Universidad de Valladolid

ESCUELA DE INGENIERÍAS INDUSTRIALES

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ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

Análisis de la resistencia de la soldadura eléctrica por puntos en la nueva generación de aceros de alta resistencia

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Resistance spot welding of advanced high strength steels

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Para todos aquellos que me dieron su apoyo…

…sobre todo cuando estaba inaguantable: mi familia y amigos.

Abstract

The thesis describes the process of study and selection of the materials, variables of the process in the electrical resistance spot welding, monitoring system and the description of the mechanical test made for measure the mechanical quality of the unions.

We want to describe and take control of all the variables of the process to be able to make correlations between the values of the different test (cross tension test and lap shear), which determinate the quality of the union, and the values with we weld. For knowing how is welding the machine, we need to study how can the machine fix the parameters. For measure the variables and verify the process, we need to use several monitoring systems

Also, it is described the manufacture process of manufacture a fixture to make the cross tension test.

Keywords

ERW , monitoring, cross tension test, lap shear, cross tension test fixture.

INDEX

INTRODUCTION

In this final project degree, we are going to study different essays of the union of two plates made by resistance spot welding. The application of the thesis is for the study of car bodies.

Welding is defined as the technology, based scientifically, that want the union of two or more metallic parts, of the same or different metals, with or without fusion, with or without new metal material input, in which you have a good continuity between the parts: physically, chemically and physic-chemically, that based the mechanical characteristics and the service comportment. All of this without make hard zones; harmonize with the material close to the weld zone.

There are a lot of kinds of welding: By electric arc, resistance welding, chemical welding, and pressure welding … And in every kind of welding a lot of technical, every one made for a different industry process.

This project is going to be focused in the electric resistance welding (since now ERW), more precisely in the spot resistance welding. This welding is used for the union of body parts (for machines or vehicles). Our study is directed for the car body part union.

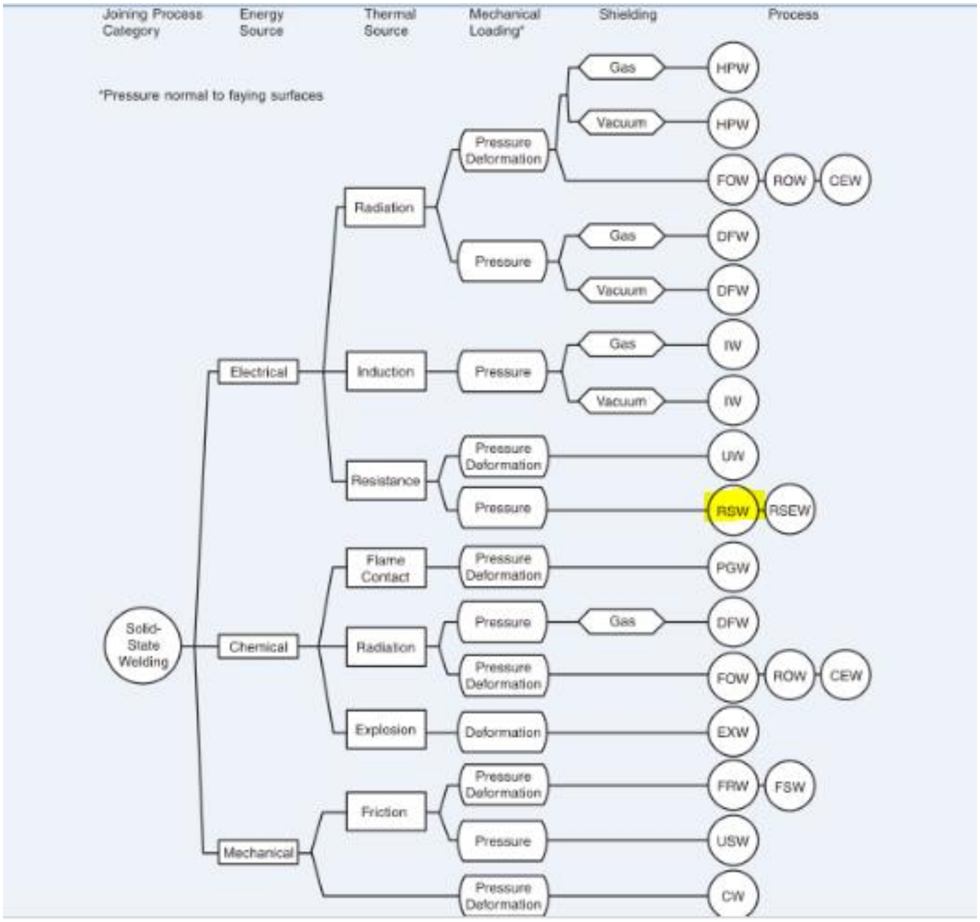


Illustration 1 Different welding process

Along this thesis we are going to analyse all the parameters that could affect to the resistance of the union and the quality of the same.

Also we are going to dissing and manufacture a fixture to can do the essays of “cross-tension test”.

For make a good essay the first thing that we have to do is select the best material for the car body , then study the welding process monitoring with the welding variables and, at the end, make the essays and compare the resistance parameters of the welding with the material and/or welding variables.

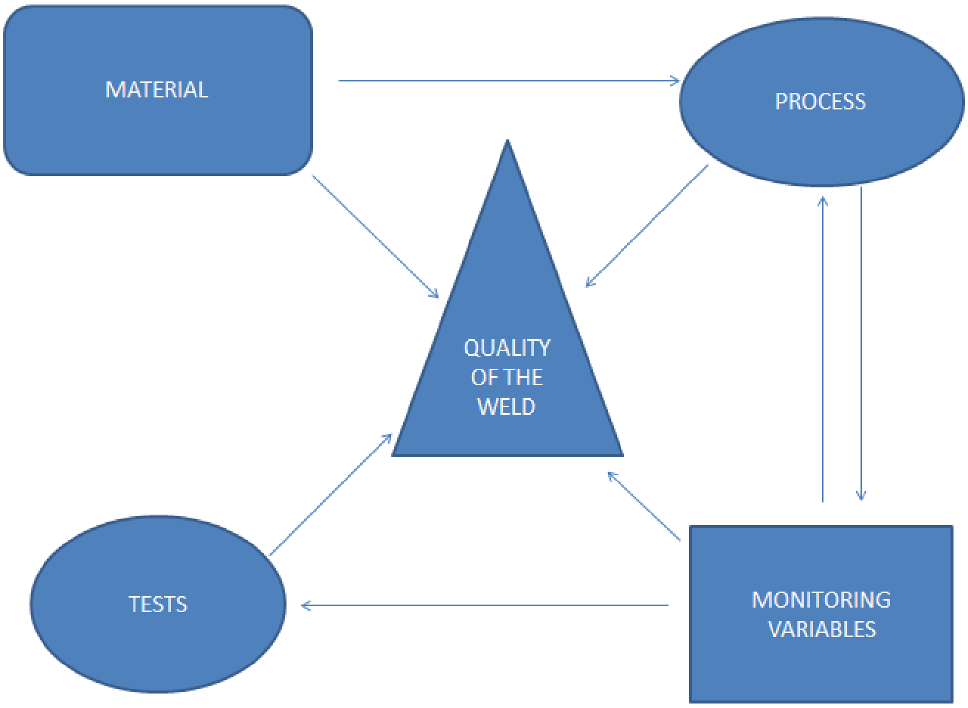


Illustration 2 Summary-Diagram

In the first part, the thesis introduces the most innovator materials for the production of car bodies that are principally the TWIP steels, TRIP steels, Dual Phase and Q&P (quenching and partitioning). We talk about the mechanical proprieties, the heat treatment and composition of the steels. As an industry application, we have to valuate also the cost of the materials.

In the second part, the thesis introduces the process of the electric resistance welding (ERW). We describe the process with all the important parameters: current, voltage, energy per second, pressure, electrode’s diameter, and electrode material, nugget diameter and electrical resistance of the union, for example. Then, in the same context, we compare the two welding machines that we have to make the welds: TECNA and DURING, and describe how these machines modify, fix or follow a trend of the value of the parameters in the process. This part it is very important because the future essays will make relationships between these parameters and the mechanical resistance, so we need to control the value of the parameters.

For this reason, the welding parameters have to have an independent system of verification. This is why the third part of the thesis is focus in the monitoring system. We can programme in the controllers the parameters but we need to be sure that all it is working well, and for this we use the external monitoring. We are going to describe how to measure the voltage, current, pressure or displacement and temperature. The voltage it is the simplest one (only measure the potential between the electrodes with a wire), but the current and the pressure or displacement are more complex. We describe the principal systems to measure these parameters.

The fourth part describes the tests that define the quality of the welds. The principal tests are the lap-shear tension and the cross tension test. The first one is made in the longitudinal direction of the coupon, the cross tension test in the transversal direction of the union. In both test, we make traction to the coupon. We describe all the parameters and the process to prepare the coupons.

For the cross tension test, we need a special fixture because we cannot fix the plates of the coupon directly to a standard traction test machine.

This is why the last part of the thesis describes the process of design and manufacture to the special fixture to connect the traction machine to the coupon. In this part, also, we make a CAD verification of the Tension reached in a test and make a verification of the geometric and dimensional tolerance of the fixture manufactured.

MATERIAL

Material Introduction

The materials that we are going to use are destined to the production of vehicles, trains, plains… It means that we want the maximum tenacity, mechanical resistance, the less cost, maximum security and the less weight possible to save fuel.

The best material for built cars, trains and the other vehicles is the steel. This is because the steel has a very good relationship between the price and the mechanical proprieties. It makes the steel the most interesting material for the industry. For the transport industry have a disadvantage, that weight too much, so we have to use the less material possible to make the vehicles. This is why we use plates, and we are going to work with plates in this thesis.

Steel is, always, an alloy of iron (principal material) and carbon (between 0 and 2% of the steel), that we could improve with others materials in the alloy (as manganese, chromium…) to give specific proprieties to the steel. There are hundreds different kinds of steels, with more or less mechanical resistance, tenacity, ductility, more or less alloyed… And not only the composition is the only thing that determinate the final proprieties, also the heat treatment; a steel with the same material composition has a very different comportment if we give a heat treatment cooling very quick the steel or slowly. (1)

Heat treatment

Heat treatment is defined as the cooling process that we do to steel since a temperature to obtain different micro-structure in the material that will define, with the chemical composition, the mechanical proprieties.

In general, when we cool a steel quickly since a high temperature (more than 750ºC), we obtain a steel very hard, with a lot of mechanical resistance but with a very poor tenacity. In the other hand, if we cool the steel slowly, we obtain a material with less mechanical resistance but with more tenacity and ductility. These differences are produced principally by the different microstructure that we obtain with these treatments.

Some of the most important are the annealing, normalizing, quenching or temping. These treatments are shown usually in the S-S cooling curves that represent the different microstructure formed when the cooling curve cut with the material curve. (1)

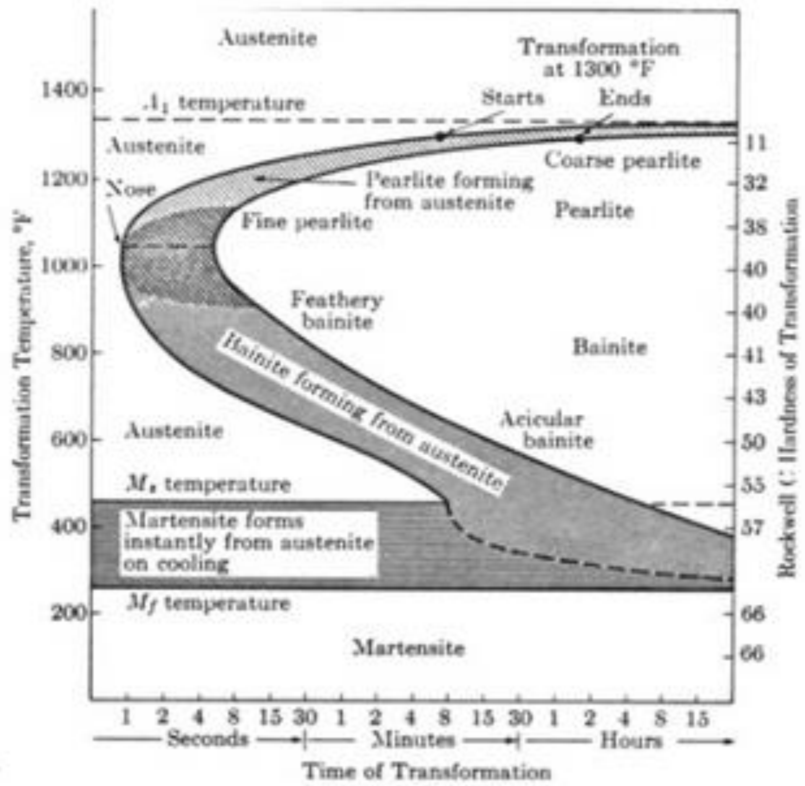


Illustration 3 each steel has different SS curves (2)

When we use steels with less than 0,68% carbon (hypo-eutectoid steel), we have principally a microstructure of ferrite and pearlite, which is a mixture of ferrite and cementite (88 and 12 weigh percent respect). This kind of steels is the most interesting for the car bodies, because they can absorber a lot of energy in an impact. The ferrite is the microstructure that makes steel very tenacious, and the perlite is the microstructure that have the best mechanical proprieties in general (not specific in anyone).

There are different kinds of pearlite and we obtain different pearlite structure with the heat treatment. If we cold slowly, we have the perlite with more tenacious and with less mechanical resistance, and if we cool quickly, we obtain other kind of it less tenacious and with more mechanical resistance, as for example the bainite.

When we cool steel very quickly we could have another important microstructure: The martensite. This microstructure is the harder and with more mechanical resistance of the steels, but with less tenacity, it is very fragile.

In the steels that we are going to use, also can appear another microstructure: The retained austenite. This microstructure appears by the combination of other materials in the steel and a specific heat treatment; because in usually steels, the austenite is only stable at high temperature (between 750ºC and 1400ºC). This microstructure is very ductile and with mechanical efforts can be transformed in martensite progressively. This will be the fundament of some of the materials that we use in car bodies.

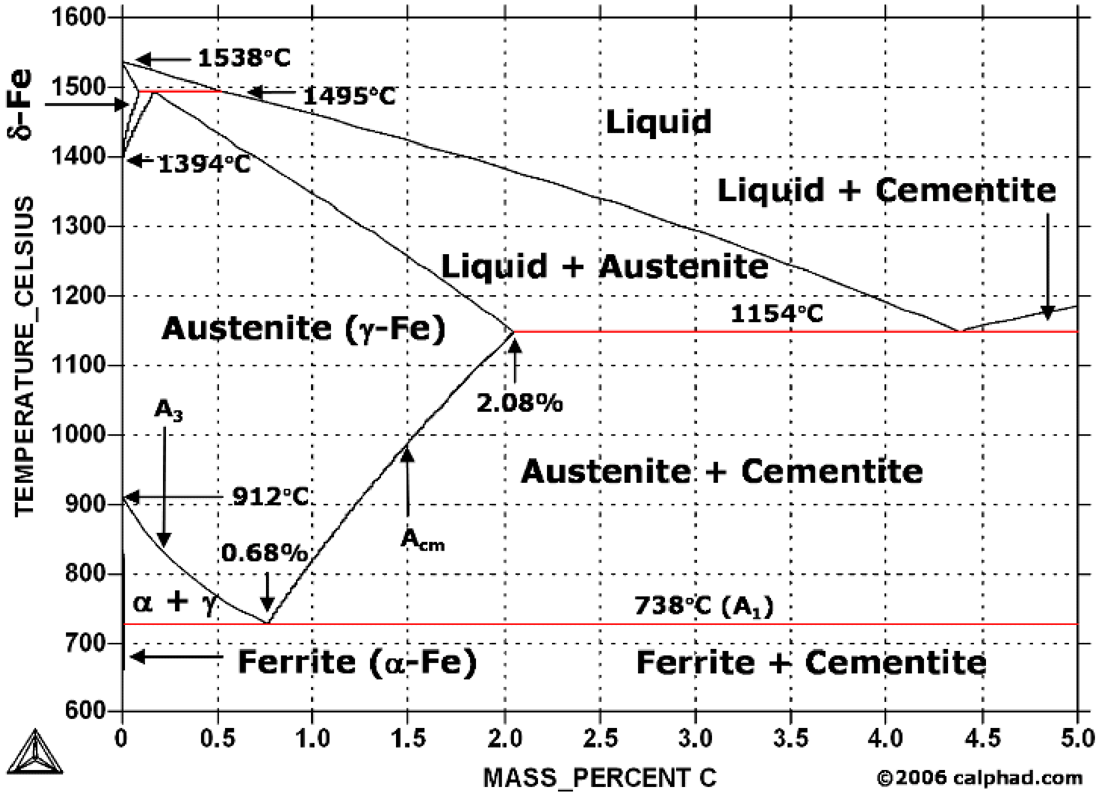


Illustration 4 Steel carbon diagram, with the temperatures (3)

For the body car we want steel with the best relationship between economic cost and energy absorber capacity in a hit and mechanical resistance. Also, as we are going to join the plates by ERW, we want that the process were the cheapest possible; so the material has to have a good weldability.

STEELS INTERESTING FOR BODY CARS

The interesting materials found are these steels: (4)

- TWIP (Twinning induced plasticity)

- TRIP (transformation induced plasticity)

- Q&P (quenching and partitioning)

- DP (Dual Phase)

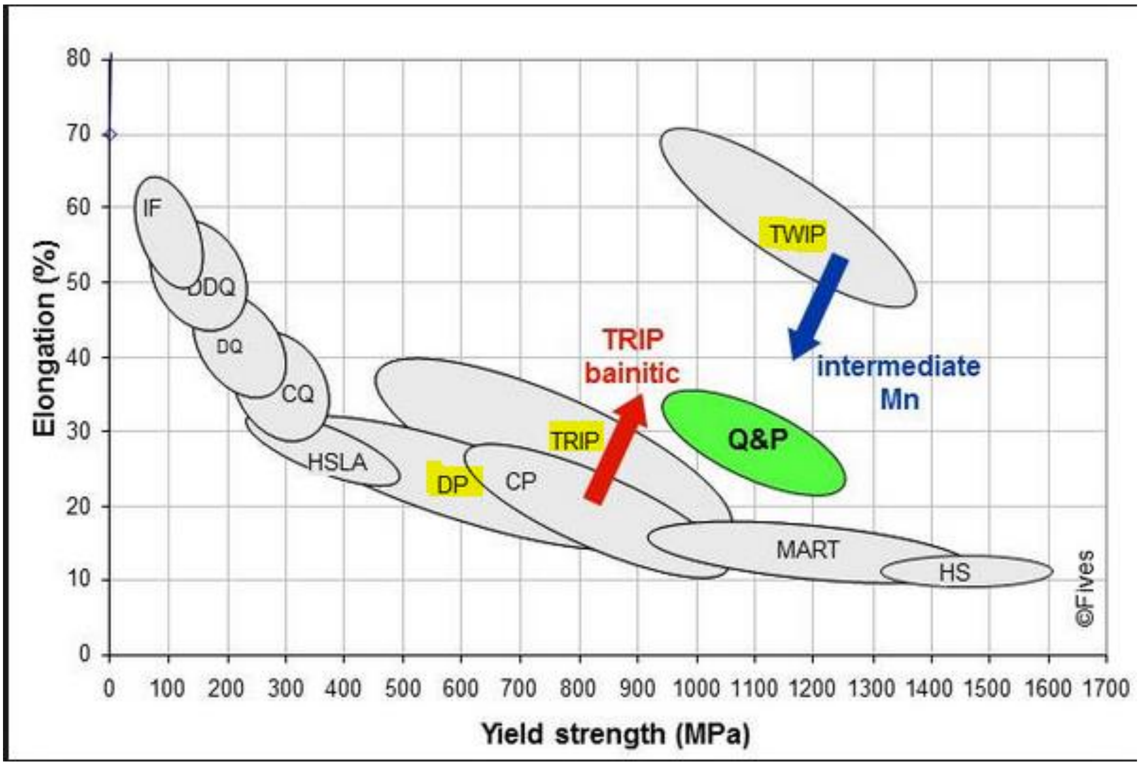


Illustration 5 DP TRIP TWIP Q&P Elongation (%) vs Yield strength (5)

The materials influence a lot in the welding; we can weld similar or dissimilar materials. We call a material similar to other when they have the same physics proprieties or very close each to the other, as thermal conduction, dilatation, mechanical resistance… We call dissimilar materials when they have not close parameters.

The more usually fact, is the union of two plates of the same thickness of similar material (or the same material), but in the coupon test is also interesting the idea of make unions between two plates of different materials with different thickness.

TWIP: (Twinning Induced Plasticity)

This kind of materials have a very good mechanical resistance (1000MPa approximately), and a big deformation before the rupture of the material (60%), (6) (7) that means that in case of a hit, the material will absorb a lot of energy in the deformation of the material. This steel exhibits no ductile-to-brittle transition-temperature even at very low temperatures of T=−196°C and shows ductile behaviour over the whole temperature range (8). This means that we cannot have problems with the temperature in the application of vehicles.

This material it is composed by a high manganese percent (between 12-30%) and percent of carbon between 0.4 to 1 percent. The steels alloyed with a high percent of manganese and a few of carbon presents an austenitic form in the metallic grains in ambient temperature. (9)

A typical treatment given to this kind of steel it is maintaining a temperature of 1100ºC for 30 minutes to two hours and then water quenched. (10)

The absorption of energy it is very important in this steel by the austenitic transformation in the final steel. As the chemical composition has aluminium, silicon and aluminium, we can have easily with the heat treatment the retained austenite. When a collision happens to this material, the austenite is transformed to martensite and makes the material progressively stronger. The energy needed to this transformation is given in the impact, so the transformation absorbs it. (11)

Austenitic steels are used widely in many applications because of their excellent strength and ductility combined with good wear and corrosion resistance. High-Mn TWIP steels are attractive for automotive applications due to their high energy absorption, which is more than twice that of conventional high strength steels,[3] and high stiffness which can improve the crash safety. (12)

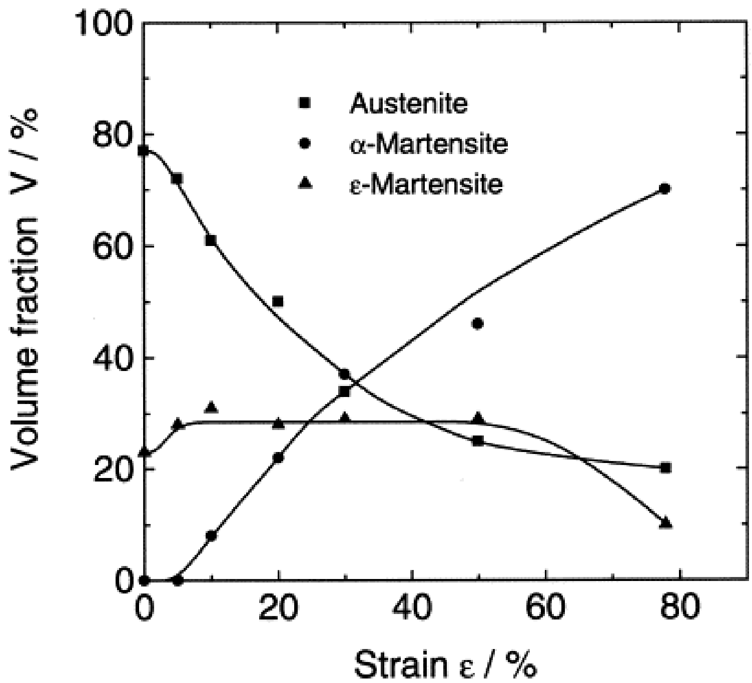


Illustration 6 Progressive transformation of austenite (13)

As we see in the Illustration 6 Progressive transformation of austenite Illustration 6, the asthenic transformation to martensite when the material is loaded is made by the energy of the impact and force that deform the metal. This principle is the same to the TRIP transformation..

In this case we have a lot of manganese in the steel, so it will be not a problem the possible fissuration of the welding if the steel has sulphur.

The manganese make to the material lightweight but more difficult to weld in point resistance welding. We may use a special electrode. It is typical the use of longer welding time, than usually, with this materials to control the nugget diameter in ERW.

TRIP: (Transformation Induced Plasticity)

This kind of steel has better proprieties than normal steel. It is composed by ferrite, bainite and austenitic grains. The austenitic grains get transformed in martensitic grains when the steel is hit or make an effort.

This steel also have a very good comportment to the hits, they can absorb lot of energy in their deformation, and make the material harder progressively. This kind of steel has a percent of carbon lower than TWIP (0.2-0.77%). Also has less manganese percent than TWIP (2% more or less). It is very important in this case the thermal treatment that changes completely the steel comportment.

Acciai TRIP PF (% in massa)					
C	Mn	Si	Al	Nb	Altri
0.2	1.5	1.5	-	-	-
0.2	1.5	0.1	1.8	-	-
0.3	1.5	0.3	1.2	-	-
0.15	1.5	0.6	-	-	P:0.1
0.15	1.5	0.1	1.0	-	Cu,Ni
0.2	1.5	1.5	-	0.04	-
0.2	1.5	1.1	-	0.04	Mo:0.3

Illustration 7 Some TRIP commercial steels. (14)

For obtain this steel we have to follow a heat specific heat treatment, maintaining between, 90 s and a few minutes, the steel between a temperature of 780ºC and 880ºC (7), followed by a isotherm heat treatment between 350ºC and 450ªC before let it cool in the atmosphere.

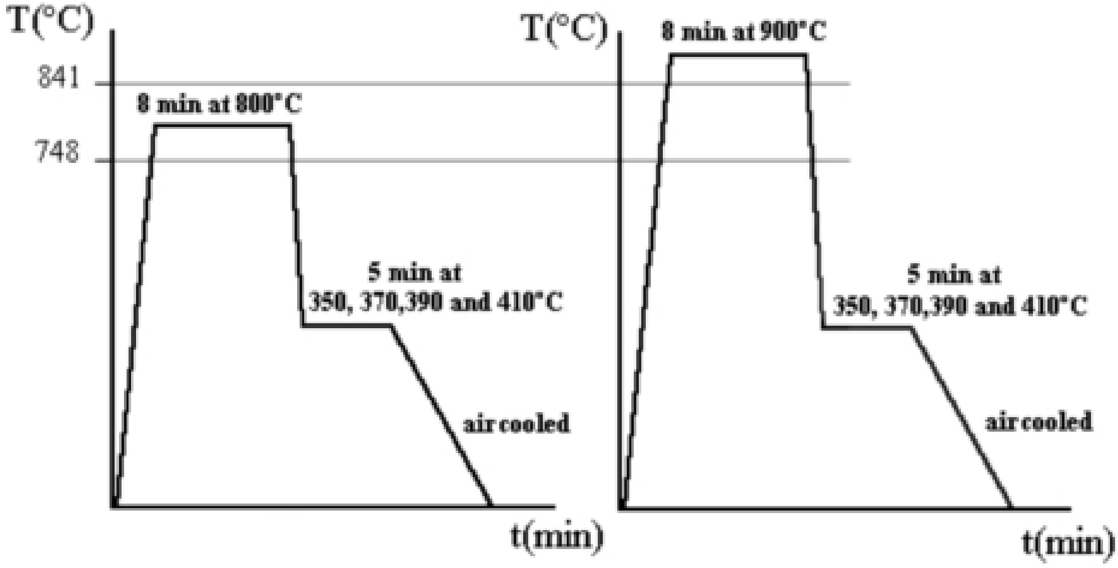


Illustration 8 Two different HT to TRIP steels. (15)

With this treatment we obtain a microstructure of ferrite (50-60%), bainite (25-40%) and austenite (5-15%). (7)

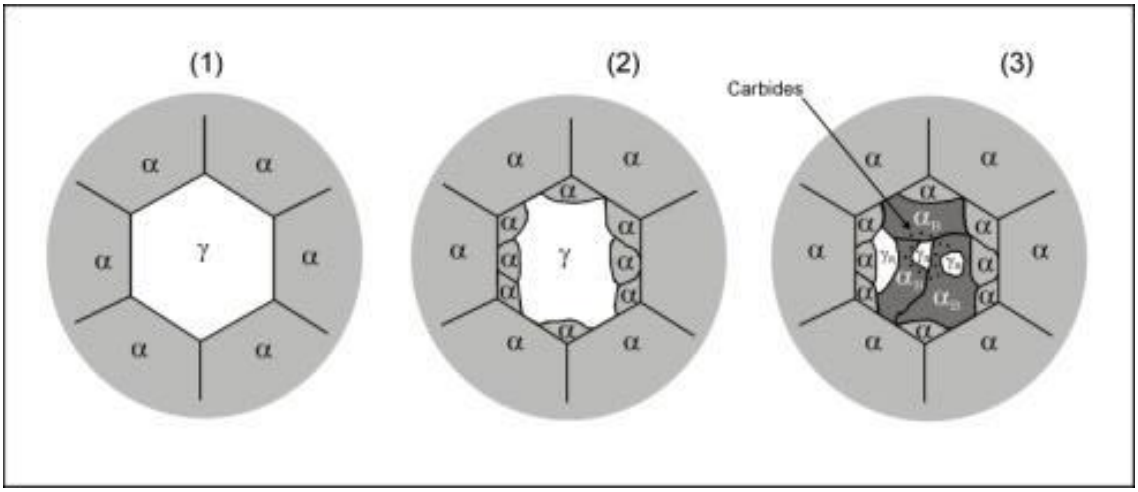


Illustration 9 Transformation of the steel, along the HT, to obtain TRIP structure. (14)

This steel has less mechanical resistance (as maximum 800MPa) and elongation (as maximum 20%) than the TWIP steels.

Q&P (quenching and partitioning):

The quench and partition (Q&P) process has been suggested as an alternative heat treatment to produce steels with retained austenite

The Q&P process has been studied in a low-carbon steel containing. By heat treatments consisting of partial austenitization at 900 °C and subsequent quickly cooling to a quenching temperature in the range between 125 °C and 175 °C, followed by an isothermal treatment (partitioning step) at 250 °C and 350 °C for different times.

Firstly, the material comes very hard by the martensitic transformation, and then get a little bit softer, but increasing the tenacity. This made the material harder and with better fatigue comportment for the martensite and with a lot of tenacity by the partitioning process, transforming partially the martensite, making the metal has less tension.

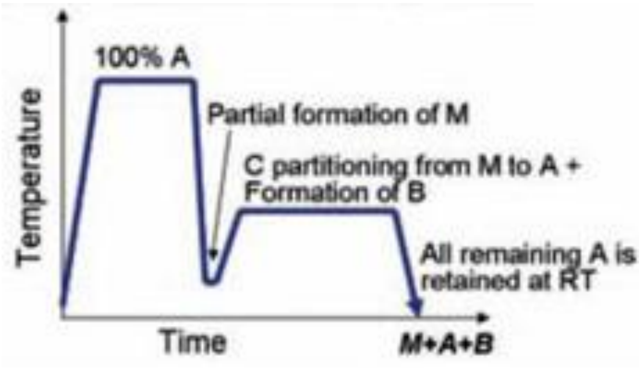


Illustration 10 Cooling curves: Q&P A (austenite), B (bainite), M (martensite) (16)

The heat treatment sequence involves quenching to a temperature between the martensite-start (*M*s) and martensite-finish (*M*f) temperatures, followed by a ‘partitioning’ treatment either at, or above, the initial quench temperature, designed to enrich the remaining untransformed austenite with carbon, escaping from the supersaturated martensite phase, thereby stabilizing retained austenite phase to room temperature. (17)

DP (Dual Phase)

The multiphase microstructure is formed by intercritical ferrite, epitaxial ferrite, retained austenite, bainite, and martensite after different stages of tempering.

Table 1. Chemistry

Alloy	C	Mn	P	S	Si	Mo	V	Ti	Al
50	.11	1.45	.020	.004	.45	.16	<.002	<.004	.041
52	.098	1.47	.014	.003	.45	.02	.080	<.004	.039
53	.11	1.44	.022	.005	.57	.18	.003	<.002	.036
55	.098	1.45	.018	.002	.58	<.02	.075	<.006	.043

Illustration 11 Chemical composition of commercial DP steel. (11)

Principally it is form by martensite and ferrite. For have this microstructure the percent of carbon has to be very low (lower than 0.2%).

The ferrite makes the material very elastic, it can be deformed “easily” without loose proprieties and absorber a lot of energy in an impact.

In the other hand, the martensite makes the material more hard and with better comportment to fatigue.

A lower percent of carbon make the steel more tenacity but less strength. In an usual test, the Dual Phase steel would have more mechanic resistance with more carbon, but in the cross direction is different, with a steel less alloyed and with less carbon we have more resistance in the cross direction. This means that the tenacity is more important than the mechanical resistance in the cross direction. (18)

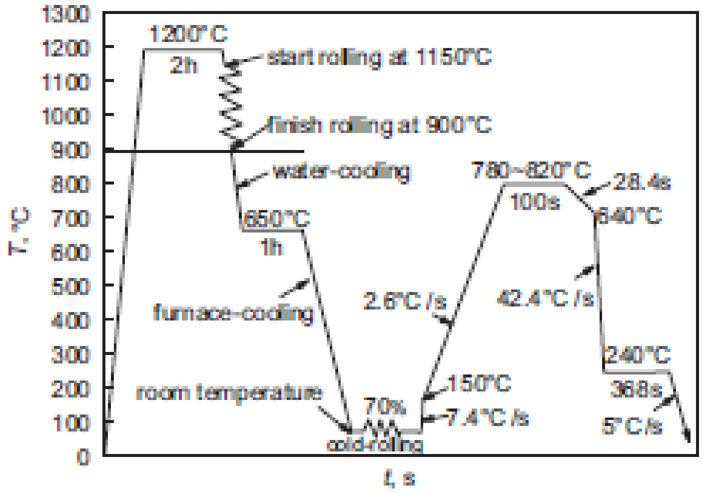


Illustration 12.Heat treatment to obtain DP steel (19)

In Dual Phase the rupture is ductile in usual test, the ferrite matrix dominate over the martensite. It means that the steel is going to be very deformed before the failure.

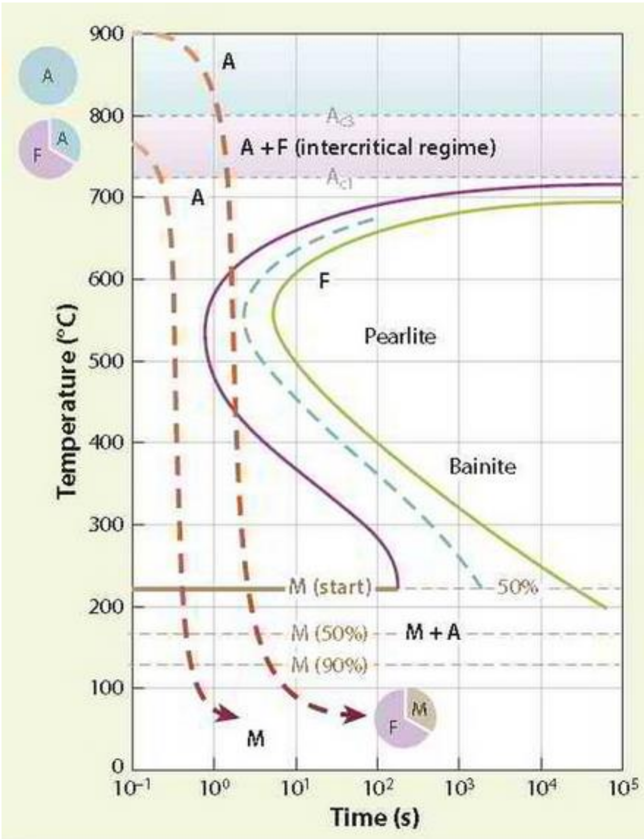


Illustration 13 A (austenite) M (martensite) F (ferrite) DP (20)

The heat treatment can be different for the same material to have different mechanicals proprieties. We can have a slower cooling since a low temperature to haven't got a total martensite transformation cold rolling-intercritical annealing (and abbreviated as CR-IA) or we could cool quickly (without an intermedia temperature) and have a totally martensite transformation this treatment is referred as intermediate-quenching (and abbreviated as IQ). The temperatures for the CR-IA could be since 750ºC to 850ºC in the intermedia heating and the IQ since 750ºC to 900ºC without intermedia warming up.

If we use CR-IA treatment, we inhibit the martensitic transformation more with less intercritical temperature (with 750 ºC the steel will be softer and more ductile than at 850ºC).

Mechanical properties of IQ samples.

T (°C)	YS (MPa)	UTS (MPa)	Total elongation (%)	Uniform elongation (%)	Local elongation (%)	Martensite fraction (%)
750	471	675	16.79	11.68	5.11	39.79
775	445	753	14.92	10.90	4.02	44.21
800	456	795	14.09	10.69	3.4	58.21
825	509	830	13.26	9.45	3.81	66.31
850	554	880	8.27	5.93	2.34	81.00

Mechanical properties of CR-IA samples.

T (°C)	YS (MPa)	UTS (MPa)	Total elongation (%)	Uniform elongation (%)	Local elongation (%)	Martensite fraction (%)
750	240	538	22.82	18.66	4.16	17.36
775	294	616	19.95	15.51	4.44	22.94
800	370	747	17.15	13.16	3.99	53.49
825	487	863	11.06	9.72	1.43	71.09
850	527	882	8.15	6.76	1.39	81.38

Illustration 14 Temperatures and martensite % VS elongation IQ//CR-IA *Effect of martensite morphology and volume fraction on strain hardening and fracture behaviour of martensite–ferrite dual phase steel (18)

PROCESS

Introduction

The electric welding resistance (ERW) spot are used for the union of, usually, two metal pieces with little thickness and if it is not needed an exigent tightness in the union (for this, we should use a continued welding, as for example electrical arc welding). This kind of welding is very productive and easily automatable. For all this reason it is perfect for the union of the car body.

ERW is based in Joule law:

$$E = R * I^2 * t = \frac{V^2 t}{R}$$

Joule's law, W= Energy (J), I= amperage/current (A), R= resistance (Ω), V=Voltage (V), t=time (s)

The heat given to the process is directly proportional to the time (t), resistance (R) and to the current-squared.

We can change the relationship also, using the Ohm law:

$$I = \frac{V}{R}$$

The current is proportional to the voltage and inversely proportional to the resistance.

If we give to the process more heat we will have more material fusion in the union, but the best welding is not product of the quantity of material otherwise of the quality of the process and all the parameters.

Parameters

In this kind of welding we have the next parameters or characteristics that we should study:

- The materials of the electrode
- The material of the plates that we are going to weld. The steel that is composed by ferrite is harder to weld with this technique. Also, the steel very allowed is difficult to weld.
- The geometry of the electrode that is changing all the time when we use them. The electrode has a finer point at the start than after a long time use.
- The amperage, maybe the most important parameter.
- The voltage between the two electrodes, with the resistance or the amperage gives to us the tease of energy per second.
- The resistance between the plates, that have to be as close as can to the total resistance of the circuit. Remember that this kind of welding is based on the

law of Joule, and we need the maximum heat in the welding with the less electric energy, for give to the process a better yield.

- The pressure of the electrodes, for principally two reasons: The first one to fix the resistance point, the second one for reduce the resistance of the total circuit and make it closer to the weld resistance, that it is which will give to the plates the heat to make the weld.
- The time that we are welding, longer time means more heat liberated and more metallic fusion.
- The cooling system of the electrode. In the welding we have high temperatures and we have to cool the plates quickly to have a better production. Also the cooling speedy of the electrode gives us different heat treatments, so it is an important parameter.

This is why we have to monitoring these parameters in the welding. We can combine all these parameters in different ways. The voltage, intensity and pressure are the parameters more interesting to measure in every moment, because the resistance will be almost constant, like the material or the time, that we can fix before start the welding. The geometry of the electrode doesn't change significantly in only one welding but it is important the geometry that we are using for the welding.

For the geometric industrially electrode studio, we have to compare one welding with the electrode new with other when the electrode had being used for a "X" number of times and we could say, more or less, when the quality of the welding it is unacceptable for our process and we must change the electrode for other new.

Welding machine

Usually the welding is made by DC, and industrially we have AC. We have to change AC to DC, so almost welding machines have a transformer between the secondary circuit, where is the AC, and the welding circuit, where we use the DC to weld the plates.

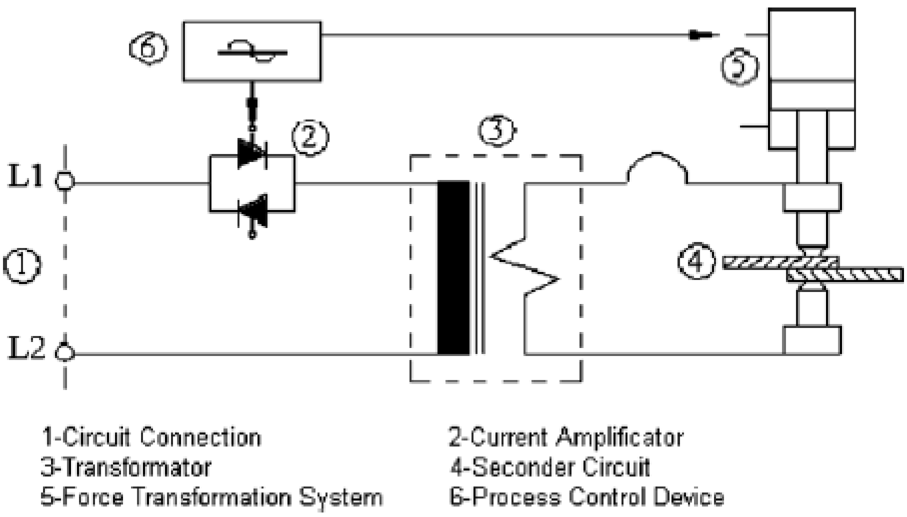


Illustration 15 Schematic illustration of the ERW welding machine (21)

Electrode

The diameter of the electrode has to be different when we want weld different thickness. There are a lot of different mathematical approximations. For American National Standards Institute (ANSI), American Welding Society (AWS) and Society of Automotive Engineers (SAE) (22), the size of the recommended electrode diameter for steel is:

$$D = 5\sqrt{t}$$

Where "D" and "t" are the nugget diameter and sheet thickness in mm respectively.

Also is recommended that the diameter of the electrode must be as minimum $4\sqrt{t}$ and as maximum $7\sqrt{t}$ (23):

$$4\sqrt{t} \leq D \leq 7\sqrt{t}$$

For every kind of metal we should use a different alloy in the electrode. Also, for different number of welding ,for example, if we want make a lot of welding without change the electrode we should use alloy more resistance and more hard in the electrode. For almost all electrodes we use copper because it is the material, industrially, more conductor. There are different kinds of materials for the electrodes:

- If we want to make it stronger, we can alloy with Wolfram and the electrode will have a longer life but with less electrical conduction.
- If we want to make a lot of pressure in the process, we have to use an electrode Cu/Be (0.5%)/Co (1%).
- If we want to weld stainless steel we have to use an electrode of Cu/Cr.

These are the more used but there are more. So, depending of the final industry process and the material, we have different types of electrodes

The geometry of the electrode is also important; there are different geometries depending of the plate's thickness. If the thickness is small, the electrode will have beaked form.

Current /amperage

The current is the most important parameter in welding, not only in ERW. When the welding is made with lower current as has to have, the deeply of the union is not enough. This happens for example when we fix the energy rate and the voltage has a high value. If we make the union with too much current we have better penetration but less mechanical resistance. For these reasons are important to control the current and has the first priority in our working parameters.

The current in the ERW is very high, to the order or thousands of amps, between 2.000 A and 15.000 A. (22)

Voltage

The voltage is important when we fix the energy rate. If we use lower voltage as we might, we will have low fusion rate. If we use higher voltage, we will have higher fusion rate and less penetration because all the fusion will be in the surface welding.

The voltage in the ERW is very low, to the order or a few V, in a range of 5-20 V, for example. (22)

Pressure

The pressure of the electrodes fixes the plates for welding giving a better and easier placement to the plates. In all the welding time have to be pressure; the electrical resistance energy fuses the metal and the pressure ensures the union.

The effect of pressure on the resistance spot weld should be carefully considered. The primary purpose of pressure is to hold the parts to be welded in intimate contact at the joint interface. This action assures consistent electrical resistance and conductivity at the point of weld. The parts to be welded should be in intimate contact before pressure is applied.

Other function is avoiding electrical power losses between the plate and the electrode. High pressures exerted on the weld joint decrease the resistance at the point of contact between the electrode tip and the work piece surface. The bigger pressure the lower the resistance factor. (24)

The magnitude of the pressure in this kind of welding it is of the order of some KN.

Electrical resistance

We have two different resistances, one call the effective resistance, between the two plates that gives to us the effective resistance for making enough heat to fuse the material and another one, call the total resistance of welding, that it is a sum of effective resistance and all the other power loses by the “circuit resistance”. Always the total resistance is going to be higher than the effective resistance. In the perfect situation, the effective resistance would be equal to the total resistance (this means that all the circuit resistance is used to fuse the welding material).

These are some parameters that increase the total resistance that we have to avoid (22):

- Surfaces of the plates not clean, with oils, water or lubricants.
- Circuit loses in the conductor material, usually copper. These loses are impossible to eliminate, but we can make it lower if we maintain the circuit cool. When the welding works the circuit is warning up and in these conditions the conductivity of copper fall down, increasing the resistance and the power loses.
- Not having enough pressure between the electrodes and the plates. The pressure helps to have a better contact between plate-electrode.
- Not changing the electrodes when they are deformed by a lot of use. Also the geometry of the electrode, if the contact section is higher, the resistance is lower.
- Loses in the secondly circuit of the machine

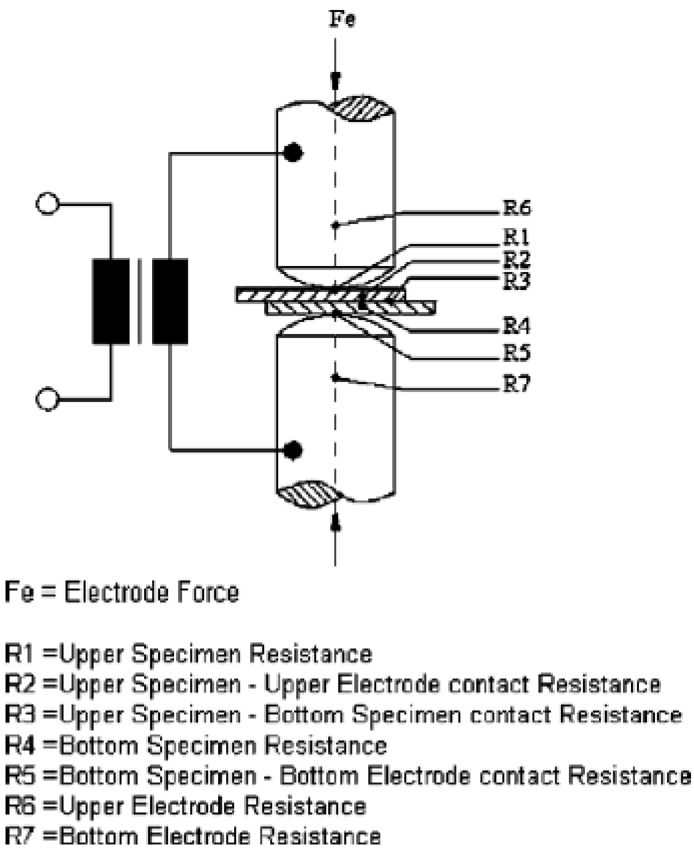


Illustration 16 Total resistance of ERW spot welding (21)

Welding Time (WT)

The welding time has to be enough to can have the best rate of material fusion with the best penetration but the lower possible to have a better production and not have an elevate fusion rate in the surface, that, although gets deep welds, weaken the mechanical connection.

The order of the WT in the ERW is of the order of the hundreds of mille-Seconds (mS) (25).

Heat treatments

With this kind of welding we can give a pre-treatment and post-treatment heat to the material. The pre-treatment is destined to have an easily welding and the post-treatment to have a lower welding zone and homogeny the micro-structure. For example, in the high carbon steels it is important the pre-heating.

It is not always necessary, but it is recommended to have a higher quality in the spot union.

Metallographic attributes

The results of the welding process give some parameters that condition the strength of the union (26):

- The weld nugget or Fusion Zone (FZ) size D which is defined as the width of the weld nugget at the sheet/sheet interface in the longitudinal direction. It is the most important factor in determination the quality of the spot welds. The fusion zone is controlled by heat input.
- Penetration of the welding, which is the width of the union in the thickness direction.
- The void in the spot welds. High temperatures, low pressure and high temperature gradient in the FZ can make expulsion and bad solidification of the material. The voids in the union decrease the surface contact between the materials and, also, make a notch effect. The principal reasons of the voids are the expulsion of the material and the contraction of the metal after the welding process. For this last reason, the cooling treatment is so important in ERW: we have to avoid the void and hard zones by the high cooling speed of some parts of the nugget.
- The plastic deformation of the plates, which is result of big pressure by the electrodes. We have to avoid this situation, because the union in this case, will be very fragile.
- The notch effect by different microstructure between the different parts of the FZ or between the FZ and the Material Base (MB). This is prevented with a correct cooling process.

As a summary, we might always to have the best homogeny in the FZ and between the FZ and MB. This is why the pre-heat treatments and post-heat treatments in ERW are so important. We have the best relationship between size of the union and the quality of the same.

How changes the parameters in the welding

In this kind of welding, we can define always 4 different steps:

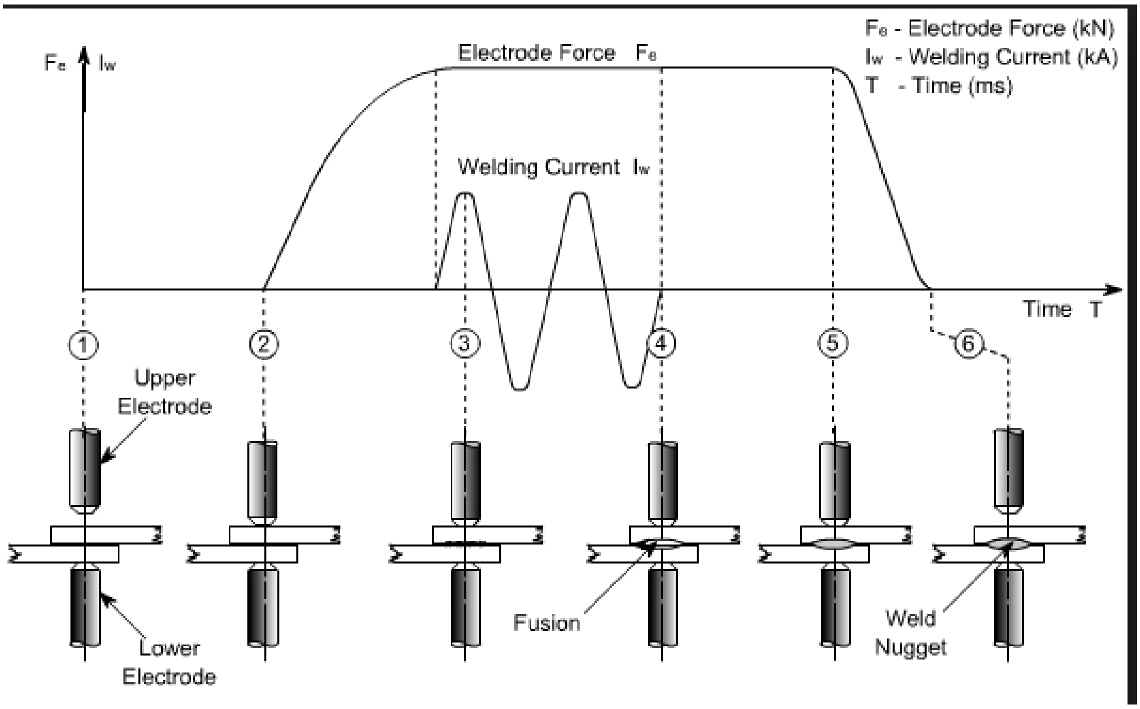


Illustration 17 Steps of the ERW (27)

- When the plates are in the position, start to pressure with the electrodes the metal.
- Then, maintaining the pressure, start to give amperage to the electrodes and start the fusion of the material.
- After it, maintain the pressure without amperage.
- At the end, reduce the pressure gradually.

In every Electric Resistance Welding (ERW), we have always these steps, but sometimes there are more than these four steps, to give a treatment to the welded material. For example, to the steel with high carbon percent or very alloy, to improve the welding, we give a preheating to improve the hardenability making less hard zones in the welded zone.

Also there are treatments after the welding when the cooling is quickly and makes hard zones.

We give heat before the welding also with the electrodes: Preheat is more common than the treatment after the welding with the electrodes, which takes more time. If we have to give an after treatment we usually give with other kind of procedure.

The preheating time is very important when the material is much alloyed. For example, when we use steels with high percent of carbon. Usually, the preheating time is of the order of hundreds of mS, as the welding time. We can give current and maintain the current to start the welding time or we could kill the current and start raising the current as shows Illustration 17.

Squeeze time (that it is not real welding time) is the time interval between the initial application of the electrode force on the work and the first application of current. It is necessary to delay the Weld current until the electrode force has attained the desired level.

After that, the weld time is measured and adjusted in cycles of line voltage as are all timing functions. When it is held long the amount of molten metal increases and fused metal spurts out and a series of peaks and valleys occur on a microscopic scale on the surfaces of meta-components and crystal structure of material changes. In addition heat affected zone (HAZ) extends. When the electrodes removed immediately, the heat dissipates and contact surface becomes dark. After the welding operation, the electrodes should be applied to the sheet to chill the weld.

Hold time is necessary to allow the weld nugget to solidify before releasing the welded parts, but it must not be too long as this may cause the heat in the weld spot to spread to the electrode and heat it (21).

Process in welding machines

We have different machines, which can fix, restrict or follow a trend of a parameter in the time that we are welding. We could, for example, fix a constant current in all the process, or the energy given to the process in every moment, the pressure or a trend as how have to change in the time.

We can make several configurations and combinations of some of the parameters that we can have a direct control. These are the current, voltage, energy per second, pressure and welding time. We are able to use two different welding machines: DURING and TECNA. Each one controls the parameters in a different way. We are going to describe deeply how they work.

DURING machine: IQR (25)

The Intelligent Quality Regulation (IQR) is the controller of the DURING welding machines. The IQR controller is divided in different working modes. We can fix regulation in different ways.

We are going to define some concepts for this machine:

- Welding Time (WT) is the time when is welding the machine, the moment that make the union, no all the process.
- Current Base (CB) is the current which we are going to use to weld in every process. We reference the others values of the current along the process to this CB in per-mille (‰).
- It is called "constant current regulation" (KSR), to one controller inside the IQR controller. The KSR is regulated, usually, by one parameter of the IQR (pressure, voltage, energy per second or the same current). Once that KSR is fixed, the IQR controller cannot change the CB.
- The machine divides the process in three steps: Pre-heating Time, Welding Time and Post-heating Time. The welding time is the only one that always exists.
- I(t), U(t), E(t)… this means that the current, voltage or energy are functions of time.

Mode 0

In this mode the controller IQR does not work. The welder can change all the parameters as he/she wants, with some restrictions:

- No preheating time
- No post-heat time
- Current time must be higher than 35ms.
- No curve current to upslope to the CB since zero or downslope since CB to 0.
- Only one pulse of welding.
- The KSR regulation has to be on.

This means that the WT it is the only time that we have in this mode, and the KSR works so the current is fixed since the other parameters that we fix. The mode 0 has not an industrial propose, it is directed to the investigation, although with so many restrictions that Mode 0 has it is hard to experiment.

Mode 1, "IQR ref"

In this mode the IQR controller fix the current for every "ms" of the welding process, so we can say that current is instantly function of time, I(t).

We can only select and change one parameter in the welding: CB, WT or pressure parameters. Selecting one, the controller instantly chooses the other variables.

With this mode we can have preheating time with a pre-pulse, a post-heat treatment, an upslope to CB with or without break time…

Mode2, “IQR”

In this mode the IQR controller fix the energy given every second (preheating, WT and post-heating treatments).

We know that:

$$E(t) = U(t) * I(t) * t$$

And we can only fix one more parameter for give the E(t) curve. In this mode we fix the U(t) curve and the IQR calculate automatically I(t) curve. So we can say that:

$$I(t) = f(U(t))$$

This mode is the best way to weld the materials that needs specifically an energy rate for the preheating or post-heating. For example in the carbon steels that needs a preheating for has a good welding.

Mode 3, “IQR-rob”

This mode is very similar to the “Mode 0”, but we can change the trend of the pressure or welding time, but with the KSR always turned on, the CB will be always the same and there will not be also preheating or post heating time. We can change some pressure parameters and WT with different CB.

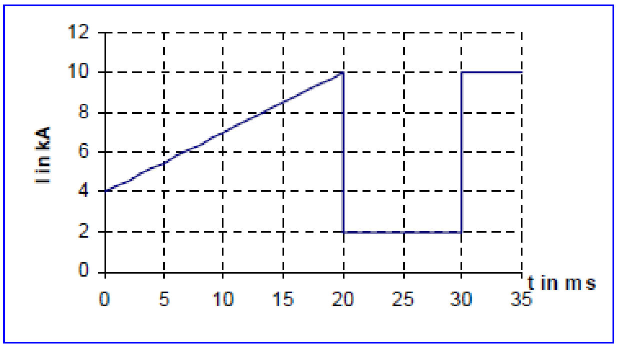
How the machine works

We have different forms in the modes that we have explained. These are some of the most important “IQR parameters” in the process.

Pre-pulse

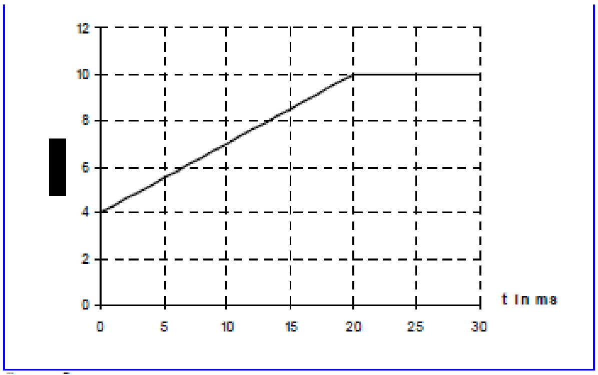
The pre-pulse, when the mode can have a preheating time; it is the curve before the WT. This curve can be referenced to the voltage, current, energy or pressure. The final propose is give a heat treatment to the material to has a better and easier welding process, no to change the final micro-structure of the plates material.

We can have a upslope curve, a pulse or other kind of curve that we want have. Also we can have a break time between the preheating time and the WT. These are some examples:



1^{st} **pulse: time** [50] = 20 ms
1^{st} **pulse: pause time** [51] = 10 ms
1^{st} **pulse: pause ampl.** [52] = 200 $^{0}/_{00}$
1^{st} **pulse: start ampl.** [53] = 400 $^{0}/_{00}$
1^{st} **pulse: stop ampl.** [54] =1000 $^{0}/_{00}$
Base current = 10 kA

Illustration 18 Amperage//time.Pre-pulse with a break time (25)



1^{st} **pulse: time** [50] = 20 ms
1^{st} **pulse: pause time** [51] = 0 ms
1^{st} **pulse: pause ampl.** [52] = 500 $^{0}/_{00}$
1^{st} **pulse: start ampl.** [53] = 400 $^{0}/_{00}$
1^{st} **pulse: stop ampl.** [54] =1000 $^{0}/_{00}$
Base current = 10 kA

Illustration 19 Amperage//time without break time (25)

Also, we can have several pre-pulses.

WELDING TIME (WT)

This is the most critical parameter time in the ERW. We need have the higher resistance between the two plates for have the maximum energy in the union.

We call "t_r" at the time when we have the maximum resistance; this is why we reference all to the CB. If we have for example, active the "Mode 2 "IQR"" which first condition was the energy in every moment, we have to increase the current to have the same energy per second after the t_r; so maybe at first the CB was for example 1000 KA to the process but for maintaining the same power we need then increase the amperage.

For this reason we have to study the perfect WT and valuate the best duration with the best parameters for waste the less possible energy (the energy given to the welding is always the same, but if we have to increase the amperage we waste industrially much more energy) and the best final union. We can fix a maximum WT and current for solve these problems, but in the industrially process must not be necessary, because this means that we are programming bad the process.

Post heat time.

This time is destined to have a better homogeny in the union, avoiding the possible fragile rupture in the welding zone. Depending of the heat treatment we have to give heat to the material more or less time, in this time it is not critical the small fluctuations in current or energy per second.

Limiting parameters in welding

We can limit energy, voltage, pressure or current if we want have one or more parameters lower than a value.

We can say in witch time is the limitation to IQR. If we have several restrictions, the one that always has priority is the current.

TECNA machine: TECNA 700 (28)

TECNA welding machine has the TECNA 700 controller. This controller is more easy to use but, also, simpler than IQR.

Characteristics of TECNA machine

TECNA welding machine use an inverter to regulate all the parameters of welding. The TECNA 700 controller works in a specific program and gives the information to the inverter to vary the current.

The welding machine inverter transforms an AC with high frequency (60HZ, for example) to a DC output current. So the inverter works as a “transformation” inside the welding machine. This kind of machines weight less and has better yield than other technics to transform AC TO DC.

The TECNA machines weld in DC. We need a secondary circuit with a transformer. Some of the parameters that we have to fix are referenced in the second circuit.

Characteristics of TECNA 700 controller

- Simplified programming via 6 keys and a backlit alphanumeric LCD. Each welding program may be given an 8-character alphanumeric identification. For example 005-FEZN10-01:
    *The three firsts number “005” make reference to the program
    *The next six letters are the word keys associated with the program
    *The last two number the number of the welding equipment.
- Inverter command with IGBT at medium, allowing choosing the inverter working frequency between 1000 Hz and 4000 Hz.
- Storage of 300 welding programs.
- Possibility of managing up to a maximum of 4 different welding transformers or up to a maximum of 4 different electrodes typologies through the same control unit.
- Thermal protection for the welding transformer.
- Up to 32 programmable parameters for each program.
- Slope, pulses, pre-weld, post-weld functions and adjustment of the welding times with 1 ms resolution.
- Display of the RMS welding current, energy, power, RMS electrodes voltage, original and final resistance, machine thermal use percentage measurements

and, optionally, of the original thickness of the welded material and of the indentation at the end of the welding process.

- 6 operating modes: FIX, constant current, constant power, constant voltage, constant energy, DYNAMIC mode.
- Limits relevant to: the welding current, electrodes voltage, energy, power, inverter use percentage, original and final resistance of the material to be welded; limit on the thickness and on the material indentation (optional).
- Double stroke function
- Stepper function to compensate the electrodes wears with programmable curves. Possibility of independently intervening on welding time and current through differentiated stepper laws. Possibility of using 4 different stepper laws associated to 4 different spot counters which may be freely associated to each welding program.
- Single and automatic cycle. WELD and NO-WELD function.
- Control of 5 solenoid valves 24 VDC max. 5 W with self-protected output.
- Self-adjustment at mains frequency 50/60 Hz.
- Serial data transmission by means of optional insulated RS232 port.
- Output for proportional solenoid valve.
- Key for selecting foot control or two-hand control.
- Possibility of upgrading the control unit Firmware via appropriate software.
- Activation and control of the electrodes dressing. Possibility of managing up to a maximum of 4 different simultaneous electrodes dressings through 4 different spot counters (optional).

Welding programs:

In the TECNA 700 we have, as in the IQR, operating modes. These programs are: FIX, constant current, constant power, constant voltage, constant energy and DYNAMIC mode.

The difference with the IQR system is that we fix the parameters current, voltage or energy and we can change any value of the parameters that we are not restricting, making pre-treatments and post-treatments, not only in the welding time. This means that we have a higher field of variables for experiment.

FIX

The FIX mode works with the power that uses the inverter. We fix the power given to the inverter, since the 5% to the 100% of the maximum value of power. If we give to the inverter more power, we will have more current in the welding circuit.

The current vary by the change of the power and material welding material, the use of the electrode and fluctuations of the voltage in the secondary circuit.

This mode is used to welding with low welding time or/and material with high resistance oscillations.

Constant current (IK)

With this mode we fix the current parameter in the welding circuit. The inverter works with a logarithmic regulation, which gives all the parameters necessary to the TECNA 700 regulation to get this fixed value.

The algorithmic works along the welding process so can make variations in the current (around the chosen value for the current).

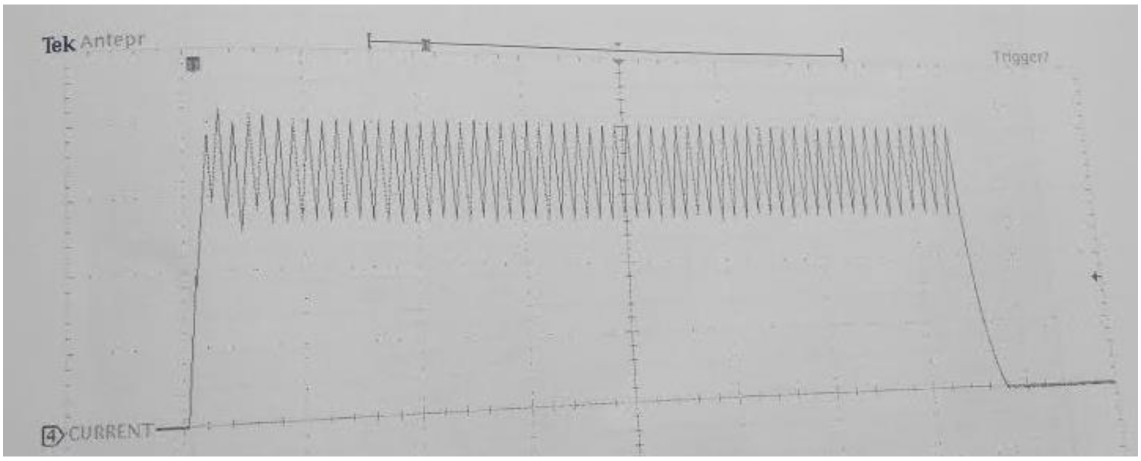


Illustration 20 Current variation around fixed value (28)

Constant Power (PWK)

In the constant PWK mode, the TECNA 700 controller calculates the secondary circuit voltage every moment and fixes a current. The voltage can oscillate along the WT but not the current (the current also oscillates, but always around a value, as in IK mode). As the voltage can oscillate, it is the parameter that makes the process being with a constant power.

This mode is used to weld materials of high resistance and high resistance variations in the welding process for avoid material projections.

Constant voltage (VEK)

In this mode, we fix the voltage in the secondary circuit. As consequence, the welding current will be a variable that depends of the voltage used (U), and the evolution of the resistance of the secondary circuit and of the welding circuit:

$$I(t) = f(U(cte) * \Omega(t))$$

For this reason, as the amperage is the most important value for the quality of our welding process, we can fix a “Current minimum” and a “Current maximum”, in the machine if we want.

This mode, it is used with almost the welding process with tungsten electrodes.

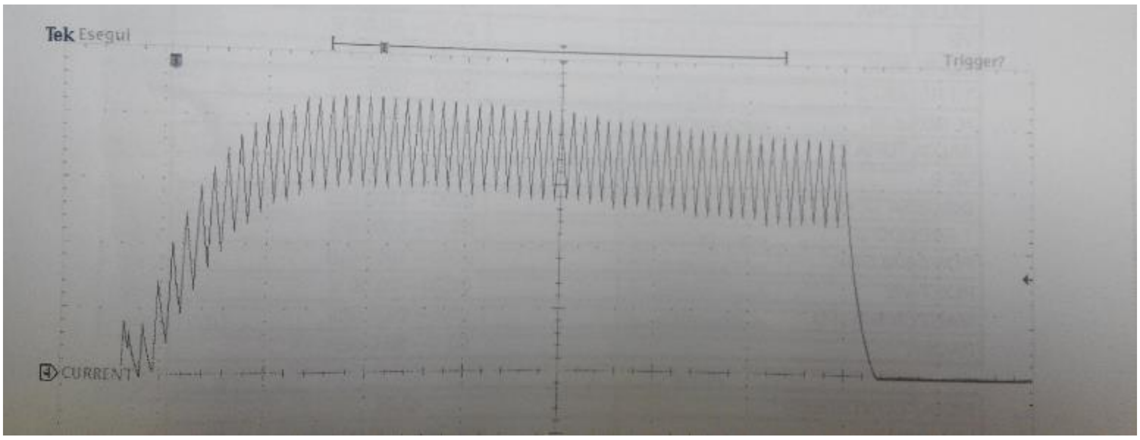


Illustration 21 Variation of the current along the WT (28)

Constant energy (ENE)
In this mode the controller oscillates the effective welding current value for have the energy imposed per second. Also, we have to fix the minimum and maximum WT.

For have the best approximation and working time, we have to fix correctly the pressure, the diameter of the electrode with the welding current. These parameters are usually in tables.

DYNAMIC mode (DYN)
In this modality make work the inverter in an “adaptive mode”. This means that we give to the machine the possibility of change all the parameters in every moment of the welding.

We use this mode for the process when we cannot have the ideal conditions in the welding, as for example, bad contact between electrode/plate, dirties surfaces in the plates or bad state of the electrode.

When this happens, the controller analyse the problem and send to the inverter how it has to changes the parameters.

Disclosing parameters

We can programme some parameters in the welding controller. As for example, maximum and minimum current, resistance, voltage or power value if we know that with a lower or higher value is impossible get a good welding.

Also, can analyse if the thickness is higher or lower as the specifications and if it is not correct not weld the plates.

As in the IQR mode, there are a pre welding time and post welding time. The difference in this mode is that we can change the parameters as we want in every mode and it is not so conditioned as IQR.

For the industrial work, it is programmed some functions:

Increase of the current along the welding process.

When we weld industrially we weld more than 1500 unions with the same electrodes. This means, that the electrode deteriorates along the use and loses contact surface with the plates. One parameter that we can change in this machine is the current along the electrode life, increasing when the surface contact decrease.

This increase can be linear or a curve. We have to make a study and approximate the ideal curve with short lineal trends.

Distance between the welding points:

We can fix the step between the welding points. We can say the number of welding point with one distance and then change to other one.

Usually problems with this kind of machines

One problem that we have with these machines is that, we fix a parameter, a trend or whatever, but we are not sure that every moment all the parameters are like we have programme in the machine. This is why we have to monitoring and measure the most important parameters, to be sure about how we are welding and then, make the co-relationship with the test experiments (with which time, current, voltage or other parameter in every moment we achieve the best mechanical resistance).

The principal problem with this kind of machines when they are working is that the entire electrical conductors are warning up at the time that we are using the machine. When a conductor material is hot, we lost electrical conductivity and we have to increase the electrical power to the transformation or/and cooling all the conductors, usually with a water heat exchanger. This also makes that the parameters have fluctuations in the machine, and we have to measure how they change (if they change only a few or they really are not assumable). (29)

Report of the process conditions for the coupons:

When we are making the union of two plates to create an ISO coupon to test, we have to represent and be sure of all the parameters. This is important because we can also make a relationship between failure and with every single parameter of the process.

We have to be sure that we make, as minimum, these annotations: (23)

- Material of the plates.
- Machine that we are using.
- Current for welding
- Welding Time
- Voltage between the electrodes.
- Energy in every moment of the welding.
- Coating of the material (if the plates have).
- Diameter and material of the electrode.

- Dimensions of every plate
- Force and pressure of the electrodes.
- Geometry of the electrodes.
- Tolerance of every measure system (monitoring).
- Cooling electrode system.
- Date of the experiment.
- Place and laboratory when it was made.
- Person who makes the union.

Piece to hold the welding coupon in cross tension test

One condition that has the coupon in the welding process is that the nugget must be in the middle of the cross in the cross tension test. For this reason, we have think up a solution, and manufacture a piece that hold the coupon to make be the weld in the middle of the union. Another advantage is that the operator with this hold do not have to sustain the coupon.

Option 1

The first option consists in only one piece that has the form of cross. The cross has inside other cross with the measures of the ISO coupon (a little bit bigger to can introduce the coupon easily) and a square hole in the middle to make the weld through it.

Illustration 22 Option I[1]

The advantages and disadvantages are:

[1] The planes of this design are in the annexes.

- It is very cheap and easy to manufacture, we can manufacture some very similar to others lengths.
- It is quickly to take inside the coupon
- The play that let the hold have to the coupon could displace a few (in the order or 1 mm) of the center.

Option 2

The other option is make an assembly of two pieces. One has 4 holes and the other 4 pintles. Bounce have a square hole in the middle were the weld is made.

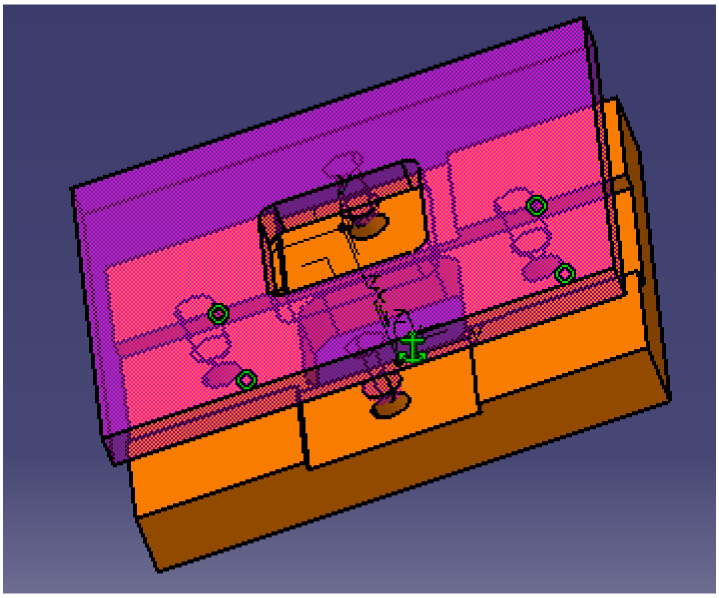


Illustration 23 Option 2[2]

The advantages and disadvantages are:

- The manufacture process is more expensive, the holds have to be aligned with the other part.
- The coupon will grab much better.
- You only can weld the plates that have the correct length in the holes, so this fixture also is used as a “pre-test dimension”, if we can weld the plates with this piece we will be able to put the coupon inside the cross tension fixture.

[2] The planes of this design are in the annexes.

MONITORING

The most interesting parameters are the current, voltage and pressure. With the measure of these parameters in every moment we could know all the physics variables.

Voltage

We have to measure the voltage between the two electrodes that are making the welding, to have the most exactly measure possible. We cannot measure never the exactly voltage of the welding resistance by the surface loses of the plates, because they are not totally clean or because we are doing more or less pressure, what makes the resistance welding higher or lower. The measure of the welding is made by two wires. We can made hole in the electrode and put into the hole the wire or only put the wire with a pin.

Illustration 24 Wires for measure voltage

Current

We have to measure the current. Almost all the interesting ERW are made with alternating current (AC) with and inverter to produce DC, but needing a secondary circuit with DC, where we can measure with this coil. For measure AC we could use this tool, the Rogowski sensor Illustration 25. We have selected the Rogowski coil because can measure high current (in a range from 300mA to 300.000A as says the supplier). Also, have a very wide bandwidth extending from typically 0.1Hz up to 17MHz. This enables the transducer to measure or reproduce the waveform of very rapidly changing currents (33).

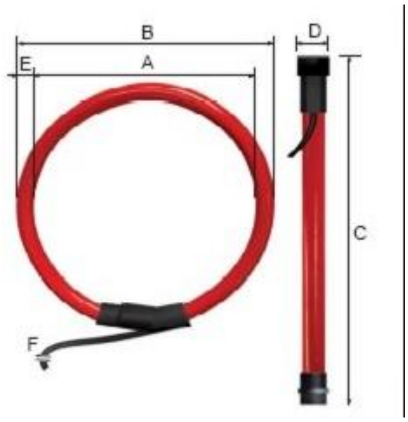


Illustration 25 Rogowski sensor (30)

The Rogowski coil is a low-cost sensor that uses a helical coil of wire around an air core to measure AC current or fast current pulses. The lead from one end of the coil returns through the centre so that both terminals are at the same end of the coil. The coil is then wrapped around the straight conductor to measure the current. As the induced voltage is proportional to the rate of change of the current in the straight conductor, the output is connected to the integrators to provide an output that is proportional to the current. Coil output voltage follows the formula: (31)

$$V = \frac{-SN\mu}{c} * \frac{dI}{dt}$$

Where S is the small area of the coil, ($S = \pi A^2$ with the parameters of the picture), N the numbers of coils around the central wire, c the coil length and I the current.

Each analog input pin requires that a simple RC filter be connected to the input to prevent aliasing by the frequency components (which are higher than half the sampling rate of the ADC) folding back and appearing in the sampled signal at a frequency that is below half the sampling rate. This is an artefact of all sampled systems and for conventional current sensors such as a current transformer; one RC filter with a corner frequency of 5 kHz should be used for the attenuation to be sufficiently high at the sampling frequency of 1.024 MHz. The 20 dB per decade attenuation of this filter is usually sufficient to eliminate the effects of aliasing.

However, a di/dt sensor, such as a Rogowski coil, has a 20 dB per decade gain. This neutralizes the 20 dB per decade attenuation produced by the low-pass filter (LPF). Therefore, when using a di/dt sensor, a second pole is required. One simple approach is to cascade one additional RC filter, thereby producing a −40 dB per decade attenuation.

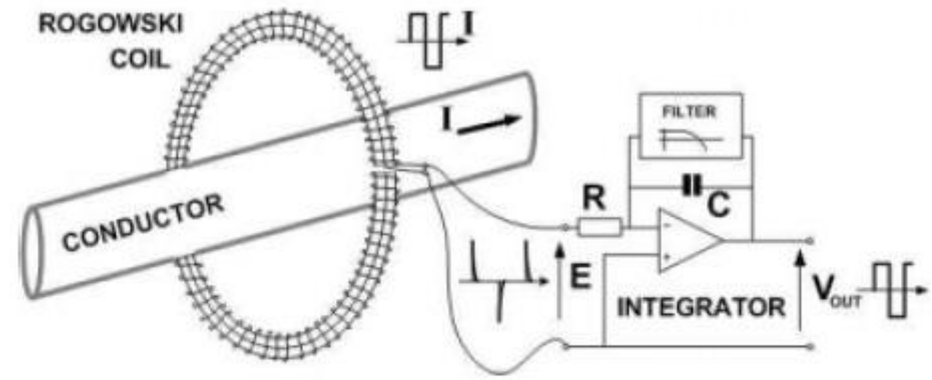


Illustration 26 The Rogowski coil an alternating-current component sensor in conductor (31)

The wires of the circuit have to pass thought the sensor. As the sensor works as a coil, has to be perpendicular to the circuit to have the best measures. So, in this case we have two different factors which can divert the real measure; the incertitude of the magnetic measure of the sensor and the position of the Rogowski sensor (if it is not totally perpendicular to the circuit). (32)

The advantages of this method are the high linearity and fast response of the sensor which enable it to register high frequency current pulses and the easy and simple installation of the measure system.

In the other hand, it is equipment very susceptible to external noises.

Here is a list with all the advantages and disadvantages of the Rogowski sensor (33):

- Can measure large currents without saturating. The size of the Rogowski coil required remains the same despite the size of current. This is unlike other current transducers which become bulkier as the current magnitude increases.
- Are easy to use - the coil is thin and flexible and easy to insert around a current carrying device.
- Are non-intrusive. They draw no power from the main circuit carrying the current to be measured.
- Have a very wide bandwidth extending from typically 0.1Hz up to 17MHz.

For use the Rogowski coil we need a transducer of signal. With the coil we take the information of the variables that give to us the capacity of knows the exactly current, but it is the transducer the instrument which makes the transformation. The Rogowski coil is connected directly to this current transducer as shows in the Illustration 27.

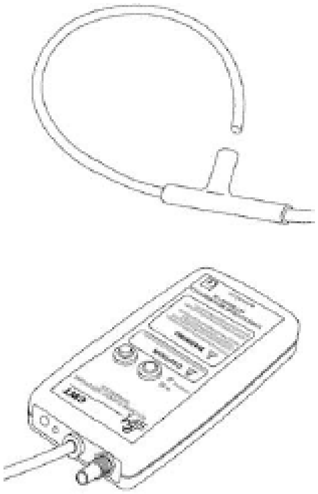


Illustration 27. Transducer connection (33)

Pressure/displacement

The pressure it is the last principal measure. It is important the relationship between pressure and amperage, and also with the total resistance of the circuit (more pressure makes that the total electrical resistance will be closer to the welding resistance, that is very interesting for save energy and have better results I the welding).

There are a lot of options to make this measure, since insert a sensor's head in the electrode or measuring the displacement or penetration of the electrode in the plates when they are welding, and with this penetration and knowing the mechanical proprieties of the material, calculate the pressure that we had had in the welding to make this displacement of the plate.

With the pressure sensor we can measure the total force made in the welding and make relationships between force or pressure directly with other parameters.

With the displacement sensor we can measure the displacement of the electrode, and make relationships between the displacement and power rate, displacement and current, displacement and the pressure imputed in the welding machine…

This second option is the one that we have chosen. There are inside this field some different kinds of methods. We can use the following instruments:

LVDT displacement sensors

These kinds of sensor are commonly used in electrode displacement measurements. They are fairly reliable in catching the signals during both initial touching and welding. The signals collected are usually cleaner than those of current or electrode force.

Almost all these kinds of sensors are intrusive, so falsifies some of the parameters of the process (34). This is why in our study it is not so interesting this kind of sensors.

One example of this kind of sensor that we have evaluated is the "eddyNCDT 3010" sensor:

The measuring principle is based on the extraction of energy from an oscillating circuit. This energy is required for the induction of eddy currents in electrically-conductive materials. Here, a coil is supplied with an alternating current, causing a magnetic field to form around the coil. If an electrically conducting object is placed in this magnetic field, eddy currents are induced which form a field according to Faraday's induction law. This field acts against the field of the coil, which also causes a change in the impedance of the coil. The impedance can be calculated by the controller by looking at the change in the amplitude and phase position of the sensor coil. (35)

In this case, we need to insert one sensor through the plates to measure the displacement, making a hole, to close the "coil" of the sensor. This can be a condition that will make the welding much weaker and it is not an acceptable condition.

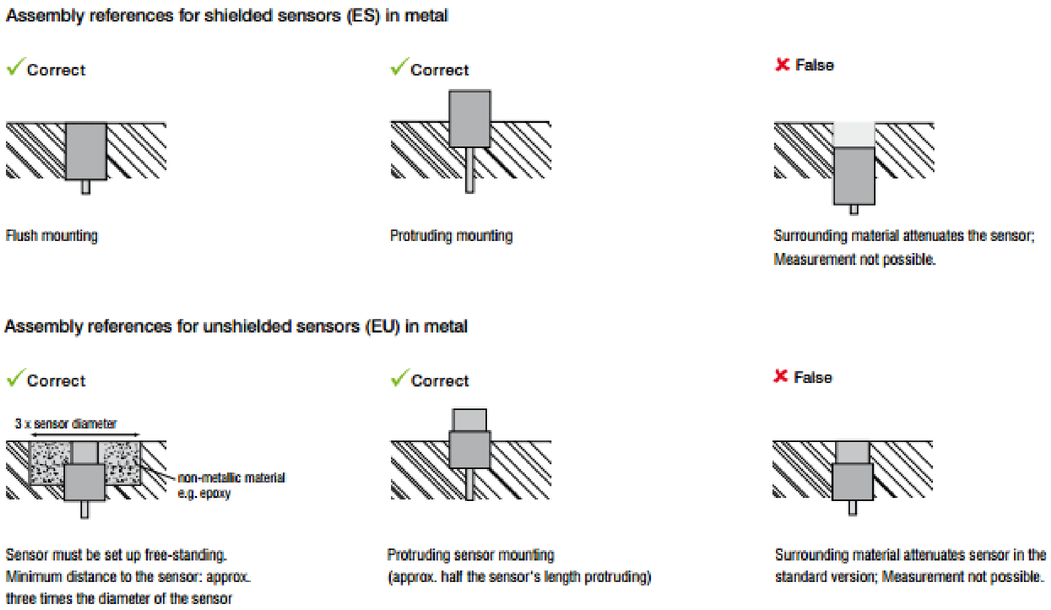


Illustration 28 the position of the sensor has to be in the surface of the element and be into the metal. (35)

Fiber optic displacement sensors:

These sensors are of a reflective type and they utilize bundled glass fibers to receive and transmit light to and from target surfaces. This method could be considerate non contacted sensor. This kind of sensor has a lower magnetic influence than the LVDT sensor as result of the high welding current of ERW (34).

This kind of sensor has also another advantage that can measure the displacement without interference in the welding process, as happened with the LVDT sensors.

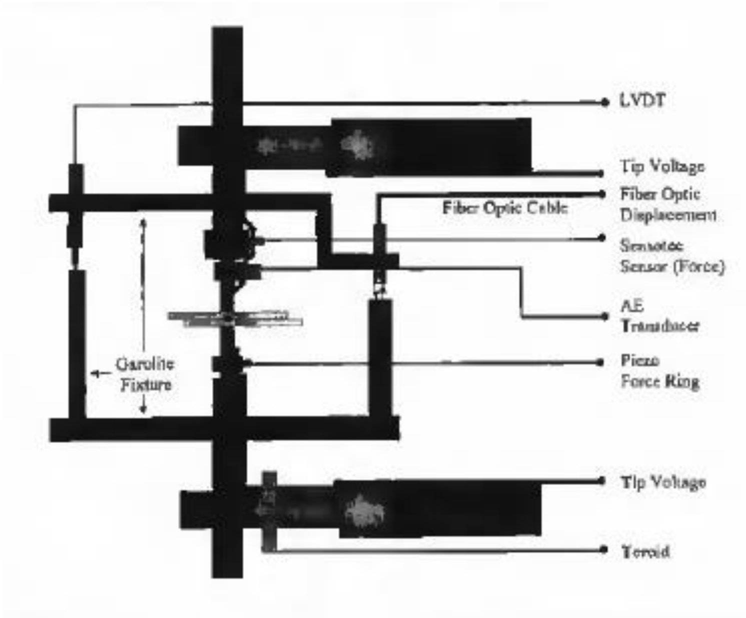


Illustration 29 Installation of the fiber optic sensor (36)

The installation of the sensor could be as show in the Illustration 29, a supportive structure to the welding machine, measuring with the sensor in a parallel surface with the sensor.

One example of a particular fiber optic sensor is the "Fiber optic Sensor Model D100". For making the measures of distances we need to convert the obtained data to an output to distance. (37)

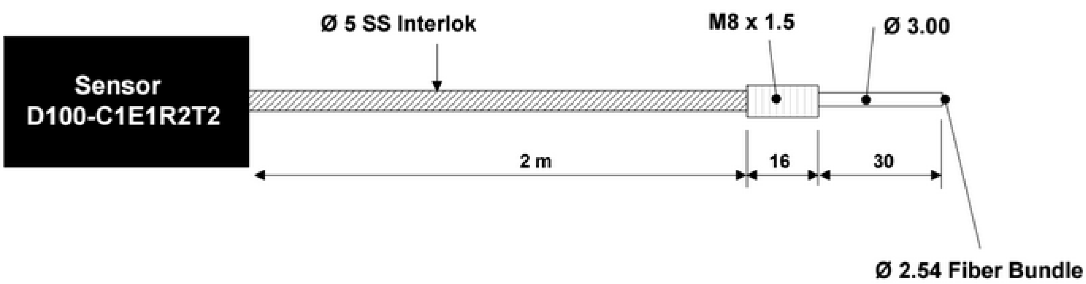


Illustration 30 D100 Product Fiber optic

A calibration chart is provided with each sensor giving the voltage output response to distance. There are three ways to derive accurate distance measurements:

- within the bounds of the linear range, convert the change in voltage output as follows: Distance = Δ milliVolts ÷ Sensitivity = µm
- over the non-linear range, create a lookup table using the XY calibration data points
- use a polynomial curve fit to accurately map the sensor's output function

Some of the general advantages and disadvantages of the fiber optic sensor are:

- They can be used on most materials, irrespective of the color or conductivity (34).
- The measure surface can be not directly the surface of work. This make that the sensor will not make interference with the welding process.
- The sensor filters better the magnetic fields as consequence of the high current in the welding process.
- The installation of the sensor it is not so easy than in the LVDT sensor, but, in the other hand, we do not need to make a hole in the pieces that we are to weld.
- The model "D100 Product" uses a kind of light in the measure that minimizes the influences of highs temperatures that we can have in ERW.

Pressure

The other option that we have not chosen is the pressure sensor, also called force sensor.

It is the same, force sensor or pressure force, because we know the surface of contact of the electrode and we can make a relationship between force and pressure:

$$Pressure = Force/Surface$$

There are two types of sensor commonly used in the monitoring of ERW: The strain gauge-based sensor and piezoelectric sensors.

This sensor can measure directly the pressure of a surface or measure the total force made by the electrode.

Temperature

The temperature it is not a value that we can control exactly in the process, but is interesting under the terms of the micro-structure formation in the HAZ. For this reason we can measure the temperature of the zones with thermal camera. The thermal camera that we are interested "model A655_sc" has the following characteristics:

- The measure time to create a new picture of the thermal state is less than 8 mS.
- The ranges of measure of this camera is between 100 °C and 650 °C principally, but with less precision, we can measure until the 2000ºC.
- The accuracy of the measure (the tolerance of the measure), is ±2ºC, that is enough precision for our study.
- The frame rate of the camera is between 50 and 60 Hz of the total picture, and of 100 and 200 Hz for the windowing of ½ and ¼ respectively.

Illustration 31 Thermal Camera A655_sc

TESTS

Introduction

One we have measure, monitoring and make the welding, we have to test the union. We can make a lot of different experiments, destructive experiments and not destructive experiments. We are going to work with this last one kind of experiments; we are going to make coupons and then test them until they fail mechanically and measure the force/tension of failure. We can measure the mechanical resistance (static) and the tenacity (impact tests).

Static Tests (ST)

Once we have the selected the material and we have controlled all the parameters of the process, we are going to do the test.

The resistance spot welding is very used in the car bodies and the quality of the welding will be very important in the resistance of the car. Every car has between 2000 and 5000 spot welding.

We can make different tests: In the direction of the plates (Lap-shear) or in the cross direction of the union.

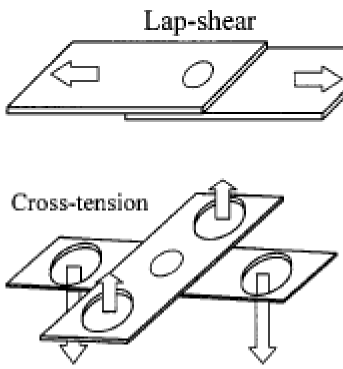


Illustration 32 Cross tension and lap-shear test sample geometries (38)

The Lap-shear it is the most common test, have a few similar comportment to the traction test, but we have to study the crack factor of the spot in the union. We have to valuate when the union will crack.

This test will tell us the capacity of the plates to resistance forces in the direction of the plates, and which kind of failure we can have in the spot welding.

In the other direction the test is more interesting. In this case the load to crack the coupon is lower than in the lap-shear and has a lineal displacement with the load until the welding crack. The welds in the cross direction crack with less displacement than in the direction of the plates and without an elastic comportment. It cracks without a really plastic/ductal deformation (without advice), we must know exactly how we can load this union.

For all these reason, we have to study the welding in both directions.

ISO Standard Conditions for ST: cross tension and lap-shear tension.

For make our tests we have to reproduce the real conditions of the spot welding. This union are called “coupons”. We have to make so many coupons as tests. The coupons are different for every kind of experiment.

In the sport welding, we usually make the union of two plates. The coupons for these kinds of experiments are normalizing, and may be as the ISO rules.

In our case when we are going to make the experiment in the cross direction, we want to measure the cross tension sample in front of the displacement.

In all the coupons, the welding must be situated in the middle of the intersection of the two plates.

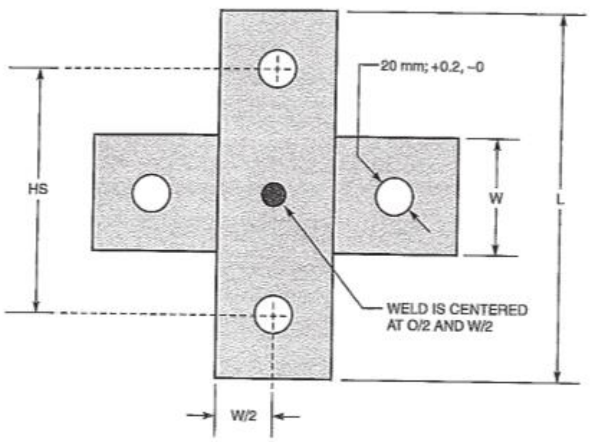


Figure 24—Schematic for Cross Tension Samples

Table 4
Cross Tension Sample Dimensions

Sheet Thicknessl (mm)	Coupon Length L[a] (mm)	Coupon Width W[b] (mm)	Overlap O (mm)	Hole Spacing HS[c] (mm)
0.60–3.00	150	50	50	100

[a] Tolerance: +0, –0.5 mm.
[b] Tolerance: +0, –1.0 mm.
[c] Tolerance: ±0.2 mm.

Illustration 33 ISO standards for the cross tension samples (39)

In the other direction, for make the test for the lap-shear, we have others ISO conditions for the coupons:

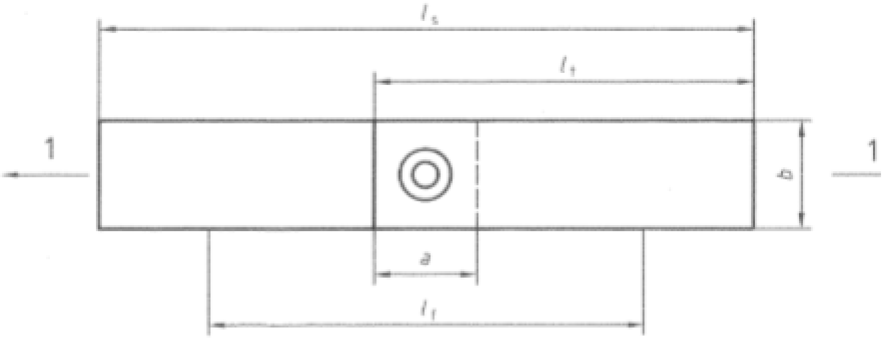


Illustration 34 Lap-shear test (39)

Dimensions in millimetres

Thickness t	Overlap a	Specimen width[a] b	Specimen length l_s	Free length between clamps l_f	Length of individual test coupons l_t
$0,5 \leq t \leq 1,5$	35	45 (30)	175	95	105
$1,5 < t \leq 3$	46	60 (30)	230	105	138
$3 < t \leq 5$	60	90 (55)	260	120	160
$5 < t \leq 7,5$	80	120 (80)	300	140	190
$7,5 < t \leq 10$	100	150 (100)	320	160	210

[a] Figures in parentheses will give approximately 10 % reduction in strength and these widths may be used only by agreement between the manufacturer and the purchaser.

Illustration 35 Measure for every thickness (39)

General Parameters of the process that affects directly to the test

In these tests we have different parameters that affects to the coupon, we have to measure:

- The electrode size and dressed face diameter, with a tolerance of ±0.1mm from the specified dressed face diameter
- Squeeze Time, that it is the time to ensure that the force is at least 98% of static force value at initiation of welding current.
- Electrode force that make in the coupon when is welding. Depending of the material, thickness and process, we need more force or less. The force tolerance has to be ±2% of the force specifications.
- Weld Time (WT), the time that we are welding, making the union.
- Welding Current
- Hold Time, that it is the time that we are making pressure in the coupon and giving a endurance.

All these parameters have to be appearing in the test report.

Impact tests: Charpy Test

Other interesting test is the Charpy test. We measure with the energy needed to break a coupon with an impact (not with progressive application). In this test, we have a hammer at a height and we drop it. The hammer will have to break the welding, we measure the height after the crash and we measure the energy used to break the coupon. There are two ways:

- First one, making approximately, that is measure the height at the start and the maximum after the crash, and the potential energy loosed is the absorbed in the rash.
- Second one, using the tables which related the height, impact velocity and energy absorbed.

In this experiment we have break the coupon at 5.5 m/s, as the ISO standard 14323 say.

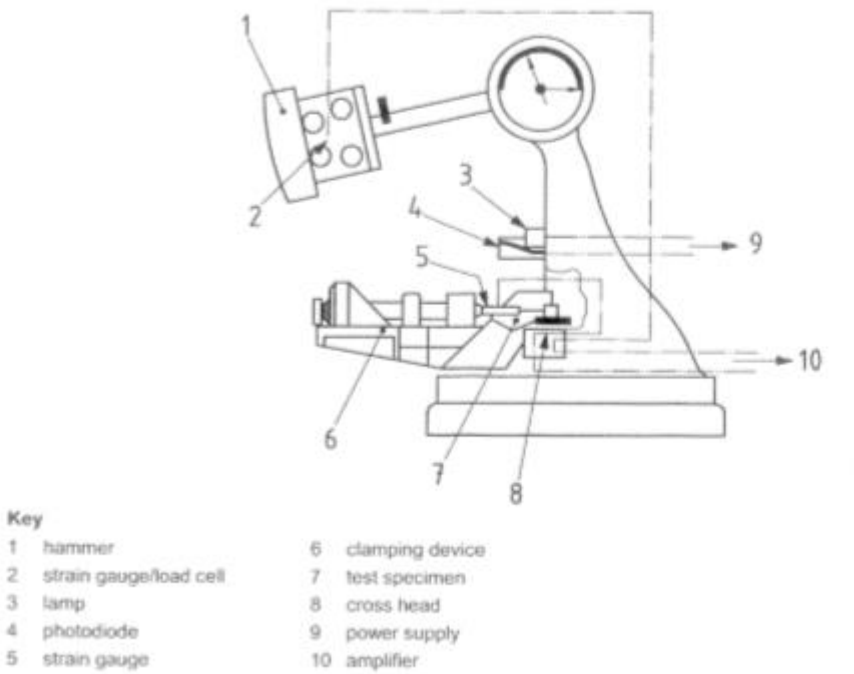


Illustration 36 Pendulum machine with U-shaped hammer, equipped for testing spot welded impact shear specimens (40)

Another important factor for these test are the temperature. The materials and the spot, work different with the temperatures. If it is very cold, the material will be more fragile, and with high temperatures the material has lower mechanical properties, the material tends to fluid easily.

For this reason, the temperature must be between 15 and 25 ºC.

Test conditions and representation of the information (ISO):

In all these experiments we have to take care of some parameters and execute some rules. (38)

- The coupon has to be polled to avoid notch effect. We can ensure that all the tests are in equal conditions if all are in the best state.
- The temperature, at which we do the experiment, has to be in the data test to measure the influence.
- Number of tests (at less 5), the value of everyone and the statistical results. The most important; the average and the typical deviation, to give the measurement uncertainty tension. All the data have to be in KN.
- The material of the plates, coupon dimension and the welding process. We include in the welding process all the variables: Welding position, electrode material, amperage, voltage, electrode geometry…
- Type of failure.
- Represents the deformation/force.
- The machine and equipment used in the test and in the welding.
- If some result is not logical, explain what happened and investigate the reason.

Usually fracture and failure of the spot welds

We have to know how it is going to be the failure and how it is going to crack the union. The experiments made by other studies give to us an idea of what we have to wait in the experiments, and the reasons of the failure.

As we have said, in the static test we have principally two different essays: Cross tension test and lap-shear test. If we talk generally we found that:

- In the lap shear test we make force in the direction of the plates. The material can be deformed easily and have more displacements in the coupon extremes. The nugget point can be deformed in along the plates, so it stands to reason that the in this direction the general comportment is ductile but, microstructurally, can be fragile.
- In the cross tension test we make force in the transversal union of the plates. The coupon has little material to deform in this direction, as the nugget. The rupture of the coupon will be abrupt but, microstructurally, can be ductile.

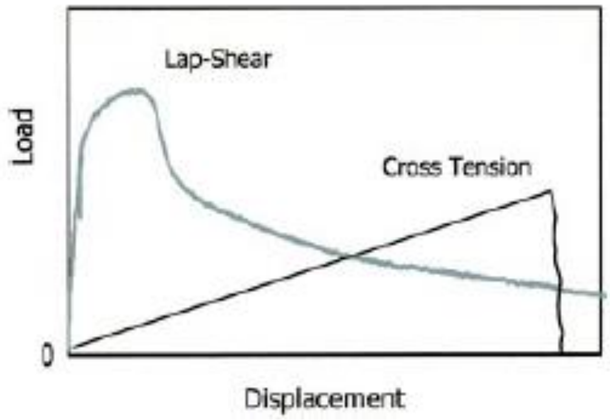


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Illustration 37. Load vs Displacement in static tests. (41)

The failure of the union it is produced by different factors in the welding process. These are some general reasons in the welding process:

- The heterogenic material in the Heat Affected Zone (HAZ). The microstructure along the HAZ it is different by the cooling gradient of the material, which makes that the material has diverse mechanical proprieties in a few spaces. This makes the material very susceptible to filature. Two of the different HAZ can be emphasized here, namely the sub-critical HAZ (SCHAZ) and the coarse grained HAZ (CGHAZ). SCHAZ would lie in the outer vicinity of the HAZ boundary and corresponds to a zone where the temperature remained below the austenitization start temperature Ac1 during the welding process. Microstructural evolution is hence hardly visible although tempering of the BM martensite or ageing of ferrite could occur and alter the mechanical properties. On the contrary, noticeable microstructural evolutions occurred in the CGHAZ, where temperatures far above Ac3 (complete austenitization) and up to the solidus were experienced. This results in significant grain growth and the formation of hard microstructural constituents (typically bainite, martensite) after cooling, characterized by an elevated hardness in comparison with the BM/SCHAZ (42).
- Not enough penetration of the material in between the plates. This makes that the surface of the union are less than the right one. To the same force, we will have more stress and the unions will failure before.
- Hard zones in the nugget spot welding, making a notch effect in the material by the hardness and fragility of the point.

As we have explained before, the current is the most important variable of the ERW. If we make the welds with “low” current (5 kA for example), the rupture of the union will be ductile. If we make the welds with higher current (7 kA for example), the rupture will not have a plastic deformation before crack. The Illustration 38 shows the two different ruptures of TWIP steel. (43)

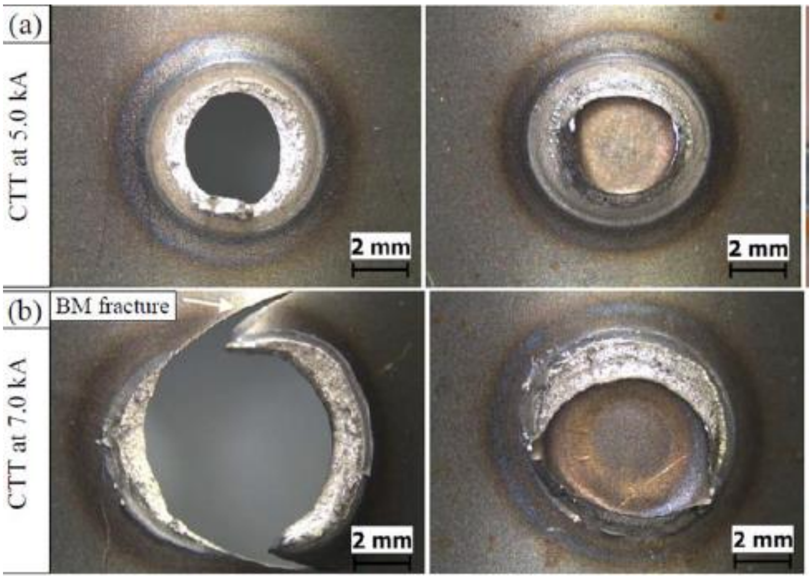


Illustration 38. Ductily crack versus fragile rupture in cross tension test. (43)

Also, the nugget diameter is bigger when we use higher value current, making more possible the apparitions of notch effect and favouring the fragile rupture (43). In the Illustration 39 we can see an example of the relationship between the weld current, ductility and nugget size. If we want to make a full comparison of all the parameters we can watch the Illustration 38, where we see clearly the kind of fracture ("a" ductile, "b" fragile) and the weld size (smaller on "a" and bigger in "b") versus the current value of every weld ("a" with 5kA and "b" with 7kA, with the same Welding Time).

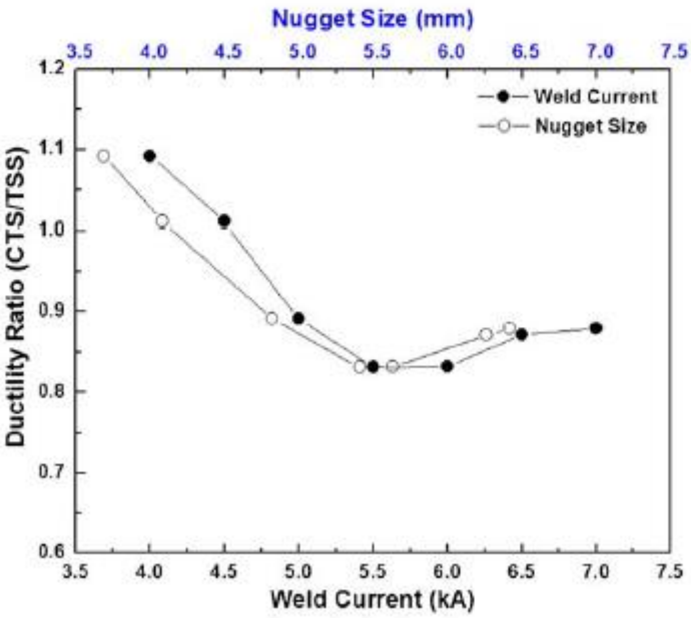


Illustration 39- Ductily ratio versus nugget size and weld current (43)

Failure criteria

We can divide the rupture in this kind of experiments in two options: The rupture produced by a fragile comportment or make by a notch effect that has as result the abrupt rupture of the union, and, on the other hand, the ductile rupture.

We can make an approximation of the results using simulation test. Some materials are easily to simulate the comportment than others, and the best way to obtain the best data is with real test, but we can make simulations of the process more or less reliable without make the experiment.

The rupture of the union depends of the tension. In the welding HAZ we have important residual tensions by the different speeds cooling of the material in every part. We can make an approximation of the residual stress using the following formula (44) :

$$\sigma = (1-\alpha) * [K * (\varepsilon_o + \varepsilon^{pl})^n] + \alpha * \left[\sigma^{sat} - (\sigma^{sat} - \sigma_o) * e^{-m\varepsilon^{pl}}\right]$$

Where σ and $\varepsilon^{pl}$are respectively the Cauchy stress and the true logarithmic plastic strain, K,ε_o and n are the parameters of the Swift law, σ_o , σ^{sat} and m are the parameters of the Voce law and a is a fitted constant so as to fulfill the Considère criterion (44).

J-integral evaluation at the notch tip

If the microstructural difference between the metal in the HAZ are so high that we can assume a notch effect, we have an abrupt failure in the union.

The J-integral is a widely accepted quasi-static fracture mechanics parameter extending the concept of the stress intensity factor to cases where the condition of Small Scale Yielding is not met anymore (44). J can be interpreted as an assessment of local material damage at the notch tip.

$$J = \int_{\lambda} \lambda(s) * n * \left(WI - \sigma * \frac{\partial u}{\partial x}\right) * q \, dA$$

Where $\lambda(s)$is a virtual crack advance in the plane of fracture, dA is a surface element along a vanishing small tubular surface enclosing the crack tip, n is the outward normal to dA, q is the direction of virtual crack extension and $W = \int_0^{\varepsilon} \sigma d\varepsilon$is the strain energy density.

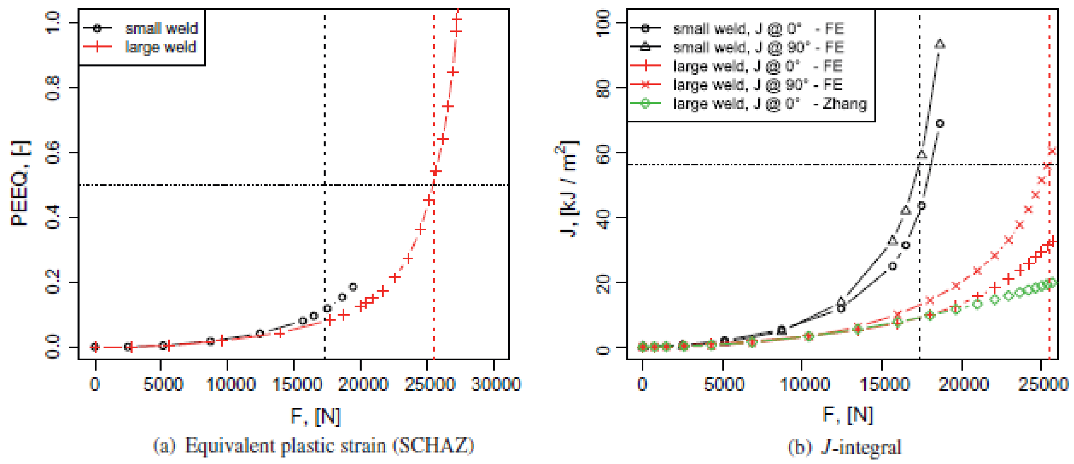


Illustration 40. Evolution of the equivalent plastic strain (PEEQ) in the strain localization area and the J-integral of TRIP780 (44)

For the spot welding we can make an easily approximation of the "j-integral" and above all, is better for small spot welding. (44)

$$J = \frac{19 * (1 - \upsilon^2) * F^2}{4\pi^2 d^2 tE}$$

Where **υ** is the poisson ratio (the factor that give to us the relationship between the deformation in the longitudinal direction (elongation) and in the transversal direction (narrowing)), E the Young Modus of the material, "d" the nugget diameter, t the thickness of the union and F the force of the experiment at 0º (lap-shear test) or 90º (cross tension test).

We can make the following observations in Illustration 40 (44):

- J increases faster for small welds than for large welds at increasing load. This is in accordance with the increased sensitivity of small welds to interfacial failure.
- J increases faster at 90º (transverse direction) than at 0º (loading direction) for both small and large welds. This is in agreement with the typical notch comportment of the material in cross tension test.
- This approximation for the J value is good in the lap shear test (0º) behind a value. Then, the no linear comportment has higher importance than the plastic deformation and the approximation it is not good. In the Illustration 40, for TRIP780 steel, is 20.000N.

With this parameter and the data that has the FEM simulation software, we can predict some "notch" comportment in the HAZ.

Ductile Fracture

On the other hand, when the local material damage it is not enough to make the failure, we can assume that the rupture it is going to failure by ductile fracture. The simulation of the welding comportment evaluates the stress load in every node of the FEM mesh. When a node arrives at the critical stress value, the metal failure spreads since this point. We have to give to the FEM software the best approximation of the real microstructure of the material in the HAZ, where the metal is going to crack.

Now, we are going to describe the particular characteristics failures with more detail of the Lap-shear test and cross tension test:

Lap-Shear test

Failure mechanism

The rupture of the plates follows the next steps (Illustration 41. Rupture mechanism of lap-shear test.):

- First of all we start the experiment, putting the lap shear coupon in the jaws. The coupon is aligned with the jaws that start to make the force.(a)
- Secondly, when is enough force, the spot nugget start to be deformed, making that one plate of the coupon rotates in reference to the other plate. Since this point, if we continuous loading the union, it will continues rotating.(b)
- When the rotation and load is enough, start the rupture of the weld in the extremes of the same. The plastifications and necking of these parts indicate the first failure of the union, which is in this point, still attached.(c)
- Finally, the union cracks in the extreme of the nugget, the first parts where the plastification success. Is in this point, where the coupon is finally divided in two pieces and is completely broken.(d)

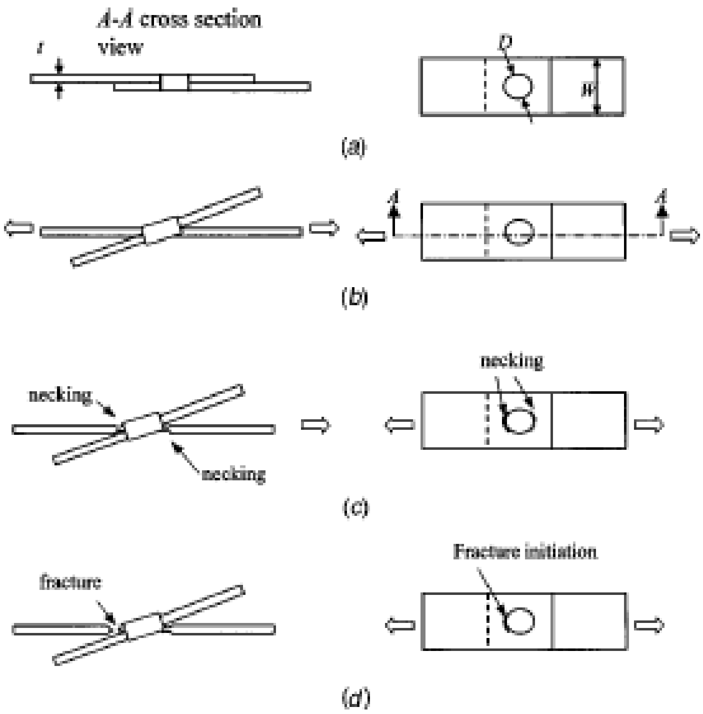


Illustration 41. Rupture mechanism of lap-shear test. (41)

This is the general failure form, but we can distinguish inside this failure mechanism some differences:

-

Minimum shear resistance strength approximation

For thee lap-shear test we can make an approximation of the minimum shear resistance strength with the next empirical formula (45):

$$ST = \frac{(-6.36 * 10^{-7} * S^2 + 6.58 * 10^{-4} * S + 1.674) * S * 4 * t^{1.5}}{1000}$$

Where

- ST=Shear Tension Strength (KN),
- S=Base Metal Tensile Strength (MPa)
- t= Material Thickness (mm)

Numerical approximation of lap-shear

We are going to discuss the forces in the lap-shear test.

Failure of spot weld is likely elated to many parameters: residual stress, material inhomogeneity, welding parameters thickness, nugget size, and material properties (41).

We can make an approximation of the forces in lap-shear test: the forces are made along the coupon, and applied in the weld nugget, which make the union. The stress forces are represented on Illustration 42 Approximation of the vector stress force in the weld nugget:

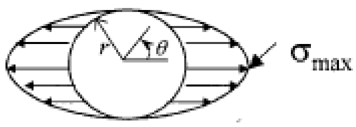


Illustration 42 Approximation of the vector stress force in the weld nugget

If we assume that the nugget it is completely round, we can describe the stress as:

$$\sigma(\theta) = \sigma(\max) * \cos(\theta)$$

Taking the centre of the nugget as the coordinate origin and the lap shear stress forces the direction to start measuring the angle "θ".

The forces are made all around the nugget so we can assume that the "θ" goes since -π/2 to +π/2, that is one half of the nugget.

The force is the surface multiplied by the pressure. The integration is:

$$P = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \sigma(\theta) * \frac{d}{2} * t * \cos(\theta)\, d\theta = \frac{\pi}{4} * t * d * \sigma(\max)$$

Where t is the thickness of the base metal sheet or one half thickness of the weld nugget, d the diameter of the weld nugget, P the load or strength of the sample and $\sigma(\max)$ the maximum tension of the nugget.

When $(\max) = \sigma(failure)$, the coupon cracks:

$$Pf = \frac{\pi}{4} * t * d * \sigma(\text{failure})$$

Where Pf is the force or load that crack the coupon.

Cross tension test

The failure process is simpler. When the union becomes to load, one of the plates has a large bending deformation of the sheet, occurs initially. Then, the weld nugget is pulled out from one coupon and stays with the other coupon.

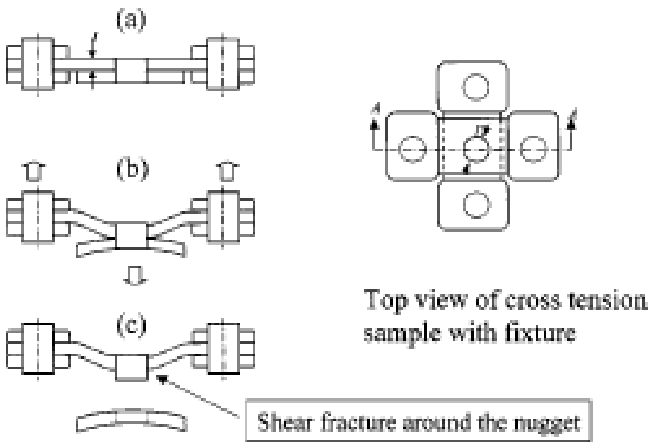


Illustration 43 Rupture mechanism of Cross tension test (41)

Minimum cross resistance strength approximation

As in the lap-shear test, we can make an approximation of the minimum cross tension strength (45):

$$CT = 1.25 * t^{22}$$

Where:

- CT= Cross Tension Strength (KN)
- T=Material Thickness (mm)

For the approximation of the minimum cross tension strength it is very curious that the CT only depends of the thickness of the union, and not of the material.

Numerical approximation of cross-tension test

If we want to make an approximation of the necessary stress for the failure of the coupon in the cross tension test we have to divide the nugget in four symmetrical parts, as we see on Illustration 44.

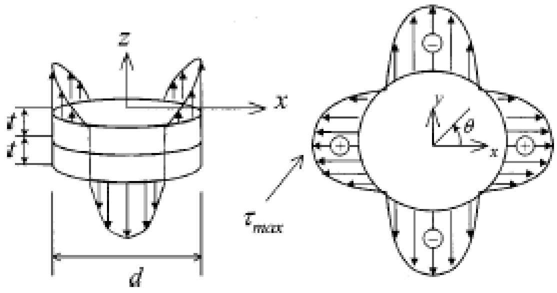


Illustration 44. Stress forces in the transversal direction

The distribution of the stress can be written as:

$$\tau(\theta) = \tau(\max) * \cos(2\theta)$$

Where t max is the maximum shear stress occurring at "θ" 0 deg and 180 deg (and 90 deg, 270 deg on the other piece of the coupon).

If we analyse one coupon (identically), since –π/4 and + π/4 multiplied by two we obtain the equilibrium force in one coupon:

$$P = 2\int_{-\pi/4}^{\pi/4} \tau(\theta) * r * t * d\theta = t * d * \tau(\max)$$

Where "P" is the force applied on one coupon, "d" the nugget diameter and "$\tau(\max)$" the maximum stress.

$$P_f = t * d * \tau_f$$

Where P_f are the rupture force and τ_f the stress force that makes the failure of the coupon.

If we want to compare the critical force on lap-shear test with cross tension test, we have to make a reference of one to the other. In lap-shear test the stress could be approximated as traction stress, and in the cross tension test, as bending stress. If we apply the Von-Mises criteria to make the relationship:

$$P_f^{cross-tension} = 0.735 * P_f^{lap-shear}$$

This is useful if we only can make an experiment (lap-shear for example because we have not the fixture to cross tension test), and we need only to know *approximately* the rupture force.

FIXTURE

Introduction

For the cross section test, that it is the most important test in this thesis (what we are going to experiment more), we need to manufacture a fixture to be possible use with a universal traction machine. The cross section test needs a specific fixture for fix the coupons.

Propose Fixtures:

As we have not the fixture made, we have to manufacture it. I have designed three different fixtures, once adhering to the ISO requirements, another one to make our own experiments (No totally ISO standards), and the last one cylindrical holder in both sides:

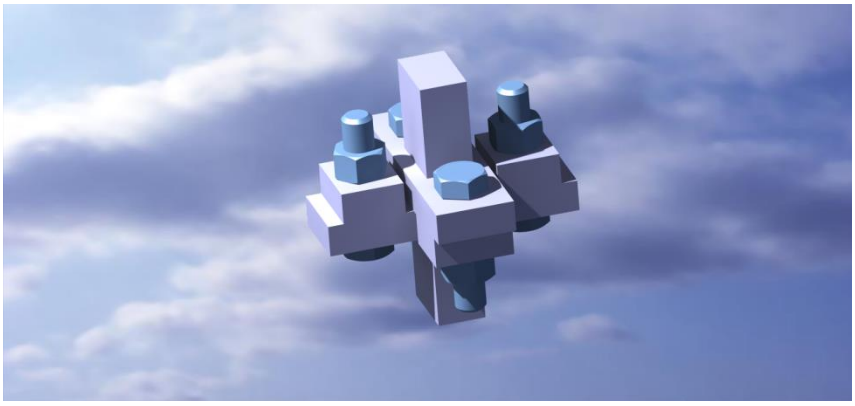


Illustration 45 ISO FIXTURE[3]

Illustration 46 NO ISO FIXTURE[4]

[3]The planes of this design are in the annexes.
[4]The planes of this design are in the annexes.

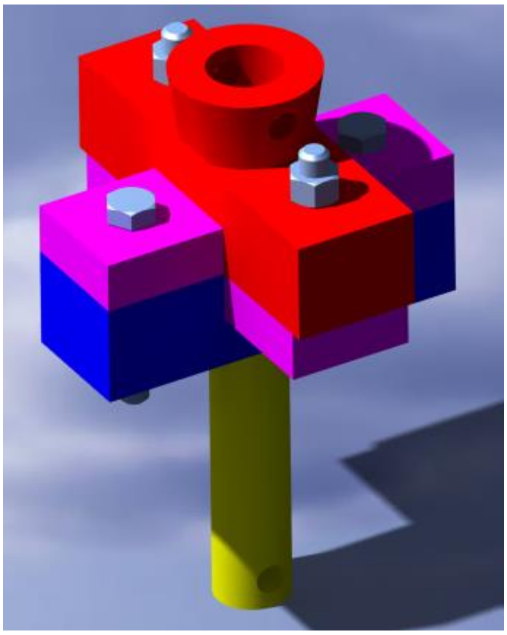


Illustration 47 Cylindrical fixture

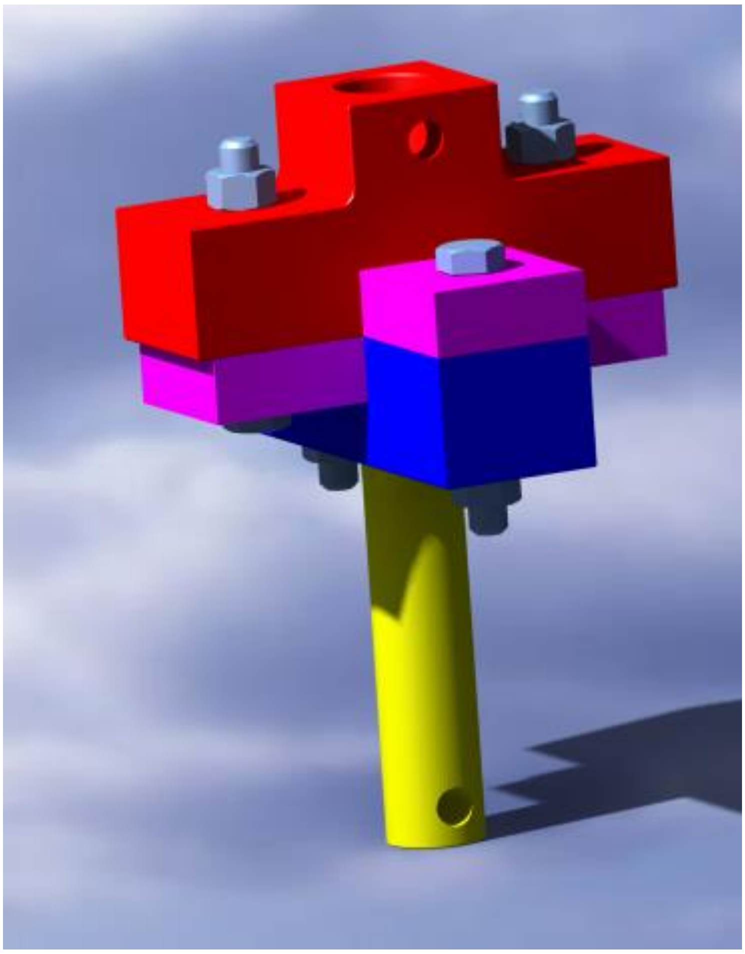


Illustration 48 Semi-cilindrical fixture[5]

[5] The planes of this design are in the annexes.

As the ISO coupon have to be of an exactly measure, we can manufacture a fixture that only can make test of ISO coupon, with the same measure of the coupon. Then, we fix the coupon with the bolt and the nut.

Other option is that we could make an elongated hole to can test different coupons of different measures. The coupon is completely fixed because two bolts fixed the coupon in one direction and the others two in the other direction, making easily put the coupon in the middle of the fixture.

The other two options are the cylindrical and semi-cylindrical fixtures, with holes in the extremes to install directly in the traction machine.

The material of this fixture has to be hard steel, for not be deformed along the experiments and give to us reliable measures. Also for have a longer durability.

For this reason, the material selected has been alloyed steel Ni 38 Cr 4.

The distances between the hold in the ISO fixture have distance tolerance between them, and the hold size in both fixture have diameter size tolerance, because they have to be higher than the bolt always but not too much to not change the results when we compare the experiments with other person that use a different fixture. In the ISO standard 14272 the hold has to have a diameter of 12 +0.7 -0 mm, that is a 12H14 hold.

In the cylindrical and semi-cylindrical fixture we made the holds of 12 mm, and we give a tolerance 20H11, the others dimensions are the ISO measures.

The coupon has to have also a tolerance: 20 +0.2 -0 mm, 20H11 in ISO standard.

With this tolerance, we ensure that the bolt is going to pass through the two hold.

The extreme fixture parts are used to fix it to the traction machine and must be identically in both extreme sides in the not cylindrical fixtures.

We finally decided to manufacture the semi-cylindrical fixture by some reasons:

- It is the easier one, the geometry are bars and perpendicular blocks of steels.
- Have the higher surface between the part of the piece that we install in the traction machine and the plate, in the red piece.
- As we do not have an operate Numeric Control Milling, it is easier to manufacture than the others (the cylindrical has a frustoconical section, and with manual milling it is impossible).
- As the cross tension essay has much lower tension than the critical tension of the fixture material, we produce a valid fixture with an assemblage of bars and plates in the top part (piece yellow and blue in the pictures, as is indicated also in the final planes).

Semi-cylindrical fixture

For this fixture we have used a bar of 60 mm of diameter, a cube steel of 200x173x65 mm and small pieces of our workshop of the same material.

The fixture is composed by three principal pieces and four small ones; the principal are this ones:

- Cylindrical part to hold to the top of the traction machine with a hole. The cylinder at the button of this piece is higher to have more area with the piece where is inserted and welded. Is manufactured by turning.

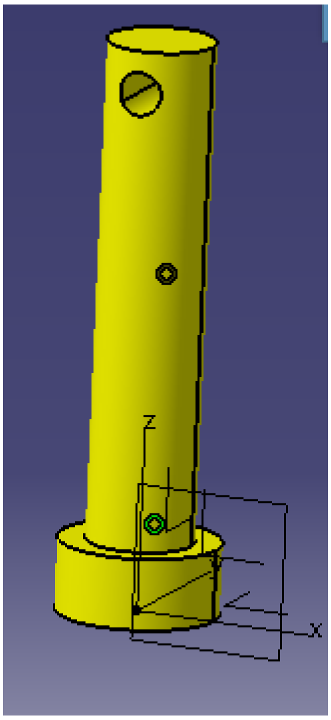


Illustration 49 Cylindrical top part. Part1

- Up rectangular piece: This is the part of the fixture that assembles with the cylindrical top part. The parts that fixture between them have tolerance.

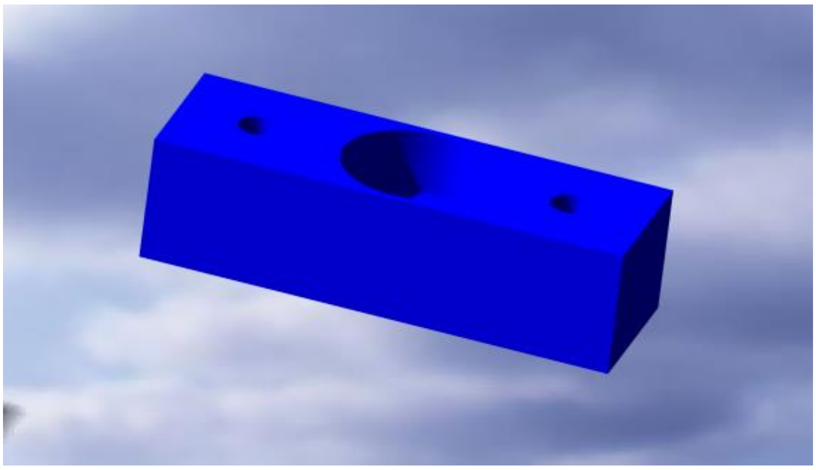


Illustration 50 Up fixture. Part 2

- Bottom part: This part is the biggest one of assemble. It is made from the steel cube by milling. The upper part in the picture is inserting at the end is fixed the traction machine with a bar, as the top cylindrical part.

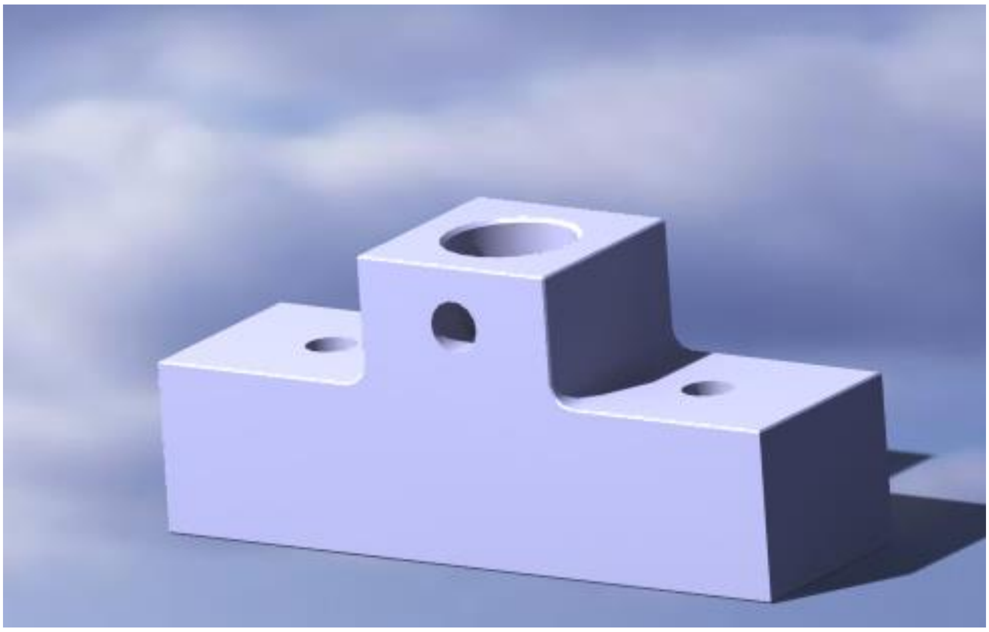


Illustration 51 Bottom part. Part 3

- The plates, that fix with the last two pieces and the bolts and nuts the coupons to make the essay.

Illustration 52 Plates. Part 4

With these components we can start to make our essay.

Tolerances in the fixture parts

The fixture has to have several measures that require a restricted tolerance. In manufacture process we can divide tolerance in two: Geometric tolerances and dimensional tolerances. All these tolerances are indicated at the planes in the annexes.

Dimensional tolerances

The references are made to the ISO standards tolerance. When we want to make an assemblage we can make the union of the pieces by two different ways (46):

- Adjusting the parts: the piece that acts as "pintle" has a bigger dimension that the one that acts as hole. The union is made by pressure. This union is made for unions that we usually do not disassemble for restrict some movements and fix pieces.

- No adjusting: We want that the piece that acts as "pintle" has a lower dimension that the one that acts as hole. The pintle piece can has a displacement "easily" in the hole if there is no other restriction. This union is made in mechanism and when we want to assemble and disassemble a set of pieces.

The dimensional tolerance is named with a letter and a number. The number indicates the quality of the measure and the letter the position of the superior or inferior measure of the measure that we can have. The quality 1 is the best one (and the expensive to verify and produce), and the 15 the worst standard quality.

The pintle is named with a lowercase letter and the hole with a capital letter.

Also, we can make the sizing of the tolerance with a low and top measure in the measure plane.

We have the following dimensions:

PART1: CYLINDRICAL PIECE

In this part, we have 3 principal dimensional tolerances to verify:

- The circumference base has a tolerance of 45g6, to adjust with the part 2. The piece is installed and uninstalled with facility. The hold have to measure between 45 mm (-9,-25)µm. with the tolerance 45H14 of the hold , the part 1 is always smaller.
- The length of the base have to be between 20 -0.05 mm and 20 -0.2 mm for not be longer than the hole of part 2 and touch part 3 of the fixture.
- The hole where is installed the bar to the traction machine has a diameter tolerance of 12H7, to insert with the axis of the traction machine, that in the specifications is 12g7.

PART 2: UP FIXTURE

In this part, we have 3 principal dimensions tolerance to verify:

- The two holes to insert the bolts to hold the coupon that have to have a tolerance of 12H 11. This tolerance ensures that the bolt will pass through the hold without problem.
- The base of the counterbored hold (the biggest one of the piece), that have a diameter tolerance of 45H14(as we commented in the PART 1).
- The small hole of the counterbored that have a diameter tolerance of 30H 11, to ensure that part 1 pass easily through part 2.

PART 3: BOTTOM PART

In this part, we have 3 principal dimensions tolerance to verify:

- The hole that is made for insert the fixture bar that has a tolerance of 12H 7.
- The big hole that insert in the pintle of the fixture.
- The two holes to insert the bolts to hold the coupon that have to have a tolerance of 12H 11. This tolerance ensures that the bolt will pass through the hold without problem, ass in the PART 2.

PART 4: PLATES

In this part we have only one dimensional tolerance, the hole has to have a tolerance of 12H7 to the same reason as PART 3 and PART 2.

Geometric Tolerances

PART 1: CYLINDRICAL PART

In this part we have two different geometric tolerances:

- A perpendicular tolerance of 0.05mm of the piece axis with the base plane. This is important to have a correct contact between part 1 an part 2 and the correct perpendicularity with the coupon along the essay.
- A parallelism tolerance of 0.05mm of the hole axis with the top piece plane. This is for having the correct direction with the alignment of the traction machine hole (for the installation).

PART 2: UP FIXTURE

In this part we have only one geometric tolerance, of perpendicularity of the central hole axis in reference to the top plane of the fixture. This is important to have a good connection with part 1 and the correct perpendicularity with the coupon along the essay.

PART 3: BOTTOM PART

In this piece we have only a tolerance of perpendicularity of the central hole axis of 30 mm respect the top plane of the piece. This tolerance is important for having a correct installation and has all the base of the piece parallel to the coupon.

The part 4 has not any geometric tolerance.

Verification of the fixture resistance

Before the start of the manufacture process of the fixture, we are going to make a simulation in the software “Catia” to verify that the tensions are not very high nowhere in the fixture.

We select a usually steel for the simulation with worst mechanical proprieties than the steel of the fixture. So, if there is no problem in the simulation there will be less problems in the real life.

We have clamped the piece in the transversal hold of PART 3. We put the forces in the transversal hold of PART 1, and we make a simulation with a total force of 30.000N. The coupons with TWIP steel, that have the best results in cross tension test, arrive to 20 KN of force, so with 30 KN we ensure all the possible forces that we could have (if we improve the results in the test we are not going to improve it 150%).

Once that the contact surface conditions between them are made and the mesh of every piece we start to calculate the resistance.

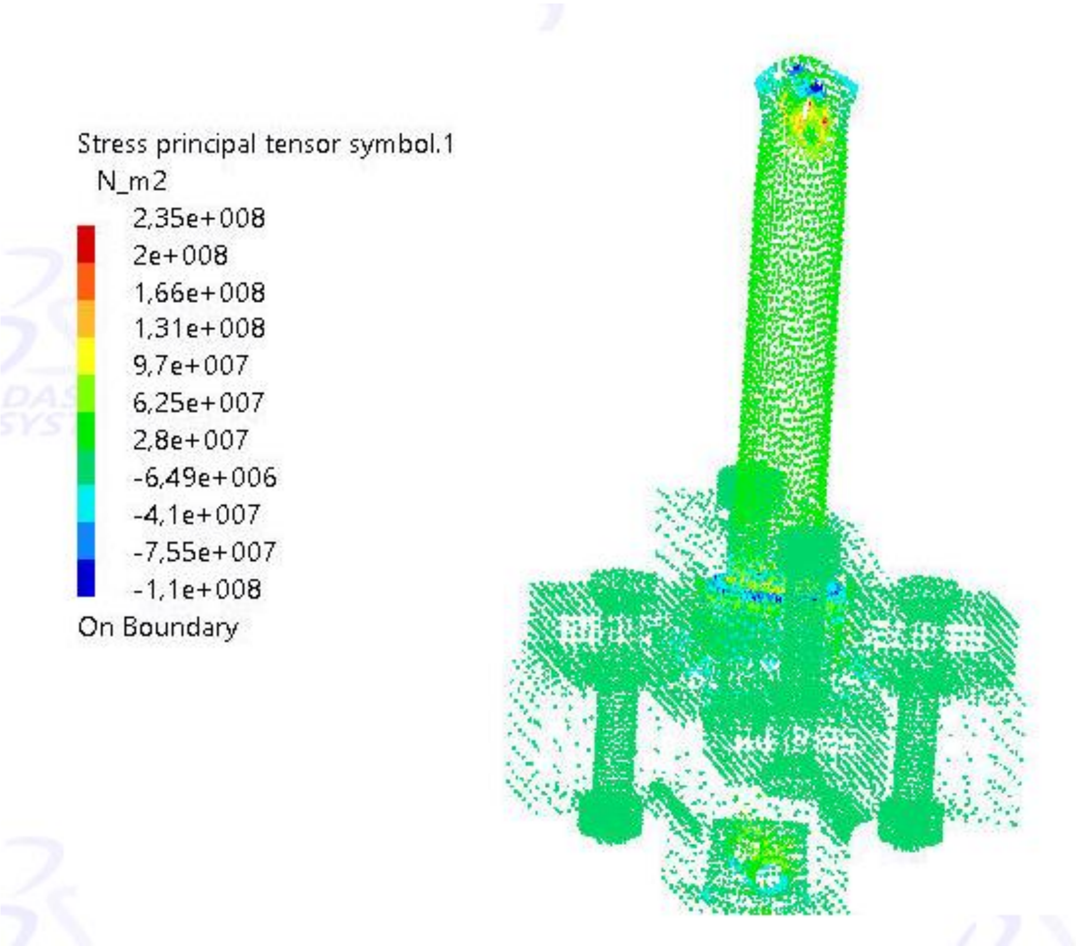


Illustration 53 Tension of the point

We have three different places where we could have problems in the assemblage:

- The hole where the forces are put on is the most critical point.
- The union between the PART1 and PART2
- The hole where is clamped the fixture.

The bigger tension is in the hole where we make the forces. With these results we can justify the assemblage of the fixture, because if it failures, the first point is the hole and no in the union between PART 1 and PART 2.

Under the terms of static resistance of the fixture, it is the same the assemblage and the milling process of all block, but under the terms of economic waste of material, it is cheaper the assemblage (we do not have to make a machining to a piece of block of high dimensions as in PART3).

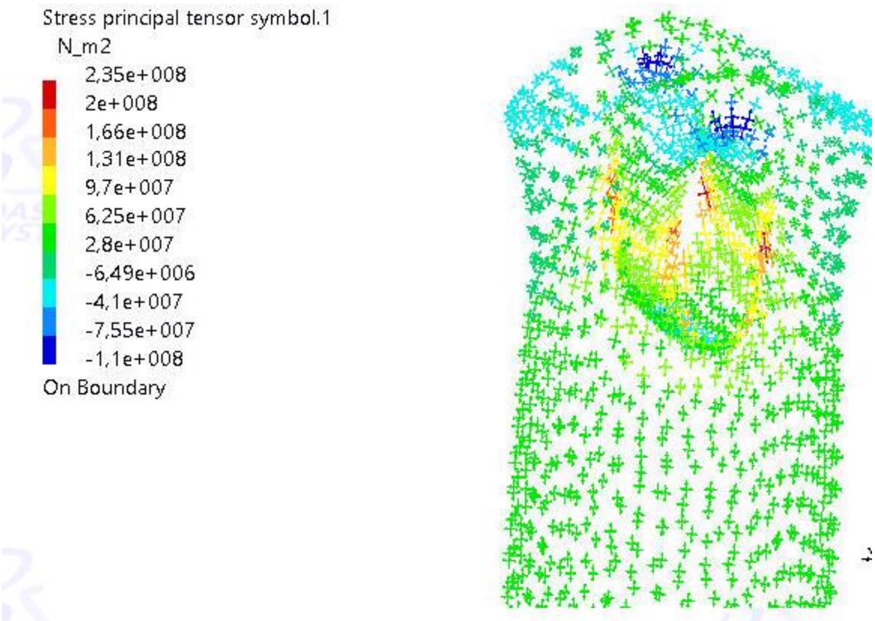


Illustration 54 The most critical point of the fixture.

With 30 KN of force it will not be a problem the maximum tension of the hole. Another advantage of the assemblage is that, if we have a failure in the hole we can only change the PART1, which it is the easier and cheaper one to manufacture.

If we compare the tension between the hole and the union of the PART 1 and PART 2 we see that in the union we have maximum tension of compression of the half value than in the hole, so there will be no problem:

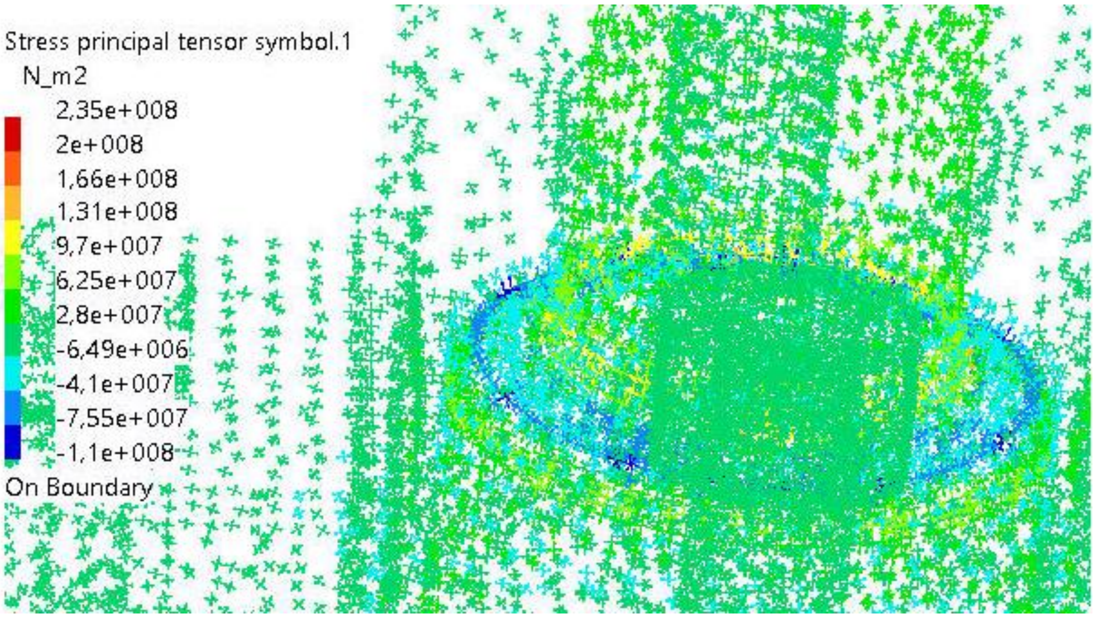


Illustration 55 Union between PART 1 and PART 2

The movements that are made by this force also not interference in the essay, they are much lower than the manufacture tolerances:

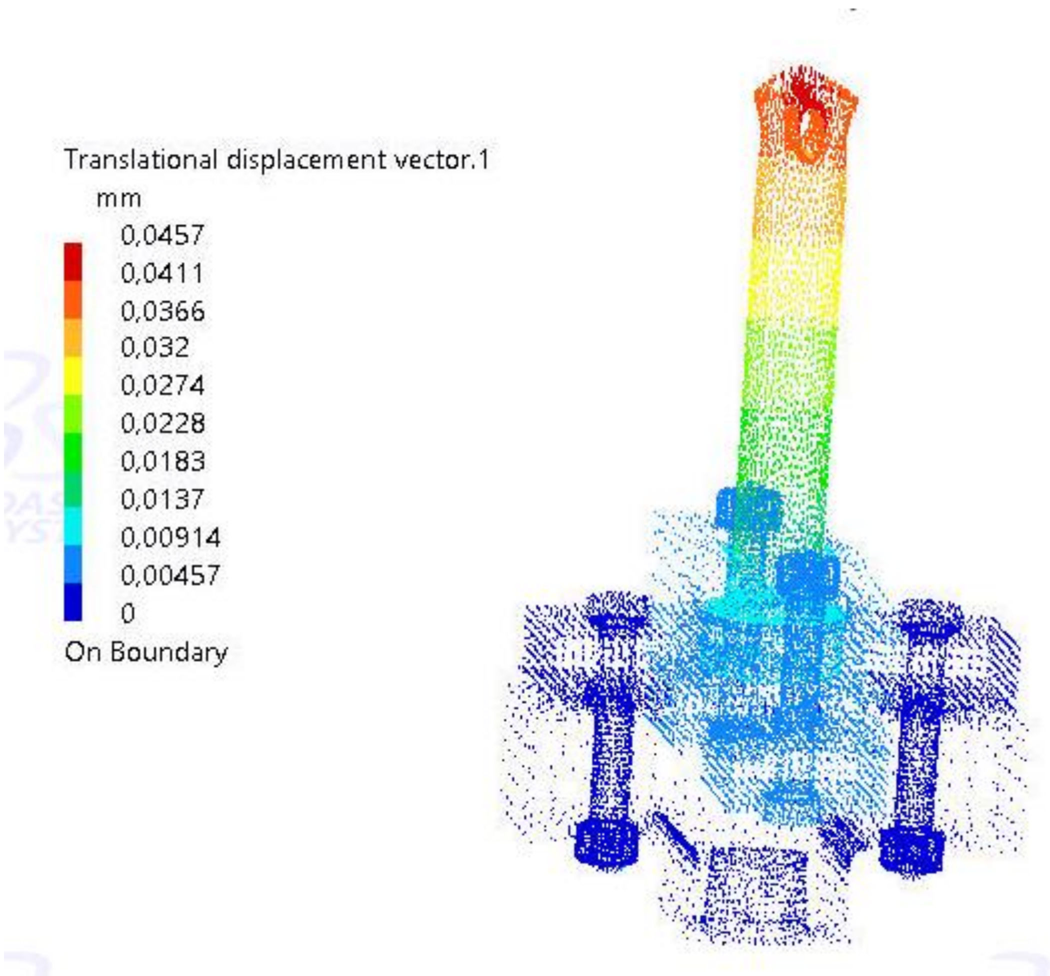


Illustration 56 Fixture displacements

Manufacture of the fixture:

To manufacture this fixture we have a bar of 60 mm diameter, a steel cube and small pieces of our iron to make the plates. Since this material we have to arrive to the final assemble.

The only usable milling machine at the moment of manufacturing this piece is a manual milling machine. The lathe is also manual.

Machines:

We are going to use the following machines in the manufacturing process:

Metal cutter machine:

Illustration 57 Metal Cutter machine

With this machine we cut all the metal blocks. Unless in part 4, we cut since the big block and then facing all the surface (the roughness that makes the machine it is not very good), so we have to over-dimension all the pieces, so that after the facing, have the correct dimensions of the piece to start milling.

Milling

Illustration 58 Milling machine

This milling machine has manual control. We use the milling for facing the pieces and give the final geometry. We use it in PART 2, PART 3 and PART 4.

Lathe

Illustration 59 Lathe machine

The lathe has manual control. We are going to use this machine only for the manufacture of the PART 1.

Manufacturing of each part

PART1: CYLINDRICAL PIECE

We make this piece using the lathe machine.

We make this piece using an initial bar of 45 mm of diameter. First we have a bar of diameter 45 mm and length 200mm. First we make a capping in the front side of the bar, to reduce the length to 180mm. Then, we remove the material of the cylinder to have the diameter of 30mm in the length of 160mm. We make the rounded in the change of the diameter.

At last, we make the fishing pass to the total length of the cylinder to have a good surface quality.

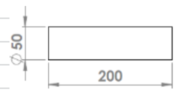
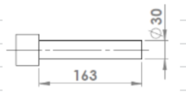
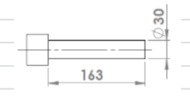
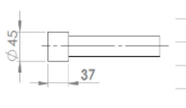
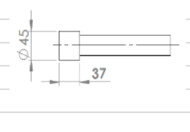
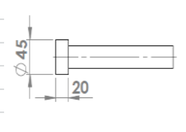
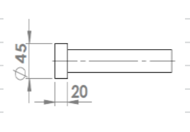
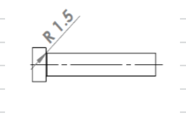
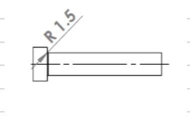
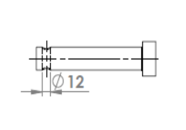
	initial	final	Process	Machine	tool	**N** (rev/min)	**f** (mm/min)	**v** (m/min)	**d** (mm)
1			turning	Lathe		380	0,145	59,698	(1,25mm)x 7 (1mm) x 1 (0,25mm) x 1
2			turning	Lathe		190	0,2	17,9094	(2mm) x 2 (0.5mm) x 2
3			cutting	Bandsaw machine	Bandsaw	N/A	N/A	N/A	17mm
4			chamfering	Lathe		190	0,2	17,9094	R 1,5
5			Boring	Boring machine			Manual		diam. 12 through-all

Illustration 60 Machine process part1

PART 2: UP FIXTURE

We make this part using the metal cutter and the milling.

First we make a dimension reduction with the metal cutter, to have 170x80x60mm. Then, we make a facing of the surfaces and obtain the geometry of 150x50x40mm. We make the two smalls holes of 12 mm and, finally, the big one on the centre changing the drill successively, since one small to other bigger. Like this is made with a manual milling, we cannot make a finishing pass with a milling cutter for has better results in the finish surface.

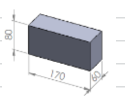
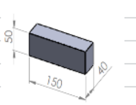
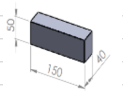
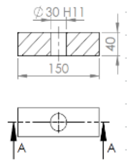
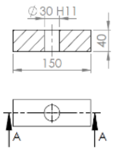
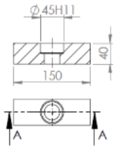
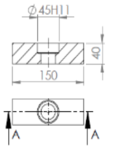
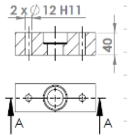
Oper. No	initial	final	Process	Machine	Tool	**N** (rev/min)	**f** (mm/min)	**v** (m/min)	**d** (mm)
1			Face milling	Milling machine	90° Face milling cutter, Ø80 (6 carbide inserts) ISO code APKT 1203PD-R	400	80	100,544	1mm every pass
2			Boring	Milling machine		100	z feed 0,07		through-all
3			Boring	milling machine		100	z feed 0,07		20mm
			Drilling (precise)	milling machine	Twist drill bits Ø5 , Ø11.5, Ø12	100	20		through-all

Illustration 61 Machine process part 2

PART 3: BOTTOM PART

We manufacture this piece using the metal cutter and the milling machine.

First of all we have a block of metal (200x173x65mm), we cut it and we obtain a block of measures 155x75x65mm.

Secondly, we make a facing in the entire block to obtain flatness obtaining a block of 150x70x60mm.

Then, we make the level lowering both sides (50x50x40 mm). Once that it’s made, we rounded the edges that make the union between the level lowering sides and the central block. The, we make the hole of diameter 30 mm and depth 23 mm. At last, the transversal hole of 12 mm.

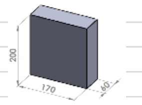
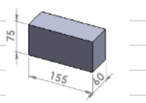
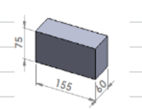
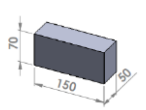
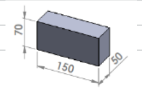
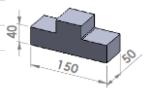
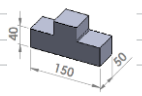
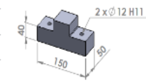
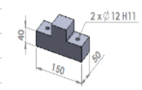
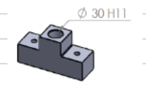
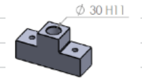
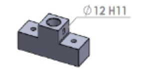
Oper	initial	final	Process	Machine	Tool	N (rev/min)	f (mm/min)	v (m/min)	d (mm)
1			cutting	Bandsaw Machine	saw	N/A	N/A	S.A	2 passes 1)20mm 2)125mm
2			Face milling (roughing & finishing)	Milling machine	90° Face milling cutter, Ø80 (6 carbide inserts) ISO code APKT 1203PD-R	400	80	100,544	2mm every pass
			milling	Milling machine		400	75	75,408	
4			Drilling & Precise reaming	Milling machine	Twist drill bits Ø5 , Ø11.5, Precise reamer Ø12 H11	100	20		through-all
5			Drilling & Precise reaming	Milling machine	Twist drill bits	100	20		23mm
6			Drilling	Milling machine		85	20		through-all

Illustration 62 Machine process part 3

PART 4: PLATES

We have to manufacture four identical pieces. We use the milling for these pieces.

We start since a piece of dimensions 85x54x55mm. The first of all is facing the surfaces of the metal.

Once that the process is finished; the block has an approximately measure of 80x50x50mm.

In this moment, the operator cut the block in 4 identical pieces with the metal cutter.

The result it is four plates of 50x50x20mm. Then we make the hole, of diameter 12mm, in the middle of the piece with a drill.

The measures of this procurement are not very accurate, but are enough to this piece. The holes fulfil the tolerance 12H11.

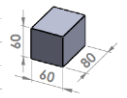
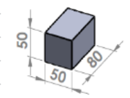
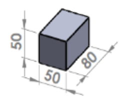
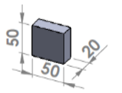
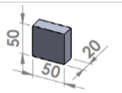
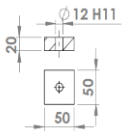
	initial	final	Process	Machine	Tool	N (rev/min)	f (mm/min)	v (m/min)	d (mm)
1			Face milling (roughing)	Milling machine	90° Face milling cutter, Ø80 (6 carbide inserts) ISO code APKT 1203PD-R	400	75	100,544	1mm per pass
2			Cutting	Bandsaw machine	Bandsaw	N/A	N/A	semi-automatic	3 cuts of 20mm
3			Precise drilling	Milling machine		100	20		through-all

Illustration 63 Machine process part 4

Verification of the dimensional and geometrical tolerances

Once we have made the fixture, we are going to measure all the tolerance given to it. This is an important step, because the good conditions and the veracity of the data obtained in the cross tension test can be not the best ones.

For example, the contact between the hole and clamp in the assemble between the Part 1 and Part 2 could no respect the restrictions imposed and reduce the surface contact between the pieces, that can reduce the life of the fixture increasing the tension in a particular zone of the piece.

Equipment and steps of the measure

To make this verification we are going to use a CMM machine DEA D101. This kind of machine is composed by an arm that touches the pieces with a "tip" (extreme of the arm).

Illustration 64 CMM machine.

First of all, we have to check the real diameter of the tip: This step is the calibration of the tip. We use a sphere reference standard, that has a diameter very verified that the software knows. The machine tries to measure the diameter with the tip. As we know the result (the diameter of the piece), the software adjust the diameter of the tip to have the best approximation of the tip diameter.

Secondly, we have to import a cad file with the perfect geometry that we want to measure. We said “perfect” because in the software we can impose have the exactly geometry, but in the real manufacturing process we cannot have never the exact measure of all the parameters, we have several uncertain measures; this is why we give to the part some dimensional and geometrical tolerances that could be important for the correct function of the fixture.

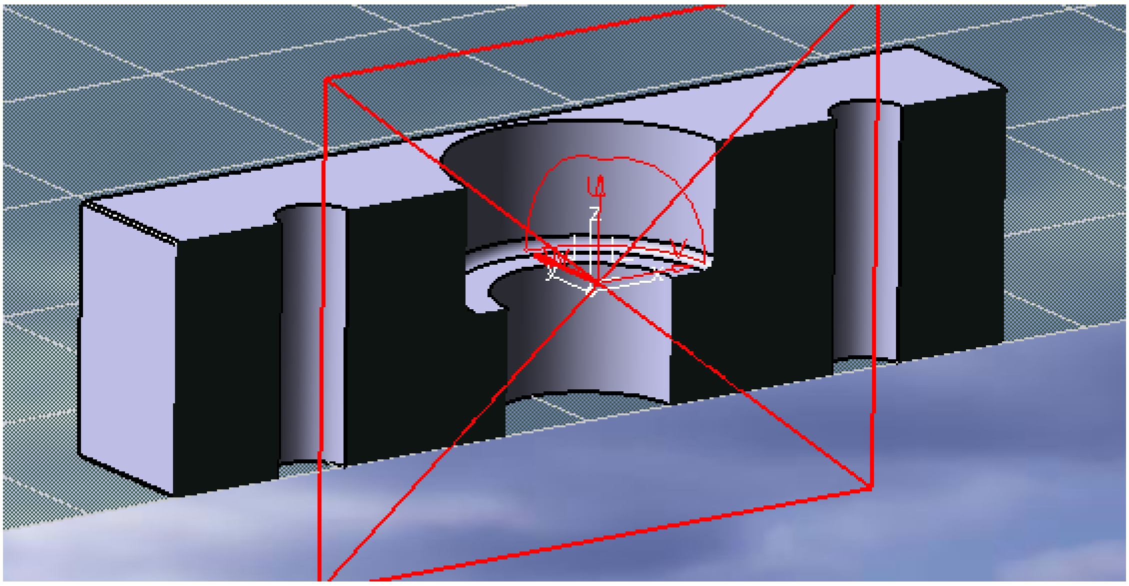


Illustration 65 Fix 6 degrees of freedom

For make the measure, we need to create a reference system in the piece fixing the plane of reference, then one vector contained into the plane, and finally, the origin point.

If we see Illustration 65, we can see the piece that we are going to measure in the CMM. If we want to take the reference system as it is show in the picture (the real one that we use for measure is in the top of the piece, not in the middle), we can say that the first step is create the inside plane of the piece (the counter board piece), where is the “XY” plane. After this first step we have restricted the “Z” displacement and the rotation around the “X” and “Y” axis. Then we have to align one vector with one axis. In this case, the “X” axis with the longitudinal length of the piece. With this step, we restricted the rotation around the “Z” axis. At last, we fix a point inside the selected plane that will be the origin of the reference system: this last step will restrict the translation in the “X” and “Y” direction: the reference system will be totally restricted.

All this proceedings are made in the “manual mode”; we have to touch the planes and faces programmed in the CAD, and with this the programme will be able to compare manufacture piece with the CAD piece (48).

The machine measure using one tip,Illustration 66, which takes points (discreet measure) to make the measure. If we want, for example, to verify the plane made in the contact surface between the coupon and the part 2 or part 3, the machine will measure several points of the plane and create a “virtual map” of the surface and give to us the real value of the flatness and we compare it with the tolerance given.

Illustration 66 Tip (red part)

Conditions for a good measure (47)

Always we have to calibrate the tip before start the process of measuring to avoid the errors by a wrong diameter, but we also another important factors:

- Temperature of the room. The material could betray. For this reason, the temperature has to be between 15ºC and 25ºC. The ideal one is 20ºC
- The humidity. There are some materials that can absorb water and increase its dimensions. The maximum humidity premised is 50% of relative humidity.
- The good condition of the instrument that we are to use, in this case, the tip.
- Take into an account the effects of the magnetic fields as result of the current that use the machine, which could damage the signal and it is value.
- The correct air supply of the machine, to have no problem between the movement and the programme control (the machine has to have enough power to can move the machine to the speed programed).

Measurement process fundaments (47)

The machine that we are to use is a Numeric Control Machine. We use software to control all the process, and programme easily the movements

The machine is composed by the following components:

- Scanning system, which touch the geometry and give to us the values of the different points measured (distance, altitude…)
- The system that generate the signal to traduce the touch of the scanning system.

- The arm that moves and situate the scanning system to make the measure.

We are going to introduce how the tip, that is the part of the measure machine which touch the piece, takes the measures:

First of all, we need to position the scanning system in the (0,0,0) (origin point), to start to measure.

Secondly, we have to know the exactly dimension of the tip. The tip is spherical. We compare the tip with a yardstick piece making measures with our tip.

Once we know the diameter of the tip, we need to move the arm of the machine to the correct place to make the measure. If we call to the plane perpendicular to the movement of the tip “plane X-Y”, and direction z to the direction of movement of the tip, the arm positions the arm in the correct place in the XY plane. Then we move in the direction “Z direction”.

When we are close to the part that we want to measure, we move first in the “z” direction and the in the perpendicular direction of the principal movement of the machine and then along the rails of the machine. This is because the structure of our measure machine is a mobile portal.

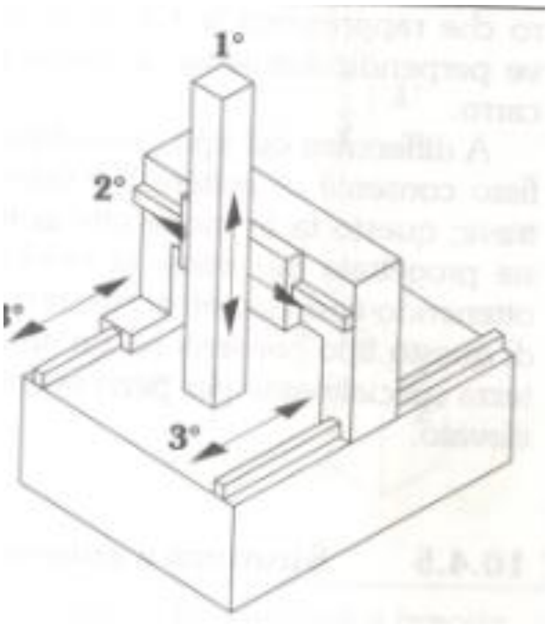


Illustration 67 Machine structure. (47)

The point of the tip which touch the tip gives to us the exactly point. At the top of the tip support we have the reference point to the tip. The scanning system measure since the centre of the tip, making and angle respect the “Z axis” and we know the distance (that it is the radius). We call “L” to the distance between the reference point and the centre of the tip. “L” it is the distance in the “Z axis”.

The measure of the point will be:

$$P = (Xo - R * \sin(\alpha), Yo, Zo - R * \cos(\alpha))$$

Where Xo, Yo and Zo are the points of the centre of the tip and α the angle of the point on respect the “Z axis”. We can see it in the Illustration 68.

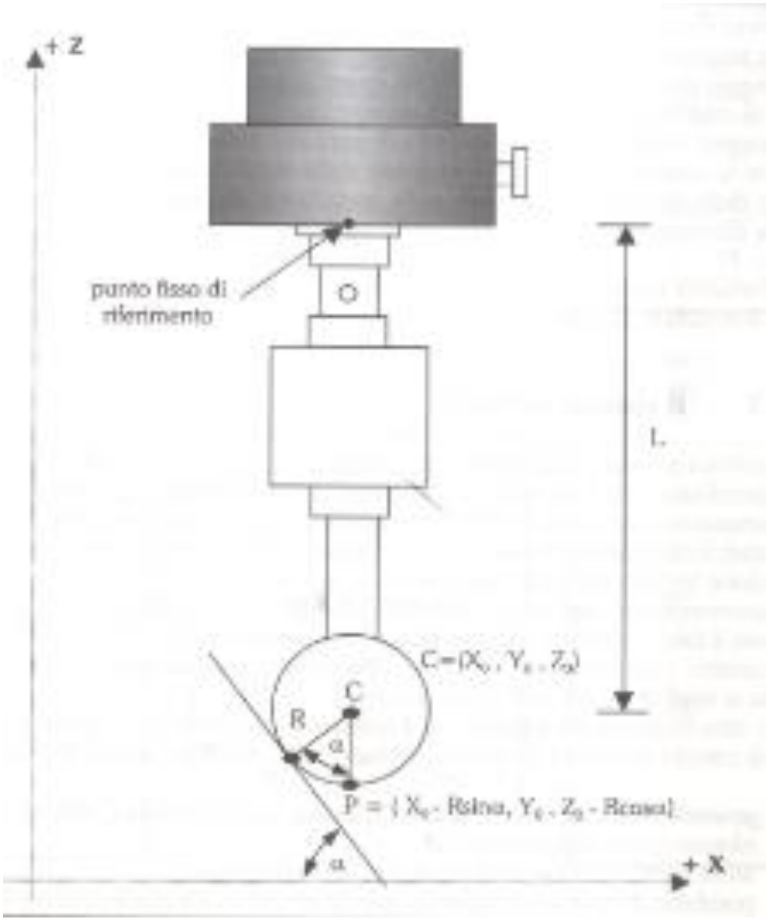


Illustration 68 Tip (47)

With the points and a reference (the origin), we can measure distances, measures and tolerances (dimensional and geometrical). For example, the measure of flatness using several points and calculating between which two imaginary perfects planes is our plane.

The others geometrical tolerances that we are to measure are the parallelism and/or perpendicularity of some axis in relative to a plane.

In this case, we have to measure the cylindrical surface as if it is generated since an imaginary axis, and compare it with the reference plane..

To measure the diameter of the holes, that is a dimensional geometry, we need to use another kind of tip, which have two probes perpendicular to the Z axis, since centre of the tip that measure with several points the diameter of the hole.

Verification

We have measured and verify the geometric tolerances of the part3. The results pass our specifications.

▱	MM	FLAT1 - PLN3				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.028	0.028	0.018
⊥	MM	PERP1 - PLN3 TO CYL1				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0	0.010	0	0.029	0.029	0.019
⊥	MM	PERP2 - PLN3 TO CYL2				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0	0.010	0	0.038	0.038	0.028

Illustration 69 Verification of the geometric tolerances.

Final result

Illustration 70 The final installation of the fixture in the traction machine.

Conclusions

The objective of this project is to develop the characteristics of the car bodies' structure. The manufacture of the car bodies is based in the union of plates of little thickness. This union is made by ERW (electrical resistance welding), that is the most productive welding process.

We are focused in the most innovated materials for the car bodies, which are using and are going to use the cars factories.

First of all, we have deepened into how the process is made. We have two different kind of welding machines available and we describe how they can work in different modes.

Then we realized that we need to monitor the process. This is needed because is important to follow all the process along the welding to can compare the exactly measures of the parameters with the mechanical results. We had studied and bought the necessaries instruments for the monitoring system.

The objective of the studio is comparing the mechanical resistance with the variables of the process. This is why we need to test mechanically the union. We have studied the most common tests to the ERW unions. For make one of the most important tests (the cross tension test), we have designed a fixture and we followed all its manufacture process.

In short, we have given the firsts steps to can make the essays and study of the industry ERW for car bodies with the new generation of materials.

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ANNEXES

SUPPORT FOR WELDING

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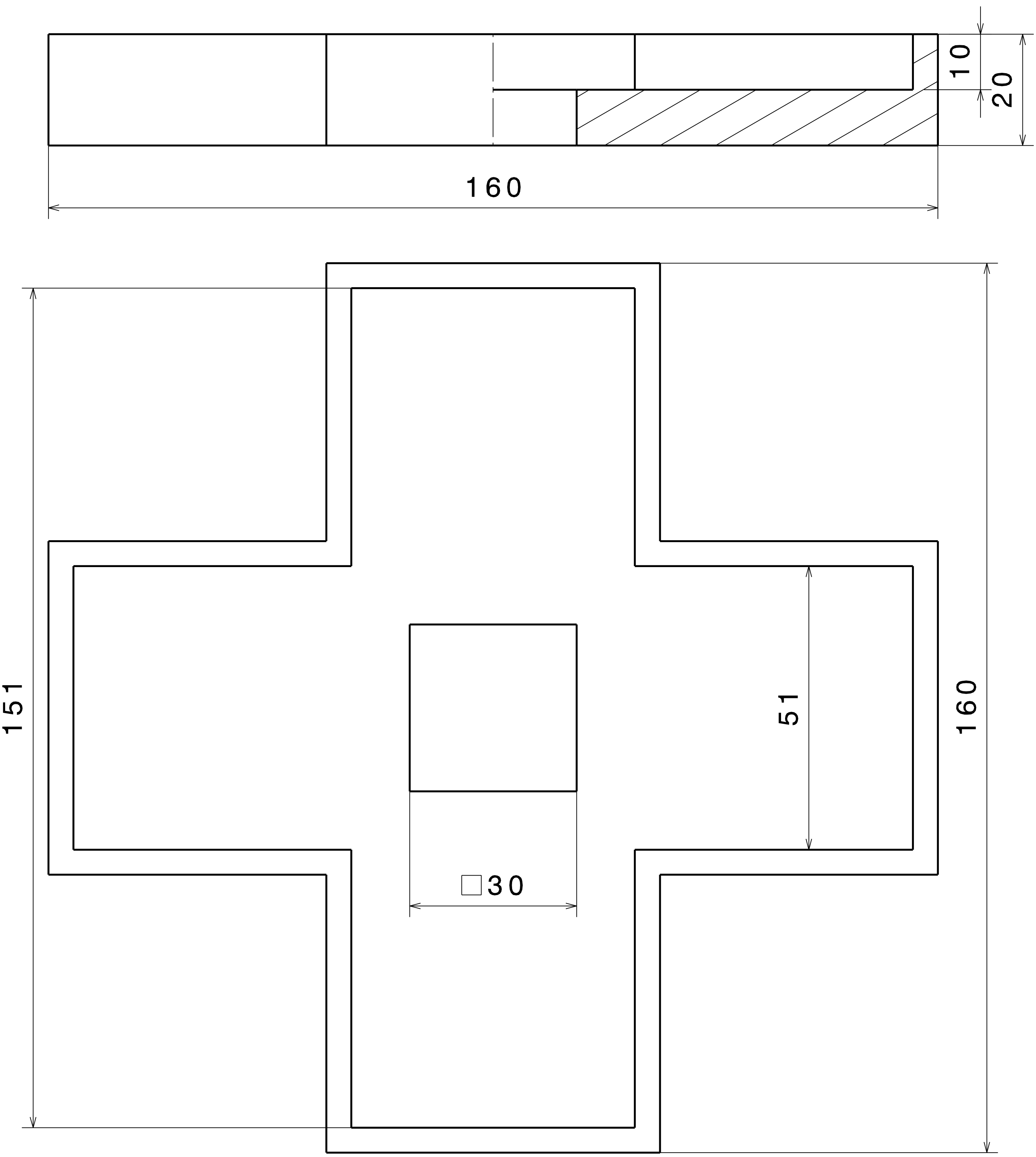

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Juan Luis Marcos
DATE:
16/06/2015
CHECKED BY:
XXX
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Option 1

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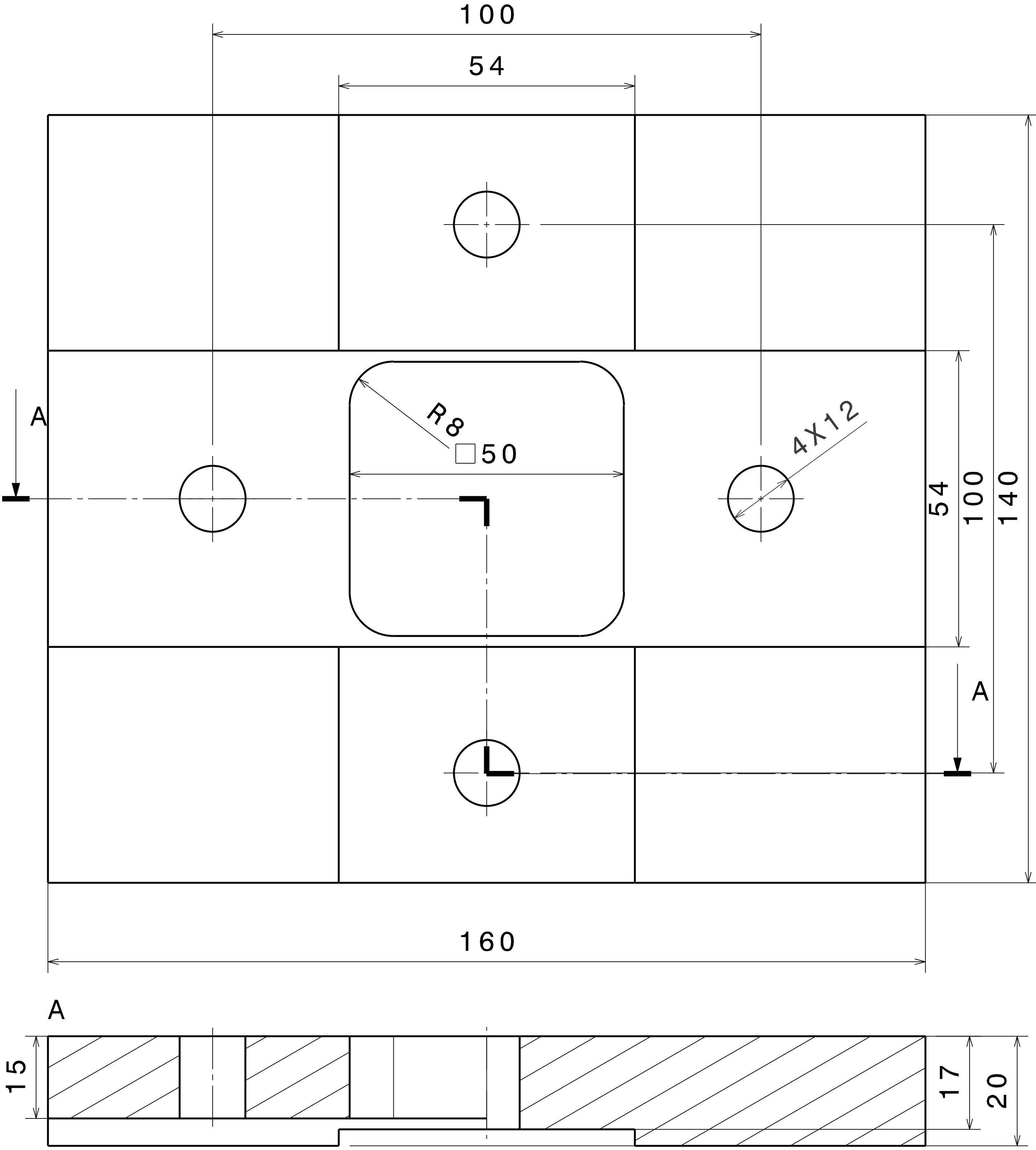
SUPPORT FOR WELDING

II



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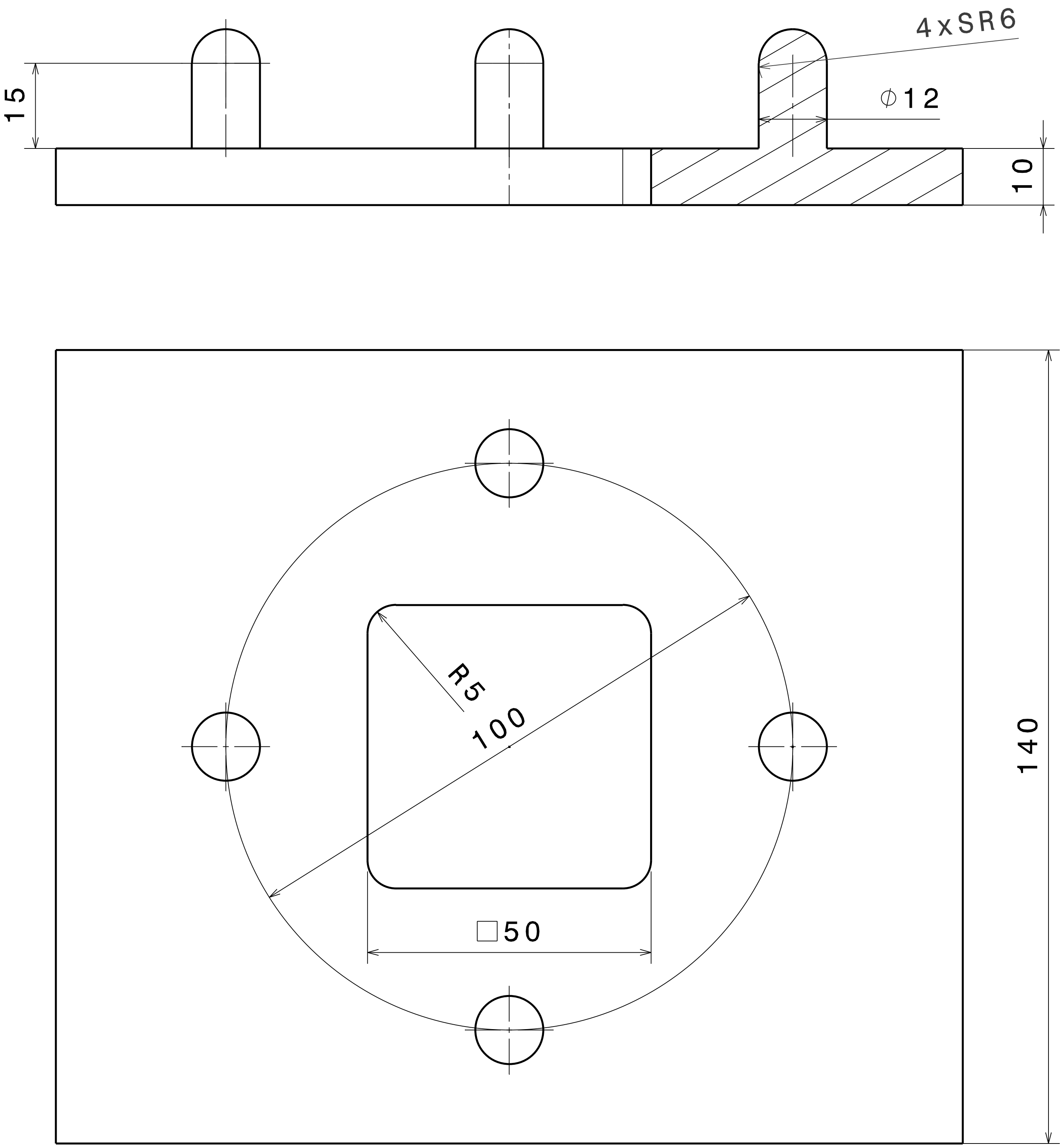

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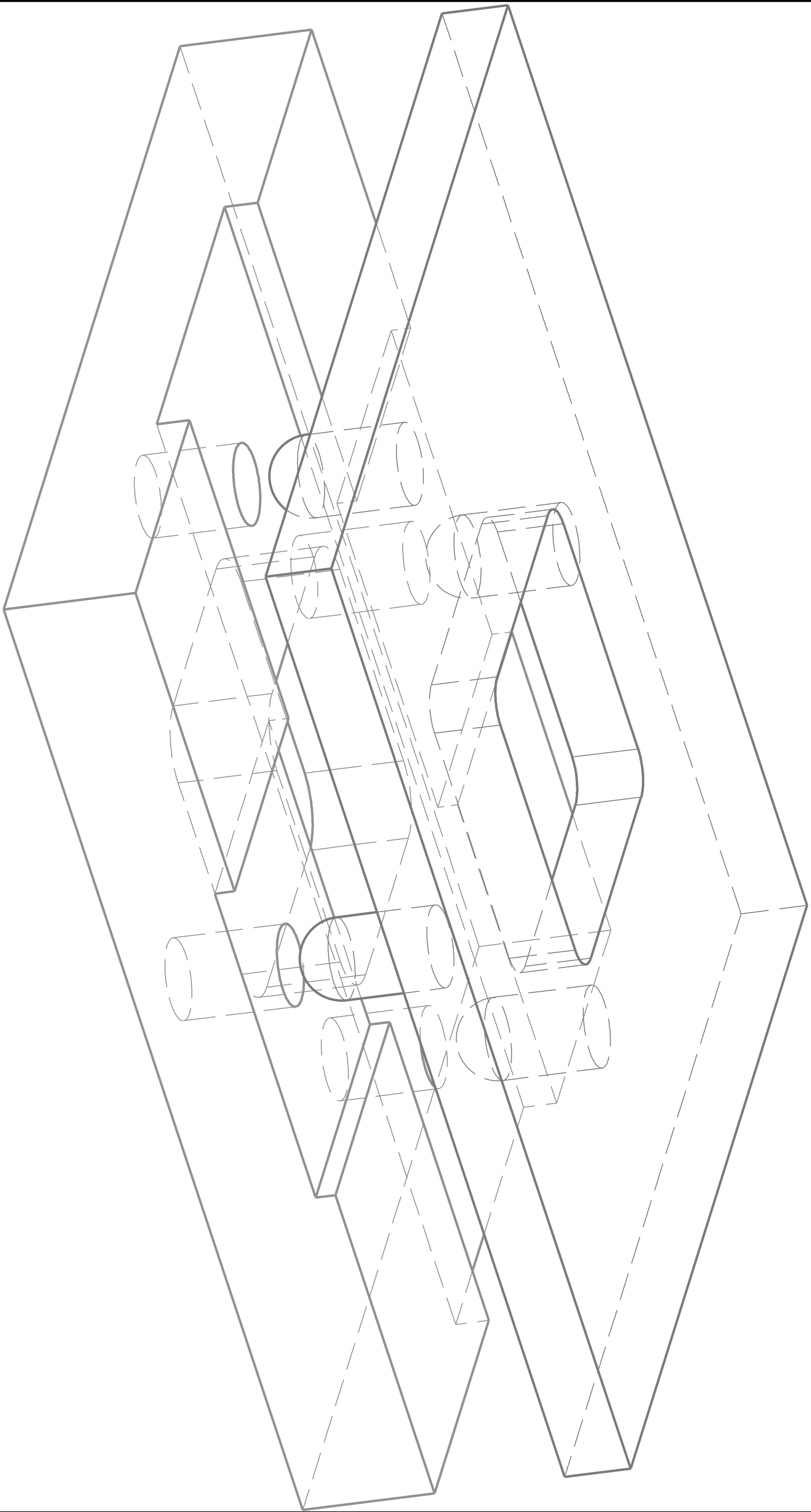

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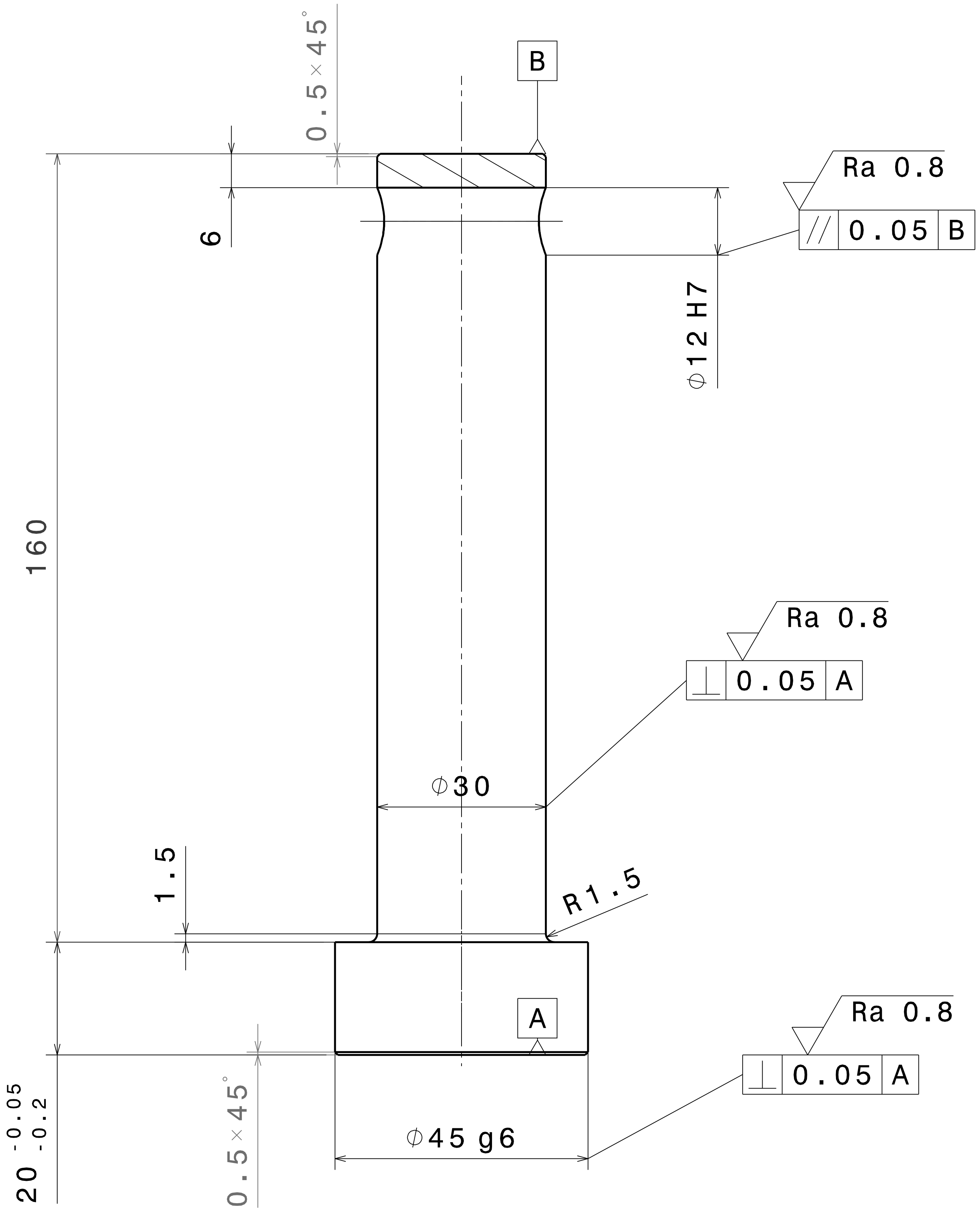

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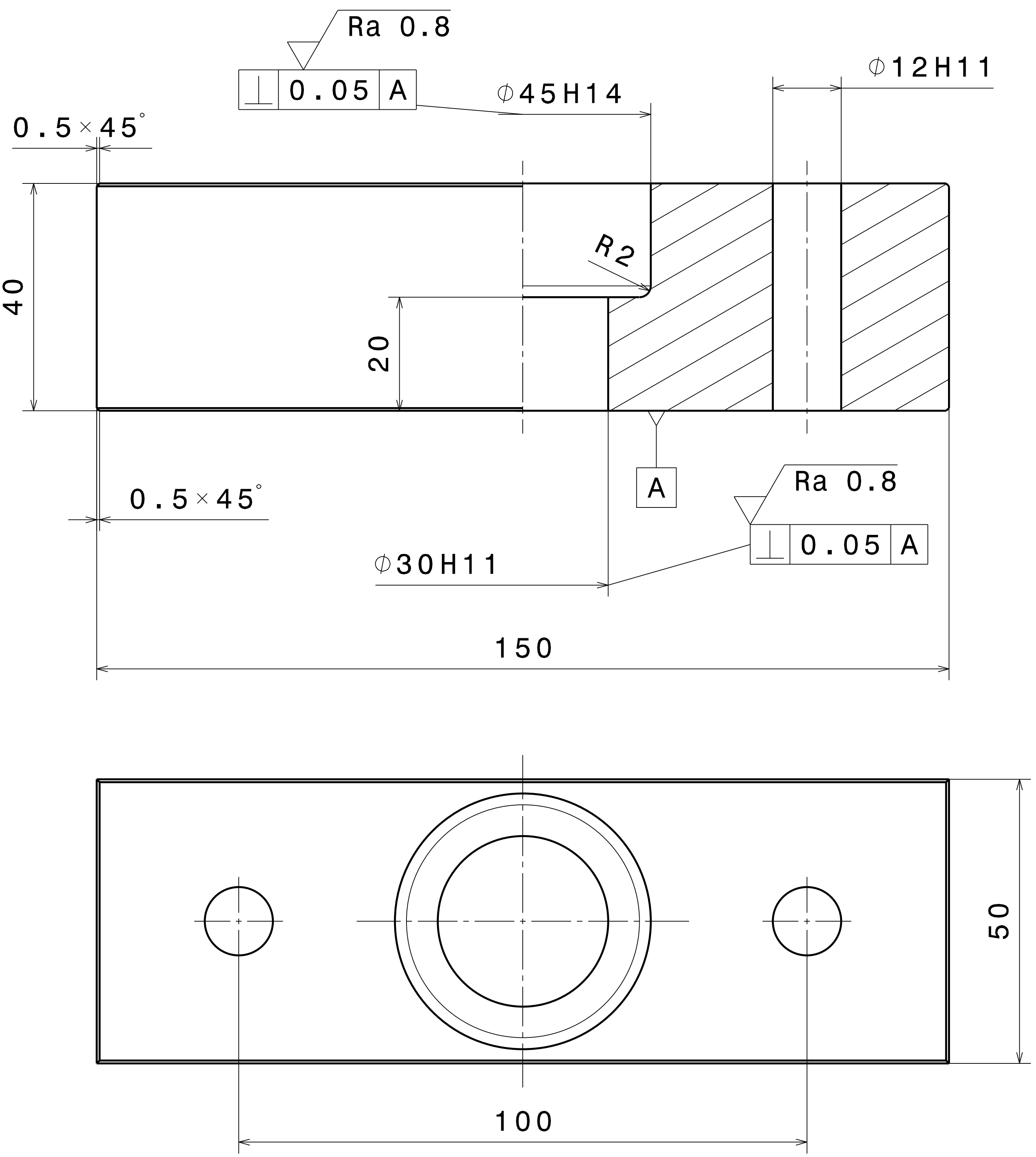

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DASSAULT SYSTEMES

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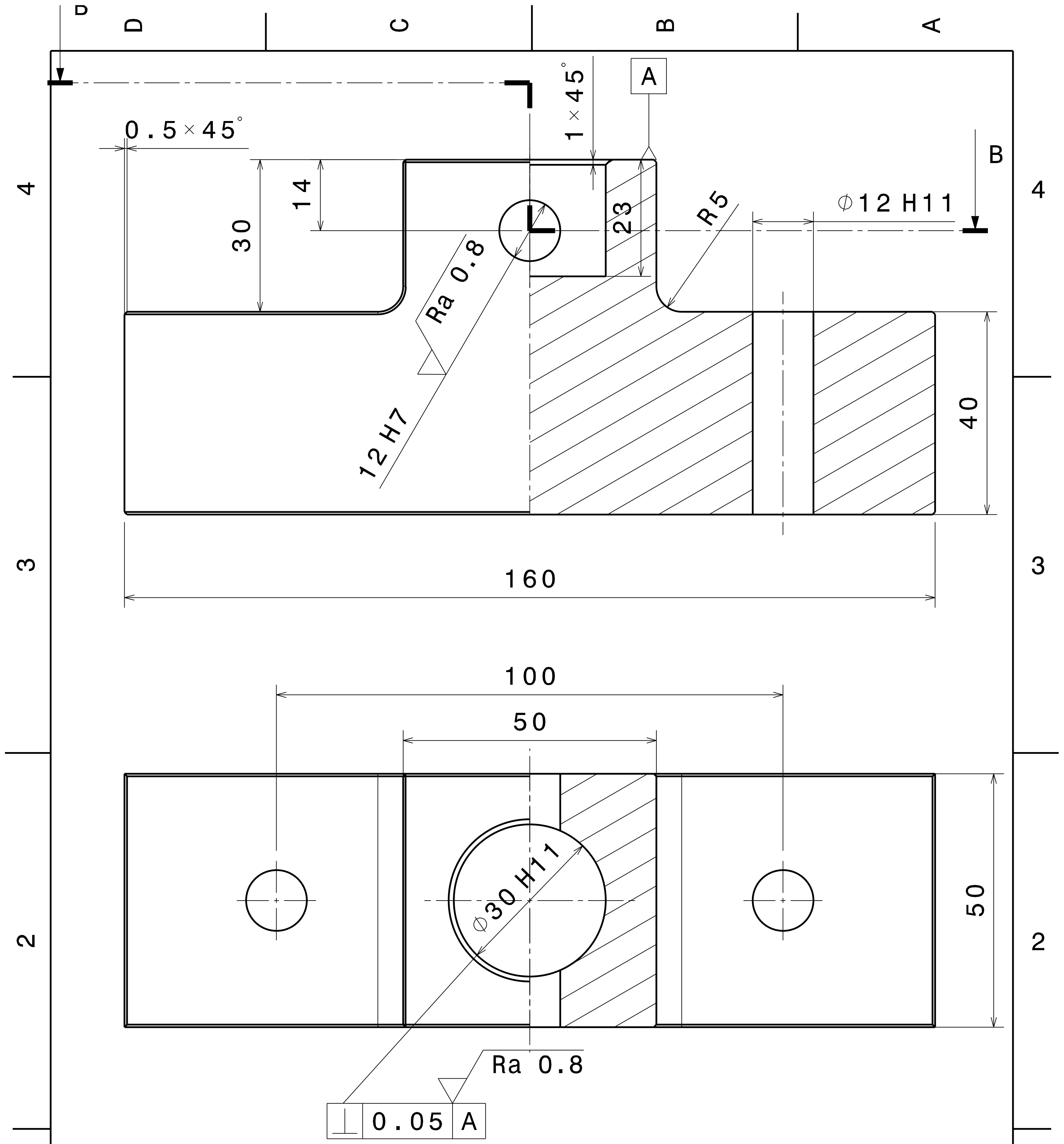

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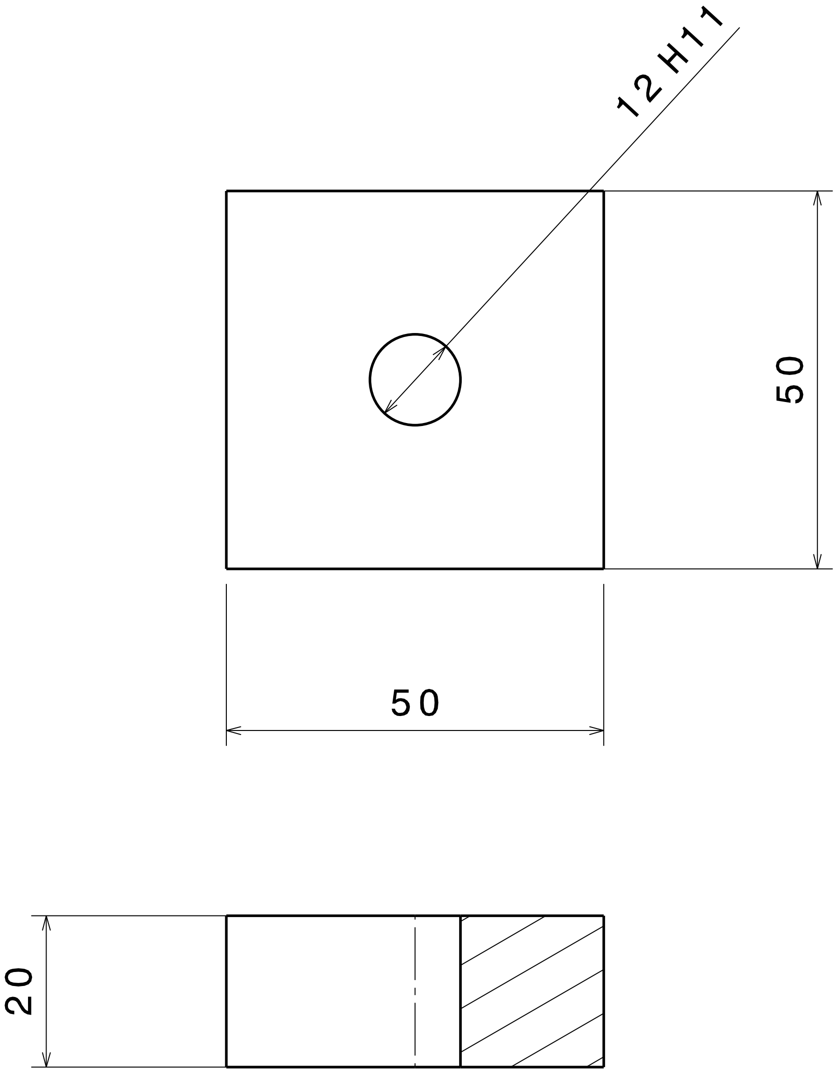

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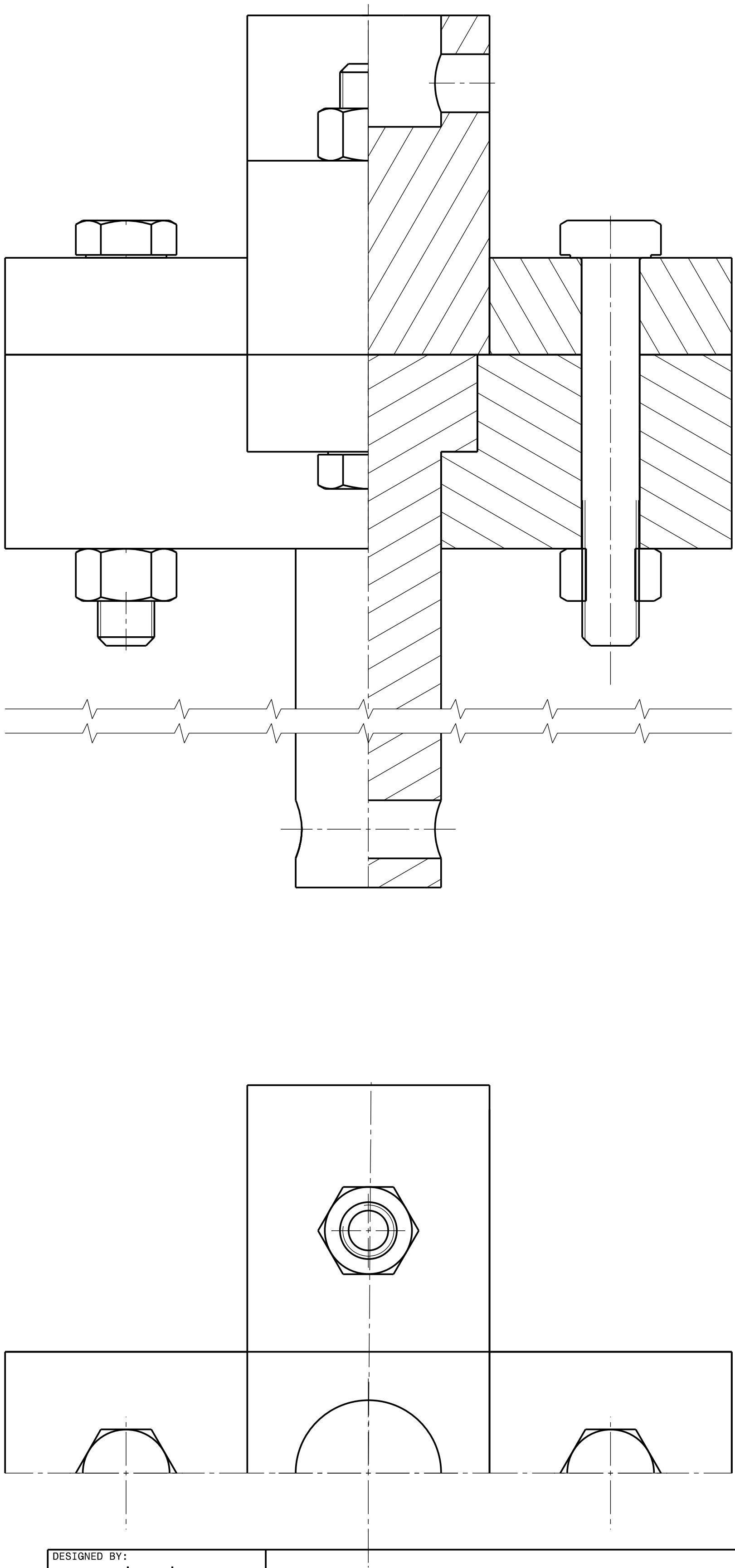

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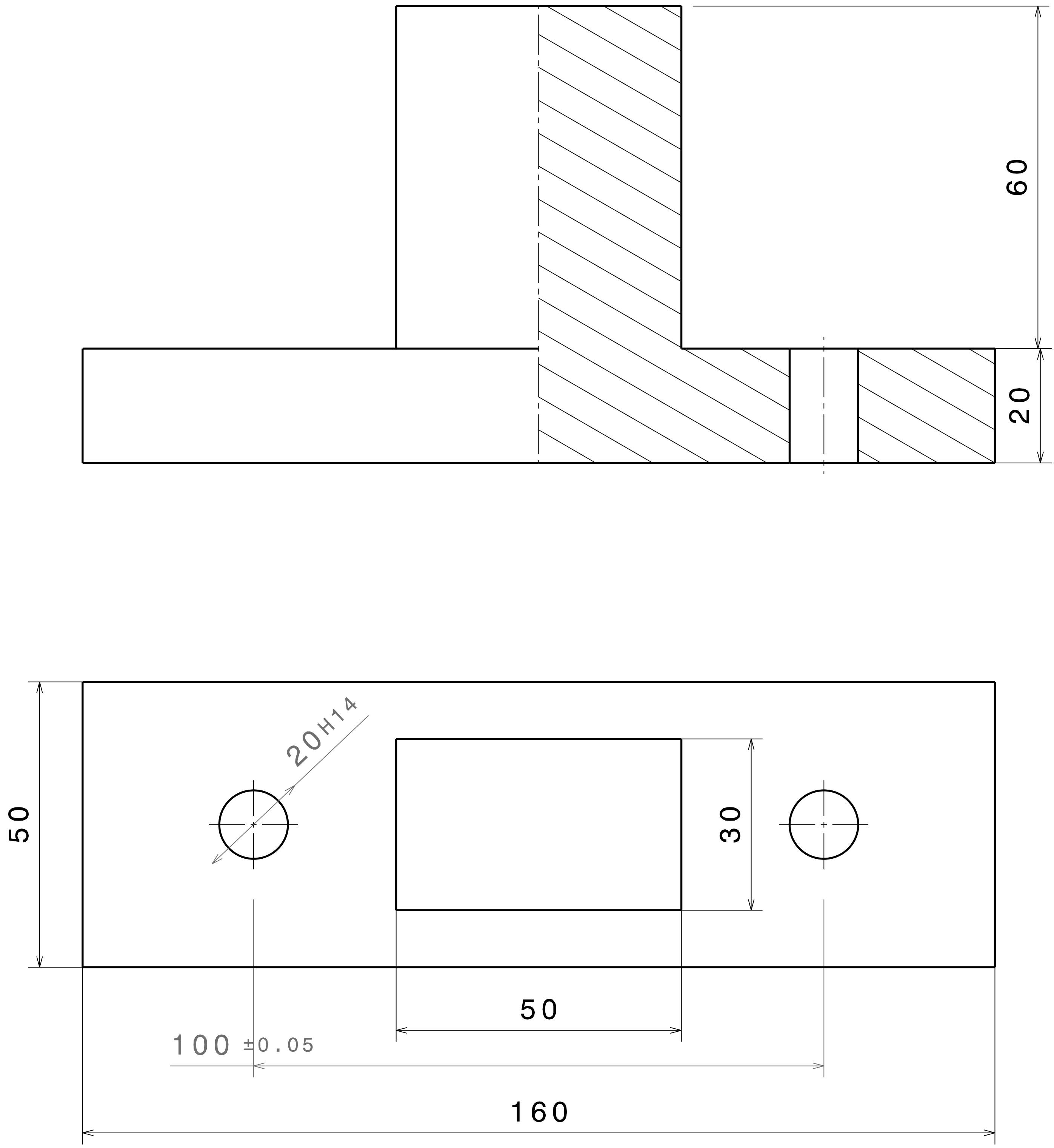

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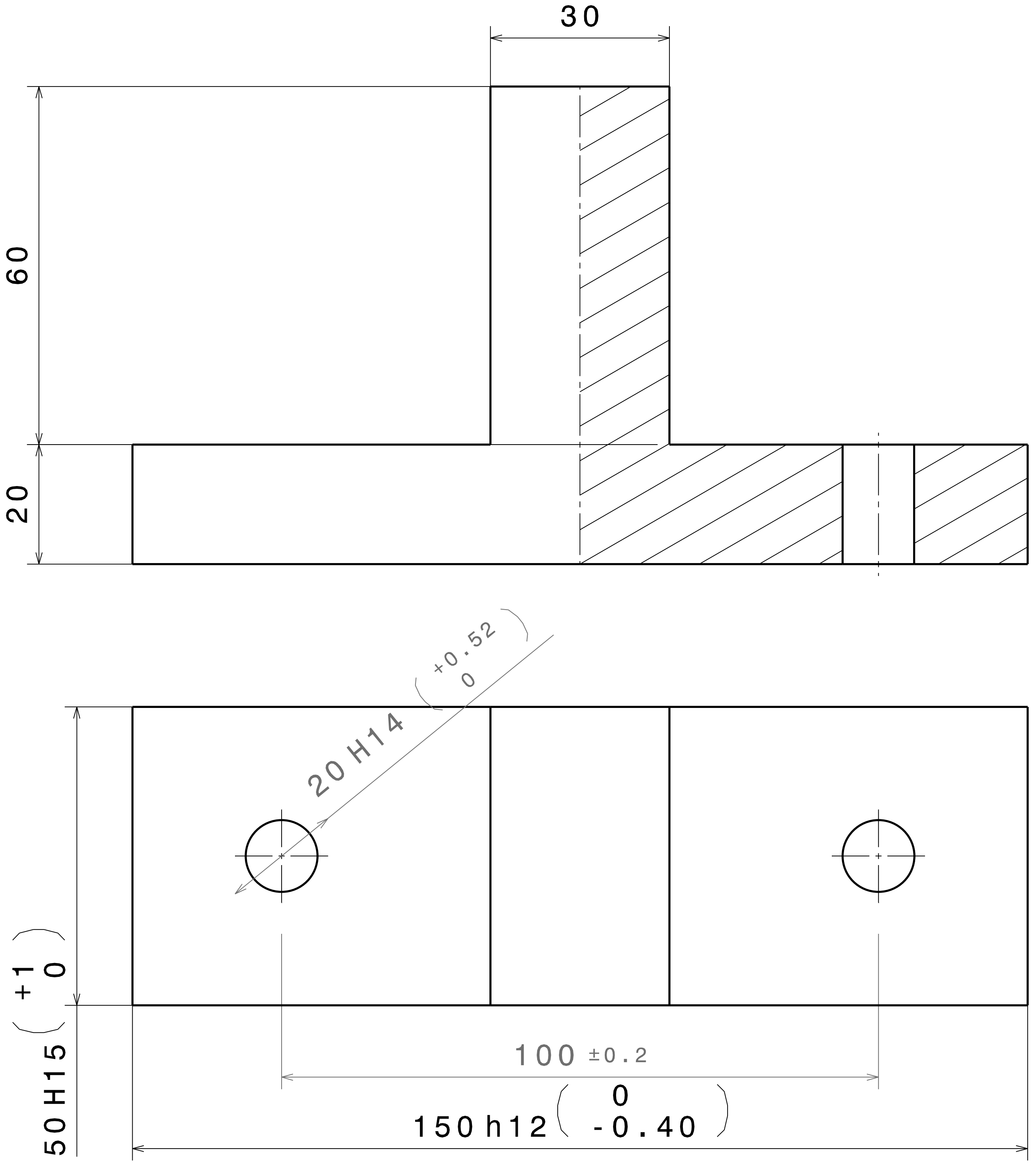

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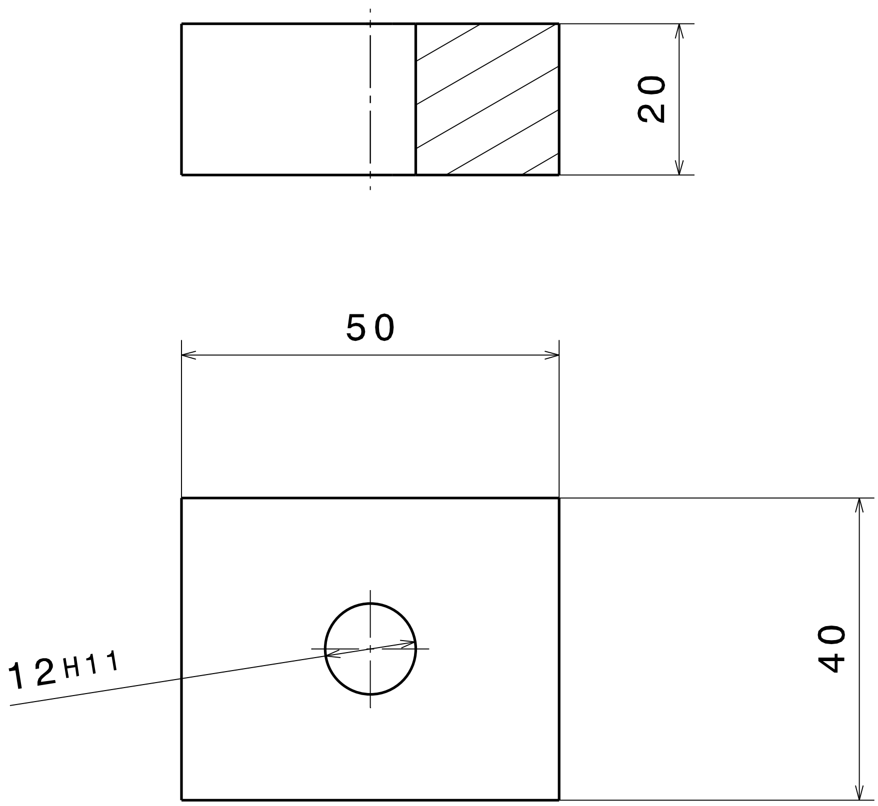

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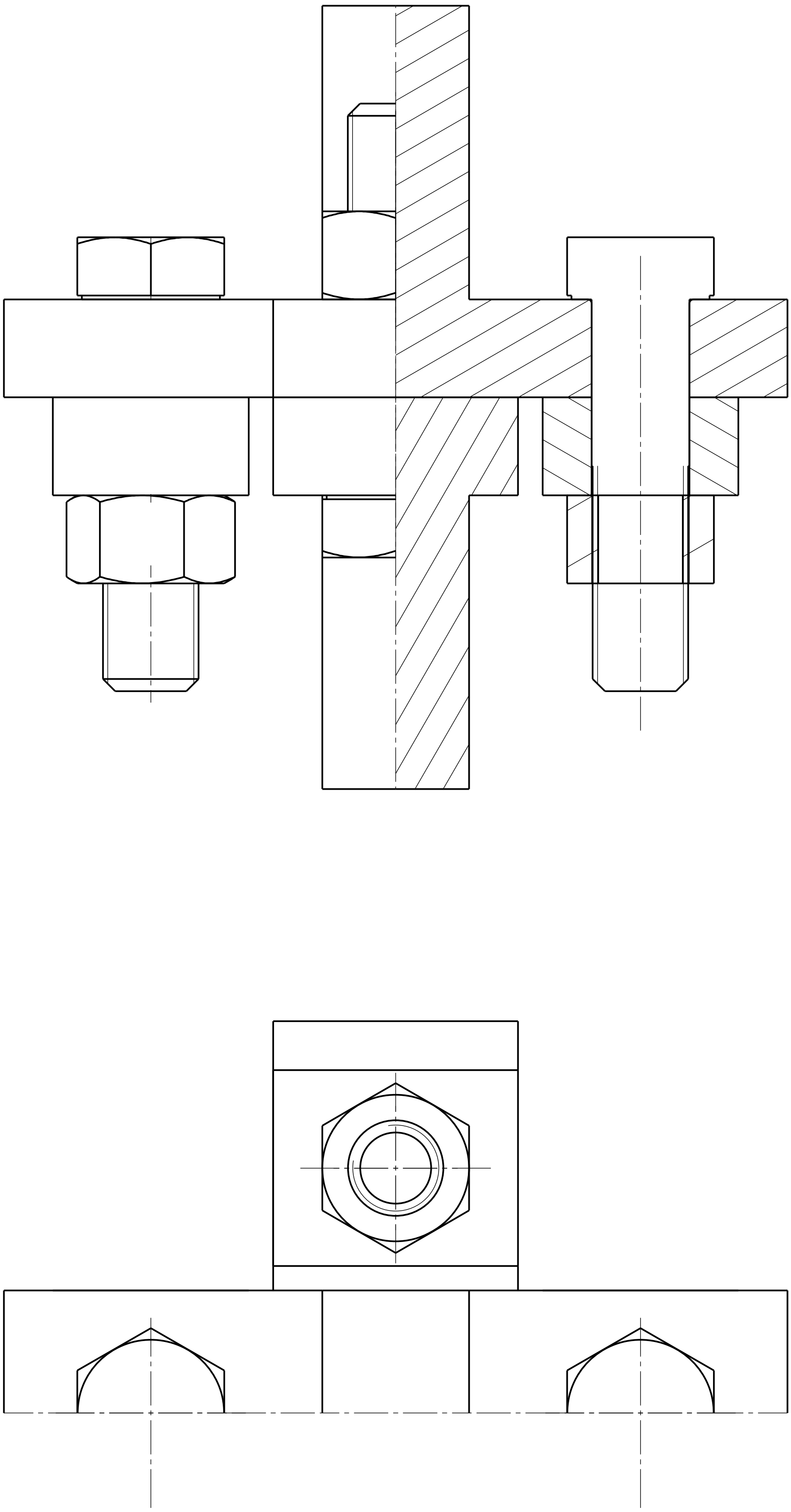
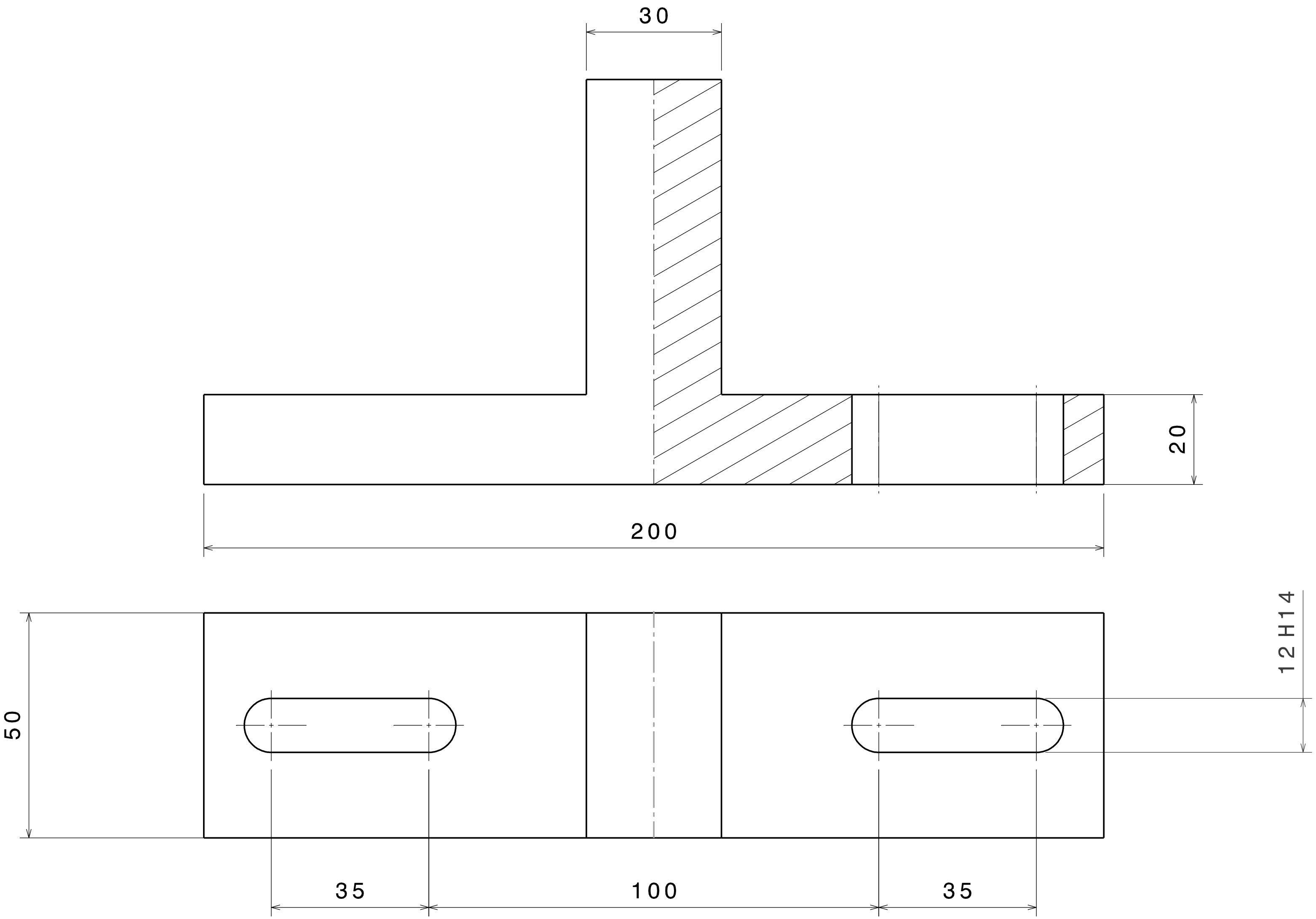


DESIGNED BY: JUAN LUIS	CROS TENSION FIXTURE "ISO"	
DATE: 30/03/2015		
CHECKED BY: XXX		
DATE: XXX		
SIZE A3	DASSAULT SYSTEMES	
SCALE 1:1	WEIGHT (kg)	DRAWING NUMBER 1	SHEET 1/1

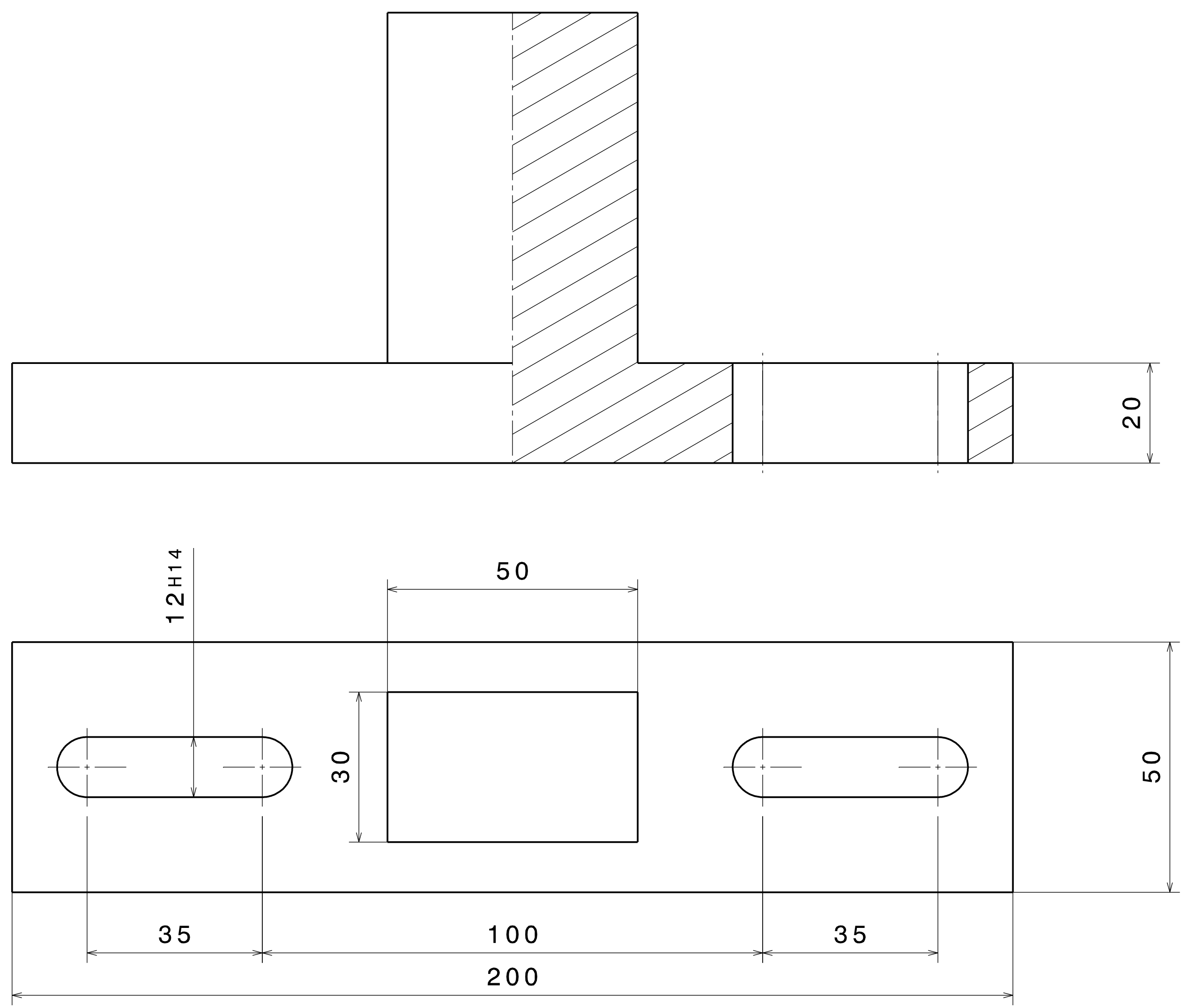
Rev.	
I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_

MODIFICATED
ISO PLANES

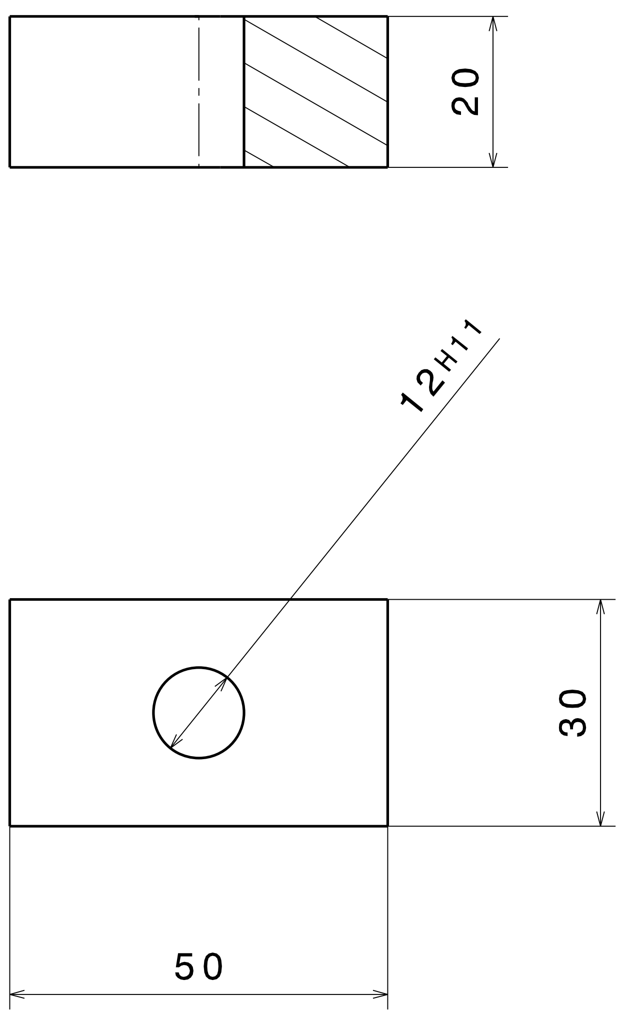


DESIGNED BY: JuanLu	
DATE: 30/03/2015	
CHECKED BY: XXX	
DATE: XXX	
SIZE A3	DASSAULT SYSTEMES
SCALE 1:1	WEIGHT (kg) 0,26
DRAWING NUMBER f.1	SHEET 1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_

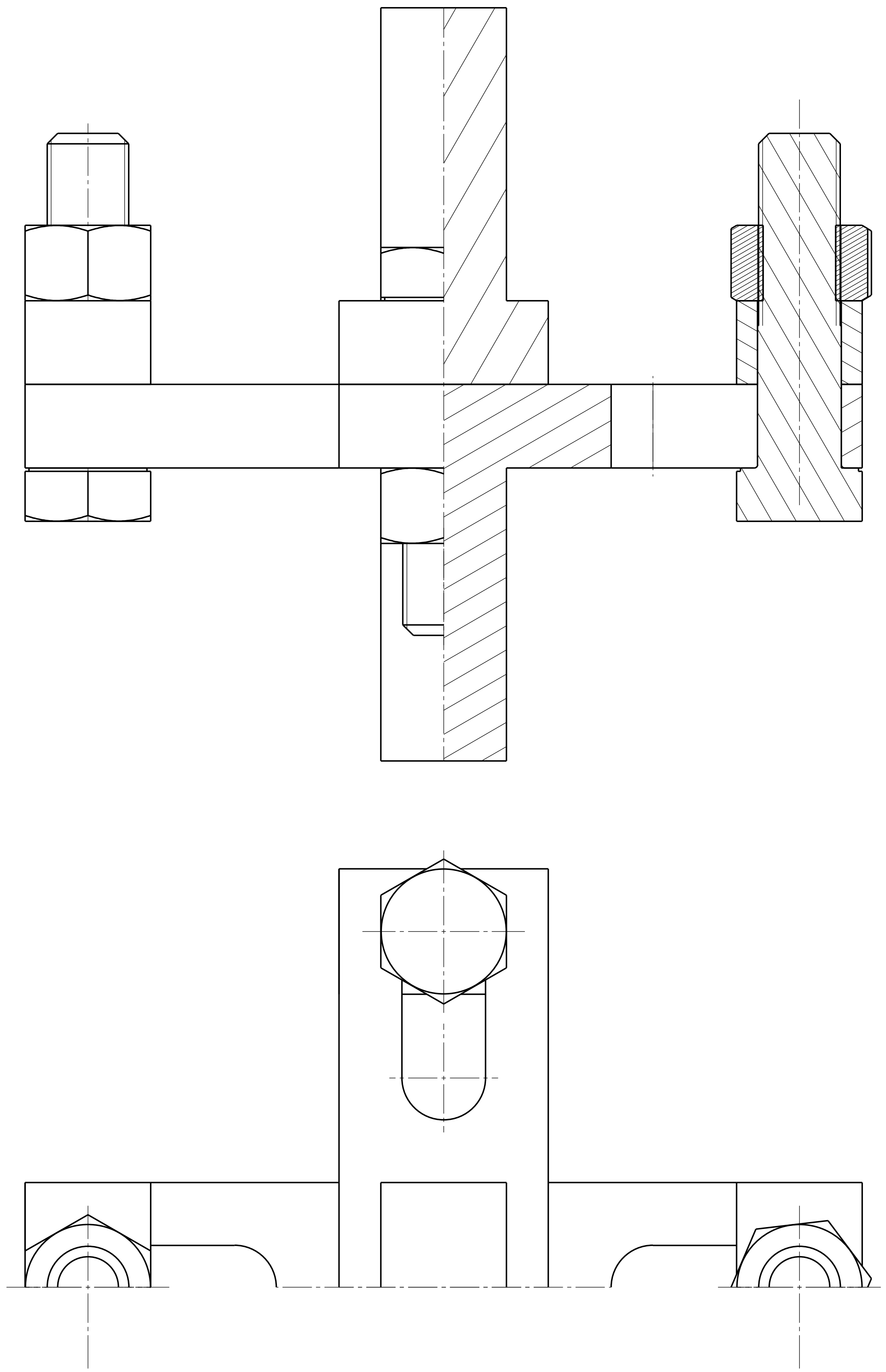


DESIGNED BY: JuanLu				I –
DATE: 30/03/2015				H –
CHECKED BY: XXX				G –
DATE: XXX				F –
SIZE A3		DASSAULT SYSTEMES		E –
				D –
SCALE 1:1	WEIGHT (kg) 0,26	DRAWING NUMBER f	SHEET 1/1	C –
				B –
				A –



DESIGNED BY: JuanLu DATE: 30/03/2015	XXX		I	_
CHECKED BY: XXX DATE: XXX			H	_
SIZE A4	DASSAULT SYSTEMES		G	_
SCALE 1:1	WEIGHT (kg) XXX	DRAWING NUMBER XXX	SHEET 1/1	F	_

E	_
D	_
C	_
B	_
A	_



DESIGNED BY: Juan Luis Marcos	CROSS TENSION FIXTURE ISO		I _
DATE: 30/03/2015			H _
CHECKED BY: XXX			G _
DATE: XXX			F _
SIZE A3	DASSAULT SYSTEMES		E _
			D _
SCALE 1:1	WEIGHT (kg)	DRAWING NUMBER 2	SHEET 1/1