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Type		
R	Document, report (excluding the periodic and final reports)	x
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc	
DATA	Data sets, microdata, etc	
DMP	Data management plan	
ETHICS	Deliverables related to ethics issues	
SECURITY	Deliverable related to security issues	
OTHER	Software, technical diagram, algorithms, models, etc	
Dissemination level		
PU	Public, fully open, e.g. project website	
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TABLE OF CONTENT

1. Executive summary8

2. Introduction9

3. Plan for verification and Validation9

3.1. General verification plan9

3.1.1. Visual inspection10

3.1.2. Dimensional control.....11

3.1.3. Non-destructive testing11

3.1.4. Destructive testing14

3.1.5. Corrosion test.....17

3.2. Industrial Use Cases19

3.2.1. Automotive use case19

3.2.2. Energy fusion use case.....27

3.2.3. Food Packaging – Heat Exchanger29

3.2.4. Food Packaging – Filling Pipe.....33

3.2.5. Hydrogen – Distribution and Bipolar plates36

3.2.6. Aerospace – Fuel Tank38

3.2.7. Space – Propellant Tank40

3.2.8. Pharma - Shelves (freeze drying)43

LIST OF FIGURES

Figure 1: Videoscope Olympus iplex. 10

Figure 2: Examples of negative root reinforcement (left) and lack of penetration (right). 11

Figure 3: Example of crack detected on a weld after penetrant inspection. 12

Figure 4: Example radiographic inspections performed on noncompliant welds. 12

Figure 5. Digital radiographic control system. 13

Figure 6. Example of digital radiography. 14

Figure 7. Laboratory instruments for metallographic preparation. 14

Figure 8: Stereomicroscopes and optical microscopes. 15

Figure 9: 3D image acquired with the microscope. 15

Figure 10: Example of penetration depth measure 15

Figure 11: Example of porosity measurement under stereomicroscope..... 15

Figure 12: Hardness test. 16

Figure 13: Measurement of diagonals in an HV10. 16

Figure 14: Temperature and welding zone relationship. 17

Figure 15: Example of Test Rig..... 18

Figure 16: corrosion potentiometer 18

Figure 17: Battery Cooling plates parts (Cornaglia)..... 19

Figure 18: Specifications of the leak tightness test 24

Figure 19: Specifications of the vacuum withstanding test 25

Figure 20: Specifications of the Pressure cycle test 25

Figure 21: Specifications of the Burst Pressure Test..... 26

Figure 22: Powerplant service pipe 27

Figure 23: V&V plan for energy fusion use case 27

Figure 24: Longitudinal welds..... 29

Figure 25: Type A welding requirements. 29

Figure 26: Heat exchanger simulacrum. 30

Figure 27: leak test..... 31

Figure 28: Filling pipe simulacrum 33

Figure 29: Distribution plate demonstrator..... 36

Figure 30: Fuel tank demonstrator..... 39

Figure 31: Propellant tank demonstrator. 41

Figure 32: Shelves (freeze drying) demonstrator. 43

LIST OF TABLES

Table 1: Penetrant testing step description. 12

Table 2: Details of the welding linear (L) paths for the cooling plates 20

Table 3: Cooling Plate Prototype requirements 20

Table 4: Main process requirements 20

Table 5: Industrial Verification and validation plan for DESIGN VALIDATION (V&VDV) 21

Table 6: Industrial Verification and validation plan for PRODUCT VALIDATION (V&VPV) 22

Table 7: Selected requirements of the V&VDV plan 22

Table 8: Selected requirements of the V&VPV plan 23

Table 9: Fusion energy use case (O = orbital welding) 28

Table 10: Product requirements 28

Table 11: Process requirements 28

Table 12: Testing requirements and sensing 28

Table 13: Heat Exchanger use case 31

Table 14: Product requirements 31

Table 15: Process requirements 31

Table 16: Testing requirements and sensing 32

Table 16: Selected requirements of the V&VPV plan 32

Table 17: Filling pipe use case 35

Table 18: Product requirements 35

Table 19: Process requirements 35

Table 20: Testing requirements and sensing 35

Table 16: Selected requirements of the V&VPV plan 36

Table 21: Distribution plate use case 37

Table 22: Product requirements 37

Table 23: Process requirements 37

Table 24: Testing requirements and sensing 37

Table 16: Selected requirements of the V&VPV plan 38

Table 25: Fuel Tank use case 39

Table 26: Product requirements 39

Table 27: Process requirements 39

Table 28: Testing requirements and sensing 40

Table 16: Selected requirements of the V&VPV plan 40

Table 29: Propellant Tank use case 41

Table 30: Product requirements 42

Table 31: Process requirements 42

Table 32: Testing requirements and sensing 42

Table 16: Selected requirements of the V&VPV plan 42

Table 33: Shelves (freeze drying) use case 44

Table 34: Product requirements 44

Table 35: Process requirements 44

Table 36: Testing requirements and sensing 44

Table 16: Selected requirements of the V&VPV plan 45

LIST OF ABBREVIATIONS

HAZ	Heat Affected Zone
TIG	Tungsten Inert Gas
GTAW	Gas Tungsten Arc Welding
NDT	Non Destructive Testing
LBW	Laser Beam welding
EBW	Electron Beam Welding
V&V	Verification & Validation
LBS	Laser Beam Shaping
VT	Visual Testing
PT	Penetrant Testing
RT	Radiographic Testing
UT	Ultrasonic Testing
LT	Leak Testing

1. Executive summary

This deliverable presents the verification and validation plan for the demonstrators. - The full document with details is saved in the project TEAMS folder at: Deliverables\D2.3\APPENDIX. D2.3. This is a live document and will be updated throughout the project duration. Details about verification and validation of the Lasers4MaaS platform will be presented in D 5.1: architecture of the Lasers4MaaS digital platform.

2. Introduction

Different use cases have been proposed in industrial fields having great relevance for EU: Food & Pharma Packaging, Automotive, Aerospace, Green Energy sectors where Europe needs to maintain/increase its leadership and/or consolidate the global market share.

Ecor production is based on the customer's design and requirements. For this reason, there are confidentiality issues on the parts that are property of the customer from each side. According to this restriction, for each of the selected components in the industrial sectors of Food Packaging, Aeronautics and Aerospace, Energy (Hydrogen), Pharma, "equivalent" prototypes have been drawn. The design criteria adopted are the requirement of leaving the max dimensions but changing some geometry details and, for the welding paths, the same industrial issues have been considered when the real parts are manufactured.

For Cornaglia, a preliminary concept prototype has been designed and developed and for the Fusion energy sector, a half pipe like the real plant pipe will be welded optimizing the process parameters.

The verification and validation plan aims to demonstrate the applicability of the achieved project results in terms of process and product requirements. From this side, there are requirements connected with product in service functions and other depending on the results of technology application (laser dynamic beam shaping welding). Both these two classes have been considered in the framework of the R&D activities.

3. Plan for verification and Validation

Welding verification is usually performed by means of a series of quality controls, inspections and checks following a determined standard, e.g. ISO5817/13919-1 or AWS D17.1, with the objective of providing a quality assessment on the weld structure, whether for structural integrity, absence or presence of admissible defects. The welding verification is usually performed on simulacra of the final product to be produced, in order to reduce the economic impact of producing a product before the joining process is fully understood and qualified.

Welding verification for each use case shall be operated on simulacra resembling the final product, while simplifying all the unnecessary geometries for the welding. The main focus of the verification activity is to assess the feasibility and overall quality of the single weld in each case. To stick as much as possible to the final geometry to be produced, the simulacra must have comparable geometries to the use case but can be limited to the area surrounding the weld, taking into account the estimated heat affected zone (HAZ). For example, in a flange-pipe welded connection, the pipe shall be manufactured as shorter as it is possible to, considering HAZ and keeping the most important parameters – such as pipe material, treatments, thickness, thermal inertia.

Moreover, verification of different cases shall take into account the different conditions of use of the final products, i.e. mechanical conditions such as pressure, tensile/bending stresses; environmental conditions such as media flowing, contact with substances, surrounding elements, temperatures, presence of chemical species etc. For this reason, the verification plan has been split into a general plan, which is shared between all or most of the use cases to be verified; and a particular plan for each of the use cases which display the necessity of additional checks, tests or other.

The validation plan related to the use cases will take place in the frame of the WP15, while the technological demonstrator will be treated and realized during the WP16, the expectation is a TRL 6 for at least one use case of each market sector.

3.1. General verification plan

A general verification plan shall include all the actions to be performed on each weld for all use cases. These propaedeutic activities are most well-known in the welding industry as the go-to verification process. Actions may be part of – partially or thoroughly – internal procedures as well as international standards.

- Visual inspection
- Dimensional control
- Non-destructive-testing [NDT]

- Surface: identification of defects on weld surface, with indication of smoothness, continuity, absence of depressions and cracks, weld coloration. Penetrant testing (visible or fluorescent) is a common inspection technique.
- Volumetric: identification of internal defects such as flaws, porosity, inclusions or cracks. X-ray or Ultrasonic testing are common inspection techniques.
- Destructive testing
 - Metallographic section

Additional tests, such as tensile and shear tests, corrosion resistance tests, and leakage tests may be required and will be reported separately for each use case in the chapters below.

3.1.1. Visual inspection

Visual inspection is the first step of weld inspection. Not only the welding can be identified as lacklustre immediately after the welding process, considering various parameters such as surface smoothness, presence of spatters, or even macroscopic defects such as visible undercuts, evidence of surface porosity and many others; but also a particular attention shall be posed to different parameters such as the weld coloration, the state of the surroundings near the weld, major deflections in the plate/main body.

Visual inspection can be carried out using a graduated lens or low magnification optical instruments such as a videoscope or a stereomicroscope.

Videoscopes are remote visual inspection (RVI) tools that allow operators to observe welds along the inside diameter of a pipe to assess, for example, penetration or to check for defects and possibly measure them. However, taking precise measurements can be difficult due to the curvature of the pipes.

Figure 1 shows the videoscope available in the company and used to document the inside or non-accessible areas of the weld under inspection.



Figure 1: Videoscope Olympus iplex.

The typical defects detected by videoscope are:

- Negative root reinforcement
- Weld discoloration or oxidations
- Lack of penetration

The pictures below show some examples of the image acquired by the instrument for the defects just listed.

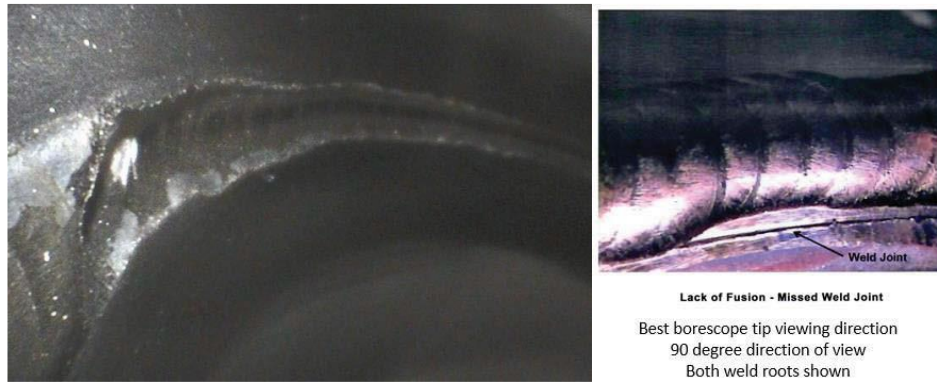


Figure 2: Examples of negative root reinforcement (left) and lack of penetration (right).

3.1.2. Dimensional control

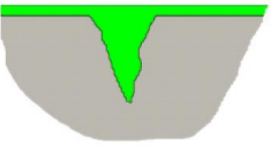


Due to the thermal energy provided to the piece during the joining process by means of a high-power source, it is likely that the various components of the welded part may be deformed slightly, therefore not responding to a designed tolerance. Dimensional control is usually performed on welded parts in order to assess the correct geometry of the final piece. Commonly used instruments range from altimeters and manual or digital goniometers to more precise instruments like coordinate-measuring machines (CMM) or non-contact alternatives, e.g. laser scanners, optical scanners, profile projectors.

3.1.3. Non-destructive testing

Non-destructive testing includes penetrant liquids (PT) and x-ray inspection (RT) of welded parts. Other techniques include ultrasonic testing (UT).

Penetrant liquids (visible or fluorescent are a non-destructive technique allowing the inspectors to detect material discontinuities on the surface of the welds.

A short description of the process phases for the PT is summarized as follow:

step	Short Description	
1.	Cleaning of the surfaces to be inspected	
2.	Application of the fluorescent penetrant by paint brush under UV light	
3.	Application of the emulsifier	
4.	Removal of excess penetrant with demineralized water under UV light	
5.	Part drying in an air circulation oven	

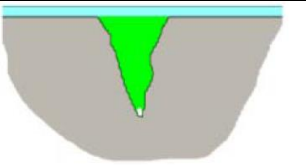
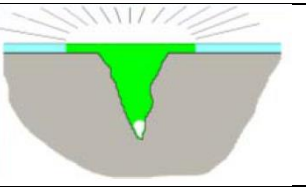
6.	Application of the developer	
7.	Indications interpretation under UV light	
8.	Final cleaning	

Table 1: Penetrant testing step description.

The PT allows the identification of surface indications usually invisible to the conventional VT – Visual Testign, such as:

- Surface microporosity
- Cracks and microcracks

The pictures below show some examples of defects detected by fluorescent penetrant inspection.

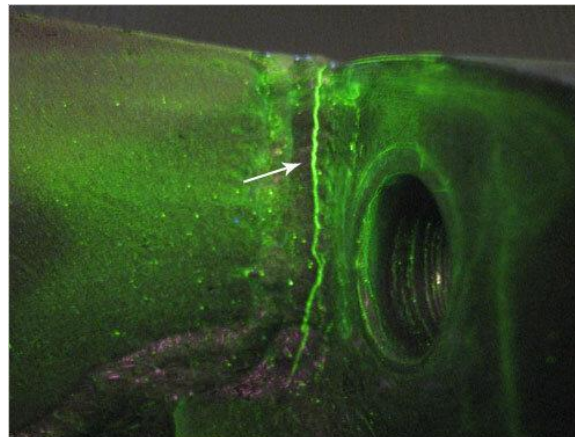


Figure 3: Example of crack detected on a weld after penetrant inspection.

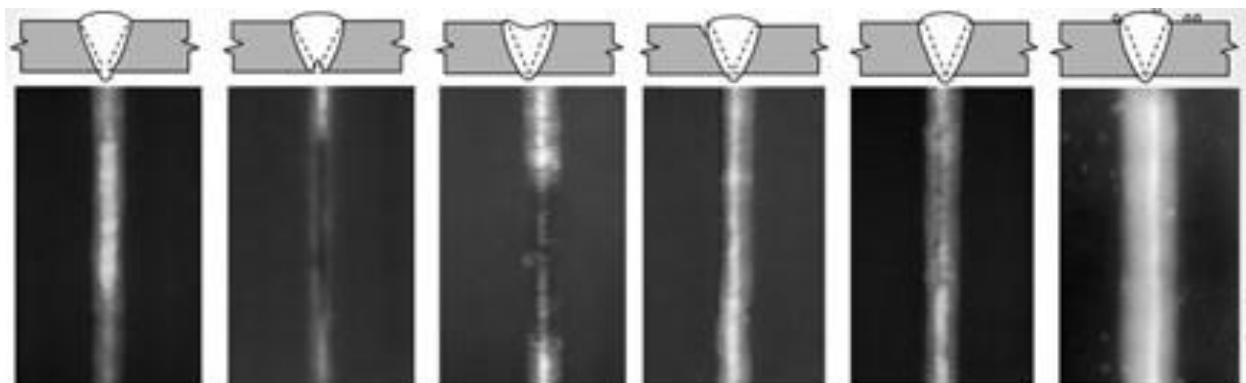


Figure 4: Example radiographic inspections performed on noncompliant welds.

The radiographic control of the welds allows to detect defects and problems inside the welded joint: it is therefore a non-destructive control that allows to identify any imperfections that may constitute a risk in terms of structural integrity of the welded materials.

The radiography of the sample shows darker areas and lighter areas: this different degree in the darkness of the image is used to determine the thickness or composition of the material and also reveals the presence of any defects or discontinuities inside the material. It is possible to observe various defects such as porosity, inclusions, lack of fusion or lack of penetration that determine the conformity or reject of the weld made.

The X-ray inspection can be performed either with conventional film radiography or digital control. In this second method, the tests can be carried out with the 80-150 SRE MAX Bosello system, shown Figure 5.



Figure 5. Digital radiographic control system.

Digital radiography uses X-ray sensitive devices other than traditional, typically analog films, to acquire an image of the analysed component that can be viewed on a video display. In particular, the 80-150 SRE MAX Bosello system uses Direct Radiography with digital panels (DDA – Digital Detector Arrays) that record the radiographic image, allowing its processing and improvement with electronic storage and transmission.

The radiographic unit is able to provide an image quality at least equal to that of the highest-class film, through a 3-10x magnification technique with an X-ray tube equipped with a $5\div 50\ \mu\text{m}$ micro-focal spot and a $200\times 200\ \text{mm}$ electronic sensor with $200\ \mu\text{m}$ pixels. With this system, the film development phase is not necessary and obtaining images is much faster.

An additional practical advantage is the numerically controlled movement inside a radiation-shielding cabin, which allows automatic exposure cycles to be programmed on identically positioned parts of the same shape without having to reposition the piece multiple times. In addition, it is possible to adjust contrast, brightness, and apply more sophisticated image processing techniques to analyze different thicknesses with a single image, to size defects, and more.

Figure 6 shows, as an example, a digital X-ray of two butt-welded aluminum plates in which there are coarse porosities and it is also possible to see how the welding bead is not regular.

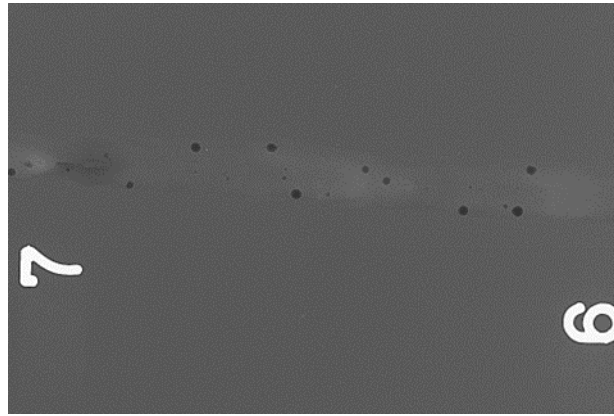


Figure 6. Example of digital radiography.

3.1.4. Destructive testing

Destructive testing includes metallographic inspection and hardness testing.

Metallographic inspections usually follow international standards, such as ASTM E3/E7 and/or ISO 3137/3138 or internal standards based on the previous international standards. The procedure steps, described in the standards, include cutting a relevant sample with a cutting blade or a micro cutter, the possibility of resin encapsulation for easy and better handling, grinding and polishing of the surface up to mirror surface and a chemical etching aiming to enhance the weld structure, grains, microstructure or any relevant characteristics of the material. Concerning welds, usually a lower magnification instrument can be employed, due to the dimension of the weld bead.

The metallographic preparation of weld samples for the V&V stage can be performed with automatic laboratory instruments as Struers Secotom-40 for cutting, Struers Citopress for sample mounting, Struers Tegramin for grinding and polishing.



Figure 7. Laboratory instruments for metallographic preparation.

Metallographic inspection, after sample preparation, requires analyse a section of weld area under high-magnification optical instruments, such as stereomicroscopes or optical microscopes to detect the weld structure characteristics.

In the stereomicroscope the light beam hits the surface of the sample allowing to observe its morphological conformation, thus highlighting for example imperfections and compositional differentiation, or the presence of any stratifications and forms of degradation. The information obtained allows to define with greater precision and detail the study or intervention plan. In Figure 8 the Leica M205C stereomicroscope is shown, this instrument is equipped with different objectives: from 7.8 X up to 160 X.

The Leica M205C stereomicroscope in the laboratory is also equipped with the Leica Application Suite software, this imaging system is an excellent solution for obtaining precise analysis and documentation.

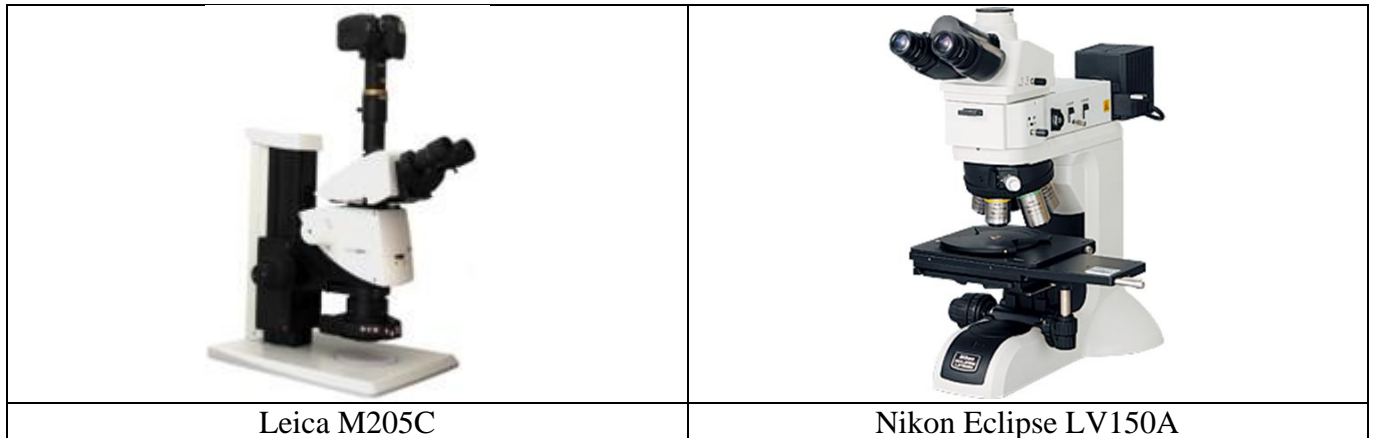


Figure 8: Stereomicroscopes and optical microscopes.

Our optical microscope is equipped with different objectives: 50 X, 100 X, 200 X, 500 X and 1000 X. The microscope is compatible with bright field, dark field, simple polarization, DIC, epifluorescence and two-beam interferometry observations. This instrument supports different and advanced research, analysis and inspections.

The microscope is equipped with NIS-Elements, an integrated software for image acquisition, documentation, image analysis and data management.

For example, through motorized focus control, NIS-Elements reconstructs and renders 3D images from multiple planes of the Z-axis. This allows for example the possibility of measuring the roughness of samples or the contact angle. Figure 9 shows a drop of ketchup that was acquired with the Nikon Eclipse LV150A.



Figure 9: 3D image acquired with the microscope.



Figure 10: Example of penetration depth measure

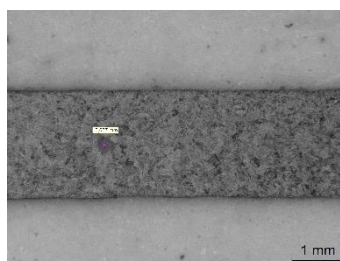


Figure 11: Example of porosity measurement under stereomicroscope

Large Image Acquisition generates a single, high-magnification, wide-field-of-view image by automatically stitching multiple adjacent frames from a multipoint acquisition using the motorized stage. Interactive measurement allows you to easily measure length and area by drawing lines or an object directly on the image. Results can be listed or exported as text or Excel files.

Metallographic analysis highlights the different characteristics/requirements of the weld, such as the depth of penetration of the weld, the presence of defects such as porosity and cracks, identifies the HAZ, identifies other singularities such as undercuts, overfilling, inclusions, microstructural defects. The combination of all this information determines whether the joint is compliant or not.

The hardness test is important destructive test for characterize the weld. We can performed different kind of hardness: HRC, HV10, microhardness. The Affri 206 EX hardness tester illustrated in Figure 12 allows direct and digital reading of HRB and HRC hardness, while this is not possible for HV10 hardness.

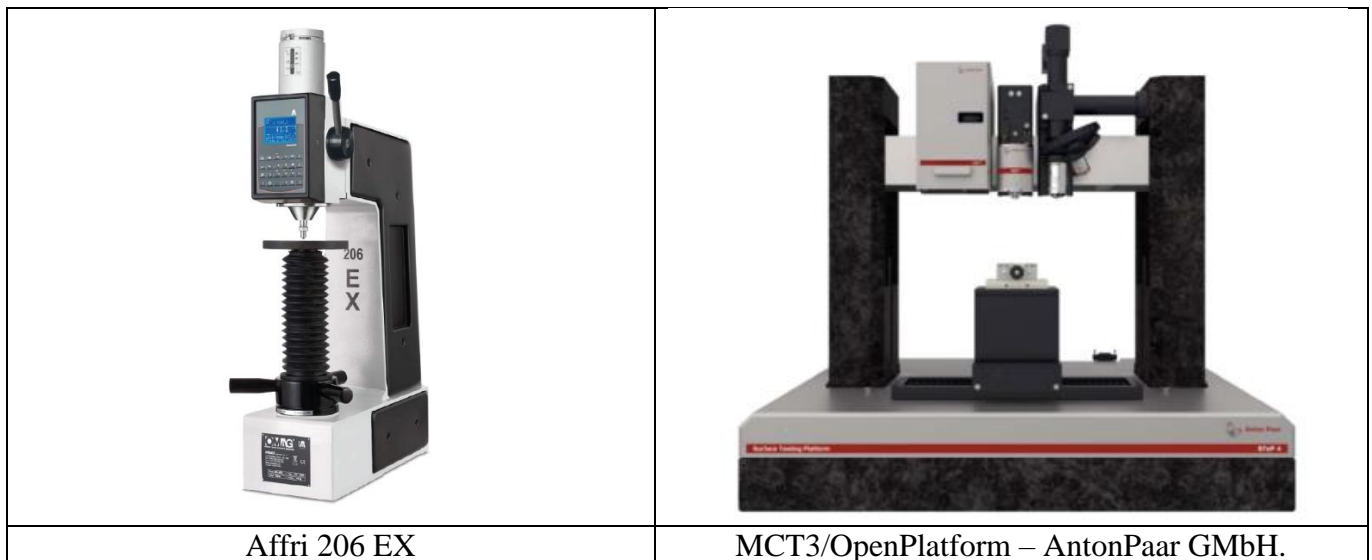


Figure 12: Hardness test.

To measure the HV10 hardness, it is necessary to proceed by taking photographs of the impression with the optical microscope and measuring the diagonals, as shown as an example in Figure 13.

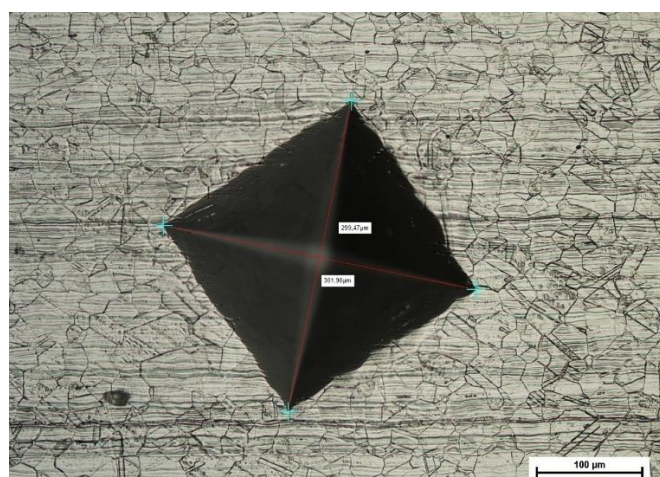


Figure 13: Measurement of diagonals in an HV10.

Once the diagonal measurements are obtained, we proceed by averaging them. The calculation of the HV10 hardness is done as follows:

$$HV10 = \frac{1,854 * 10}{(d_{mean} * 10^{-3})^2}$$

where d_{mean} is the mean of the measure of the two diagonals.

Micro- Hardness is measured via instrumented indentation on the MCT3/OpenPlatform – AntonPaar GmbH. Groups of 6 indentations in different significant positions with controlled maximum load is performed. Load-vs-penetration depth curves are registered for each indentation. Hardness is calculated from resulting curves according to ISO 14577 as average value on the acquired indentations.

For the tests, the following parameters were chosen:

- Indenter type: Vickers
- Indenter material: diamond
- Type of loading: linear
- Maximum Load: 1000mN
- Loading/unloading rate: 2000 mN/min
- Holding at maximum load: 15 s

Hardness evaluation, especially in a profile following the direction of heat dissipation along the base material, can be pivotal during the identification of HAZ. Welding a material creates a fusion zone, where the temperature is highest, and a gradient of temperature away from the weld zone. Between the melting temperature of the weld bead and the original temperature of the base material there is a zone, called Heat Affected Zone (HAZ), in which the microstructure is affected by the heat given to the piece by the welding element. While it is true that laser welding is one of the best technologies in keeping the HAZ as contained as possible, the microstructural alterations due to the thermal cycle can still be detrimental for the resistance of the material. Therefore, performing a series of hardness indentations perpendicular to the laser direction will provide information on the thickness and state of the HAZ.

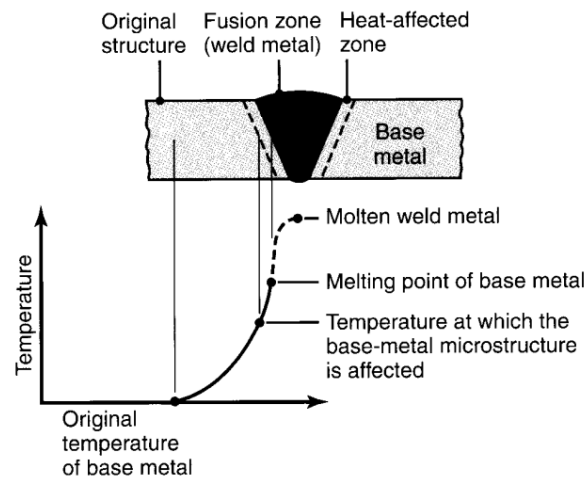


Figure 14: Temperature and welding zone relationship.

3.1.5. Corrosion test

For the V&V process it is very important to consider the corrosion resistance of the weld with respect to the cleanability of the detergent as well as the working environment. Typically, in the food industry, there are:

- CIP detergents
- Detergents for external cleaning
- Sanitization
- Product

The CIP cycle uses the commercial solution NaOH and HNO₃; the external cleaning uses the detergent with surfactants; the sanitization phase uses H₂O₂; the product acts both as a corrosion agent and as a factor that determines the cleanability parameters.

Different test rigs can be used to evaluate the single or combined effect, the type and time of contact, the cycle frequency. The parameters of individual tests may be different, depending on the use case, working conditions and the type of accelerated test you want to perform. Typically, we will perform benchmark tests to compare the performance of the new product/technology/material with the solution currently on the market. The tests are carried out according to industrial procedures adopted to validate new materials, new treatments, new component design by specific test rigs simulating the real industrial environments. The procedures have been consolidated with the industrial customers in the Food Packaging Industry.

In Figure 15, the SimuCorr and Cleanability test rig are shown. The first one is dedicated to test the corrosion resistance with the chemicals used in the packaging plant and the second one, developed in the H2020 Tresclean Project, for the measurement of the external cleaning properties.

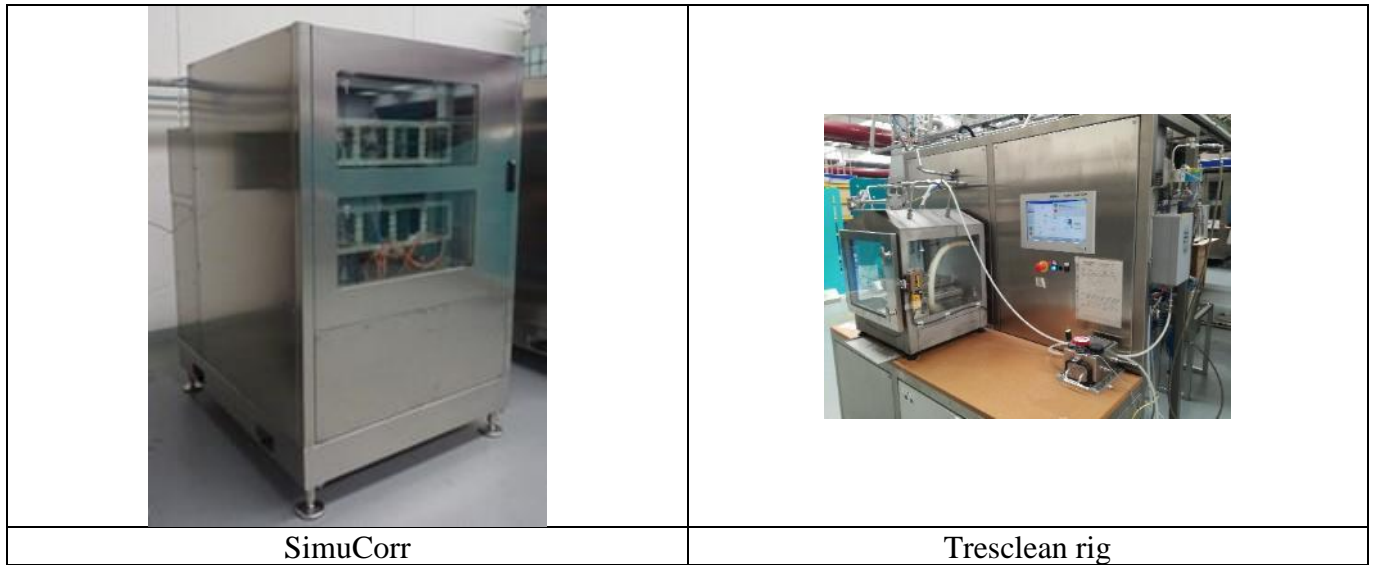


Figure 15: Example of Test Rig.

The cleanability assessment consists of two methodologies:

- analysis by ImageJ of stereoscopic images before and after cleaning
- ATP measurements: organic contamination is measured by detecting adenosine triphosphate (ATP) + ADP (adenosine diphosphate) + AMP (adenosine monophosphate).

These data can be correlated to the quality of the surface finish. While the evaluation of corrosion resistance in addition to the stereomicroscope observation that allows to identify the presence of holes or other surface defects, the weight before and after the test is used. Significant variations correspond to high corrosion.

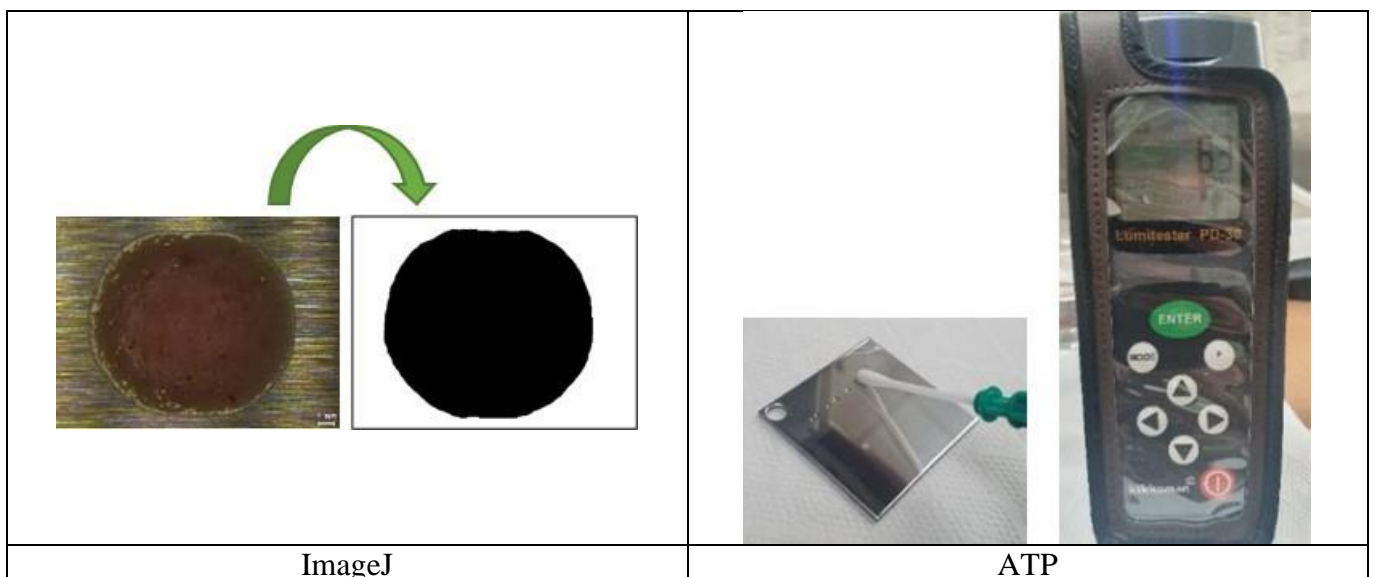


Figure 16: corrosion potentiometer

3.2. Industrial Use Cases, verification and validation

The selected case studies are represented by high added value components, with complex processing cycles and significant dimensions.

For these reasons it was decided to plan the V&V phase on simulacra capable of representing the selected case study in terms of material and joint geometry.

3.2.1. Automotive use case

A battery cooling plate (BCP) have been selected for the development of use case for the automotive sector. Cooling plates in an EV thermal management system allow liquid coolant to remove heat from the battery.

One cooling plate design circulates coolant between two thin aluminum (Al) plates. The coolant flows through stamped channels in the base plate, which is joined to a top plate. To prevent coolant leakage, the base and top plates must be joined to create a tight, hermetically sealed joints. The welded joints must also be free of cracks that can lead to mechanical failure in the field.

These typologies of components can reach dimensions up to 2000 x 1500 mm for automobile applications. At present they have been produced by brazing process requiring the adoption of vacuum furnaces (high energy consuming plant).

These plants have a high CAPEX increasing with the dimension of the industrial oven.

The adoption of laser processing technology accelerates with increased reliability, robustness. Compared to the traditional welding processes, laser welding has great potentiality to reduce production costs and increases manufacturing flexibility and productivity because of the welding speed.

Laser welding technology also has less heat input then could minimize distortion potential.

Looking at the common cooling battery geometrical configurations, the main attention is driven by the dimension and the complexity in geometries.

The recirculating cooling liquid, the thermal and pressure cycles require a high quality bead during all the working life. In particular, no micro-craks, porosities and undercut defects should be find in the joining.

An example of parts of cooling plates from Cornaglia are shown in **Error! Reference source not found.**

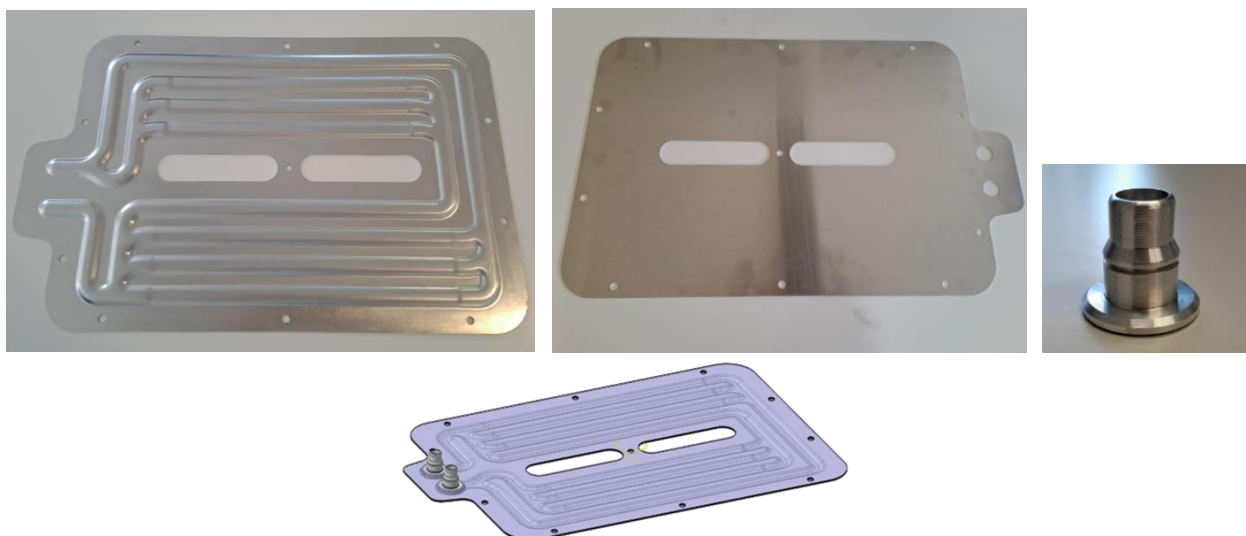
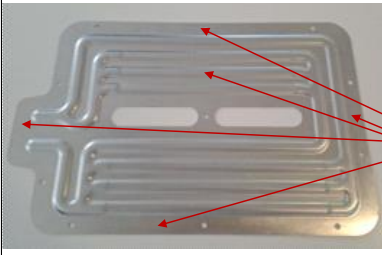
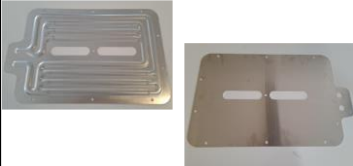


Figure 17: Battery Cooling plates parts (Cornaglia)

The laser welding process has to be developed along the perimeter of the plate and in some internal areas (Table 2).

Table 2: Details of the welding linear (L) paths for the cooling plates

Sector	Use case	Visual image	Visual image of the industrial prototype	Type of samples for LAB tests and preliminary process optimization
Name	Name	Image	Image	Image
Automotive	Battery cooling		Plates with reduced dimensions and flat samples (CORNAGLIA)	
			Prototypes for welding (CORNAGLIA)	

Geometry data, material, mass and joint type can be found in

Table 3: Cooling Plate Prototype requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
Aluminium alloys 3xxx/5xxx	1 to 2 mm	max 400 mm	max 400 mm	NA	NA	1,26	Lap weld	
Aluminium alloys 3xxx/5xxx	1 to 2 mm	1400 mm	1300 mm	NA	NA	14,38	Lap weld	

The main data about process and IT requirements are shown in Table 4.

Table 4: Main process requirements

Process requirements					Connectivity and IT requirements and interoperability
Gas shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up, fixture, robot	Comment
GAS EXT	N/A	0	1G	X-Y table + galvo-scanner	Firewall configuration/setup and IP port
GAS EXT	N/A	0	1G	6-axis robot or X-Y table	Firewall configuration/setup and IP port

The CBP is required to fulfil specific product requirements connected with the service conditions.

This requirements are part of the extended industrial verification and validation plan for Design Validation are reported in Table 5 and in Table 6 for the extended industrial verification and validation plan for Product Validation.

Table 5: Industrial Verification and validation plan for DESIGN VALIDATION (V&VDV)

Requirement text	Connector/Pipes	Holding pad	DV
Geometric inspection		X	X
Leak tight test and vacuum operation			X
HTC	X	X	X
Temperature Homogeneity	X	X	X
Pressure Drop	X		X
Vacuum	X		X
Degazing	X		X
Filling	X		X
Fixations withstanding		X	X
External corrosion		X	
Low temperature	X	X	X
High temperature	X	X	X
External thermal shock	X	X	X
Internal thermal shock	X	X	X
Pressure cycle	X		X
Internal cleanliness	X		X
Erosion	X		X
Decelerations (non-reparabile and incident)	X	X	X
Vibrations	X	X	X
Stone impact - load 1	X	X	X
Stone impact - load 2	X	X	X
TIM Compression withstanding	X	X	X
Geometric inspection		X	X
Leak tight test and vacuum operation			X
By-Pass			X
High temperature until failure	X	X	
External thermal shock until failure	X	X	
Internal thermal shock until failure	X	X	
Pressure cycle until failure	X		X
Burst until failure	X	X	X
Stone impact until failure	X	X	X

Table 6: Industrial Verification and validation plan for PRODUCT VALIDATION (V&VPV)

Requirement text			
	Connector/Pipes	Holding pad	PV (OTOP)
Geometric inspection		X	X
Leak tight test and vacuum operation			X
HTC	X	X	X
Temperature Homogeneity	X	X	X
Pressure Drop	X		X
Vacuum	X		X
Degazing	X		X
Filling	X		X
Fixations Withstanding		X	X
External corrosion		X	
Low temperature	X	X	
High temperature	X	X	
External thermal shock	X	X	
Internal thermal shock	X	X	
Pressure cycle	X		X
Internal cleanliness	X		X
Erosion	X		X
Decelerations (non-reparabile and incident)	X	X	
Vibrations	X	X	
Stone impact	X	X	
TIM Compression withstanding	X	X	X
Geometric inspection		X	X
Leak tight test and vacuum operation			X
By-Pass			X
High temperature until failure	X	X	
External thermal shock until failure	X	X	
Internal thermal shock until failure	X	X	
Pressure cycle until failure	X		X
Burst until failure	X	X	X
Stone impact until failure	X	X	X

In the framework of the project activities, the main V&VDV and V&VPV have been selected adopting the criteria of considering the ones with strong impact in validating the welding properties.

The main requirements to be validated in the design phase are by simulation modelling are reports in Table 7 while the V&VPV is shown in Table 8.

Table 7: Selected requirements of the V&VDV plan

Requirement text			
	Connector/Pipes	Holding pad	DV
HTC	X	X	X
Temperature Homogeneity	X	X	X
Pressure Drop	X		X
Vacuum	X		X
Filling	X		X
Fixations withstanding		X	X

Table 8: Selected requirements of the V&VPV plan

Requirement text			
	Connector/Pipes	Holding pad	PV (OTOP)
Leak tight test and vacuum operation			X
Pressure cycle	X		X
Burst until failure	X	X	X

The validation of the welding process (parameters and welding paths steps) could be performed also on smallest prototype because the object of the validation is the welding bead and not the thermal performance of the cooling plate. In fact, the last ones depend on the design and geometry details of the system.

The specific test conditions for the validation and verification plan are detailed respectively:

- Figure 18 for the leak tightness
- Figure 19 for the vacuum operation
- Figure 20 for the pressure cycle test
- Figure 21 for the burst cycle test (2,5 bar for nominal working conditions and 5 bar for the max burst pressure)

LEAK TIGHTNESS AND VACUUM CONDITIONS

Leak tightness test (Air / Coolant / He)

The cooling plate undergo the leak tightness test and the vacuum operation test described below:

Step 1: Air under water test

The cooling plate must be at ambient temperature and free of moisture, in order not to influence the measurement.

Cycle description: leak tightness control. cf. Figure 3 Leak tightness test conditions

- Pre-filling: 25 sec
- Pre-emptying: 3 sec
- Filling: 5 sec
- Stabilization: 60 sec
- Test: 2 sec
- Emptying: 4 sec

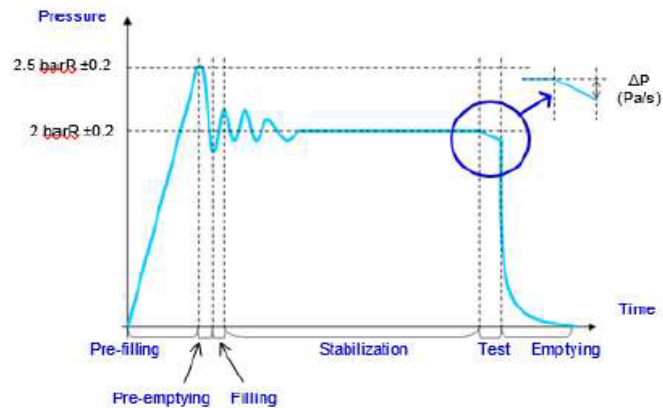


Figure 3 Leak tightness test conditions

Additional measurement devices: During test, inlet/outlet air temperature and environmental air temperature should be monitored and reported.

Step 2: With coolant circulation

Test conditions:

- Ambient air temperature: 25 +/- 2°C
- Coolant temperature: 25°C
- Coolant flow rate: 16.5 l/min +/- 0.5 l/min
- Inlet Pressure: 1.7 barR +/- 0.05 bar
- Stabilization phase: 30 min

Test precautions

- Ramp-up phase: 5s
- Maximum conditions during ramp-up phase
 - Coolant inlet pressure: 2.5 barR
 - Coolant inlet temperature: 27°C
 - Coolant flow rate: 18 l/min

Additional measurement devices: During test, outlet coolant temperature and outlet volume flow rate should be recorded and reported.

Figure 18: Specifications of the leak tightness test

Vacuum withstanding test

Test conditions are describe in Figure 5 Vacuum test conditions

- Vacuum pressure: 10 mbarA
- Vacuum duration: 20s
- Test duration: 30s
- Temperature: 25°C +/-2°C

Test report:

The test report must at least include the curves of the pressure profiles that the cooling plate undergoes during both tests.

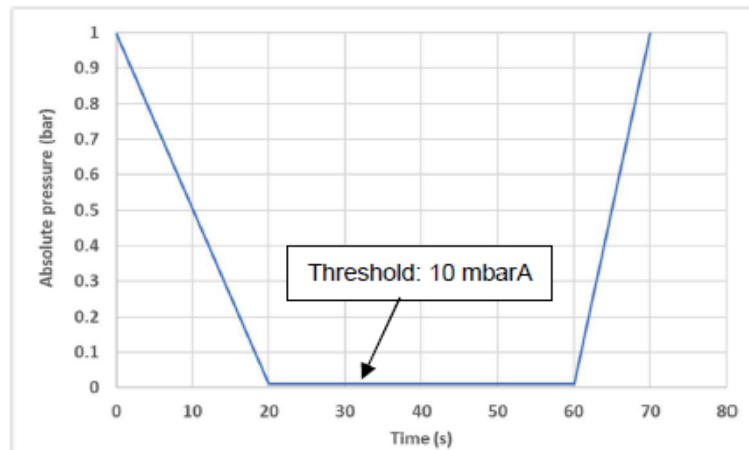


Figure 19: Specifications of the vacuum withstanding test

Pressure cycle withstanding

Test conditions

2 configurations should be tested:

- Free state (cooling plate can be fixed on 4 corners if needed to ensure the safety)
- Under load (in vehicle conditions): under module and battery pack constraints and with representatives hydraulics connection (QC and pipes/hoses)
 - For under load conditions thermal pad used should have the same characteristics as the thermal pad used for thermal performances validation (refer to section 4.6.2).

Test procedure:

- **Step1 : 2 000 cycles**
 - Environmental temperature: < 25 °C
 - Coolant temperature: 50°C +/- 2°C
 - Frequency: 1 hz (sinusoidal shape)
 - Pressure range: 0 barR to 1.2 x P_{work}
 - At the end of the cycle, a coolant temperature decreases to 23°C is required.
- **Step2: 98 000 cycles**
 - Environmental temperature (< 25 °C)
 - Coolant temperature: 50°C +/- 2°C
 - Frequency: 1 hz (sinusoidal shape)
 - Pressure range: 0 barR to P_{work}
 - At the end of the cycle, a coolant temperature decreases to 23°C is required.
- **Step3: 20 000 cycles**
 - Environmental temperature: < 25 °C
 - Coolant temperature: 50°C +/- 2°C
 - Frequency: 1 hz (sinusoidal shape)
 - Pressure range: 0 barR to 1.2 x P_{work}
 - At the end of the cycle, a coolant temperature decreases to 23°C is required.

Figure 20: Specifications of the Pressure cycle test

Burst Pressure test

Test procedure:

Each cooling plate is tested following two conditions

- Free state
- As in the vehicle: under module and battery pack constraints and with representatives hydraulics connection (QC and pipes/hoses)

The tests should be done at ambient temperature and under water.

Internal cooling plate pressure should be increased by level until burst. Below are the different levels:

1. From ambient pressure until P_{max} with a speed of 0.1 bar/sec
2. Keep P_{max} during 5 min
3. From P_{max} until 5 barR with a speed of 0.1 bar /sec
4. Keep 5 bar R during 5 min
5. From 5 barR until burst with a speed of 0.1 bar/sec.

Note: the supplier should take precautions to avoid that other parts (such as pipes or QC) are the weakest point.

Figure 21: Specifications of the Burst Pressure Test

3.2.2. Energy fusion use case

Background: Replacing blanket modules and divertor cassettes in the fusion reactor require the rapid removal and welding of hundreds of service pipes (700+ to be processed) during maintenance downtime. Laser welding tools are being developed for use within these pipes. With in-vessel components needing replacement approx. every five years and given the space constraint, servicing can only be done from inside (in-bore welding) the pipes which are 219 mm in diameter. The overarching aim in developing these laser welding tools is to significantly reduce maintenance time and enhance the efficiency of operations. This advancement is crucial in overcoming the challenges of working within confined spaces and managing the complexities of in-bore welding. The fusion plant component is a Powerplant service pipes (Figure 22)



Figure 22: Powerplant service pipe

The welding process is performed in-bore circumferential butt joint configuration.

The main challenge in the laser welding can be identified in:

- Material Thicknesses: may be over 15 mm wall thickness
- Laser tool damage such as overheated optics being the process carried out inside the pipe
- Automated deployment and remote operation
- Process monitoring and control for weld quality enhancement
- Avoidance of post welding heat treatment
- In-situ inspection/NDE
- Fast and reliable process in radiation environment

The step by step Verification and Validation Plan is described in Figure 23. It involves 3 steps, from the preliminary dynamic laser beam shaping process optimization, process monitoring, welding quality prediction up to the final full validation on the power plant service pipe.

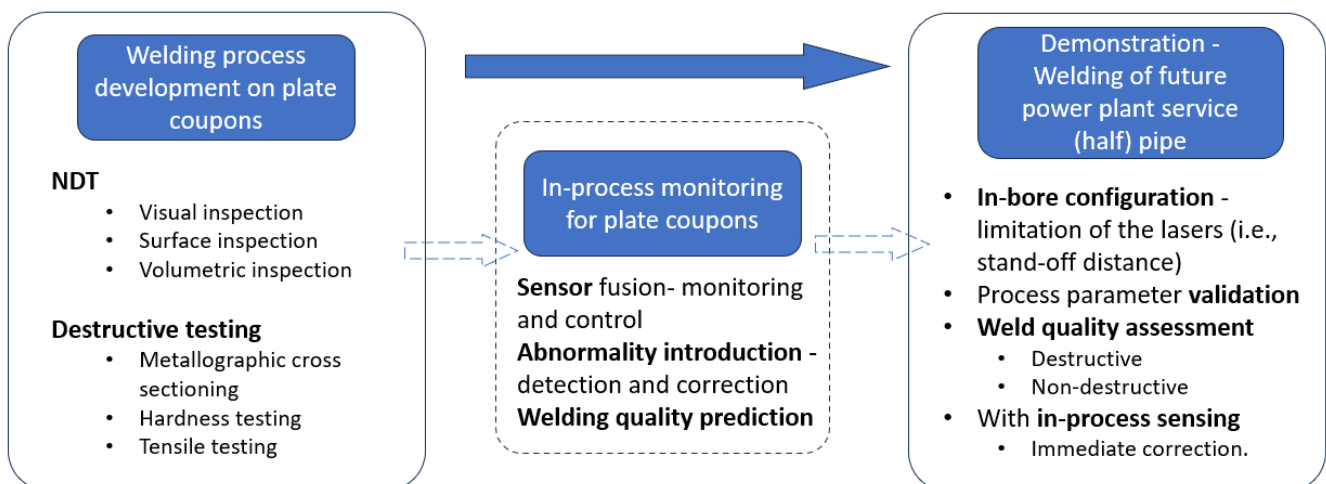


Figure 23: V&V plan for energy fusion use case

The general geometry details for the selected prototype, the welding paths, product, process and IT requirements plus testing requirements and sensing are reported from Table 10 to Table 12.

Table 9: Fusion energy use case (O = orbital welding)

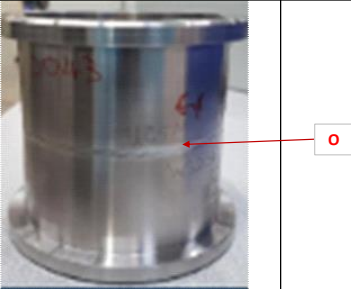
Sector	Use case	Visual image	Visual image of the industrial prototype	Type of samples for LAB tests and preliminary process optimization	Location of the demonstrator	Project phase
Name	Name	Image	Image	Image	Site	Name
Future fusion plant	Pipe welding				WMG	Coupon
					WMG	Coupon
					WMG	Actual pipe
					WMG	Actual pipe

Table 10: Product requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
316 plate	16mm	300mm	150mm		NA		square edge butt weld	BS EN 1011-6 (ISO/TR 17671-6) BS EN ISO 15609-4 BS EN ISO 15614-11 BS EN ISO 13919-1
P91 plate	16mm	300mm	150mm		NA	square edge butt weld		
316 half pipe	16mm	600 with weld in the middle	NA		DN200	square edge butt weld		
P91 half pipe	16mm	600 with weld in the middle	NA		DN200	square edge butt weld		

Table 11: Process requirements

Process requirements					Connectivity and IT requirements and interoperability
Shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up, fixture, robot	Comment
GAS EXT+INT (top and bottom)	NA	0	2G	X-Y table with rotary axis and galvo-scanner	Firewall configuration/setup and IP port
			2G	X-Y table with rotary axis and galvo-scanner	
			2G (bore side)	X-Y table with rotary axis and galvo-scanner	
			2G (bore side)	X-Y table with rotary axis and galvo-scanner	

Table 12: Testing requirements and sensing

Testing requirements and sensors					
In-process monitoring	Sensors for machine monitoring	PWHT	NDT and general quality acceptance	Mechanical testing	Microstructure
photo diode, acoustic sencer, high speed camera, thermal camera,etc.	flow meters water, flow meter gas, process gases, temperature, current meter	no	visual, surface, volumetric (x-ray)	tensile	Hardness, metallography
photo diode, acoustic sencer, high speed camera, thermal camera,etc.	flow meters water, flow meter gas, process gases, temperature, current meter	yes	visual, surface, volumetric (x-ray)	tensile	Hardness, metallography
down-select from coupon trials	flow meters water, flow meter gas, process gases, temperature, current meter	n/a	visual, surface, volumetric (x-ray)	tensile	Hardness, metallography
down-select from coupon trials	flow meters water, flow meter gas, process gases, temperature, current meter	n/a	visual, surface, volumetric (x-ray)	tensile	Hardness, metallography

3.2.3. Food Packaging – Heat Exchanger

The first use case is the heat exchanger made of austenitic stainless steel AISI 316L. This product has 2 types of welding:

- A- the longitudinal welds between adjacent plates of the body
- B- the welds between the body and the interfaces of the heat exchanger.

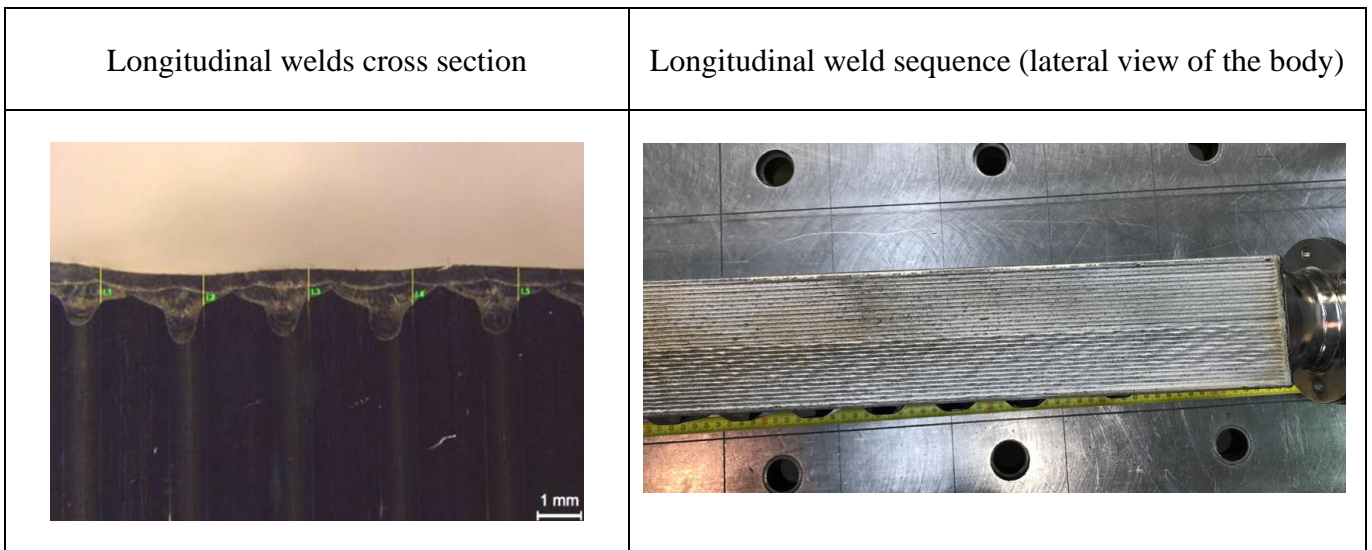


Figure 24: Longitudinal welds.

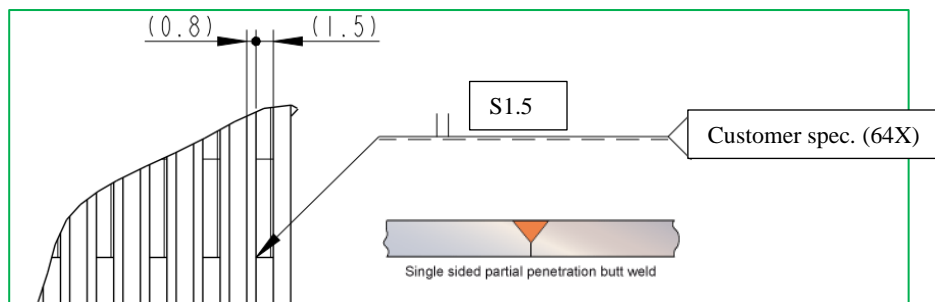


Figure 25: Type A welding requirements.

Connections to the conic flanges is excluded from this project as the welding technology currently in use is different.

The actual laser beam process is based on:

- Power = 1400 W
- Feed = 800 mm/min

And the cycle time (active phase) is about $2 \times 25' / \text{side} = 50'$ to weld both the sides of the body.

Verification simulacrum is a series of flat sheet metal with thickness of 1.5 mm and 0.8 mm. The weld required are butt welds with partial penetration in the range of 1.5 to 2.0 mm as reported in the Figure 25. Quality of the weld shall be verified with reference to international standard ISO13919-1 Class C.

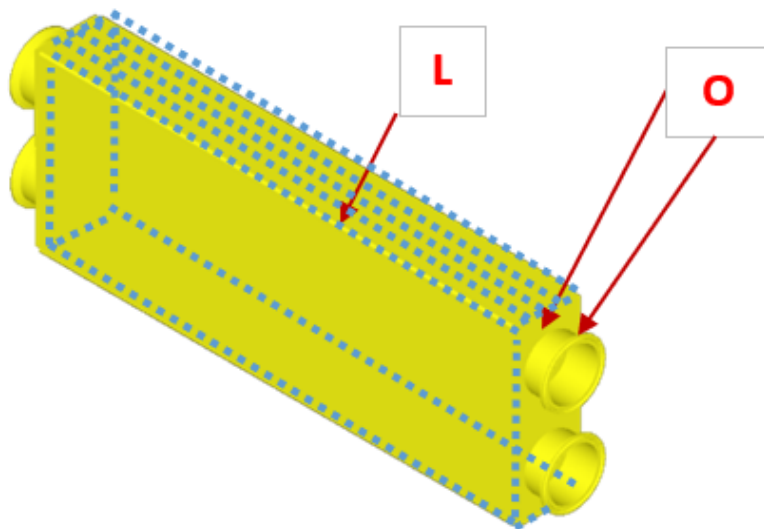


Figure 26: Heat exchanger simulacrum.

The verification plan of use case #1 include the general verification (by means of VT, dimensional, PT and metallographic analysis) and a pressure test for leakages.

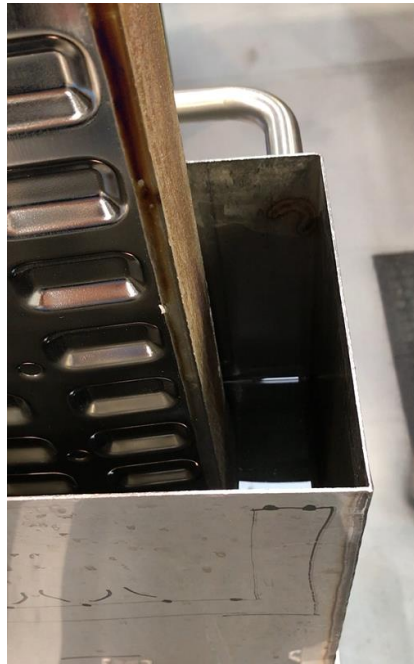


Figure 27: leak test.

The pressure test consists in applying an internal overpressure (1.0 Barg) then submerge the heat exchanger body in a water tank for at least 5'. Any leakages are visually detected and visible in forms of bubbles coming out from the component, in this case the component shall be repaired or rejected. The general geometry details for the selected prototype, the welding paths, product and process requirements, testing requirements and sensoring are reported from Table 13 to Table 16.

Table 13: Heat Exchanger use case


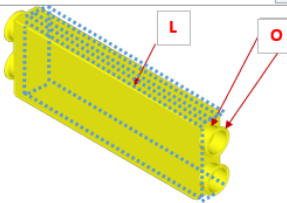
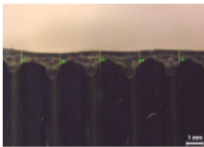
Use case	Visual image	Visual image of the industrial prototype	Type of samples for LAB tests and preliminary process optimization	Location of the demonstrator	Project phase
Name	Image	Image	Image	Site	Name
Heat exchangers				ECOR	Actual parts/ Industrial prototypes

Table 14: Product requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
AISI 316 stainless steel	HE Plates: 1,5 mm Plates: 8 mm Inner plates: 0,8 mm; 1,5 mm	650 mm	212 mm	80 mm	NA	35	butt weld (partial penetration)	ISO5817/13919-1

Table 15: Process requirements

Process requirements					Connectivity and IT requirements and interoperability
Gas shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up, fixture, robot	Comment
GAS EXT	N/A	0	1G / PA	X-Y table with rotary axis (2 axis) and galvo-scanner	Firewall configuration/setup and IP port

Table 16: Testing requirements and sensoring

Testing requirements and sensors					
In-process monitoring	Sensors for machine monitoring	PWHT	NDT and general quality acceptance	Mechanical testing	Microstructure
photo diode, acoustic sensor, high speed camera, thermal camera, etc.	flow meters water, flow meter gas, process gases, temperature, current meter	mechanical and chemical finishing (pickling, electropolishing, passivation)	visual, surface, dimensional pressure test (leakage)	N/A	Hardness, metallography

The following table summarizes the validation tests and requirements for the test coupon and demonstrators.

Table 17: Selected requirements of the V&VPV plan.

ID	Title	Requirement Text and Acceptance Criteria	Applicable / Not applicable
1	Visual inspection	The weld shall be compliant to the ISO13919-1 Class C	X
2	Dimensional and geometrical inspection	Dimensional and geometrical conformity to applicable manufacturing drawings.	X
3	FPI (Fluorescent Penetrant Inspection)	The surface inspection of the weld shall be compliant to the ISO13919-1 Class C	X
4	X-ray inspection	The volumetric inspection of the weld shall be compliant to the ISO13919-1 Class C	N/A
5	Leak test	The weld shall be leak/proof tested with air, P = 1.0 Barg with no visible leak under water for at least 5 min	X
7	Metallography Analysis	The metallographic inspection of the weld shall be compliant to the ISO13919-1 Class C The hardness profile along the weld shall be collected as reference	X
8	Mechanical Testing	Tensile or Shear test shall be compliant with the base material requirements	N/A
9	Corrosion Testing	Corrosion test shall be compliant with the base material requirements	N/A

The possibility of implementing the LBS Laser Beam Shaping could allow higher power density and process speed compared to the actual manufacturing cycle.

3.2.4. Food Packaging – Filling Pipe

Use case #2 is an austenitic stainless steel bended pipe made of AISI 316L, inspired by filling machines in food industry, where TIG welding is actually performed to join both ends with clamp flanges and a lateral branch connection.

The actual manual GTAW (TIG) welding process is based on:

- Current=50 A
- Voltage= 10 V
- Feed= 70 mm/min

And the average cycle time (active phase) is about $3 \times 5' / \text{weld} = 150'$ to weld a complete pipe.

Verification simulacrum for use case #2 resemble a circular sample and a branch connection, produced in AISI 316L with thickness of 1.65 mm and a diameter of 38.1 mm The laser weld required is a butt weld with full penetration. Quality of the weld shall be verified with reference to the international standard ISO13919-1 Class C.

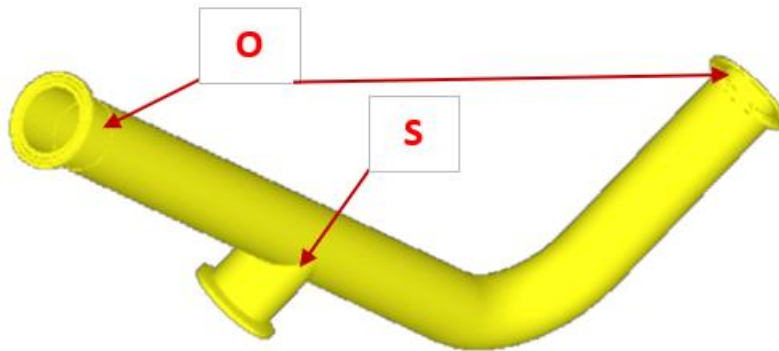


Figure 28: Filling pipe simulacrum

In addition to the general verification plan, use case #2 welds shall be verified with:

- A pressure test for leakages (hydrostatic pressure test, air pressure inside at 2-3 Bar, and then submerge the item under water).
- NaOH corrosion resistance
- Cleanability
- H₂O₂ corrosion resistance.

The general geometry details for the selected prototype, the welding paths, product and process requirements, testing requirements and sensoring are reported from

Table 18 to Table 21.

Table 18: Filling pipe use case


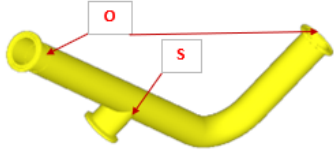
Sector	Use case	Visual image	Visual image of the industrial prototype	Type of samples for LAB tests and preliminary process optimization	Location of the demonstrator	Project phase
Name	Name	Image	Image	Image	Site	Name
Food	Filling pipes			Circular samples	ECOR	Actual parts/ Industrial prototypes

Table 19: Product requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
AISI 316 stainless steel	PIPE 1,65 mm	450 mm	230 mm	100 mm	38,1mm	1	butt weld (full penetration)	ISO5817/13919-1

Table 20: Process requirements

Process requirements					Connectivity and IT requirements and interoperability
Gas shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up fixture, robot	Comment
GAS EXT+INT (top and bottom)	N/A	0,5	1G-2F / PA-PB	6-axis robot or rotary axis	Fire wall configuration/setup and IP port

Table 21: Testing requirements and sensoring

Testing requirements and sensors						
In-process monitoring	Sensors for machine monitoring	PWHT	NDT and general quality acceptance		Mechanical testing	Microstructure
down-select from coupon trials	flow meters water, flow meter gas, process gases, temperature, current meter	mechanical and chemical finishing (pickling, electropolishing, passivation)	visual, surface, x-ray, Dimensional Pressure test, NaOH Corrosion resistance; Cleanability; H2O2 Corrosion resistance		N/A	Hardness, metallography

The following table summarizes the validation tests and requirements for the test coupon and demonstrators.

Table 22: Selected requirements of the V&VPV plan.

ID	Title	Requirement Text and Acceptance Criteria	Applicable / Not applicable
1	Visual inspection	The weld shall be compliant to the ISO13919-1 Class C	X
2	Dimensional and geometrical inspection	Dimensional and geometrical conformity to applicable manufacturing drawings.	X
3	FPI (Fluorescent Penetrant Inspection)	The surface inspection of the weld shall be compliant to the ISO13919-1 Class C	X
4	X-ray inspection	The volumetric inspection of the weld shall be compliant to the ISO13919-1 Class C	X
5	Leak test	The weld shall be leak tested according to the drawing requirements (e.g. helium leak test with 1.2 Bar abs, Leakage < 1x10E-5 mbar*l/s)	X
7	Metallography Analysis	The metallographic inspection of the weld shall be compliant to the ISO13919-1 Class C The hardness profile along the weld shall be collected as reference	X
8	Mechanical Testing	Tensile or Shear test shall be compliant with the base material requirements	N/A
9	Corrosion Testing	Corrosion test shall be compliant with the base material requirements: <ul style="list-style-type: none"> • NaOH corrosion resistance • Cleanability • H2O2 corrosion resistance. 	X

The possibility of implementing the LBS Laser Dynamic Beam Shaping could allow higher process speed compared to the actual manufacturing cycle based on the manual TIG welding, as well as a higher quality level in terms of surface appearance and discoloration.

3.2.5. Hydrogen – Distribution and Bipolar plates

Distribution and bipolar plates for Fuel Cell is another use case that will be implemented during the project. It consists of a combination of ferritic stainless steel sheet metal and a plate in the middle, joined together by laser welding.

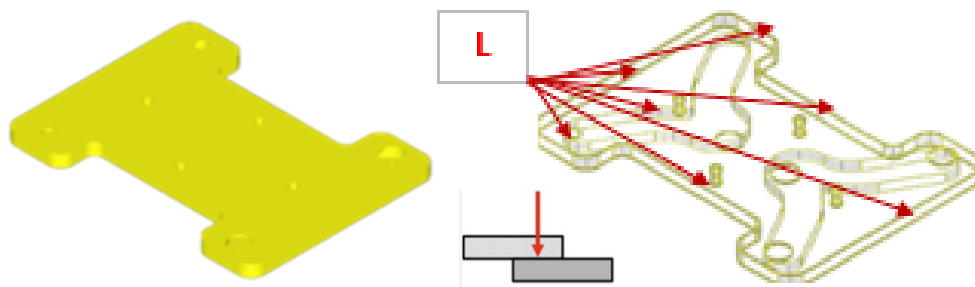


Figure 29: Distribution plate demonstrator.

The actual laser beam process is based on:

- Power = 1600 W
- Feed = 1600 mm/min

And the cycle time (active phase) is about 2 x 60''/side = 2' to weld both the sides of the body.

Verification simulacrum for use case #3 resemble a lap joint, produced K41 with thickness of 1.5 + 6 + 1.5 mm and an overall size The weld required is a butt weld with full penetration. Quality of the weld shall be verified with reference to the international standard ISO 13919-1 Class C.

The verification plan of use case #3 include the general verification (by means of VT, dimensional, PT and metallographic analysis) and an air pressure decay test for leakages.

The general geometry details for the selected prototype, the welding paths, product and process requirements, testing requirements and sensing are reported from Table 23 to Table 26.

Table 23: Distribution plate use case

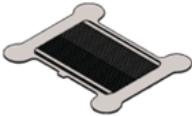

Sector	Use case	Visual image	Visual image of the industrial prototype	Type of samples for LAB tests and preliminary process optimization	Location of the demonstrator	Project phase
Name	Name	Image	Image	Image	Site	Name
Hydrogen	Distribution and bipolar plates			Flat samples with 1,5 and 6 mm thickness;	WMG	Coupon/surrogate parts
					ECOR	Actual parts/ Industrial prototypes

Table 24: Product requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
Ferritic Stainless Steel	1mm						Lap joint (partial penetration)	ISO 13919-1
Ferritic Stainless Steel	9 mm (1,5 mm+6 mm+1,5mm)	190 mm	143 mm	9 mm (1,5 mm+6 mm+1,5mm)	NA	1	Lap joint (partial penetration)	ISO 13919-1

Table 25: Process requirements

Process requirements					Connectivity and IT requirements and interoperability
Gas shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up fixture, robot	Comment
	N/A	0	1G / PA	X-Y table + galvo-scanner	Fire all configuration/setup and IP port
GASEXT	N/A	0	1G / PA	6-axis robot or X-Y table	Fire all configuration/setup and IP port

Table 26: Testing requirements and sensing

Testing requirements and sensors					
In-process monitoring	Sensors for machine monitoring	PWHT	NDT and general quality acceptance	Mechanical testing	Microstructure
photo diode, acoustic sensor, high speed camera, thermal camera, etc.	flow meters water, flow meter gas, process gases, temperature, current meter	machining and grinding after welding	visual, surface, x-ray, Dimensional	N/A	Hardness, metallography
down-select from coupon trials	flow meters water, flow meter gas, process gases, temperature, current meter	machining and grinding after welding	visual, surface, x-ray, Dimensional pressure test (leakage)	N/A	Hardness, metallography

The following table summarizes the validation tests and requirements for the test coupon and demonstrators.

Table 27: Selected requirements of the V&VPV plan.

ID	Title	Requirement Text and Acceptance Criteria	Applicable / Not applicable
1	Visual inspection	The weld shall be compliant to the ISO13919-1 Class C	X
2	Dimensional and geometrical inspection	Dimensional and geometrical conformity to applicable manufacturing drawings.	X
3	FPI (Fluorescent Penetrant Inspection)	The surface inspection of the weld shall be compliant to the ISO13919-1 Class C	X
4	X-ray inspection	The volumetric inspection of the weld shall be compliant to the ISO13919-1 Class C	X
5	Leak test	The weld shall be leak tested with air, P = 2.5 Barg with a pressure decay lower than 10% mbar in 1 min	X
7	Metallography Analysis	The metallographic inspection of the weld shall be compliant to the ISO13919-1 Class C The hardness profile along the weld shall be collected as reference	X
8	Mechanical Testing	Tensile or Shear test shall be compliant with the base material requirements	N/A
9	Corrosion Testing	Corrosion test shall be compliant with the base material requirements	N/A

The possibility of implementing the LBS Laser Dynamic Beam Shaping could allow higher power density and process speed compared to the actual manufacturing cycle.

3.2.6. Aerospace – Fuel Tank

Fuel tank for aerospace applications is another use case that will be implemented during the project. It consists of formed sheet metal and flanges made of aluminium alloys, joined together by manual TIG welding.

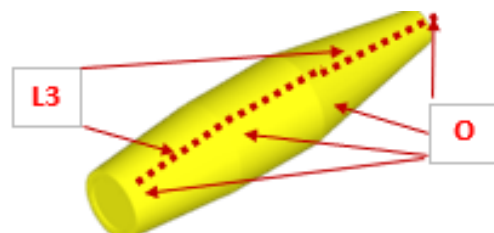




Figure 30: Fuel tank demonstrator.

The actual manual GTAW (TIG) welding process is based on:

- Current=160 A
- Voltage= 14 V
- Feed= 135 mm/min

And the cycle time (active phase) is about $4 \times 45' / \text{subcomponents} = 180'$ to weld a complete tank.

Verification simulacrum for use case #4 resemble a butt joint, produced of Al6061 with thickness of 2.5 mm. The weld required is a butt weld with full penetration. Quality of the weld shall be verified with reference to the international standard AWS D17.1 Class A.

The verification plan of use case #4 include the general verification (by means of VT, dimensional, PT, RT and metallographic analysis), mechanical testing on test samples, and air pressure test for leakages.

The general geometry details for the selected prototype, the welding paths, product and process requirements, testing requirements and sensoring are reported from Table 28 to Table 31.

Table 28: Fuel Tank use case

Sector	Use case	Visual image	Visual image of the industrial prototype	Type of samples for LAB tests and preliminary process optimization	Location of the demonstrator	Project phase
Name	Name	Image	Image	Image	Site	Name
Aeronaut	Tanks				ECDR	Actual parts/ Industrial prototypes

Table 29: Product requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
Al 6061	2,5 mm	2000 mm	600 mm	NA	Dmax=500 mm Dmin=210 mm	15	butt weld (full penetration)	AWS D17.1

Table 30: Process requirements

Process requirements					Connectivity and IT requirements and interoperability
Gas shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up fixture, robot	Comment
GASEXT+INT (top and bottom)	Yes, Al4043 (To be verified with LBW)	0	1G / PA	6-axis robot or XYZ table and rotary axis	Firewall configuration/setup and IP port

Table 31: Testing requirements and sensing

Testing requirements and sensors					
In-process monitoring	Sensors for machine monitoring	PWHT	NDT and general quality acceptance	Mechanical testing	Microstructure
down-select from coupon trials	flow meters water, flow meter gas, process gases, temperature, current meter	Pickling (prior welding), mechanical and chemical finishing (after welding), painting	visual, surface, x-ray, Dimensional pressure test (leakage)	tensile (on preliminary verification samples)	Hardness, metallography

The following table summarizes the validation tests and requirements for the test coupon and demonstrators.

Table 32: Selected requirements of the V&VPV plan.

ID	Title	Requirement Text and Acceptance Criteria	Applicable / Not applicable
1	Visual inspection	The weld shall be compliant to the AWS D17.1 Class A	X
2	Dimensional and geometrical inspection	Dimensional and geometrical conformity to applicable manufacturing drawings.	X
3	FPI (Fluorescent Penetrant Inspection)	The surface inspection of the weld shall be compliant to the AWS D17.1 Class A	X
4	X-ray inspection	The volumetric inspection of the weld shall be compliant to the AWS D17.1 Class A	X
5	Leak test	The weld shall be leak tested with air, P = 1.0 Barg with no visible leak under water for at least 5 min.	X
7	Metallography Analysis	The metallographic inspection of the weld shall be compliant to the AWS D17.1 Class A The hardness profile along the weld shall be collected as reference	X
8	Mechanical Testing	Tensile or Shear test shall be compliant with the base material requirements	X
9	Corrosion Testing	Corrosion test shall be compliant with the base material requirements	N/A

The possibility of implementing the LBS Laser Dynamic Beam Shaping could allow higher process speed compared to the actual manufacturing cycle based on the manual TIG welding, as well as a higher quality level in terms of surface and volumetric defects. As a matter of fact, aluminium alloys are prone to entrap gas porosity or form hot cracks, such defects in the aerospace field cause the rejection of the item with subsequent cost and lead time impact. Moreover, weld length approximately of 1 meter are very difficult to manage in a single weld pass for the welder.

3.2.7. Space – Propellant Tank

Propellant tank for space applications is another use case that will be implemented during the project. It consists of machined elements from round bar made of titanium grade 5/23 alloys, joined together by Electron Beam Welding.

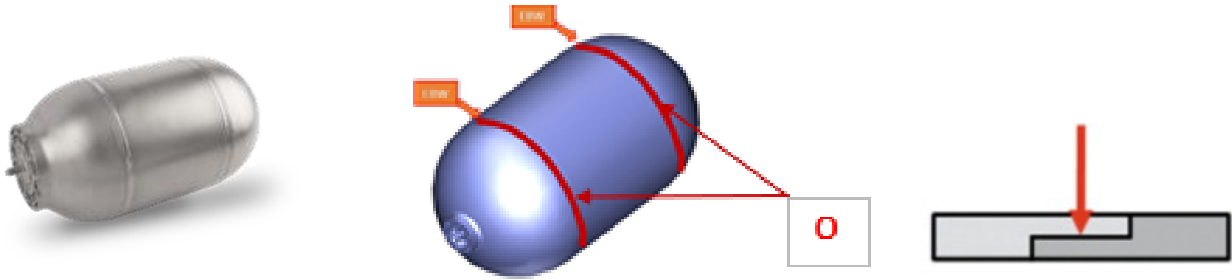


Figure 31: Propellant tank demonstrator.

The actual EBW process is based on:

- Voltage = 150 kV
- Beam Current = 18 mA
- Feed = 600 mm/min

And the cycle time (active phase) is about $2 \times 1.5' / \text{side} = 3'$ to weld both the sides of the body. This calculation does not take into account the time to put under vacuum the EBW chamber, that could take several minutes (30-60').

Verification simulacrum for use case #5 resemble a butt joint with material backing, produced of Ti Grade5/23 with thickness of 5.2 mm. The weld required is a butt weld with full penetration up to the material backing. Quality of the weld shall be verified with reference to the international standard ISO13919-1 Class B.

The verification plan of use case #5 include the general verification (by means of VT, dimensional, PT, RT and metallographic analysis) and Leak/Proof/Leak Test.

The general geometry details for the selected prototype, the welding paths, product and process requirements, testing requirements and sensoring are reported from Table 33 to

Table 36.

Table 33: Propellant Tank use case

Sector	Use case	Visual image	Visual image of the industrial prototype	Type od samples for LAB tests and preliminary process optimization	Location of the demonstrator	Project phase
Name	Name	Image	Image	Image	Site	Name
Aerospace	Tanks				ECOR	Actual parts/ Industrial prototypes

Table 34: Product requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
TiGrade5/23	5,2 mm	320 mm	NA	NA	D _{max} =220 mm	6	butt weld (full penetration, material backing)	ISO 13319-1

Table 35: Process requirements

Process requirements					Connectivity and IT requirements and interoperability
Gas shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up fixture, robot	Comment
GAS EXT+INT (top and bottom)	N/A	0	1G / PA	rotary axis	Fire wall configuration/setup and IP port

Table 36: Testing requirements and sensing

Testing requirements and sensors						
In-process monitoring	Sensors for machine monitoring	PWHT	NDT and general quality acceptance		Mechanical testing	Microstructure
down-select from coupon trials	flow meters water, flow meter gas, process gases, temperature, current meter	Pickling (prior welding), stress relieving mechanical and chemical finishing (after welding)	visual, surface, x-ray, Dimensional He leak test and proof test		N/A	Hardness, metallography

The following table summarizes the validation tests and requirements for the test coupon and demonstrators.

Table 37: Selected requirements of the V&VPV plan.

ID	Title	Requirement Text and Acceptance Criteria	Applicable / Not applicable
1	Visual inspection	The weld shall be compliant to the ISO13919-1 Class B	X
2	Dimensional and geometrical inspection	Dimensional and geometrical conformity to applicable manufacturing drawings.	X
3	FPI (Fluorescent Penetrant Inspection)	The surface inspection of the weld shall be compliant to the ISO13919-1 Class B	X
4	X-ray inspection	The volumetric inspection of the weld shall be compliant to the ISO13919-1 Class B	X
5	Leak/Proof test	The weld shall be leak/proof/leak tested according to the product requirements. Reverse He Leakage from the tank shall not exceed 5.88 x 10-8 mbar*L/s GHe The tank shall withstand the Proof Pressure of 255 bar (water) for at least 5 minutes, no damages or deformations are allowed.	X
7	Metallography Analysis	The metallographic inspection of the weld shall be compliant to the ISO13919-1 Class B The hardness profile along the weld shall be collected as reference	X
8	Mechanical Testing	Tensile or Shear test shall be compliant with the base material requirements	N/A

ID	Title	Requirement Text and Acceptance Criteria	Applicable / Not applicable
9	Corrosion Testing	Corrosion test shall be compliant with the base material requirements	N/A

The possibility of implementing the LBS Laser Dynamic Beam Shaping could allow similar power density and process speed compared to the actual EBW process. The advantage could be associated with the lower operative cost of the equipment: EBW are expensive equipment, and the associated running costs are affected by the vacuum pumping time necessary to perform the weld and the subsequent venting of the system.

3.2.8. Pharma - Shelves (freeze drying)

Shelves for freeze drying equipment of pharma application applications is another use case that will be implemented during the project. It consists of machined elements from square bar, sheet metal and square tubing made of austenitic stainless steel, joined together by vacuum brazing and additional GTAW activities.

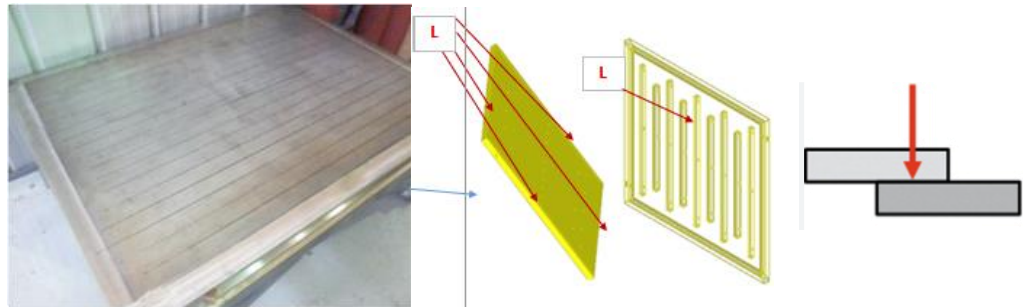


Figure 32: Shelves (freeze drying) demonstrator.

The actual vacuum brazing process is based on:

- Power = 100 kW
- Cycle time = 3-4 days

The cycle time is usually performed to braze simultaneously more than one single plate, the maximum capacity is a stack of 6 plates.

Verification simulacrum for use case #6 resemble butt and lap joint with material backing, produced of A316L with thickness of 3 mm. The weld required is a butt weld with partial penetration up to the material backing. Quality of the weld shall be verified with reference to the international standard ISO13919-1 Class C.

The verification plan of use case #6 include the general verification (by means of VT, dimensional, PT, RT and metallographic analysis) and Helium Leak Test.

In addition to the general verification plan, use case #7 welds shall be verified for:

- Corrosion resistance with cleaning and sterilization media
- Cleanability

The general geometry details for the selected prototype, the welding paths, product and process requirements, testing requirements and sensoring are reported from Table 38 to Table 41.

Table 38: Shelves (freeze drying) use case


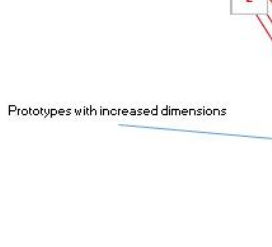
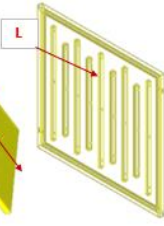
Sector	Use case	Visual image	Visual image of the industrial prototype	Type of samples for LAB tests and preliminary process optimization	Location of the demonstrator	Project phase
Name	Name	Image	Image	Image	Site	Name
Pharma	Shelves (freeze drying)				ECOR	Actual parts/ Industrial prototypes

Table 39: Product requirements

Product requirements								
Material	Thickness	Overall length	Overall width	Overall depth	Diameter	Overall mass (KG)	Joint design	Standard
AISI 316 stainless steel	Plates: 3 mm Square pipe (12x12mm): 1 mm machined profile: min 12mm; max 18mm	1800 mm	1500 mm	18 mm	NA	130	butt weld (partial penetration, material backing)	ISO 13313-1

Table 40: Process requirements

Process requirements					Connectivity and IT requirements and interoperability
Gas shielding	Filler wire	Gap tolerance	Welding position	Manipulation set up (fixture, robot)	Comment
GASEXT+INT (top and bottom)	N/A	0	1G / PA	6-axis robot or X-Y table	Fire wall configuration/setup and IP port

Table 41: Testing requirements and sensoring

Testing requirements and sensors						
In-process monitoring	Sensors for machine monitoring	PWHT	NDT and general quality acceptance		Mechanical testing	Microstructure
down-select from coupon trials	flow meters water, flow meter gas, process gases, temperature, current meter	mechanical grinding/polishing (Ra<0,2 um - mirror finish)	Corrosion resistance (cleaning & sterilization media); Cleanability visual, surface, Dimensional Leakage test (Helium)		N/A	Hardness, metallography

The following table summarizes the validation tests and requirements for the test coupon and demonstrators.

Table 42: Selected requirements of the V&VPV plan.

ID	Title	Requirement Text and Acceptance Criteria	Applicable / Not applicable
1	Visual inspection	The weld shall be compliant to the ISO13919-1 Class C	X
2	Dimensional and geometrical inspection	Dimensional and geometrical conformity to applicable manufacturing drawings. Roughness after post processing shall be $Ra < 0,2 \mu m$ – mirror finish	X
3	FPI (Fluorescent Penetrant Inspection)	The surface inspection of the weld shall be compliant to the ISO13919-1 Class C	X
4	X-ray inspection	The volumetric inspection of the weld shall be compliant to the ISO13919-1 Class C	N/A
5	Leak test	The weld shall be leak tested according to the product requirements. Reverse He Leakage from the plate shall not exceed $1.0 \times 10^{-5} \text{ mbar} \cdot \text{L/s GHe}$	X
7	Metallography Analysis	The metallographic inspection of the weld shall be compliant to the ISO13919-1 Class C The hardness profile along the weld shall be collected as reference	X
8	Mechanical Testing	Tensile or Shear test shall be compliant with the base material requirements	N/A
9	Corrosion Testing	Corrosion test shall be compliant with the base material requirements: <ul style="list-style-type: none"> • Corrosion resistance with cleaning and sterilization media • Cleanability 	X

The possibility of implementing the LBS Laser Beam Shaping could allow lower power consumption and manufacturing cycle time compared to the actual technology.