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CAR BODY STRUCTURE WELD WITH SOLDAMATIC ROBOTICS
Case study

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CASE STUDY

Car body structure WPS weld with SOLDAMATIC ROBOTICS

The objective of this case study is to know how to set up and perform a simulated welding practice on car body structure WPS fillet weld (overlapped) in PB (horizontal) configuring an exercise and using a ROBOTIC arm with SOLDAMATIC.

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SOLDAMATIC



Is the name of the simulator where the Augmented Reality welding practices are performed.
Both its external elements (welding torches, helmet, etc.) and its functionalities (welding sound reproduction, vision module, etc.) have been designed to make this experience as close to reality as possible.

The simulator has been designed to be configured according to European Standards (based on the **EWF** regulations), American Standards (based on the **AWS** regulation); and **Metric and Imperial system.**

SOLDAMATIC ROBOTICS

Soldamatic IE enables robotic welding training. With Augmented Reality technology it is possible to use the actual programming console of a robot for specific welding routines, reduces risks and costs during training and increases the number of practical hours. We have named this system Soldamatic Robotics and it can work with any robot on the market.

STEPS

In order to carry out this type of welding in SOLDAMATIC ROBOTICS, you will have to follow these steps to learn how to do an exercise:

1. Go to the Lab

You will enter the lab where your teacher will have previously installed and integrated the robotic arm to work with SOLDAMATIC IE. The welding process is 131 Gas Metal Arc Welding so your teacher need to choose GMAW Torch.

2. Choose the welding joint

Fillet weld is in PB horizontal position so you need to choose **T angle plate to plate joint**

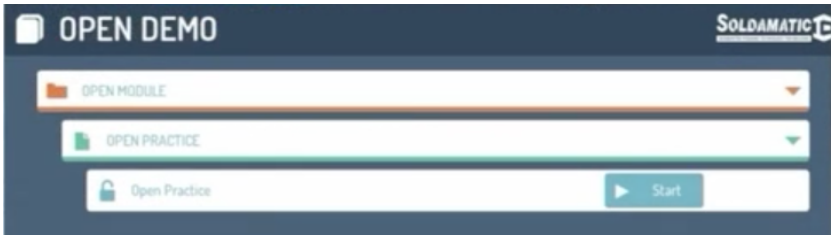
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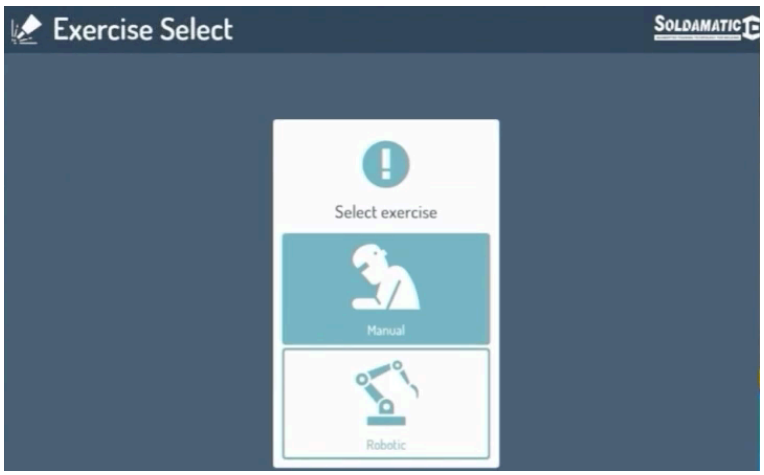


3. Configure the exercise in SOLDAMATIC

You must enter in Open practices for demo and configure the exercise that the robot is going to carry out.



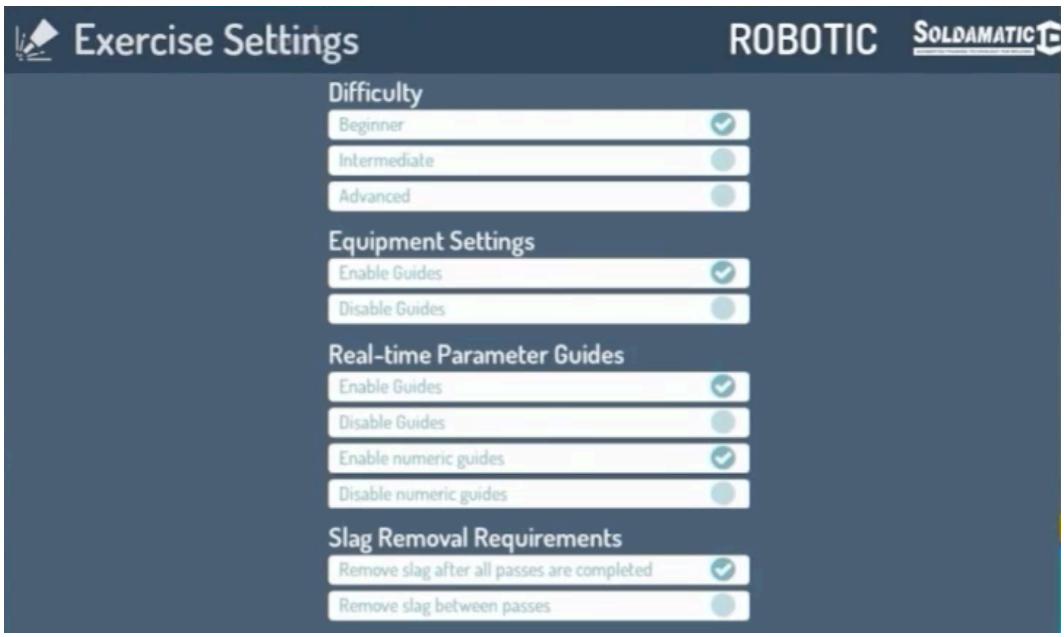
In this case, you will select "Robotics" and create the exercise in the same way as we do in manual welding.



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Exercise settings



Difficulty
There are **3 levels** and each level makes the bead assessment more restrictive. Each parameter has an "objective" value and a range that delimits what is "allowed". The difficulty adjusts that range to make the exercise assessment less permissive.**The greater the difficulty, the less margin of error**, in other words, the user should get closer to the objective value.

Choose advanced level

Equipment Settings
You may activate or deactivate the on-screen indicators that appear during the exercise referring to voltage, wire speed, amperage, gas, etc. Some users may prefer to hide them in order to make experience seem more real.

You will also have to choose if you prefer the exercise to begin with the equipment parameters correctly adjusted or not. If you choose the second option, the exercise will not begin until the equipment adjustments are the correct ones.

Choose disable guides and set correct equipment values at start

Real-time Parameters Guides
This refers to the on-screen guides the user finds to perform the welding practice correctly. You can deactivate this option if you consider them not necessary because you are an expert welder.

Choose enable guides

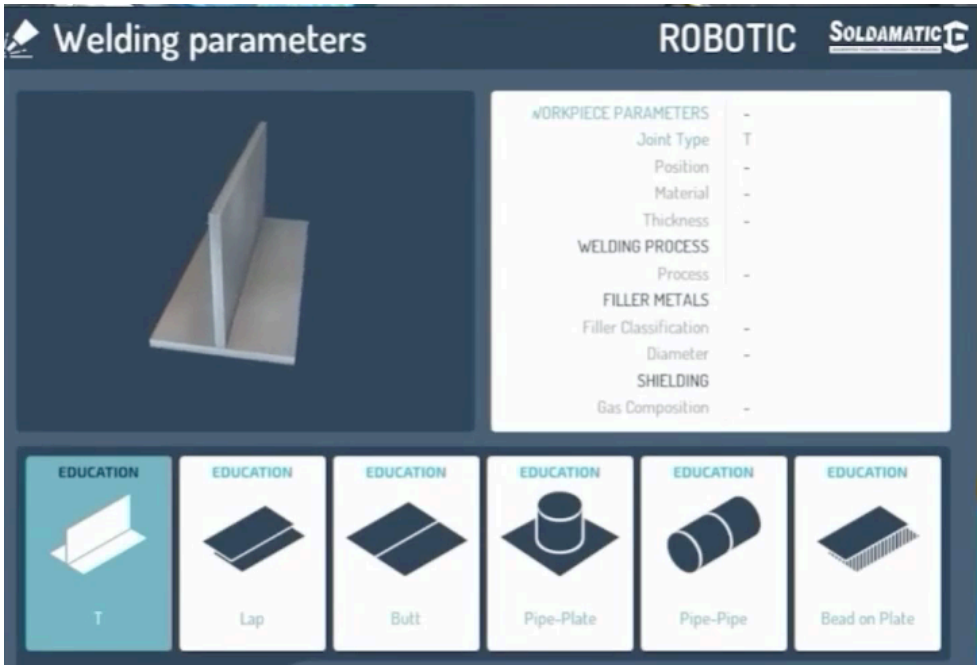
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Slag Removal Requirements
You many choose to clean the slag in between passes or do it after you have completed them. This option will activate only in the **SMAW-MMA** and **FCAW** processes.

Choose remove slag after all passes are completed

Welding parameters



- Next, we have to select some of the parameters that intervene in the exercise.
- The system will guide you through so you will not leave any without being marked.
- The screens show you each one of them in an easy and intuitive way.
- We will begin by choosing the Coupon we are going to weld: *Choose T angle plate to plate joint*

After choosing the coupon the following screens will appear:



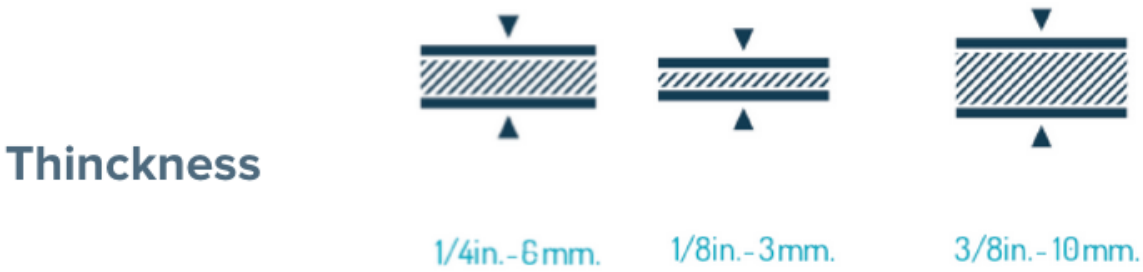
Choose PB position

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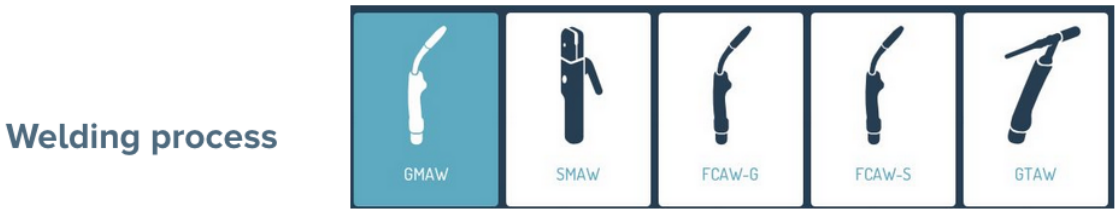


Choose Carbon steel



Choose 1/8in- 3mm

After choosing the coupon the following screens will appear:



Choose GMAW



The system only allow you to choose ER70S-6

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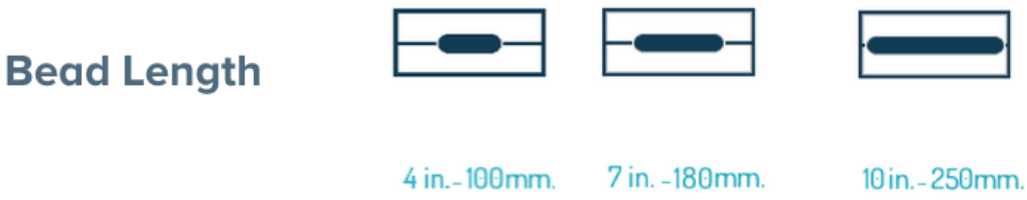
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Choose ,030in-0'8mm



Choose Argon-CO_2



Choose 10in-250mm

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Choose 1 pass



Choose straight



Choose continuous



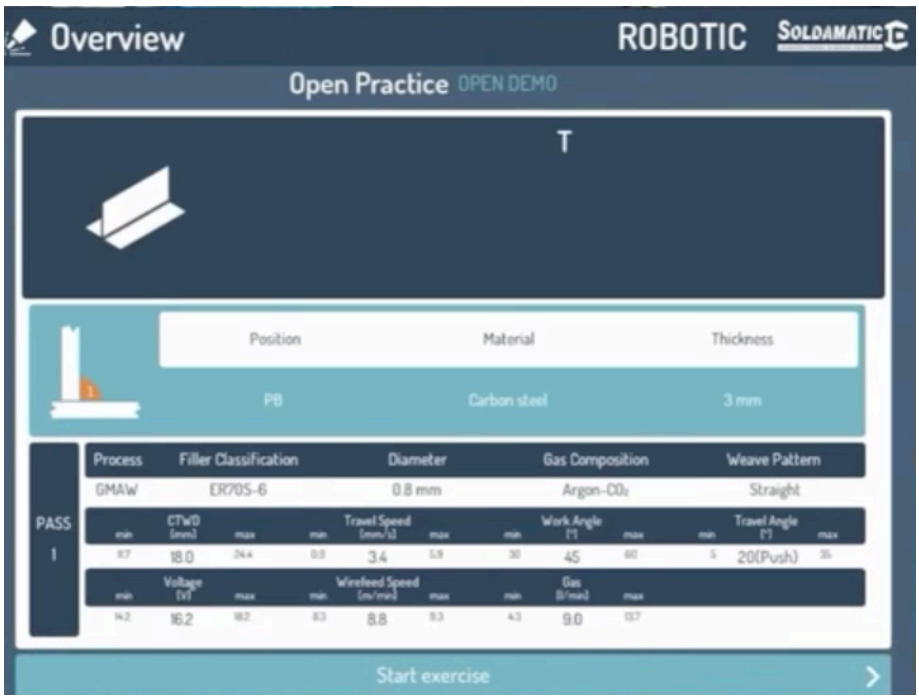
Choose push

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Overview

Now you already have all the necessary parameters to begin doing the exercise.
You will see a summary of them in this screen.
You will be able to review all parameters that appear in this WPS and if there is one you want to change, you may go back pressing the **Cancel button.**



Getting ready for the welding practice





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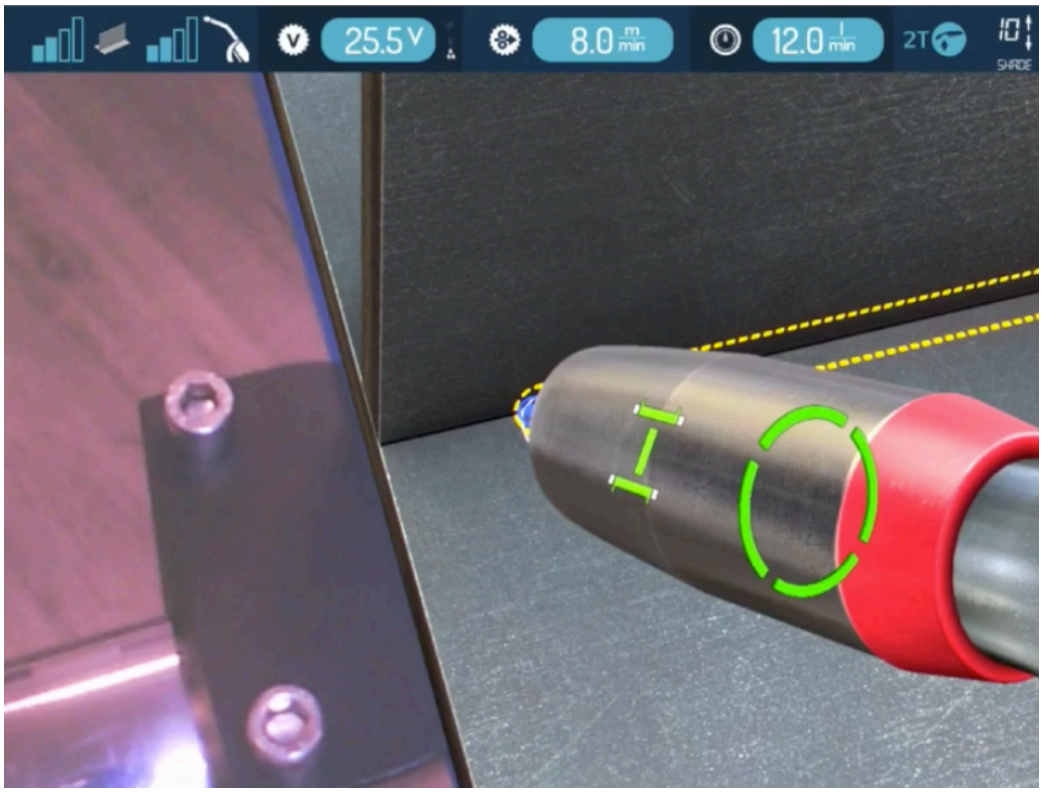
NOTE

If we take a piece different from the one selected in the exercise configuration the system will not recognize it, you will have problems for the mask to detect it correctly and you will not be able to start the exercise. It is also important that there are no other pieces nearby that may interfere when generating the AR.

4. Let´s Weld

You perform the exercise configured in the robot's Teach Pendant to trigger the robot. Now you can see how we simulate a weld with the integrated robot.

You can also see the positioning of the torch along the entire path and the different numerical aids: work angle, travel angle, and CTWDAs we can see on the metal piece there are some arrows and marks in red, yellow, blue and green. These signs are the Help Icons that will guide us during the exercise to give us information about the correct way to execute the Welding.



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5. View results

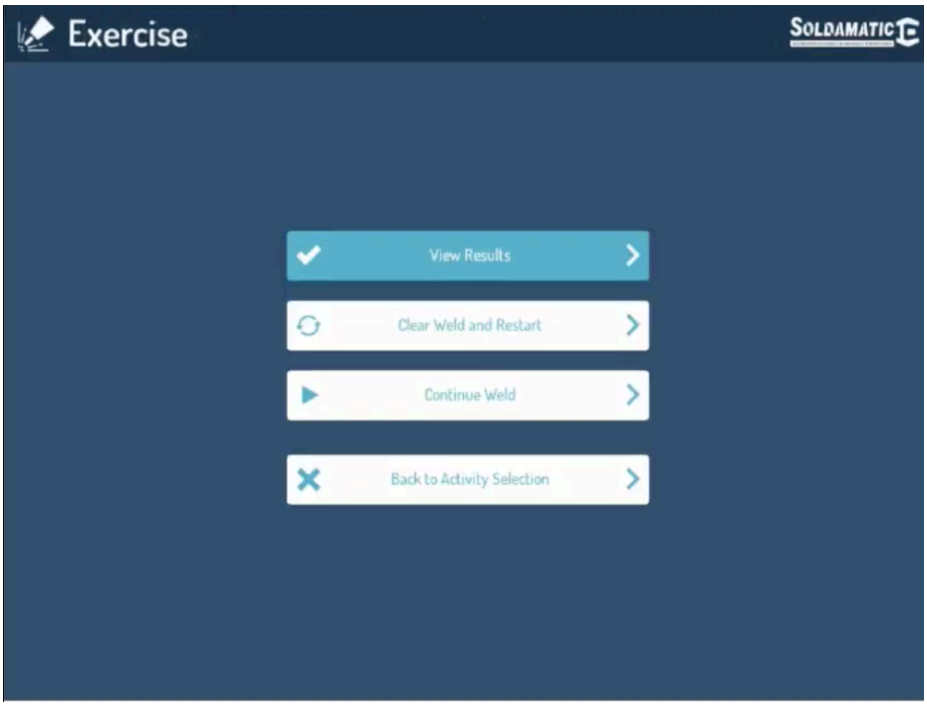
Analysis module

Soldamatic has a system that collects all the data of the execution of the weld bead for later analysis.
It will give us details of each analyzed parameter that we could hardly see in the real weld.
This will allow us to know in more detail what are the aspects that the student should improve, and therefore, we will be able to design reinforcement exercises that focus on these aspects.
In addition, it contains the video reproduction of the execution from different angles, as well as a view of the piece in 3D.

We call this system the Analysis Module, and you have access to it once the exercise has been completed.

As we have seen previously, at the end of the weld bead we must press the Cancel button on the front panel to confirm that we have finished.

Next, the system gives us the following options:



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View result
If we click on this option all the results will be saved and we will access the Analysis Module that is available in both the simulator and the e-learning platform.

Clear Weld and Restart
The data of the exercise carried out will not be saved and you can start again.

Continue Weld
We will press this option if we want to review what we have done before confirming the exercise.
If you don't like the result, you can repeat it.

Back to Activity selection
This option takes us back to the Open Demo screen or to the course we are in.

Interpreting results

Once in the Analysis Module, we will see the following graphic.
Let's detail which information is given by each of the options it is composed of.



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Scoring

It indicates the score obtained as a result of an equation that takes into account the parameters, equipment settings, defectology and everything that is involved in the welding process that makes the bead qualified or not.

✓ will appear if the quality of the bead has achieved the score set by the teacher in the exercise (i.e. 90 points or above); and an X if the score has not been reached.

The total scoring of an exercise is the average of the score of all the passes.

In the previous image we see a total evaluation of 96 points, the minimum required grade was 90, for this reason the welding bead is considered of quality.

The maximum mark would be 100 points.

Technical Parameters

These data are related to each one of the parameters and their progression throughout the exercise performance.

We can press the Ok button to locate ourselves at the desired point on the bead for further analysis.

The white background of the graphs indicates that we have stayed within the values of the range.

And the red background is informing us, that for a period of time (considered excessive) we have gone out of range.

In this image we see that, throughout the length of the bead, the working angle has been brought to an average of 48º. Therefore, we have not gone out of the established range (60º-30º).

The interval will be more closed depending on the exercise's level of difficulty that we have selected. In other words, the greater the difficulty, the lower the range or margin of error.

The total score for this parameter was 98, as shown to the right of the exercise graph.

Pass

It indicates the number of passes that have been carried out and it allows us to analyze each one of them, showing a different graph for each pass.

WPS

Shows the summary of the parameters that are configured for the exercise we are analyzing. It will help us to see, in just one click, the values that have been taken into account for the evaluation.

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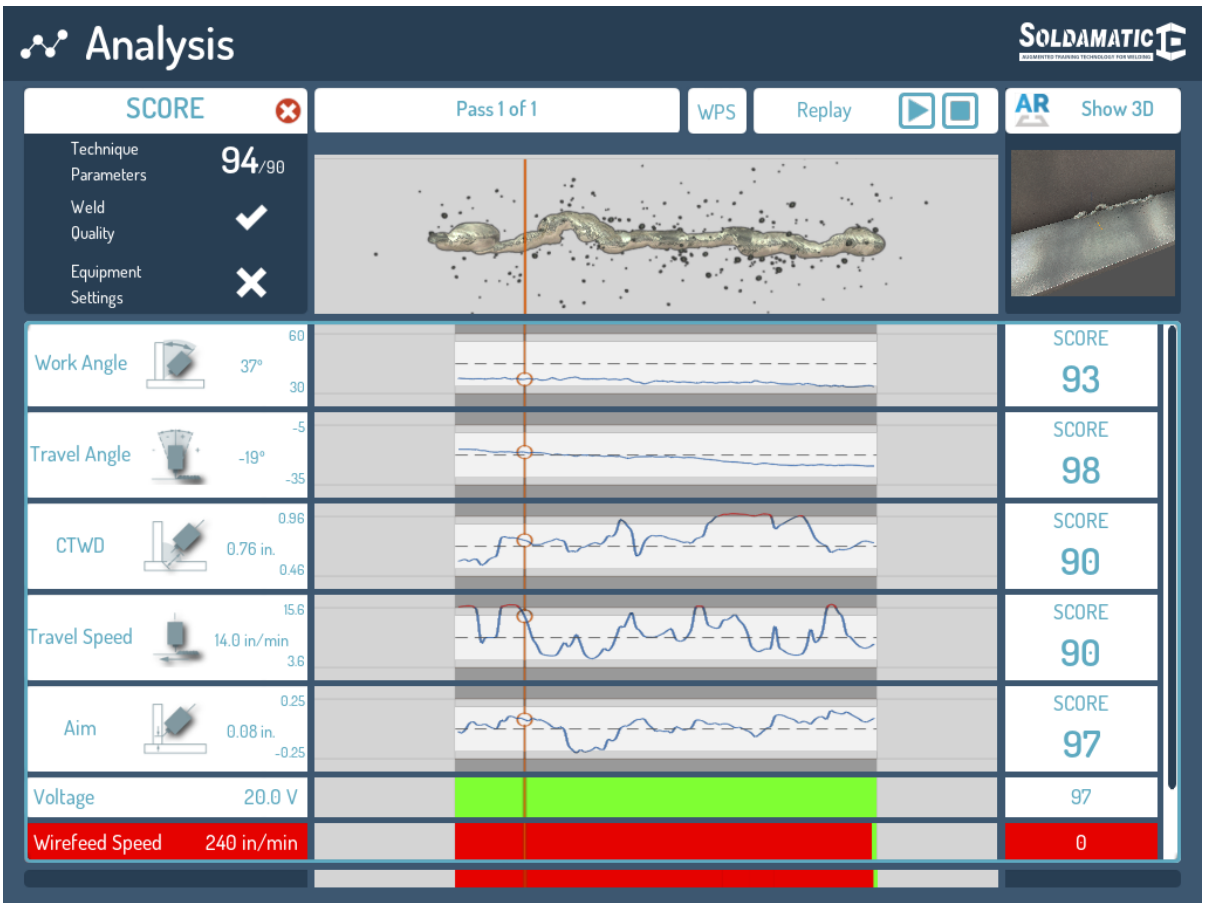
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Replay
This system allows us access to the exercise replay. If we click on this section, we will see how the bead has been performed with all the details from the beginning to the end.
You can start or pause the execution of the video and watch it from different perspectives.

Show 3D
If we were in a real welding workshop, we could take the welded coupon and see its appearance from different angles. If we click on this section, we will see the same, although, we will not be able to touch the coupon, of course.

This graph shows the entire length of the welding bead path and next to it we see the total scoring obtained in each parameter.
When the line is in the grey area of the graph it is shown in red and it means that you have gone out of the marked range. If we see it in the white area, it appears in blue and means that you have stayed within the allowed range.

If we press the **OK button** on the front panel, in this section of the Analysis Module, we will obtain more detailed information about the parameters' progression at each stage of the welding execution. Using the navigation buttons to scroll through the graphs, you will see the obtained values, on the point of the bead that you desire.



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Defects

As we see in the image, the Analysis Module shows data and graph about the **Porosity** of the bead.



The part of the bead where this defect occurs will be shown in red, and the part of the bead that is free of defects will be shown in green.

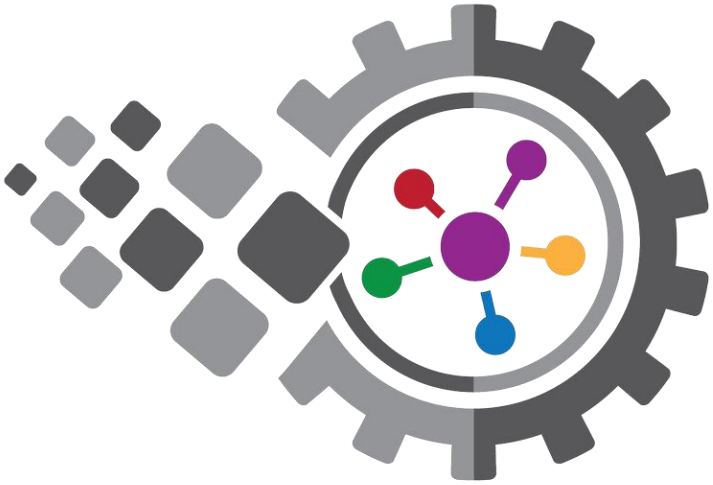
The score will indicate the percentage of the bead where this defect does not occur. For example, a 90% porosity means that in 10% of the bead there is the possibility pores and 90% of the bead is theoretically free of pores.

We will see the same rating when evaluating (depending on the welding process) the **Spatters** and **Contamination defects.**

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Quality Assurance and Quality Control in AM
Case study

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Case study: Development of benchmark models to assess the part quality of Fused deposition Modeling

1. Summary

Fused deposition modeling (FDM) is a additive manufacturing technique that allows, by depositing layers of material in the molten state, the construction of 3D models. The quality of the resulting models is significantly affected by the process parameters. This case study aims to analyze the effect of various process parameters such as the layer height, printing temperature, print speed, retraction, print direction, among others on the process quality. To attain this goal, it will be necessary to develop a methodology for assessing Geometrical accuracy and mechanical properties of parts produced by FDM using PLA as filler.

2. Introduction

Additive manufacturing techniques consist in creating 3D geometric models by layering. Various technologies can generate 3D models of additive manner, layer by layer. Benchmarking is the process of identifying the highest standards of excellence for products, services, and processes. It is the systematic measure of a process against a well-established and the implementation process, and then adopted referenced functions or processes that are more effective. The term is also used in identifying best practices or manufacturing processes. Organizations that use benchmarking strategies effectively can achieve time savings, with improved quality.

Additive fabrication techniques are relatively new technologies for manufacturing 3D models where the models are built directly from a CAD file. With the help of benchmarking, the ability of a particular system can be tested, measured, analyzed, and verified through a standardized procedure using standard models. Various benchmarking models were designed and developed in the last decade, primarily to evaluate the performance of rapid prototyping systems and specific processes. Kruth models proposed by [1], Juster and Childs [2] were developed to test the geometric precision, symmetry, parallelism, repeatability, straightness, roundness, cylindricity. Benchmarking can be used in order to help identify suitable to different kinds of parts manufacturing parameters.

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Most benchmark studies published to date typically involve the production of a model for each instance of material and process. In addition to the process and material, there may be other factors such as the specific print parameters that may affect the accuracy and finish of the workpiece. This research analyzes the print parameters, specific to technology - FDM. In summary form, the objective of the study is to develop reference models and procedures for benchmarking assessment of additive manufacturing systems in terms of geometrical and mechanical characteristics.

2.1. Benchmarking Models in AM Evaluation a review

Benchamarking models have been developed to evaluate the performance in order to optimize additive manufacturing systems. One of the first models was produced by Kruth (1991) which evaluated the performance and the possibility of application in four additive manufacturing processes (SLA, SLS, FDM and LOM) using a benchmarking model that contained inclined protrusions cylinders [1]. Gaggiulo (1992) presents a model with only intention to be tested in SLA technology equipment. Its symmetrical design allows an analysis of linear precision. All geometries are planar and do not test geometric tolerances related to circularity, roundness and concentricity. [3] Juster and Childs (1994) proposed a model of a more complex benchmark allowing to evaluate the performance of various manufacturing additive technologies (SLA, SLS and LOM FDM) in terms of dimensional accuracy, geometric tolerances, repeatability and manufacturing limitations. This model included hubs, vertical and horizontal holes [2] Still in same year Aubin (1994) presents results with a benchmark model initiated by IMS - Intelligent Manufacturing Systems. The objective of this model was to characterize commercially available rapid prototyping technologies, identifying economic factors and technical capabilities. The benchmarking part consists of holes, thin walls and free forms. [4]. Xu Fen (2000) presents a model that allows to evaluate dimensional precision horizontal (XY plane). This study consisted of a model with multiple thin walls, grooves, bumps and cylinders [5].
In order to characterize and measure different characteristics, Mahesh (2004) identifies three different types of benchmark models. According to Maesh (2004), models of geometric benchmark are defined as a way to evaluate a system or technology in terms of geometric accuracy, ability to manufacture certain geometries, repeatability and roughness. Mechanical benchmarking intended as a way to evaluate different materials and mechanical properties of the models produced due to the way they were manufactured (density, position on the board, layer height).

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Process benchmarking is intended as a way to evaluate and optimize the parameters of the manufacturing process. The optimization of parameters usually depends on the desired quality or the available time to produce the models. [6].

Scaravetti and Campanelli (2008) sought to improve the process of SLA models using their own benchmarking model. Campanelli determined optimal process parameters in order to minimize dimensional errors, the position and shape relative to the lead CAD model [6] Basically, most models and benchmarking studies are limited by the model size and mostly aim to evaluate processes of additive manufacturing technologies as geometric accuracies, surface roughness and repeatability. The models typically consist of a rectangular base, with various geometric elements such as cylinders, cubes, vertical walls, balls, base overhangs.

3. FDM Process evaluation

3.1.Equipment and material

In the last decade, appeared on the market FDM equipment's quite affordable in terms of cost. The 3D open source "Prusa i3" printer was developed under the RepRap [7] project. The goal of the RepRap project was to develop a 3D printer, capable of manufacturing their own components. This type of equipment is focused on creating generic objects, and has received limited literary evaluation. The Prusa i3 printer can be divided into two distinct groups: the drive and the extrusion group. The drive group consists of the horizontal displacement (in the X - Y) of a heated platform with a construction area of approximately 200x200 mm and vertical movement (in the Z direction) of an extrusion nozzle with a maximum overall height of 200mm. In the horizontal axis for each position (X and Y) the motion is made by the system belt - pulley by the action of a stepper motor. The extruder system also uses a stepper motor which rotates a toothed shaft which grips the filament and forces it into the extrusion nozzle. The Z position is made by two stepper motors which control two threaded shafts. The extrusion group uses a filament of 3mm thickness. The extrusion nozzle heats up the filament at a set temperature and has a diameter of 0.5mm. The equipment is controlled via USB connection to a computer capable of running the software CURA. The material used was PLA (polylactic acid) in the form of filament. PLA is a thermoplastic aliphatic polyester derived from renewable resources such as corn starch, cassava roots and sugar cane.

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3.2. Geometric Benchmark Model

Geometrical benchmaking models are intended as a way of evaluating a system or technology in terms of geometric accuracy, ability to manufacture certain geometries, repeatability and roughness [9]. In order to be able to assess and quantify features of the proposed model, two distinct geometric benchmarks models were developed:

a) Benchmark of exterior geometries.
b) Benchmark of interior geometries

The benchmark of exterior geometries has several geometric figures and details, each having a different purpose of evaluation. The geometric features proposed in this model were designed with the following purpose: The square base supports all geometries and serves to evaluate flatness. The size of the base is 100x100x2.5 mm in order to be possible to produce in most of the FDM equipments. Five cubes are used to measure linear precision, flatness, parallelism, and repeatable position on the base. The distance between these and the parallelism can be measured between their faces which are symmetric. A half sphere serves to evaluate sphericity and its symmetry, and the sphericity is measured in terms of its area. The cylinders evaluate roundness and concentricity against the inner cylinder. The cone evaluates the taper and is measured as a function of their area. The vertical walls evaluate the minimum possible thickness to achieve with a vertical geometry, as well as parallelism. The towers intend to evaluate the angularity.

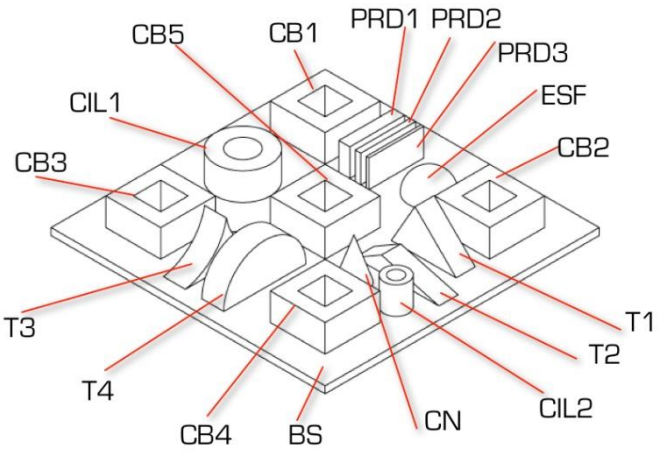


Figure 1 – Design of the benchmark model used to evaluate the external geometries

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Table 1 - Summary of features from the Benchmark model of external geometries

Features	Purpose	Dimensions LxCxH / RxH (mm)
(Cube) CB1 CB2 CB3 CB4 CB5	Linear precision, Flatness, Parallelism, Repeatable position	5x (20x20x10)
(Thin Wall) PRD1 PRD2 PRD3	Minimum possible thickness, Parallelism	1- (4x20x10) 2- (2x20x10) 3- (1x20x10)
(CIlinder) CIL1 CIL2	Roundness, Concentricity	1 - raio 20 x 10 2 - raio 8.8 x 10
(Tower) T1 T2 T3 T4	Angularity	1- 60° /45° 2 - 30°/ 15°
(Conce) CN	Taper	raio 5 x 15
(Half sphere) ESF	Sphericity, Symmetry	raio 15 x 15
(Base) BS	Flatness	100x100x2.5

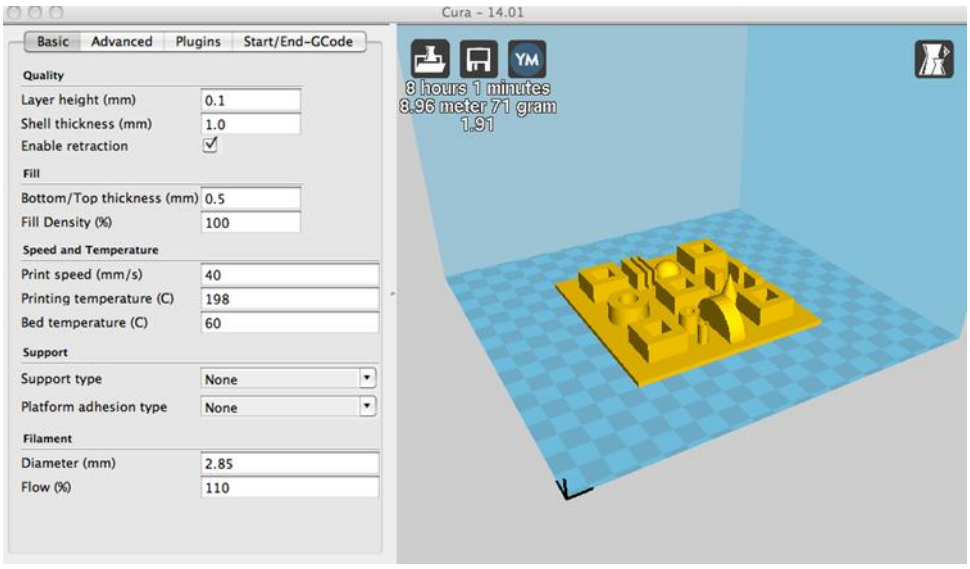


Figure 2 – CURA software Interface used to print

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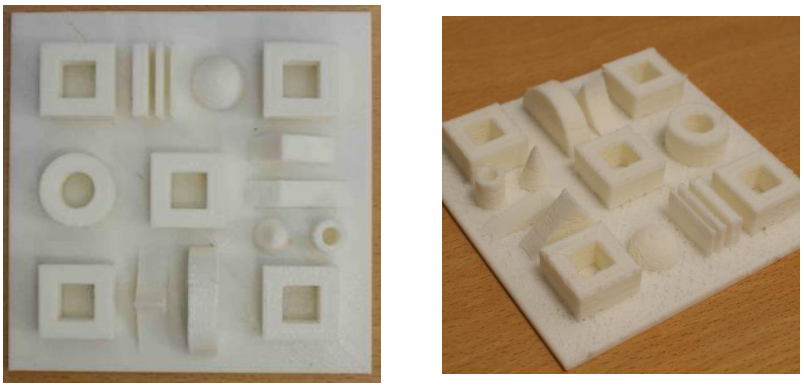


Figure 3 – Example of some printed Benchmark models of external geometries

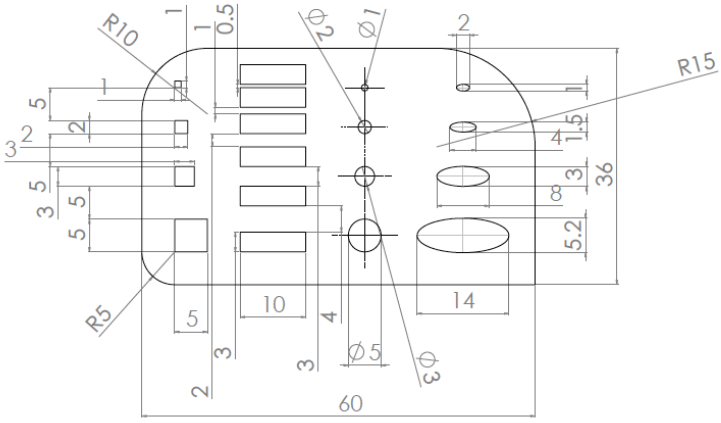
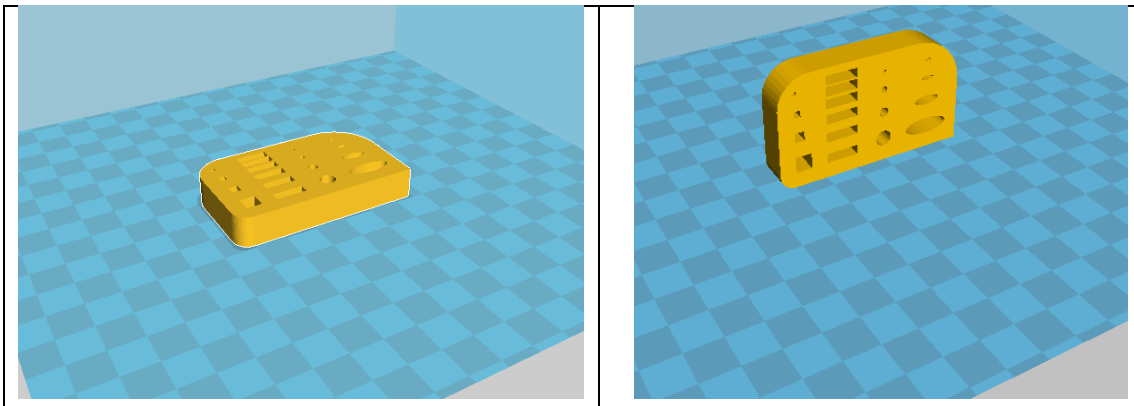


Figure 4 – Design of the benchmark model used to evaluate the internal geometries



Holes in the direction of deposition - HOR	Holes perpendicular to deposition - VER

Figure 5 – benchmark model being prepared in Cura software to evaluate the internal geometries

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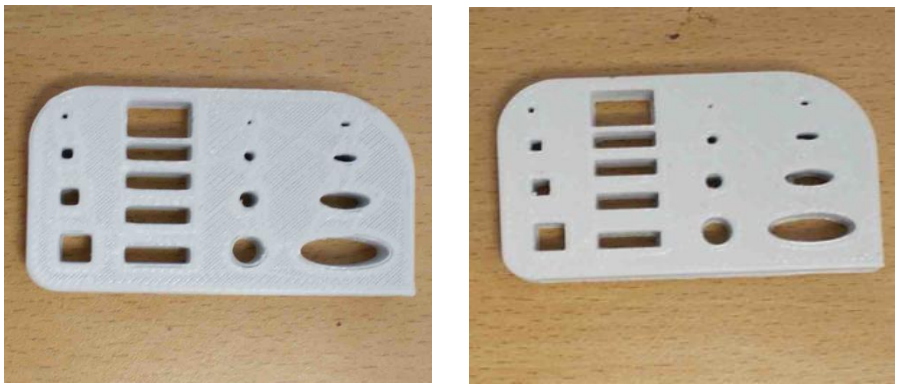


Figure 6 – Example of printed benchmark models used to evaluate the internal geometries

In order to achieve a more profound influence on the variation of parameters, the benchmark model of interior geometries allows to evaluate the ability to produce holes.

3.3.Results concerning dimensional accuracy

Face the study and characterization developed in the benchmark model of exterior geometries, it is possible to highlight the following conclusions regarding the variation of the printing parameters:

- A reduction of the height of the layer produced smaller deviations from the CAD model in the vertical direction (Z axis) as well as minor deviations in the angles of T1 and T2. Parallelism and flatness values also improved due to the decrease of the height of the layer.
- An increase in speed has the greatest deviation for virtually all geometries as well as a worse visual finish
- The printing temperature has a tendency to change the level of geometric accuracies
- The retraction has had a major influence on trim visual level however due to flaws in their geometries the evaluation was compromised
- An increase in acceleration presents a better finish on the visual level
- The temperature of the base platform has influence on the warping of the produced model
- The choice of location for the model to be produced on the building platform has influence on the accuracy of the final model
- Only a few geometries presented in the geometric model are reliable in terms of evaluation. Considering the study and characterization developed in the benchmark interior geometry model, it can be highlight the following conclusions regarding the variation of the printing parameters:
    - The reduction in layer height produce larger holes for the square and circular geometries
    - An increase in printing speed has produced smaller holes, in some cases it is not

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possible to produce the holes with smaller area A temperature increase produced holes smaller area for the square geometry, and this trend is not observed in other geometries

- The direction has enormous relevance on the model quality. Holes should be produced preferably in the direction of the extrusion head - horizontal direction

4. Mechanical characterization

4.1. Tensile test

The specimens were constructed according to EN ISO 527-2 (Geometry 1A) in 3 different directions with contour of 1mm thick.

The results are the mean of 3 samples per test. Pieces being built in the X and Y direction had the highest mechanical strength values, and in the Z direction due to the welding between the layers not being strong enough, had the lowest resistance values. According to Bagsik [38] the results obtained from the change of the direction of printing are very similar. The variation of the layer height influenced the values obtained with the tensile test. For a decrease of this parameter increases the mechanical strength. Basir [10] reports the same results from the change of the layer height. The decrease in the density of the model resulted in a decrease of mechanical strength in all directions of printing.

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Table 2 - Summary of results from the tensile test

Ref.	Layer height	Density	Build direction	σ_f (MPa)	ε_f (%)	σ_m (MPa)	ε_m (%)	E (GPa)	$\sigma_{0,2\%}$ (MPa)
D1	0.3	100	X	47,57	3,00	50,45	2,07	3,19	44,87
D2	0.3	100	Y	48,15	3,17	53,33	2,15	3,27	47,02
D3	0.3	100	Z	19,58	0,64	19,58	0,64	3,04	0
D4	0.2	100	X	49,04	4,10	55,27	2,14	3,31	48,74
D5	0.2	100	Y	49,72	2,97	52,74	2,14	3,23	46,72
D6	0.2	100	Z	35,69	1,10	35,69	1,10	3,51	0
D7	0.1	100	X	50,70	4,40	58,60	2,15	3,46	50,60
D8	0.1	100	Y	50,30	2,47	53,25	2,13	3,27	46,94
D9	0.1	100	Z	15,76	0,44	15,89	0,45	3,65	0
D10	0.2	50	X	29,04	4,62	31,48	2,19	1,99	26,95
D11	0.2	50	Y	29,47	3,59	31,068	2,20	1,98	26,68
D12	0.2	50	Z	20,12	0,86	20,12	0,86	2,58	0
D13	0.2	25	X	26,25	2,89	27,77	2,12	1,79	24,02
D14	0.2	25	Y	27,91	2,78	28,46	2,07	1,88	24,99
D15	0.2	25	Z	12,21	0,81	16,02	0,81	2,07	0

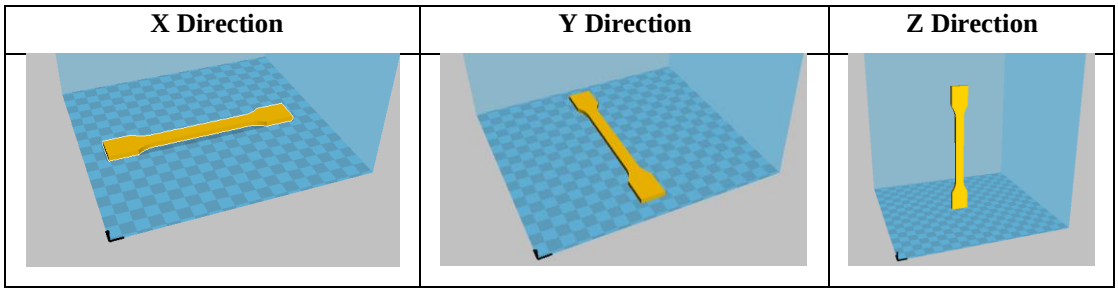


Figure 7 - Directions of fabrication of tensile test specimens



Figure 8- Specimen detail printed in z direction

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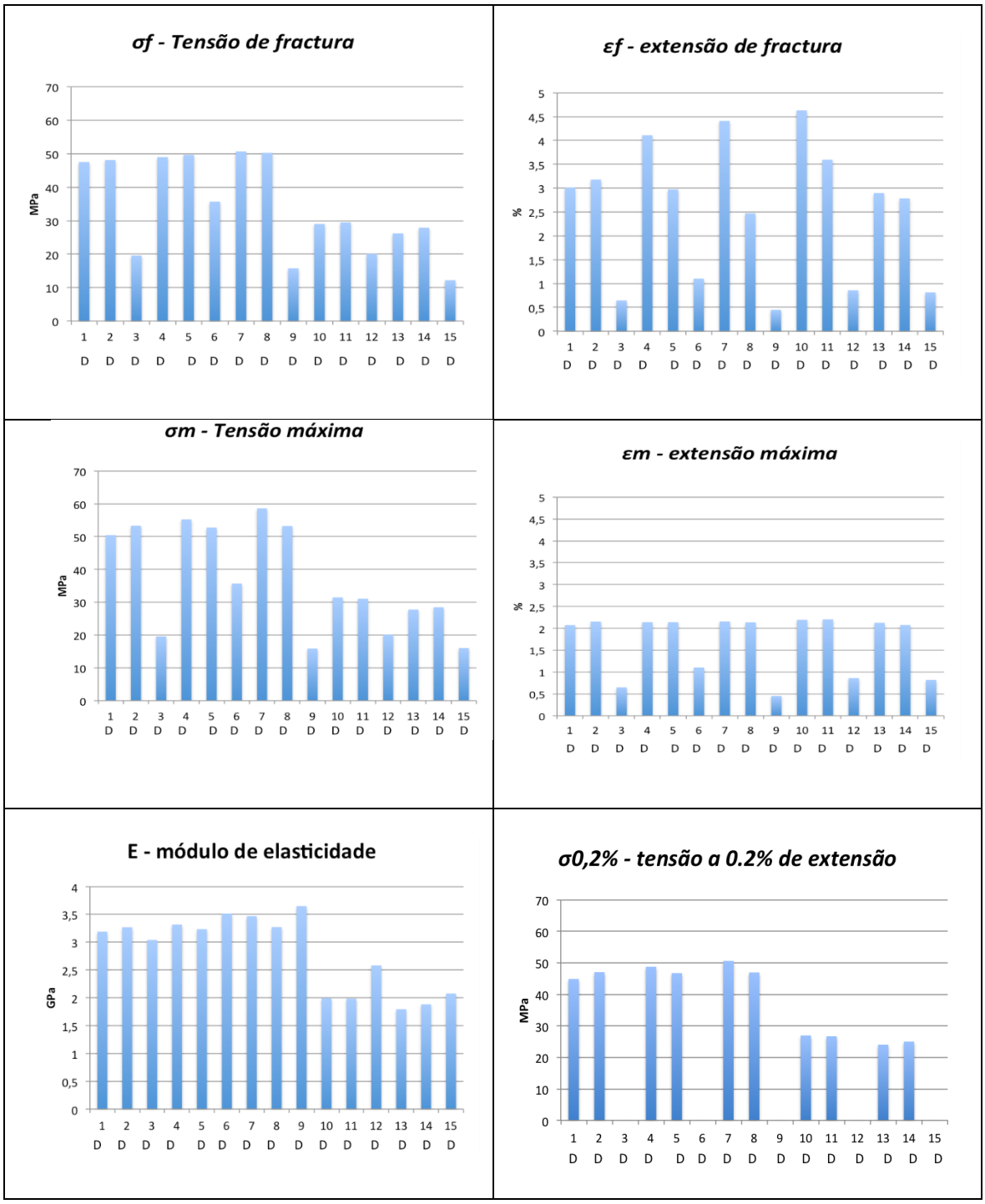


Figure 9 – Plots representing the tensile test results

4.2. Compression test

The compression test pieces were produced according to ASTM with a cylindrical geometry (10mm

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in height, h 7mm diameter d). Its manufacturing was carried out in two different directions. The experimental compression tests allowed quantifying some mechanical properties depending on the printing parameters. The variation of a parameter will have an impact on the mechanical properties of the constructed model [11-13]. There is a need to compare the mechanical strength for all samples and since not all cracks opened, a value of a nominal length of 30% was established as a basis for comparison for all.

The mechanical strength values of the samples built in the X / Y direction are higher than those constructed in Z. The tensile modulus (E) presents higher values for the X / Y direction compared to the direction Z. The decrease in layer height produces increased mechanical resistance test specimens, in all directions. The decrease in density makes mechanical strength values lower. According to Bagsik [14], the same results are obtained from the change of build direction.

Table 3 - Summary of results from the tensile test

Ref.	Layer height	Density	Build direction	σ_c (MPa)	E (GPa)	$\sigma_{30\%}$ (MPa)
E1	0.3	100	X/Y	76,48	2,18	77,24
E2	0.3	100	Z	74,40	1,41	77,62
E3	0.2	100	X/Y	88,17	2,31	103,07
E4	0.2	100	Z	80,33	1,47	90,48
E5	0.1	100	X/Y	100,05	2,54	113,05
E6	0.1	100	Z	94,33	1,58	109,09
E7	0.2	50	X/Y	57,93	1,61	70,26
E8	0.2	50	Z	50,20	1,15	0
E9	0.2	25	X/Y	42,53	1,23	37,41
E10	0.2	25	Z	39,56	0,84	29,97

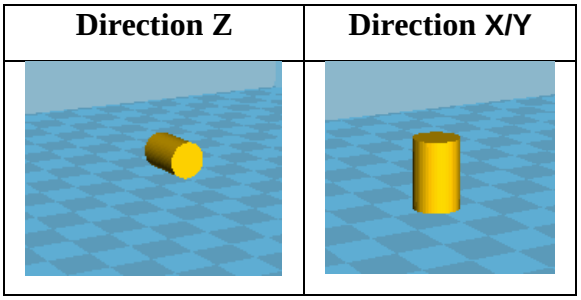


Figure 10 - Directions of fabrication of compression test specimens

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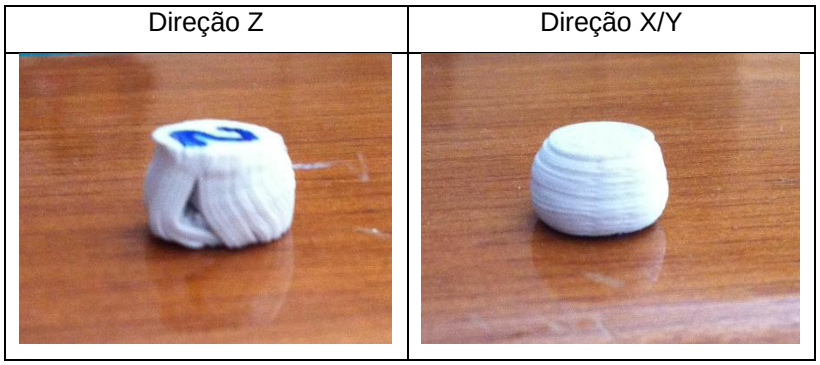


Figure 11 - Compression specimens manufactured in different directions after tested

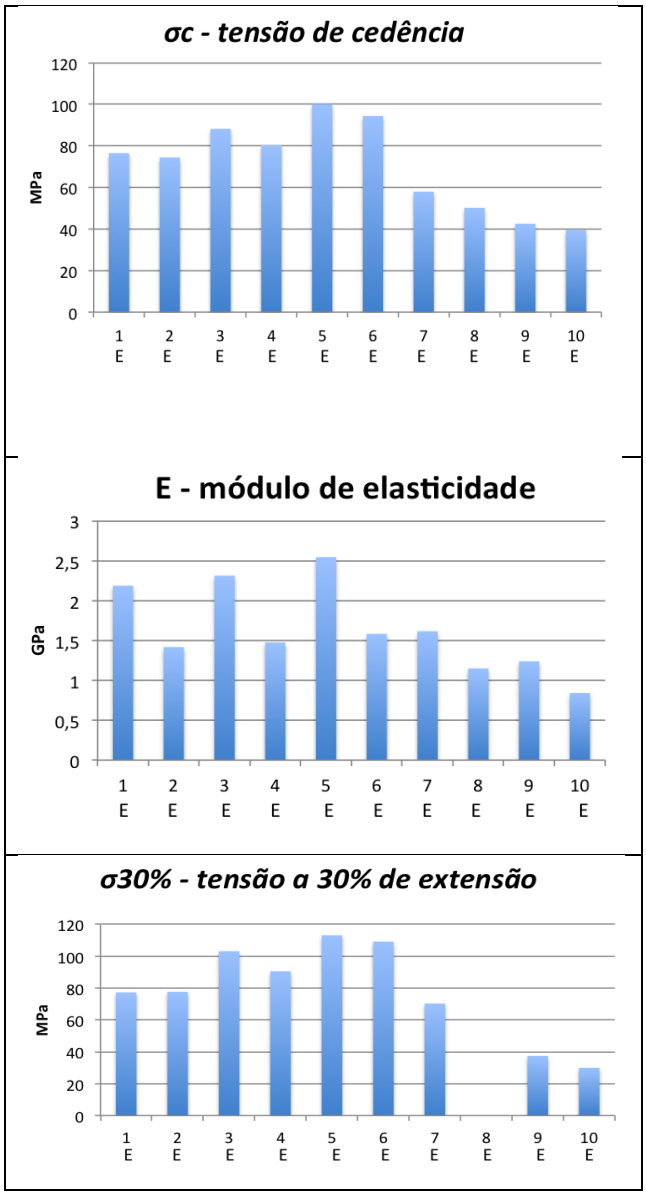


Figure 12 – Plots representing compression test results

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5. Conclusion

This case study aims to analyses the influence of different printing parameters on part quality for that and has therefore been developed and standardized geometrical benchmark models and mechanical testing specimens.

The findings of this case study relate to:

i) the characterization of the 3D printing process through an FDM machine.

ii) the geometric characterization through the analysis of benchmark developed models

iii) the characterization of the mechanical properties of normalized parts according to different production parameters. The results obtained under the characterization of 3D printing using an FDM equipment in the construction of models with different geometries have shown that:

- Not all geometries present in the benchmark model of external geometries were subject to a consistent trend of variation. Cubic, cylindrical and tower forms have shown consistent results over elaborate study. The cone, half sphere and the thin walls did not follow consistent trends of change
- Similarly, as with the benchmark model of external geometries, with the model of interior geometries also limitations in the model were discovered, and mostly just the square geometry followed a pattern of variation as a function of a variation of the printing parameters

In general, it is concluded that the printing parameters have influence on the mechanical and geometrical properties of the produced model, with:

- In assessing the benchmark of exterior geometries, parameters as the layer height and print speed are those that most influence the offset value of the model produced against the CAD model.
- A decrease in layer height produces a more defined model in the Z axis (perpendicular to the platform), and a speed increase produces a model with fewer definition in all axes. Parameters such as the retraction and acceleration only had a impact on the visual level. In the evaluation of the benchmark of interior geometries, parameters as the layer height, printing speed and printing temperatures are those that most influence this type of geometries (holes).
- A decrease in layer height, lower printing temperature and lower print speed produces the best accuracy results.
- The mechanical behavior of a part is also influenced by the printing parameters. The print direction about the vertical Z axis, always presents results of mechanical strength much lower than in other directions. For a lower layer height, the models have greater mechanical strength.

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Digital Manufacturing Master Degree to set specialists for the dawn of the Industry 4.0



BOARD OF BARGE IN SOLDAMATIC
Case study

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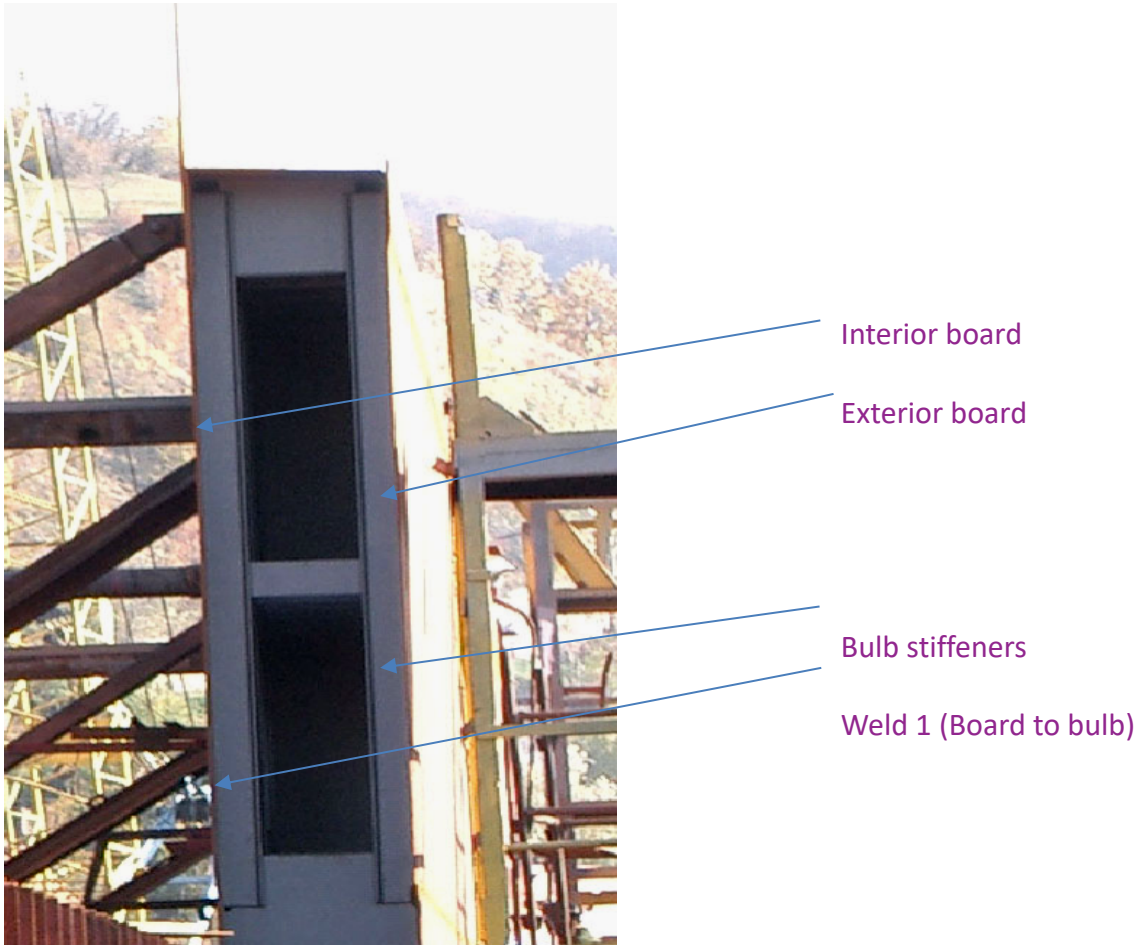
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CASE STUDY

Board of barge – WPS weld 1
Interior or exterior board to the bulb stiffeners

The board of a barge is component of a ship having fillet and butt joints. The fillet welds are used to create the shape of the board and the stiffening of the board.
According to the figure, the interior/exterior board to the bulb stiffeners from the section are fillet weld. Due to that:

The objective of this case study is to know how to set up and perform a simulated welding practice on Weld of board (interior or exterior) to bulb stiffeners in SOLDAMATIC.



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SOLDAMATIC



Is the name of the simulator where the Augmented Reality welding practices are performed.
Both its external elements (welding torches, helmet, etc.) and its functionalities (welding sound reproduction, vision module, etc.) have been designed to make this experience as close to reality as possible. Module.

The simulator has been designed to be configured according to European Standards (based on the **EWF** regulations), American Standards (based on the **AWS** regulation); and **Metric and Imperial system.**

STEPS

In order to carry out this type of welding in SOLDAMATIC, you will have to follow these steps:

1. Choose the torch

The welding process is 136 Flux Cored Arc Welding so you need to choose **FCAW Torch**



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2. Choose the welding joint

Fillet weld is in PF position so you need to choose **T angle plate to plate joint**



3. Configure the exercise in SOLDAMATIC

Exercise settings

Difficulty
There are **3 levels** and each level makes the bead assessment more restrictive. Each parameter has an "objective" value and a range that delimits what is "allowed". The difficulty adjusts that range to make the exercise assessment less permissive.**The greater the difficulty, the less margin of error**, in other words, the user should get closer to the objective value.

Choose advanced level

Equipment Settings
You may activate or deactivate the on-screen indicators that appear during the exercise referring to voltage, wire speed, amperage, gas, etc. Some users may prefer to hide them in order to make experience seem more real.

You will also have to choose if you prefer the exercise to begin with the equipment parameters correctly adjusted or not. If you choose the second option, the exercise will not begin until the equipment adjustments are the correct ones.

Choose disable guides and set correct equipment values at start

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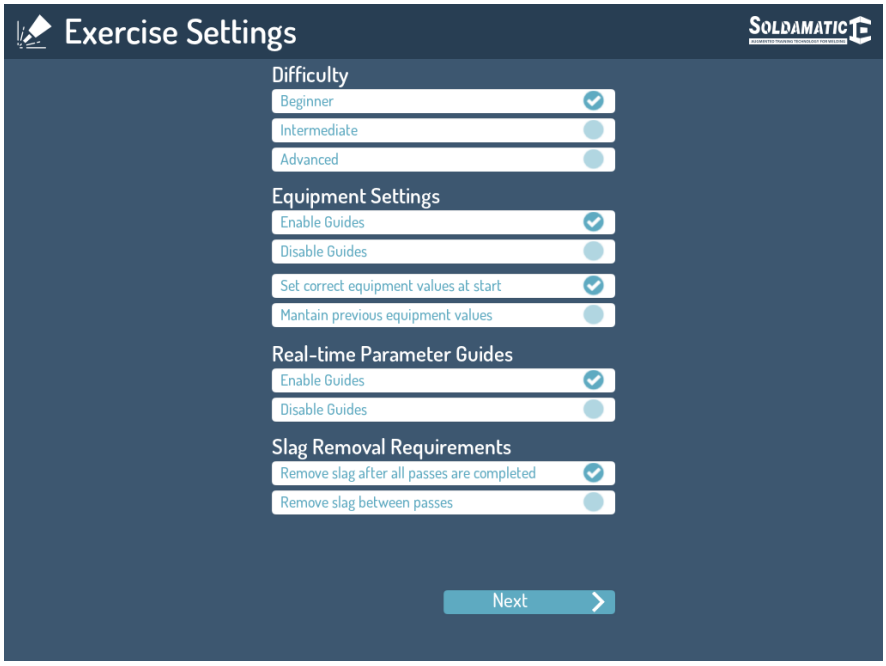
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Real-time Parameters Guides
This refers to the on-screen guides the user finds to perform the welding practice correctly. You can deactivate this option if you consider them not necessary because you are an expert welder.

Choose enable guides

Slag Removal Requirements
You many choose to clean the slag in between passes or do it after you have completed them. This option will activate only in the **SMAW-MMA** and **FCAW** processes.

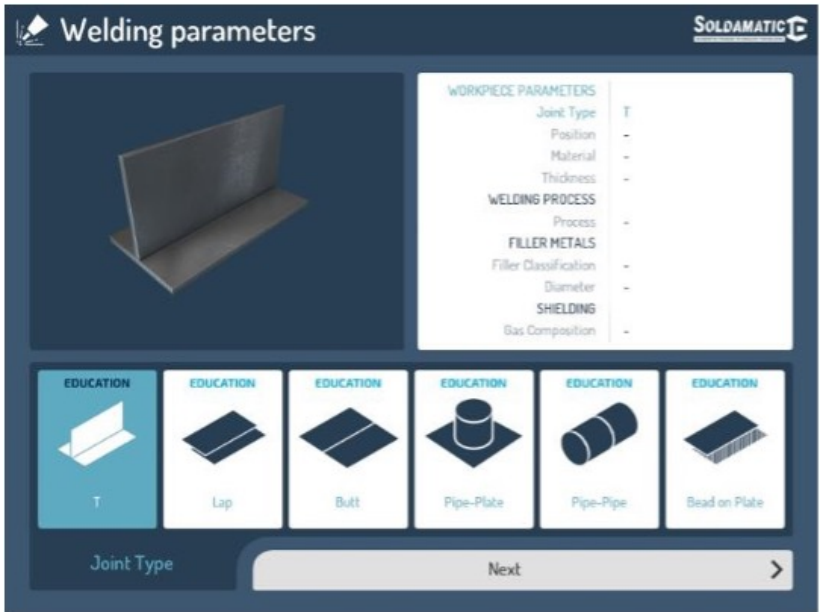
Choose remove slag after all passes are completed



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Welding parameters



- Next, we have to select some of the parameters that intervene in the exercise.
- The system will guide you through so you will not leave any without being marked.
- The screens show you each one of them in an easy and intuitive way.
- We will begin by choosing the Coupon we are going to weld: *Choose T plate*

After choosing the coupon the following screens will appear:



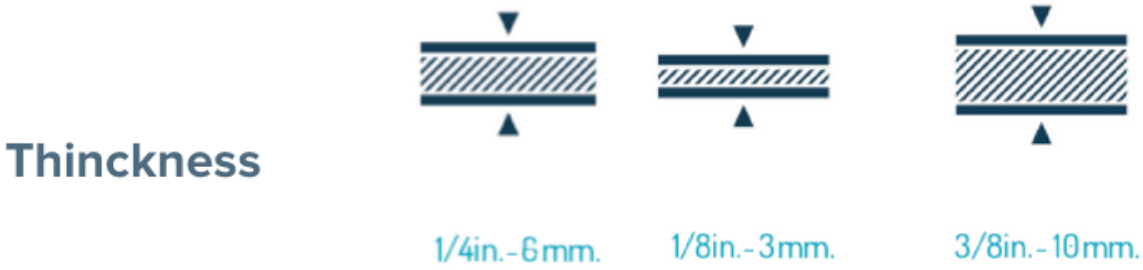
Choose PF position

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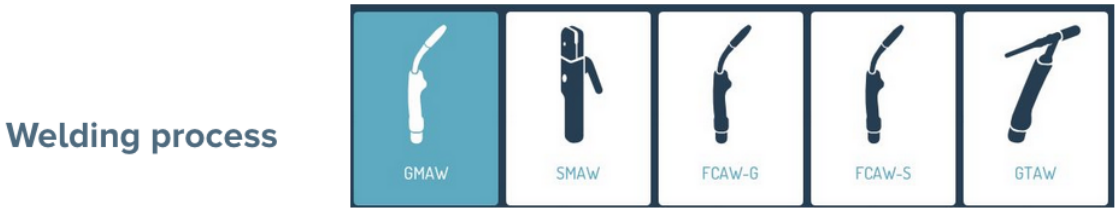


Choose carbon steel



Choose 1/8in- 3mm

After choosing the coupon the following screens will appear:



Choose FCAW-G



The system only allow you to choose ER70S-6

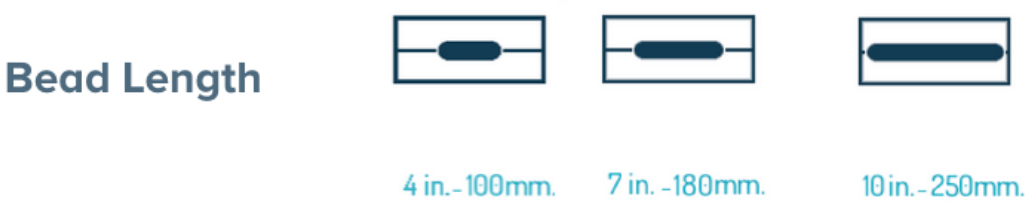
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Choose ,045in-1'2mm



Choose CO_2



Choose 7in-180mm

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Choose 1 pass



Choose straight



Choose continuous



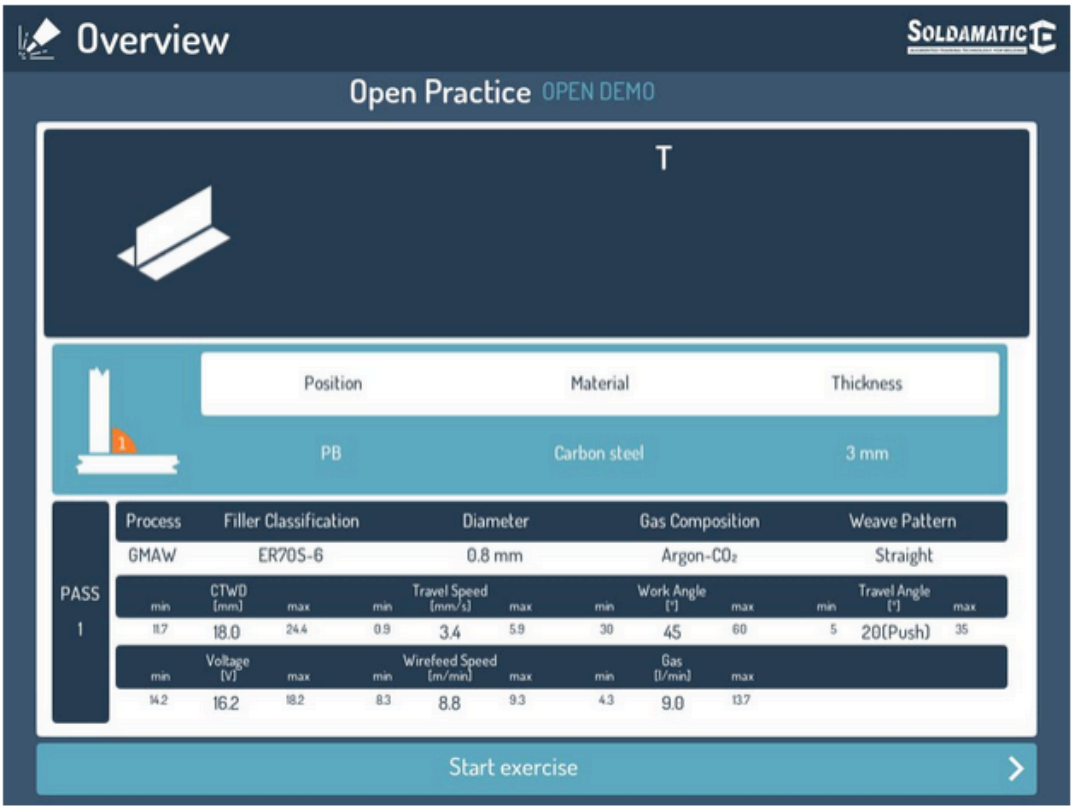
Choose Drag

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Overview

Now you already have all the necessary parameters to begin doing the exercise.
You will see a summary of them in this screen.
You will be able to review all parameters that appear in this WPS and if there is one you want to change, you may go back pressing the **Cancel button.**



Getting ready for the welding practice

You must have well placed (welding position) the same coupon you have chosen in the previous menu.
And you must have corresponding the selected welding process torch connected to the unit.

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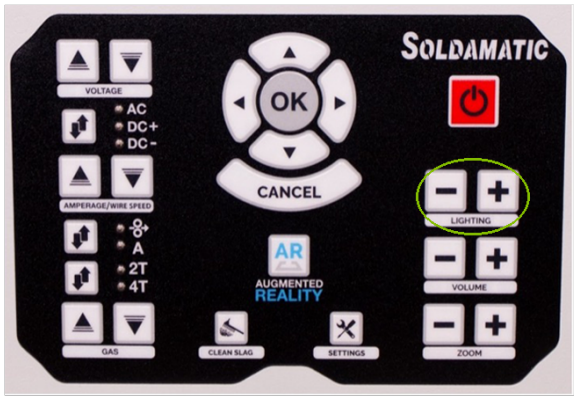


NOTE

If we take a piece different from the one selected in the exercise configuration the system will not recognize it, you will have problems for the mask to detect it correctly and you will not be able to start the exercise. It is also important that there are no other pieces nearby that may interfere when generating the AR.

Light calibration

The first time you use your simulator you must perform the **Light calibration of the helmet** to **adjust the video device settings** (temperature, intensity) based on the room lighting conditions where the simulator is located.
Light is essential *for a proper detection of the coupon and the welding torch, so it is very important that you* ***perform this calibration*** *to ensure the best Augmented Reality experience.*



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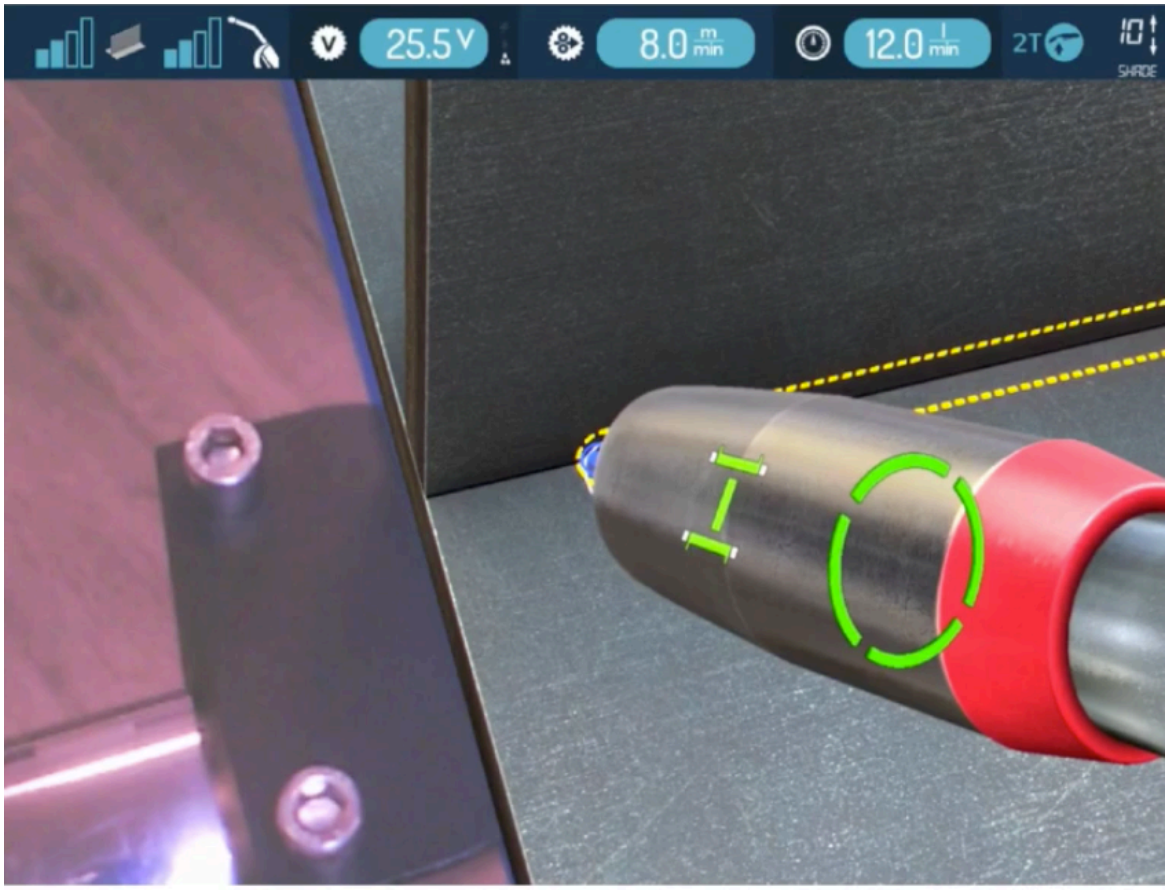
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Helmet LED lights

In the calibration process, the system will find the most adequate intensity so that the mask will be in its optimum point of detection. We recommend maintaining this measure, but if you want more or less light, remember we have on the frontal panel a button +/- to increase or lower the intensity.

4. Let´s Weld

As we can see on the metal piece there are some arrows and marks in red, yellow, blue and green. These signs are the Help Icons that will guide us during the exercise to give us information about the correct way to execute the Welding.



1. Shipbuilding Board of barge - WPS Weld 1

5. View results

Analysis module

Soldamatic has a system that collects all the data of the execution of the weld bead for later analysis.

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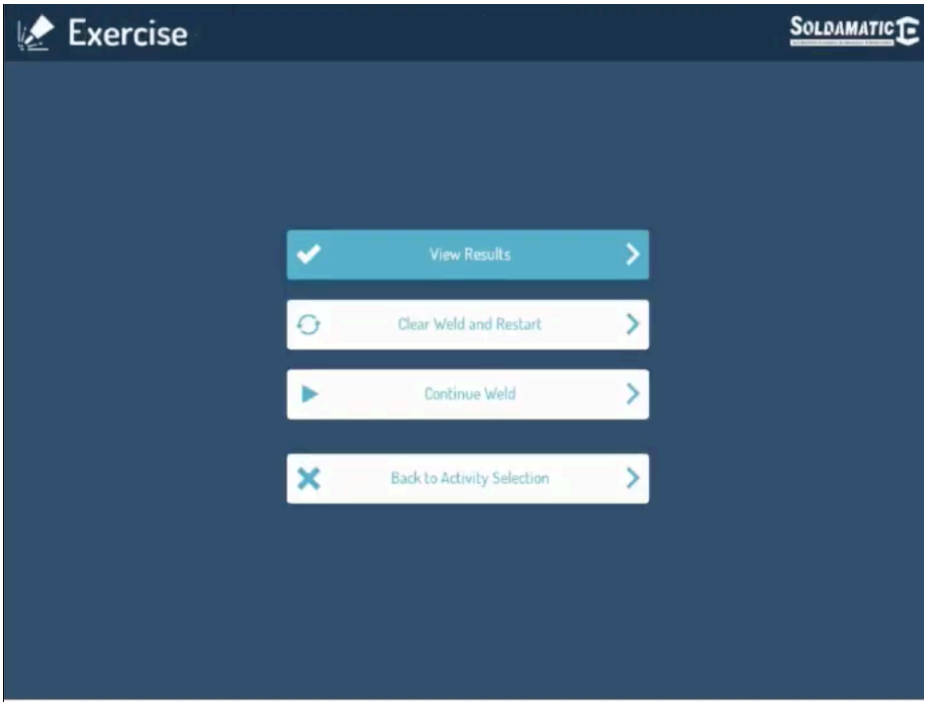
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It will give us details of each analyzed parameter that we could hardly see in the real weld. This will allow us to know in more detail what are the aspects that the student should improve, and therefore, we will be able to design reinforcement exercises that focus on these aspects.
In addition, it contains the video reproduction of the execution from different angles, as well as a view of the piece in 3D.

We call this system the Analysis Module, and you have access to it once the exercise has been completed.

As we have seen previously, at the end of the weld bead we must press the Cancel button on the front panel to confirm that we have finished.

Next, the system gives us the following options:



View result
If we click on this option all the results will be saved and we will access the Analysis Module that is available in both the simulator and the e-learning platform.

Clear Weld and Restart
The data of the exercise carried out will not be saved and you can start again.

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Continue Weld
We will press this option if we want to review what we have done before confirming the exercise.
If you don't like the result, you can repeat it.

Back to Activity selection
This option takes us back to the Open Demo screen or to the course we are in.

Interpreting results

Once in the Analysis Module, we will see the following graphic.
Let's detail which information is given by each of the options it is composed of.



Scoring
It indicates the score obtained as a result of an equation that takes into account the parameters, equipment settings, defectology and everything that is involved in the welding process that makes the bead qualified or not.

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will appear if the quality of the bead has achieved the score set by the teacher in the exercise (i.e. 90 points or above); and an **X** if the score has not been reached.
The total scoring of an exercise is the average of the score of all the passes.
In the previous image we see a total evaluation of 96 points, the minimum required grade was 90, for this reason the welding bead is considered of quality.

The maximum mark would be 100 points.

Technical Parameters
These data are related to each one of the parameters and their progression throughout the exercise performance.

We can press the Ok button to locate ourselves at the desired point on the bead for further analysis.

The white background of the graphs indicates that we have stayed within the values of the range.
And the red background is informing us, that for a period of time (considered excessive) we have gone out of range.

In this image we see that, throughout the length of the bead, the working angle has been brought to an average of 48º. Therefore, we have not gone out of the established range (60º-30º).
The interval will be more closed depending on the exercise's level of difficulty that we have selected. In other words, the greater the difficulty, the lower the range or margin of error.

The total score for this parameter was 98, as shown to the right of the exercise graph.

Pass
It indicates the number of passes that have been carried out and it allows us to analyze each one of them, showing a different graph for each pass.

WPS
Shows the summary of the parameters that are configured for the exercise we are analyzing. It will help us to see, in just one click, the values that have been taken into account for the evaluation.

Replay
This system allows us access to the exercise replay. If we click on this section, we will see how the bead has been performed with all the details from the beginning to the end.
You can start or pause the execution of the video and watch it from different perspectives.

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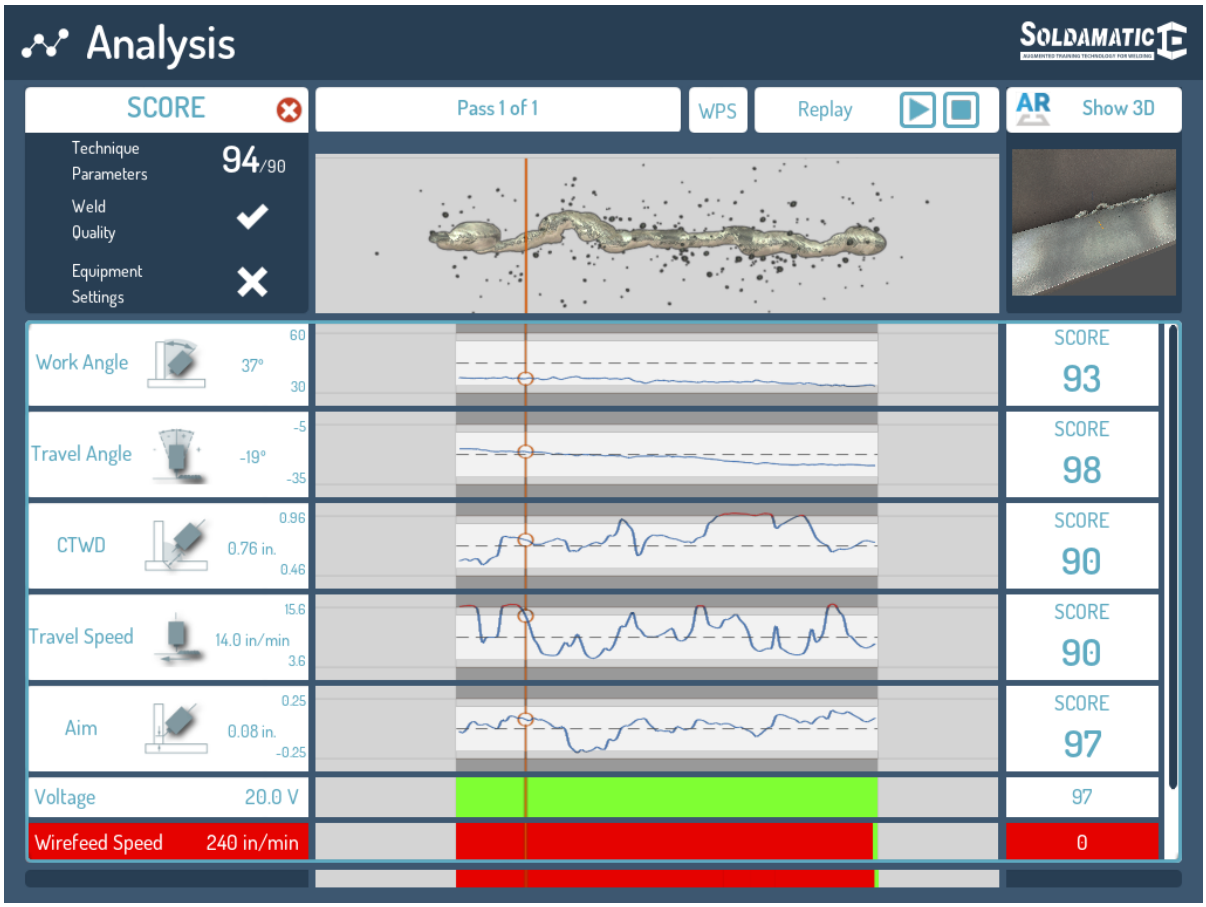
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Show 3D

If we were in a real welding workshop, we could take the welded coupon and see its appearance from different angles. If we click on this section, we will see the same, although, we will not be able to touch the coupon, of course.

This graph shows the entire length of the welding bead path and next to it we see the total scoring obtained in each parameter.
When the line is in the grey area of the graph it is shown in red and it means that you have gone out of the marked range. If we see it in the white area, it appears in blue and means that you have stayed within the allowed range.

If we press the **OK button** on the front panel, in this section of the Analysis Module, we will obtain more detailed information about the parameters' progression at each stage of the welding execution. Using the navigation buttons to scroll through the graphs, you will see the obtained values, on the point of the bead that you desire.



Defects

As we see in the image, the Analysis Module shows data and graph about the **Porosity** of the bead.

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The part of the bead where this defect occurs will be shown in red, and the part of the bead that is free of defects will be shown in green.
The score will indicate the percentage of the bead where this defect does not occur. For example, a 90% porosity means that in 10% of the bead there is the possibility pores and 90% of the bead is theoretically free of pores.
We will see the same rating when evaluating (depending on the welding process) the **Spatters** and **Contamination defects.**

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Case study

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Case study
Computer-Aided Design of a component of a box transmission assembly

Figure 1 presents the assembly of the Box transmission, namely body and lid, together with the mounting bolts and nuts.

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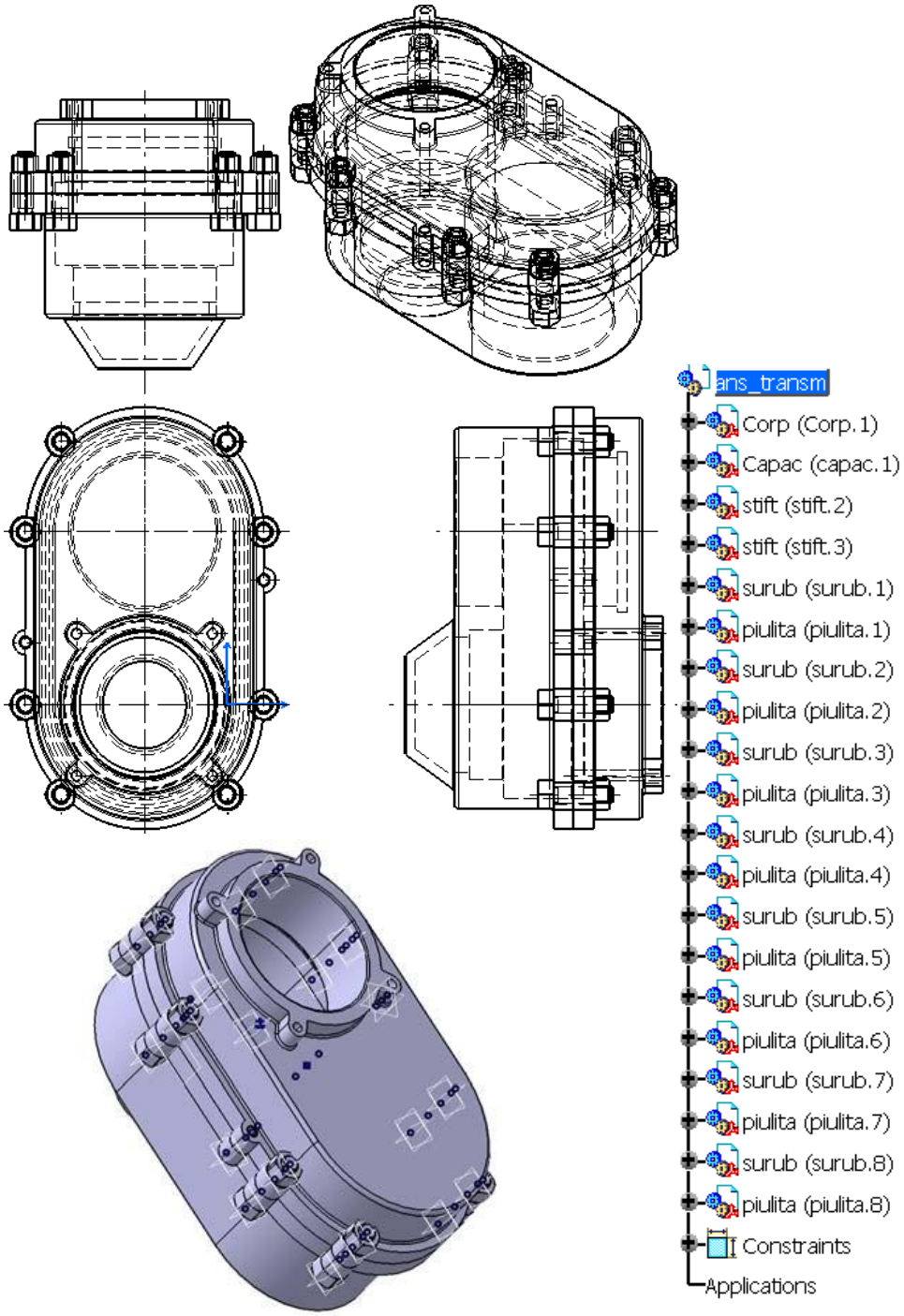


Fig. 1. Transmission assembly and Specification tree

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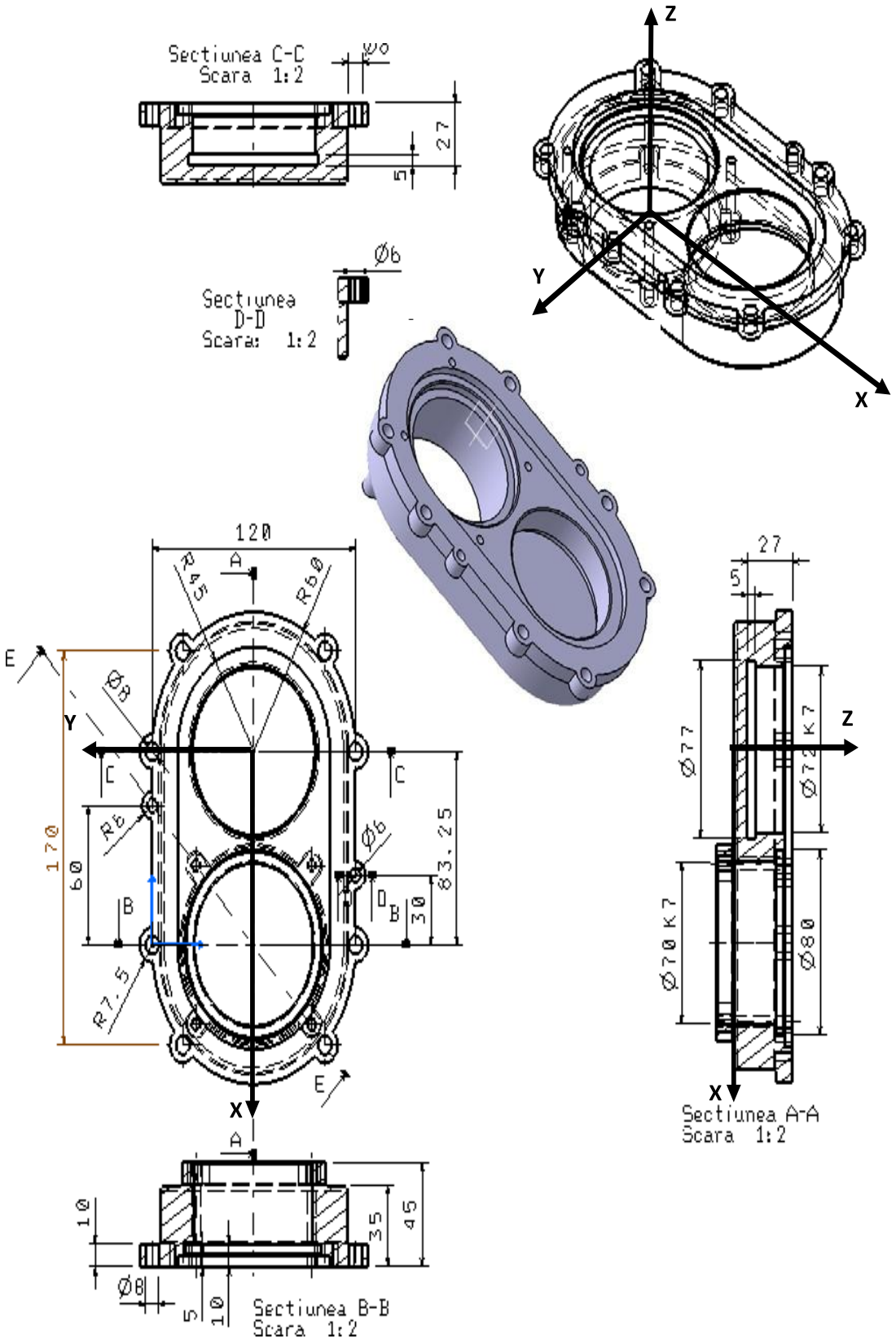


Fig. 2. Reference system attached to the body″

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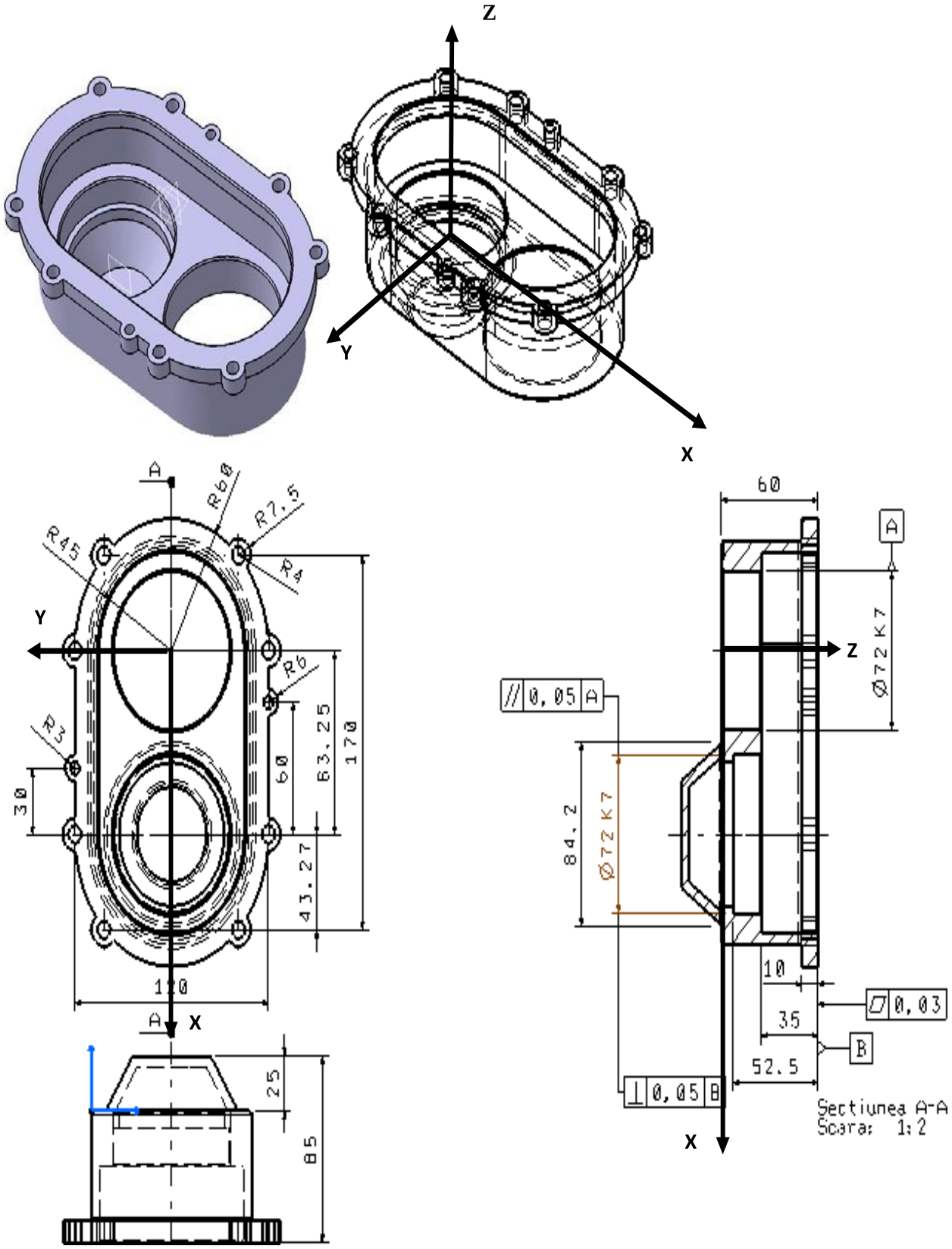


Fig. 3. Reference system attached to the lid

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1. Design of the Lid

A new work session is opened: **CATIA: File>New>Part,** which follows to be saved as "**LID**".

After the selection of the work plane**, XY,** from the **Specification tree**, the icon **"Sketch"** is selected.

In order to develop the sketch, using the submenu, **Profile,** the icon **Profile** is selected. After the sketch development, using the **Constraint** submenu, all the necessary dimensions are attached to the drawing (see below figure 4).

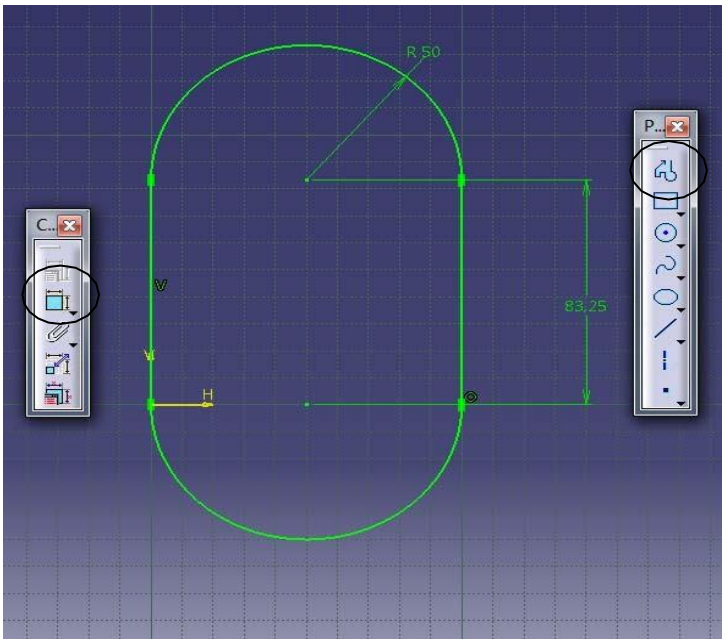


Fig. 4 Attaching dimensions to the drawing

After this step, using the icon **Exit Workbench**, then the **Pad** icon with the **Length** of **50 mm**, the model is obtained (see figure 5).

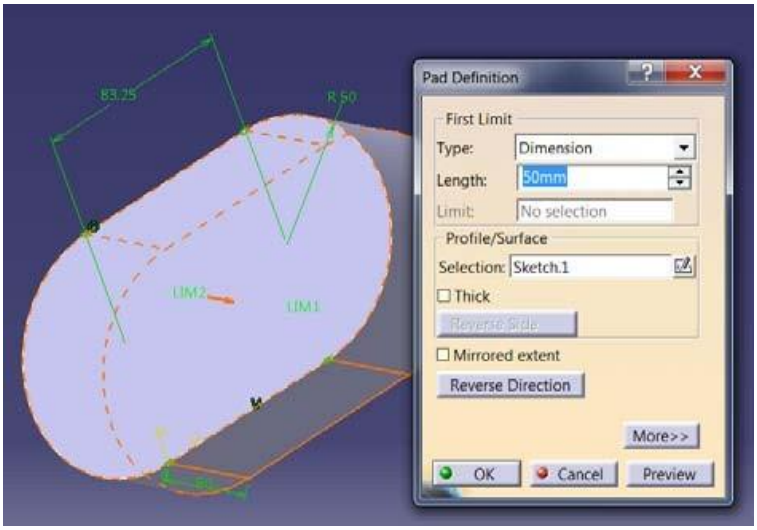


Fig. 5 Obtaining the model from the PAD icon

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In order to develop a new sketch, a new plane is defined. This new plane can be one of the frontal surfaces of the part (inferior or superior surface). After that the **Sketch** icon is selected, a new profile is drawn using the same step as for the first sketch. This new profile will be geometrical and dimensional constrained as in the first step (see below figure).

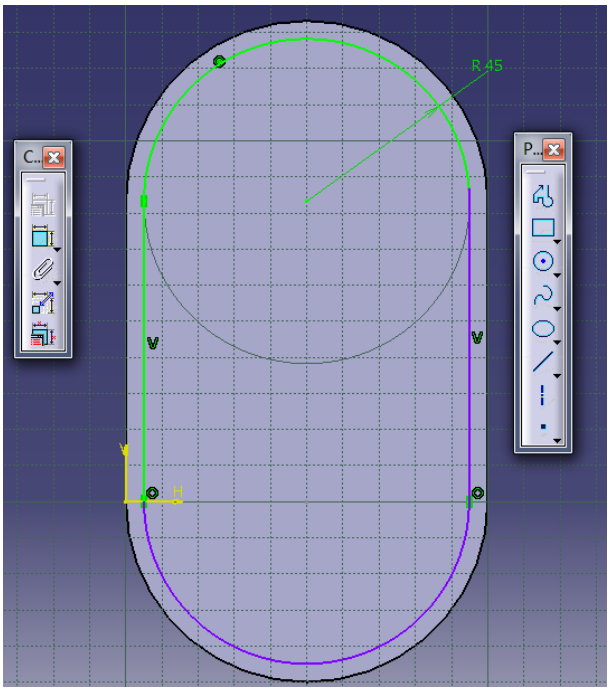


Fig. 6 New profile constraints

Using the **Exit Workbench** icon, and then **Insert - Sketch-Based Feature-Pocket,** a new window is opened (see figure 7). On this window **Depth,** is fixed at **25 mm**.

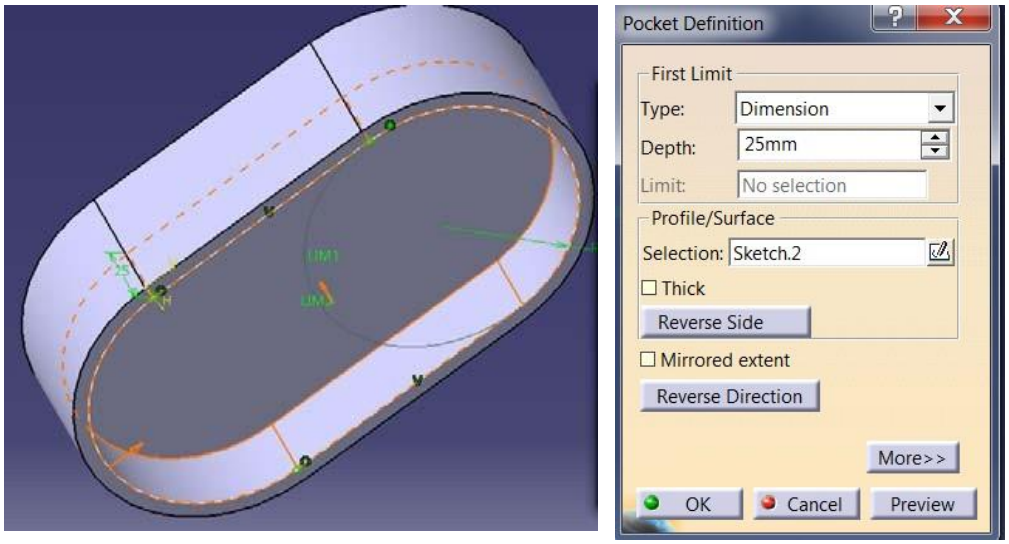


Fig. 7. Pocket definition

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To obtain the conical surface, the first step is to define a new work plane. A new work plane is defined using the **Reference Elements** submenu, where the **Plan** icon is selected (see below figure).

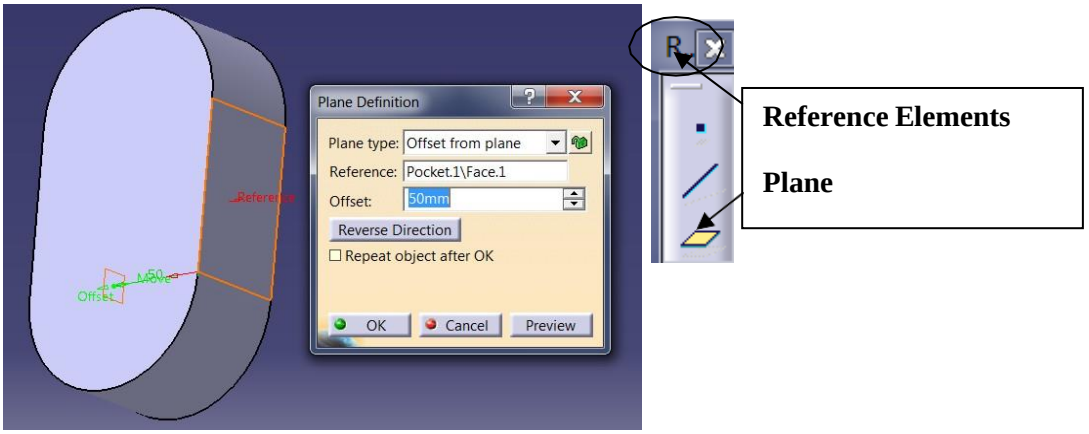


Fig. 8 Plane definition

On the **Plane Definition** window, the **Reference** is fixed as in the above figure andalso, the Offset value must be 50 mm.

Then, the defined plane is selected. By pushing the **Sketch** button, an orthogonal view will allow the drawing for the profile (see below figure). Then, the symmetry axis is drawn. This new profile will be geometrical and dimensional constrained as in the first step (see below figure), using **Constrains** icon.

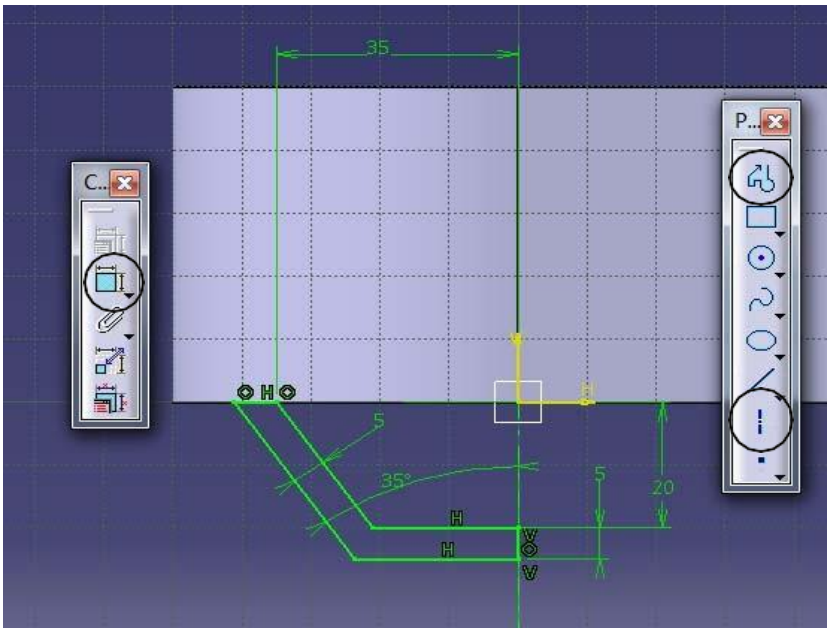


Fig. 9 Constraints applied to the new profile

Using the **Exit Workbench** icon, and then **Insert** > **Sketch-Based Feature** > **Shaft**, thebelow window is opened, where, in the field **Axis, Selection**, the drawn axis is selected.

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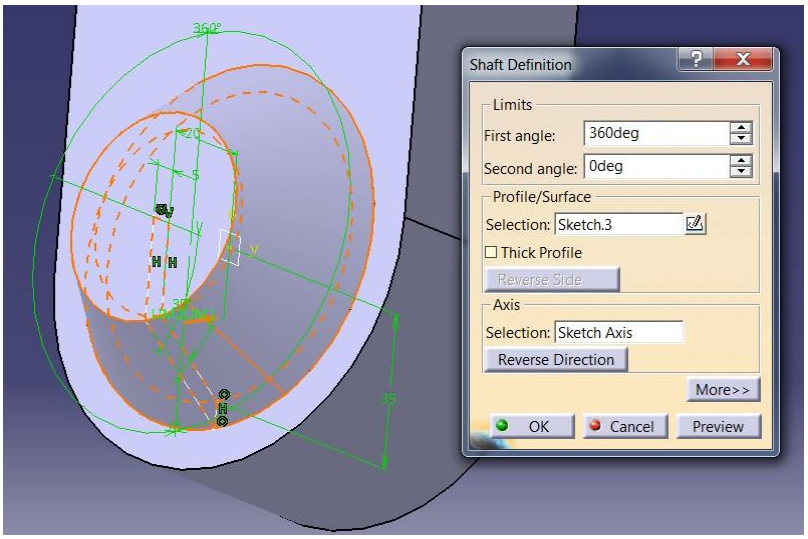


Fig. 10 Drawing axes

To draw the internal cylindrical surface of ϕ**72 mm** diameter, the next steps are followed:

- The part is rotated so that the internal bottom surface of the lid can be viewed.
- Here a new wok-plane is defined, by selecting this internal bottom surface
- The **Sketch** icon is selected and an orthogonal view of the lid will be appear
- By selecting the Circle icon, a circle having ϕ**72 mm** diameter is created.
- A geometrical constrain, concentricity is defined, between the new circle and oneof the cylindrical edges, previously generated (see below figure).

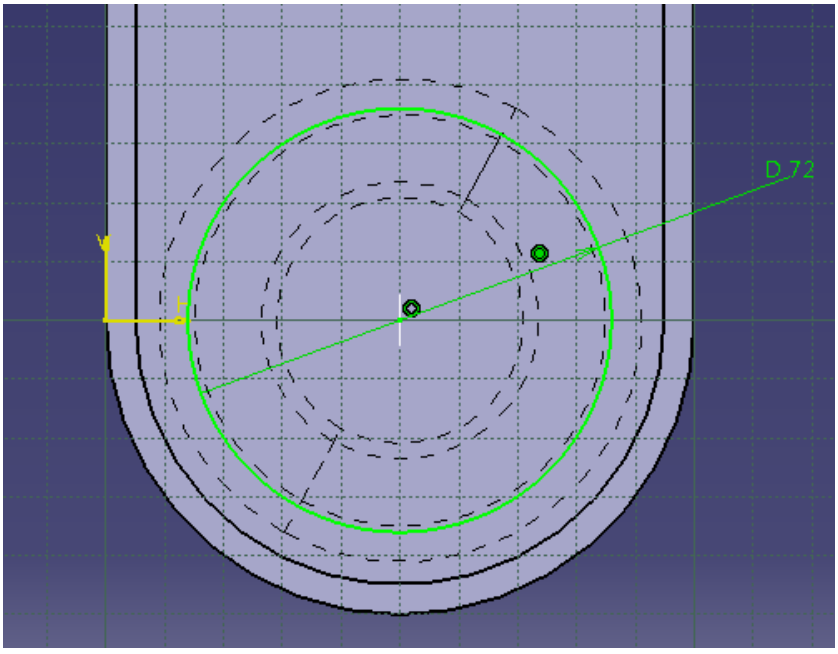


Fig. 11 Creation of 72 mm diameter circle

Using the **Exit Workbench** icon, and then **Insert - Sketch-Based Feature-Pocket** the below window will be opened, where the **Depth** is fixed at **17,5 mm.**

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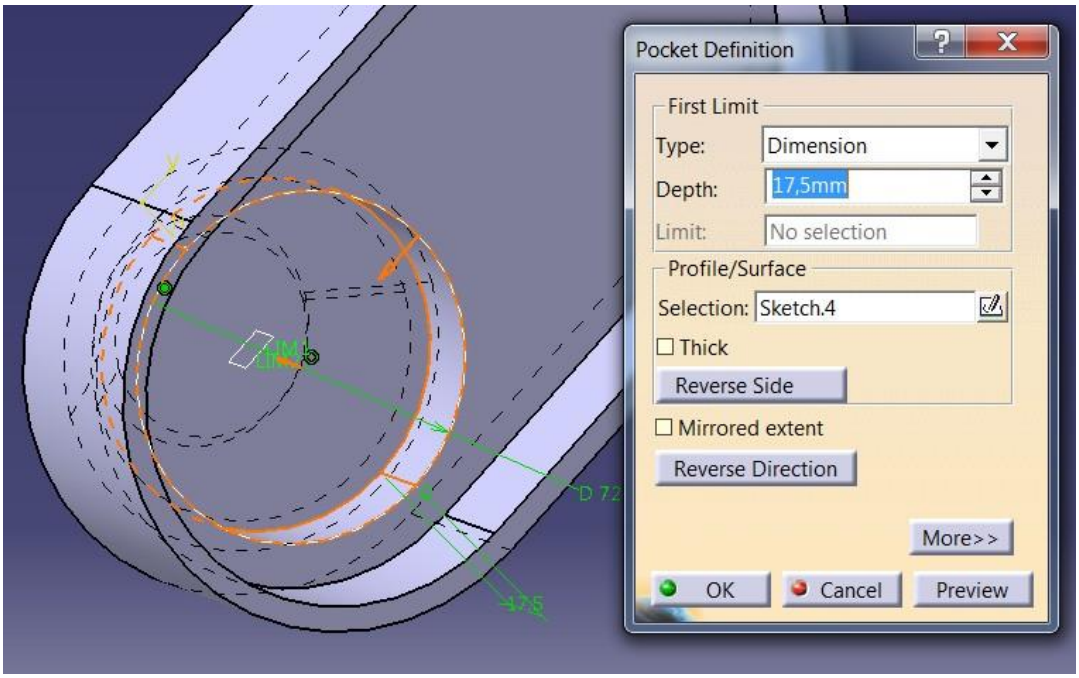


Fig. 12 Pocket definition for the new profile

Using the new surface previously created, this internal bottom surface is selected, the Sketch icon is selected so that an orthogonal view is possible now. Here a new circle is drawn, having ϕ **65 mm** diameter. Then a geometrical constrain is applied (again concentricity). Using **Exit Workbench**, and **Insert - Sketch-Based Feature- Pocket** for the **Depth the value of 7.5mm is fixed.**

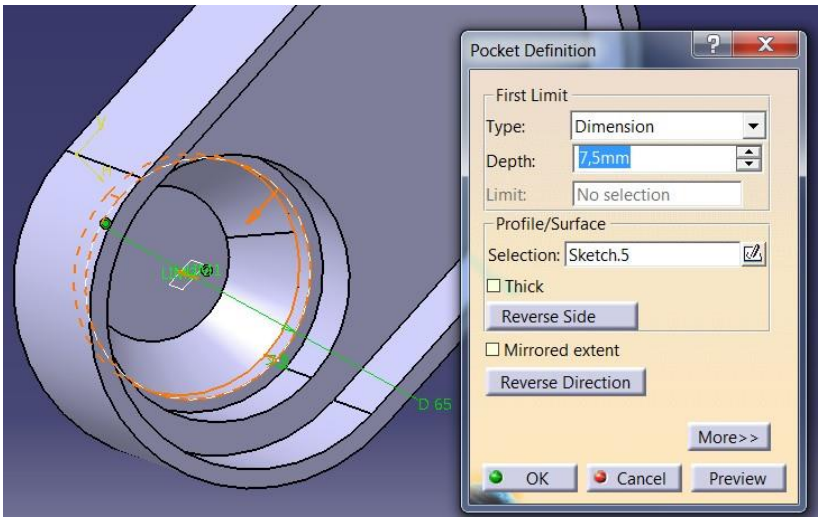


Fig. 13. Creation of a concentric circle with a 65 mm diameter

Drawing of the fixing shoulder

First, the upper surface of the lid (opposite surface related to the surface contained the conical surface) is selected, as a work-plane. Then, using the **Sketch** icon, the two concentric profiles are drawn. After the first profile is drawn, the second profile can be drawn using the icon **Offset,** and distance of 15 mm (can be found in submenu **Operation**, see below figure).

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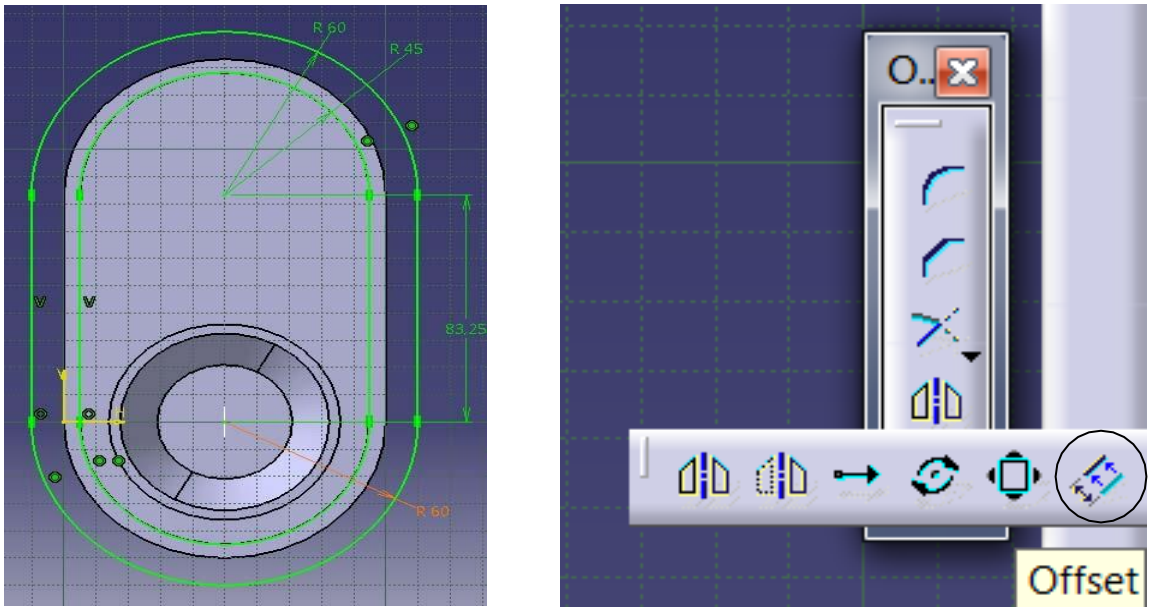


Fig. 14 Drawing of the two concentric profiles

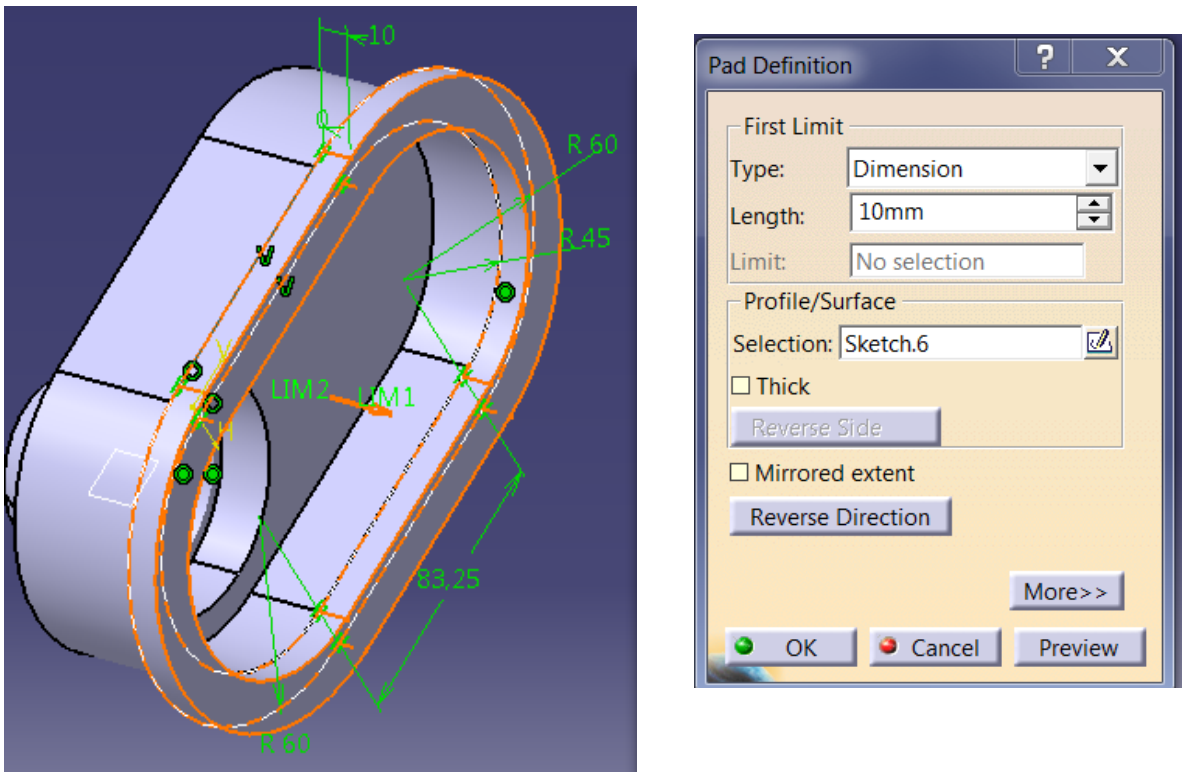


Fig. 15 Fixing the length

After the two sketches are drawn, using the **Exit Workbench** icon, the **Pad** window is opened, and the **Length** is fixed at a value of 10 mm (see above figure).

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The second internal cylindrical surface of ϕ**72 mm** diameter, can be now drawn, using the next steps: the bottom surface is selected as a work-plane; then using the **Profile** submenu, a circle with ϕ**72 mm** diameter is drawn. Also, the concentricity constraint is applied. The **Exit Workbench** is selected, and then with the sequence **Insert- Sketch-Based Feature- Pocket.** On the **Pocket** window, the Depth of 25 mm is applied.

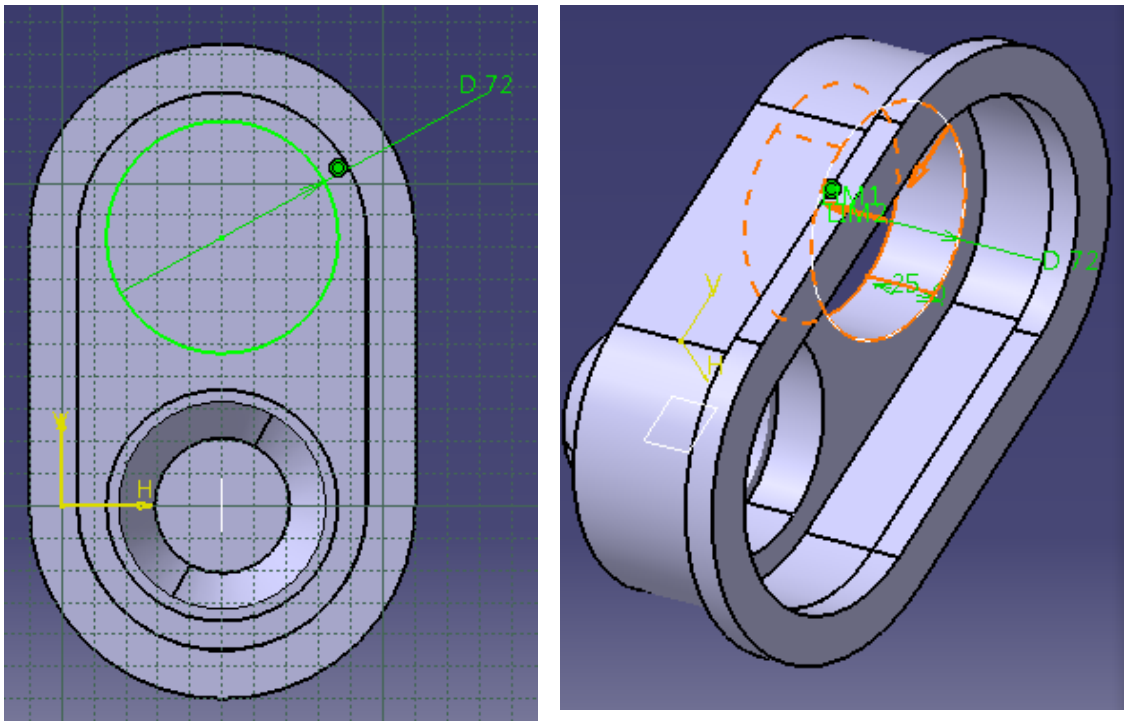


Fig. 16 Creating the 72 mm diameter circle with a depth of 25 mm

Drawing of the ϕ15 mm cylinders and then the holes with ϕ8 mm diameter

The upper surface of the shoulders is selected, and then the **Sketch** button. The circle with ϕ15mm diameter is drawn. The circle is dimensionally constrained as shown in figure 17. Also, a symmetry axis is necessary. Using the **Mirror** icon, and the axis of symmetry, the second circle is obtained (see below figure).

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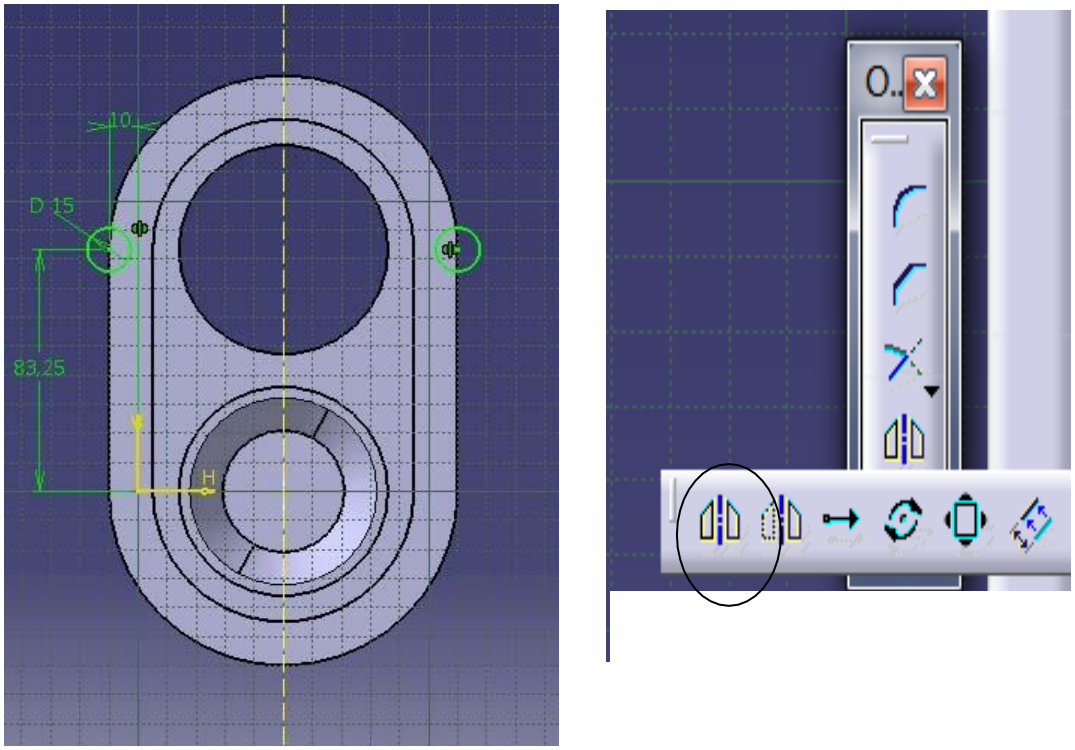


Fig. 17 Drawing of the circle with15 mm diameter and the symmetry axis

Using **Exit Workbench**, and then **Insert - Sketch-Based Feature- Pad,** sequence**,** with the **length** of 10 mm, on the **Pad** window, the first two cylinders are obtained**.**

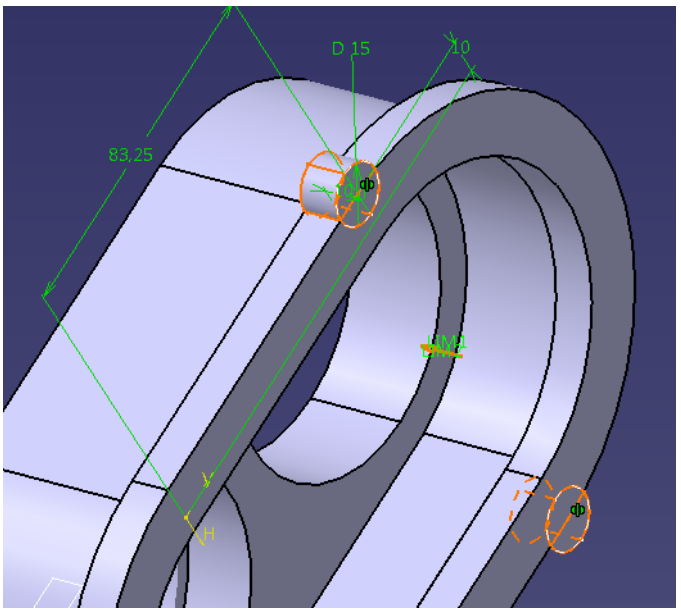


Fig. 18 Obtaining the two cylinders

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From the main menu:
Insert > Transformation Features >Rectangular Pattern (see the figure**)**
The two cylinders ϕ**15 mm** are to bemultiplied

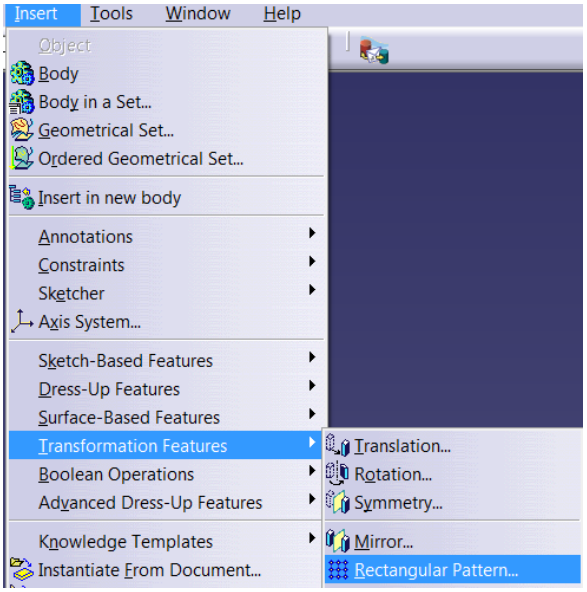
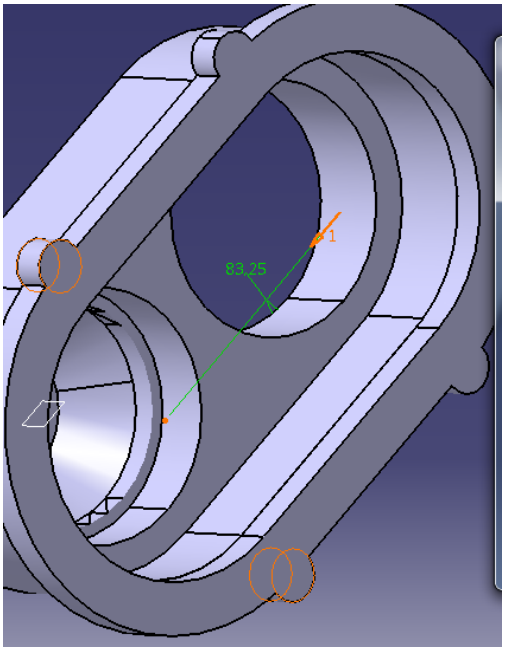


Fig. 19. Multiplying of the 15 mm diameter cylinders

In the Rectangular Pattern Definition **window**:
First Direction,
Instance(s) -2 , **Reference Element:** Edge 1, **Object:** Pad.3
and **Spacing** – 83,25 mm



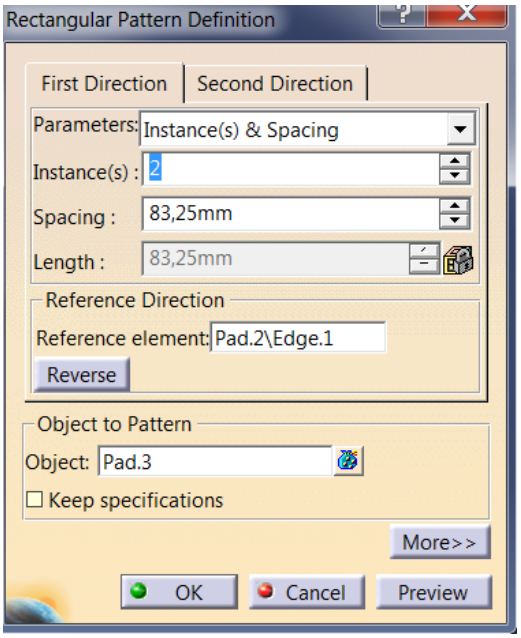


Fig. 20 Spacing at 83.25 mm the PAD 3 object

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Drawing of the next 4 cylinders with ϕ15 mm diameter

The upper surface of the shoulders is selected as a work plane. Next, using the Sketch icon and circle, two circles having ϕ120 mm diameter are drawn. Also, four axes are drawn. These four axes are fixed so that the angle must be 45^0. Using the Quick Trim command, the fourth segments that are positioned outside of the circles are eliminated (see below figure). On the intersection points (circles of ϕ120 mm diameter and the axis) four cylinders having ϕ15 mm diameter are drawn.

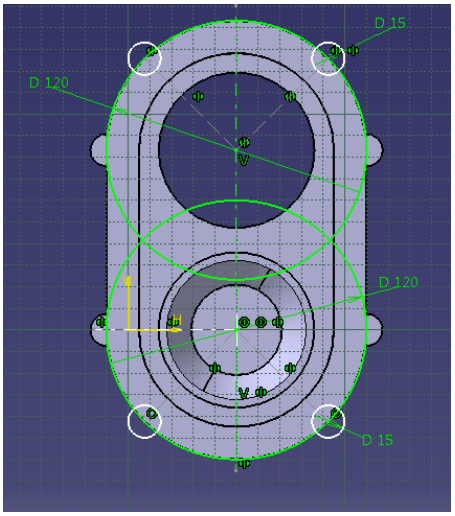


Fig. 21 Drawing the other 15 mm diameter 4 cylinders

Using **Exit Workbench**, and then **Insert - Sketch-Based Feature- Pad, the** sequence with the **length** of 10 mm, on the **Pad** window, another four cylinders are obtained

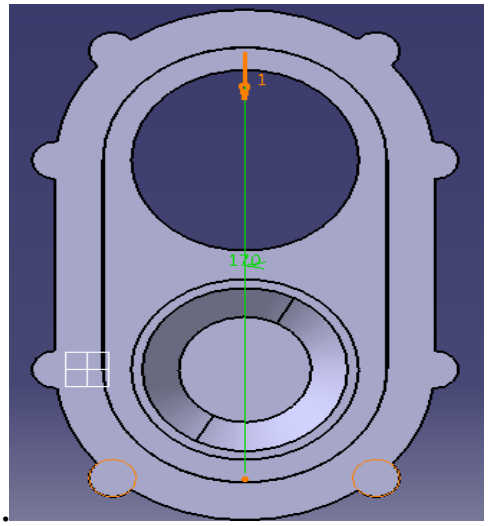


Fig. 22 Obtaining another 4 cylinder

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For all the eight holes having ϕ8 mm diameter, first, the upper surface of the shoulder is selected, as a work-plane, then, **Sketch** button is selected and, on the orthogonal view 8 circles having ϕ8 mm diameter are drawn, using **Circle** command, symmetry axis and **Mirror** command.

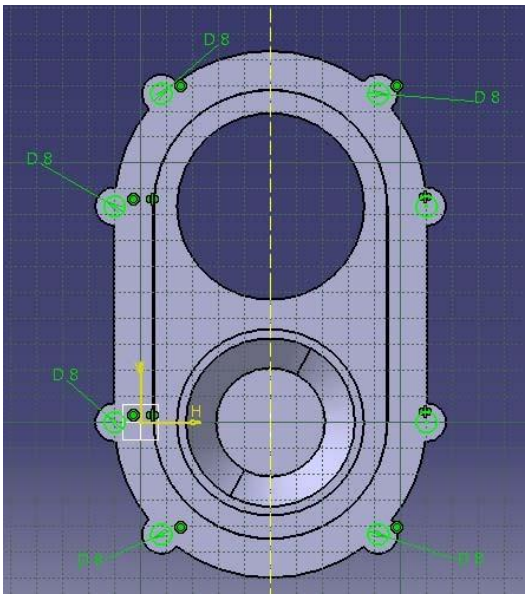


Fig. 23 The 8 circles with 8 mm diameter are drawn

Using **Exit Workbench**, and then **Insert - Sketch-Based Feature- Pocket,** sequence**,** with the **Depth** of 10 mm, on the **Pocket** window, all the eight holes are obtained**.**

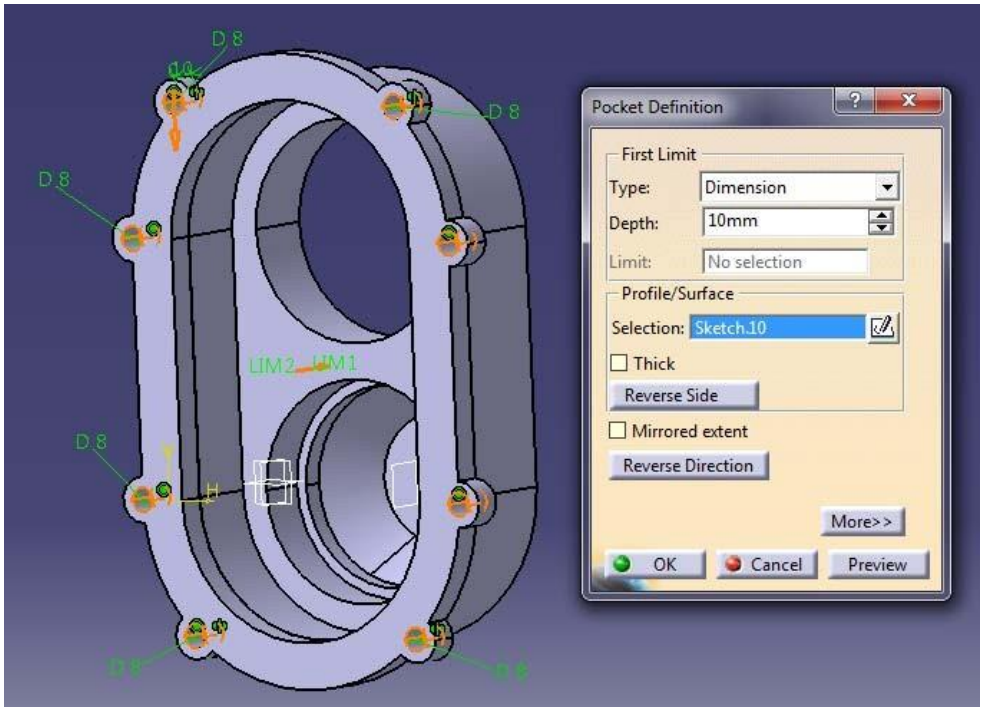


Fig. 24 Using **Pocket** command the depth of the 8 holes is set up at 10 mm

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Using the sequence: **Insert > Dress-Up Features > Edge Fillet**, for the edges as in the figure below, the fillets having the radius **R = 2 mm** are obtained.

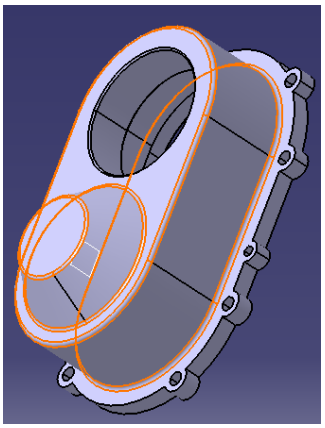


Fig. 25 Edge fillet

Weight analysis

From Desktop select the icon „**Measured inertia**",

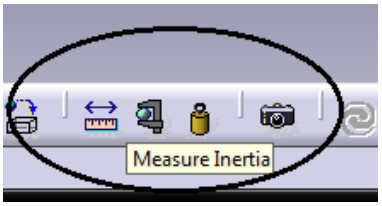


Fig. 26 Measure inertia icon

and then from **Specification Tree**, select the part, **Part Body.** Now a new window will beopen (see below figure).

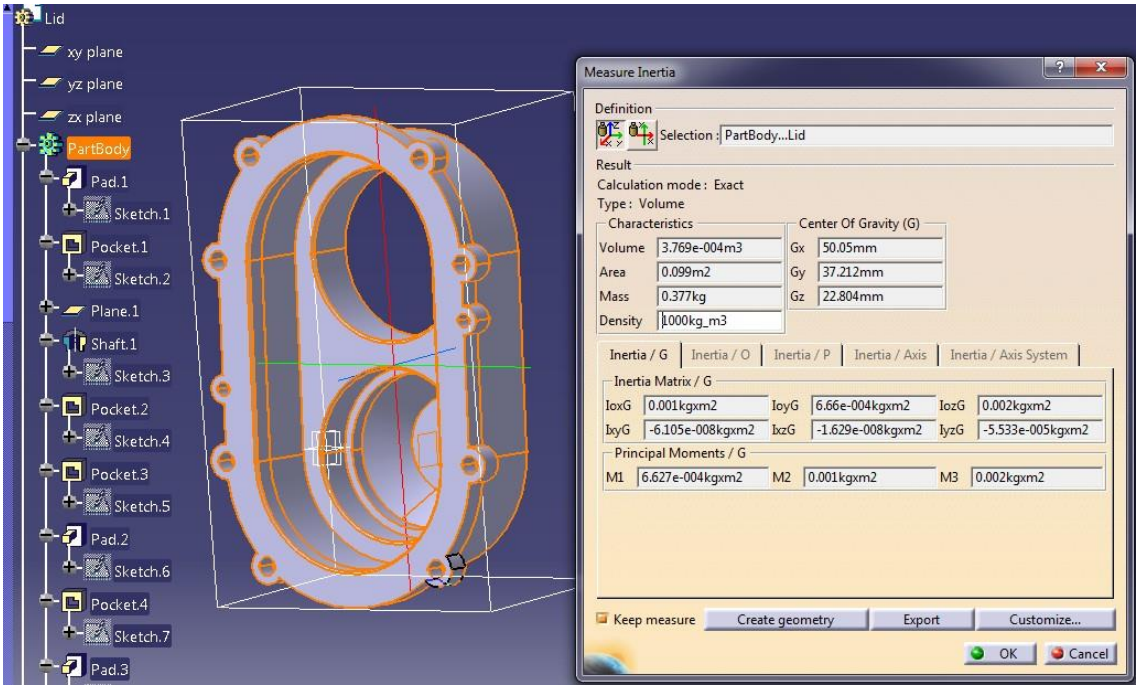


Fig. 27 Opening the Part body Lid to check its properties

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In this window, the density values can be changed as a function of the material

For example, if the part material is aluminum alloy, the density is (2,6 – 2,8)g/cm^3 =(2600-2800) kg/cm^3. In this case, the mass of the part will be 1.055 Kg.

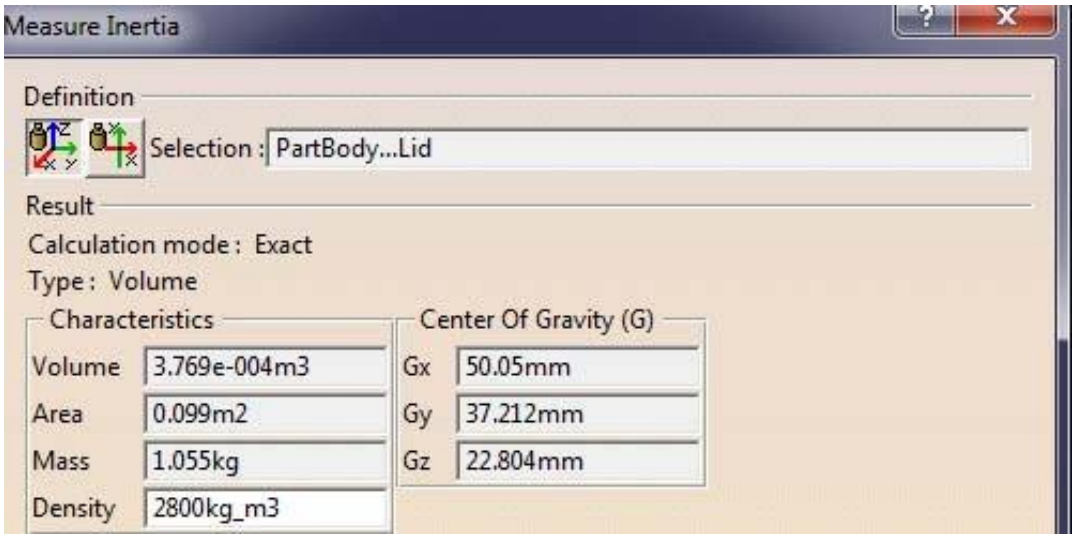


Fig. 28 Characteristics of the lid in Measure Inertia window

2. Rapid prototyping for the part Lid using 3D Dimension SST 1200 es printing

2.1 Rapid prototyping. Introduction

Prototyping is an important stage in any product development process and the prototype can be defined as "an approximation of a product (or system) or its components in some form for a definite purpose in its implementation".

Prototype definition, mainly, involves the three aspects that follow:

the implementation of the prototype

- ✓ from the entire product to its subassemblies and components;

the form of the prototype

- ✓ from the virtual shape (computer-aided drawing) to a real,physical object

the degree of approximation of a prototype

- ✓ from a rough representation to anaccurate replicate of the part.

In Rapid Prototyping (RP) virtual designs are "taken" from computer-aided design (CAD) or animation modelling software and transformed into thin, virtual, horizontal cross-sections.

Each cross-section is created in physical space, one after the next until the model is finished, so it is a WYSIWYG (What You See Is What You Get) process where the virtual model and the physical model correspond almost identically.

An important difference between this and conventional machining is that the prototype is obtained by layer to layer addition, as opposed to removing material from a

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"block".

In Rapid Prototyping, objects can be formed with any geometric complexity or intricacy without the need for an elaborate machine setup or final assembly. They can be made from multi-materials such as composites, and materials can be varied in a controlled fashion at any location in the object.

There are three main Rapid Prototyping systems, depending on initial the form of materials involved:

- ✓ liquid-based RP systems – the initial form of material is in a liquid state and, by a curing process, the liquid is converted into solid-state; the system includes: 3D Systems' Stereolithography (SLA), Light Sculpting, Rapid Freeze and Two Laser Beams;
- ✓ solid-based RP systems – the initial form of material is in solid-state, except for powders (wire, roll, laminates, pellets); this system includes: Stratasys'Fused Deposition Modeling (FDM), 3D Systems', Multi-Jet Modeling System (MJM) and Papers lamination Technology (PLT);
- ✓ powder-based RP systems – the initial form of material is a powder; the system includes 3D Systems' Selective Laser Sintering (SLA), Precision Optical Manufacturing's Direct Metal Deposition (DMD) and Z Corporation's Three Dimensional Printing (3DP).

2.2 Description of the 1200es Series 3D printer. Introduction

Offer a bigger build volume of 254 × 254 × 305 mm, options for two-layer thickness (0.254 and 0.303 mm) and provide soluble support and breakaway support options for support removal.

Dimension 1200es 3D Printers use ABS*plus*™ modelling material, a production-grade thermoplastic that is durable enough to perform virtually the same as production parts.

Models printed with Dimension 3D Printers have customer-proven toughness – from commercial sprayers tested at pressures up to 60 psi, to final parts on M1 tanks normally machined in aircraft-grade aluminium.

Models are printed from the bottom up with precisely deposited layers of modelling and support material. There's no waiting for models to "cure" — they're ready for support removal right from the printer. The SST 1200es uses Soluble Support Technology which dissolves the supports in a water-based solution.

Model material:

ABS*plus* in ivory, white, black, red, olive green, nectarine, fluorescent, yellow,blue or grey

Support material: Soluble Support Technology (SST) or Breakaway Support Technology (BST)

Layer thickness

0.254 mm (.010 in) or .330 mm (.013 in) of precisely deposited ABS*plus* model and support material

The main parts of the 3D Dimension 1200es Series machines are presented in fig. 29 and in fig. 30 material cartridge and modelling base are presented

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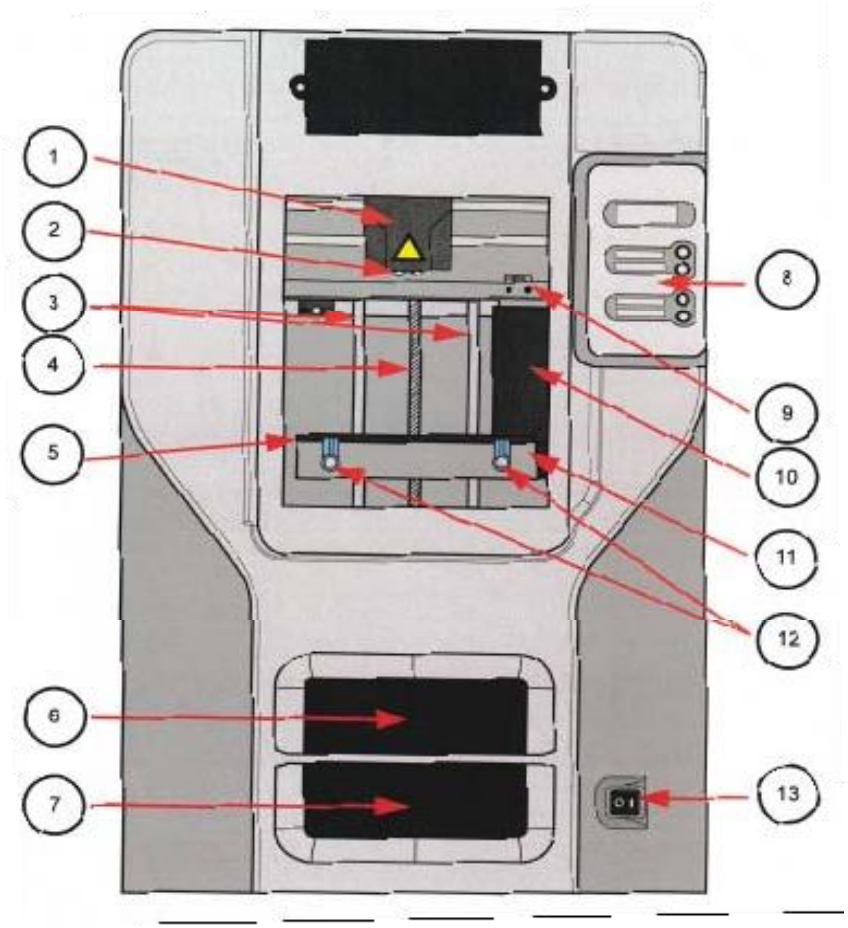


Fig. 29 Front view of the 3D Dimension 1200es printing machine

1- Extrusion head; 2 – Extrusion tips; 3- Guide rods; 4 – Lead Screw; 5 – Modeling base; 6- Model Material Cartridge; 7 – Support Material Cartridge; 8 – Display Panel; 9 – Tip Cleaning Assembly; 10 – Purge Container; 11 – Z stahe Platen; 12 – Modeling Base Retainers; 13 – Power Switch

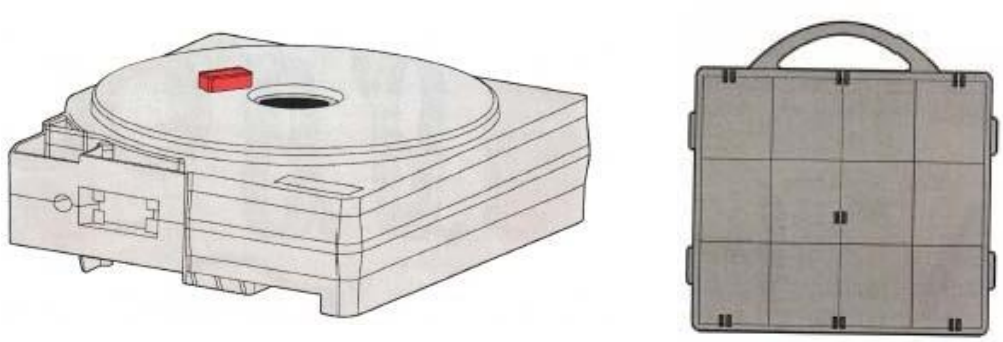


Fig. 30 Material Cartridge and Modeling Base

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In fig. 31 the mode of inserting the modelling base is shown. By the handle, slide the modelling base toward the back of the unit until its front edge is flush with the front edge of the tray.

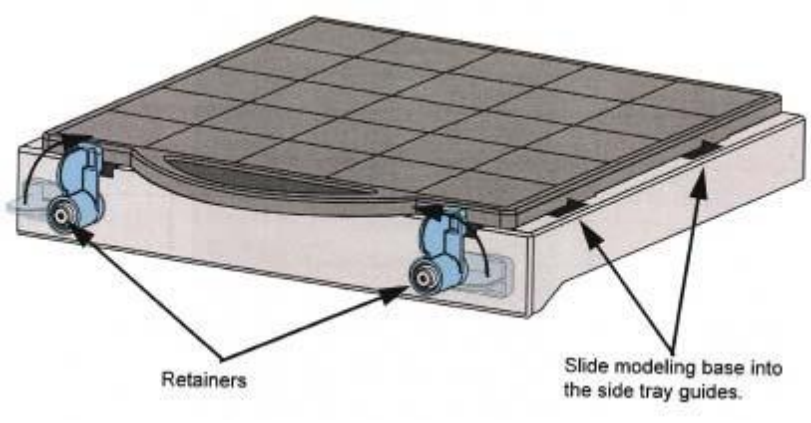


Fig. 31 Inserting of the modelling base

2.3 3D Printing of the part

To print a part, the first step is to develop the 3D model of the part, fig. 4, using a 3D program (SolidWorks, Catia, Inventor, Creo etc.) and then it must be saved as “stl” file, fig. 32.

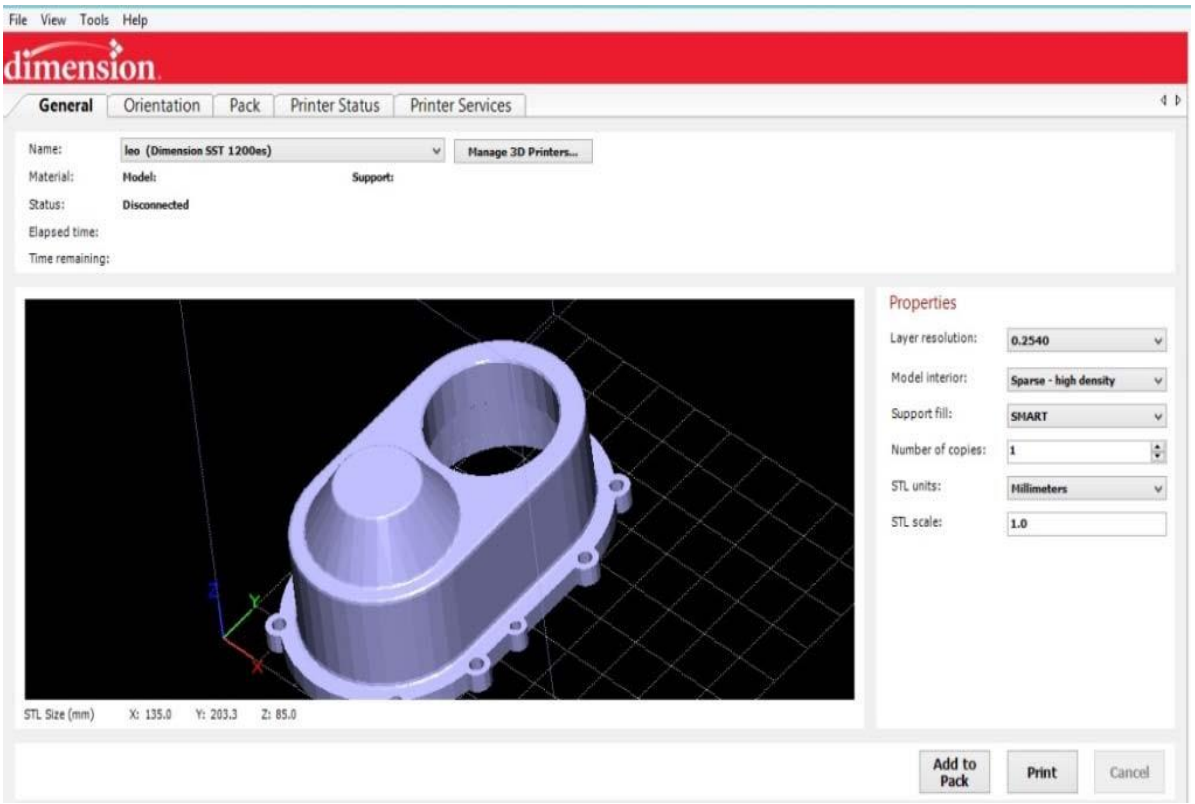


Fig. 32 Transforming the CAD part into STL file

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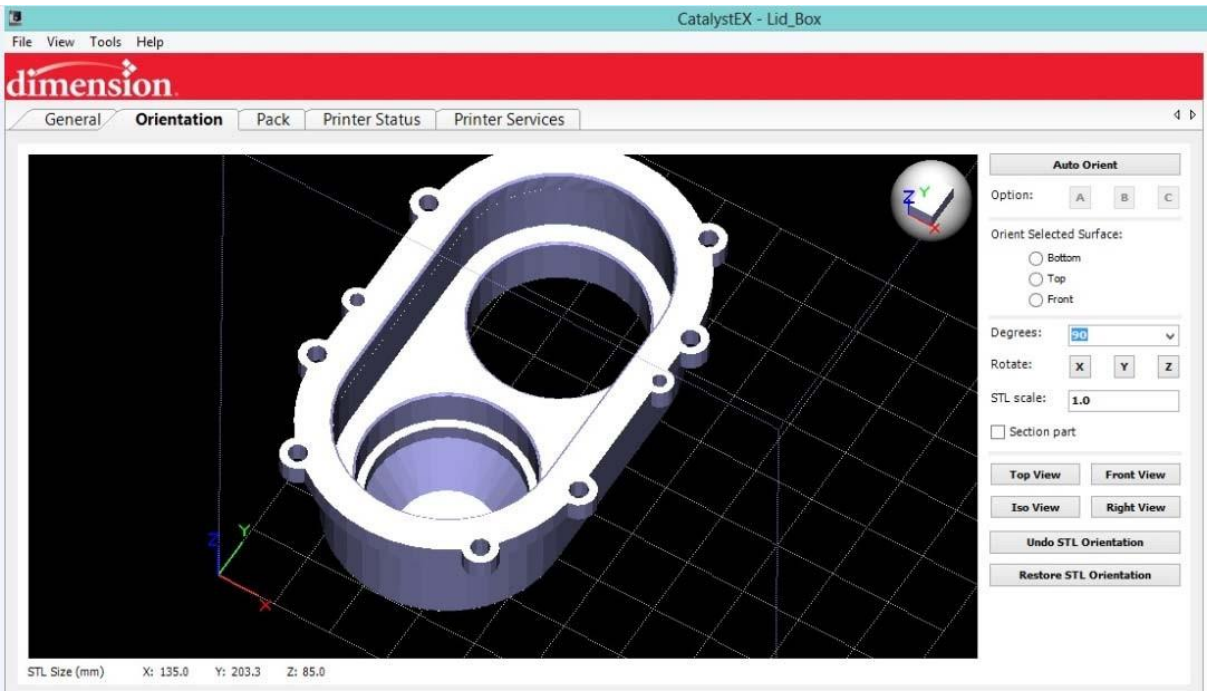


Fig. 33 The part in the 3D space of the 3D printer.

At the same time can be printed more parts, depending on the dimension of the modelling base, and the height of the parts.

are:

The model and support material and the time consumed to print the Lid part are:

For model material: 228.49 cm^3
For support material: 97.22 cm^3
Time: 12.26 hours

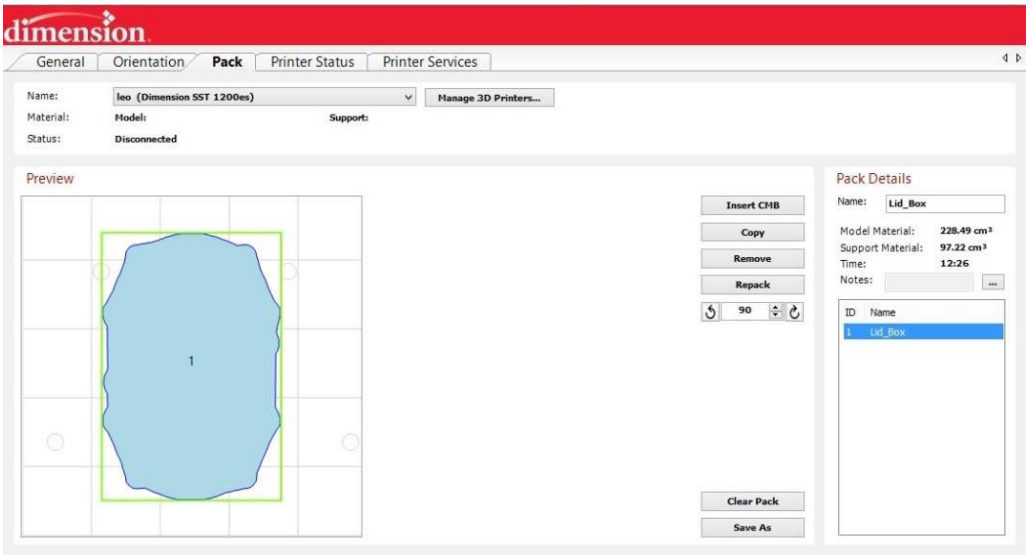


Fig. 34 The position of the parts on the modelling base, with the main parameters(time, the volume of the materials, name of the parts etc.)

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After work time is consumed, the parts on the modelling base are obtained as is shown in fig. 35.



Fig. 35 The positions of the final parts after the 3D printing, on the modelling base

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Digital Manufacturing Master Degree to set specialists for the dawn of the Industry 4.0

Computer modelling and simulation

Case study

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Case study: From the model generating to the simulation

1. Introduction

In general, a model is nothing more than a copy of a real or imagined object, its mapping with constrained information. The computer geometric model depicts the shape and dimensions of the object. Initially, computer modelling was mostly satisfied with the planar, two-dimensional (2D) projection of objects, but nowadays, the computer geometry model is increasingly understood as the three-dimensional (3Ds) wireframe, surface, or body model. Nowadays, the image of the object to be displayed must be as realistic and clear as possible. In the following section, welding joints modelling and simulation are presented.

2. Build a model

If we can draw in 2D, it is a good skill to produce a 3D model because at first, we must sketch the object. Drawing lines, curves, shapes is allowed for the creation with ‘free hand’. After that, central line, dimension, offsets can be set.

To create a 3D model from a sketch, several possibilities are available: extrude, revolve, sweep. If the model requires, fillet and rib can be used as well.

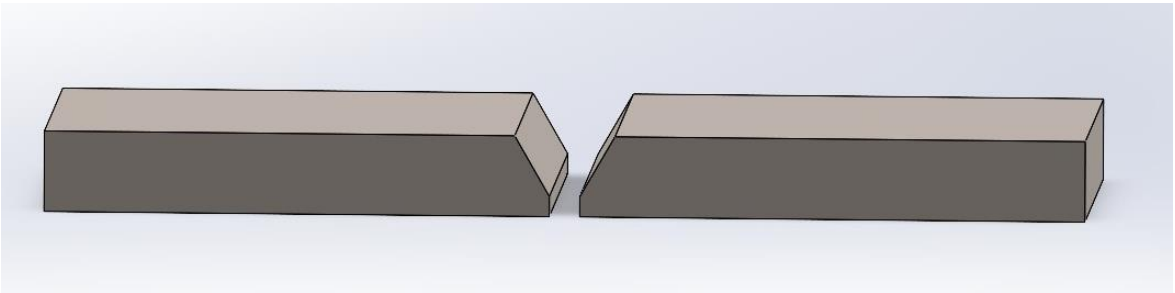


Figure 1. Model for welding simulation

The wire-frame model gives an image of the structure by showing the edges of the body (Figure 2). However, it can be a problem that it is often impossible to clearly represent the depicted body in this form, as it is impossible to see which edges are visible and obscured. On the other hand, the advantage of display is fast display and short computation time.

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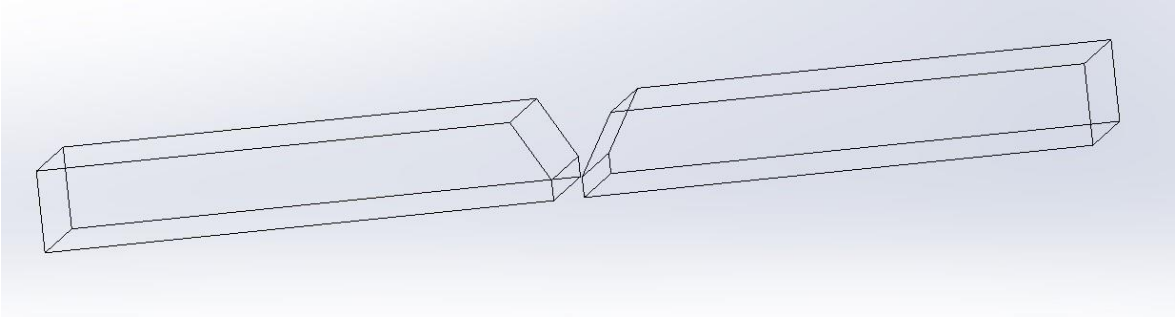


Figure 2. Wire-frame model

If the model is done, igs. or stl. supposed to be chosen for the export because most of the simulation programs can work with this type.

3. Simulation

CAD models can easily import into the simulation program. The last step was to save the model in a portable file, like as stl. or igs. The imported file does still not have any properties, only the contour exists.

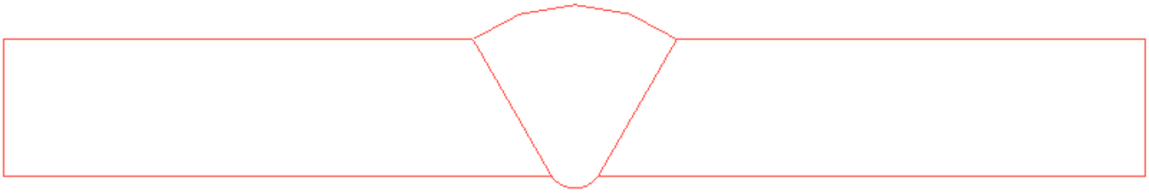


Figure 3. Imported igs. file to the simulation program

The next step is to create nodes and the mesh. For this, it is necessary to divide the contour to pay attention to the critical point (such as the welding joints now).

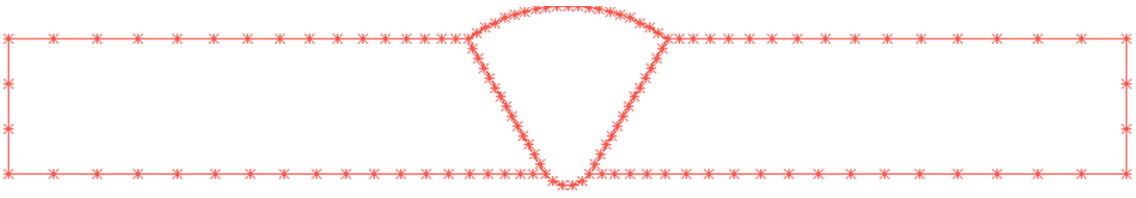


Figure 4. Divided contour

If it is ready, the mesh can be created. It is important to know that the welding joint will have different conditions like a base material, so it has to be separated.

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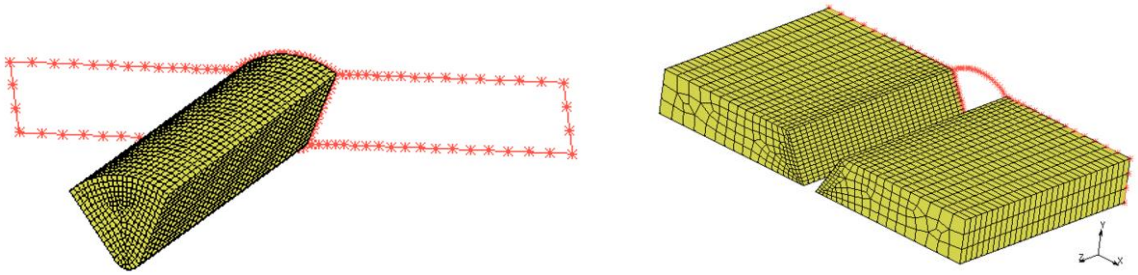


Figure 5. Mesh of the model

Material properties have to be given, e.g. thermal conductivity, density, young-modulus etc. Thermal analysis has to be used for welding because heat is transmitted to the material. A weld path should be generated for the proper way of welding. If the weld joints element is activated, the welding simulation can be started, as shown in Figure 7.
Cooling is not negligible. Not only the welding but also the base material is cooled down, so all of the faces have to be used. The purple arrows show the cooling in Figure 6.

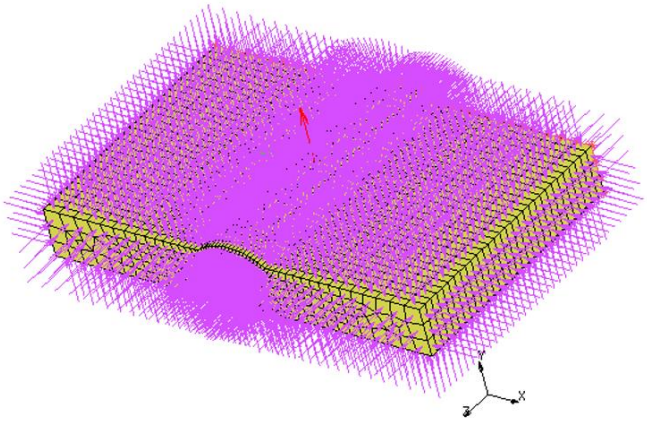


Figure 6. Cooling method

For the results, only the job parameters have to be set. Boundary conditions are the velocity of the welding, the activation of the base materials element, if the welding reaches that node, and finally, the cooling on the face film. As a loadcase, transient steps have to be used during the heat transfer and after the cooling. Lots of possibilities are there among the results, but in this simulation, the temperature, equivalent stress, phase transformation etc. are the important factor. Figure 7-8. shows an example for the representation of the result.

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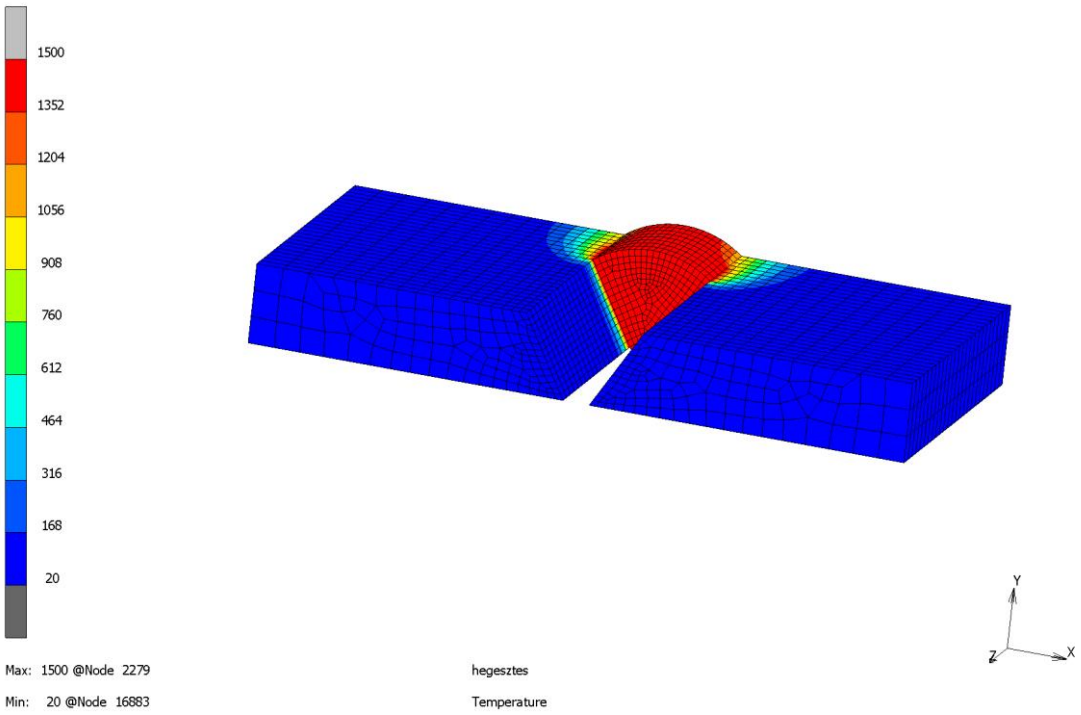


Figure 7. The temperature at the beginning of the welding

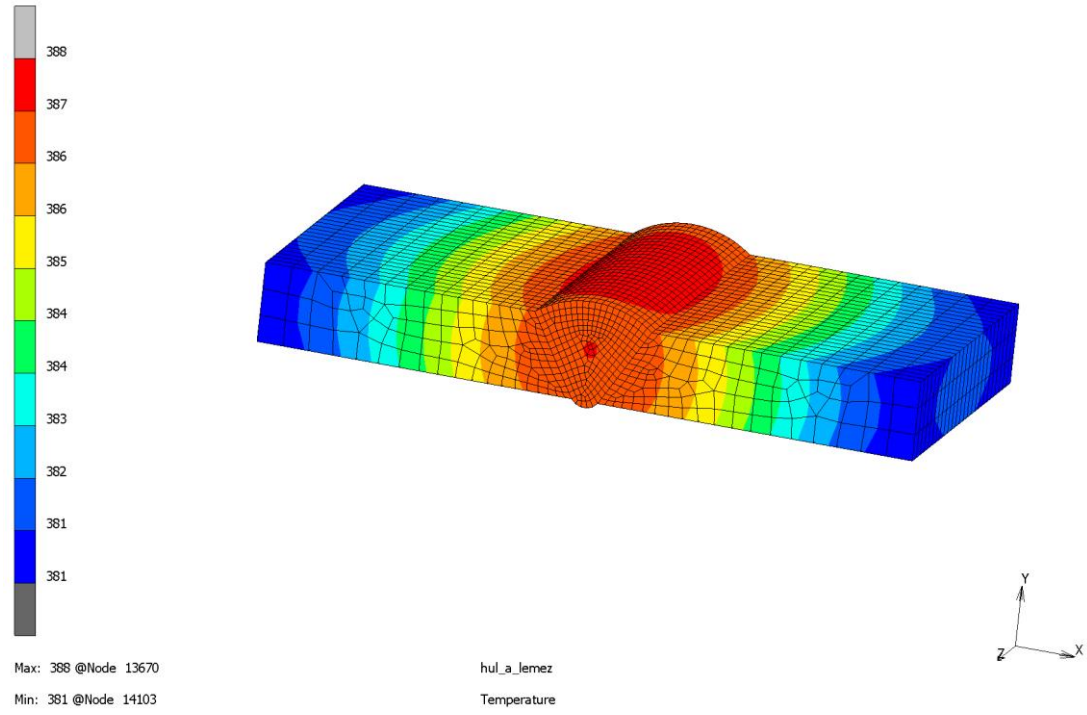


Figure 8. The temperature at the end of the welding

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Design of Digital Manufacturing

Case study

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Case Study – Aerospace part to be Produced by Additive Manufacturing

Figure 1 presents a part that was produced by Additive Manufacturing. The material used was a Titanium Alloy and the set of requirements established for the final piece were the ones listed below. Figure 2 demonstrates the part before and after the post processing steps:

- Very good fatigue properties
- 100% density (or very close).
- Structural component.
- Demanding Quality assurance requirements
- Material savings
- High productivity, at least one part per machine per hour
- No tight tolerances since the part will be machined after Additive Manufactures
- Approximate dimensions: 400 mm x 150 mm x 170 mm



Fig. 1. Titanium part produced by Additive Manufacturing



Fig. 2. Final part prior (left) and post (right) processing

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Questions

1.	Which Metal AM process would you choose to manufacture the part in Figure 1 and 2? Please justify. Also, relate the required characteristics with the chosen process.
2.	What type of tests and/or verifications would you carry out in order to qualify the selected AM process?
3.	What Post-Processing procedures and /or processes could be put in place for this application? Why?
4.	What quality assurance procedures and/or processes could be put in place for this application? Why?

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Proposed Solution

1. Which Metal AM process would you choose? Please justify? Also, relate the required characteristics with the chosen process.

The following topics/criteria should be covered/identified:

- DED process:
  - Volume/size of the part
  - No high tolerances
  - Material used
  - High deposition rate when compared with other processes
- DED Wire based process:
  - Explain the reasoning behind wire instead of powder
  - No high tolerances
  - 100% dense material, with good fatigue properties without the need of extensive post processing
  - Demanding quality assurance requirements
  - Structural component, justifying that the other processes can also achieve this but with DED wire characteristics make this easier to implement without the need of extensive post processing or process preparation
- Compare all types of DED-Wire processes that currently exist (all could be used for this application, but the student would need to provide information on why he/she chooses a specific one) ensuring he/she identifies and compares the following ones:
  - DED-LB; DED-Arc; DED-EB

2. What type of tests/verifications would you carry out in order to qualify the chosen AM process.

The following topics/criteria should be covered/identified:

- Qualification of the feedstock for the material being used
- Qualification of the AM process being used
- Qualification of the AM personal
- Qualification of the facilities
- Characterize the obtained material properties after deposition and identify the need of post-processing, being Heat Treatment, cold work (like cold rolling or peening) or hot rolling

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– Destructive testing of the part to ensure that the needed mechanical properties are obtained. Since machining is needed the destructive testing should be carried out after machining of the deposited material. The same thing applies if other post-processing techniques are used.

3. What Post-Processing procedures/processes could be put in place for this application? Why?

The following post-processing procedures/processes should be listed as possible:

– Heat-treatment – for reducing residual stresses and/or to obtain the desired microstructure
– Machining

4. What quality assurance procedures/processes could be put in place for this application? Why?

The following post-processing procedures/processes should be listed as possible:

– Control of the feedstock
– Process monitoring, in this case, and in accordance with the chosen process they should identify the following:
    - Beam profiling and power meter measurement for LB, and in this specific case due to the cost of the used material in-line monitoring systems (back reflection, temperature measurement)
    - Voltage and Current monitoring and control for ARC
    - Layer height control and monitoring
    - Temperature measurement during the deposition and between each layer
– NDT, including visual inspection, ultra-sound, X-ray and Eddy currents (some of these techniques should be applied after machining)

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Digital Manufacturing Master Degree to set specialists for the dawn of the Industry 4.0



Mold made by SLM, for injection molding of the plastic parts

Case study

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Case study

Mold made by SLM, for injection molding of the plastic parts

This case study was developed at TUCN, within the AMaRaP Research Centre.

OVERVIEW

Objective: Design and SLM-manufacture a mold with cooling channels to increase production. The mold will allow to fabricate an automotive plastic part used to control the computer board of Renault Scenic EG car.

Need: In the field of plastic injection, the time of cooling is often between 60-90% of the total time necessary for a production cycle and new concepts are needed to develop and test.

Difficulties: Conventional casting molds often endure cyclic thermal influences that lead to thermal fatigue. To increase the structural resistance to thermal fatigue, the mold should be designed with some compliance for thermal expansion. This can be achieved by applying lattice structures in some areas of the mold.

Designing Software's used: SolidWorks, Creo Parametric, Rdesigner, and Autodesk MeshMixer.

Material used for SLM: Stainless steel 316L powder with 50 µm spherical grains, provided by MCP HEK Tooling Realizer (Germany).

Equipment used for SLM: Realizer II SLM 250 (Germany) which has incorporated selective laser melting technology and contains a solid-state laser type Nd:YAG (neodymium-doped yttrium aluminum garnet) with 200 W maximum laser beam power.

Benefits of SLM manufacturing:

- It could be designed special cooling channels which provide a higher heat transfer rates and a less variation in tooling temperatures;
- The cooling channels developed will reduce the cycle time of the plastic injection process, increasing the production rate;
- The active elements of mould will have a reduced weight (15% lighter).

CONVENTIONAL MOLD AND REDESIGNED FOR SLM

Application details: The functional role of the button is to command, control and set up the dashboard of Renault Scenic EG automobile (Fig. 1). The button is positioned in the

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front mask computer board. The active elements of mold will be used to test the injection process of various materials.



a) *b)*

Fig. 1. a) Renault Scenic car, b) Computer board button which requires the new SLM mould

The main activities developed to complete this objective:

1) Determination of the **optimum technological parameters required for the injection** of plastic parts such us: injection point, injection pressure and the filling time, thickness analysis, volumetric shrinkage, and clamping force.
2) **Redesign for Additive Manufacturing (SLM process**) the active elements of mold. Figure 2 presents the conventional mold for computer board button and the CAD model of mold with integrated cooling channels (a top view). It was designed 12 main cooling channels with 38 mm length and 1.5 mm width.

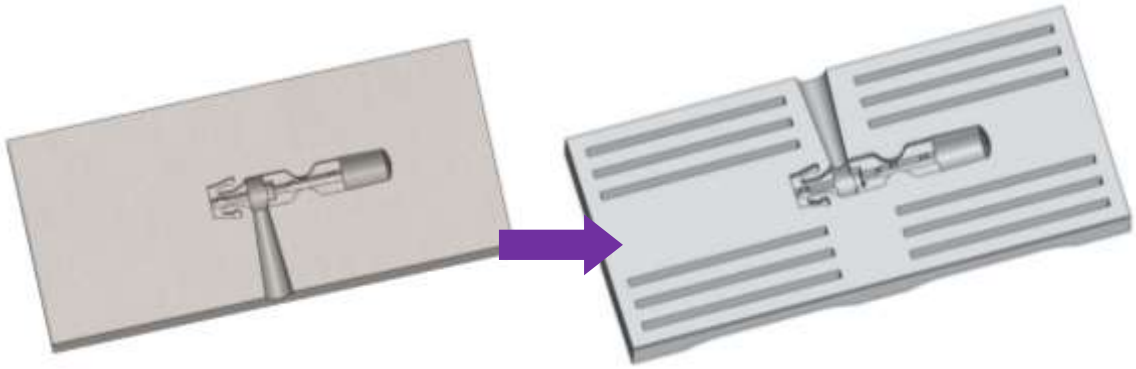


Fig. 2. Conventional mold and Redesigned for SLM with integrated cooling channels (15% lighter)

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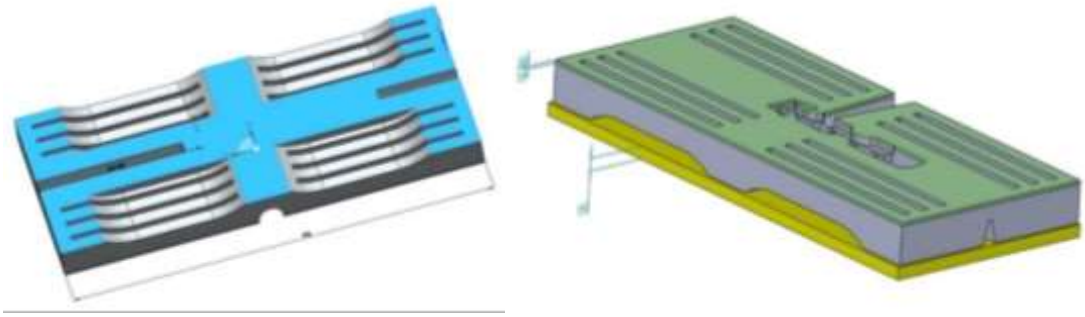


Fig. 3. CAD model of mold with integrated cooling channel; Bottom view showing the contact areas topological optimized between SLM-manufactured part and platform (blue color)

THE VIRTUAL MODEL OF THE LATTICE STRUCTURES

3) **Design and incorporate the lattice structures** into mold cooling channels. The lattice unit used represents a body-centred cubic structure and it was designed in RDesigner software with an edge length of 0.55 mm (Figure 4). This lattice structure was incorporate into all the mold cooling. The new concept of mold is with 15% lighter than conventional counter one.

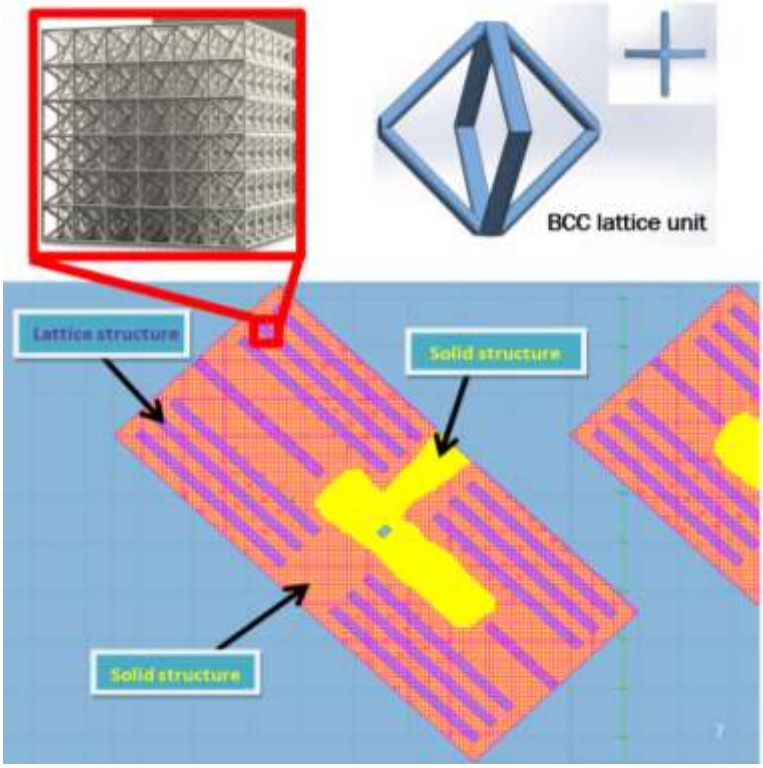


Fig. 4. Virtual model of lattice structure (macro-porous scaffold), active element of mold with solid areas (yellow color) and lattice structures into cooling channels (mauve color)

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THE HORIZONTAL BUILT ORIENTATION

4) **SLM preparation** of new mold. The main steps are detailed above in Section 2. Figure 5 shows 5 examples of possible built orientation. We prefer a horizontal orientation to reduce the production time, but the convex surface of active element will have a pronounced "stairs effect" (normal to high roughness, Figure 6).

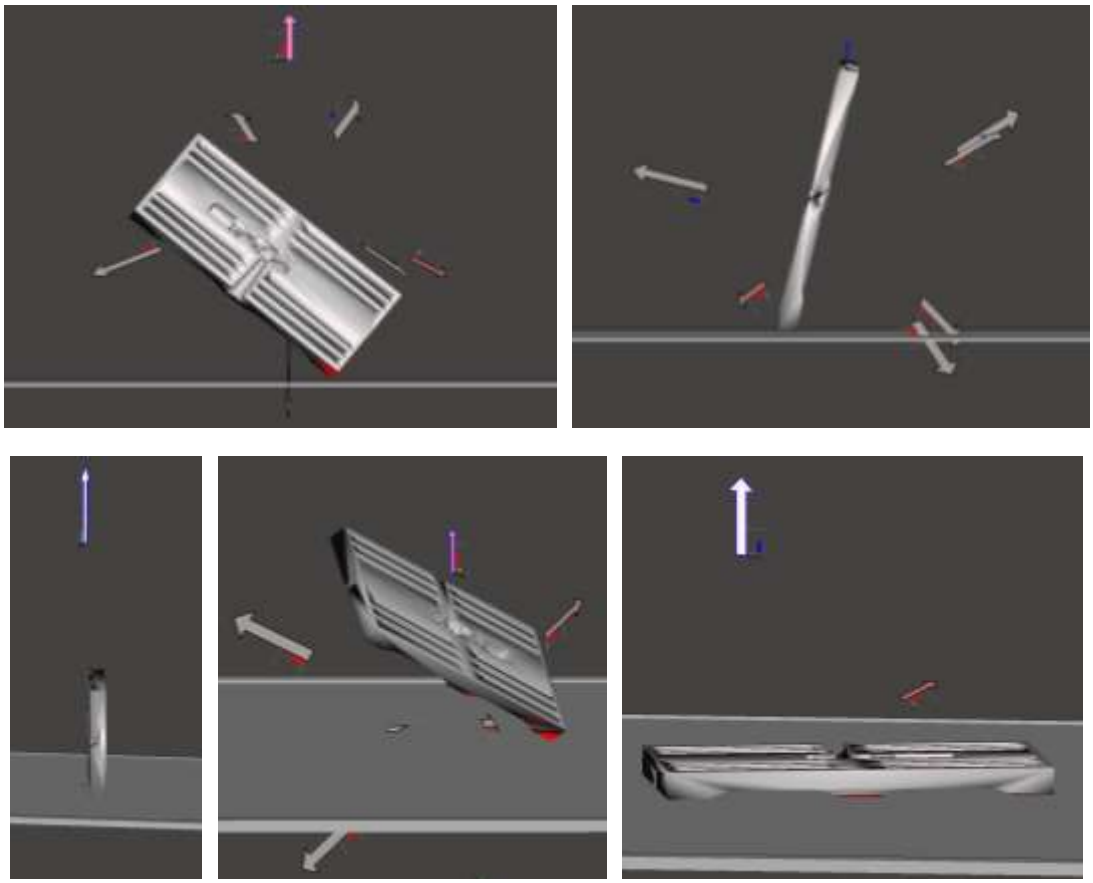


Fig. 5. Orientation optimization of semi-mold, 5 examples

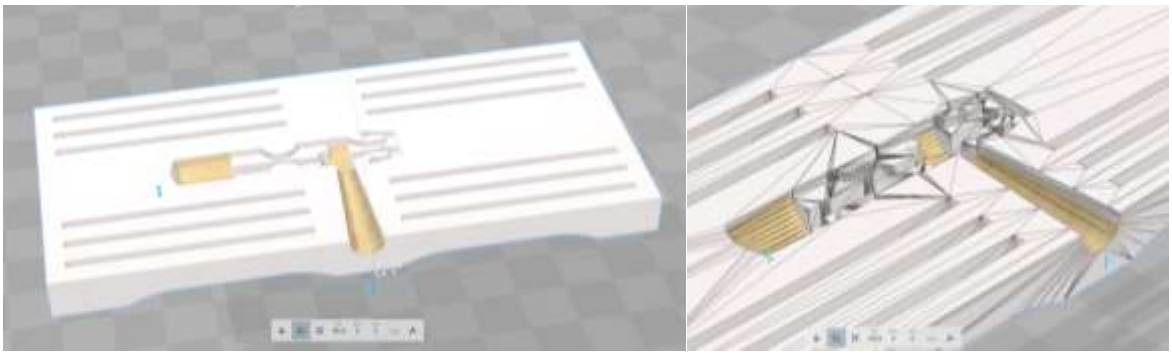


Fig. 6. Horizontal built orientation, minim time to SLM manufacture this semi-mold;

Built the convex surface of active element will have a pronounced "stairs effect" (normal to high roughness).

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SLM SIMULATIONS

5) **SLM simulation** of semi-molds fabrication having lattice structures integrated into cooling channels (Figure 7 and Figure 8). Different scanning functions can be seen as following: Outer-boundary, Inner-boundary, Hatch in X and Y direction, X and Y Support, Outer Support. Each of them has configured a value for laser power (Lp, in mA where 5000 mA = 200 W) and scanning speed. The scanning speed is expressed by Exposure time (Exp) and Point distance (Pd). The scanning strategy was alternating X/Y.

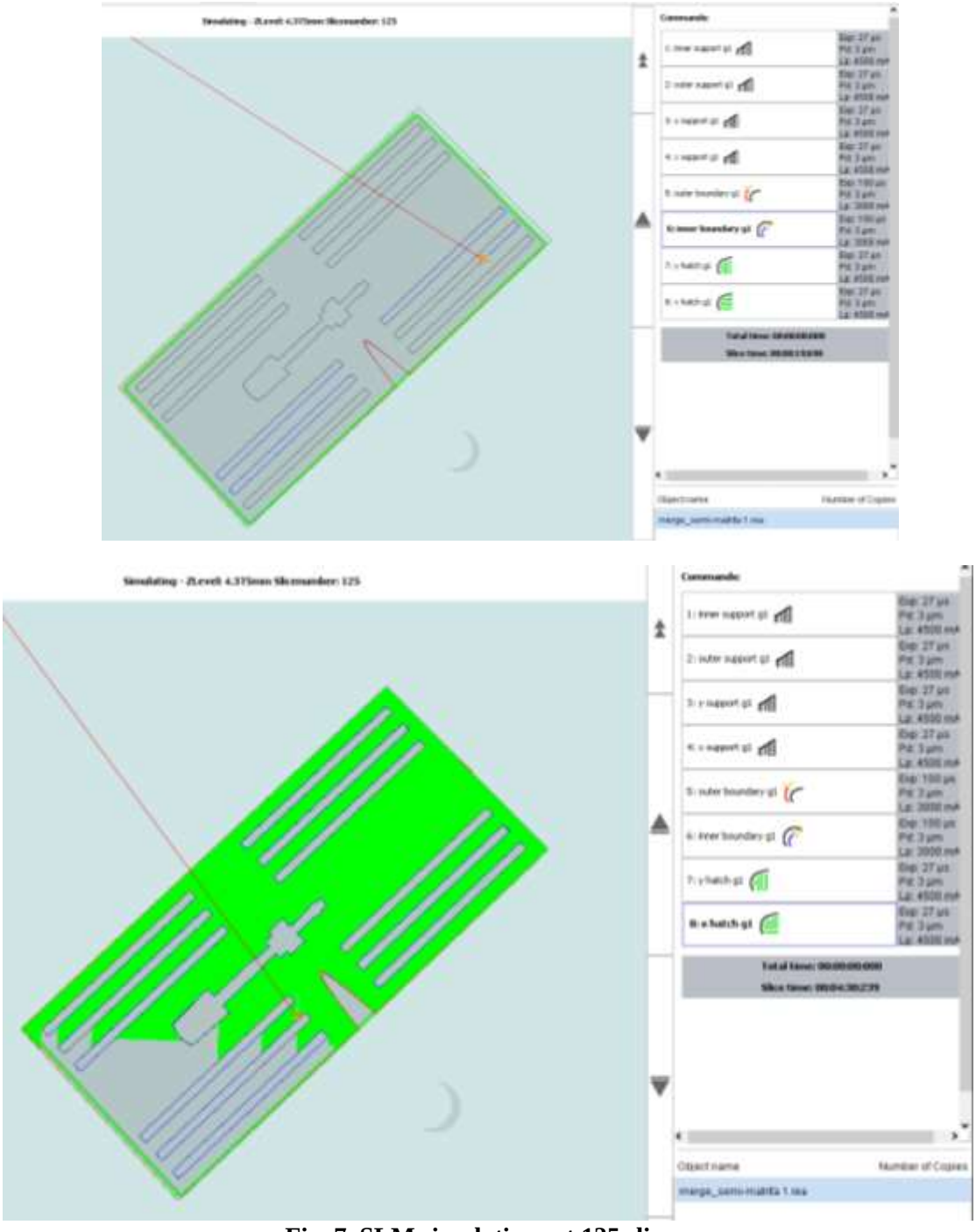


Fig. 7. SLM simulations at 125 slice

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To limit the impact of internal tension, the semi-molds were fabricated direct on SLM plate with-out support structures.

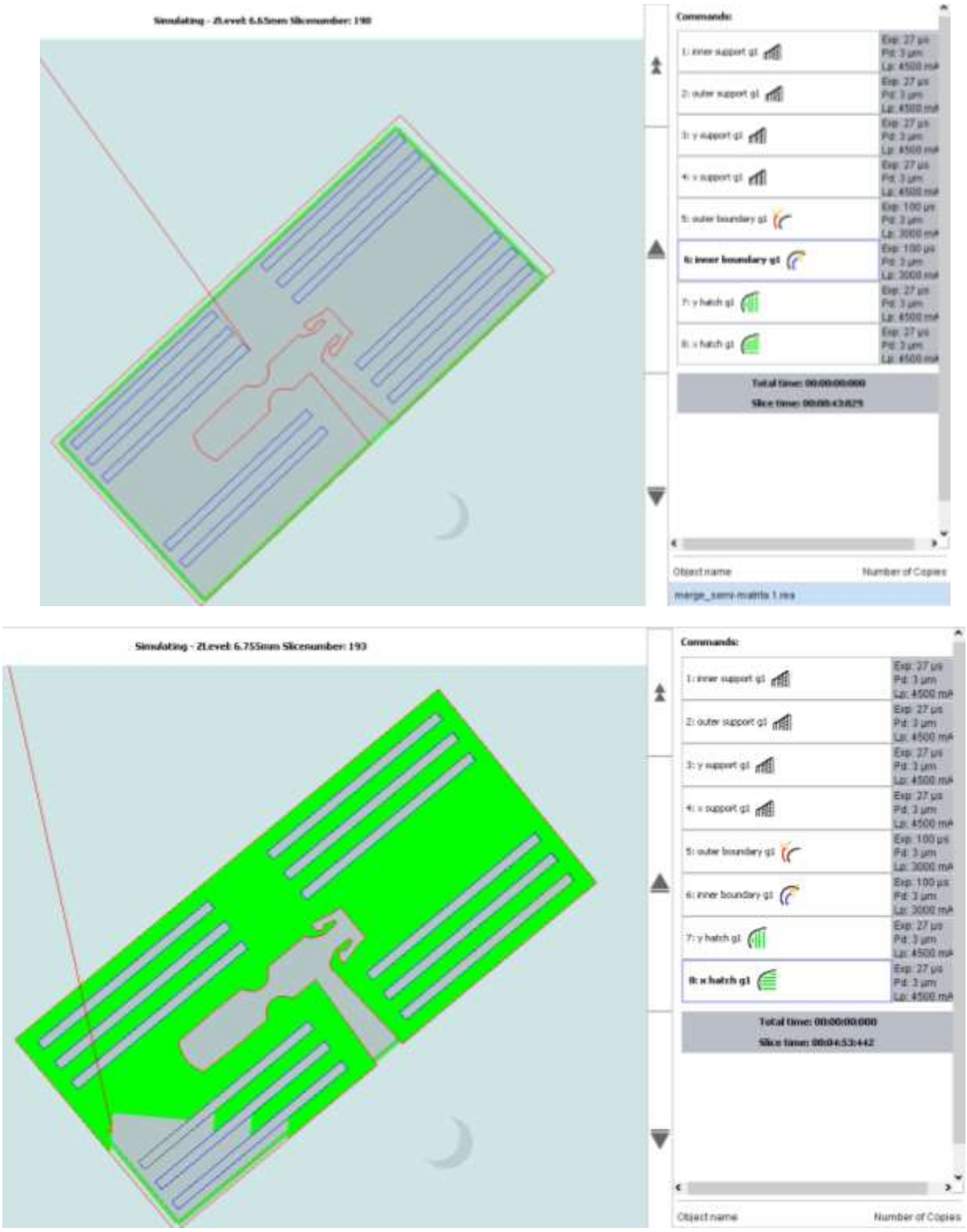


Fig. 8. SLM simulations at 190 and 193 slices

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Figure 9 shows an estimation of manufacturing costs using RCalculator tool. Using the REA file with all the SLM parameters and parts slices, this app calculates a cost of 985€ for semi-molds, where 80 €/h is the processing fee, and the production time is around 11h.

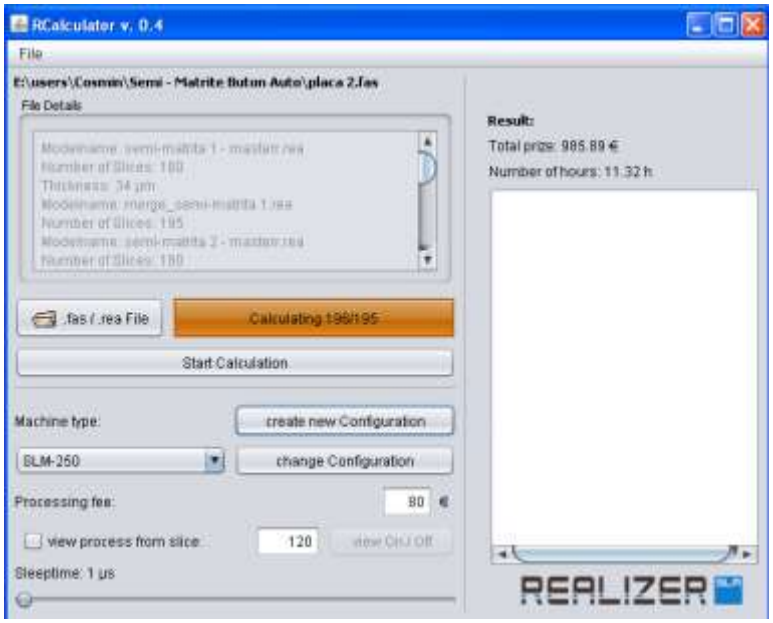


Fig. 9. Cost estimation and manufacturing time

SLM MANUFACTURING OF MOLDS

6) **SLM manufacturing of semi-molds** was developed in optimal conditions without any unfavorable issues or defects (Figure 10). The production time was 12h because the lattice structures require more time for scanning of each strut slice.

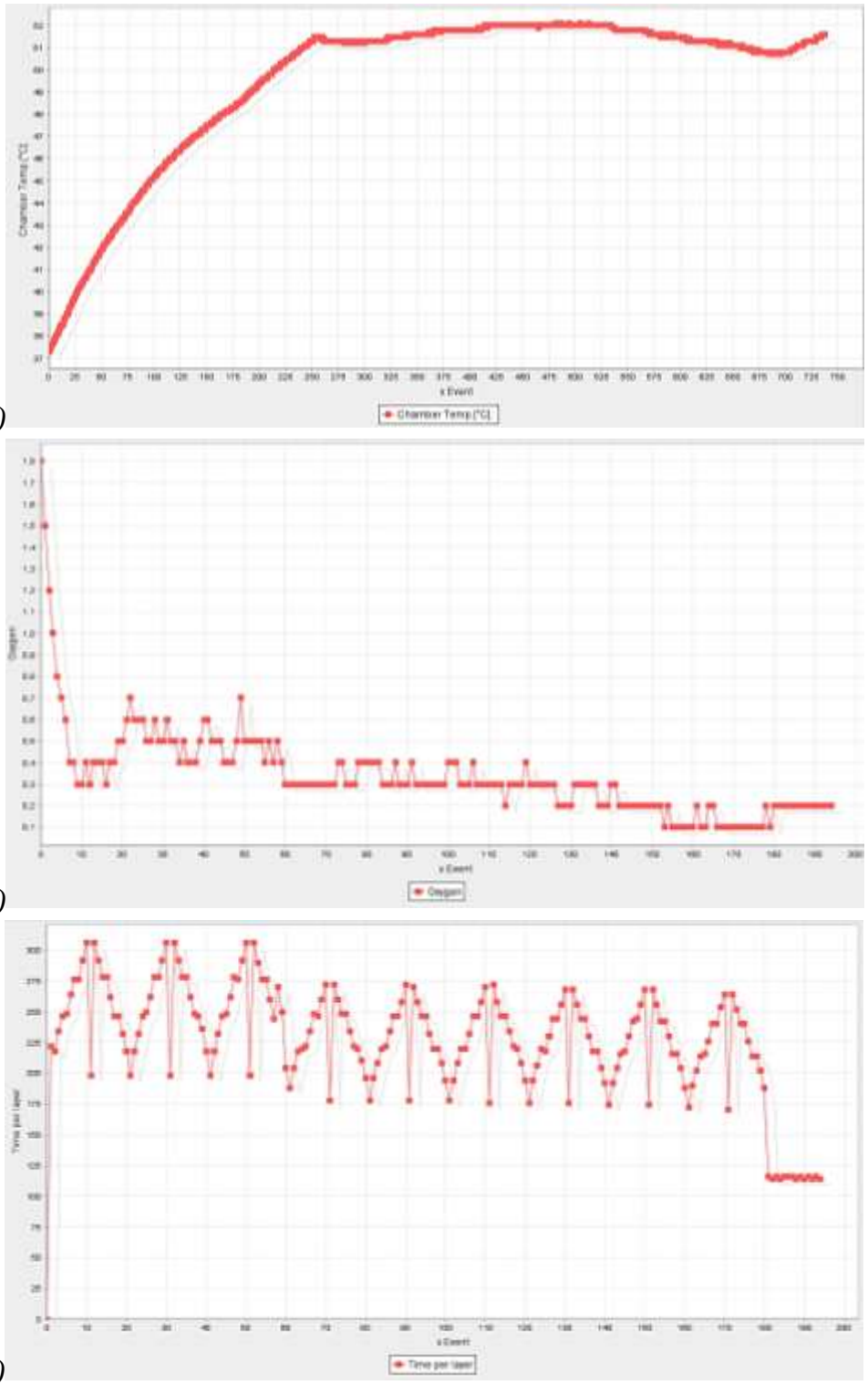


Fig. 10. SLM manufacturing of molds

Figure 11 details some diagrams generated during the SLM fabrication of semi-molds. The working chamber recorded a temperature up to 52°C. After the SLM machine scan the first

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10 layers, the oxygen content decrease from 1.8% to 0.3%, and was main constant at approx. 0.4% in an argon atmosphere. In general, the time needed to scan a powder layer varied between 200 s to 300 s being influenced by its area.



a)

b)

c)

Fig. 11. Diagrams generated during the SLM fabrication by machine sensors: a) Chamber working temperature, b) Oxygen content from working chamber; c) Time per each layer expressed in seconds

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THE SLM MOLD CAVITIES, FINISHED BY CNC MILLING

7) **Post-processing** of SLM-manufactured semi-molds. Initially, the lattice structures were ultrasonic cleaned and then the semi-molds were subject of stress relieved treatment at 540°C. The active zone was sandblasted with glass and the contact surfaces were processed using a CNC milling machine (Figure 12).

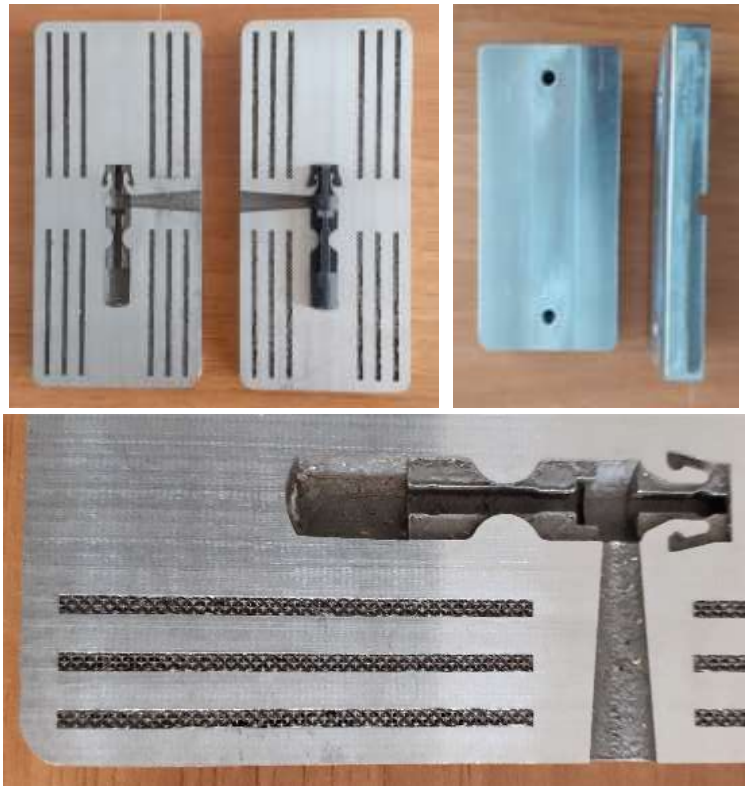


Fig. 12. Active elements of mold SLM-manufactured, and CNC milled on contact surfaces

Figure 13 shows the morphological aspects of lattice struts investigated by scanning electron microscopy (SEM). This type of lattice structures presents stair-stepping effect, unmolten or half-attached particles on struts, and the balling phenomenon. The lattice struts have a build angle of 45°, a value which is the minimum recommended to avoid the need for supports.

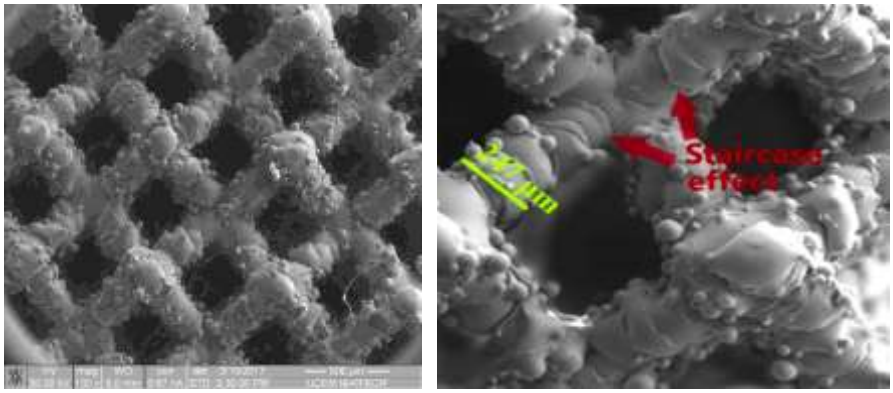


Fig. 13. Lattice structures SLM-manufactured in mold cooling channels; SEM analysis

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INJECTION MOLDING TESTS, USING THE MOLD MADE BY SLM

8) **Injection molding tests performed**. It was analyzed the injection behavior of ABS. The plastic used was MABS XG568 which is an anti-scratch, high gloss methylmethacrylate acrylonitrile butadiene styrene (ABS) copolymer. The main injection parameters configured were melting temperature of ABS (270°C) and injection pressure (10 bar). An injection cycle takes 12 s/piece and the ABS part have a Ra roughness around 3,8 µm.



Fig. 14. Injection test using the SLM mold and ABS plastic

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