SOUNDCAST

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

D5.2: Summary report of validation results

Instrument	Collaborative Project – Research for the benefit of SME		
Grant Agreement No.	315506	Call identifier	FP7-SME-2012-1
Start date of project	1/11/2012	Duration	37 months
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Review	1.0	Date of preparation	28/12/2015

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DOCUMENT MODIFICATIONS CONTROL

Review	Date	Modifications	Author/Organisation
0.0	10/12/15	First draft	E. Roset / Ruffini S. Greis /Schmale & Schulte M. da Silva / Eurecat A. Niklas / IK4-AZTERLAN S. Muller / TU-BS
1.0	28/12/15	Revision	A. Fernández / IK4-AZTERLAN

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1. Introduction

The present document presents the validation results of the components produced during the demonstration activities carried out at the HPDC foundries RUFFINI and SCHMALE & SCHULTE showing the main validation results of the produced parts, as high mechanical properties demonstrator and high weldability demonstrator, respectively. In both demonstrators VDS vacuum equipment and Chem-Trend die lubricants were used. The components are described in deliverable 5.1. The demonstration trials were performed with the collaboration of all industrial partners and all RTDs. Soundcast procedures described in Deliverable 5.3 were followed for all the demonstration activities. RTDs assisted HPDC foundries in the demonstration trials and also specifically trained them in order to transfer the knowledge acquired in the project as it is described in Deliverable 6.6 (Training and demonstration for SMEs). Additionally, the activities carried out at Diace (former Soundcast partner) in demonstration are also summarised in section 4.

2. Ruffini – High mechanical properties demonstrator

The present section presents the validation results of the components produced during the demonstration activities carried out at Ruffini, Rubí (Spain).

2.1 Component and die selection

RUFFINI selected a component for the demonstration activity of the SOUNDCAST Project according to the following criteria:

1. A component with two existing dies in order to have one die to be modified for vacuum HPDC and have another for standard production.
2. A component with requirements of low porosity in which vacuum assisted die-casting may represent a competitive advantage.
3. A component with a geometry that allows the extraction of tensile specimens as well as X-ray tomography analysis.

The component finally selected, taking into account the beforehand defined criteria, is part of a transmission cover of a gear box was selected. An existing die of the component was selected for the modification.

2.2 Initial State: conventional HPDC process, as-cast state

First of all, several castings manufactured at Ruffini and ready to be delivered to its customer were selected for analysis. These castings were manufactured following the conventional process at Ruffini without applying the Soundcast technology. The results of these castings will be used as starting point in terms of porosity and mechanical properties. Therefore, a comparison with the Soundcast improvements will be done.

Figure 2.1 Picture of the Ruffini casting manufactured following conventional process after shoot peening.

The porosity of the casting in as-cast state is very low when it is analysed through CT-Tomography analysis, as it is demanded by the actual client of Ruffini (tightness required). The soundest zone was selected for extracting the tensile test samples and also the samples for metallographic analysis (VDG P202 analysis). However, if T6 heat treatment is applied, the porosity is significantly increased. It should be noted that conventional Ruffini casting does not require the application of T6 heat treatment. This heat treatment is performed only for comparison purposes. The porosity obtained after T6 heat treatment is associated to the no application of vacuum, no use of die lubricants with low gassing effect, no degassing treatment applied to the melt and the no application of all the other Soundcast procedures described in deliverable 5.3.

2.3 Design of the vacuum channels and die modification for Ruffini's demonstrator

Taking into account the existing die the modifications that were required in order to be adapted to vacuum assisted HPDC were defined in Soundcast technologies:

- Introduce the housing for the vacuum valve.
- Implement a vacuum channel to canalize the air from the cavity to the vacuum valve.
- Close the air vents present in the existing die by welding them.

Housing for the vacuum valve

Due to the existence of the sliding core present in the top-left part of the fixing side of the die it was decided to situate the vacuum valve in the top-right part of the fixing side. In addition, because of the lack of available space, it was required to remove the sliding core and close the whole with a plug. Due to this change the geometry of the part was slightly modified, which made it useless from a point of view of subsequent use as commercial product, nevertheless it should not affect substantially to the final quality of the part and their mechanical properties, allowing the comparison with standard produced parts.

Design and implementation of the vacuum channels

In order to design and implement the vacuum channels in the existing die it was followed the recommendations for design of the vacuum channels defined in Deliverable 2.4:

- The access to the vacuum channels was placed on the opposite side of the gates and the last regions to fill up (Figure 2.2). It was decided to introduce 3 vacuum channels in the last 3 overflows to fill up during the filling process.
- The main runner for the vacuum valve was given by their aspiration channel: isosceles trapezium of B: 15 mm, H: 10 mm and α: 15º.
- The minimum section of the whole vacuum channel should be the effective aspiration section of the selected vacuum valve and chill-vent. After analyzing the whole aspiration channel it was found that the minimum section was on the overflow gates. The original section was about 40 mm^2, much smaller than the 120 mm^2 of the vacuum valve and therefore not the whole venting section of the vacuum valve would be used. The section of the overflows gates were increased to reach a total value over 136 mm^2 a 10 % larger than the vacuum valve aspiration section.

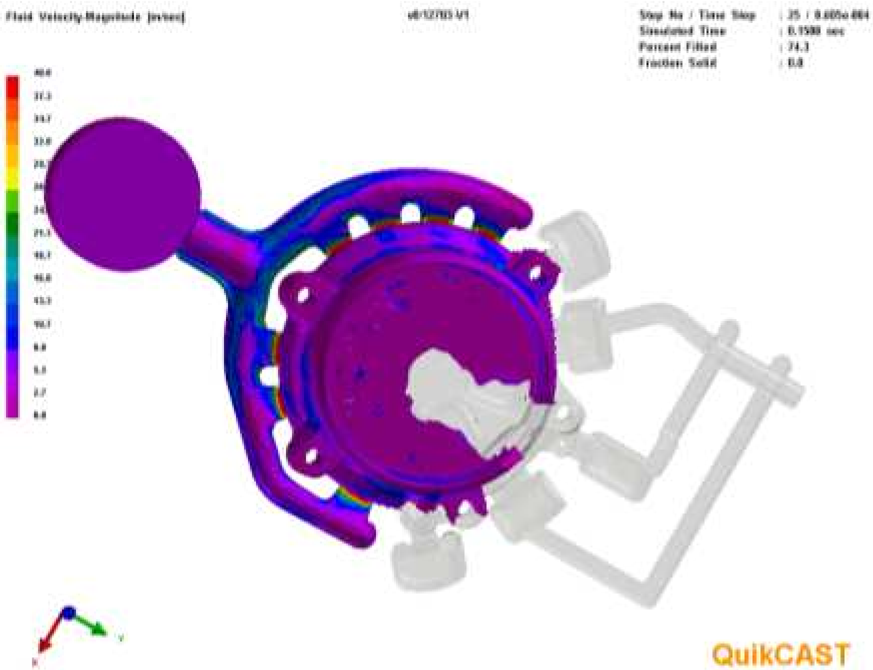


Figure 2.2 Simulation image showing the last regions of the component to fill up.

- Dead-ends have been introduced in the channels transition, from the channel coming from each overflow to the main aspiration channel of the vacuum valve, in order to retain the metal, with a higher density than the air, and to have more time to evacuate the air (Figure 2.3).

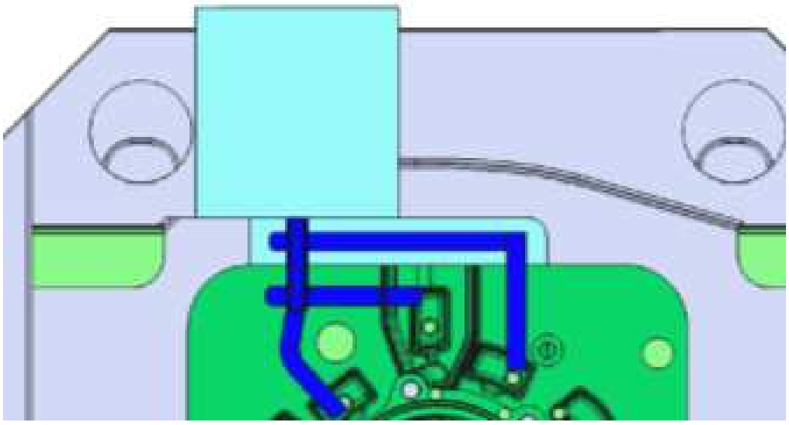


Figure 2.3 Design of the vacuum channels with the dead-ends in the transition from the individual channels to the main channel.

Welding of the air vents and necessary adjusting distance

A very important point in vacuum assisted HPDC is the die tightness. In order to ensure good die tightness and prevent die flashes it is recommended to guaranty a minimum adjusting distance of 25 mm along the whole parting line of the die. Thus, the air vents of original die were welded a minimum of 25 mm. In addition, part of the original frame was welded, surrounding the new inserts, in order to ensure a minimum adjusting distance of 25 mm everywhere.

2.4 Use of numerical simulation to verify the design

Numerical simulations with the software QuickCast were conducted in order to verify the good filling behaviour of the new geometry, as well as determining the behaviour during the solidification phase. In Figure 2.4 is presented a images of the simulation of filling process. The filling process of the part is correct. The metal in the gates does not overcome a velocity of 40 m/s, which is perfectly in the safe range of operation, as well as the speed in the gate of the overflow.

In addition, the filling process is quite gradual, from the back to the front with little metal joints and overlaps. The last parts of the cavity to fill are the overflows, which will guarantee that the air, oxides and rest of non metallic particles present in the metal front will flow into the overflows.

Figure 2.4 Image sequence of the filling simulation.

2.5 High Mechanical properties demonstrator fabrication at Ruffini facilities

2.5.1 Melt treatment

The SOUNDCAST alloy was molten in a gas melting furnace with a capability of 2500 kg/h of metal. The composition of the SOUNDCAST alloy was adjusted in the melting furnace by adding Mg and master alloy of Mn. Once the composition was adjusted, the metal was transferred to a transport ladle, where fluxes were spreader on the melt surface, just before degassing treatment. The metal was degassed in the transport ladle for 15 min with a rotor. After the degassing treatment the dross formed was skimmed from the surface and the metal was transferred to the holding furnace with 1200 kg capacity.

Thermal analysis of the melt was conducted in the holding furnace and Sr was added according to a modification rate ≥ 3. Strontium has to be adjusted during the melt treatment optimization process because it has a medium fading with time.

The analysis of the melt has done by:

- Thermolan-Al software to control the Sr content (Figure 2.5)
- D80 and Dross test to control the density (hydrogen dissolved in the melt) and the oxides in the melt.
- K mould to measure the oxides and inclusions.

Figure 2.5 Images of the vacuum tester used for controlling the metal quality (left), the rotor used for the degassing treatment (centre) and the thermal analysis equipment (right).

After fulfilment of all the control tests, as they are described in Deliverable 5.3 (Soundcast Procedures) the melt was approved to be casted. The chemical composition of the two manufacturing days at Ruffini facilities are within the specified Soundcast range. The image of the result of Thermolan-Al test of the second day is shown in Figure 2.6. A modification rate of 4 was predicted in both manufacturing days.

Figure 2.6 Image of the screen results of Thermolan-Al equipment for the second day of manufacturing of Ruffini's demonstrator. Modification rate prediction = 4.

2.5.2 Casting equipment and parameters

For the trials the smallest machine from RUFFINI equipped with the necessary accessories was used:

- Die casting machine: 700 tn
- Crucible furnace: 1200 kg
- Metal dosing feeder: ceramic 2kg capacity
- Tempering unit
- Vacuum unit: VDS PLC 350

Figure 2.7 Image of the die casting machine, 700 tn (left), and the vacuum equipment, VDS PLC 350 (right), used to cast Ruffini's demonstrator.

The main casting parameters used in the trials are presented in Table 2.1. Since the high pressure die casting machine of Ruffini is comparable to the existing machine of EURECAT, existing parameters could be adapted. However, some preparation was necessary regarding fittings and the connection of the vacuum system with the high pressure die casting machine. Ruffini is not used to operate this vacuum system. Thus, foundry workers need to be made familiar with this new equipment. Training was received in the Soundcast demonstration trials.

2.5.3 Lubrication parameters

The lubrication parameters (like release agents and plunger lubricants) have an important influence on the porosity formation and on the final quality of high-pressure die cast parts. The lubricants selected in WP4 after a lot of trials were used in the demonstration. Both of them were supplied by the partner Chem-Trend:

- Release agent : Chem-Trend SL1697S (wax free, mixing ratio 1:80)
- Plunger lubrication: Chem-Trend Power –Lube 766 (minimum application)

The spraying is done by Wollin spray technology. The lubrication of the plunger was done with a Chem-Trend dosing equipment of oil droplets with a volumetric pump. The spraying head with the nozzles used in the trials, as well as the oil dosing tube for the plunger, are shown in Figure 2.8.

Figure 2.8 Image of the die releasing agent device from Wollin (left) and the plunger lubrication system from Chem-Trend (right).

2.6 Demonstrator validation

Once all the improvements in the die were performed, vacuum assisted injection process is adjusted to Ruffini's HPDC machine following the procedures described in Deliverable 5.3 (Soundcast procedures). After melt treatment validation, the Soundcast demonstrator for high mechanical properties, named Ruffini's demonstrator was casted (see Figure 2.9).

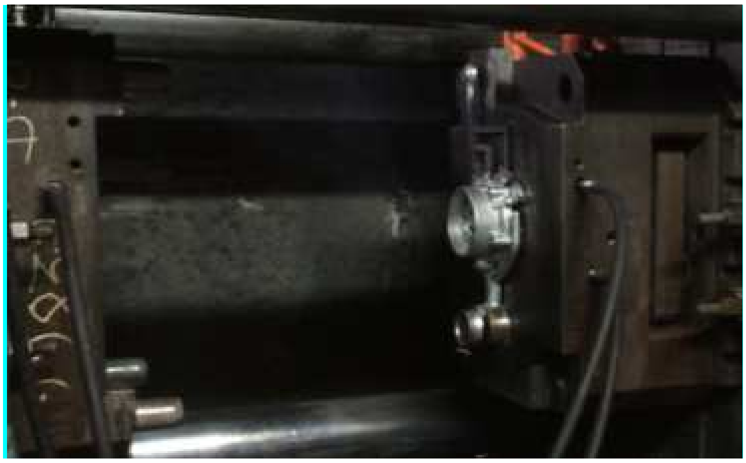


Figure 2.9. Ruffini demonstrator manufactured using the full Soundcast technology. The cut for metallographic analysis is indicated.

2.6.1 Metallographic structure

The structure of the soundcast alloy in Ruffini's demonstrator has been checked by metallographic means. The figure 2.10 shows a SDAS of approximately 12 µm with a fine Silicon structure in the as-cast (F temper), as it was expected taking into account the Thermolan-Al prediction of modification rate equals to 4. Regarding the intermetallic phases, no beta phases appear. All the iron rich phases are compact alfa phases.

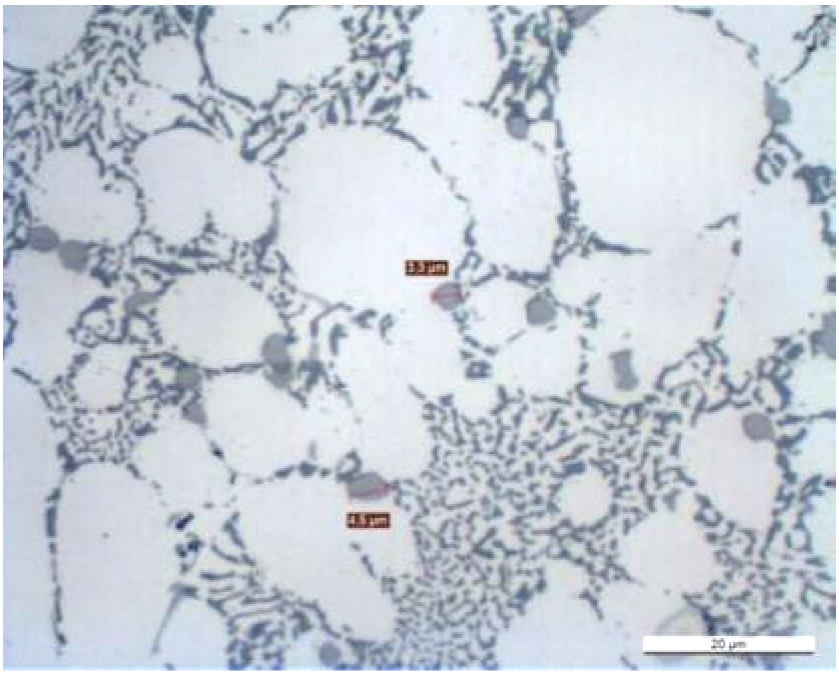
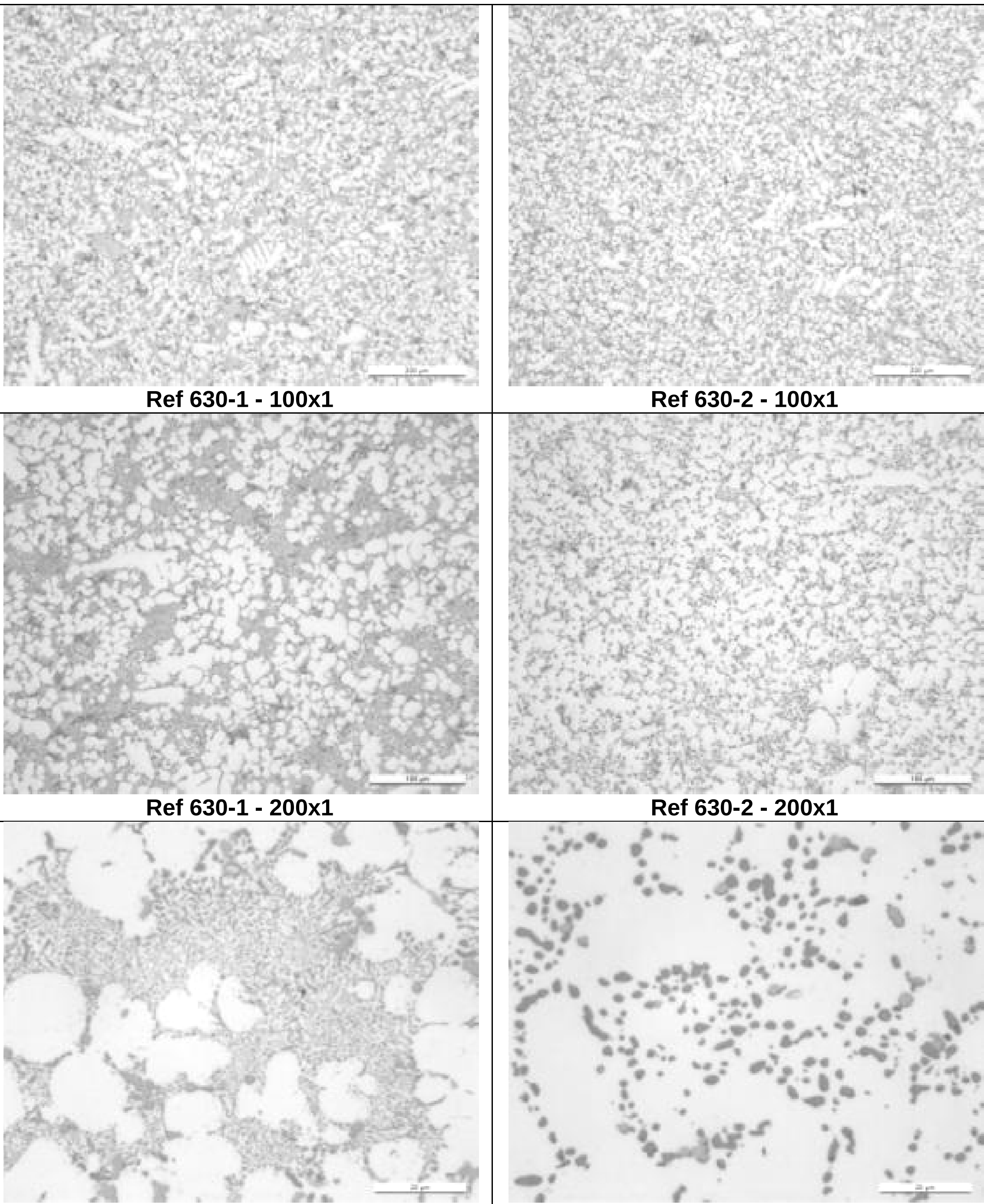


Figure 2.10. Micrograph of the Ruffini's demonstrator.

The T6 heat treatment effect on microstructure is shown in Figure 2.11. Silicon particles grow with the heat treatment as it is usual for castings with a high solidification rate as HPDC are.



Ref 630-1 - 100x1 | Ref 630-2 - 100x1

Ref 630-1 - 200x1 | Ref 630-2 - 200x1

Ref 630-1 - 500x1,88 | Ref 630-2 - 500x1,88

Figure 2.11. Comparison between the microstructure of the Ruffini's demonstrator in As-Cast condition and in T6 temper

2.6.1 Porosity evaluation: Computed Tomography (CT) and VDG P202 analysis

The first analysis performed is the CT- inspection which includes a comparison between the vacuum assisted process and the atmosphere injection process (no vacuum assisted process). The effect of vacuum assisted process **in reducing the porosity level both in defect volume and maximum defect was evident**.

Additionally the soundness zone determined by CT inspection has been selected for metallographic analysis and tensile test evaluation, as it is indicated in Figure 2.12 and Figure 2.13.

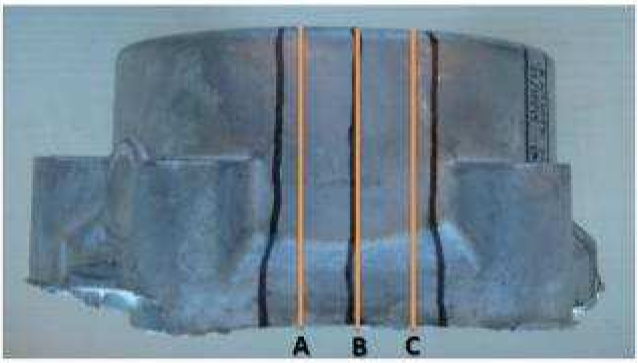
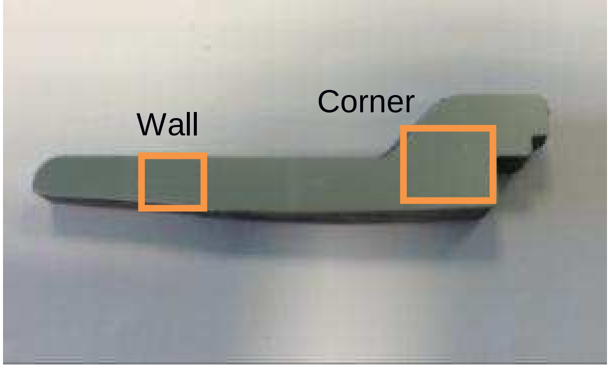
Sections	Zones
	

Figure 2.12. Areas where the VDG P202 2010 porosity has been measured.

The porosity has been analysed through the VDG P202 2010 metallographic analysis method in the same area where the tensile tests have been obtained. A comparison between both conditions As-Cast and T6 temper in the same casting have been carried out:

- Reference: 630
- Pressure (third phase): 1000 Bar.

Three sections have been prepared for each temper condition and the porosity has been evaluated in 2 zones of each section: wall and corner (see figure 2.13).

Table 2.1. VDG P202 2010 metallographic porosity in the Ruffini's demonstrator casting in both conditions As-Cast (F temper) and T6 temper.

Porosity VDG P202 2010		AS-CAST		T6	
		%	Max. pore length	%	Max. pore length
A	corner	0.048	180	**0.19**	**390**
	wall	0.023	72	**0.14**	**200**
B	corner	0.044	155	**0.14**	**145**
	wall	0.013	78	**0.16**	**170**
C	corner	0.350	410	**0.25**	**200**
	wall	0.039	65	**0.13**	**195**

The main results of table 2.1 are summarized below:

- The porosity in the wall (where tensile test are evaluated) is below 0.04 % in the three analysed cuts.
- The porosity in the wall increases up to 0.14 % when T6 treatment is applied.
- The porosity in the corner is in general higher than in the wall in the as-cast state, probably due to the thicker section that may cause small shrinkage concentration, as it is the case of sample C.
- After heat treatment, the porosity in the corner remains about the same value than in the wall and always below 0.25 %.

The results of the comparison with the VDG P202 porosity evaluated in the same area for conventional casting (see section 2.2) is summarized below

- The VDG P202 porosity evaluated in the same area for conventional Ruffini casting is very similar to the porosity evaluated at Soundcast demonstrator in as-cast state.
- However, after T6 treatment, the porosity of conventional Ruffini casting increases significantly meanwhile **the porosity of Soundcast demonstrator after T6 remains still low, below 0.25 %.**

2.6.2 Mechanical properties

The mechanical properties are the key point in terms of the real improvements achieved in the Ruffini's demonstrator when full Soundcast technology is applied. The tensile test samples (figure 2.13) have been obtained from the zone where the tomography shows the lowest porosity (see figure 2.19). The external skin of the casting has been kept; meanwhile the internal has been partially removed due to the necessity of flattening. The final tensile sample dimensions are: 6.4 mm x 6.0 mm x 25 mm.

Figure 2.13. Tensile test samples obtained from each Ruffini's demonstrator.

The mechanical properties of the different tempers obtained in the demonstrator of Ruffini (F, T4 and different T6 tempers) are presented in Figure 2.14. A significant increase in Elongation is observed with respect to the state of the art of conventional HPDC parts manufactured without applying Soundcast technology.

T6 temper: It can be observed in Figure 2.14 that the elongation values in the T6 temper are within the mechanical property range of the primary AlSi10MnMg alloy Trimal-05 or very close to it for both different ageing treatment of 2 and 3 hours. The yield strength is well in the middle of the specified range for 3 hours treatment and in the lower range for 2 hours.

Thus, in order to increase elongation the yield strength of the alloy should be reduced. This could be achieved by reducing the Mg content of the secondary alloy from 0.34-0.39 wt.% to 0.25 wt.% (see Appendix I: Influence of Mg content on mechanical properties of AlSi10MnMg primary alloys). Values down to 0.15 wt. % of Mg are reported to achieve high elongation values and reduced yield strength. The reduction of Mg content is the best solution to achieve higher elongation values for any temper while strength is decreased.

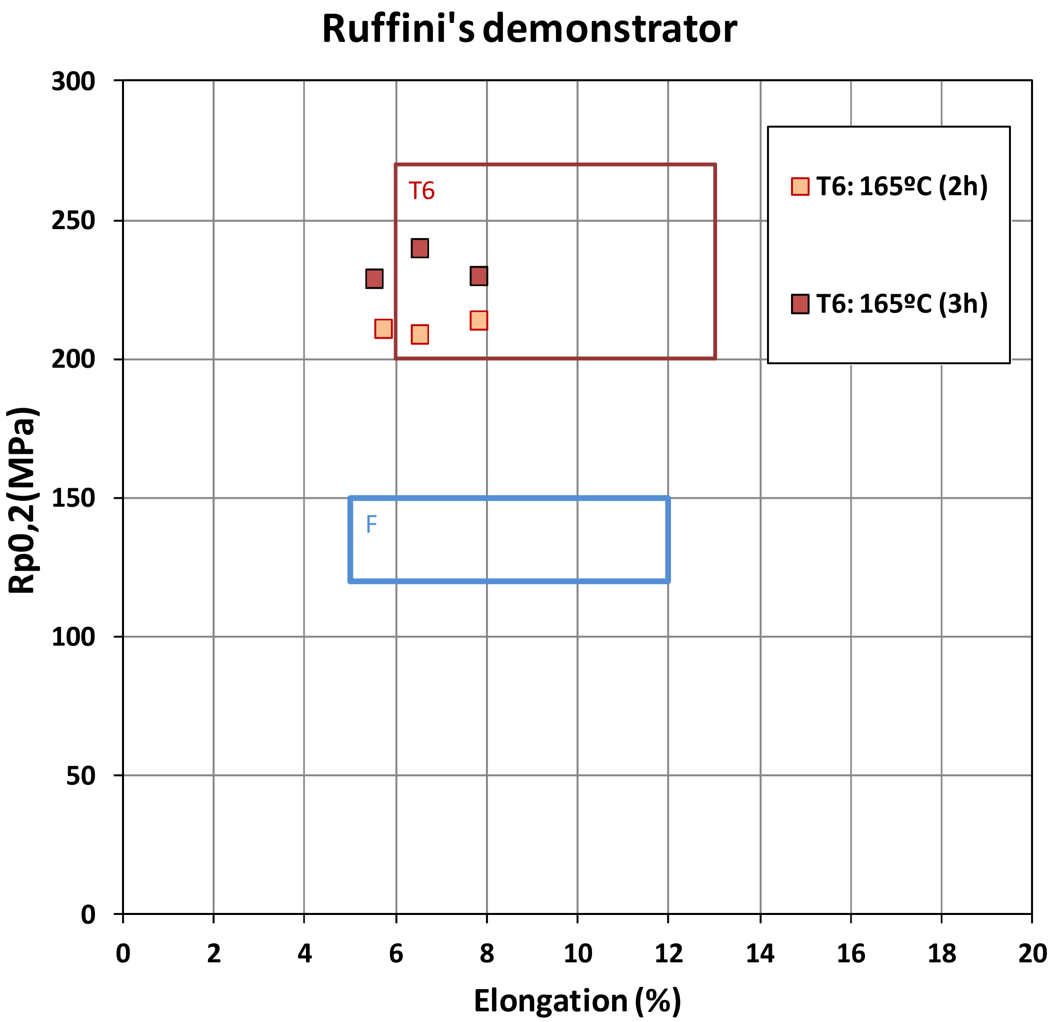


Figure 2.14. Summary of mechanical properties of Ruffini's demonstrator for 6.4 mm thickness after different heat treatments. Trimal-05 in different tempers is indicated by rectangles [Trimal®-05 data sheet, TRIMET Aluminium AG, Germany, www.trimet.de, 2008].

2.7 Conclusions of Ruffini demonstrator: High mechanical properties

The main conclusions from the present work are as follows:

Casting at Ruffini (Soundcast demonstrator):

- An existing die of Ruffini with low porosity requirements and suitable for extracting tensile samples for validation of the mechanical properties has been selected and modified for vacuum application.
- Numerical simulation was performed on the modified die in order to verify the good filling behaviour of the new geometry, as well as determining the behaviour during the solidification phase.
- Melt preparation and control at Ruffini were carried out according to Deliverable 5.3 (Soundcast Procedures).
- During the casting session at Ruffini, no unexpected interruptions occurred.
- Since the high pressure die casting machine of Ruffini is comparable to the existing machine of EURECAT, existing parameters could be adapted. However, some preparation

was necessary regarding fittings and the connection of the vacuum system with the high pressure die casting machine. Vacuum unit: VDS PLC 350 was used in the trials.
- Ruffini is not used to operate this vacuum system. Thus, foundry workers need to be made familiar with this new equipment. Training was received in the Soundcast demonstration trials.
- Release agent: Chem-Trend SL1697S (wax free, mixing ratio 1:80) and Plunger lubrication: Chem-Trend Power -Lube 766 (minimum application) were used in the trials.

Mechanical property validation:
- Castings were manufactured following the conventional process at Ruffini and applying the Soundcast technology, in order to determine the improvements achieved by the Soundcast technology.
- The main results of the ***metallographic analysis*** are:
  - Eutectic Si modification is as required fine and fibrous and no harmful β-iron phases are observed.
  - The VDG P202 porosity in the wall (where tensile test are obtained) of the part produced by Soundcast technology is below 0.04 % in the as cast state and increases up to up to 0.14 % when T6 treatment is applied.
  - After T6 heat treatment, the porosity in the corner remains about the same value than in the wall and always below 0.25 %. It is mainly shrinkage porosity.
  - The VDG P202 porosity evaluated in the same area for conventional Ruffini casting is very similar to the porosity evaluated at Soundcast demonstrator in as-cast state.
  - The porosity of the Soundcast demonstrator after T6 remains still low, below 0.25 %, thus a significant reduction in porosity is achieved with respect to the conventional HPDC parts.

- ***Mechanical properties*** have been determined at different T6 tempers for the casting manufactured by Soundcast technology: elongation values are within the mechanical property range of the primary AlSi10MnMg alloy Trimal-05 or very close to it for the ageing treatment of 2 and 3 hours at 165 ºC. Further increase of elongation could be obtained by decreasing the Mg content to 0.25 wt. % or up to 0.1 wt. % at the expense of yield strength.

3. Schmale &Schulte – High weldability demonstrator

The present section presents the validation results of the component produced during the demonstration activities carried out at Schmale & Schulte GmbH, Lüdenscheid (Germany).

3.1 Concept of the demonstrator - component selection

Up to project stage of demonstration activities, the welding tests performed within the SOUNDCAST project have been done by welding flat surfaces of the same high pressure die casting component. Within the framework of demonstration activities, the high-pressure die casting product “terminal box” of Schmale and Schulte was employed to demonstrate the weldability taking account the SOUNDCAST technology. This product is composed of three parts: a frame (cf. Figure 3.1,❷), a baseplate (not shown) and a cap. In its original state, these three parts are intended to be joint by bolds and sealed by a gasket. Hence, the design is not optimized in terms of the weldability. Nevertheless, the terminal box is a very well suited demonstrator for the SOUNDCAST technology package, since there a comparable products on the market that are manufactured by welding. Here, welding allows cost & weight savings by elimination of bolts and gaskets. Due to the relatively complex structure of the frame, it is very likely that the filling process will be very inhomogeneous. Therefore, the cavity evacuation is more difficult and high flow lengths may result in high values for air and die lubricant entrapment. By examining a more complex part, the stability of the welding process is also tested for inhomogeneous welding conditions. In order to have a valid and weldable demonstrator, a new cap (cf. Figure 3.1,❶) was designed that ensures the weldability.

❶
Corresponding die casting tool owned by ifs, TU Braunschweig. Applied to the die casting machine at Schmale and Schulte for SOUNDCAST demo activities

❷
Corresponding die casting tool generally used by Schmale and Schulte

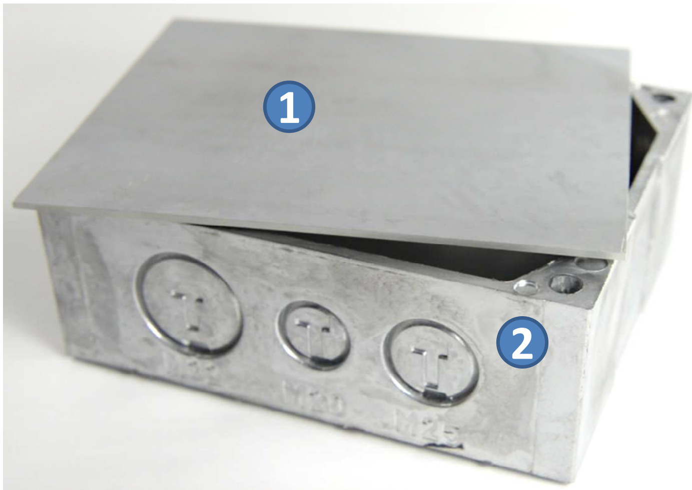


Figure 3.1: Terminal box of Schmale & Schulte for Soundcast welding demonstrator

3.2 Demonstrator fabrication

In its original design, the die-casting mould of the frame only features an atmospheric venting – no vacuum system is applied. This is reasonable, since in its original state, no welding technologies at this high-pressure die casting part are applied. Due to design limitations, it was not possible to equip the die-casting tool of the frame with a vacuum system. In all other aspects (e. g. alloy composition, die lubricants) there are no limitations, regarding the application of the SOUNDCAST procedures described in deliverable 5.3.
However, the die casting tool of the cap is equipped with full SOUNDCAST vacuum technology. The external dimensions of the casted plate allow a fabrication of the needed plate (cf. Figure 3.1,❶). Hence, within the framework of the SOUNDCAST research project, the die-casting tool of TU-BS was installed at the die-casting machine FRECH DAK 500/315 SDC at Schmale & Schulte shown in Figure 3.2. This approach ensured that the complete SOUNDCAST technology was available for the company for demonstration activities. Note: The cap is machined to fit to the frame, as it is shown in Figure 3.1.

3.2.1 Casting equipment

Table 3.1 contains the data for the casting equipment. Figure 3.2 and 3.3 show the high pressure die casting machines at Schmale and Schulte whereas the Figures 3.4 to 3.6 illustrate the used vacuum equipment.

Figure 3.2: Picture of FRECH DAK 350

Figure 3.3: Picture of FRECH DAK 500

Figure 3.4: Typhoon vacuum runners - ejector die half

Figure 3.5: Vacuum valve with control piston and ejector pins - cover die half

Figure 3.6: Vacuum tank with control unit and vacuum pump

3.2.2 Casting parameters

Generally, the part "frame" features the standard casting parameters of Schmale & Schulte. For the part "*cap*", TU-BS standard casting parameters were adapted to the die casting process at Schmale & Schulte. The density index was measured immediately several times before the casting session. For the demonstration activities, the SOUNDCAST release agent and plunger lubricants were applied.The lubrication parameters (like release agents and plunger lubricants) have an important influence on the porosity formation and on the final quality of high-pressure die cast parts. The lubricants selected in WP4 after a lot of trials were used in the demonstration. Both of them were supplied by the partner Chem-Trend. Table 3.1 contains specific data for the die and plunger lubricants and the mixing ratio.

Table 3.1: Die and plunger lubricants for the SOUNDCAST casting session

Part	*frame*	*cap*
Release agent	*Chem-Trend* SL 1697 S (wax free, mixing ratio 1:125)	*Chem-Trend* SL 1697 S (wax free, mixing ratio 1:125)
Plunger lubrication	*Chem-Trend* Power-Lube 766 (minimum application)	*Chem-Trend* Power-Lube 766 (minimum application)

3.2.3 Production process

During the casting session at Schmale and Schulte, no unexpected interruptions occurred. The casting session for both parts lasted about 3 hours per part, about 90 "*frames*" and "*caps*" were casted. However, the downtime of the die casting machine was much longer since the die casting tool needed to be mounted previously. Preparation time also was necessary for connecting the vacuum system with the high pressure die casting machine. The SOUNDCAST alloy was composed according to the SOUNDCAST procedures; the alloy content was measured with mass spectrometry. Melt treatment was carried out with a standard degassing unit. When analysing a series of measurements, it slight increase of the minimum pressure can be noticed (cf. Figure 3.7). The increase of the minimum pressure results from aluminium deposits at the vacuum valve. The deposits reduce the effective flow cross-section and the corresponding volume flow rate. Since there is no big difference in the absolute value of the minimum pressure, the tendency was detected not until after the casting session. The results stress the importance of a periodic cleaning and maintenance of the vacuum valve. Subsequent to the production process, X-ray and blister-tests were used to verify the quality, as it is established in deliverable 5.3 (Soundcast procedures, section 5: quality checks). No gas-porosity was observable inside the frame (especially near the joint area).

3.3 Welding of the Demonstrator

3.3.1 Welding Equipment

The welding trials performed were carried out using welding equipment designed and developed at the Institute of Joining and Welding (TU-BS). The vacuum chamber consists of an X/Y manipulator, slots for PC and PA welding and different windows for process observation (cf. Fig. 3.12). A TRUMPF TruDisk 6002D was used as solid state, diode pumped disk laser beam source with a wavelength of 1030 nm. The characteristic wavelength avoids the laser to couple into glass, thus enables the usage of flexible beam guidance made from fibreglass. Moreover, the vacuum chamber is equipped with a multi-stage roots pump *"Axidien A 100 L"*. Due to a pumping speed of 100 m³/h the pump is capable to reduce the pressure inside the vacuum chamber to 10/1/0.1 mbar in 60/90/240 s. **In order to find suitable welding parameters for the demonstrator, a parameter study was performed. The parameter study contained a variation of welding speed, ambient pressure, and laser power.**

Figure 3.7: Welding equipment designed and developed at the TU-BS.

3.3.2 Welding Sequence and Parameters

The demonstrator was welded using the welding sequence according to Figure 3.8 and 3.9. At first, the bits highlighted in orange were tack welded at 10 mbar ambient pressure, a welding speed of 4 m/min, -2 mm focus position and 1900 W of laser power to reduce weld distortion. After tack welding, the full weld path length was welded using the tack welding parameters at 1 mbar ambient pressure in order to achieve a firmly bonded joint.

Tack Welding:	**Welding at reduced pressure:**
p = 10 mbar	p = 1 mbar
v = 4 m/min	v = 4 m/min
z_F = -2 mm	z_F = -2 mm
P = 1900 W	P = 1900 W

Figure 3.8: Weld bead position for tack welding

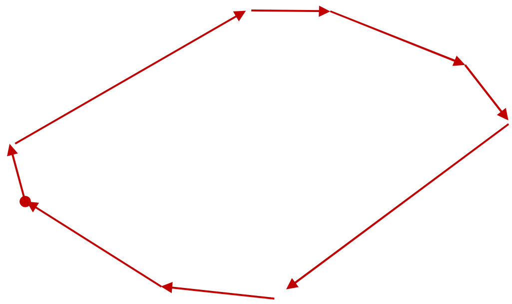


Figure 3.9: Weld bead position for continuous welding

3.3.3 Welding Results

The parameters chosen for laser beam welding at reduced ambient pressure showed good results. Due to the application of high welding speeds, produced weld beads possess a narrow appearance. The reduction of ambient pressure caused a significant decrease of outer weld bead defects as shown in Figure 3.10. However, it a thin soot layer was observed at the surface of the weld bead and its direct surroundings. It is assumed that this soot layer is caused by an incomplete combustion during the welding process which in turn results from the low oxygen content at reduced pressure. The soot layer could be easily removed after welding by using an alcohol-based solution.

Besides the regular outer weld appearance, the inner weld quality was observed as good as well. The porosity content was low enough. Both metallurgic cross section and CT-Scan showed low porosity contents. Furthermore, the CT-Scan displays the constancy of the welding result and proofs that a continuous bonded joint was achieved. The porosity found is assumed to be a result of the casting quality of the frame (part 2) of the demonstrator, which was casted without vacuum assistance.

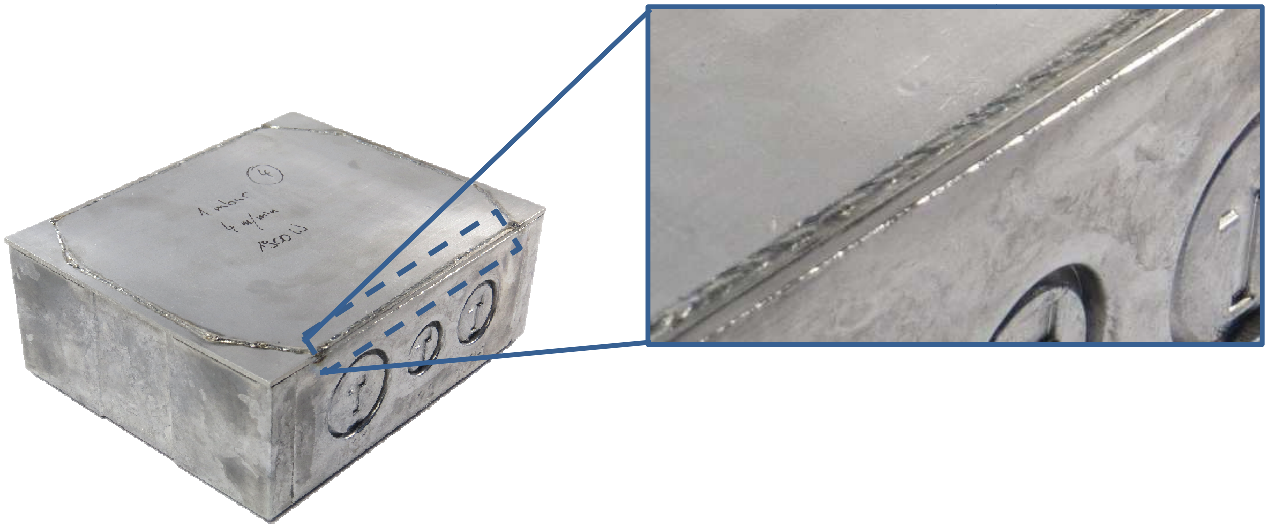


Figure 3.10: Detailed view of the weld bead after cleaning with an alcohol-based solution

3.4 Conclusions of Schmale & Schulte: high weldability demonstrator

The main conclusions from the present work are as follows:
Casting Session:

- During the casting session at Schmale and Schulte, no unexpected interruptions occurred.
- Since the high pressure die casting machine of Schmale and Schulte is comparable to the existing machine of TU-BS, existing parameters could be adapted. However, some preparation was necessary regarding fittings and the connection of the vacuum system with the high pressure die casting machine.
- Foundry workers need to be made aware of the potential but also of the necessity of the vacuum system. A periodic cleaning of the valve and careful handling of the whole vacuum system is necessary. A (periodic) training should keep the foundry workers well informed.
- Compared to the previous die lubricant of Schmale and Schult, the separation effect of the SOUNDCAST release agent Chem-Trend 1697 S is lower, which means that the necessary force for the ejector pins to eject the part is higher.
- For future HPDC parts that are critical in terms of shrinking onto the die casting die, it should be assured that there are enough ejector pins. Failing this, the mixing ratio must be decreased to values of 1:100 or even less. This might have a slight negative influence on the weldability.

Laser beam welding:

- Produced parts were welded by laser beam welding at reduced ambient pressure using a solid state disk laser (SOUNDCAST technology).
- A constantly bonded joint was achieved over the entire weld path length. Both, the weld bead appearance and the level of porosity (verified by CT scans and cross sections) turned out to be good.
- It could be proved that if at least one high pressure die casting part is manufactured in vacuum assisted condition (here: the “*cap*”), the SOUNDCAST technology is capable to produce reproducible and constant weld bead quality and therefore is a suitable welding process option for welding HPDC parts.
- Nevertheless, the demonstrator part proved that the welding quality strongly depends on the quality of the HPDC part. Here, vacuum assisted die casting is a key factor for the welding outcome, thus highly recommended.

- An ambient pressure inside the vacuum chamber of 1 mbar was established since this value turned out to be a good compromise between weld quality and processing time. If the HPDC-part quality increases, the pressure inside the vacuum chamber could be increased by an order of magnitude, as academic investigations in earlier project stages of SOUNDCAST proved. By doing so, the process time could be decreased by 30 s, which is an aim worth striving for.