0/+0,4	0/+0,5	0/+0,7
>2,0 & < 3,0	0/+0,4	0/+0,5	0/+0,6	0/+0,8

Properties on the simulation of the hot stamping process

Table A.8: Yield and tensile strength, elongation and hardness for each thickness range

Thickness [mm]	Yield strength (Rp0,2) [MPa]	Tensile strength (Rm) [MPa]	Elongation [%]			Hardness
			A80 [%] Min.	A50 [%] Min.	A5 (5,65) [%] Min.	HV 30
>1,2	1250	1700	>4,5	>5	>6	550
<1,2	950	1300	>4	>4,5	>5,5	400

Thickness of the Al-Si coating, after hot stamping

$> 35\ \mu m$

Table A.9: Tolerances of the coatings, after hot stamping

Thickness [mm]	Tolerance
0,8 – 1,9	+/- 0,0065
1,2 – 1,49	+/- 0,075
1,5 – 1,79	+/- 0,009
1,8 – 2,59	+/- 0,13
2,6 - 3	+/- 0,14

A.2 Coatings

The first developments concerning the hot stamping process presented some "problems" concerning the surface finishing of the stamped products. Considering the high temperatures at which the plates are processed, they presented superficial oxidation because they were exposed to the air at very high temperatures. Consequently, this oxidation caused the appearance of iron oxide "residues" on the stamping tools, which in turn caused irreparable damage to the parts produced. Applied to this process, the solution found was to have an Al-10%Si coated material, which at high temperatures becomes an integral part of the final FeAl(Si) stamped product. Tests on the amount of coating recommend a range of 120 to 160 g/m2 . The coated final product, after hot stamping, shows good paintability without the need for a phosphate treatment and also good spot-welding characteristics.
In short, in the absence of this coating, there are surface oxidation problems after cooling off the steel sheet. This is solved by an Al-Si coating that gives rise to a final protection - FeAl(Si) alloy.

The microstructure of Usibor® 1500 before heat treatment exhibits a ferrito-pearlitic matrix, as shown on Fig. A.2.

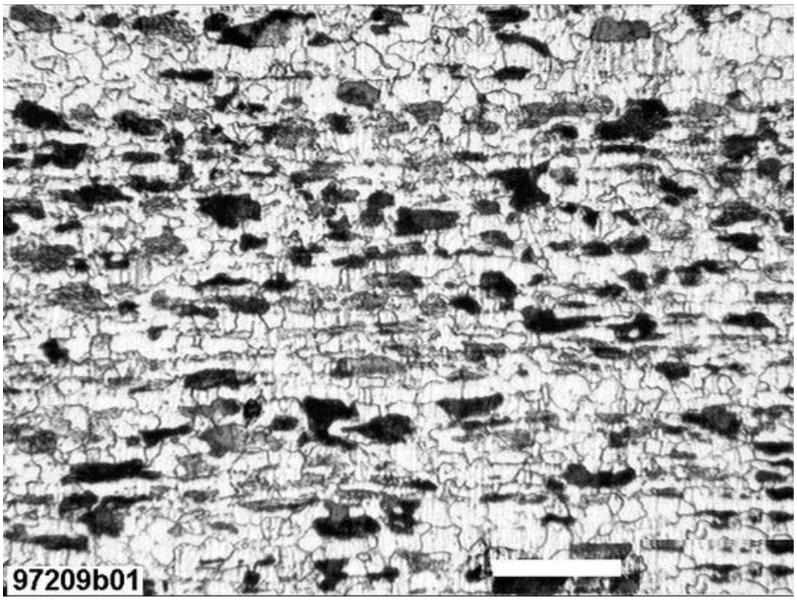


Figure A.2: Usibor® 1500 microstructure before hot-stamping heat treatment (delivery condition) [50]

The Usibor® 1500 coating in the delivery condition is split into one ternary layer of alloy at the steel-coating interface and an overlay of binary aluminium-silicon alloy (Fig. A.3).

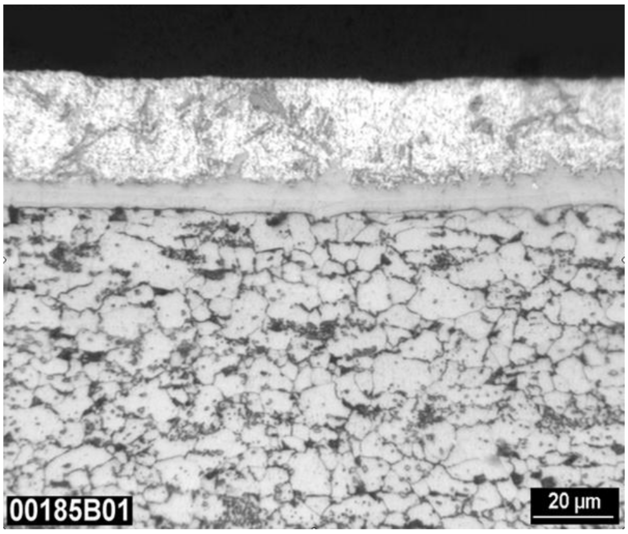


Figure A.3: Section of Usibor® 1500 coating prior to hot stamping [50]

Following heat treatment and quenching, the microstructure is 100% martensitic (Fig. A.4).

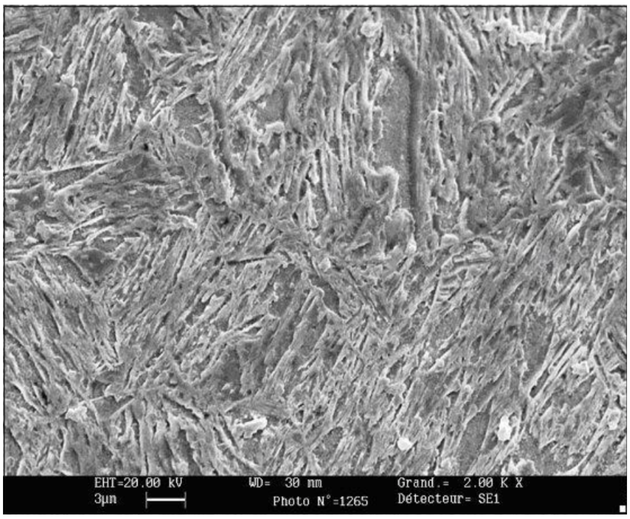


Figure A.4: Usibor® 1500 martensitic microstructure following hot-stamping heat treatment (example: 5-minute austenitisation at 900°C, followed by water quenching or die quenching). Scanning electron micrograph [50]

The Usibor® 1500 Al-Si coating is transformed in the furnace (interdiffusion and solidification reactions), forming different intermetal Al-Fe-Si alloy protective layers providing perfect adhesion (Fig. A.5).

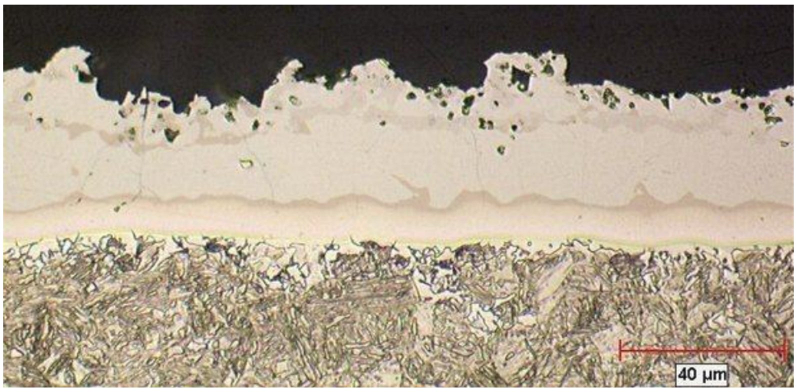
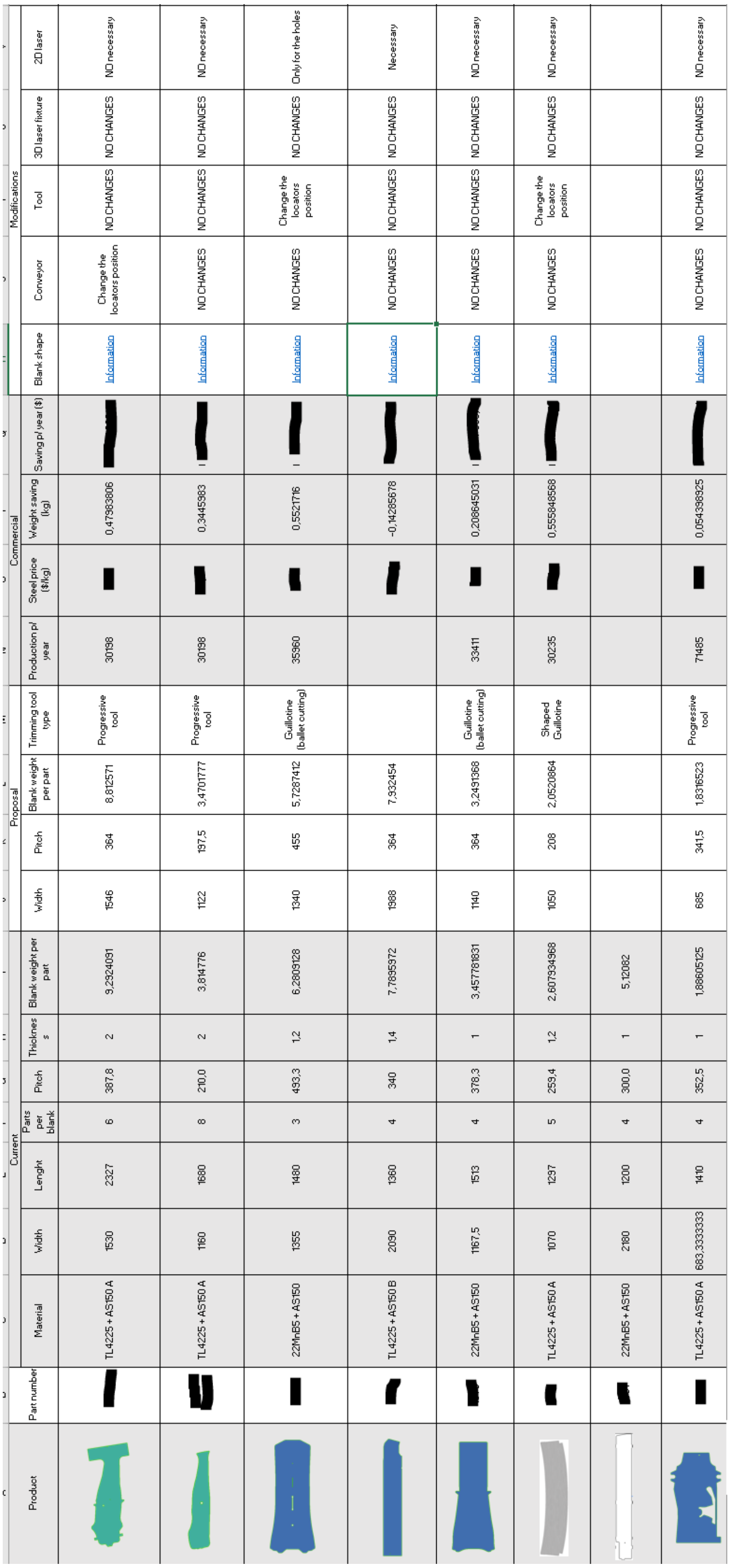


Figure A.5: Appearance of the coating after hot stamping (optical microscopy) [50]

The use of coatings have a big impact in reducing the scaling on the components as visible on Fig. A.6 .

Figure A.6: VW Passat transmission tunnel hot stamped using: (left) uncoated blank causes scales; (right) coated blank has no scale problems [45]

A.3 Future Work



Product	Part number	Current: Material	Width	Lenght	Parts per blank	Pitch	Thicknes s	Blank weight per part	Proposal: Width	Pitch	Blank weight per part	Trimming tool type	Production p/ year	Commercial: Steel price ($/kg)	Weight saving (kg)	Saving p/ year ($)	Modifications: Blank shape	Conveyor	Tool	3D laser fixture	2D laser
	[redacted]	TL4225+AS150 A	1530	2327	6	387,8	2	9,2924031	1546	364	8,812571	Progressive tool	30198	[redacted]	0,47983806	[redacted]	Information	Change the locators position	NO CHANGES	NO CHANGES	NO necessary
	[redacted]	TL4225+AS150 A	1160	1680	8	210,0	2	3,814776	1122	197,5	3,4701777	Progressive tool	30198	[redacted]	0,3445983	[redacted]	Information	NO CHANGES	NO CHANGES	NO CHANGES	NO necessary
	[redacted]	22MnB5+AS150	1355	1480	3	493,3	1,2	6,2803128	1340	455	5,7287412	Guillotine (ballet cutting)	35960	[redacted]	0,5521716	[redacted]	Information	NO CHANGES	Change the locators position	NO CHANGES	Only for the holes
	[redacted]	TL4225+AS150 B	2090	1360	4	340	1,4	7,7895972	1988	364	7,332454			[redacted]	-0,14285678	[redacted]	Information	NO CHANGES	NO CHANGES	NO CHANGES	Necessary
	[redacted]	22MnB5+AS150	1167,5	1513	4	378,3	1	3,457781831	1140	364	3,2491368	Guillotine (ballet cutting)	33411	[redacted]	0,208645031	[redacted]	Information	NO CHANGES	NO CHANGES	NO CHANGES	NO necessary
	[redacted]	TL4225+AS150 A	1070	1297	5	259,4	1,2	2,607934968	1050	208	2,0520864	Shaped Guillotine	30235	[redacted]	0,555848568	[redacted]	Information	NO CHANGES	Change the locators position	NO CHANGES	NO necessary
	[redacted]	22MnB5+AS150	2180	1200	4	300,0	1	5,12082													
	[redacted]	TL4225+AS150 A	683,3333333	1410	4	352,5	1	1,88605125	685	341,5	1,8316523	Progressive tool	71485	[redacted]	0,054398925	[redacted]	Information	NO CHANGES	NO CHANGES	NO CHANGES	NO necessary

Figure A.7: Excel with other components to analyze the process change

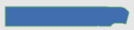
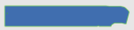
Product	Part number	Current							Proposal				Commercial				Modifications				
		Material	Width	Lenght	Parts per blank	Pitch	Thicknes s	Blank weight per part	Width	Pitch	Blank weight per part	Trimming tool type	Production p/ year	Steel price ($/kg)	Weight saving (kg)	Saving p/ year ($)	Blank shape	Conveyor	Tool	3D laser fixture	2D laser
	[redacted]	TL4225 + AS150 A	671,6666667	1360	4	340,0	1,5	2,6821665	634	350	2,6062155	Progressive tool	[redacted]	[redacted]	0,075951	[redacted]	Information	NO CHANGES	NO CHANGES	NO CHANGES	NO necessary
	[redacted]	TL4225 + AS150 A	522,5	1160	3	386,7	1	1,581921	371	525	1,52508825	Progressive tool	[redacted]	[redacted]	0,05683275	[redacted]	Information	NO CHANGES	NO CHANGES	NO CHANGES	NO necessary
	[redacted]	TL4225 + AS150 B	2090	1360	4	340,0	1,6	8,9023968				KEEP LASER						NO CHANGES	NO CHANGES	NO CHANGES	Necessary
	[redacted]	TL4225 + AS150 B	2090	1360	4	340,0	1,4	7,7895972				KEEP LASER						NO CHANGES	NO CHANGES	NO CHANGES	Necessary
	[redacted]	22MnB5 + AS150	515	1300	4	325,0	2	2,6210925	502	319	2,50776108	Progressive tool	[redacted]	[redacted]	0,11333142	[redacted]		Change the locators position	NO CHANGES	NO CHANGES	NO necessary
	[redacted]	22MnB5 + AS150	2050	1200	4	300,0	1	4,81545													

Figure A.8: Excel with other components to analyze the process change (continuation)