SOUNDCAST
VACUUM-ASSISTED HIGH PRESSURE DIE CASTINGS WITH REDUCED POROSITY AT LOW COST

D5.3: SOUNDCAST Fabrication Procedures

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Introduction

The present deliverable collects all the SOUNDCAST fabrication procedures to be applied in order to manufacture sound and weldable vacuum-assisted HPDC (VPDC) components at a competitive cost by using secondary alloys with enhanced mechanical properties and high weldability.

The present Soundcast Procedures has been updated and revised after the demonstration phase in the two foundries, Ruffini and Schmale & Schulte, including the experience gained in these demonstration trials. The present deliverables pretend to be a first guide for HPDC foundries that are willing to get introduced in the vacuum assisted HPDC process. And it compiles the basic aspects to have into account in order to adapt the standard HPDC process to the innovative and not well known VPDC, starting from the selection of the vacuum elements and the design of the vacuum channels to the optimization of the different process parameters and ancillaries involved in the HPDC process. Additionally, the melt treatment and heat treatment procedures are compiled for the new recycled alloy. As well as the methodology for the new welding process. Finally, quality checks are revised.

The SOUNDCAST technology package is divided in the following fabrication procedures:

- **Soundcast Procedure-1: "Melt treatment"**
- **Soundcast Procedure-2: "Optimized HPDC parameters and vacuum technology for porosity reduction and mechanical properties improvement"**
- **Soundcast Procedure-3: "Heat treatment of the new recycled alloy"**
- **Soundcast Procedure-4: "Methodology for a new welding process"**
- **Soundcast Procedure-5: "Quality checks"**

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SOUNDCAST PROCEDURE - 1: “MELT TREATMENT”

1. INTRODUCTION

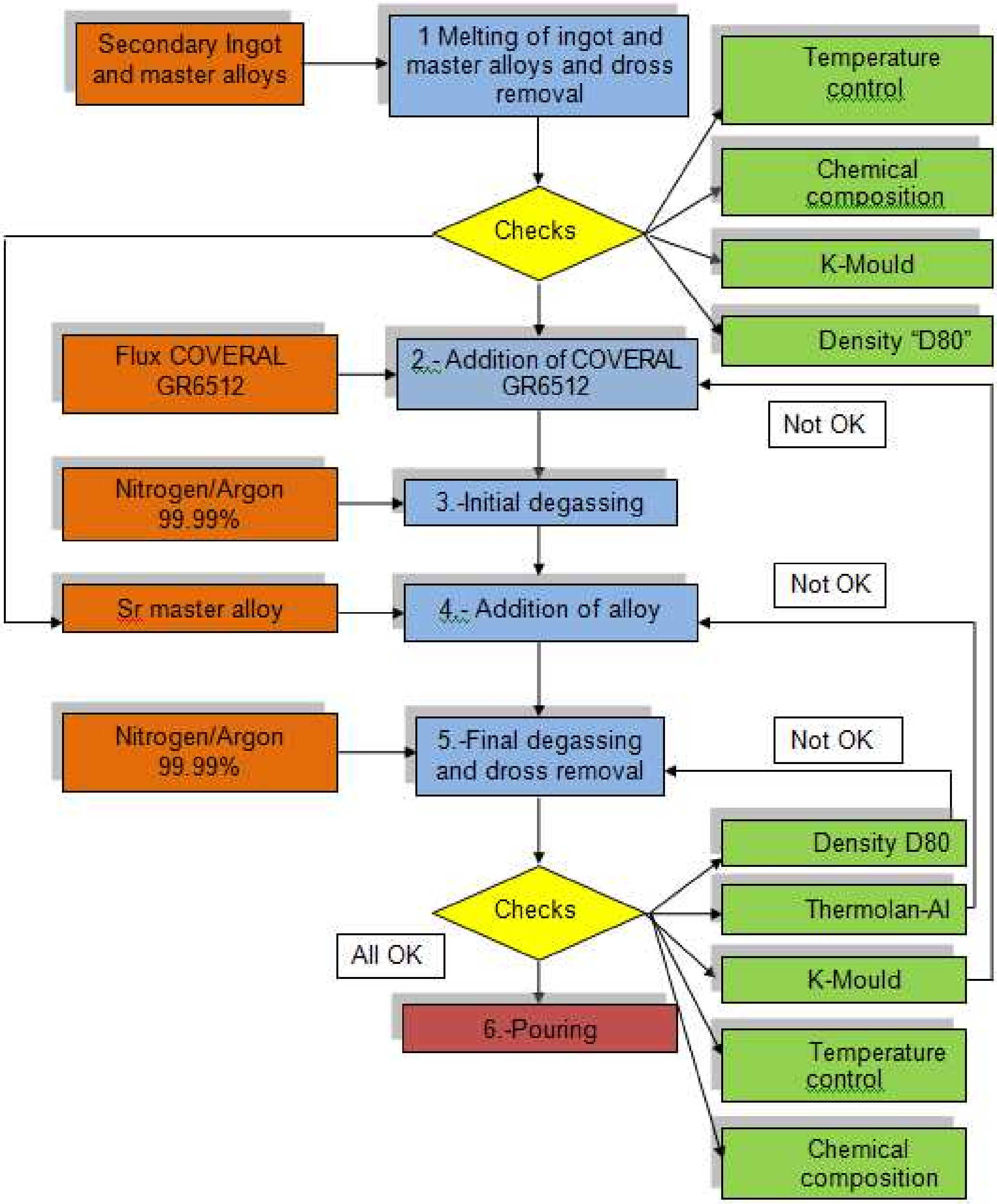
The present document comprises the procedure "Melt treatment". Further details are presented in "Deliverable D3.2: Report on melt treatment optimization" and "Deliverable D3.3: Software for melt control of the new recycled alloy". A summary of the melt treatment is also included as part of the "Section 6: Methodology for mechanical properties improvement of Deliverable D3.5: Final report on mechanical property improvement".

A good melt treatment is mandatory in order to get sound vacuum-assisted HPDC (VPDC) components at a competitive cost with high mechanical properties and high weldability.

The *main targets* of the melt treatment are:

- Adjust the **chemical composition** of the melt.
- Reduce the **content of Hydrogen** of the melt.
- Reduce the **oxides and inclusions** in the melt.

The flow chart that summarizes the different stages of the process is shown in the next figure.

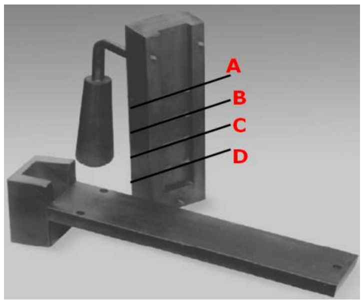


The *equipment*: In order to achieve a high molten metal quality the use of the following equipments or similar are recommended:


FDU: Equipment to guarantee a sound degassing process.

Thermolan-Al: Equipment to measure the modification of eutectic Si.


D_{80}: Equipment to measure the density solidified at 80 mbar.



K Mould or Dross test: Equipment to measure the oxides and inclusions in the melt.

2. PROCEDURE FOR MELTING AND MELT TREATMENT

- Ingots shall be cleaned from dirtiness before charging them into the furnace. The furnace should be covered to avoid temperature losses and capture of hydrogen from air moisture.
- Then the furnace shall be adjusted to its maximum power and to the final pouring temperature.
- The chemical composition of the Soundcast alloy is achieved by addition of new ingots and the required alloying elements and master alloys. All those materials have to be cleaned and dried before introducing them into the molten metal. Any kind of wet material or tool can produce metal splashes out of the furnace.
- Dross produced during the melting operation has to be removed with a preheated tool.
- Furnace temperature should be set up to 750 ºC and intense stirring have to be performed to favour the dissolution of the new alloying products.
- After 10 minutes, all the remaining rests have to be removed.

2.1. ADJUSTING THE CHEMICAL COMPOSITION

The target for the chemical composition of SOUNDCAST alloy (wt. %) as it is defined in Deliverable 3.5 in terms of Si, Fe, Mn, Mg, Cu, Ti and Sr.

Chemical analysis: should be carried out in order to assure that the chemical composition of the melt fulfills the defined range of the new alloy shown in the table. In case deviations are observed the chemical composition has to be adjusted.

Recommendations:

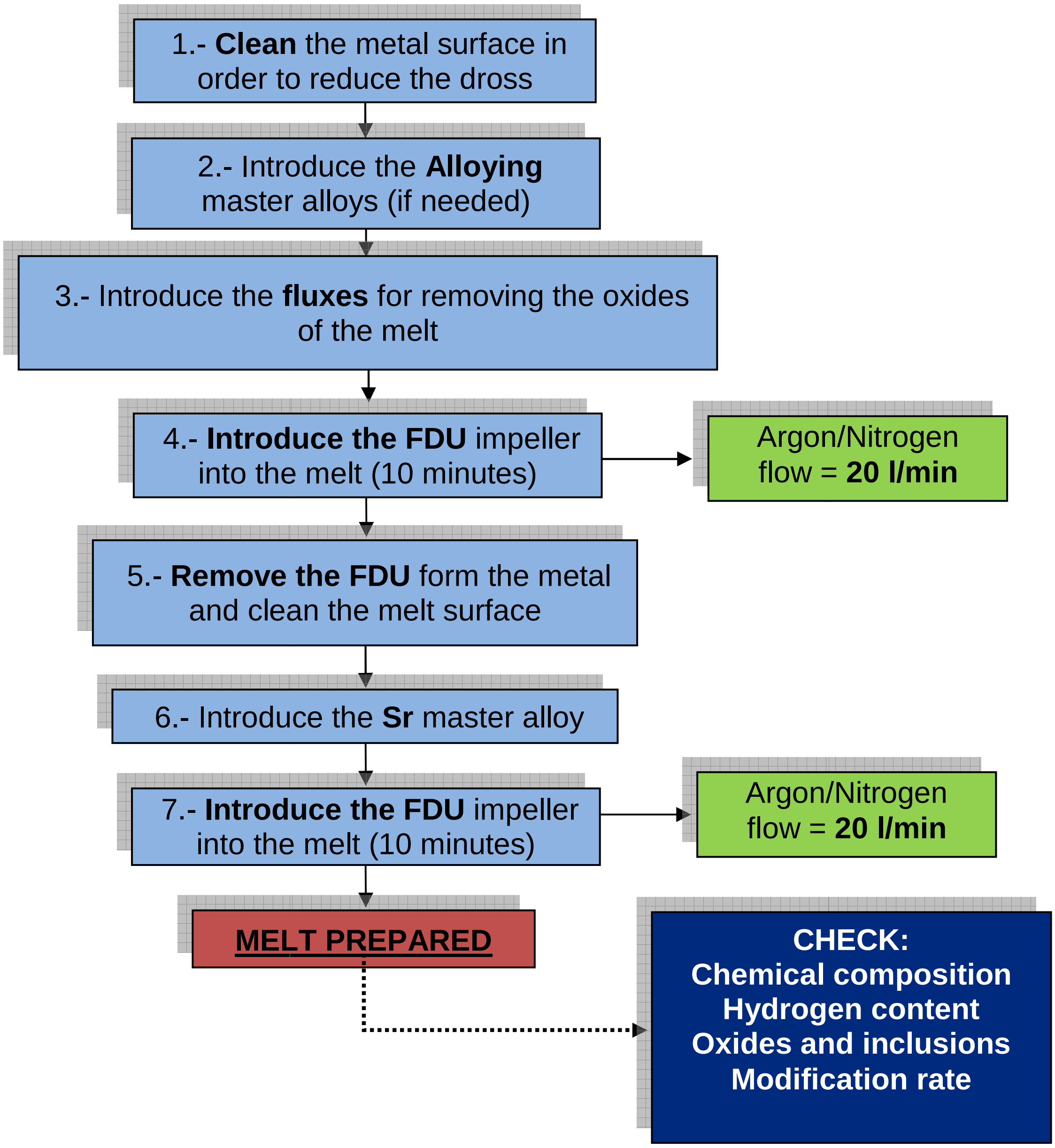
- **Temperature of the melting has to be less than 780ºC**.
- **The addition of Mg if necessary**.
- **The addition of Sr if necessary**. .
  The content of Sr is controlled by the new developed Thermolan-Al Software.
- **The addition of Mn depends on the content of Fe and Mn in the melt.**

2.2. REDUCING THE HYDROGEN CONTENT, OXIDES AND INCLUSIONS

The use of the *FDU equipment* is recommended: It is a metal treatment system for the degassing and cleaning of aluminium alloys in foundries. The FDU unit uses the impeller principle with a rotor which mixes fine inert gas (usually Nitrogen or Argon) with the melt. The gas bubbles are distributed widely through the melt whilst maintaining a smooth melt surface. This results in short treatment times, effective degassing and melt cleaning.

A ceramic plate for avoiding vortex should be positioned. Bubbles break on the molten metal surface without promoting splashes should be observed.

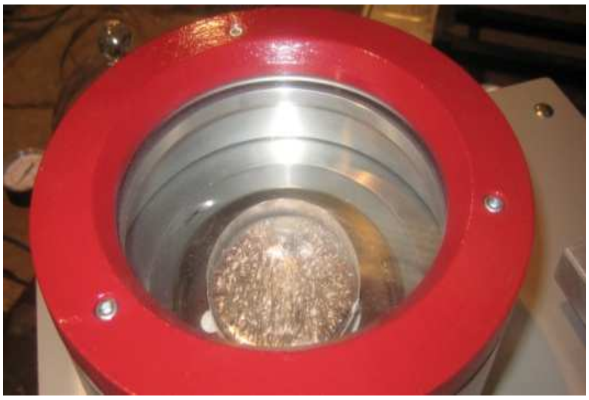
REDUCING THE HYDROGEN CONTENT, OXIDES AND INCLUSIONS



3. PROCEDURE FOR THE EVALUATION OF MELT QUALITY

3.1. HYDROGEN CONTENT (D80 EQUIPMENT)

- *Description:* The metal is poured into a metallic cup and it is introduced into the D_{80} equipment.

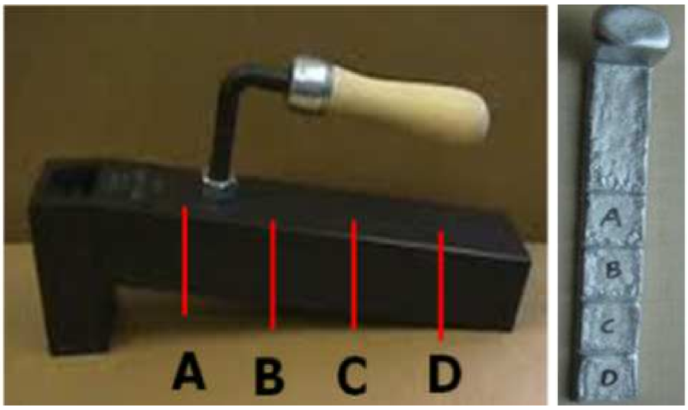
The hydrogen content of the melt is controlled by means of the **D_{80} vacuum test**. The sample of the molten metal solidifies under 80 bar of residual pressure **during 4 minutes**. When it finishes, the aluminium cup is weighed in air and under the water using a balance:

- *Objective:* The objective for primary and secondary AlSi10MnMg(Fe) alloys must be a density level of higher to the level defined in the Soundcast project to assure a good degassed metal. An example of a well degassed metal sample is shown below:

- *Actions:* If the value is below 2.65 g/cm^3 the degassing process is repeated.

3.2. OXIDES CONTROL USING K-MOLD EQUIPMENT.

- *Description:* The metal is poured into the K-Mold. Before pouring it is recommended to heat the mold. A minimum of three samples are required to have representative results.



- *Objective:* The K-Mould index is calculated by examining the fracture surfaces using a magnifying glass and the defects are counted and measured using a ruler with the size in mm. **K-mold index** or rating would be calculated as the average (on the 3 samples) of the weighted numbers of defects. A k mold index critical values is defined in the project.
- *Actions:* If the oxides content gives value of K-mould index above the critical value, the K-mould test is not OK and the process will start adding fluxes and degassing for another 10 minutes.

3.3. OXIDES CONTROL USING DROSS TEST

- *Description:* The metal is poured into a metallic cup (the big metallic cup provided with the equipment) and it is introduced into the Dross test equipment.

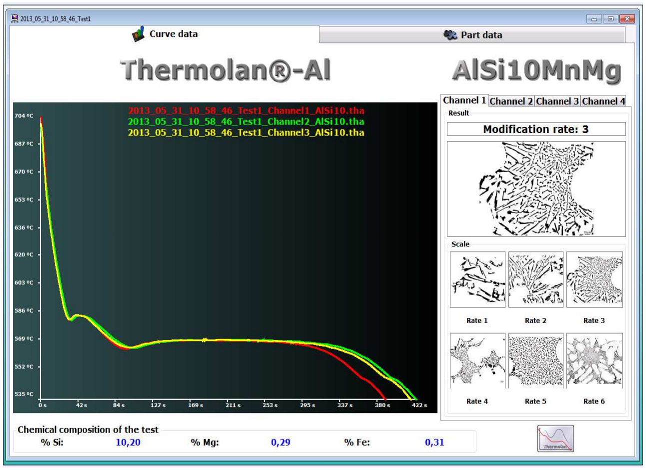
The oxides appear in the external surface of the melt when solidifies under 2 mbar, being in this case the residual pressure of 2 mbar. It is a visual analysis of the surface of the aluminum sample.

- *Objective:* The objective for the dross test must be a flat and free of oxides surface. An example of a bad and good oxides level samples are shown below:

- *Actions:* If the surface of the dross sample is not free of oxides, fluxing and degassing process is repeated.

CONTROL OF Sr MODIFICATION RATE

- *Description:* The control of Sr modification is done using the Thermolan®-Al test: Solidification curve control equipment. The software predicts the modification level of AlSi10MnMg alloys.



- *Objective:* The objective to obtain a good modification, is the modification rate of 3 or higher
- *Actions:* If the correct modification is not obtained the Sr master alloy must be added and degassing process is repeated.

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SOUNDCAST PROCEDURES - 2: “OPTIMIZED HPDC PARAMETERS AND VACUUM TECHNOLOGY FOR POROSITY REDUCTION AND MECHANICAL PROPERTIES IMPROVEMENT”

1. INTRODUCTION

The present document comprises the procedures "Optimize HPDC parameters and vacuum technology" and "Methodology for porosity reduction", presented in the final section of Deliverable 2.4 and 3.4, respectively. They summarized the experience compiled by all RTDs on WP2 and WP3, regarding the optimization of vacuum die casting process in order to reduce the porosity present on the cast components and improve the mechanical properties.

As both aspects, porosity and mechanical properties, are closely related the recommendation for new companies implementing vacuum die casting are quite similar in the case they are looking to minimize the porosity of their components or they intend to maximize the mechanical properties of the cast parts.

Therefore, the issues addressed in both documents (Deliverable 2.4 and 3.4) have been compiled in this single procedure. The present document has been updated and revised after the demonstration phase in the two foundries, Ruffini and Schmale & Schulte, including the experience gained in these demonstration trials.

The document pretends to be a first guide for HPDC foundries that are willing to get introduced in the vacuum assisted HPDC process. And it compiles the basic aspects to have into account in order to adapt the standard HPDC process to the innovative and not well known VPDC, starting from the selection of the vacuum elements and the design of the vacuum channels to the optimization of the different process parameters and ancillaries involved in the HPDC process.

2. VACUUM EQUIPMENT SELECTION

The **vacuum equipment** has to be **selected according to the specific application**:

- Which **kind of vacuum element** better fits with the requirements according to their benefits and drawbacks: electronic valve or metal activated valve.

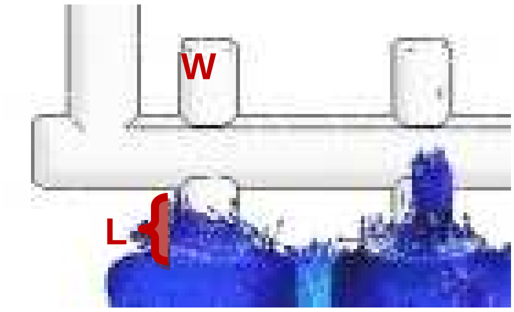
	Advantages	***Drawbacks***
Chill-vent	Permanently opened. No risk of pollution at all.	The aspiration section is very limited, about 1/4 of the aspiration section of a vacuum valve of similar size.
Metal activated valve	The valve can be kept open until the metal is actually in its proximity.	Due to metal splashes and irregularities in the metal flow the valve can be either closed much before the metal reaches or be polluted by molten metal going into de valve. It is not possible to build big aspiration section, limiting it for small dies.
Electronic valve	Small risk of pollution, once the closing time is correctly set up. No limitation of aspiration section.	The valve should be closed in advance (in the less favorable event) in order to prevent metal pollution.

- Then, in order to **select the specific model**, has to be taken into account the air volume present in the die cavity and the target vacuum level.

3. DESIGN OF THE VACUUM CHANNEL

A good **design of the vacuum channels** is a basic element in order to apply correctly the vacuum in the die and take **benefit of the whole aspiration section and aspiration time** available:

- Place the **vacuum channels in the last filling region** of the component, according to numerical simulation prediction.
- Introduce **necks** in the connection between the overflows and the vacuum channels to increase the resistance to the metal flow.
- Introduce several **90º turns** to reduce the metal speed.
- Place **dead-ends on the 90º turns** to increase the residence time of the metal.
- The **length (L)** of the straight section of the exhausting channel before the **90º turn** should be at least **twice its width (W)**.
- Check the **aspiration section** on the different zones of the **aspiration channels**, including the gates to the overflows, it should be at least a **20 % larger than the aspiration section of the vacuum element**.



4. HOUSING OF THE VACUUM ELEMENTS

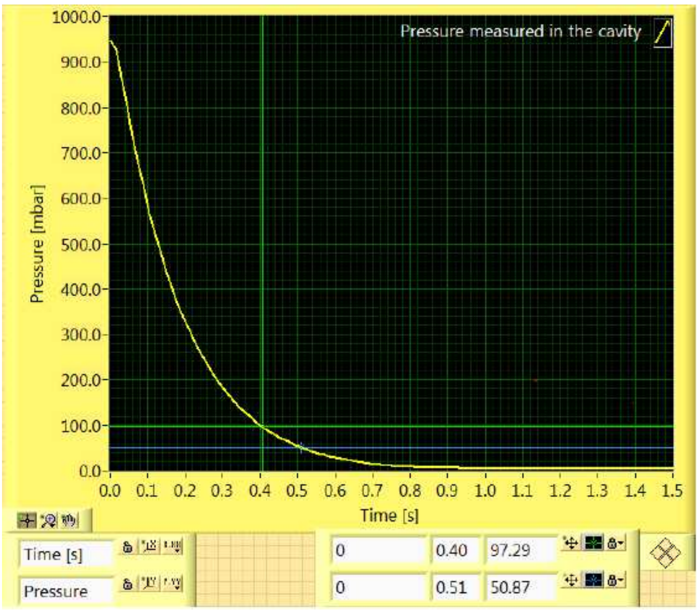
A **tight sealing of the die**, including the vacuum elements, is a must in order to reach a **good vacuum level in the die cavity**:

- Ensure a **good housing** in the back of the vacuum elements, in order to guaranty good die tightness.
- The **sealing** of the valve and other vacuum elements is a main issue in order to reach a low and stable vacuum level.

5. OPTIMIZATION OF THE VACUUM ASPIRATION TIME

Another critical point necessary to reach a low vacuum level in the die cavity is to **optimize the aspiration time** taking into account the **singularities and requirements of the each specific component**:

- The required aspiration time should be calculated according to the **vacuum level** desired in the die cavity, as well as the total **volume of air** to be sucked.
- In case of electronic activated valves, should be delayed little by little **the valve closing position** until a good and stable value is reached, without problems of metal aspiration.
- **Analyze the available aspiration time** and maximize it, reduce the injection 1st phase if it is required in order to reach the desired vacuum level.
- The commutation point from 1st to 2nd phase has to be adjusted in order to **avoid pre-filling** of the die cavity.
- The **adjustment should be checked with the same equipment and with the same conditions** that are going to be used under production.



6. OPERATION OF THE VACUUM EQUIPMENT

In order to avoid the filling of the valve with molten metal it is highly recommended to follow a step by step conservative approach before starting the vacuum equipment:

- **Verify all the connections** and the set up of the Vacuum System.
- **Open and close several times the valve manually** with the selector in order to check that it is moving properly.
- **Close manually the valve** with the selector during the shoots at reduced speed.
- **Check the program** on the HPDC machine and arrange it to close the valve in advance to the 2nd phase starts.
- **Check the good functioning of the valve** after every splash of the die, as the mechanisms can be affected.

7. OPTIMIZATION OF THE LUBRICATION

Applying vacuum helps to reduce the air present in the cavity, nevertheless, a very important source of gas porosity, that cannot be compensated by the use of vacuum is the gases generated during lubricant combustion. Therefore it is very important to take an special care of the lubrication in VPDC process:

- Select carefully **the methodology and release agents** used to lubricate both, **die and the plunger**.
- **Reduce** the amount of **release agent** applied to your **die**. Consult the lubricant provider in order to decide if it is better to increase the concentration or the **amount of lubricant** applied without changing the **dilution rate**.
- **Reduce** as much as possible the amount of **lubricant** provided to the **plunger** without having sticking problems between plunger and shot sleeve**.** Nevertheless, it is important to **provide lubricant to the plunger at each cycle.**

8. OPTIMIZATION OF THE 2nd PHASE SPEED

The **2nd phase speed** should be **optimized** by analyzing the **cavity filling process and the quality of the parts**:

- **AlSi9MgMn alloy and SOUNDCAST alloy require higher 2nd phase speeds** than traditional casting alloys such as AlSi9Cu3(Fe).
- Part **quality increase with speed until a maximum value** and then **further increase revert in an increment of porosity**.

9. OPTIMIZATION OF INTENSIFICATION FINAL PRESSURE

3rd phase compacting pressure should be optimised in order **to prevent flashes at the same time that a good part quality is achieved**:

- In the present tests **3 different final pressures** have been analysed **300, 575 and 900 bar**. **The best porosity level was obtained with the highest intensification pressure**.

10. POROSITY QUALITY CHECK ON PARTS

X-ray porosity is very effective method for optimizing shrinkage porosity and all the HPDC parameters that affect to it, such as compacting pressure and second phase speed. The porosity present on the cast parts should be checked (see Quality checks: Soundcast procedure-5).

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SOUNDCAST PROCEDURE - 3: "HEAT TREATMENT OF THE NEW RECYCLED ALLOY"

1. INTRODUCTION

The heat treatment determines the mechanical properties and porosity formation in the part, therefore the selection of an adequate heat treatment is the key to select the mechanical properties of a sound casting. Further details about heat treatments are presented in “Deliverable D3.5: Report on mechanical property improvement”.

According to the required mechanical properties of the casting an appropriate heat treatment can be selected from the graph below:

- ***High ductility***: a T4 or T7 heat treatment which provides elongation values above 10 %.
- ***Intermediate strength and moderate ductility:*** T5 heat treatment offers intermediate strength and moderate elongation between 5 and 10 %. The strength is between F and T6 heat treatment. Porosity and blistering are low, distortion is avoided because no solution heat treatment is performed. And it is cheaper than T6 because high temperature solution treatment is not applied.
- ***High yield strength:*** Highest yield strength and tensile strength are achieved by T6 heat treatment at moderate elongation between 6 and 10 %.

2. HEAT TREATMENT STEPS

The following heat treatments are adequate for parts manufactured by Soundcast technology.

2.1.- Solution heat treatment

- **Temper at 490º C for 3 h**: In order to minimize internal porosity and blister formation for T4, T7 and T6 treatments.
- The **yield strength can be increased** at expense of ductility **by increasing the solution temperature or time.** Or by raising the Mg content.

2.2.- Quenching

- After solution heat treatment the **samples should be quenched immediately in water at 20ºC**, in order to maintain as much as possible Mg and Si in solid solution: this will **guarantee high and stable mechanical properties**.
- In large and complex shaped castings, which may present distortions after quenching in water, less severe quenching media such as oil, polymers could be used.

2.3.- Ageing heat treatment

2.3.1.- Natural Ageing: T4 heat treatment

- After quenching, the parts should be kept at least for **5 days at room temperature before being tested or delivered for assembly,** in order to achieve stable mechanical properties.

2.3.2.- Artificial ageing treatment: T5 heat treatment

- This treatment could only be applied to parts that have been **quenched immediately** after removing it from the die.
- Mechanical properties of the T5 condition are achieved by **artificial ageing at 165 ºC for 3h**.
- **An increase of strength** can be obtained **by increasing the ageing time to 6 h** or **by raising the Mg content**.

2.3.3.- Artificial ageing treatment: T6 heat treatment

- **Ageing at 165 ºC for 3 h** allows achieving mechanical properties comparable to the primary alloy.

- Further **increase of strength** at the expense of ductility can be achieved by:
  - **raising the solution temperature**
  - **increasing the solution time**
  - **increasing the Mg content to 0.6 wt. %**

2.3.4.- Artificial ageing treatment: T7 heat treatment

- High elongation can be achieved by ageing:
  - at **220 ºC for 10 h**
  - by **reducing the Mg** content from 0.37 **to 0.25%** (or up to 0.1 %) and ageing a **220 ºC for 4-7 h,** this is a more economic solution.

3. HEAT TREATMENT SUMMARY

The proposed economic heat treatments for achieving high mechanical properties in the secondary alloy are:

Temper	SOLUTION		Water quench at 20ºC	AGEING	
	Temperature [ºC]	Time [h]		Temperature [ºC]	Time [h]
F	-	-	-	-	-
T6	490	3	X	165	3
T5	-	-	-	165	3
T7	490	3	X	220	10*
T4	490	3	X	20	120

* The ageing time can reduced by reducing the Mg from 0.37 to 0.25 wt. % or up to 0.1 %.

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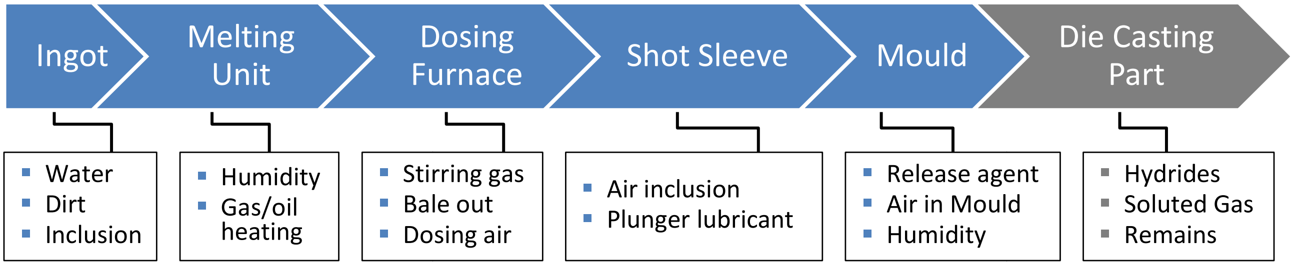
SOUNDCAST PROCEDURE - 4: “METHODOLOGY FOR THE NEW WELDING PROCESS”

1. INTRODUCTION

Aluminum die cast is only conditionally weldable. The reason for this can be attributed to the manufacturing process of high pressure die casting parts. Problems can result from a mechanical pore formation manly caused by inclusions or impurities and by a metallurgic pore formation mostly caused by hydrogen (see Figure below). The dissociation of hydrides releases hydrogen which is trapped during solidification. In the subsequent welding proves, a thermal expansion of soluted gas and release agent remains causes voids.



Sources of hydrogen during the casting process

By using different measures, it is possible to produce high-pressure die castings with low porosity. These measures include for example the prevention of excessive melt movement in the first casting phase, a gating concept which provides a low-turbulence flow of metal, an effective venting system and a heat management of the mould, in particular allowing use of a low amount of release agent.

In addition, the choice of a suitable welding process is a crucial point for joining aluminum die castings. By applying the laser welding process under reduced pressure it is possible to improve the weld quality of high-pressure die castings. Here, the vacuum in the process environment can lead to a positive degassing and thus a considerable improvement in quality.

Further details about weldability are presented in “Deliverable D4.3: Final report on lubrication and welding process optimization.

2. LUBRICATION

Concerning the porosity and thus weldability, die release agents and plunger lubricants have an important influence on the quality of high-pressure die cast parts.

- The use of the **wax-free release agent** with a high dilution for example 1:125 is recommended.
- The die lubricant selected for this project is the wax-free, silicon-based release agent SL 1697 S of the project partner ChemTrend. For the lubrication of the plunger, the product PL 766, developed by ChemTrend, is recommended.
- In the case of an **insufficient demolding performance**, the first step should be the decrease of the dilution of the wax-free release agent.

Additional advice:

- **Switching to a wax-containing release agent should be avoided by all means** since it significantly decreases the weldability.
- Release agents have a **specific operating range**. This assumes that the release agent should be adapted to characteristic temperature range of the die casting mould

3. CASTING PROCESS

The casting process has a main influence of the weldability of casted parts. To achieve this weldability some facts have to be considered:

3.1.- Molten metal treatment

- A **degassing treatment** of the melt with nitrogen has to be done.
- The **density-index** shows the level of gassing and should be measured afterwards the degassing. The SOUNDCAST experiments revealed that a value of 1.6 % or less is necessary to reach a good weldability (Density index = $(\rho_{at}-\rho_{80})/\rho_{80}x100$ = 1.6 % is equivalent to 2.628 g/cm^3).
- The **nitrogen must not have a purity of less than 5.0**. Otherwise the residual amount of water in the nitrogen is too high and the effect of degassing will be reversed.

3.2.- Vacuum system

- A **vacuum supported casting process** with a well arranged venting system is required to produce weldable HPDC parts.
- A pressure level of around 200 mbar during the 2nd phase (filling of the cavity) is recommended.
- The quality control system of VDS allows a permanent monitoring of the cavity pressure. Deviations from the nominal value of the cavity pressure shall be detected immediately by the production staff so that countermeasures can be taken.
- In order to avoid deviations from the nominal value of the cavity pressure or even a total failure, periodic cleaning and maintenance of the vacuum valve has to be done. The maintenance interval depends on the individual production conditions. However, as a rough guide value, a daily check respectively cleaning of the valve should be encouraged.

3.3.- Spraying technology

- A **fully automatic die spraying system** is essential for a reproducible quality since it ensures the application of a precisely metered volume of release agent.
- The **nozzles** have thereby to be arranged in that way, that an overlap of the spraying cone and thus an overspraying will be minimized.

3.4.- Process and die-casting curves

- Each casting alloy and casting part needs special established casting parameters. Hence, the **die-casting curve and the temperatures** have to be adapted so that the filling process avoids as much as can be gas-conditioned porosities.

4.

5. PERFORM LASER WELDING AT REDUCED PRESSURE

In order to achieve a sound laser welded HPDC it is recommended to perform the laser welding process at reduced ambient pressure as follows:

4.1.- Vacuum

- Although a pressure of 10 mbar leads to a significant improvement of the weld seam quality, **best welding results** will be obtained by a **decrease in pressure up to 0.1 mbar** within the laser vacuum chamber.
- For future parts, it a meaningful compromise between weld quality and processing time must be found. Generally, the aim should be to work with a pressure of 10 mbar. In this case, the time for the evacuation of the vacuum chamber is in a competitive range (in this research project: 60 s). The pressure reduction to 1 mbar adds another 30 s to the evacuation time, which can be still acceptable.
- However, the decrease of chamber pressure for another order of magnitude (0.1 mbar) leads to an evacuation time of about 240 s. Usually, this parameter is not desirable and the quality of the HPDC part should be critically examined and optimized.

4.2.- Focal settings

- For vacuum laser welding a focal diameter of df = 300 µm is recommended.
- Studies have shown, a larger focal diameter or the use of double focus technology is only sufficient for welding a speed below 1.0 m/min. A focal position of zF = -2 mm below the surface of the work piece has to be used.

4.3.- Welding speed

- In order to achieve sufficient penetration the **welding speed has to be chosen in relation to laser beam power and ambient pressure**.
- Table below gives an overview about the dependency mentioned. At the recommended pressure of 0.1 mbar e.g. the welding speed should be chosen between 2.0 – 6.0 m/min and the beam power depends on welding speed then.

Beam source	Focal diameter	Beam power					
		Welding speed [m/min]					
		0.5	1.0	2.0	3.0	4.0	6.0
Laser beam	300 µm	1600 W	2000 W	2500 W	-	4300 W	5400 W

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SOUNDCAST PROCEDURE - 5: "QUALITY CHECKS"

1. INTRODUCTION

This procedure summarizes the quality checks applied in Soundcast project to assess the quality of the casting manufactured following Soundcast® technology. It is divided depending of the final application: high mechanical requirements or high weldability. For the castings in which both requirements are necessary, all the quality checks will be necessary to assess its quality (see scheme on the last page of this procedure).

2. VISUAL INSPECTION

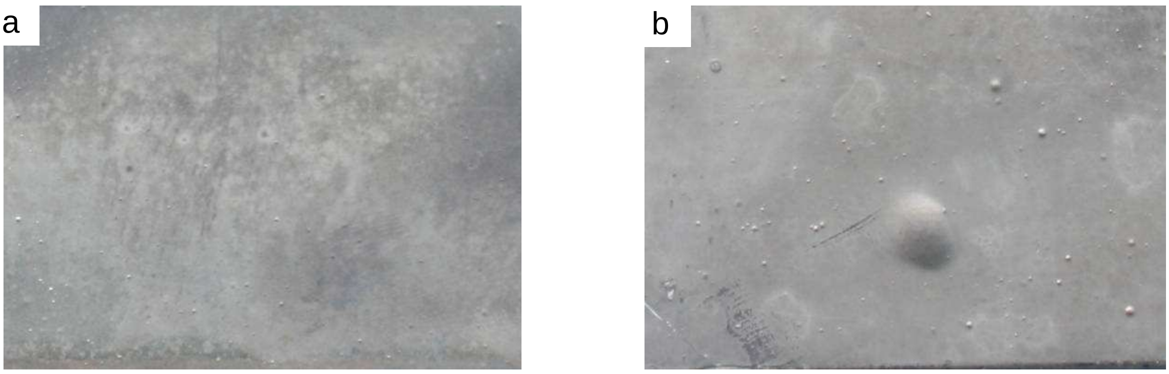
A visual inspection after casting should be performed in order to detect any casting defects.

This quality check will be repeated after applying any post-processing treatment, such as heat treatment and/or welding processes.

2.1. After heat treatment

In these cases of heat treatment is applied a visual inspection at naked eye after heat treatment should be also performed in order to detect the presence of blisters on the casting surface.

- In case **large blisters** are observed these parts should be rejected and inspected by metallographic analysis, as these indicate the presence of lamination defects which are very detrimental to elongation.
- On parts which show **plenty of small blisters** metallographic analysis and tensile tests should be carried out in order to determine the amount of internal porosity and to check if the elongation is affected by this porosity. A maximum allowable porosity value where mechanical properties still fulfill the requirements should be established for each casting type.



Blisters observed on the casting surface: (a) acceptable blisters and (b) inacceptable blisters: small blister combined with big blisters.

2.2. After welding

Generally, it can be stated that a “good” surface of the weld seam is an indicator for a reasonable weld quality in terms of porosity. This includes the following aspects:

- a narrow weld seam without sink marks,
- no or only sporadic weld spatter,
- an uniform formation of the weld seam shape.

A thin soot layer at the part surface can be accepted, since it is related to the welding process. However, the soot layer must be removed by an alcohol-based solution before visual inspection.

3. HIGH MECHANICAL PROPERTIES

3.1. X-Ray / Tomography analysis

The porosity present on the cast parts should be checked:

- by selecting some parts every shift and inspecting them with X-ray and or CT-tomography in order to reveal the presence of big pores.
- Shrinkage defect and entrapped gas porosity are detected by CT-tomography. Thus, it is very useful for HPDC parameters optimization. However, small micro pores are not detectable. Thus, the absence of porosity in X-ray and/or CT-Tomography does not assure high mechanical properties.

It is recommended to select some of the inspected parts to conduct a destructive analysis, cutting; polishing and analyzing the microstructure with quantitative metallography (see VDG method)

3.2. MECHANICAL PROPERTY CONTROL

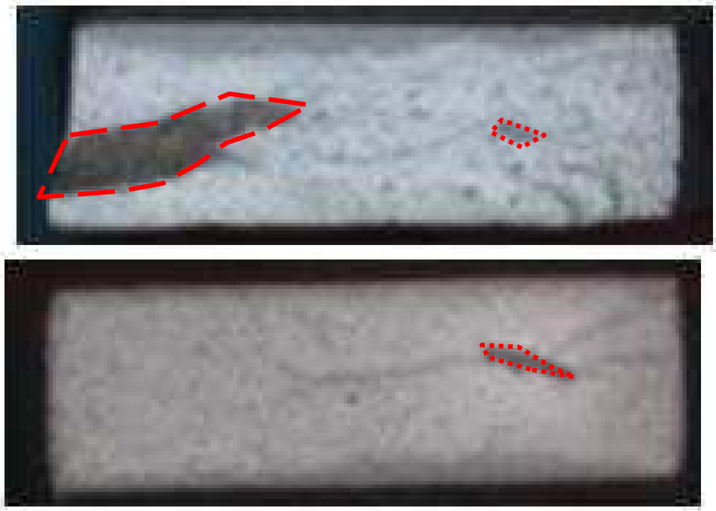
For each casting batch the mechanical properties should also be determined on a few castings that have passed the visual and X-ray/CT-Tomography inspection successfully in order to:

- Guarantee that the **quality of the casting in case of F state**
- Guarantee that the **heat treatment has been performed correctly** for **T4, T5, T6** and **T7** heat treatments.
- Determine that the castings are **free from casting defects** and thus **high mechanical properties are achieved**.

If possible, flat tensile specimens were prepared maintaining the casting skin and tested according to UNE-EN ISO 6892-1:2010. The component requirement in terms of yield strength and elongation will be defined by the casting specification.

Depending of the requirements, the Mg content will be define and also the most adequate heat treatment between: F state (no heat treatment), T4, T5, T6 or T7.

If low elongation values are achieved, the fracture surface of tensile samples should be analyzed in order to determine the defect that has caused this low elongation values. If low elongation values are achieved, the die casting process should be checked particularly in terms of most frequent defect to minimize it in the subsequent batches (see Deliverable 3.4 and 3.5)

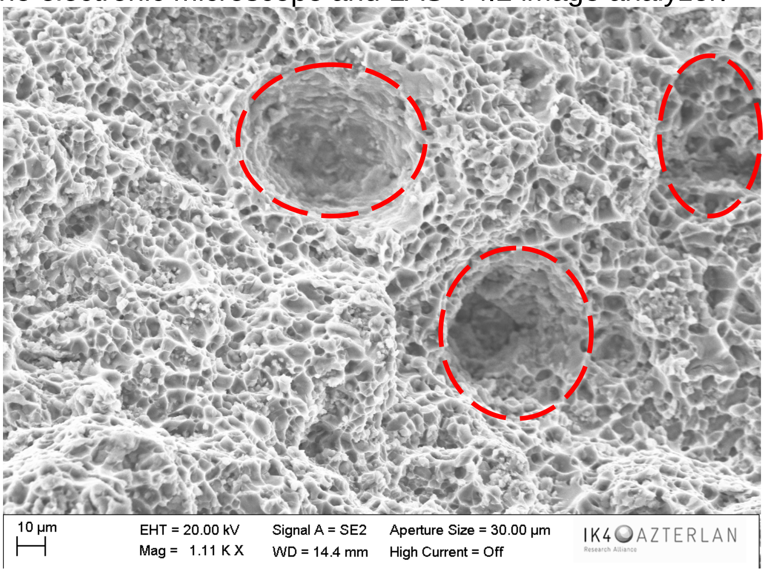


Example of the measurement of percentage of defect on the fracture surface of tensile specimen

3.3. POROSITY EVALUATION

The porosity presents on the cast parts should be checked on the fracture surface analysis or by metallographic analysis:

Porosity analysis on the fracture surface: A porosity analysis of the fracture surface of the tensile samples is made using the electronic microscope and LAS V4.2 image analyzer.



Example of the measurement of gas porosity on the fracture surface of tensile specimen

- Metallographic analysis **according to the norm VDG P202 2010**: The norm VDG P202 2010 it is a standard specification to determine the porosity of the parts that applies to casting made from Al, Mg and Zn casting alloys. In the following table it is described the procedure with an example of the porosity measurement of a component section of a well polished part. In our case the sample selected is a square with length equal to step thickness which contains the higher amount of porosity of the polished plane.

  - Porosity according to VDG P202 < 5 % is consider as acceptable for conventional HPDC with tightens requirement but not high mechanical properties requirement.
  - **In Soundcast project, VDG P202 lower to a define value is required** in the area in which mechanical properties have to be tested.

4. WELDING PROPERTIES

4.1. BLISTER TEST

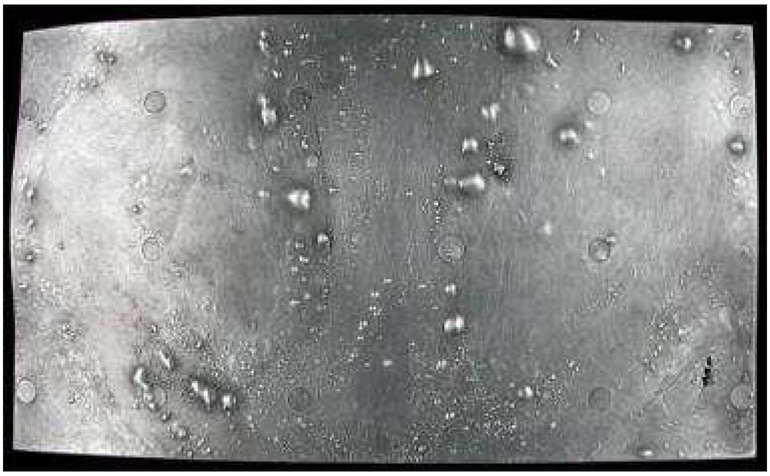
The blister test minimizes the risk of welding problems, related to the hydrogen dissolved in the material. As welding implies a local re-melt of the die-casted parts, dissolved hydrogen causes pores, because the solubility of hydrogen in aluminum is different in the solid and liquid states.

The blister test should be done at a temperature of 50 K below liquidus temperature of the SOUNDCAST alloy and with a holding time of 30 minutes. If the foundry is not experienced in the field of heat treatment, it is essential for them to check the exact temperature of the specimen.

Otherwise, deviations between the indicated furnace temperature and the true specimen temperature may occur.

- A good weldability can be achieved, if no or only little blisters occur at the part surface. Little blisters mean that the diameter should be not more than about 5 mm.
- A bad weldability is very likely, if numerous large blisters (diameter > 5 mm) occur at the part surface.

If large blisters occur at the part surface, the die casting process should be checked particularly in terms of the degassing and the application of the vacuum system. Figure shows the example of a plate surface made of AC-AlSi9Cu3 blistered at 500 °C for 4 h.



Blistered 2 mm plate made of EN-AC-AlSi9Cu3

4.2. TIG WELDING TESTS

A TIG-welding test should be performed in order to test the influence of the release agent residuals on the weldability of the die-casted parts. The visible results correlate to the measurement of the carbon layer thickness by EPMA. For the welding test, a TIG (Tungsten Inert Gas) arc is driven above the cast plate surface under defined conditions (distance, speed, current). Welding parameters depend on the individual part geometry. However, it must be ensured that the casted material is not melted.

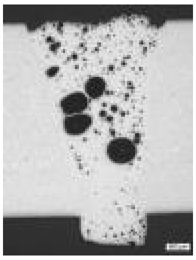
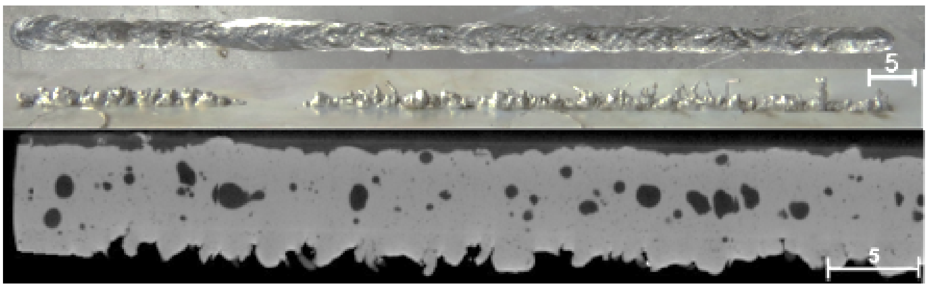
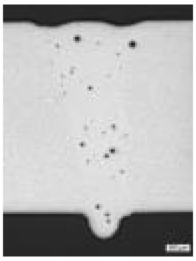
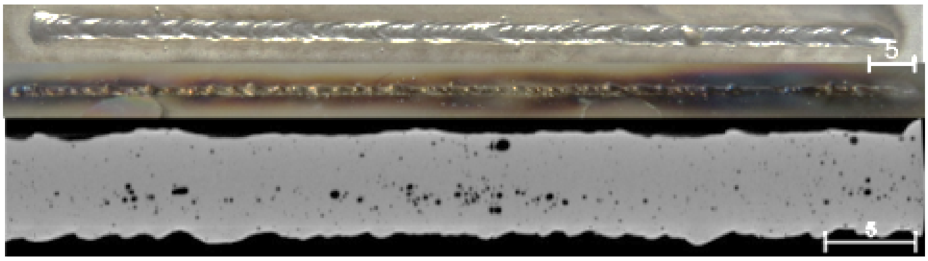
- According to the TIG-welding test, a good weldability is achieved, if the welding arc has a constant formation throughout the welding process. Usually, only a thin and small soot layer is existent around the weld seam. There should be no or very low weld spatter on the part surface.
- A bad weldability is very likely, if the welding arc has an unsteady formation throughout the welding process. This mostly correlates to a thicker soot layer and weld spatter on the surface of the die-casted part.

If a bad weldability according to the TIG-welding test occurs, first, it should be checked if the correct type of release agent was applied. If so, the mixing ratio should check critically. It should be aimed at a low mixing ratio of 1:125. The mixing ratio shall be increased only, if problems related to the ejection process occur. The next option is to evaluate the spray process. If the spray process lasts to long (“overspray”), too much release agent is applied onto the die surface, which in turn decreases the weldability. Considering all of the mentioned actions, a positive TIG-welding test should be achieved.

4.3. REDUCED PRESSURE LASER WELDING

In case of castings which require welding by the developed laser welding procedure at reduced pressure the following quality checks are required to assure the quality of the welding.

- **Non-destructive weld quality testing** should be performed by visual inspection and x-ray testing or computer tomography.
- The **welds visual appearance** has to be checked first followed by x-ray testing or a CT-scanning using a software which is capable to perform porosity analyses.
- Regarding destructive testing it is necessary to take **metallurgic cross-sections** from the welded part at significant positions.
- Also perform **tensile testing** in case mechanical properties are from interest.
- It is recommended to evaluate metallurgic cross-sections concerning the **occurrence of imperfections according to DIN EN ISO 13919-2**.

Low quality welding	 A_{Pore} = 15.5%	
High quality welding	 A_{Pore} = 1.0%	

Metallographic cross section (left), weld seam surface and root and longitudinal section as computer-tomography image (right)

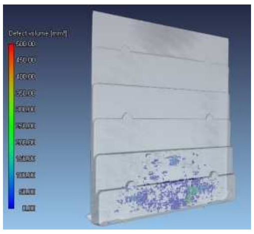
QUALITY CHECKS of SOUNDCAST CASTINGS depfending of the applied post-treatment: HEAT TREATMENT and/or WELDING

HIGH MECHANICAL PROPERTIES

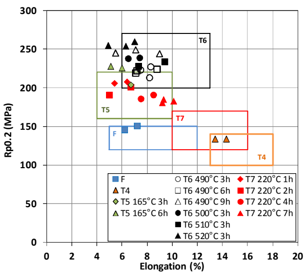
WELDING PROPERTIES

Visual inspection

X-ray / CT-Tomography analysis



Mechanical properties evaluation



Porosity and defect evaluation

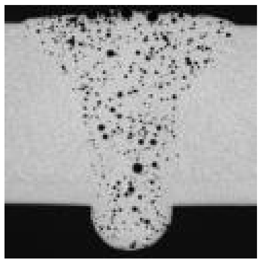
METALLOGRAPHIC ANALYSIS (VDG method)

FRACTURE SURFACE:
- **to evaluate defects and/or porosity**

Blister test

TIG Welding test

Reduced pressure laser welding



A_{Pore} = 9,7%