Zachodniopomorski
Uniwersytet
Technologiczny
w Szczecinie

Master Thesis

MATERIAL AND TECHNOLOGICAL ANALYSIS OF CAR BODYWORK ELEMENTS

Author:

Carlos Ramírez Menéndez

Supervisor:

Jerzy Nowacki

Wydział
Inżynierii Mechanicznej
I Mechatroniki

Master in Industrial Engineering

June 2017

TRABAJOS DE FIN DE GRADO / FIN DE MÁSTER

Escuela de Ingeniería y Arquitectura
Universidad Zaragoza

DECLARACIÓN DE AUTORÍA Y ORIGINALIDAD

(Este documento debe acompañar al Trabajo Fin de Grado (TFG)/Trabajo Fin de Máster (TFM) cuando sea depositado para su evaluación).

D./Dª. CARLOS RAMÍREZ MENÉNDEZ,

con nº de DNI 77216818E en aplicación de lo dispuesto en el art. 14 (Derechos de autor) del Acuerdo de 11 de septiembre de 2014, del Consejo de Gobierno, por el que se aprueba el Reglamento de los TFG y TFM de la Universidad de Zaragoza,

Declaro que el presente Trabajo de Fin de (Grado/Máster) Máster, (Título del Trabajo) "MATERIAL AND TECHNOLOGICAL ANALYSIS OF CAR BODYWORK ELEMENTS",

es de mi autoría y es original, no habiéndose utilizado fuente sin ser citada debidamente.

Zaragoza, 13/June/2017

Ramírez

Fdo:

MATERIAL AND TECHNOLOGICAL ANALYSIS OF CAR BODYWORK ELEMENTS

SUMMARY

This Master Thesis is a work done to finish my Master of Industrial Engineering. This has been done at the University ZUT (Zachodnipomorskiego Uniwersytetu Technologicznego), located in Szczecin, during my Erasmus stay in the second year of the Master.

This work is focused on the automotive industry, in the same way as I carried out my Final Grade Project, because it is a field in which I have interest and it seems important to me.

In particular this work as explained later in the introduction focuses on the structural elements of a vehicle, AHSS materials used to make them and suitable welding methods. There are also a couple of examples to compare which method is most appropriate in two different cases of two pieces that have been selected.

Table of contents

Chapter 1: Introduction

The present Master Thesis is going to be treated a very important field at present that is the automotive industry. With the emergence and discovery of new composite materials, it is possible to use them in this field to improve on many factors such as safety or reliability of the vehicles. Some of these factors will be explained later.

Thanks to these new materials better results are obtained in different fields, such as the resistance to the crashes of a vehicle or the consumption of this, among others

New materials in many cases imply new technologies, or discover which technology is the most appropriate.

In this project we will compare two methods of welding applied to one of these new materials that have appeared in the last years. This material is an AHSS, and in particular, the one used in this work is an AHSS CP, ie a Complex Phase, within the category of Advanced High Strength Steel

The following is a brief description of the technical objective pursued in doing the work, the scope of the project and the structure of the work.

1.1 Purpose

The objective of this project is to choose the right methods for joining two pieces selected in the bodywork of a vehicle. To do this, the selected parts and the possible methods of welding can be identified visually. It will be based on the project in which the pieces are made of an Advanced High Strength Steel, AHSS.

In particular, parts selected are the roof panel and the pillar B, and welding methods are Micro Plasma and Spot Resistance Welding.

To accomplish the objective, first designing of these parts will be done with the SolidWorks program and after this a small simulation will be done with finite elements in the SolidWorks Simulation section. Tests are also carried out in the laboratory. After all the above the different methods of welding are compared to draw conclusions.

On the other hand, with this work, it is possible to learn how to use a design and calculation tool (SolidWorks) that is used and required in a lot of companies. Also the introduction to tests in a laboratory is a good part of this project because besides virtual part, the practical part is important also. All this allows me to complement my training and improve my future possibilities in the workplace.

1.2 Scope

Therefore, with this work, the most suitable method for welding is achieved based on a specific material such as the AHSS that has been selected for this project.

Thanks to tensile tests and microscopy test, it is possible also know the weaknesses and defects that appear in each of the two methods of welding (Spot Resistance Welding and Micro Plasma Welding) that are used. Thanks to these tests we obtain conclusions of the best method for this type of material applied in two parts of the structure of an automobile, the roof panel and the B-pillar.

1.3 Structure of work

This Master Thesis is structured in 9 chapters.

After this section of Introduction the next chapter focuses on the revision of the state of the art related to the different types of vehicle structures, the materials with which they can be made, as well as the types of welding to realize the structure.

Chapter 3 presents the main elements of the structure of a vehicle.

In Chapter 4 the two parts of the structure in which the welds are to be simulated are chosen.

Chapter 5 shows the results of the tests that have been performed with SolidWorks.

In the Chapter 6 you can find the preparation of the WPS of each of the unions.

Tests carried out in the Micro Plasma Welding and Spot Resistance Welding laboratory are described in Chapter 7. These tests are tensile strength test and microscopy test. The results of these are shown in Chapter 8.

The general conclusions of the work are summarized in Chapter 9.

Chapter 2: Review of the state of art

2.1 Types of structure of a Motor Vehicle.

Nowadays, structural elements of a motor vehicle are very important due to different reasons **[1]**. Main causes are two, increase security in passenger cars and decrease pollution on these.

For pollution, in addition to try to use better engines, it is necessary to reduce weight in cars. Less weight means less energy to move them and therefore less pollution. The other cause is security. Since 20 years ago, safeness has been greatly updated. It has been developed new structures of cars and new materials with better features.

There are different types of structures in passenger cars. They can be classified according different criteria.

2.1.1 According to construction:

Body on frame: This structure has a chassis that is independent of the bodywork. Here bodywork does not have any structural function. The chassis sustains all the weight and to the chassis are united the different parts like the engine, suspension or the bodywork.

This type was used a lot in the past, but nowadays it is only implemented in trucks, freight cars, and sometimes in sportive passenger vehicles whose bodywork will be made with special materials like carbon fiber for example. The advantages of using this type of body are mainly for freight vehicles and for vehicles used for circulation on dirt roads or poor roads.

Spaceframe: Sometimes it could be called tubular chassis, due to this chassis is like a truss. The tubular or superlight body is used in classic sports cars and currently in handmade sport models.

This technique uses as a vehicle structure with a network of thin welded metal tubes, then it is coated with metal sheets, often of metals such as aluminum or magnesium. This technique achieves a huge stiffness and resistance but sheets do not have any structural function. However, this technique is very expensive and it needs a lot of work.

Central tunnel: Sometimes there are some cars with different designs like this. There is a thick beam in the middle of the base under seats. This designs use to have hybrid techniques.

Monocoque: This design is the most implanted by cars currently and it is made with a self-supporting body. This means that chassis and bodywork are the same and body supports himself in one unique piece. All the structure works together to achieve good flexibility, rigidity and resistance to different efforts. Most parts are welded, so welding is a very important topic. Later in this project it will be discussed about the different techniques of welding. Sometimes some parts can be screwed to facilitate the replacement or repair.

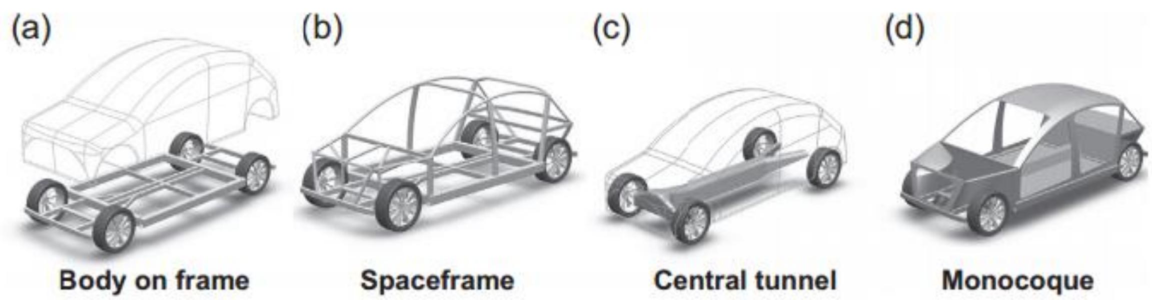


Figure 2.1 *Types of structure according to construction* ***[2]***

2.1.2 According to volumes: [3]

One volume: It is called minivan and it is a body in which there is no difference of more than one volume. The engine room, the cabin and the boot are fully integrated.

Figure 2.2 *Renault Espace. One volume* ***[4]***

Two volumes: It is possible to difference two volumes. Two volume designs articulate a volume for the bonnet with the engine and a volume that combines the passenger compartment and the luggage compartment.

Figure 2.3 *Volkswagen Scirocco. Two volumes* ***[5]***

<u>*Three volumes:*</u> A volume for the bonnet with the engine, another volume for the passenger compartment and a third for the boot.

Figure 2.4 *Volkswagen Santana. Three volumes* ***[6]***

2.1.3 According to shape:

There are a lot of different shape in cars. The most usual are sedan, familiar, hardtop, coupe, off road, sport utility, sportive, limousine and van.

There has been talked of cars in particular but there are also different structures in motorcycles. They are these: monocoque, double cradle system, tubular, or double beam.

2.2 Different materials used nowadays in structural parts of vehicles

Depending of the form or car structures, safety and combustible can be reduced, but besides of this it is very important update materials that are utilized. **[7,8]** These materials will reduce combustible due to less weight in the car, but they will increase security due to increased energy absorption (crashworthiness).

We need to find in materials a lot of mechanical characteristics that would be good for vehicle cars. **[9]** An example of these characteristics are the followings. It will be explained more deeply in next chapter linked with Advanced High Strength Steel.

"Elasticity, plasticity, resilience, toughness, malleability, ductility, brittleness, stress, hardness, **weldability"**

There are other criteria beside lightweight and safety. They are for example economic effectiveness, recyclability and life cycle.

In the following lines, main materials are explained.

<u>2.2.1 Steel</u> [10]

It is an iron and carbon alloy. Steel is a very good option due to its mechanical resistance, its easy manufacture and its durability.

In the last years, lot of different steel has been utilized. These steels have better quality and they have better features in spite of thinner sheets.

There are different types that update its features. They can be seen in the *Figure 2.5*.

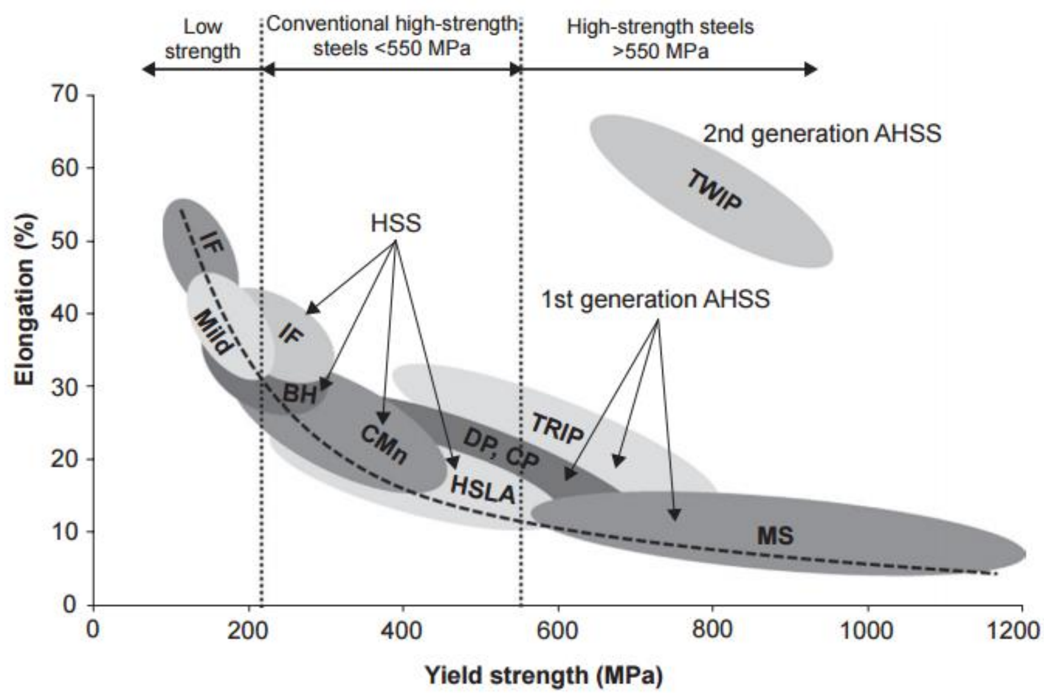


Figure 2.5 *Different types of steel* ***[2]***

It is possible to compare in the before image yield strength vs elongation of different steels that have been discussed.

- **IF:** Interstitial Free. These steels usually have low yield strength due to they have a small quantity of carbon. There are another IF in HSS. **[11]**

- **Mild**: It is popular due to its low prize but it has not got good structural strength, but it is good to project when the quantity required of steel is very high.

After these two types, a new type of steel starts. It is called High Strength Steel and it includes different steels.

- **IF**: Nowadays these steels are used with low quantities of C, Si, Mn, P, S, N, Al, Nb and Ti. They have a good mechanical strength and they have good fatigue. They get a potential weight reduction.
- **BH**: Bake Hardenable Steels. They have a ferritic microstructure, but are more resistant than IF, since they are baked to increase their value of yield strength without affecting their formability, so they have high resistance to the dent and are often selected for closing panels on doors and hoods for cars.
- **CMn**: Carbon- Manganese. The manganese is added and it gets better toughness and strength. These steels including since 1% unto 2% of manganese.

The following materials described are the most used in the field of automotive, especially focused on structural elements.

- **HSLA**: High Strength Low Alloy. Have a ferritic matrix with aggregates of perlite and they use to have only a few carbon. Due to this weldability will be better that without carbon.They contain microelement elements such as V, Nb, Ti, Cu, N, Ni among others which favor the precipitation of microalloying. Hsla steels have higher strength than mild steels, BH and IF, in addition to being corrosion resistant, conformable and weldable. Such properties have made these steels to be used for body structure, suspension components and chassis. **[12]**

These steel used to be used in automotive functions, but currently they are appearing new materials. They are called Advanced High Strength Steels (AHSS). They can be divided in 1st generation or 2nd generation. First four are from 1st generation:

- **DP**: Dual phase. They have a ferritic matrix with aggregates of martensitic (10-20%). It has good formability despite martensitic is hard because the ferritic matrix is soft. These steels have Cr, Mn, Ni and other elements that they advantage martensitic formation. Because they manage to lighten the weight of the pieces by 15% and they have very good mechanical properties it is used for pieces of great structural importance such as the pillars A in the cars or the bases of the seats.

- **CP**: Complex phase. They have a matrix of ferrite and bainite with small amounts of martensite, retained austenite and perlite. Unlike dual-phase steels, these have a higher yield strength with the same tensile strength of a maximum of 800 MPa. Because of its high resistance to deformation, the parts that are manufactured with this type of steel are those whose mission is to prevent the intrusion of elements in the passenger area as well as in motor parts, frame rails, chassis components and reinforcement of the B-pillar. These steels are welded more difficultly due to their high yield strength. **[13]**
- **TRIP**: Transformation – induced plasticity. These steels are formed by 0,1-0,4 % in weight of carbon. The microstructure of TRIP steels contains islets of retained austenite embedded in a matrix of ferrite, bainite or martensite. They are characterized by a balance between resistance and especially high ductility that derives from its microstructure. Get high elongations thanks to the transformation of residual austenite in martensite by effect of plastic deformation **[14]**
- **MS**: Martensitic. It is necessary to transform austenite almost entirely to martensite. This steel is formed by a martensitic matrix with small quantities of ferrite and bainite. Ms have the highest yield strength that it can reach up to 1800 MPa. (In the following graphic it reaches only 1200 MPa, but nowadays it reaches more). With post-quench tempering is possible to get good ductility and formability even with high strengths.

And belong to 2nd generation:

- **TWIP**: Twinning – induced plasticity. They have very good mechanical properties like tensile strength up to 1GPa and good ductility because TWIP have an elongation to fracture up to 100%. Elongation up to 100% means that the material can be stretched up to twice its initial length before breaking. These metal are austenitic steels and they are formed by Mn (15-20% in weight) and C, Si, or Al (1-3% in weight). High strain-hardening is due to low stacking fault energy. **[14]**

The most used material is different types of iron but, currently other materials are emerging. These are aluminum and plastic among others.

<u>2.2.2 Aluminum</u> [15,16]

Aluminum is starting to be used in a lot of parts from vehicles. Only the change from steel to aluminum gets pieces of the structure up to 55 % lighter than traditional mild steel structure.

The problem with the creation of aluminum pieces, is that this metal is not as friendly for the processes, as the steel. Both in the welding and the stamping, the delicate aluminum requires new manufacturing processes.

Aluminum has a better energy efficiency compared with mild steel vehicles. Using aluminum, save a big quantity of petrol is possible.

Aluminum can also absorb twice as much crash energy as mild steel with a small amount.

<u>2.2.3 Plastic</u> [17]

In recent years the percentage of plastic in vehicles has been growing. It is no longer used only in the production of interior parts but, increasingly, we find plastics in the structure and interior of the car.

The benefits of carbon fiber as a key to reducing weight (70% lighter than steel, 40% than aluminum and 35% than magnesium), flexible design and low investment (great reduction of cost and time in the assembly process). It is a cheap material, does not corrode and with which it can be made complex forms. However, its application is conditioned by its capacity of mechanical resistance.

Some prototypes are starting to use Kevlar, carbon or glass fiber in their bodyworks, but nowadays there are not made complete plastic bodies.

Composition of different parts of the bodywork					
Pieces	**Mild Steel**	**Treated Steel**	**Alloys**	**Aluminum**	**Plastics**
External elements	Yes	Yes	No	Yes	Yes
Stiff structural elements	No currently	No	Yes	No	No
Vehicle structural elements	Yes	Yes	Yes	Yes	Prototypes
Bumpers	No	No	No	No	Yes

Table 2.1 *Composition of different parts of bodywork*

From here, will be discussed about AHSS only.

2.3 Different ways to weld AHSS in automotive industry

This section is going to talk about different ways to weld AHSS in automotive industry. There are more methods, but the followings are the most used, due to other methods can't be used with AHSS. **[18,19,20]**

2.3.1 Resistance Welding:

In this thermoelectric process, the pieces to be joined are pressed together and they are heated with an electric current. This resistance weld is based on the heating that occurs due to the resistance of current passing through the parts being welded. High electrical currents and large pressing forces during a specified time are required for this operation. Heat is defined like $Q(Jules) = I^2 \cdot R \cdot t$

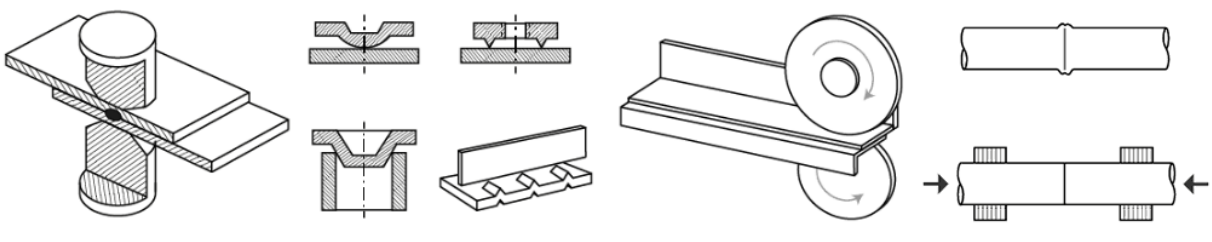


Figure 2.6 *Examples of Resistance Welding* ***[21]***

- **RSW:** *Resistance Spot Welding*. How its name says, it is a resistance welding. It is used to join metal sheets and it is based on pressure and temperature, where the metal surfaces join together by passing electric current through them and opposite electrodes, to merge a small circular section. It is different to arc welding because there are no protective gases, or filler metals used in the arc welding. It is a usual joining process in automotive industry.
- **RSeW:** *Resistance Seam Welding***.** This welding method uses rolling electrodes to create a seam between two metal sheets.
- **RPW:** *Resistance Projection Welding*. It is a process of resistance welding in which coalescence occurs at one or more relatively small points of contact on the parts. These points of contact are determined by the design of the pieces to be joined and they consist of projections in the pieces.

- **RFW:** *Resistance Flash Welding***.** This is a process in which coalescence is produced simultaneously over the entire area of both surfaces. The heat for welding is obtained by the resistance to electric between both surfaces.

2.3.2 Arc Welding

This methods are very used in cars and they are applied in chassis parts, because it is important to secure the strength and rigidity of the joint. For this reason, this method is the most used in bodyworks of the automotive industry.

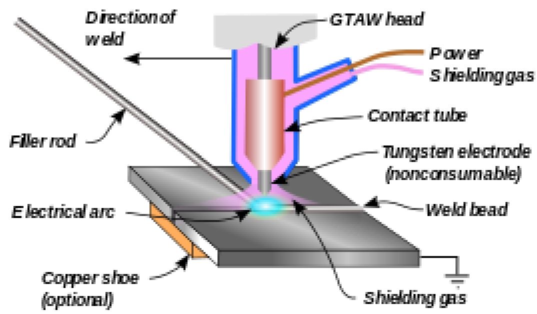


Figure 2.7 *Example of Arc Welding. GTAW* ***[22]***

- **GMAW:** *Gas Metal Arc Welding*. This process can be denominated **MIG** (*Metal Inert Gas*) or **MAG** (*Metal Active Gas*) depending on the gas used. It is the most common welding method. It can be used with electrodes with solid wires or cored wires, but always with consumable electrodes.

  Some cored wires require shielding gases. These can be CO2, Argon with O2 or Argon with CO2. Each gas has different properties and they affects to the welding.

- **MMA:** *Manual Metal Arc*. This method used with coated electrodes. Welding can be done in all positions and also be carried out outdoors. The quality of the weld is highly dependent on the competence of the welder because it is a completely manual method.

- **GTAW:** *Gas Tungsten Arc Welding*. This process can be called **TIG** (*Tungsten Inert Gas*). It is good method to weld thinner sheets. It is used with tungsten, and TIG cannot compete with GMAW about productivity.

- **PAW:** *Plasma Arc Welding*. It is similar to GTAW, but PAW reaches a high temperature and a high energy density. This method has a narrow heat affect zone and little deformation of the sheets.

  It is mainly used in high quality joints, because it does not contaminate the parent metal and it does not produce slag.

- **SAW:** *Submerged Arc Welding*. Submerged arc welding is an arc-welding process in which the welding arc is not seen. This arc is burning between the endless electrode and the piece.

  The electric arc and the melting bath are covered by a granulated powder. The slag formed by the powder serves to protect the welding zone from the influence of the atmosphere.

- **SW:** *Arc Stud Welding*. It is used for a quickly and efficiently welding. This method consists in join a stud with a plate/sheet. This method uses a gun that put the stud in the correct position.

- **SMAW**: Shielded Metal Arc Welding. Uses coated electrodes and it does not need special gases. This method is more economic than other arc welding methods.

2.3.3 Laser Welding

Laser beam welding **(LBW)** is a fusion welding process that uses the energy provided by a laser beam to melt and recrystallize the materials to be joined, obtaining the corresponding union between the elements involved. In laser welding there is usually no external material input. The welding is done by heating the area to be welded, and the subsequent application of pressure between these points. Laser welding is usually carried out under the action of a protective gas, which are usually helium or argon.

This method offers advantages like: low heat input, little deformation, no subsequent straightening of the structure, high travel speed.

2.3.4 Solid State Welding

Solid State Welding consists on joining steel without the requirement for molten metal.

- ***FW:*** *Friction Welding Process*. Friction welding is a method of welding that takes advantage of the heat generated by the mechanical friction between two moving parts. It is used to join two pieces, even though they are from different materials, which confers advantages over another type of welding such as GMAW welding with which stainless steel or aluminum alloys cannot be welded.

- **HFW:** *High Frequency Welding*. It is used for pieces of PVC in cars, but nowadays this method is being experimented in AHSS. It consists on joining pieces supplying HF energy in the form of an electromagnetic field (27.12 MHz). **[23]**

In the next figure there is a sum about different methods of welding that have been described previously.

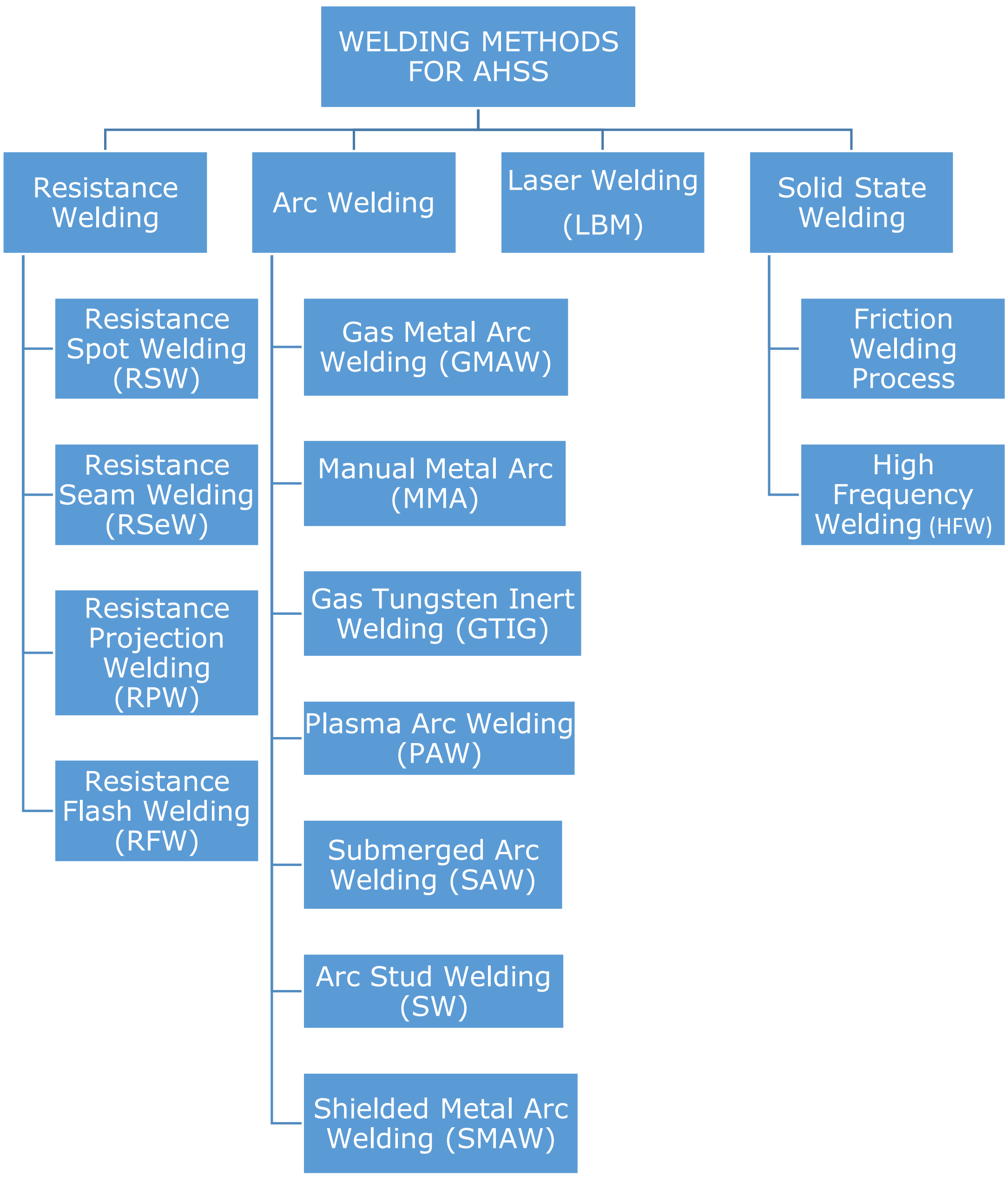


Figure 2.8 *Summary of Welding Methods for AHSS*

Chapter 3: Main structural elements in monocoque cars and AHSS used

As explained above, the structure most commonly used in vehicles is monocoque. From now, this project will focus on this structure and as welding parts of the structure and which are linked to these. **[24]**

The project is based solely on the AHSS as explained in the previous chapter, and now will increase the information about the required features that must have.

It is possible to difference in the next two images different structural elements in cars. The first figure, key elements of the bodywork are indicated more generally. However in the second figure, it is an example from an AHSS manufacturer (Docol) and different types of AHSS depending on the elements.

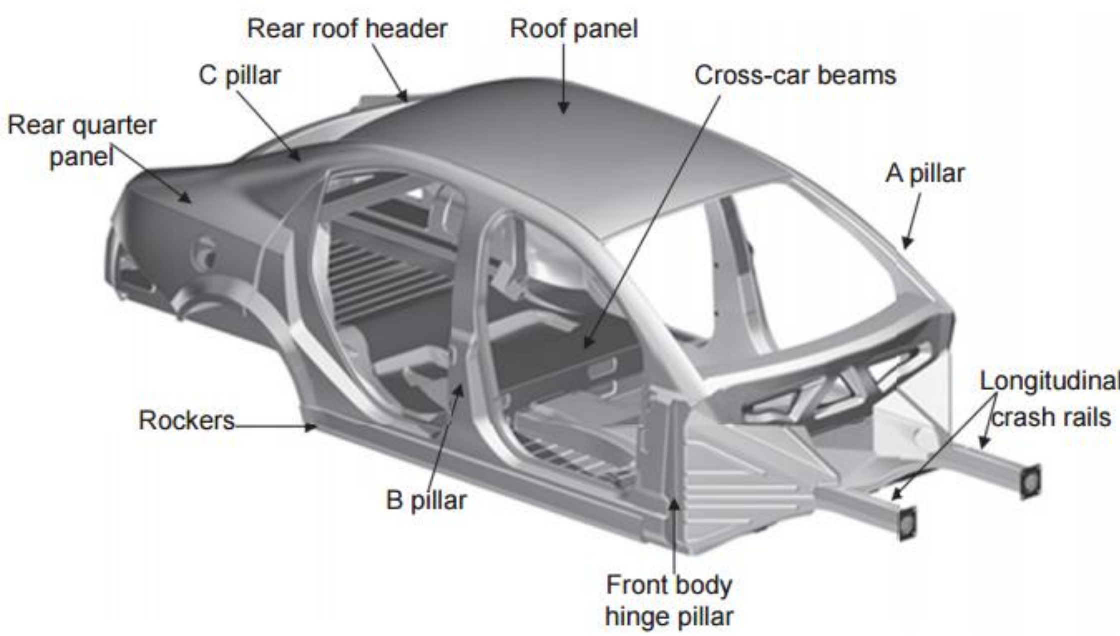


Figure 3.1** A brief overview of some key body structure elements **[2]

The most of these elements form the “Safety cell”. This safety cell is the compartment where driver and passengers are located.

• **Pillar A,B,C:** They are important structural elements because they are . Pillars are elements that attach the roof from a vehicle to the rest of the habitable structure. A supports the windshield of an automobile. B is the one from which the front seat belt hangs. It is located behind the driver’s position. C supports the rear window.

• **Roof rails:** They are in charge of protecting the area of passengers when a rollover happens. Also of great importance is the roof panel that must be of a material that does not deform excessively or allow objects to enter the safety zone in an accident.

• **Rockers:** A rocker is a stamped steel part of the bodywork. Rocker panels are placed on the sides, between the wheels of the vehicle, just below the doors. Rockers are the only parts that connect the front and rear of the car. **[25]**

• **Cross car beams and member cross:** These parts serve to enhance structural rigidity and to reduce the movement between the wheels in the event of a collision. They also support the transmission and the motor.

• **Crash box system / Longitudinal crash rails:** These elements, adding also a bumper, protect the vehicle when a front collision happens. These parts do not matter if they deform after a collision. The important thing is that they absorb as much energy as possible so that it is not received by passengers.

There are others elements in the structure. Some of these are side impact beam, tunnel reinforcement, suspension head, rear quarter panels, rear roof panel, among others.

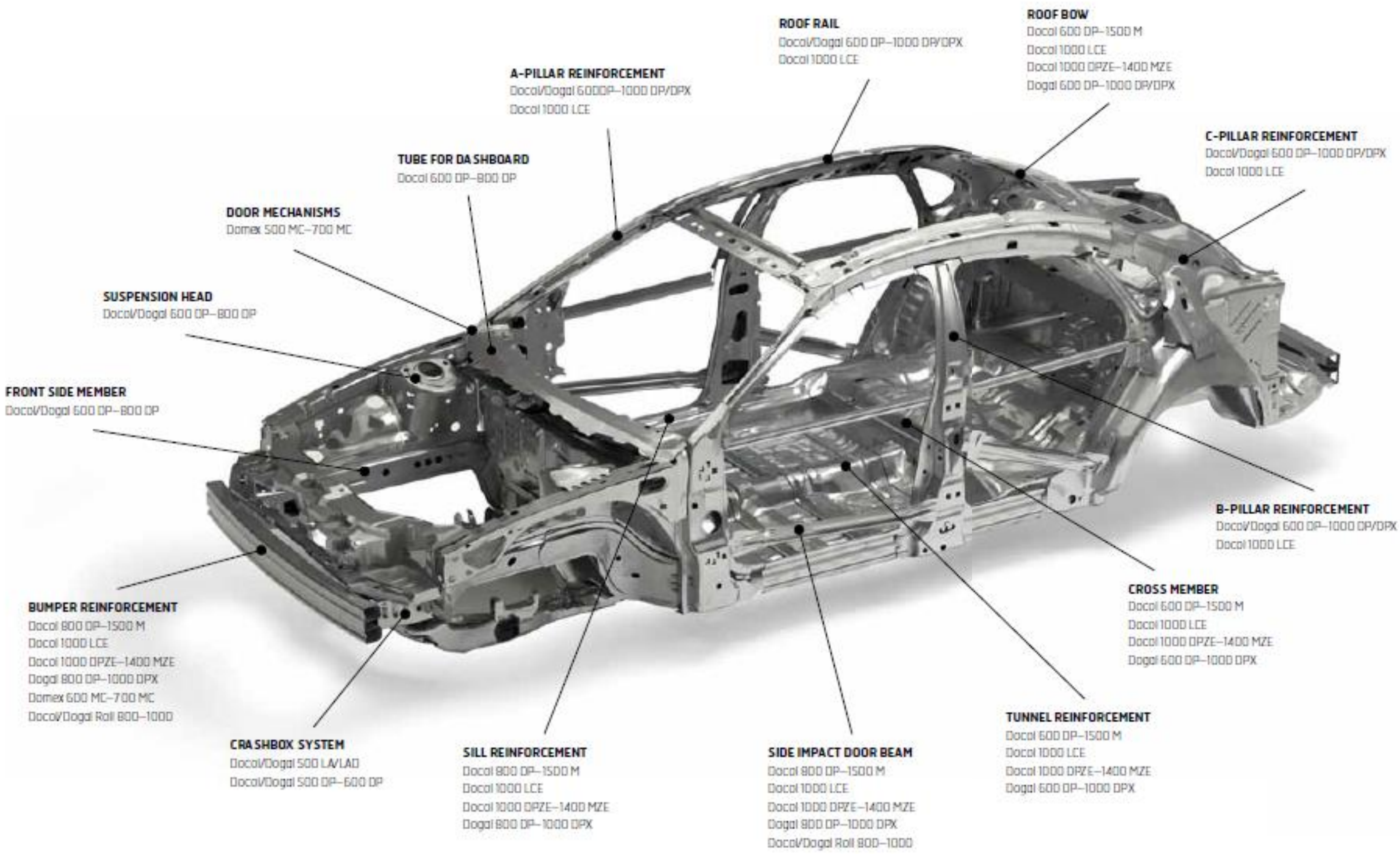


Figure 3.2 *Example of different AHSS materials used in structural elements of a car bodywork* ***[26]***

As we can see in the last figure, AHSS steel are utilized. Noting that depending on the type of AHSS, characteristics are different, but the most important that must be fulfilled for use in the automotive industry are:

• Yield Strength: AHSS should be elasticity and plasticity, because the passenger safety cage requires a high deformation resistance. AHSS have good yield strength, and it has been shown in Chapter 2, Complex Phase and Martensitic Steels are the best within this feature.

• Energy absorption: It is very important that the materials absorb the maximum energy so that it is not transmitted to the passengers. This feature is highly related with yield strength and resiliencie. In this case Complex Phase, Martensitic Steel and TRIP have good toughness.

• Weldability: AHSS materials can be welded easily, if suitable parameters are achieved. Failure to weld with the proper parameters can lead to defects in welding.

• Elongation: It is a magnitude that measures the length increase that a material has when it is subjected to a tensile force before its rupture takes place. It uses to be lower than 30 % before rupture occurs, except in TRIP steels.

Chapter 4: Selected joints

In this part of the project, it has been chosen two joints and methods to realize the welding.

The first joint and more important is the Pillar B of the bodywork. It is joint to the upper rail and lower rail.

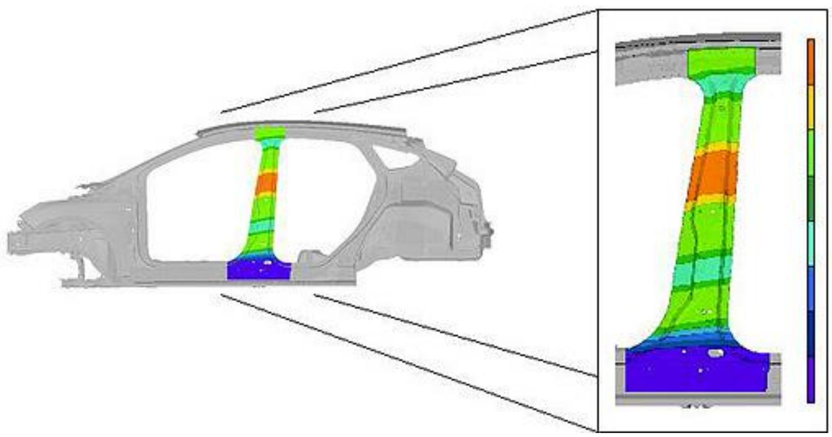


Figure 4.1*Example of Pillar B in a bodywork car* ***[27]***

The second joint consists of joining the roof of the car with the upper rails of this.

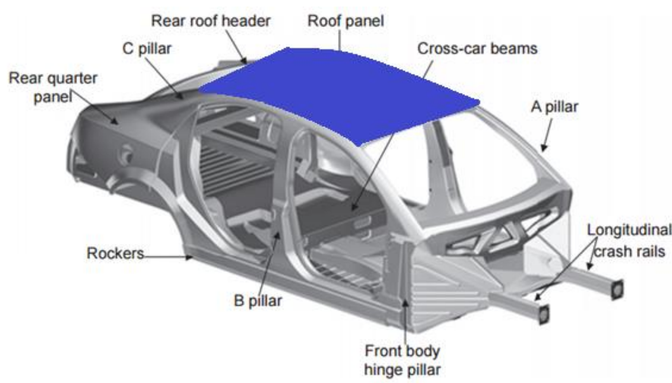


Figure 4.2 *Example of roof panel in a bodywork car* ***[2]***

These pieces belong to monocasque bodywork, and this structure is done by welding. Welding joints is a better option than mechanical joints, because bodywork will be more compact but it has a disadvantage. This disadvantage is that repair and maintenance is more difficult.

This analysis has many steps. To begin with, the most important was the selection of the unions that has already been made in the previous lines. After that is necessary to create pieces in 3D with the software SolidWorks. Pieces to create are Pillar B, roof, upper rails and lower rails.

When these pieces are drawn, assemblies have to be done in the same software. These assemblies will be joined in different ways depending on the type of welding to be performed.

After all of this, virtual tests will be done in SolidWorks, and laboratory tests will be done in the welding room

Two different methods have been selected to joint this pieces. Spot Resistance Welding and Micro Plasma Welding will be used. Spot Resistance Welding has been chosen because it is widely used in automobile manufacturing. And Micro Plasma method has been chosen because it is an arc welding method and it does not require filler material.

4.1 Pillar B

This piece is going to be welded to the roof rail and the rockers with two different methods. These methods are Plasma Welding and Spot Resistance Welding.

It has be done the 3D Pillar B in Solidworks. It is possible to see in the next images.

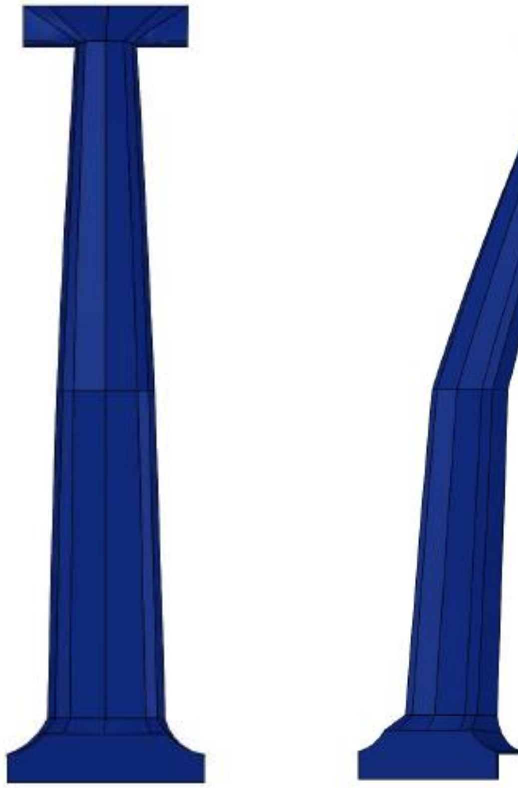


Figure 4.3 *Pillar B design in Solidworks*

Upper rails and lower rails need to be drawn too. When they have been drawn, it will be possible to do the assembly.

This assembly appears in the following figures.

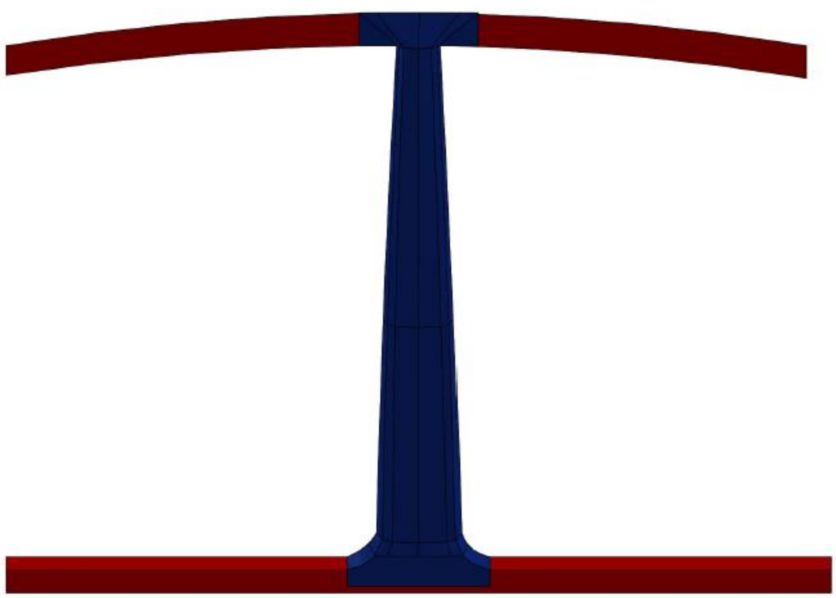


Figure 4.4 *Assembly Pillar B – Rails designed in Solidworks*

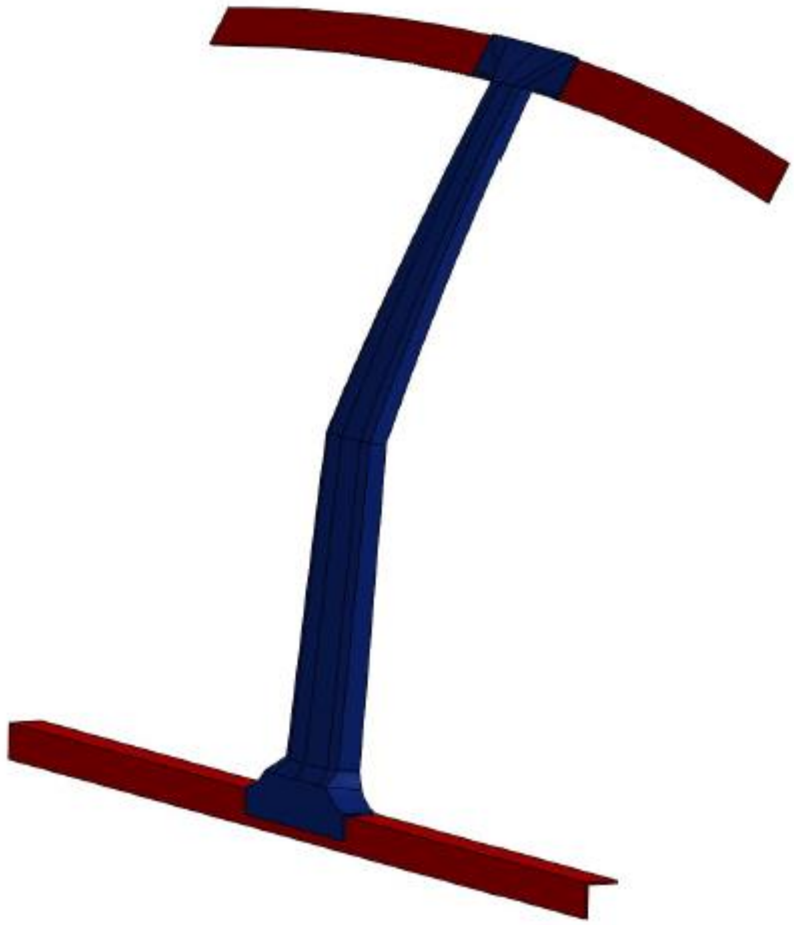


Figure 4.5 *Assembly Pillar B – Rails. Another angle*

In the Pillar B with the rails, small variations occur between the two types of welding. Both methods have to be designed in SolidWorks with rigid joints that do not allow penetration so that the welding is realistic, since if penetration were allowed the different forces and tensions would be transmitted as if it were a single piece and not different pieces welded.

4.1.1 Plasma Welding

In this case, this welding is one single fillet lap welding. It consists in join both sheets parallel. In laboratory tests, this method (lap fillet) will not be done due to lack of means.

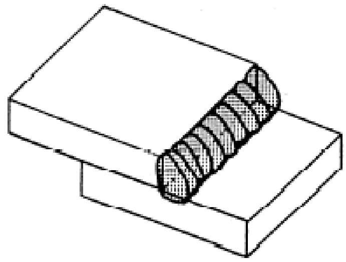


Figure 4.6 *Lap fillet weld* ***[28]***

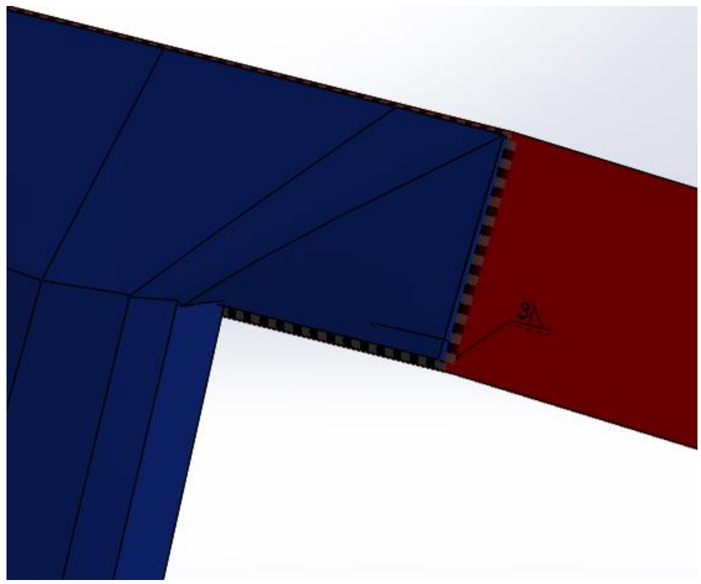


Figure 4.7 *Detail of Micro Plasma Welding in SW on the upper side of Pillar B*

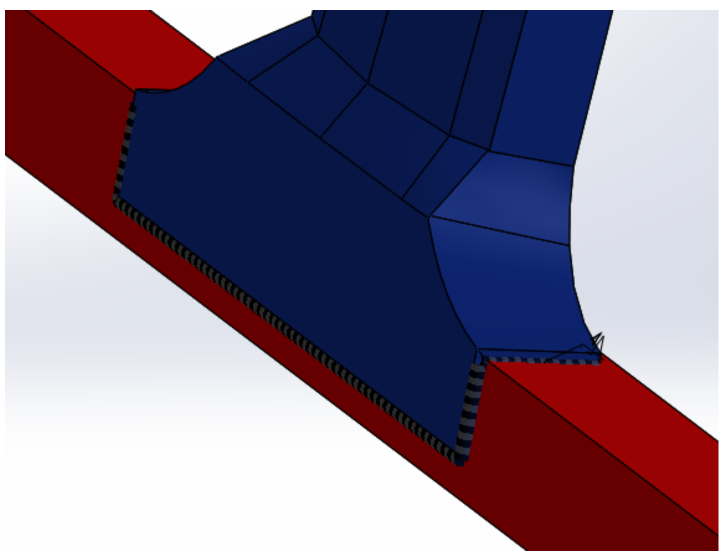


Figure 4.8 *Detail of Micro Plasma Welding in SW on the lower side of Pillar B*

4.1.2 Spot Resistance Welding

In the spot welding of Pillar B this piece is to be joined with the two rails, the lower and the upper. SolidWorks will make a union with penetration in the points marked in the piece.

The points will be 30 mm apart and will have a diameter of 5 mm. These values are within the range specified in the standard ISO 14373:2015 **[29].**

In the next pictures, it is possible to see where spots will be between pillar B and rails.

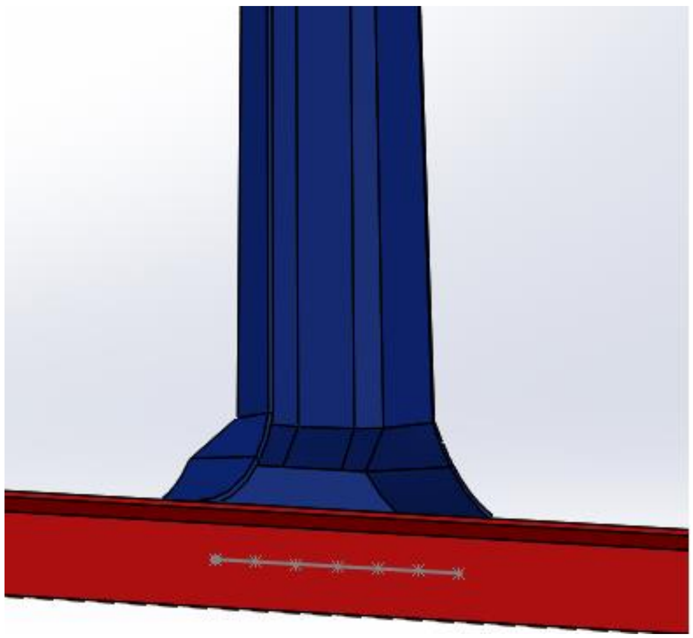


Figure 4.9 *Detail of places where spots weld are located in lower rail*

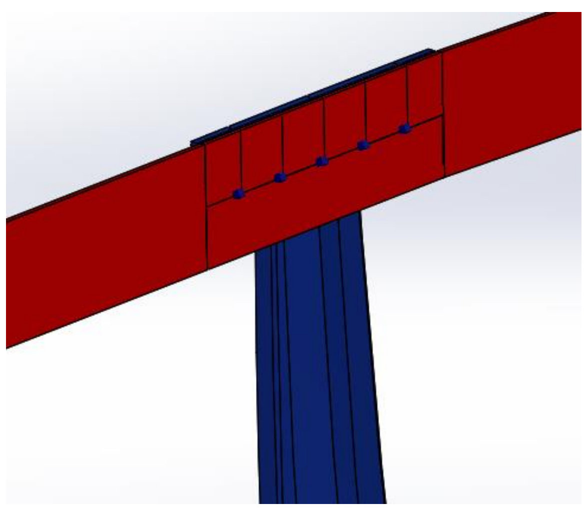


Figure 4.10 *Detail of places where spots weld are located in upper rail*

4.2 Roof panel

This panel is going to be welded with two different methods too. The first method is Plasma welding and the second y Spot Resistance Welding like in the previous piece. The difference is in plasma welding.

Both, the roof panel and the top rails have been drawn in 3D in SolidWorks.

As in the previous piece the assembly has been made with this software. The only difference is that in this piece, two different models have been made, because the measures of the pieces are somewhat different according to the welding Then, it is possible to appreciate differences in each method of welding.

In both models of SolidWorks will be used rigid union without penetration.

Later, laboratory tests will be carried out to simulate the two types of welding that occur in these parts.

4.2.1 Plasma welding

In this method of welding, unlike the spot welding, which uses overlap, a butt square weld is used. This weld will not be as large as that produced in a TIG-type weld, but the method is similar. This shape of welding in SW will be represented like a small V groove weld, because if not, it will not be possible to appreciate it.

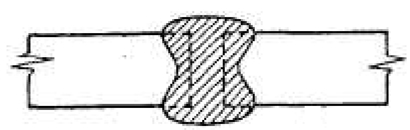


Figure 4.11 *Butt Square Welding* ***[30]***

In this process, the designed ceiling panel is shorter, because it has to fit into the upper rails, and not overlap as it would be in the following method (SRW).

In the followings pictures (Image 4.12 and Image 4.13), model of this welding method designed in SolidWorks is showed.

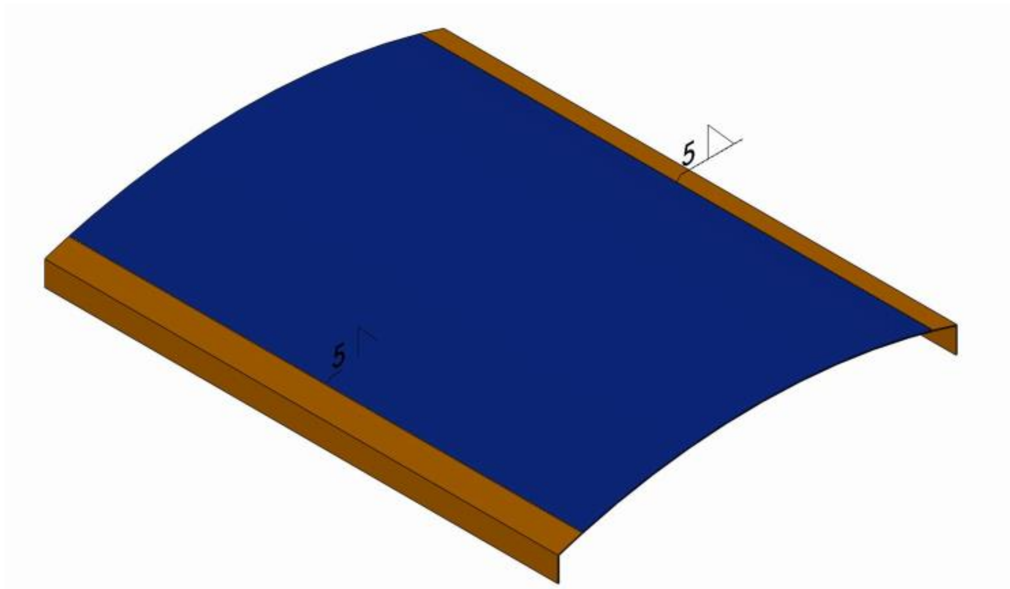


Figure 4.12 *Assembly in SW of Roof Panel and rails joined by Micro Plasma Welding*

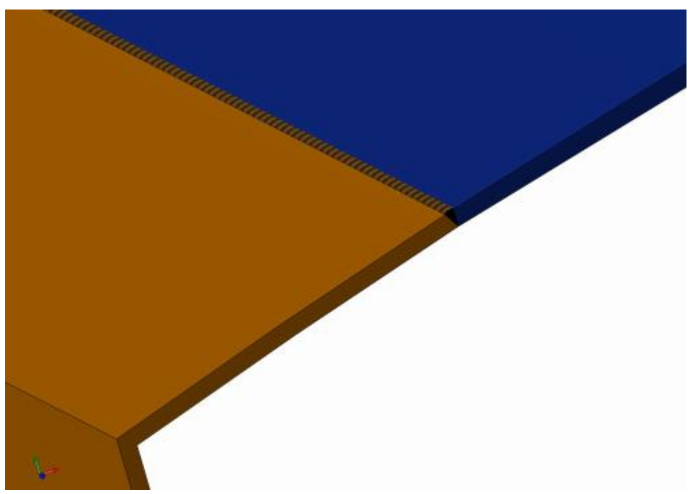


Figure 4.13 *Detail of Micro Plasma Welding in SolidWorks*

4.2.2 Spot Resistance Welding

With this method, roof needs to be wider, because both sheets have to be overlapped.

Rails have been designed with a curve so it fits perfectly with the roof panel.

In the first figure, roof and rails are showed separated to appreciate both pieces. And in the second picture, the assembly is showed shown positioned properly.

Distance between spots will be 6 times de diameter. The diameter will be approximately 5 mm, so distance between spots will be 3 cm. Spots will be on the middle of the rail.

In the next pictures, assembly of pieces are shown (Figure 4.14 and Figure 4.15). It is possible to see the places where spots are placed in the Figure 4.16.

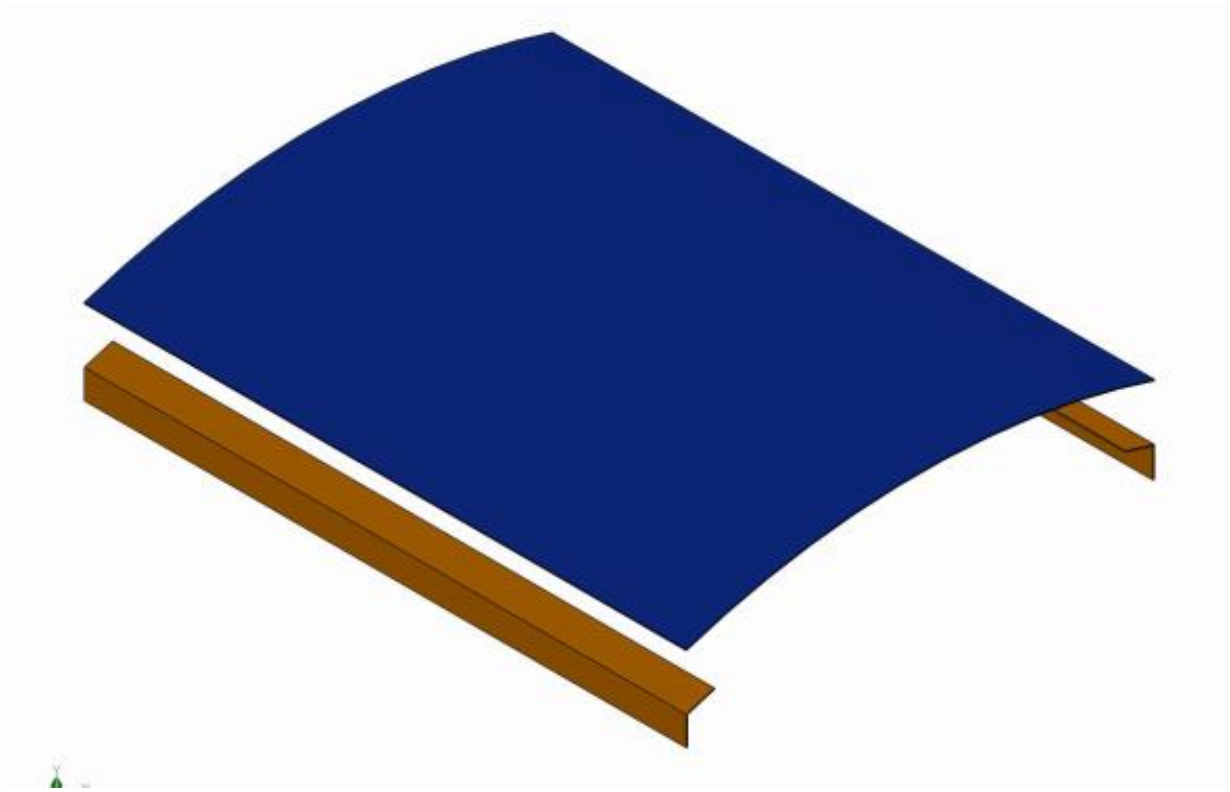


Figure 4.14 *Roof panel and upper rails designed by SolidWorks*

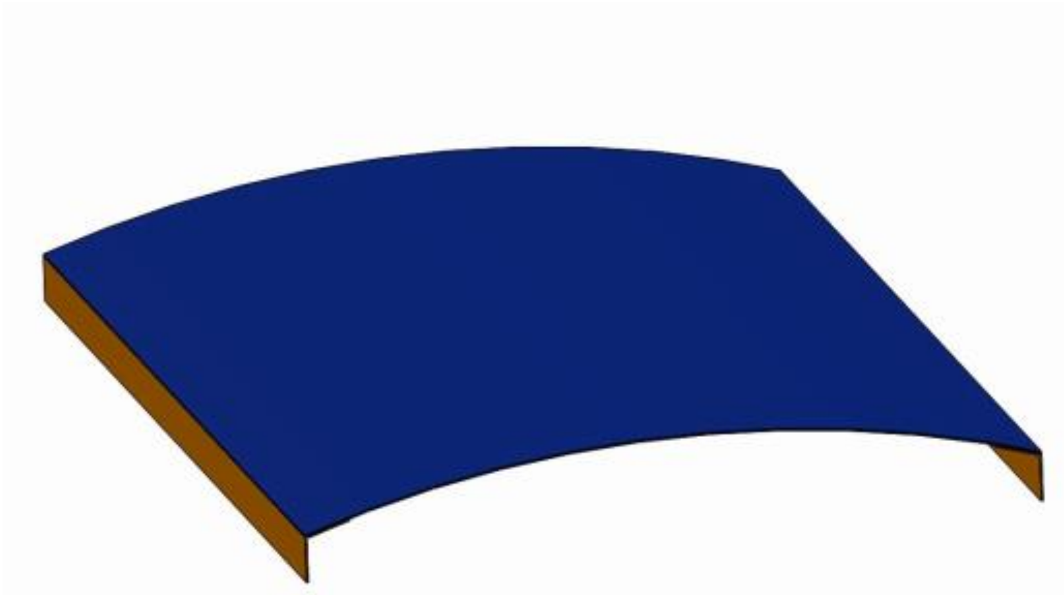


Figure 4.15 *Assembly of Roof Panel and upper rails in SW*

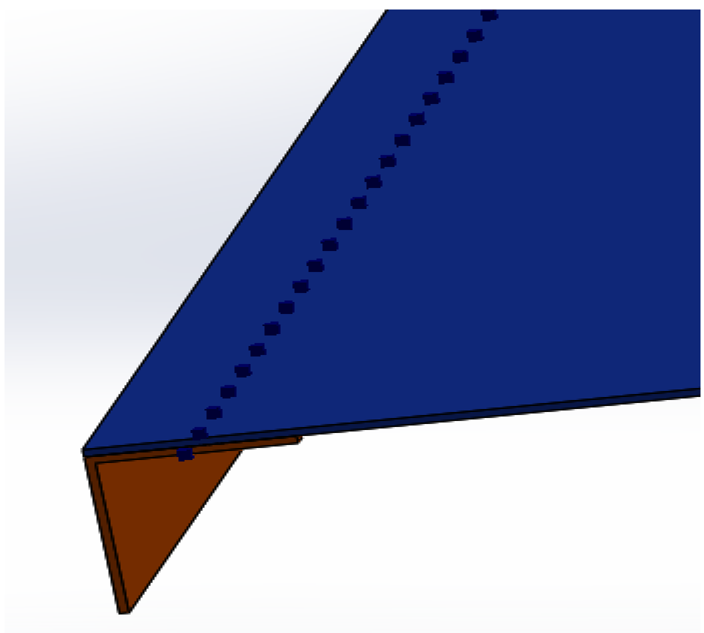


Figure 4.16 *Detail of places where spots weld are located*

Now, in Chapter 5, tensile strength simulation will be done in SolidWorks to check different strains and differences between both welding methods in both assemblies.

After that, in Chapter 6, preparation of welding tests and Welding Procedure Specification (WPS) will be performed for realize laboratory tests later.

Chapter 5: Virtual welding tests

Tensile strength test is going to be carried out to check which welding method is better.

Both methods are going to be compared. Because of this, the data of the force to be applied is not the most important. The important thing is that this force be the same in the two methods so that a conclusion can be reached between the two types of welding

• Loads

The loads to be used do not matter much as explained above, but a heavy load is to be chosen so that the difference can be better appreciated if there were between the two methods of welding.

For the roof the load chosen is 15000 N because it is approximately the weight of the car, and it would be the load that the roof will support if the car turns over.

The load selected to perform the test in the Pillar B is 7500 N. This is the half that has been used in the roof. The reason is that the car has two sides and that load will be divided by both of them.

• Material

It is necessary to select the material in the SolidWorks program. As any AHSS material is, it will be defined one in the library with the features wished. This will be the same material that in the next chapter is explained why it has been chosen and its characteristics.

This material has Yield Strength of 500 MPa and an Ultimate Tensile Strength of 600 MPa.

This material will have a thickness of 1.2 mm.

In the next sections of this chapter, results of test of Pillar B and roof panel are shown. General conclusions between both welding methods will be discussed in chapter 9.

5.1 Pillar B

In this section, joints between pillar B and rails of the car are going to be analyzed.

Two methods of welding are going to be compared, micro plasma welding without filler material and spot resistance welding. Characteristics of these methods in SolidWorks have been explained in the last chapter.

5.1.1 Micro Plasma Welding

As can be seen in the following images, in this test, welding zones do not sustain big deformations or pressures.

This is because all the load is absorbed by the rails and the pillar at its midpoint which is weaker.

Therefore the plasma welding here works effectively and it will later be checked if the spot welding also works correctly. However, the Pillar B would be designed better or with wider thickness because in the middle it gets over the maximum yield strength of the material.

This maximum stress in weld zone can be seen in the next figure (Figure 5.1).

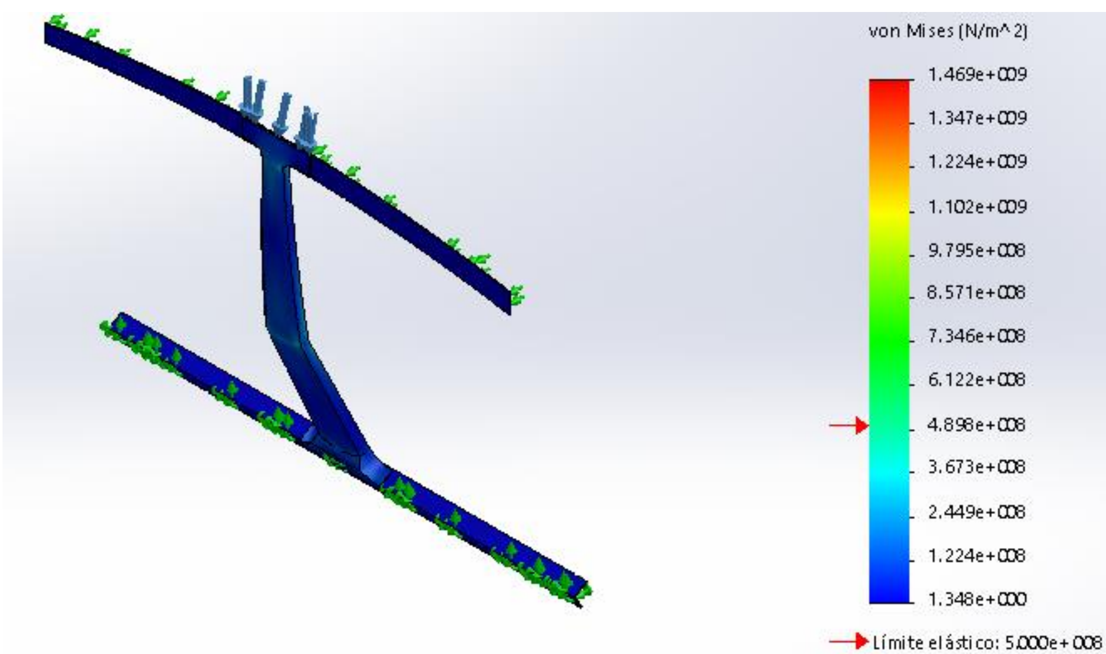


Figure 5.1 *Tensile strength of Pillar B. Micro Plasma welding*

Displacements are not very high. In the middle of the pillar is 6.5 mm and displacement around weld zones is 0.5 mm.

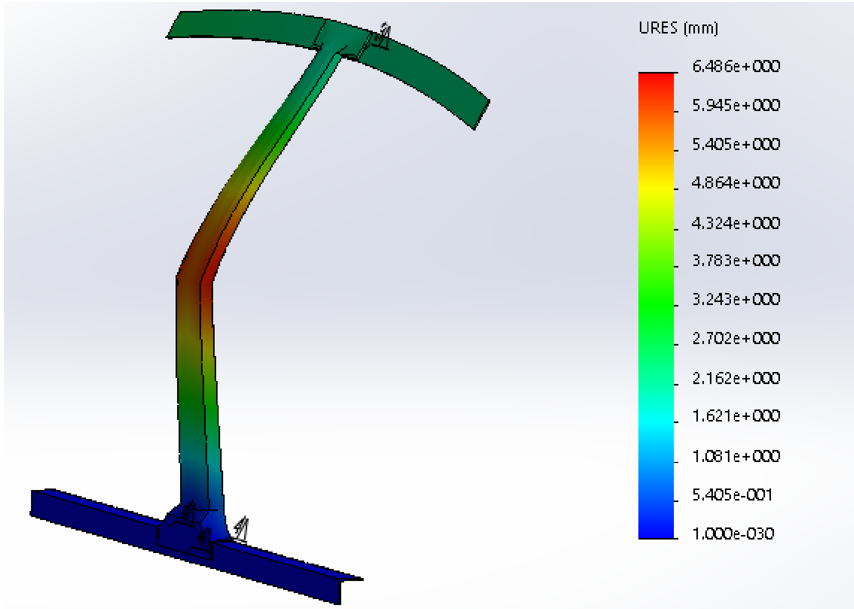


Figure 5.2 *Displacement of Pillar B. Micro Plasma welding*

Next table (Table 5.1) shows the summary with maximum values of pillar B using Micro Plasma welding method.

Part of the piece	Maximum stress (MPa)	Maximum displacement (mm)
Joint upper rail	125	1
Joint lower rail	60	0.5
Pillar B	525	6.5

Table 5.1 *Summary Pillar B. SW test. Micro Plasma welding*

5.1.2 Spot Resistance Welding

As in the previous test, there is no great effort in welding. Therefore spot welding could also be used perfectly in this material and this piece.

This is because all the load is absorbed by the rails and the pillar at its midpoint which is weaker.

Therefore, spot resistance welding here works effectively. However, the Pillar B would be designed better or with wider thickness because in the middle it gets over the maximum yield strength of the material. In this case Pillar B works similar than in the previous case.

This maximum stress in the piece can be seen in the next figure (Figure 5.3). And maximum stress in spot points is showed in Figure 5.4.

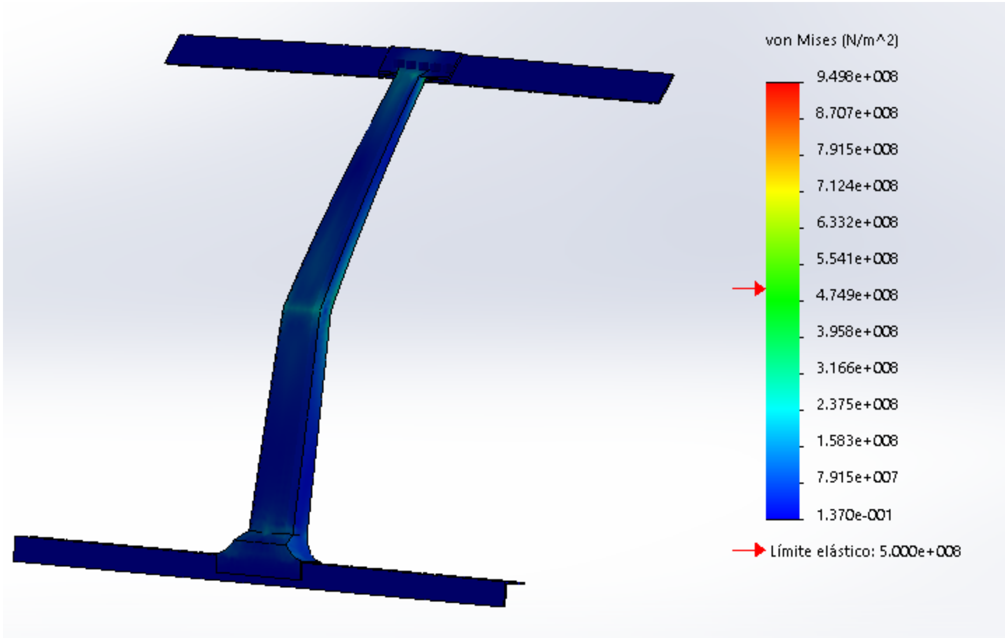


Figure 5.3 *Tensile strength of Pillar B. Spot Resistance welding*

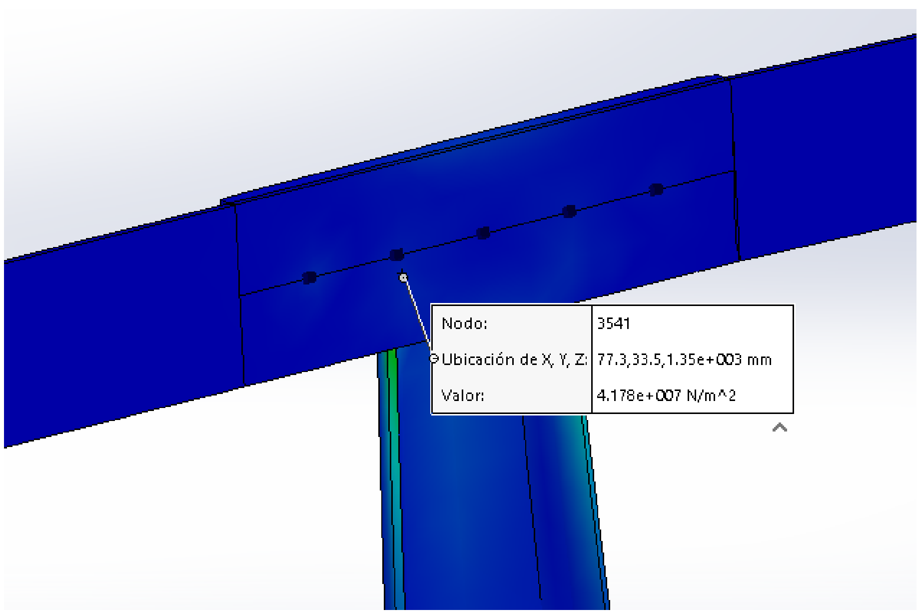


Figure 5.4 *Details of tensile close to Spots**.** Tensile strength of Pillar B.*

Displacements are not very high. In the middle of the pillar is 5.1 mm and displacement around weld zones is 1.5 mm.

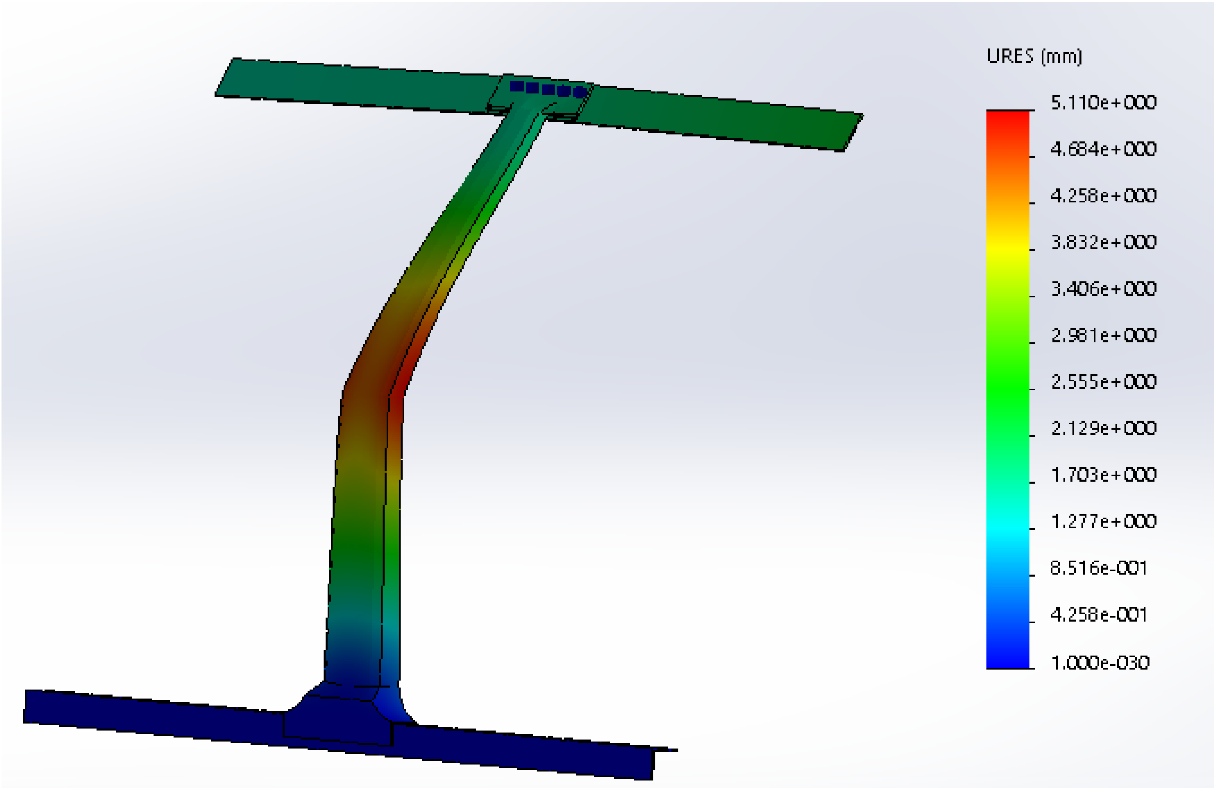


Figure 5.5 *Displacement of Pillar B. Spot Resistance welding*

Next table (Table 5.2) shows the summary with maximum values of pillar B using Spot Resistance welding method.

Part of the piece	Maximum stress (MPa)	Maximum displacement (mm)
Joint upper rail	41.8	1.5
Joint lower rail	23	0.5
Pillar B	316	5.1

Table 5.2 *Summary Pillar B. SW test. Spot Resistance welding*

5.2 Roof panel

In this section, joints between roof panel and upper rails of the bodywork are going to be analyzed.

It is going to be compared two methods of welding, micro plasma welding without filler material and spot resistance welding. Characteristics of these methods in SolidWorks have been explained in the last chapter.

5.2.1 Micro Plasma Welding

In this test, a welding simulation by the micro-plasma method is to be analyzed.

In the following photographs it is possible to see the stress efforts and displacements produced in the roof panel and in the rails that support it.

In the next image (Figure 5.6), it can be seen that the maximum values of tension are just in the union of the two pieces that is to say in the weld. This is shown by the orange and red colors.

In addition, the maximum value of this stress is found at the edge of these parts at the welding site (Figure 5.7). This tension is 560 MPa, and it is over the yield strength, but a bit lower than theory ultimate tensile strength that is 600 MPa, so joint will resist but it will be a fix.

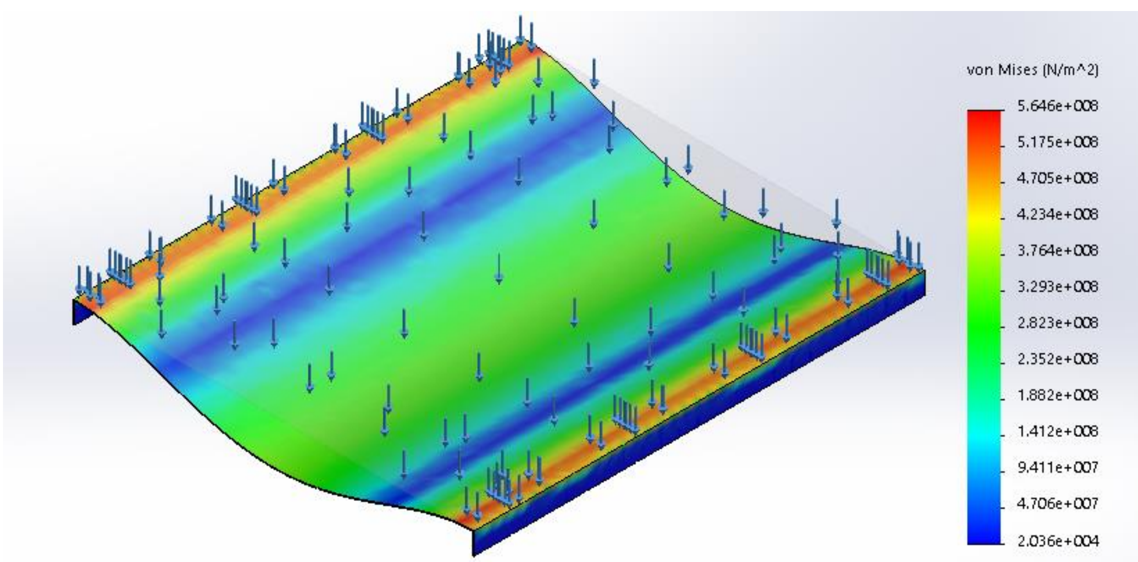


Figure 5.6 *Tensile strength of roof panel. Micro Plasma welding*

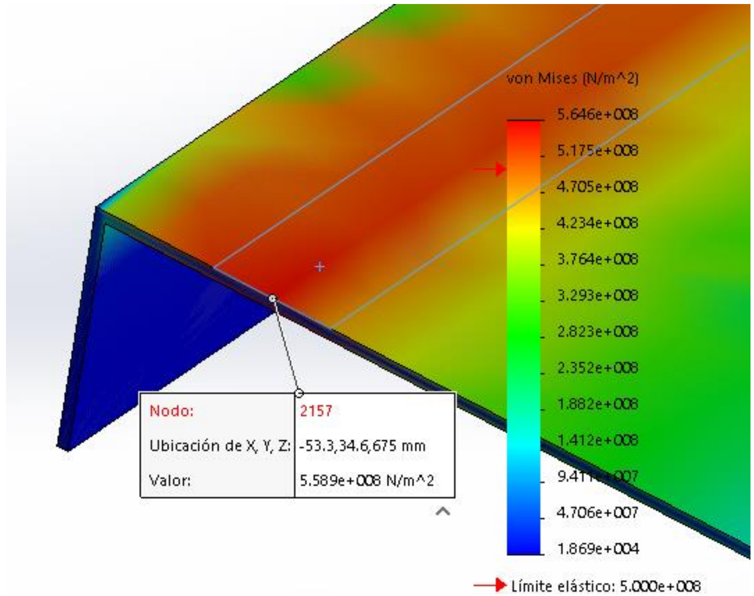


***Figure 5.7** Detail of roof panel stress in micro plasma welding zone.*

On the other hand, displacements (Figure 5.8) are very low in welding zones, but is big in the roof. But roof only bends 10 cm, so it would not be dangerous for the passengers.

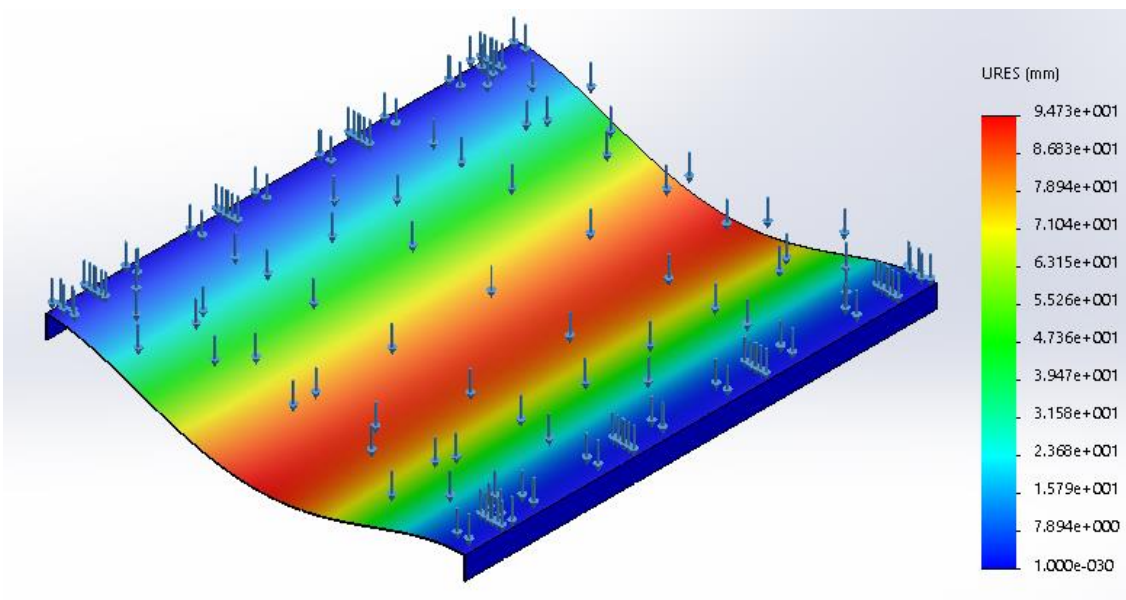


***Figure 5.8** Displacement of roof panel. Micro Plasma welding*

Next table (Table 5.3) shows the summary with maximum values of roof panel using Micro Plasma welding method.

Part of the piece	Maximum stress (MPa)	Maximum displacement (mm)
Welding zone	558	2.4
Rail*	558	2.4
Roof*	558	94.7

*Maximum stress are in the welding zone too.

Table 5.3 *Summary roof panel. SW test. Micro Plasma welding*

5.2.2 Spot Resistance Welding

In this test, a welding simulation by the spot resistance method is to be analyzed.

In the following photographs it is possible to see the stress efforts and displacements produced in the roof panel and in the rails that support it.

In the next image (Figure 5.9) can be seen that the maximum values of tension are just in the spot welds. This is shown by the yellow and orange colors.

In addition, the maximum value of this stress is found at the edge of the union, in one spot weld (Figure 5.10). This tension is 209.3 MPa, and it is under the yield strength, so joint will resist.

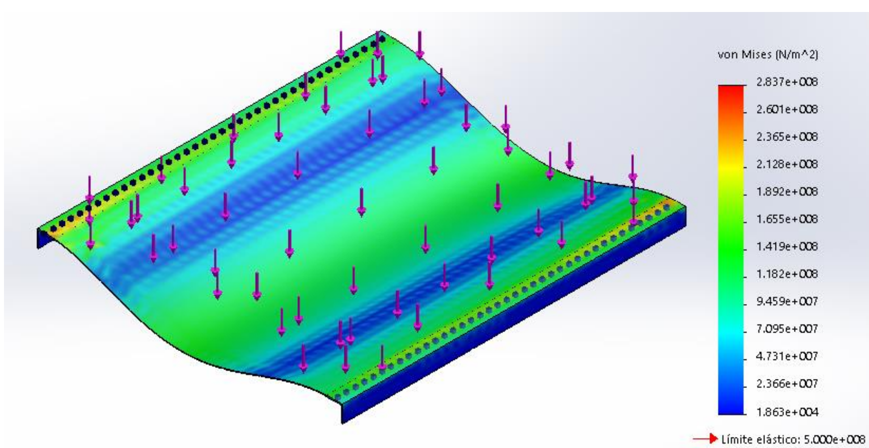


Figure 5.9 *Tensile strength of roof panel. Spot Resistance welding*

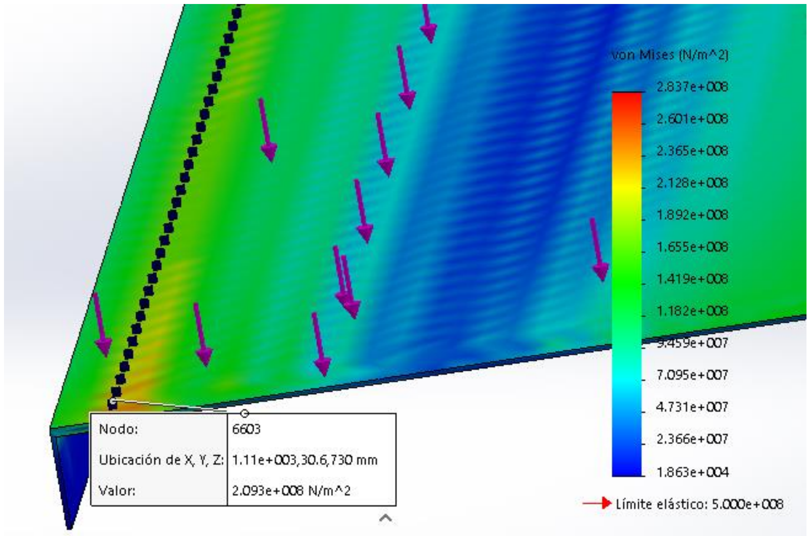


Figure 5.10 *Detail of roof panel stress in spot resistance welding zone.*

Otherwise, displacements (Figure 5.11) are very low in welding zones, and it is similar to 0, but in the roof is bigger. This roof bends only 3 cm, so it is a good result too.

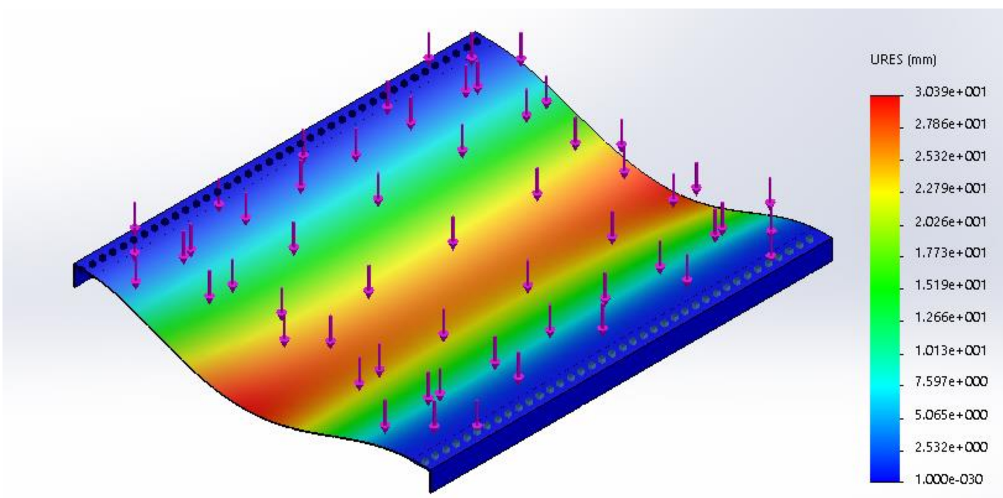


Figure 5.11 *Displacement of roof panel. Spot Resistance welding*

Next table (Table 5.4) shows the summary with maximum values of roof panel using Spot Resistance welding method.

Part of the piece	Maximum stress (MPa)	Maximum displacement (mm)
Welding zone	209.3	0.7
Rail*	260	2.5
Roof*	260	30.1

Table 5.4 *Summary roof panel. SW test. Spot Resistance welding*

Chapter 6: Preparation of the WPS of selected sheet joints

In this chapter different topics will be discussed about the preparation of welding joints.

To do this, briefly explain the characteristics that the material of the pieces must have and this will be chosen.

Then the parameters necessary to weld the parts will be found and the WPS (Welding Procedure Specification)

6.1 Characteristics of pieces

Joints that have been chosen to join are Pillar B/ Down and up rails and Roof/Up rails.

These parts belong to structural parts of the car and for this reason these pieces need to have many characteristics. They are the followings:

- **Stiffness.** A too soft structure is dangerous as it assumes that the passenger compartment will not remain intact. Conversely, a very rigid structure is also bad so that the occupants are subjected to strong accelerations. At the structural level, the chassis should not be twisted or flexed by the effect of the forces acting on it.
- **Durability.** For get this feature, a solid and stable construction, use of materials that do not age easily and an adequate corrosion protection.
- **Crashworthiness.** In case of collision, the structure must be deformed in a programmed or predefined way, transforming the maximum possible kinetic energy into deformation work. It is possible to protect from collisions with pillars, roof panels, and side panels that protect the part of the passenger. Cross bars are added too.

6.2 Material selected

For the before features, it is necessary to get a material that can get them.

How it has been explained in the beginning, AHSS materials are good for the automotive industry because they fulfill the characteristics explained.

Within these AHSS materials, the first generation explained above are the most widely used and widespread. These are the CP (Complex phase) and DP (Dual Phase)

Finally, a CP steel has been chosen because Yield strength/ Tensile strength ratio is higher than DP steels and is recommended for small bending radius.

Specific steel LITEC 600 CP + ZF 100-B **[31]**. This metal-coated is especially suitable for automotive industry and for applications that need with good corrosion resistance and light structure. For this reason, this material is a good option for this project.

In addition the manufacturer recommends it especially for cross beams, vertical beams, side impact beams and safety elements. One of the pieces is a Pillar B which is within these recommendations. And roof panel can be considered a safety element.

The thickness of this material will be 1.2 mm because Pillar B and roof panel have 1.2 mm of thickness.

6.2.1 Characteristics

The name LITEC 600 CP + ZF 100-B indicate characteristics of this metal.

- Thickness: 1.2 mm
- The number 600 is the tensile strength in MPa.
- ZF say to us that its coating is Galvannealed zinc-iron alloy. Number 100 indicates a 10% of coating
- The letter B says the surface quality. In this case is improved surface that is obtained by skin pass rolling.

  There are minor flaws in the surface, such as skin pass marks, minor scratches, small indentations, run-off marks and minor passivation stains are allowed.

Properties of this material can be seen in next table (Table 6.1):

Steel grade	Coating	Yield strength R_{p02} MPa	Tensile strength R_m MPa min	Elongation A80 % min Thickness 1)		Bake hardening BH_2 MPa
DP steels						
Litec 500DP	Z, ZA	300 - 380	500	21	23	30
Litec 600DP	Z, ZA, ZF	340 - 420	600	18	20	30
Litec 800DP	Z, ZA, ZF	450 - 560	780	12	14	30
Litec 1000DP	Z	600 - 750	980	8	10	30
CP steels						
Litec 600CP	Z, ZA, ZF	350 - 500	600	14	16	30
Litec 800CP	Z, ZA, ZF	500 - 700	780	8	10	30
Litec 1000CP	Z	700 - 900	980	5	7	30

1) For ZF coatings, the minimum elongation value reduced by 2 units applies.

Table 6.1 *Properties of AHSS materials. DP and CP* ***[31]***

As can be seen in the table, Yield strength is between 350 and 500 MPa. Tensile strength as explained before is 600 MPa.

Elongation A80% is 16 units, because this material has ZF coating.

The chemical composition of the material is the following boxed in the Table 6.2.

Stal	Skład chemiczny, %										
	C	Si	Mn	P	S	Cr	Al	V	B	Cr-Mo	Nb-Ti
CP-K 60/78	0,12	0,8	2,2	0,04	0,015	0	1,2	0,2	0,005	1	0,15
CP-W 800	0,12	0,8	2,2	0,04	0,015	0	1,2	0,2	0,005	1	0,15
CP-W 1000	0,17	0,8	2,2	0,04	0,015	0	1,2	0,2	0,005	1	0,15
Dogal 600 CP	0,12	0,3	1,66	0,02	0,004	0,5	0,02	0	0	0	0
Dogal 800 CP	0,16	0,25	1,9	0,02	0,004	0,5	0,015	0	0	0	0
Litec 600CP	0,18	0,8	2,2	0,02	0,004	0	2	0	0	1	0,15
Litec 800CP	0,18	0,8	2,2	0,02	0,004	0	2	0	0	1	0,15
Litec 1000CP	0,23	0,8	2,2	0,02	0,004	0	2	0	0	1,2	0,15
Opracowanie własne na podstawie danych producentów											

Table 6.2 *Chemical composition of AHSS CP* ***[32]***

6.3 Welding methods selected

In Chapter 1 of this project, an analysis of the different types of welding methods was carried out. Thanks to this analysis, it has been possible to choose two methods of welding that are going to be used to weld the AHSS metals.

The two best methods in the automotive industry are Laser Welding and Spot Resistance Welding.

In addition spot welding is widely used because of its great speed and efficiency, but it has to be used with the appropriate parameters if a good joint is wished.

However, finally in the laboratory, Micro Plasma welding will be used instead of Laser welding because there is not right equipment in the laboratory to perform the union. This method is not equal but it is similar, based in arc welding, high temperatures and small welding zone.

This is because there is only the laser welding machine shown in Figure 6.1 is available and it is only capable of welding thicknesses of up to 0.5 mm.

Figure 6.1 *Laser welding machine*

So, tests will be carried out with Micro Plasma welding and Spot Resistance welding. In the next section, parameters will be calculated to perform the welds.

Micro Plasma welding and Spot Resistance welding will be explained in greater detail in Section 7.2 of this project.

6.4 Parameters for welding

To perform a welding correctly, there are some parameters that have to be chosen correctly.

6.4.1 Micro Plasma Welding

These parameters are amperage and voltage in Plasma Welding (Figure 6.1). In order to know which ones are suitable for our metal and our thickness, different attempts must be carried out, testing different factors. These tests will be done with the extra samples that have been mentioned few lines before.

Figure 6.2 *Micro Plasma machine. Amperage and Voltage*

If the amperage or voltage are too high, specimens will note welded because, there will be too much energy. It is necessary to try many times to calculate optimal parameters.

Once nominal parameters have been achieved, the welds can be made. But an interval of low and high parameters will be selected too.

For this project, the optimal parameters are:

Parameter	Amperage (A)	Voltage (V)
Micro Plasma Welding	30	11

Table 6.3 *Optimal parameters Micro Plasma Welding*.

Low parameters will be:

Parameter	Amperage (A)	Voltage (V)
Micro Plasma Welding	25	10.5

Table 6.4 *Low parameters Micro Plasma Welding*

And high parameters will be:

Parameter	Amperage (A)	Voltage (V)
Micro Plasma Welding	35	11.5

Table 6.5 *High parameters Micro Plasma Welding*

6.4.2 Spot Resistance Welding

For Spot Resistance Welding, parameters that have to been considered are amperage and welding time. With low parameters or high parameters, specimens could not be welded or be burnt.

For this project, optimal parameters are:

Parameter	Amperage (A)	Welding Time (sec)
Spot Resistance Welding	60	0.03

Table 6.6 *Nominal parameters Resistance Spot Welding*

Low parameters will be:

Parameter	Amperage (A)	Welding Time (sec)
Spot Resistance Welding	45	0.025

Table 6.7 *Low parameters Resistance Spot Welding*

And high parameters will be:

Parameter	Amperage (A)	Welding Time (sec)
Spot Resistance Welding	80	0.05

Table 6.8 *High parameters Resistance Spot Welding*

6.5 Welding Procedure Specification (WPS)

In the next pages, it is possible to see the six WPS reports that are going to be used in this project. This documents are necessary

For WPS of low and high parameters, these have been selected according to nominal parameters achieved in the before section.

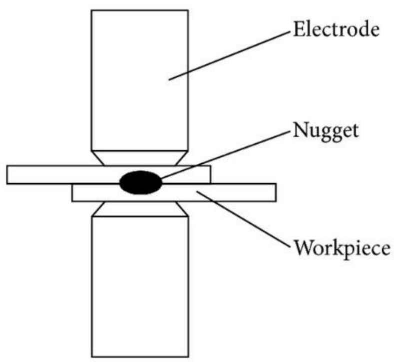
These WPS are in the following sequence:

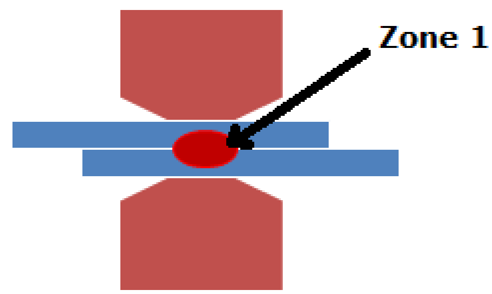
- WPS #1: Resistance Spot Welding, Low parameters
- WPS #2: Resistance Spot Welding, Nominal parameters
- WPS #3: Resistance Spot Welding, High parameters
- WPS #4: Micro Plasma Welding, Low parameters
- WPS #5: Micro Plasma Welding, Nominal parameters
- WPS #6: Micro Plasma Welding, High parameters

They have been done according to standards EN ISO 4063 **[33]**, EN 287-1 **[34]**, EN ISO 14341 **[35]** and EN ISO 14175 **[36]**.

University Mechanical Engineering (Szczecin)	**WELDING PROCEDURE SPECIFICATION (WPS)**	*WPS No:* ***1***

Welding method: **21** (acc. to EN ISO 4063)	*Identification general of base material:* ***AHSS***	*Page No:* ***1/1***
Joint type weld: Lap weld	*Identification specific of base material:* ***600 CP + ZF 100-B***	
Welding position: **PA** (acc. to EN 287-1)	*Thickness of base material:* ***1.2 mm***	
Welder's name: Carlos Ramírez	*Plate specimen*	
Sketch of joint:	***Welding sequence:***	



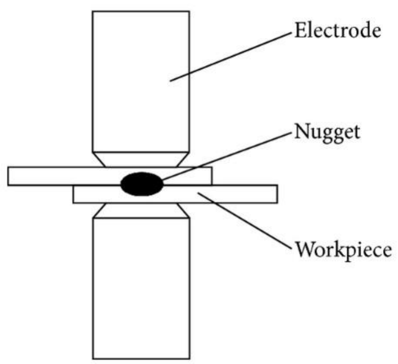


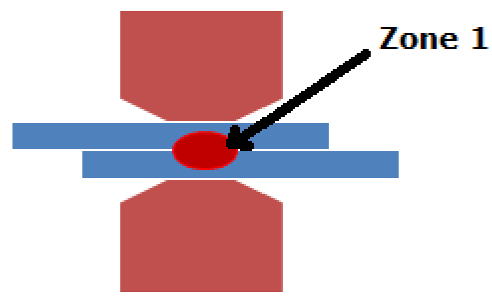
Number of layer	*Welding method*	*Dimension of filler material [mm]*	*Current [A]*	*Welding time [sec]*	*Kind of current polarity [V]*	*Wire feed speed [m/min]*	*Welding speed [mm/min]*	*Heat input [kJ]*
1	**21**	**No filler material**	**45**	**0.025**	**DC+**	**-**	**-**	***0.45***

Filler material, **mm. No filler material**	*Preheating temperature: -*
Special recommendations for drying: Leave half hour in contact with the air.	*Interpass temperature: -*
	Postweld heating
Gas / Flux: -	*Metod, temperature, time:-*
Gas flow rate [l/min]: -	*Heating and cooling speed:-*
Kind of tungsten electrode, diameter: ***Truncated cone Electrode, 5mm***	
Gouging (root grinding):-	*Additional information:*
Produced by: Carlos Ramírez Menéndez	***Approved by: Damian Sobków, Jerzy Nowacki***

University Mechanical Engineering (Szczecin)	**WELDING PROCEDURE SPECIFICATION (WPS)**	*WPS No:* ***2***

Welding method: **21** (acc. to EN ISO 4063)	*Identification general of base material:* ***AHSS***	*Page No:* ***1/1***
Joint type weld: Lap weld	*Identification specific of base material:* ***600 CP + ZF 100-B***	
Welding position: **PA** (acc. to EN 287-1)	*Thickness of base material:* ***1.2 mm***	
Welder's name: Carlos Ramírez	*Plate specimen*	
Sketch of joint:	***Welding sequence:***	

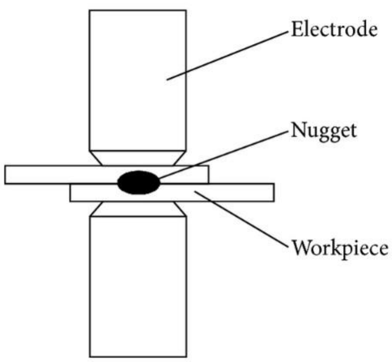


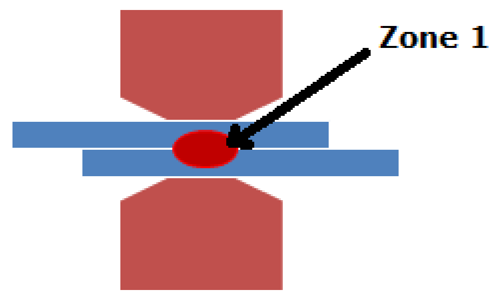


Number of layer	*Welding method*	*Dimension of filler material [mm]*	*Current [A]*	*Welding time [sec]*	*Kind of current polarity [V]*	*Wire feed speed [m/min]*	*Welding speed [mm/min]*	*Heat input [KJ/mm]*
1	**21**	**No filler material**	**60**	**0.03**	**DC+**	**-**	**-**	***0.72***

Filler material, **mm. No filler material**	*Preheating temperature: -*
Special recommendations for drying: Leave half hour in contact with the air.	*Interpass temperature: -*
	Postweld heating
Gas / Flux: -	*Metod, temperature, time: -*
Gas flow rate [l/min]: -	*Heating and cooling speed: -*
Kind of tungsten electrode, diameter: ***Truncated cone Electrode, 5mm***	
Gouging (root grinding): -	*Additional information:*
Produced by: Carlos Ramírez Menéndez	***Approved by: Damian Sobków, Jerzy Nowacki***

University Mechanical Engineering (Szczecin)	**WELDING PROCEDURE SPECIFICATION (WPS)**	*WPS No:* ***3***
Welding method: **21** (acc. to EN ISO 4063)	*Identification general of base material:* ***AHSS***	*Page No:* ***1/1***
Joint type weld: Lap weld	*Identification specific of base material:* ***600 CP + ZF 100-B***	
Welding position: **PA** (acc. to EN 287-1)	*Thickness of base material:* ***1.2 mm***	
Welder's name: Carlos Ramírez	*Plate specimen*	
Sketch of joint:	***Welding sequence:***	



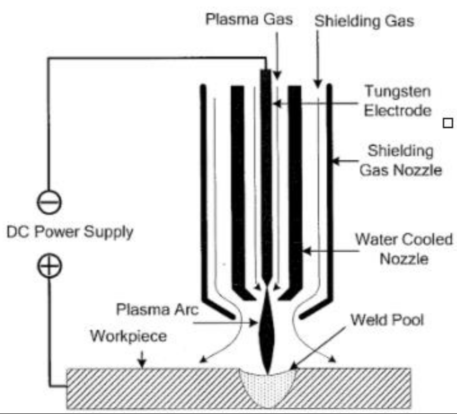


Number of layer	*Welding method*	*Dimension of filler material* [mm]	*Current* [A]	*Welding time* [sec]	*Kind of current polarity* [V]	*Wire feed speed [m/min]*	*Welding speed [mm/min]*	*Heat input [KJ/mm]*
1	**21**	**No filler material**	**80**	**0.05**	**DC+**	**-**	**-**	***1.6***

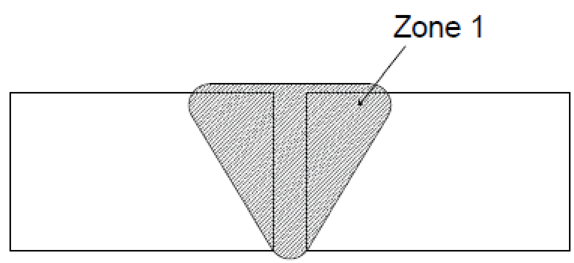
Filler material: **mm. No filler material**	*Preheating temperature: -*
Special recommendations for drying: Leave half hour in contact with the air.	*Interpass temperature: -*
	Postweld heating
Gas / Flux: -	*Metod, temperature, time: -*
Gas flow rate [l/min]:-	*Heating and cooling speed: -*
Kind of tungsten electrode, diameter: ***Truncated cone Electrode, 5mm***	
Gouging (root grinding): -	*Additional information:*
Produced by: Carlos Ramírez Menéndez	***Approved by: Damian Sobków, Jerzy Nowacki***

University Mechanical Engineering (Szczecin)	WELDING PROCEDURE SPECIFICATION (WPS)		WPS No: **4**
Welding method: **15** (acc. to EN ISO 4063)		*Identification general of base material:* ***AHSS***	*Page No:* ***1/1***
Joint type weld: Butt square welding		*Identification specific of base material:* ***600 CP + ZF 100-B***	
Welding position: **PA** (acc. to EN 287-1)		*Thickness of base material:* ***1.2 mm***	
Welder's name: Carlos Ramírez		*Plate specimen*	

Sketch of joint:



Welding sequence:

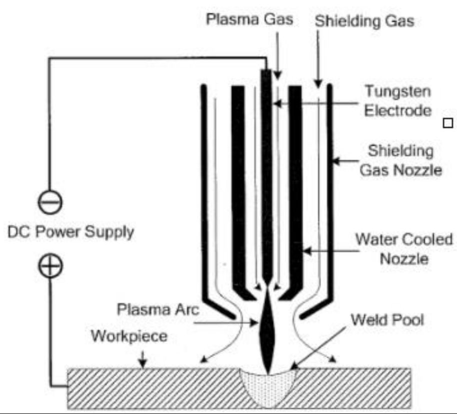


Number of layer	*Welding method*	*Dimension of filler material [mm]*	*Current [A]*	*Voltage [V]*	*Kind of current polarity [V]*	*Wire feed speed [m/min]*	*Welding speed [mm/min]*	*Heat input [KJ/mm]*
1	**15**	**No filler material**	**25**	**10.5**	**DC+**	**-**	***12000***	***1.312***

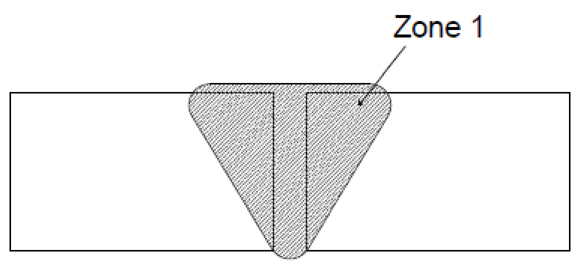
Filler material, **mm. No filler material**	*Preheating temperature:* -
Special recommendations for drying: Leave half hour in contact with the air.	*Interpass temperature: max. :* -
	Postweld heating
Gas / Flux: ***M 21*** *(acc. to EN 439)*	*Metod, temperature, time:-*
*Gas flow rate [l/min]:**14÷16***	*Heating and cooling speed:* -
Kind of tungsten electrode, diameter: ***Radius Electrode, 1 mm***	
Gouging (root grinding): -	*Additional information:* ***Specimen number 9***
Produced by: Carlos Ramírez Menéndez	***Approved by: Damian Sobków, Jerzy Nowacki***

University Mechanical Engineering (Szczecin)	WELDING PROCEDURE SPECIFICATION (WPS)	*WPS No:* ***5***
Welding method: **15** (acc. to EN ISO 4063)	*Identification general of base material:* ***AHSS***	*Page No:* ***1/1***
Joint type weld: Butt square welding	*Identification specific of base material:* ***600 CP + ZF 100-B***	
Welding position: **PA** (acc. to EN 287-1)	*Thickness of base material:* ***1.2 mm***	
Welder's name: Carlos Ramírez	*Plate specimen*	

Sketch of joint:



Welding sequence:

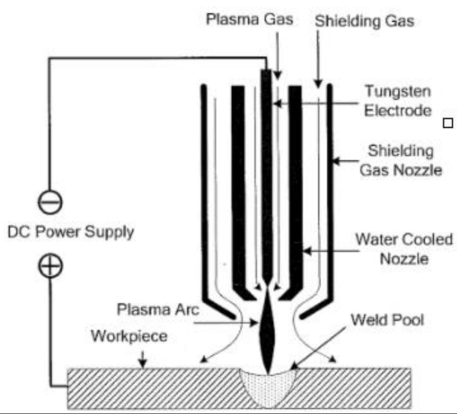


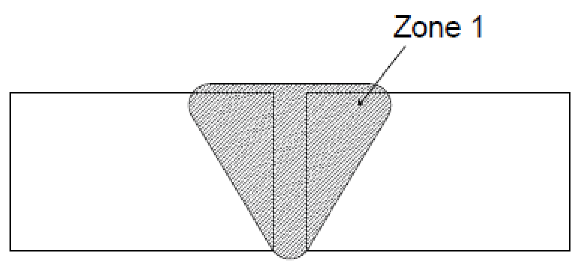
Number of layer	*Welding method*	*Dimension of filler material [mm]*	*Current [A]*	*Voltage [V]*	*Kind of current polarity [V]*	*Wire feed speed [m/min]*	*Welding speed [mm/min]*	*Heat input [KJ/mm]*
1	**15**	**No filler material**	**30**	**11**	**DC+**	**-**	**12000**	***1.65***

Filler material, **mm. No filler material**	*Preheating temperature: -*
Special recommendations for drying: Leave half hour in contact with the air.	*Interpass temperature: max. : -*
	Postweld heating
Gas / Flux: ***M 21*** *(acc. to EN 439)*	*Metod, temperature, time:-*
*Gas flow rate [l/min]:**14÷16***	*Heating and cooling speed: -*
Kind of tungsten electrode, diameter: ***Radius Electrode, 1 mm***	
Gouging (root grinding): -	*Additional information:* ***Specimen number 7***
Produced by: Carlos Ramírez Menéndez	***Approved by: Damian Sobków, Jerzy Nowacki***

University Mechanical Engineering (Szczecin)	**WELDING PROCEDURE SPECIFICATION (WPS)**	*WPS No:* ***6***
Welding method: **15** (acc. to EN ISO 4063)	*Identification general of base material:* ***AHSS***	*Page No:* ***1/1***

Joint type weld: Butt square welding	*Identification specific of base material:* ***600 CP + ZF 100-B***
Welding position: **PA** (acc. to EN 287-1)	*Thickness of base material:* ***1.2 mm***
Welder's name: Carlos Ramírez	*Plate specimen*
Sketch of joint:	***Welding sequence:***





Number of layer	*Welding method*	*Dimension of filler material [mm]*	*Current [A]*	*Voltage [V]*	*Kind of current polarity [V]*	*Wire feed speed [m/min]*	*Welding speed [mm/min]*	*Heat input [KJ/mm]*
1	**15**	**No filler material**	**35**	**11.5**	**DC+**	**-**	**12000**	**2.05**

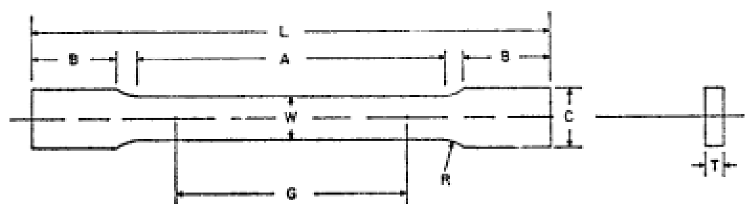
Filler material, **mm. No filler material**	*Preheating temperature: -*
Special recommendations for drying: Leave half hour in contact with the air.	*Interpass temperature: max.: -*
	Postweld heating
Gas / Flux: ***M 21*** *(acc. to EN 439)*	*Metod, temperature, time:-*
*Gas flow rate [l/min]:**14÷16***	*Heating and cooling speed: -*
Kind of tungsten electrode, diameter: ***Radius Electrode, 1 mm***	
Gouging (root grinding): -	*Additional information:* ***Specimen number 11***
Produced by: Carlos Ramírez Menéndez	***Approved by: Damian Sobków, Jerzy Nowacki***

Chapter 7: Laboratory tests

7.1 Cutting of the sheet

The first step that has to be done to be able to perform the experiments is to make cuts in the sheet of the material that has been chosen. These cuts are made according to the shape and size of the specimens to be created.

This size can be selected according to Standard ASTM E8 **[37]** or Standard PN-EN ISO 4063:2002 **[38]**. For American case, sheet thickness is 1,2 mm, so it will be used subsize specimen number 3 used for thickness under 6mm



Dimensions			
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1.500 in.] Wide	Sheet-Type, 12.5 mm [0.500 in.] Wide	6 mm [0.250 in.] Wide
	mm [in.]	mm [in.]	mm [in.]
G—Gage length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W—Width (Note 3 and Note 4)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T—Thickness (Note 5)		thickness of material	
R—Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L—Overall length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced section, min	225 [9]	57 [2.25]	32 [1.25]
B—Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C—Width of grip section, approximate (Note 4 and Note 9)	50 [2]	20 [0.750]	10 [0.375]

Figure 7.1 *Specimen dimensions according to ASTM E8*

v

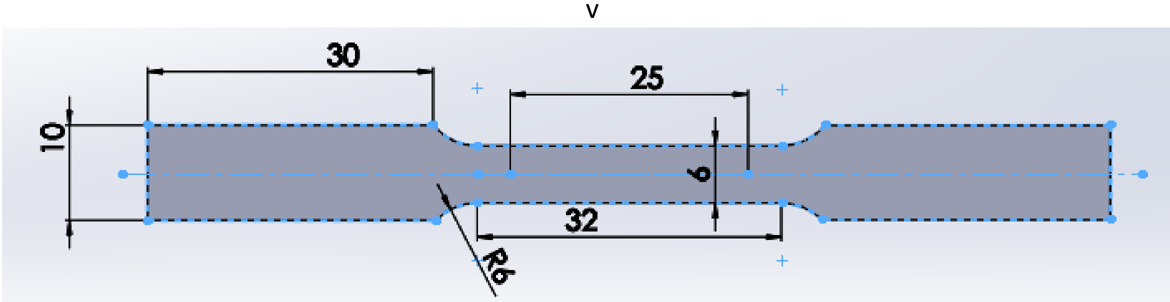


Figure 7.2 *Specimen according American Standard*

But, if we check Polish Standard PN-EN 4136, specimen dimensions are different. For this thickness of 1.2 mm would correspond this:

Dimensions in millimetres

Denomination		Symbol	Dimensions
Total length of the test specimen		L_t	to suit particular testing machine
Width of shoulder		b_1	b + 12
Width of the parallel length	plates	b	12 for $t_s \leqslant 2$ 25 for $t_s > 2$
	pipes	b	6 for $D \leqslant 50$ 12 for $50 < D \leqslant 168,3$ 25 for $D > 168,3$
Parallel length [a b]		L_c	$\geqslant L_s + 60$
Radius at shoulder		r	$\geqslant 25$

[a] For pressure welding and beam welding (process groups 2, 4, and 5 in accordance with ISO 4063:2009), $L_s = 0$.

[b] For some other metallic materials (e.g. aluminium, copper and their alloys) $L_c \geqslant L_s + 100$ may be necessary.

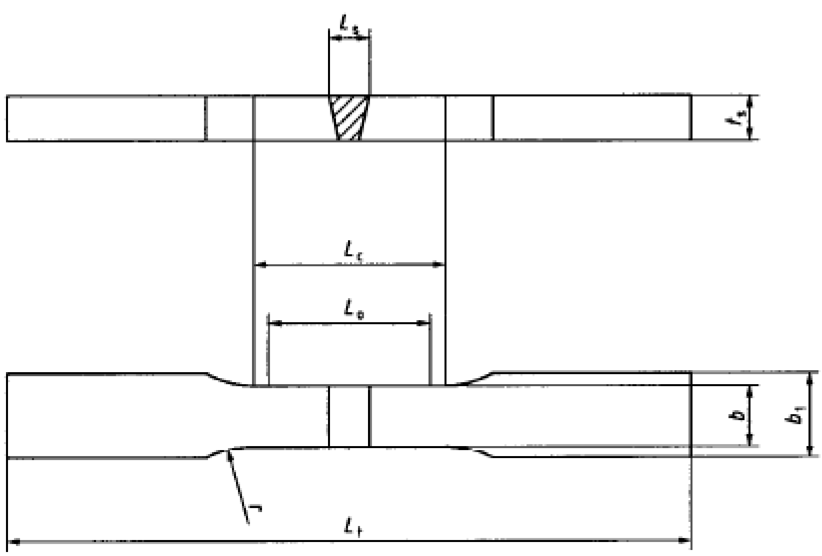


Figure 7.3 *Specimen dimensions according to PN-EN 4136*

As difference it is appreciated that in the American standard the width in the middle of the piece is 6 mm, while in the Polish it is 12 mm. In this case, a width of 10 mm has been finally chosen, located between the two standards but closer to the norm pertaining to Europe.

Finally, specimens used in our project will be like in Figure 7.4.

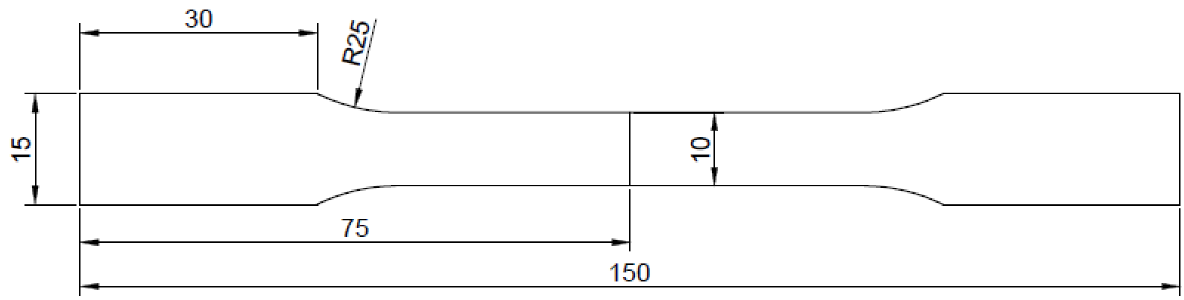


Figure 7.4 *Specimen dimensions used for Micro Plasma Welding*

Nevertheless, for resistance spot welding, it is not necessary to mill the sample, so specimen will be like Figure 7.5.

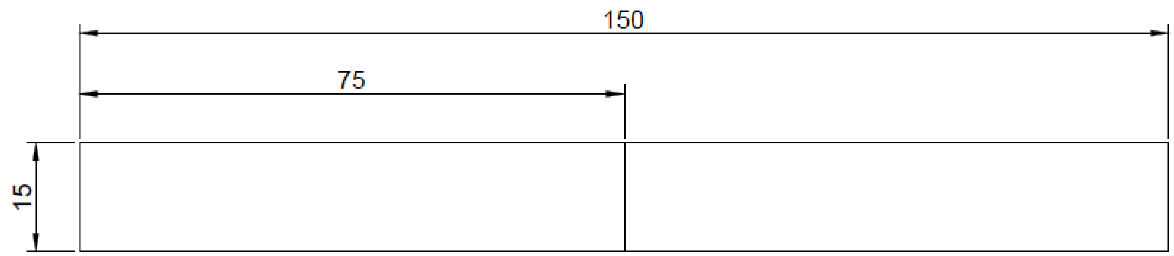


Figure 7.5 *Specimen dimensions used for Spot Resistance Welding*

These samples has been drawn in the metal sheet (Figure 7.6). First thing is to make rectangular strips with the desired width dimension, drawing lines where cuts will be realized. After that it is possible to cut these specimens and tests will be able to be done.

It is important to be careful realizing cuts, because subsize thickness specimens are more likely to suffer variations with small errors.

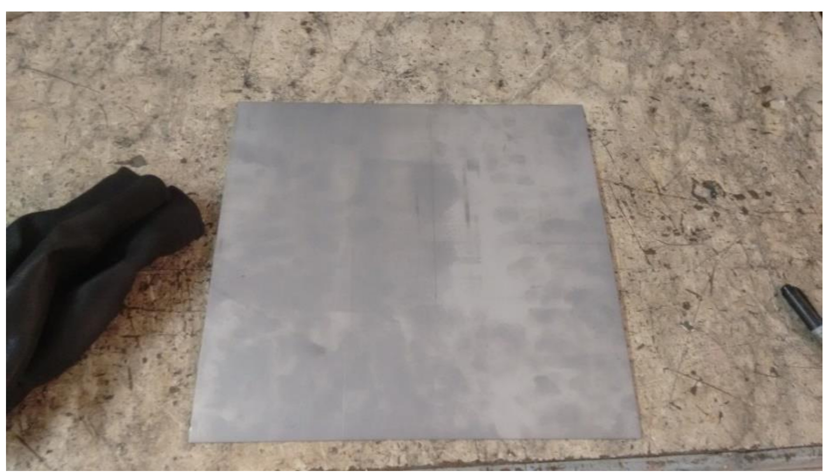


Figure 7.6 *Sheet where samples are going to be drawn*

To do cuts in the beginning, it has been used a cut machine (Figure 7.7), but the precision of this machine was not adequate, since 1 mm of sheet was lost each time a sample was made and the cut was done with imperfections.

Figure 7.7 *Cutting metal machine*

Therefore, it has been decided to use a guillotine (Figure 7.8) because for small thicknesses plates it is a suitable solution. With this machine, the finish of future specimens is better.

Figure 7.8 *Guillotine machine for metals*

It is possible to obtain two specimens of each strip of the sheet. It is necessary to cut these strips (Figure 7.9) in two parts. After that, parts need to be cut again because they have to be welded, so they will be cut in half.

Figure 7.9 *Strips after cuts*

When cuts has been done, the result is different strips in two parts. Six of these specimens are chosen to Micro Plasma Welding, and other six will be chosen to Spot Resistance Welding. (Figure 7.10)

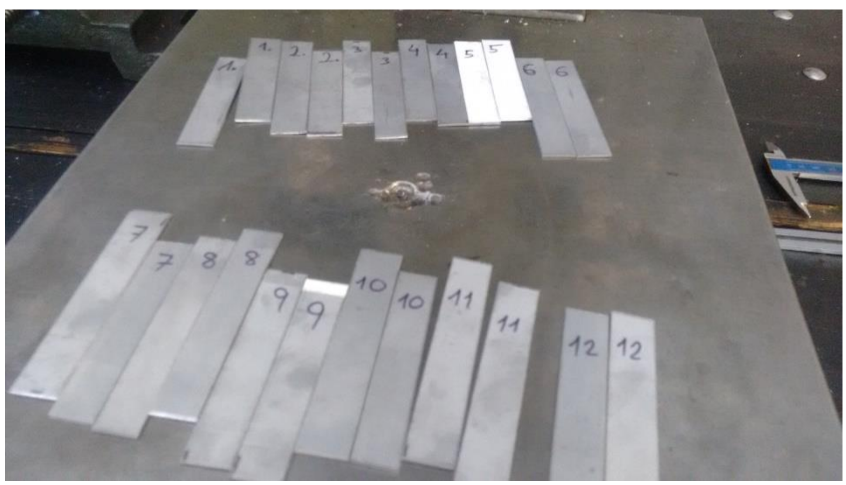
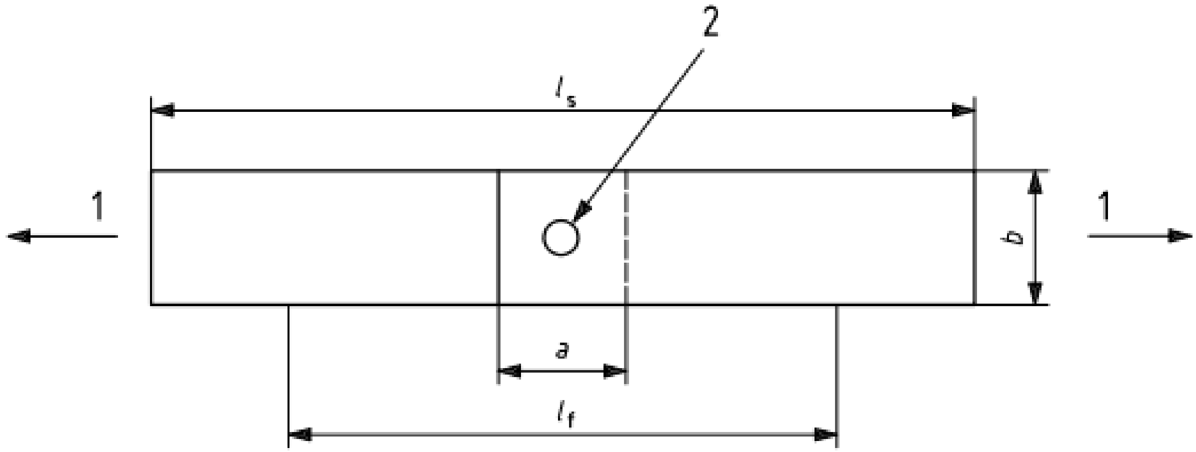


Figure 7.10 *Samples ready to be welded*

More samples has been realized because they will be necessaries. Once they have been done, before milling on the samples, welding have to be done.

The milling step will only be carried out in Plasma Welding. This is because for Spot Resistance Welding, one spot is only necessary according to the Standard ISO14373 **[39]**.



Key
1 direction of test load
2 weld

Figure 7.11 *Method of Destructive Essays according to Standard*

In this project, the welding point will be approximately 5 mm, and a separation should be left to the edges of the same diameter as this point. Therefore as shown in Figure 7.5 the weld width will be 15 mm.

7.2 Welding process

Welding can now be done. For the future tests, six samples will be chosen for each welding process.

In addition to welding with optimum values that have been chosen, it will also be done with a smaller interval and a greater interval to appreciate the differences with respect to the different parameters, so one of those six samples will be used for each interval. The other three samples will be used for microscopy tests.

The parameters low, medium and high are the ones that the following table shows. It is possible to see them on the WPS reports from the before chapter.

Parameters	Amperage (A)			Voltage (V)		
	Low	Medium	High	Low	Medium	High
Micro Plasma	25	30	35	10.5	11	11.5
Parameters	Amperage (A)			Welding Time (sec)		
	Low	Medium	High	Low	Medium	High
Spot Resistance	45	60	80	0.025	0.03	0.05

Table 7.1 *Parameters of Plasma Welding and Resistance Spot Welding*

In SRW,with a lower welding time of 0.025 sec, welding is not produced.

Now, both methods are going to be explained more depth.

7.2.1. Micro Plasma Welding

As has been briefly introduced in section 1.3.2 the plasma welding (Figure 7.12) is based on the fusion of the materials by an electric arc that is produced in the tungsten electrode assisted by the argon gas and protected by an inert gas. The velocity of plasma is approximately sound speed and tempeture is up to 25000ºC.

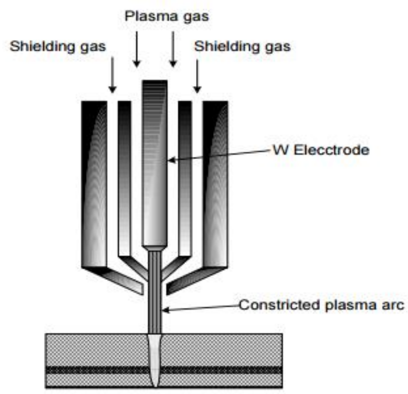


Figure 7.12 *Plasma Welding* ***[40]***

With this soldering we are going to make that the finish of the weld is good as well as precise, also useful thing in the finish of a car.

In this case, a Micro Plasma machine has been used. It is called Micro because the maximum amperage is 50 A.

Figure 7.13 *Micro Plasma machine used in laboratory tests*

This method produces narrow welds, deel penetratiosn and rapid welding speeds. It can be used with filler material. In this project, welding will be done without filler material.

In this tests, specimens with low parameters are samples 9,10, with nominal parameters are 7,8 and with high parameters are 11,12.

7.2.2. Spot Resistance Welding

As has been introduced in Section 1.3.1, this welding method is used to join metal sheets and it is based on the pressure and temperature where a current pass trought opposite electrodes.

It is based on Joule effect: $Q = I^2 \cdot R \cdot t$. These parameters are

- Q = Amount of heat generated (J)
- I = Intensity of the welding current (A)
- R = Electrical resistance of the joint to be welded (Ω)
- t = Time during which the current flows (s)

Intensity is the most important parameter along with welding time. For faster welding, more intensity and less time are required and on the contrary, less intensity and more time will get a slower welding.

The parameter corresponding to the electrical resistance of the joint is a parameter to be taken into account since it directly influences the amount of heat generated in the weld. The factors that influence the electrical resistance are:

- The temperature, whose increase causes a decrease of the resistance.

- The force applied to the electrodes, which by increasing the pressure to the parts to be joined, causes a decrease in the contact resistances.

- The surface condition of the surfaces to be joined, their cleaning and the elimination of roughness occasionally lower contact resistances.

- The state of preservation of the electrodes, whose wear and deterioration causes an increase in contact resistance with the parts to be joined.

- Tightening pressure is also considered a very important parameter to take into account.

Only uniform welds are obtained if the sheets to be welded are clean, the surface oxides or the presence of polymers cause changes in the size and strength of the welding points.

In this project, the tests are only going to vary the two most important parameters, the amperage and the time of welding.

Figure 7.14 *Spot Resistance Welding machine used in laboratory tests*

The electrodes used in welding can vary greatly depending on the application that we are going to make, each type of electrode has a different function.

- Radio electrodes for high temperature applications.
- Electrodes with a truncated tip for high pressures.
- Eccentric electrodes are used to weld corners, or to reach corners and small spaces.

In the following tests a truncated electrode (Figure 7.15) will be used because is the most adequated.

Figure 7.15 *Truncated electrode in SRW machine*

Phases of spot welding:

1. Placement of the sheets to be welded between the clamps.
2. Electrode lowering, which corresponds to the time that elapses from the approaching operation of the electrodes until the passage of the current begins. (Figure 7.16)
3. Welding time, which consists of the time during which the electric current is passing.
4. Forging time, is the time elapsed between the power cut and the electrode lift.
5. Cooling time, consists of the disappearance of the pressure in addition to the electrodes.

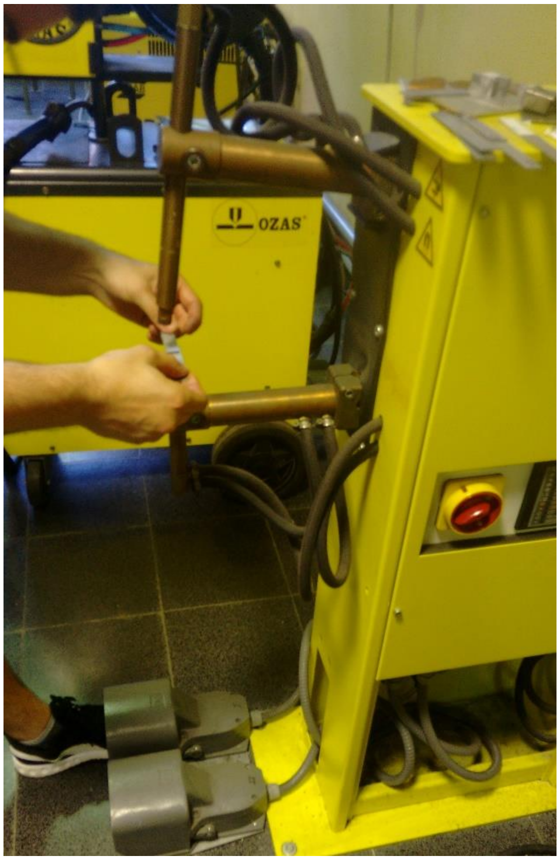


Figure 7.16 *Electrode lowering in RSW*

Figure 7.17 *Welding Time in RSW*

After all weldings have been done, specimens have to be allowed to cool to room temperature because very high temperatures have been reached in the weld.

In the next image (Figure 7.18) specimens welded specimens with low parameters (specimens 1 and 2), medium parameters (specimens 3 and 4) and high parameters (specimens 5 and 6) are showed.

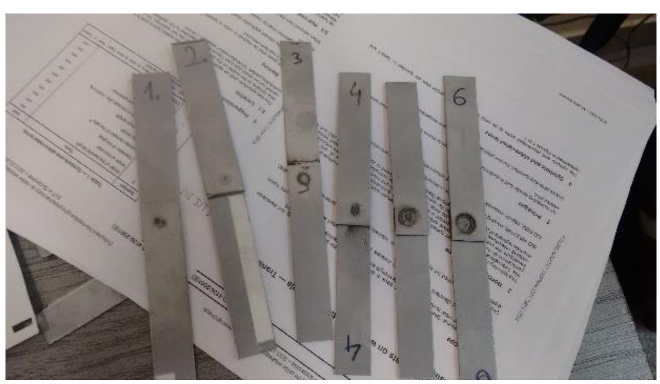


Figure 7.18 *Samples of SRW ready to tensile strength test*

7.3 Tensile strength test

The test is to be carried out with three samples of each weld. One with low, nominal and high parameters.

For Micro Plasma welding is it necessary to mill the surface to create the correct radius. Then, samples will be ready for tensile strength test.

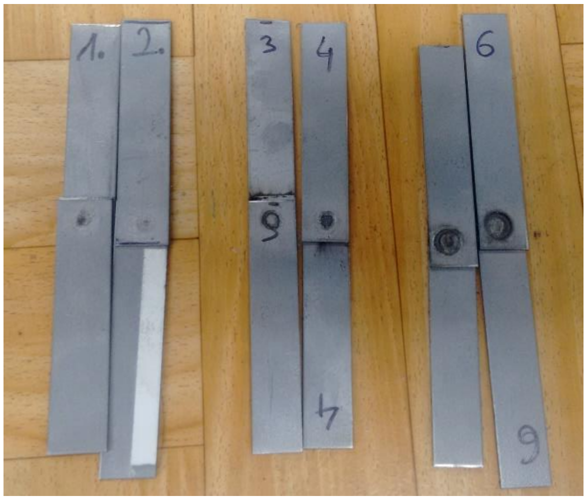


Figure 7.19 *Samples for RSW*

Figure 7.20 *Samples for MPW*

A destructive tensile testing machine Instron 5585H (Figure 7.21) will be used. This machine has a computer program in which the type of test piece, its measurements and the parameters of the material are introduced.

Figure 7.21 *Machine "Instron 5585H" for tensile strength tests*

The parameters to be introduced are the length of the specimen, the thickness, the elastic limit, breaking limit and the amount of bonding zone between the samples.

The test piece can already be placed in the machine. After this, the machine will increase the traction until the rupture takes place.

After the rupture takes place we must retake some measures to introduce them into the program and then show us a report with the results obtained.

Figure 7.22 *Tensile strength test in process*

Figure 7.23 *Tensile strength test finished*

The broken specimens can be seen in the following image. The results of this test are detailed in the following chapter, in section 8.1.

7.4 Microscopy test

This test will be used to analyze microscopically the welds that have been made. We will use the three samples of each type of welding that have not yet been used.

In addition, thanks to this test the real weld diameter of spot resitance can be appreciated. Different zones in welding like fusion line, heat zone and parent material can be viewed too.

First of all, it is necessary to cut samples in small pieces that will be analyzed. They will be cutted with this machine. (Figure 7.24).

Figure 7.24 *Cutting machine*

After the cuts are done, the result is showed in the Figure 7.25. It is also shown which piece belongs to each specimen to distinguish the parameters with which it has been welded. Micro Plasma Welding (8,10,12) are ready for the next step of microscopy test but Resistance Spot Welding (1,3,5) needs one cross cut section.

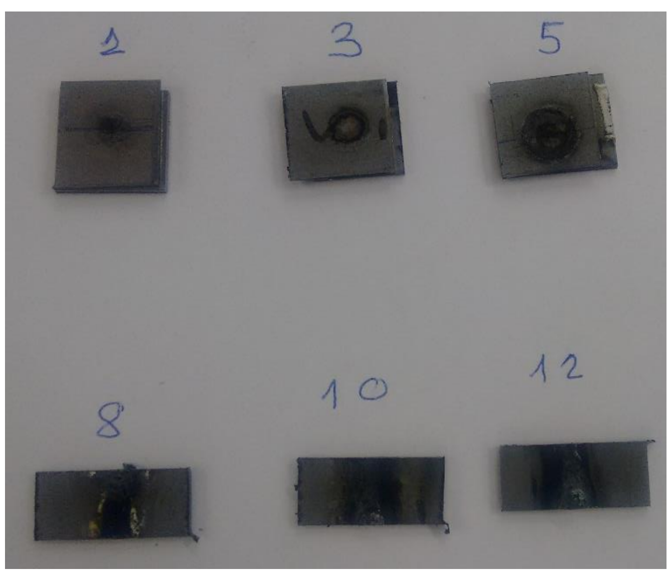


Figure 7.25 *Samples after cutting*

Resistance spot welding after the other cut is like in the Figure 7.26.

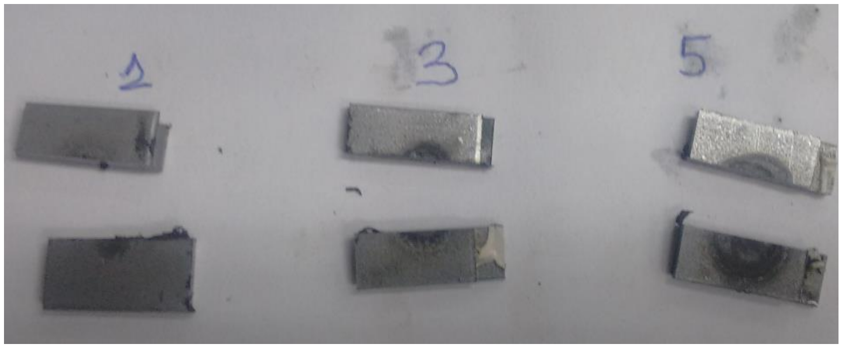


Figure 7.26 *Samples of RSW ready to next step*

The next step in order to make the microscope test is to prepare the samples in a Phenolic resin so that it is possible to observe them in the microscope. To do this, samples are placed in one hot mounting press machine "Presi Mecapress II" (Figure 7.27 and Figure 7.28) for cover them with the resin and then the machine will make a resin cylinder with the samples inside.

Figure 7.27 *Hot mounting press machine*

Figure 7.28 *Samples placed in mounting press machine*

After that, a cylinder is obtained (Figure 7.29 and Figure 7.30), and it is necessary to polish that with different size of grain (Figure 7.31), because surface of samples need to be seen without any impurity so that the weld can be well appreciated by observing it under a microscope.

Figure 7.29 *Samples of MPW inside the resin cylinder*

Figure 7.30 *Samples of SRW inside the resin cylinder*

Figure 7.31 *Polishing samples*

When the pieces are polished, they will be applied an acid so that the different areas of the weld can be seen through the microscope.

The results of this microscope are shown in the next chapter in section 8.2.

The sum of the specimens used in each method is the following:

	Tensile Strength Test	Microscopy Test
Spot Resistance Welding	2,4 and 6	1, 3 and 5
Micro Plasma Welding	7,9 and 11	8, 10 and 12

Table 7.2 *Specimens of each welding method and for which test are used*

Chapter 8:
Results of the tests:

8.1 Tensile strength test

Before showing the results of this test, it should be specified that in spot welding, the test is not exactly traction, but cutting because the parts are superimposed, but still behaving in a similar way.

Characteristics used in this test are the followings:

Operator	Carlos Ramírez
Company	Zachodniopomorski Uniwersytet Technologiczny w Szczecinie
Name of laboratory	PoliTEST
Rate	10 mm/min
Temperature (ºC)	21
Humidity (%)	33
Re/Rp min (MPa)	350
Rm min (MPa)	600
Rm max (MPa)	940
A min (%)	14

Table 8.1 *Characteristics used in the Tensile Strength Test*.

8.1.1 Micro Plasma Welding

The specimens 7, 9, 11 belong to Micro Plasma welding. The visual result after the test is as follows:

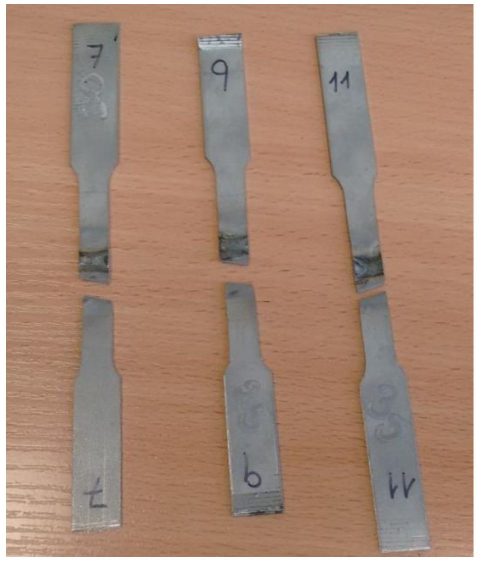


Figure 8.1 *Micro Plasma specimens after Tensile Strength Test*

As can be seen in the image, at first glance no difference can be seen in the three samples, although they have been welded with different amps. None of the samples has been broken by the welding zone and has been broken by a normal area of the specimen, so the welding is very resistant.

Visually no differences are appreciated, but the test machine provides the different parameters used and the results that have occurred during the test.

In the next images, elongation, tensile strain, load and tension stretching can be viewed. Besides, different points of the stress–strain can be observed. These points are Elastic Limit, Yield Point Ultimate Strength, and Rupture Strength (Figure 8.2)

Specimens are shown from less amperage to high amperage during welding.

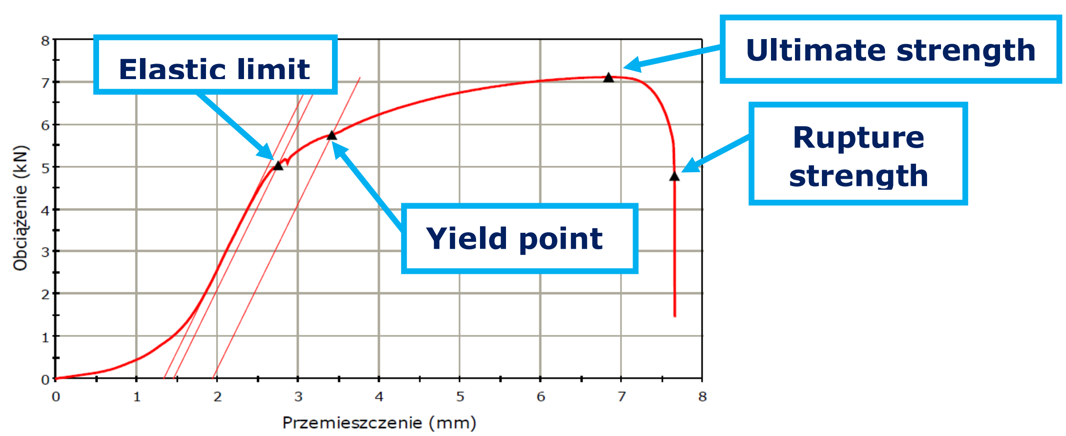


Figure 8.2 *Different points in Stress-Strain diagram*

Then, there are two curves in each specimen. One of those is made with the applied load and the displacement of the sample.

The next curve is calculated beginning with the first curve. If load is divided by area of the specimen, second curve is obtained.

In this curve is showed the elongation too and not displacement. This elongation is calculated with the displacement of the specimen and its initial length.

- **Specimen 9:**

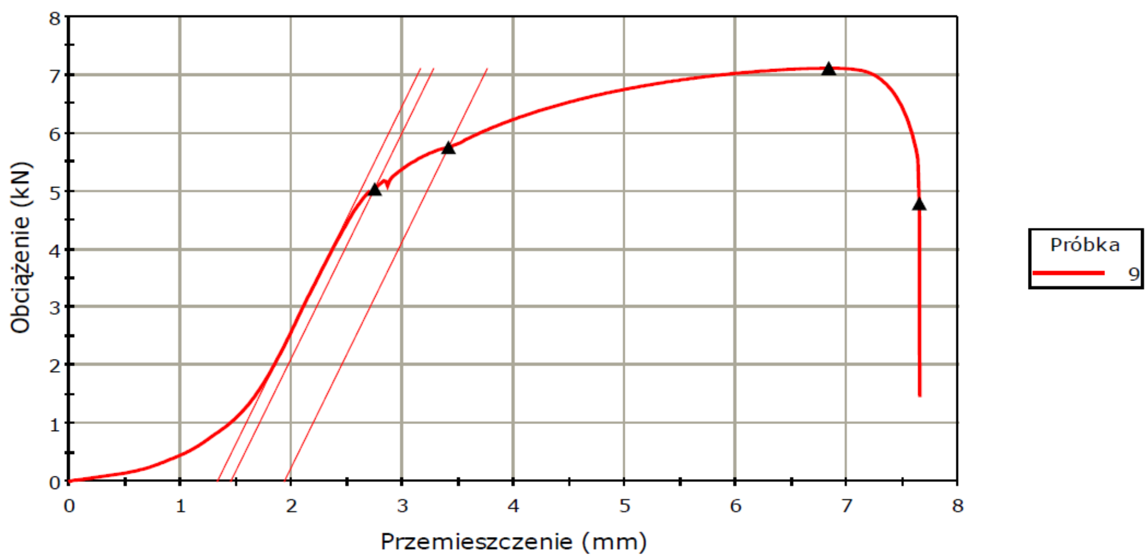


Figure 8.3 *Load vs Displacement. Specimen number 9.*

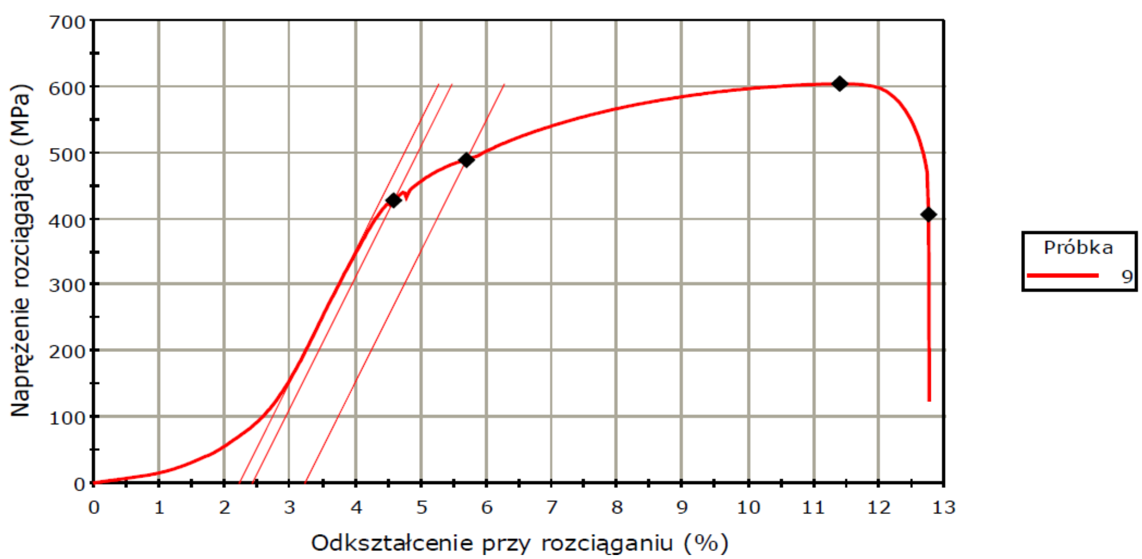


Figure 8.4 *Tensile Stress vs Tensile Strain. Specimen number 9*

- **Specimen 7:**

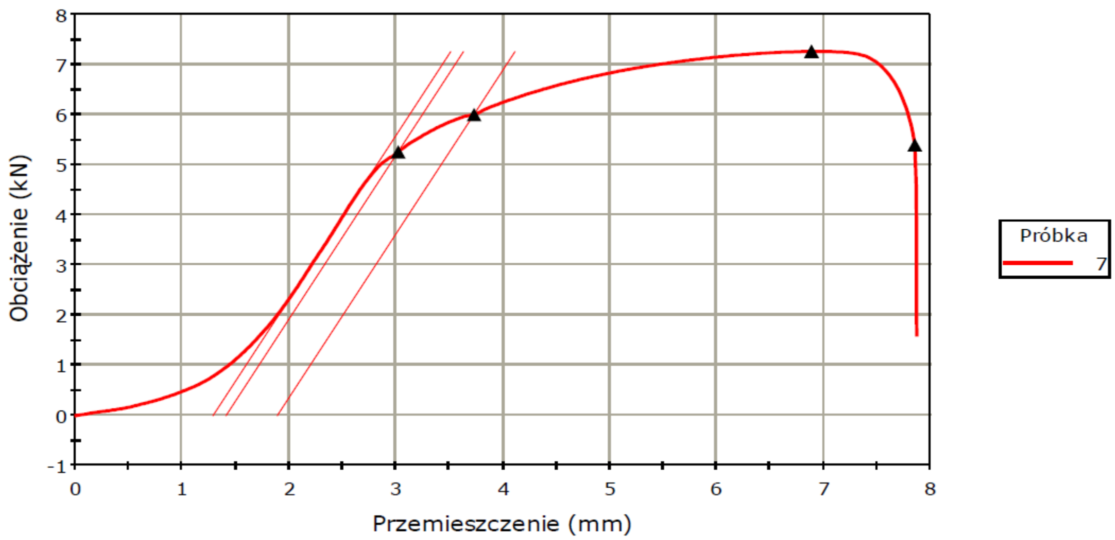


Figure 8.5 *Load vs Displacement. Specimen number 7.*

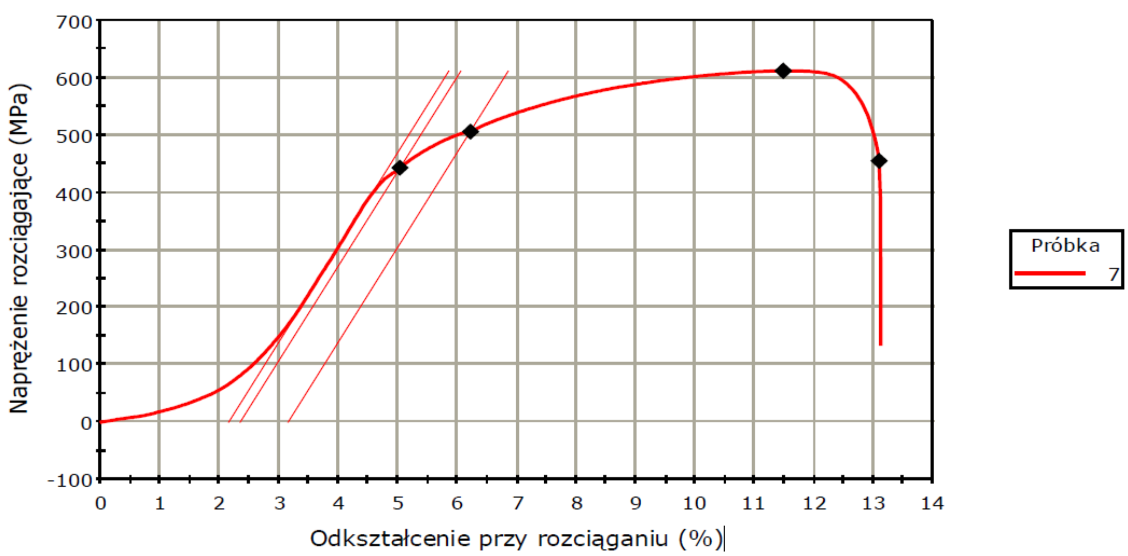


Figure 8.6 *Tensile Stress vs Tensile Strain. Specimen number 7.*

- **Specimen 11:**

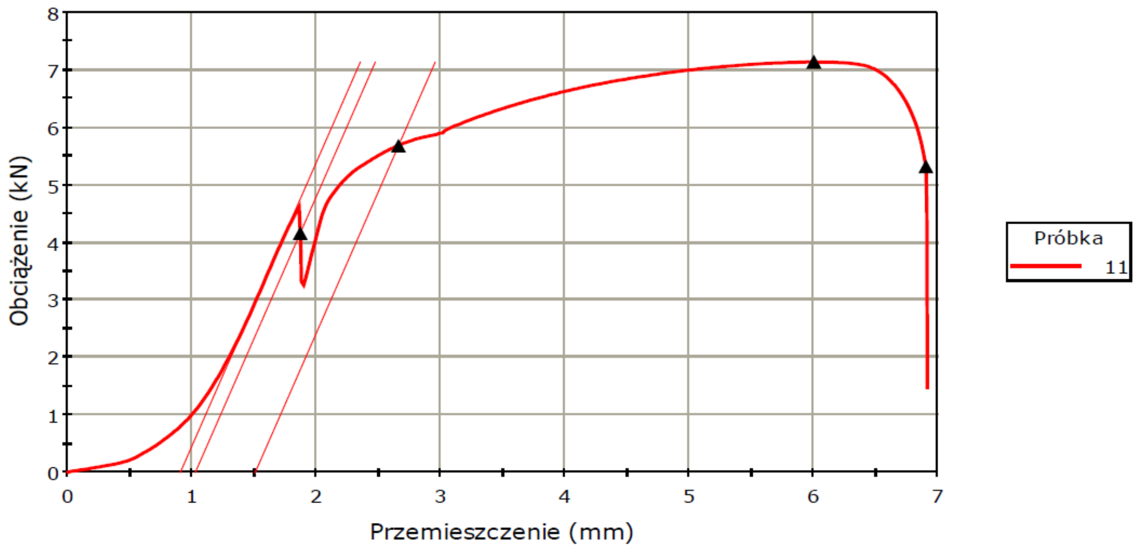


Figure 8.7 *Load vs Displacement. Specimen number 11.*

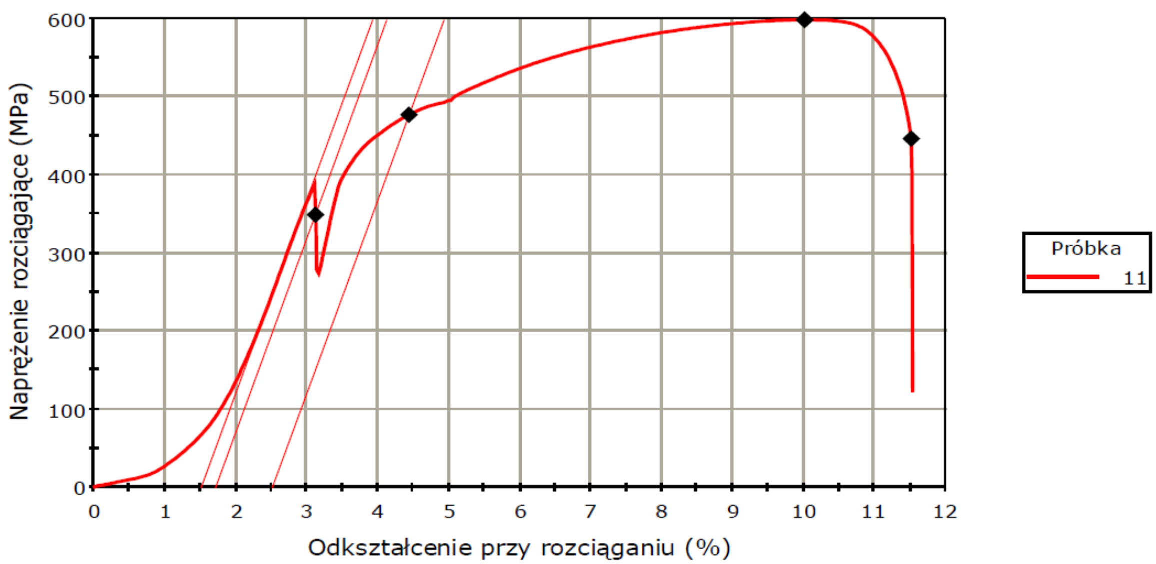


Figure 8.8 *Tensile Stress vs Tensile Strain. Specimen number 11.*

The results are shown in the following tables ordered by the lower to higher amperage test specimens. With this tables, results shown in the previous curves can be compared. The first table (Table 8.2) shows results of stress and loads. Second table (Table 8.3) indicates geometric results.

Specimen	Amperage of welding	Thickness (mm)	Width (mm)	Surface area (mm^2)	Force Fe (kN)	Force Fp02 (kN)	Force Fp1 (kN)	Force Fm (kN)	Stress Re (MPa)	Stress Rp02 (MPa)	Stress Rp1 (MPa)	Stress Rm (MPa)
9	25	1.2	9.81	>11.8	7.1	5.0	5.8	>7.1	603.9	427.7	488.5	>603.9
7	30	1.2	9,88	>11.9	7.3	5.2	6.0	>7.3	611.6	442.8	505.8	>611.6
11	35	1.2	9,94	>11.9	7.1	4.2	5.7	>7.1	598.1	349.0	475.4	>598.1

Table 8.2 *Results of Strength tests. Micro Plasma specimens*

In this last table, "F" are loads and "R" are stress. Subscript "e" is about ultimate strength, "p02" about elastic limit, "p1" about yield point, and "m" is rupture strength.

Specimen	Amperage of welding	L0 (mm)	Lu (mm)	Elongation (%)	S0 (mm^2)	Su (mm^2)	Reduction of area (%)
9	25	140	157	12.8	11.8	6.8	42.37
7	30	146	165	13.1	11.9	10.9	8.40
11	35	153	171	11.5	11.9	7.9	33.61

Table 8.3 *Geometric Results. Micro Plasma specimens*

In these tests with Micro Plasma specimens, it is possible to see Strain-Stress curves very common.

There is any creep in the material. In the specimen 11 is seen a little creep, but the elongation produced when the load is reduced is very low.

Maximum applied load is bigger in specimen number 7. This specimen was welded with optimal parameters. In specimens with low and high parameters maximum load is lower. Ultimate strength is 611.6 MPa in sample number 7 vs 603.9 and 598.1 in samples 9 and 11.

Strain in specimens 7 and 9 is about 13% but in specimen 11 is only 11.5%. This last sample has been broken before the others.

After this test, optimal parameters have been the best.

Although it is possible to emphasize that in none of the three samples this one has been broken by the area of the weld. This means that welding is effective and is a good method of welding for this material.

8.1.2 Spot Resistance Welding

The specimens 1, 3, 5 belong to Spot Resistance welding. As stated above, this test is more a shear test due to it has different thickness in the middle of the sample, but the behavior has been similar to a stress test. The visual result after the tests is as follows:

Figure 8.9 *Spot Resistance specimens after Tensile Strength Test*

- **Specimen 2:**

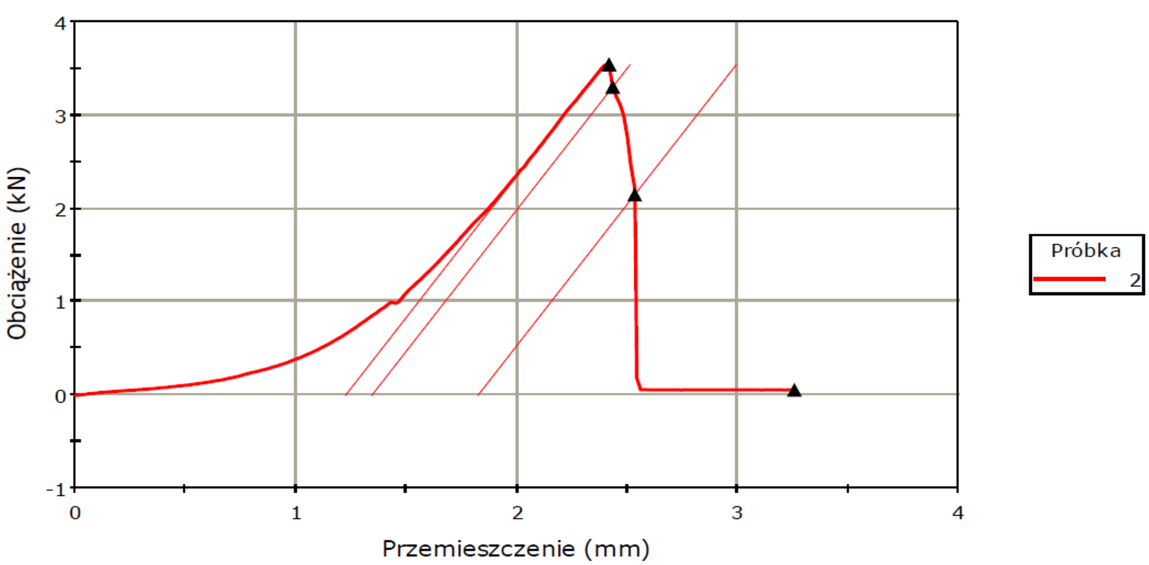


Figure 8.10 *Load vs Displacement. Specimen number 2*

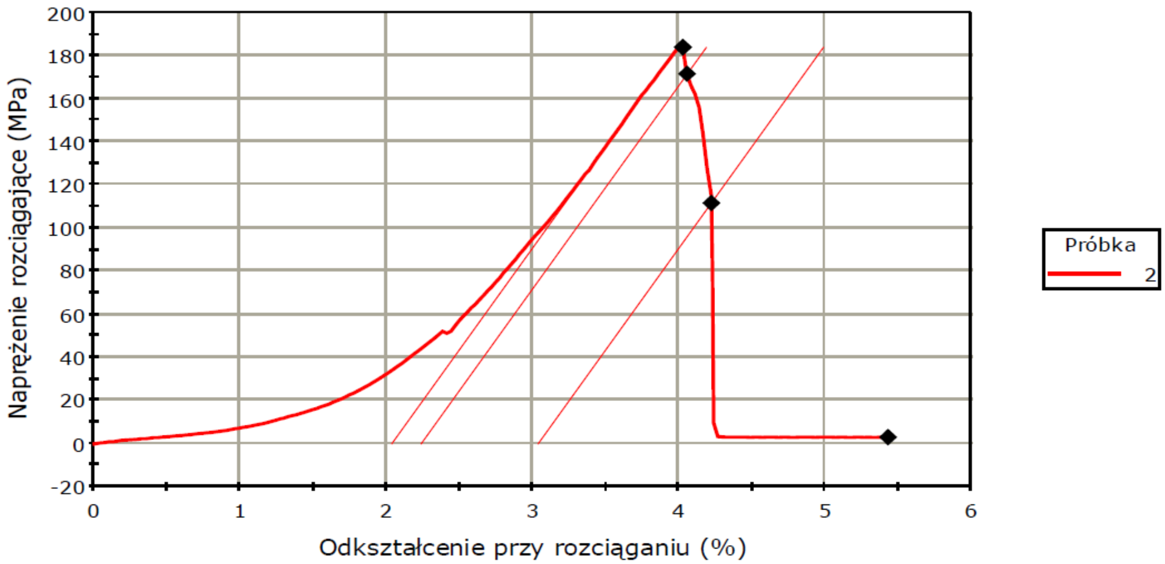


Figure 8.11 *Tensile Stress vs Tensile Strain. Specimen number 2*

- **Specimen 4:**

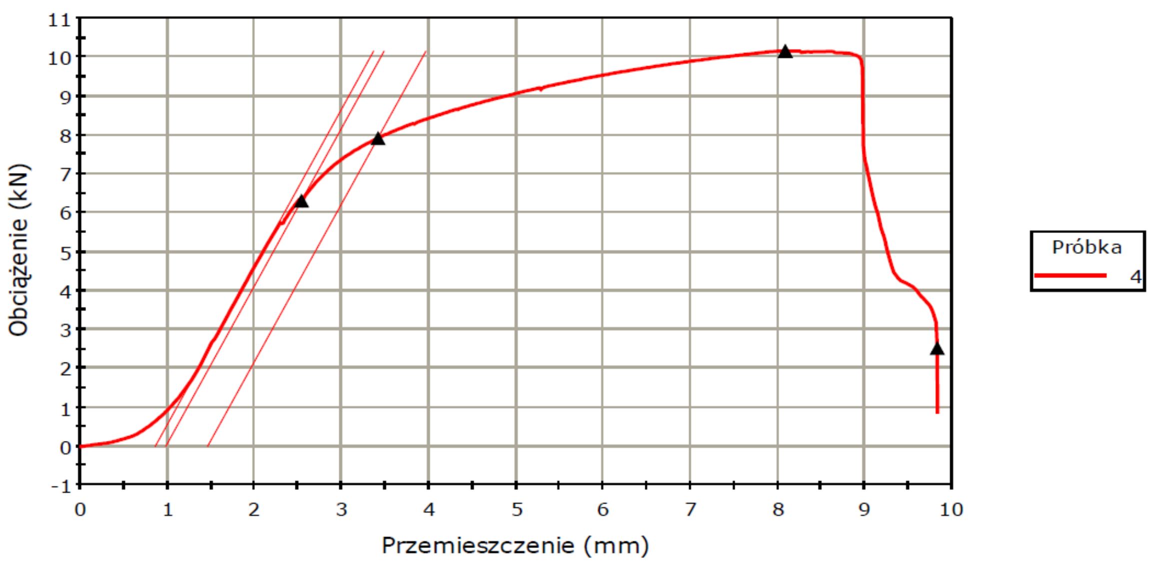


Figure 8.12 *Load vs Displacement. Specimen number 4*

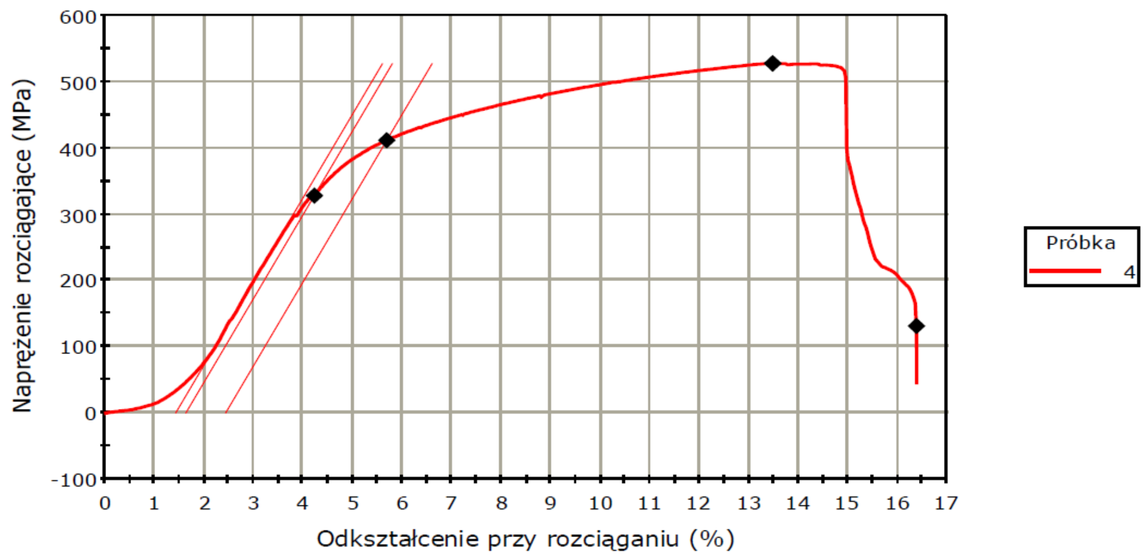


Figure 8.13 *Tensile Stress vs Tensile Strain. Specimen number 4*

- **Specimen 6:**

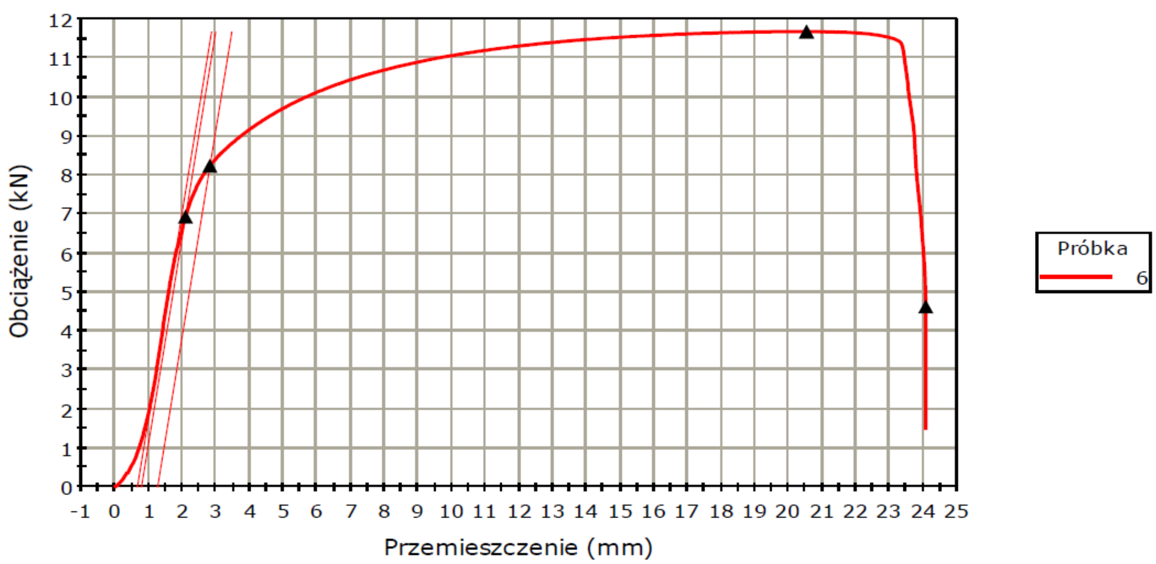


Figure 8.14 *Load vs Displacement. Specimen number 6*

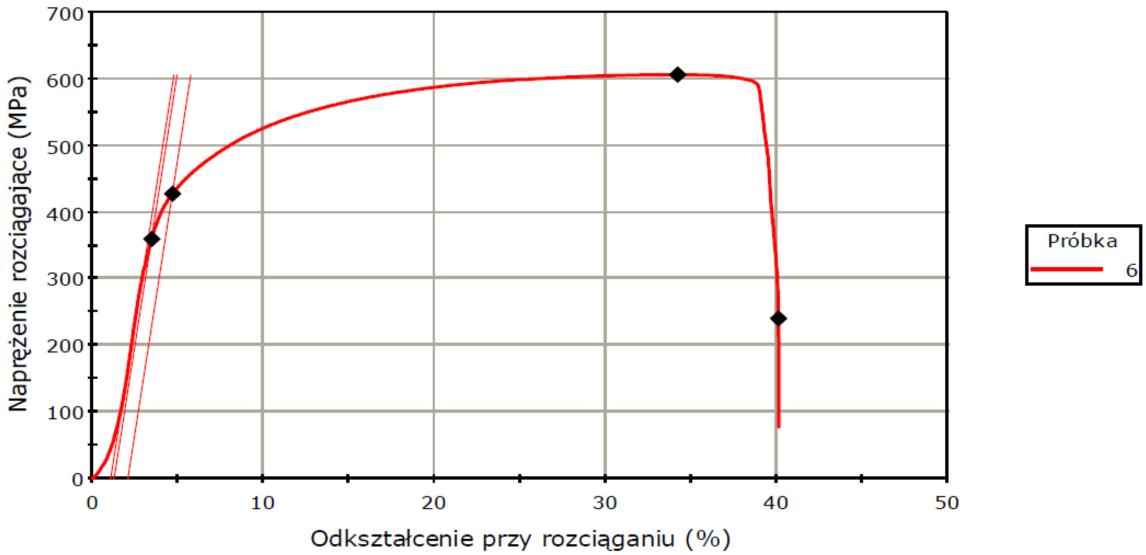


Figure 8.15 *Tensile Stress vs Tensile Strain. Specimen number 6*

The results are shown in the following tables ordered by the lower to higher amperage test specimens. With this tables, results shown in the previous curves can be compared. The first table (Table 8.4) shows results of stress and loads. Second table (Table 8.5) indicates geometric results.

Specimen	Amperage of welding	Thickness (mm)	Width (mm)	Surface area (mm^2)	Force Fe (kN)	Force Fp02 (kN)	Force Fp1 (kN)	Force Fm (kN)	Stress Re (MPa)	Stress Rp02 (MPa)	Stress Rp1 (MPa)	Stress Rm (MPa)
2	45	2.4	14.9	>19.2	3.5	3.3	2.1	>3.5	183.8	171.4	111.5	>183.8
4	60	2.4	15.1	>19.2	10.1	6.3	7.9	>10.1	527.1	327.8	411.2	>527.1
6	80	2.4	14.9	>19.2	11.7	6.9	8.2	>11.7	605.8	359.8	427.6	>605.8

Table 8.4 *Results of Strength tests. Spot Resistance specimens*

In this last table, "F" are loads and "R" are stress. Subscript "e" is about ultimate strength, "p02" about elastic limit, "p1" about yield point, and "m" is rupture strength.

Specimen	Amperage of welding	L0 (mm)	Lu (mm)	Elongation (%)	D0 (mm)	Du (mm)	S0 (mm^2)	Su (mm^2)
2	45	150	156.5	104.3	-	-	19	19.6
4	60	145	168.8	116.4	2.69	2.71	5.68	5.76
6	80	145	203	140	6.67	6.8	34.95	36.32

Table 8.5 *Geometric results. Spot Resistance specimens*

In these tests with Spot Resistance specimens, it is possible to see Strain-Stress curves very common in number 6. However, in number 2, there is not good stress-strain curve because sample was not welded well with those parameters and it broke very soon with a small load. And in number 4, there is a strange end curve.

There is any creep in the material that it is possible to appreciate.

Maximum applied load is bigger in specimen number 6. This specimen was welded with high parameters. In specimens with low and nominal parameters maximum load is lower.

In specimen number 2 with load parameters, maximum stress is only 183.8 MPa because probably with that amperage, both sheets were not welded correctly. In microscopy test, this will be able to see it.

Ultimate strength in number 4 is 527.1 and in number 6 is 605.8.

Strain in specimens 2 is only 4%. In specimen 4 is 16% and in specimen 6 is 40%.

Number 2 was broken too fast, number 4 was broken in the spot weld and number 6 was broken in the parent material after a big deformation. It is possible to appreciate in the next images (Figure 8.16, Figure 8.17 and Figure 8.18).

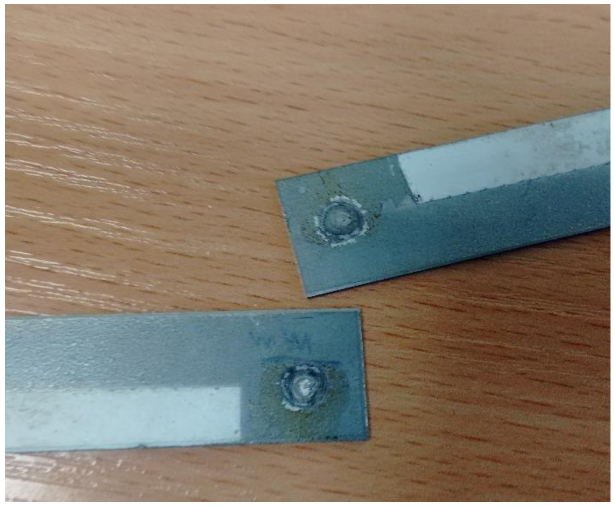


Figure 8.16 *Detail of the rupture of the test piece 2*

Figure 8.17 *Detail of the rupture of the test piece 4*

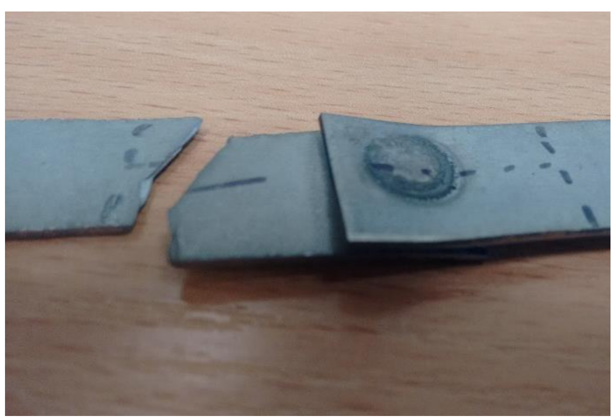


Figure 8.18 *Detail of the rupture of the test piece 6*

After this test, high parameters have been the best.

8.2 Microscopy Test

As explained above, this test has been carried out in order to perceive the different parts of the weld in the specimens, as well as to be able to appreciate possible defects.

8.2.1 Micro Plasma Welding

Each specimen has only one sample. Samples used to this test are number 8, 10 and 12. They are Figure 8.19, Figure 8.20 and Figure 8.21.

- **Specimen 8:**

This sample has been welded with nominal parameters. It is possible to see the triangle showed in WPS. This is because it has been welded only from one side.

It the image, there are three zones. Nugget zone, HAZ and parent material. In this case, nugget zone and HAZ are similar.

Figure 8.19 *Microscopy test. Specimen 8*

- **Specimen 10:**

This sample has been done with low parameters. How image shows, it is not possible to difference the triangle and there is not good nugget zone. It is due to amperage in welding was too low.

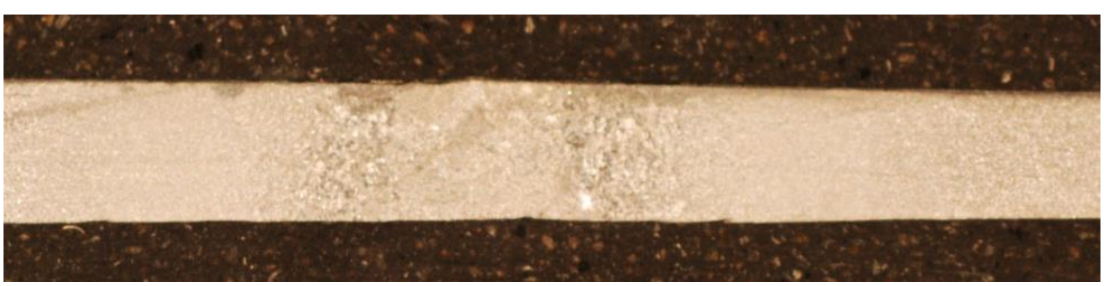


Figure 8.20 *Microscopy test. Specimen 10*

- **Specimen 12:**

In this sample, with high parameters, fusion zone is very big and nugget is not a perfect triangle. This is probably because amperage was too high during welding.

It is possible to difference parent material and HAZ too.

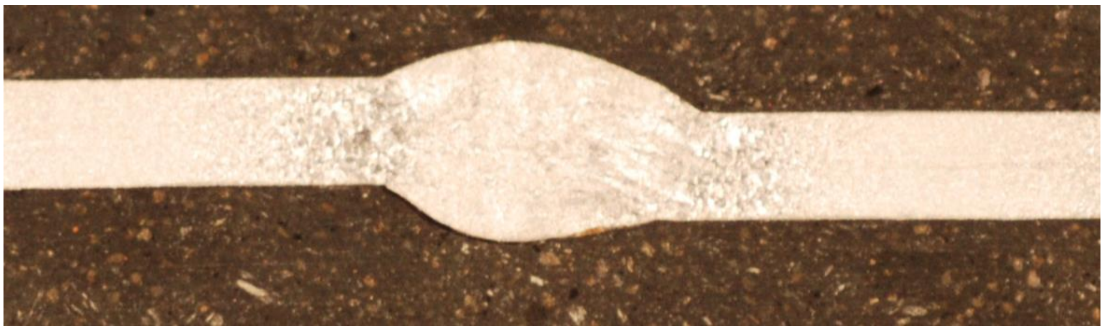


Figure 8.21 *Microscopy test. Specimen 12*

Number of specimen	Amperage used to weld (A)	Voltage (V)	Quality
10	25	10.5	Bad welding
8	30	11	Optimal welding
12	35	11.5	Good welding

Table 8.6 *Results microscopy test. Micro Plasma specimens*

Thanks to this experiment with the microscope conclusions can be drawn about the welding. The best parameters for this type of welding were those obtained in specimen 8, that it is nominal parameters as defined in chapter 7.

However, specimen number 12 could be good welding too. It will be known due to tensile strength tests that have done.

It can be seen that in this test the best sample is the one made with the optimum welding parameters, that is, the number 8.

In the stress test it was also the sample made with these parameters that had the best results.

8.2.2 Spot Resistance Welding

Each specimen in spot welding has two samples, as it has been the point split into two parts. These samples are 1.1, 1.2, 3.1, 3.2, 5.1 and 5.2.

The diameter and thickness will be measured in case there is a welding nugget and the different areas of the welding will be appreciated. These parts are the spot (nugget), fusion line, heat affect zone (HAZ) and the parent material (sheet metal).

- **Specimen 1:**

It is possible to see in the next two images (Figure 8.22 and Figure 8.23) the fusion line more black than the other parts and HAZ with one grey different to the color sheet. This part is the parent material. In this sample there is not any spot and as it is possible to see in the Figure 8.23 material is not joined.

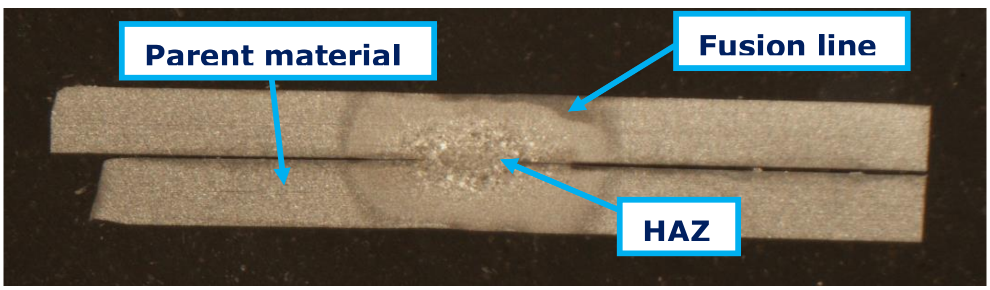


Figure 8.22 *Microscopy test. Specimen 1.1*

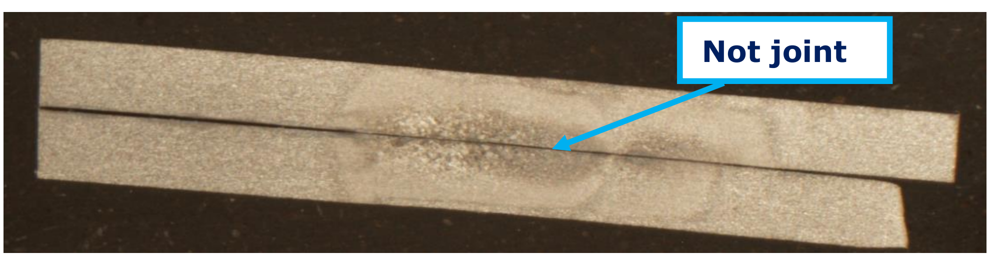


Figure 8.23 *Microscopy test. Specimen 1.2*

- **Specimen 3**

In this specimen, it is possible to observe the same zones that in the specimen 1 and one zone more, the spot. Around the spot is the HAZ.

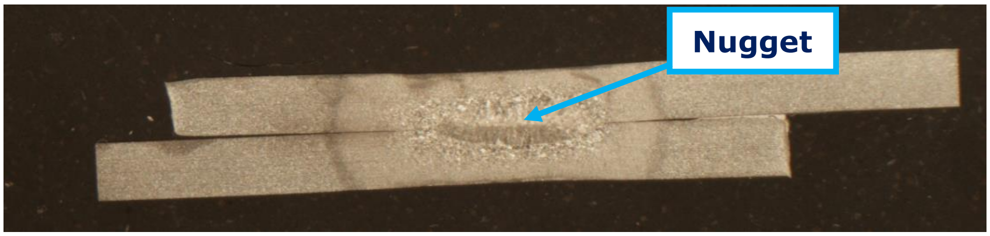


Figure 8.24 *Microscopy test. Specimen 3.1*

Figure 8.25 *Microscopy test. Specimen 3.2*

In this specimen, dimension spots (Diameter and depth) are measured in the next images (Figure 8.26 and Figure 8.27). Both pictures are the same spot, but when this has been cut, a part of this nugget has been removed by the circular saw.

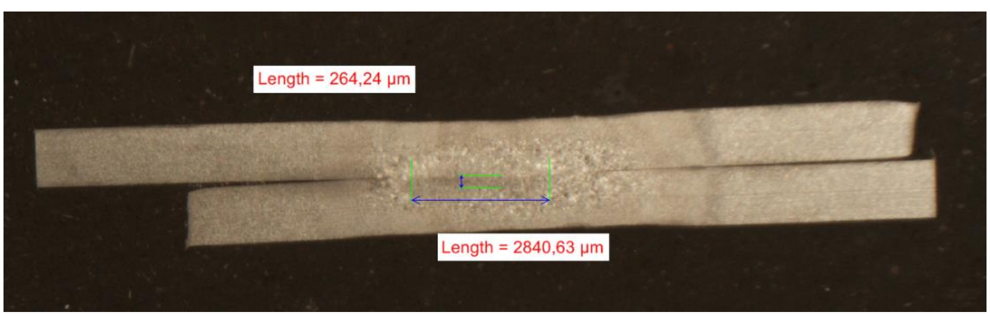


Figure 8.26 *Dimensions spot. Specimen 3.1*

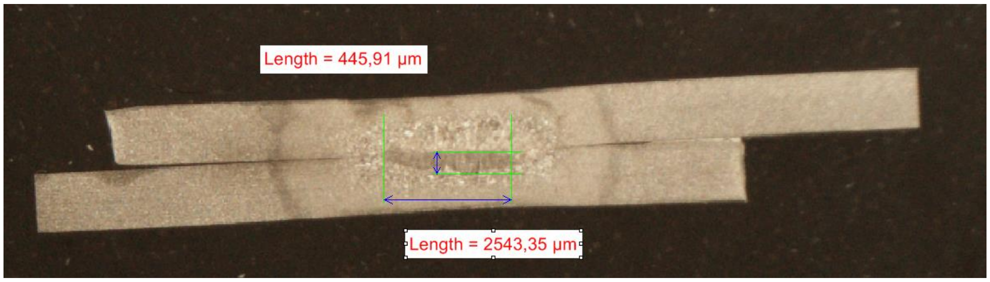


Figure 8.27 *Dimensions spot. Specimen 3.2*

For implement a table with the summary, an average will be done with this measurements.

- **Specimen 5:**

This sample has been cut different to the others samples. In order to be able to measure the diameter exactly the cut has been made with the circular saw but it has removed material from the center to one side and not from the center to both sides. Therefore in this sample the valid value is the one obtained in the first image (Figure 8.28).

Figure 8.28 *Microscopy test. Specimen 5.1*

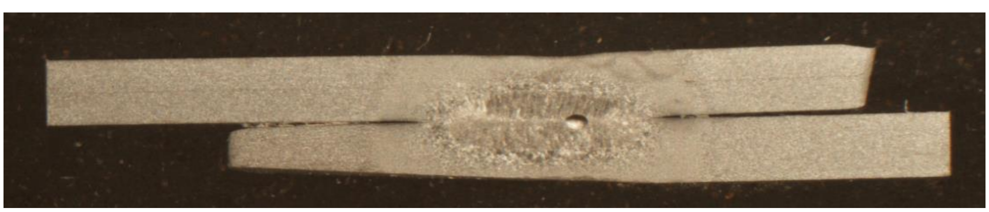


Figure 8.29 *Microscopy test. Specimen 5.2*

It is possible to see in the Figure 8.29 a small bubble of air at the end of the spot.

How it has been said few lines ago, in this case only first image is going to consider for dimension of spot.

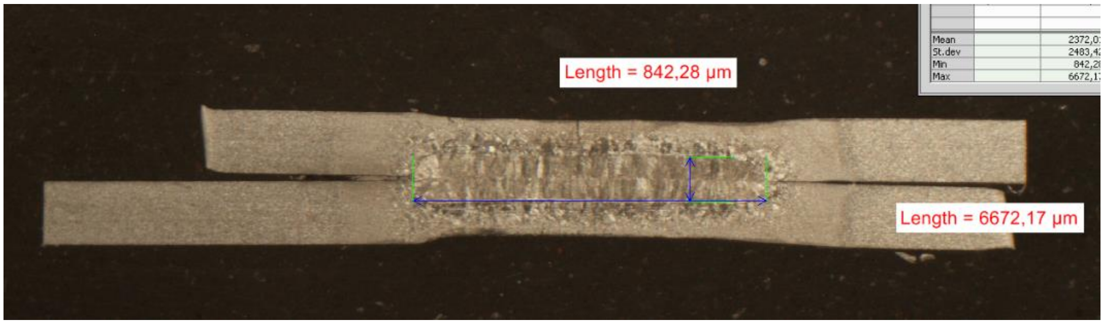


Figure 8.30 *Dimensions spot. Specimen 5*

In the next table (Table 8.7), a summary is showed about different specimens in Spot Resistance Welding.

Number of specimen	Amperage used to weld (A)	Time used to weld (sec)	Diameter of spot (mm)	Depth of spot (mm)
1	45	0.025	No spot	
3	60	0.03	2.691	0.355
5	80	0.05	6.672	0.842

Table 8.7 *Results of microscopy test. Spot Resistance specimens*

The first specimen has had a very low joint, because there is only HAZ and not spot so it has been welded with very low amperage. Sample number 3 has a diameter of spot of 2.69 mm. However, number 5 has 6.67 mm.

Comparing with results obtained in tensile strength tests, it will be possible to know which parameters has been better.

In my opinion the best welding spot is the one realized in sample number 5 because the diameter of the welding point of sample number 3 is a little small.

So, best sample is number 5, made with high parameters. In the stress test it was also the sample made with these parameters that had the best results.

Chapter 9: Conclusions of the project

In this chapter, conclusions will be drawn from the different tests that have been carried out through the results obtained.

The obtained results have already been analyzed but here tests will be related depending on the welding method used.

After this we will get some final overall conclusions.

9.1 SolidWorks Test

With SolidWorks, two pieces have been analyzed with two different welding methods. Conclusions between these methods are going to be showed.

9.1.1 Pillar B

In pillar B, maximum stress and maximum displacement are showed in the next table (Table 9.1).

	Zone	Maximum Stress (MPa)	Maximum Displacement (mm)
Micro Plasma Welding	Pillar B	525	6.5
	Weld Zone	125	1
Spot Resistance Welding	Pillar B	316	5.1
	Weld Zone	41.8	1.5

Table 9.1 *Summary of SolidWork tests of Pillar B*

How is possible to see in the before summary, in both cases stresses that have occurred using spot welding have been lower.

Displacements have been lower in the Pillar B, but in the weld zone, this time Spot Resistance welding have bigger displacements. This may be due to the fact that the spots have been displaced and thanks to this tensions that have been concentrated in them have been smaller.

Thanks to this summary it can be deduced that Spot Resistance welding has proved to be more efficient for welding the pillar-B.

But, it would be possible to use both methods, because both are valid and within the range of stress-strain.

9.1.2 Roof panel

In roof panel, maximum stress and maximum displacement are showed in the next table (Table 9.2).

	Zone	Maximum Stress (MPa)	Maximum Displacement (mm)
Micro Plasma Welding	Roof panel	558	94.7
	Weld Zone	558	2.4
Spot Resistance Welding	Roof panel	260	30.1
	Weld Zone	209.3	2.5

Table 9.2 *Summary of SolidWork tests of roof panel*

How is possible to see in the before summary, in both cases stresses that have occurred using spot welding have been lower. There is a great difference. Using micro plasma welding, these stresses are above yield strength of AHSS used.

Displacements have been lower in the roof panel, but in the weld zone, these displacements have been similar. Any displacement is very big as to be dangerous.

Thanks to this summary it can be deduced easily in this case that Spot Resistance welding has proved to be more efficient for welding the roof panel.

In the before case, both methods could be used, although spot resistance welding was better, but in this case, it is necessary to use spot resistance welding due to in micro plasma welding yield strength has been overcome.

9.2 Tensile Strength Test

Specimens with best results were the number 7 in Micro Plasma and the number 6 in Resistance Spot corresponding with nominal and high parameters respectively.

	Maximum Load (kN)	Maximum Stress (MPa)	Elongation (%)
Micro Plasma (#7)	7.3	611.6	13
Resistance Spot (#6)	11.7	608.8	40

Table 9.3 *Summary of Tensile strength tests*

As can be seen in the above table, spot welding has been able to withstand a greater load, and a very large displacement has occurred before it has broken.

Therefore, according to this experiment the best method of welding between the two compared is spot resistance welding.

9.3 Microscopy Test

In this experiment, best samples have got with optimal parameters in Micro Plasma welding and high parameters on Spot Resistance welding.

With this test is not possible to get any conclusion between both welding methods due to any comparison can be done.

So, this test has been used to know which parameters have been better in each welding method. This parameters have been analyzed in the before chapter.

9.4 Final overall conclusions

From this project can be obtained several conclusions. It is possible to get from the tests and the initial theoretical analysis of the different materials used in the automotive industry and different ways of soldering them.

Thanks to the study that has been carried out at the beginning of the project, it is concluded that there is a very large quantity of materials used in the automotive company.

But in the last years the use of different types of AHSS has been improved, since they offer very good properties, being the sector of the automobile in which more these materials are used.

In this case, a complex phase metal CP was chosen because it was considered to be the most appropriate as explained in previous chapters. However other materials could have been chosen since many AHSS have properties very useful.

Regarding the method of welding, different ways have also been analyzed at the beginning of the project.

Finally two methods have been chosen that are widely used in the automobile company and have been considered two that could work better to weld an AHSS material. These methods are Laser welding and Spot Resistance welding. Micro Plasma has been selected instead of Laser welding because equipment at university is not enough how it has explained in previous chapters. Besides, micro plasma welding has similar characteristics to laser and it has a cheap maintenance.

However, other methods could have been used, and could be analyzed in a future research line of this project, as well as other AHSS material.

As for the selected welding methods, in this project the spot resistance welding method has been better than the micro plasma method. This applies to the material used. With other materials that could be used for other parts of the car bodywork this result could vary.

In addition, the method of spot welding is efficient, fast and does not require much skill. Also in the automotive company can be used massively with the use of robots.

Bibliography

The bibliographical references that have been used for the realization of this Master Thesis are the following. All those images that do not have bibliographic source are of own elaboration.

[1] Web"El Chapista" **<**http://www.elchapista.com/chasis_carrocerias_vehiculos.html>

[2] Properties and automotive applications of advanced high-strength steels (AHSS), Pages 9-28, *T.B. Hilditch, T. de Souza, P.D. Hodgson* <http://www.sciencedirect.com/science/book/9780857094360>

[3] Wikipedia **<**https://es.wikipedia.org/wiki/Carrocer%C3%ADa#Referencias>

[4] Autobild <http://www.autobild.es/coches/renault/espace>

[5] Volkswagen <https://www.volkswagen.es/es/modelos/scirocco.html>

[6] Volkswagen <http://www.wbwagen.com/b6bca04be1874176-revista-coche-se-cumplen-30-aos-del-volkswagen-santana.html>

[7] Autocasion <http://www.autocasion.com/actualidad/reportajes/materiales-utilizados-en-la-carroceria-del-automovil>

[8] Web "Escuela del trabajo" http://www.escueladeltrabajo.net/eleestveh.pdf

[9] Linkedin <https://www.linkedin.com/pulse/materials-automotive-body-chassis-structure-pooyan-nayyeri>

[10] Web "Ciencia cierta" <http://www.cienciacierta.uadec.mx/2016/12/13/tendencia-de-los-aceros-y-su-aplicacion-en-la-industria-automotriz/>

[11] Web "Ispatguru" <http://ispatguru.com/interstitial-free-steels/>

[12] Wikipedia <https://en.wikipedia.org/wiki/High-strength_low-alloy_steel>

[13] Dierk Raabe <http://www.dierk-raabe.com/trip-steels/>

[14] Dierk Raabe <http://www.dierk-raabe.com/twip-steels/>

[15] Drivealuminum <http://www.drivealuminum.org/>

[16] Web “Aluminum” <http://www.aluminum.org/product-markets/automotive>

[17] Plastics Car <https://plastics-car.com/Todays-Automobiles/Automotive-Chassis-Design-NVH-Performance/Structure.html>

[18] Introduction to welding and joining of advanced high-strength steels (AHSS), Pages 1-8, *M. Shome, M. Tumuluru* <http://www.sciencedirect.com/science/book/9780857094360>

[19] Resistance spot welding techniques for advanced high-strength steels* (AHSS), Chapter 4, Pages 55-70, *M. Tumuluru* <http://www.sciencedirect.com/science/book/9780857094360>

[20] Advanced High Strength Steels Application Guidelines Version 5.0 <www.worldautosteel.org>

[21] Swantec <https://www.swantec.com/technology/resistance-welding/>

[22] Wikipedia <https://en.wikipedia.org/wiki/Gas_tungsten_arc_welding>

[23] Forsstrom <http://www.forsstrom.com/pages/default_uk.asp?sectionid=314>

[24] Web “Scuderiacarparts” <http://www.scuderiacarparts.com/diagram/ferrari/512-m/bodywork-parts/central-tunnel-not-for-usa/23-44-1935.html>

[25] Carid <https://www.carid.com/articles/rocker-panels.html>

[26] Catalog. DOCOL High Strength Steel. Advanced High Strength Steel for Automotive Industry. <www.ssab.com>

[27] Web <http://carroceria.blogspot.com/2010/07/inovacao-na-coluna-b.html>

[28] Web “tpub” <http://www.tpub.com/steelworker1/18.htm>

[29] ISO 14373:2015 Resistance Welding. Procedure for spot welding.

[30] Web “tpub” <http://navyaviation.tpub.com/14018/css/Butt-Joints-649.htm>

[31] Web “pcproductos” <http://www.pcpprodutos.net/downloads/produtos/litec-ultra-high-strength-formable-steel.pdf>

[32] Mikrostruktura i właściwości stali o wysokiej wytrzymałości AHSS, *Jerzy Nowacki and Sławomir krajewski*

[33] EN ISO 4063:2009. Welding and allied processes - Nomenclature of processes and reference numbers

[34] EN 287-1. Welding Qualification Position - Part 1: Steels

[35] EN ISO 14341. Welding consumables - Electrodes and wires for arc welding with metal electrode in gas sheathing of non-alloyed and fine-grained steel - Classification

[36] EN ISO 14175. Welding consumables - Gases and gas mixtures for fusion welding and allied processes

[37] ASTM E8 Standard. Test Methods for Tension Testing of Metallic Materials

[38] EN ISO 4136:2012. Destructive tests on welds in metallic materials – Transverse tensile test

[39] ISO 14373:2015. Resistance welding -- Procedure for spot welding

[40] Web “Idc online” <http://www.idc-online.com/technical_references /pdfs/mechanical_engineering/The_Influence_Of_Process_Parameters.pdf>

Index of tables and figures

Index of tables:

Index of figures: