PROJECT FINAL REPORT

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Project acronym: EFEVE

Project title: Development of a new high performance material associated to a new technological Energetic, Flexible, Economical, Versatile and Ecological process to make super strong and lightweight components.

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Project coordinator name: Ms. Ane Miren Irazustabarrena (TECNALIA)

Tel: + 902760000

Fax: +34-943003800

E-mail: Ane.Irazustabarrena@tecnalia.com

Project website address: www.efeve.eu

Final publishable summary report

Executive Summary

The general objective of the EFEVE project has been to develop, implement and demonstrate real solutions to improve casting components performance, reduce weight, energy and costs. Real solutions to priority sectors of the industry like the automotive and wind power, which are demanding new efficient and versatile processes to produce competitive and innovative casting components.

With the aim of achieving this general objective, it has been necessary to define an approach to work in parallel in two core pillars, one related with the materials and the other with the casting processes. Simplifying, these two lines could be described as the one related with new advanced light materials and the other with enhanced low pressure and high pressure casting technologies and processes. It is worth mentioning that the proposed developments will not involve only technological objectives, others such us economical or environmental will also be taken into account. This is mainly to ensure that the successful results will lead to an industrial outcome that will be exploited by the different members of the EFEVE Consortium.

For the development of advanced light alloys that significantly influences the final performance, it has been necessary to prioritize the industrial scalability, safety aspects and cost. The enhancement of the casting technologies to meet performance requirements, flexibility and energy efficiency has been tackled through the development of Squeeze Casting for Magnesium (MgSC) castings, enhancement of the current Low Pressure Casting technology (LPSC) for aluminium castings and the development of new high resistance sand cores (INSA) suitable to be used in the new LPSC process.

Finally, to assess the developments carried out in the EFEVE project, four demonstrators have been carefully selected and defined from the Automotive (Cylinder Head, Body Joint, and Sub-frame) and Wind power (Bell Housing) sectors. The objective has been to monitor and evaluated the improvements achieved through the development and manufacture of these demonstrators.

It is important to keep in mind that the proposed alternatives of the EFEVE project materials should comply also with manufacturability restrictions (e.g. be easy to cast and machine) and be as cost effective as possible), keeping the fabrication process lean and reasonably simple to avoid high maintenance and operation costs.

1.- Summary description of project context and objectives

The general objective of the EFEVE project has been to develop, implement and demonstrate real solutions to improve casting components performance, reduce weight, energy and costs. Real solutions to priority sectors of the industry like the automotive and wind power, which are demanding new efficient and versatile processes to produce competitive and innovative casting components.

The specific technical objectives of the project completed to reach the overall goal set by EFEVE project (according to the DoW) have been the following;

A. Definition and development of manufacturing technologies for light alloys with nano element:

- 4 different types of nanoreinforcements and their production process have been investigated: nanodiamonds, TiC, B_4C (coated with Cu), Al_2O_3.
- Aluminium alloys based on the 2xxx and 3xxx series and AM60 for the magnesium case have been investigated.
- It has been concluded that nanoreinforcements that are added in the master alloy form got incorporated in a much easier way that those added in a loose manner. Two different ways to produce nanoreinforced master alloys (highly concentrated composites) have been investigated; mechanical alloying and SHS.
- The systems that present most promising results have been; 356/ND and AM60/TiC
- The main health, safety and environment issue that may be linked to nano reinforcements manufacturing and implementation under EFEVE project has been described.

B. Definition and development of new casting manufacturing technologies:

- A new casting process, Low Pressure Squeeze Casting (LPSC) process for aluminium based alloys has been developed. The new process combines the advantages of squeeze casting as well as low pressure casting. It consists of an adjustment of the conventional low pressure casting by adding a squeeze sequence.
- A process, based on nanotechnology, has been developed (INSA process) to produce more resistance cores required by the new LPSC process. The cores due to the new process requirements they should withstand higher pressures.
- A new casting technology, Squeeze Casting, has been developed to produce new magnesium alloy based components. The main features have been to use slower filling rates to avoid turbulences during the mould filling, to finally obtain low levels of porosity and thus possibility to apply thermal treatments.
- New designs for new components in automotive and wind power have been run.
- Simulations of new components manufacturing to new process have been run.

C. Definition, development and implementation for LPSC plant pilot for aluminium alloys:

- General analysis of the industrial facilities to install the demonstrator for casting aluminium based alloys by the new LPSC casting technology developed in the EFEVE.
- Modification of the current Low Pressure equipment for the new process.
- Detailed engineering for the construction of a new LPSC technology equipment.
- Construction of a new LPSC equipment

- A sound and transparent assessment in terms of environmental impacts, costs effectiveness and energy savings through life cycle studies:
    i. LCA of the LPSC technology
    ii. Thermoeconomic analysis and energy optimization
    iii. Holistic diagnosis and advisory feedback

D. Definition, development and implementation for SCMg plant pilot for magnesium alloys:

- General analysis of the industrial facilities to install the demonstrator for casting magnesium based alloys by the new SCMg casting technology developed in the EFEVE.
- Adaptation of the current high pressure die casting equipment for the new process.
- A sound and transparent assessment in terms of environmental impacts, costs effectiveness and energy savings through life cycle studies:
    i. LCA of the SCMg technology
    ii. Thermoeconomic analysis and energy optimization
    iii. Holistic diagnosis and advisory feedback

E. Development and implementation of INSA technology to produce high resistance cores able to withstand the pressures associated to the new LPSC process:

- Development of the equipment to produce high resistance cores by the the INSA technology.

F. An strategic and business oriented commercialization plan including dedicated business models has been developed:

- A market analysis in the sectors of interest of the EFEVE technologies and market size estimation for EFEVE technologies has been provided. The analysis has been developed at European level as well as globally, providing information from other target countries such as USA and Asia.
- A plan and strategy to prepare the project contractors for the exploitation of their research and development work results and enhance their chances of entrepreneurial success has been developed.
- An outline of the Business Plans corresponding to the business models that have been identified for EFEVE project's results has been provided.

Four demonstrators have been carefully selected to validate the results of the EFEVE project. 3 of them correspond to the Automotive (Cylinder Head, Body Joint, and Sub-frame) sector and one of them (Bell Housing) to the wind energy sector. The objective has been to monitor and evaluate the improvements achieved through the development and manufacture of these demonstrators

Wind-generated electricity is the least expensive form of renewable power, and is becoming one of the cheapest forms of electricity — from any source. In some locations, the cost of electricity from wind is comparable to that from conventional fossil-fuelled power plants. Wind power has a high initial investment compared to operating costs, but the latter are low.
The cost of energy (total cost of generating 1kWh of power form a power plant, and includes the cost of building and operating the power plant) is the driver in the development of the wind technology. Manufacturers work in a focused way to continue lowering the cost of energy through technological advances in turbine technology. Key focus area is to make the power production from turbines efficient as possible: greater output, less weight, improved production and installation. The weight advantages gained through this enhance economic viability across all project phases, from fabrication to transport, foundations and installation all the way up to operation. Reduce the cost and weight of the internal component like pitch drive means increase the efficiency and reduce the cost of energy.

In the automotive sector future efforts should focus on investigating new lightweight alloys and effective production processes that are both cost effective and affordable. Materials and technologies in the near future will contribute to lightweight vehicles, better fuel economy and lower emissions. The materials (aluminiuim and magnesium based alloys) and processes under development in the EFEVE project are new opportunities to advance in this away.

Structural and powertrain components for automotive applications are facing a critical development point, the always increasing demands for efficiency and the compliance of new emissions regulations are pushing modern vehicle designers towards nonferrous metals intensive solutions which, in the specific case of vehicles structure, result in the substitution of steel and iron alloys for chassis, suspension and other structural components. These conditions require the current aluminium alloys static, dynamic mechanical properties as well as corrosion resistance to be increased in order for the component not to fail prematurely. State of the art Aluminium structural components normally use a combination of extruded and cast aluminium alloy segments welded or bolted together to produce the final shape with all the limitations and disadvantages that having joints in a component that requires high stiffness represents. This is the reason why a one piece casting (as the demonstrators developed in the EFEVE) is desired since joints of dissimilar materials always carries the risk of failure from corrosion (galvanic cells produced by putting dissimilar materials in electric contact) or fatigue at the joints areas.

In the powertrain, Internal Combustion Engines are facing a critical development point, pushing the engine designers towards downsizing components which, in the specific case of Cylinder Heads, result in higher operating temperatures and pressures. These conditions require the current aluminium alloys static and dynamic mechanical properties at room and elevated temperatures to be increased in order for the component not to fail prematurely. State of the art cylinder heads for high power density applications normally use aluminium alloys cast in semi-permanent moulds either by gravity or Low Pressure Injection. Nevertheless, it is forecasted that the mechanical properties of these materials will be borderline to comply with the engines designs of the mid-long term applications.

2.- A description of the main S&T results/foregrounds

The general objective of the EFEVE project has been to develop, implement and demonstrate real solutions to improve casting components performance, reduce weight, energy and costs. Real solutions to priority sectors of the industry like the automotive and wind power, which are demanding new efficient and versatile processes to produce competitive and innovative casting components.In order to assess the strengths and constraints of these new technologies under study, 4 different demonstrators from the automotive and wind power sectors have been selected.

For the description of the main results and foregrounds of the project, and also taking into account the publishable character of it, it has been decided to describe it through the description of each demonstrator. It is considered a suitable format, easily to understand by the wide audience, including the general public.

Structural magnesium part for the automotive sector produced by squeeze casting process (SCMg)

The technical concept of the development and evaluation of the new SCMg technology is illustrated in Figure 1. In a multidisciplinary approach a new demonstrator component has been designed, produced and evaluated using state-of-the-art methods and advanced technologies.

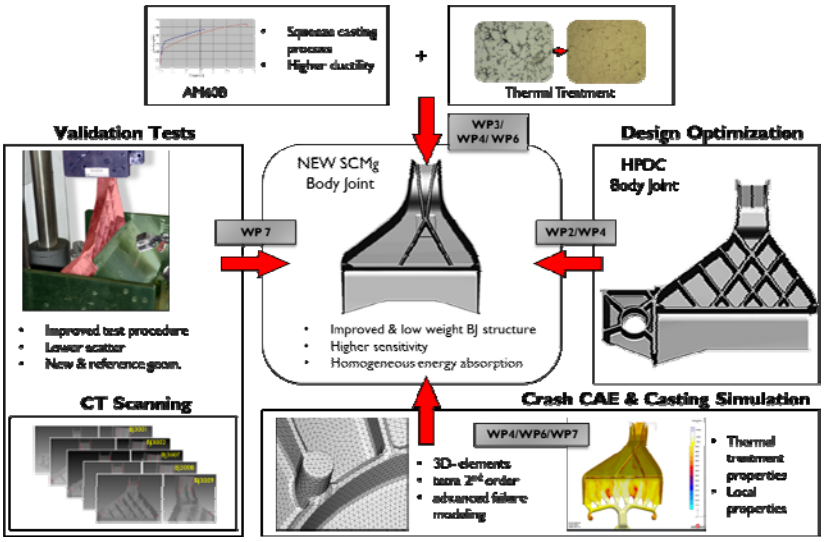


Figure 1: EFEVE project concept for the development of lightweight SCMg components.

The main task done over the new Squeeze casting Magnesium process have been:

1. Define the demonstrator

A new body joint part has been designed using topology optimization tools with similarities to the demonstrator used in NADIA (Previous European project) to compare the results of the new developed process.

For the re-design of the Body Joint the following requirements were set:

- Process feasibility for both SCMg and HPDC production (HPDC is reference process).
- Peak force reduction to reduce passenger body loads.
- Homogeneous energy absorption.
- Increased part symmetry to prevent bifurcation.

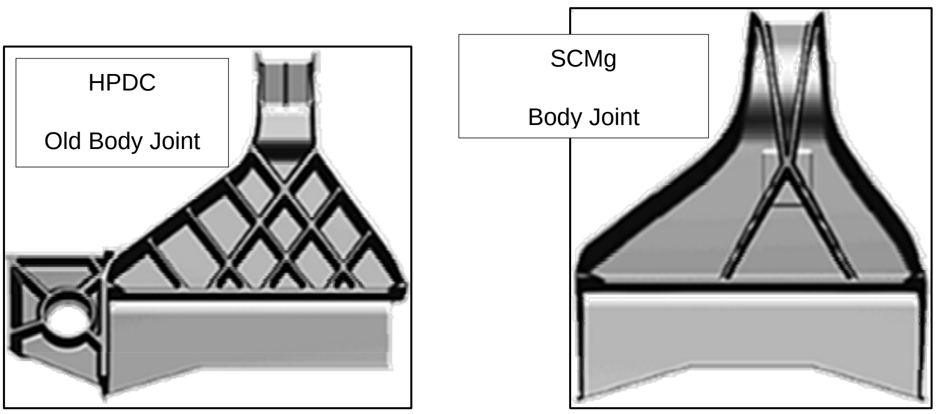


Figure 2: Definition of the new geometry of the Body Joint.

For this a 3-stage re-design process for numerical SCMg Body Joint optimization has been used, as illustrated in the following Figure.

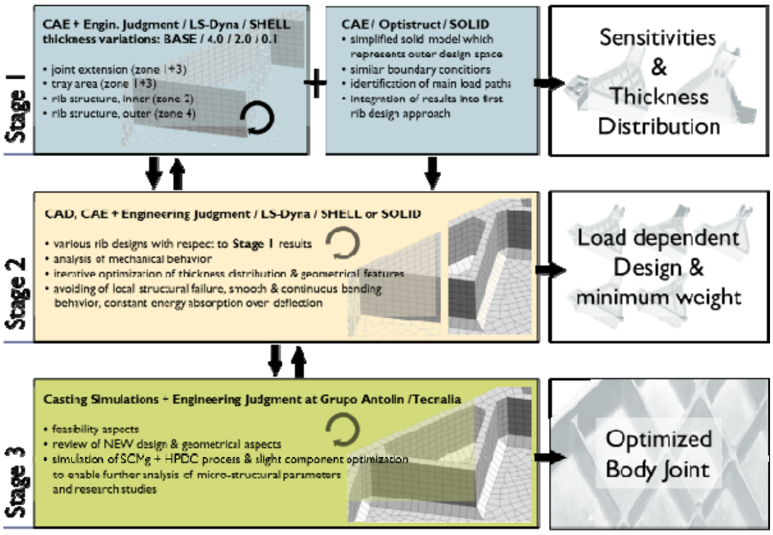


Figure 3: FORD 3-stage re-design process for numerical SCMg Body Joint optimization.

Following a topology optimization of the ribbed structure and resulting CAD-design are shown:

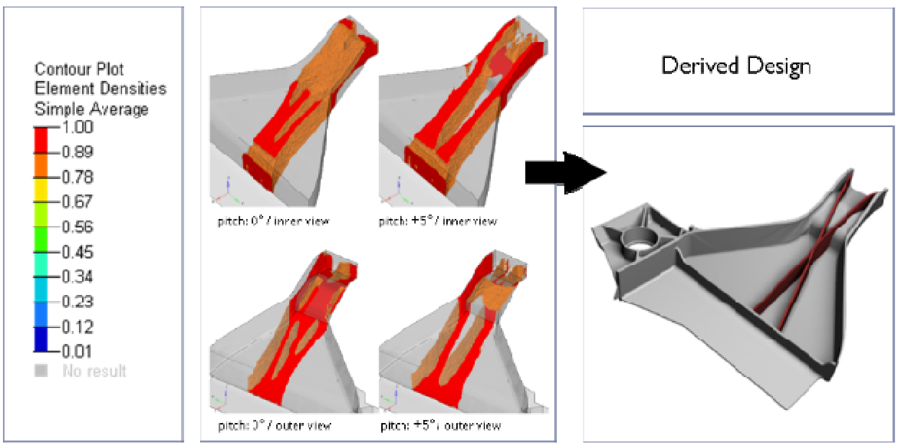


Figure 4: Topology optimization of the ribbed structure and resulting CAD-design.

2. <u>Define the equipment needed for the new process</u>

- Squeeze valve: A valve incorporated at the cellule permits to obtain second injection speeds from 0.5 to 1 m/s.

- Vacuum: The cellule has been equipped with vacuum equipment.

- Controls: Advanced data controllers have been installed in the HPDC cellule in order to control the parameters of the process.

3. Define the die for the demonstrator

New monitoring and intelligent control of cooling and heating temperatures of the die: Die thermal evolution and control has been assessed at industrial trials by controlling with a thermography camera the evolution of die's temperature and its stability. In case any valve is not working properly, an augmentation of local die temperature would have been observed.

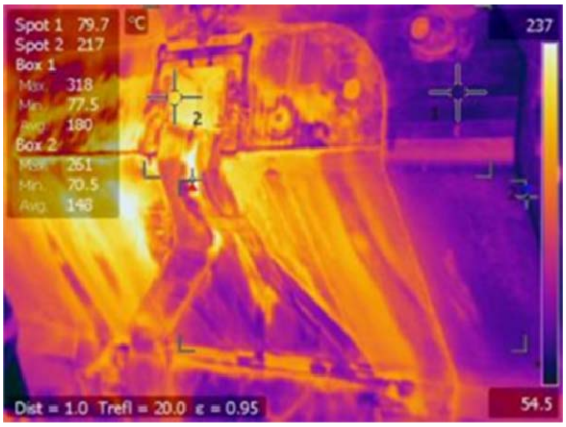


Figure 5: Thermal control of die's temperature with a thermocamera.

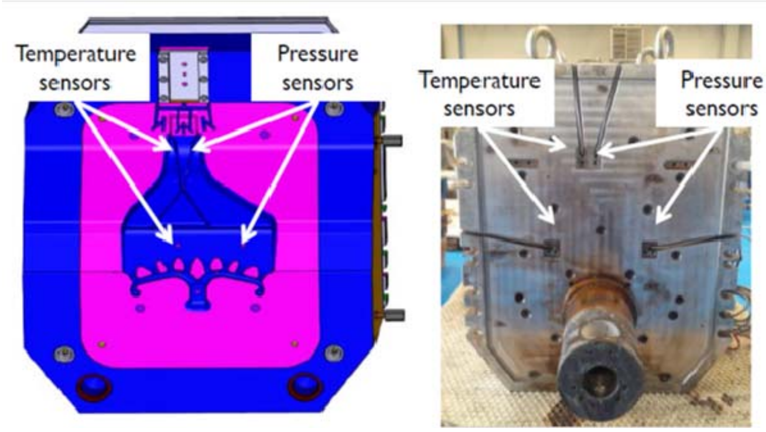


Figure 6: Sensoring of the die with temperature and pressure sensors in contact with molten metal

4. Casting Simulation:

Several simulations have been performed with Magna and Procast with SCMg parameters in order to check if there is a good correlation between simulation and real parts and to improve the design of the die.

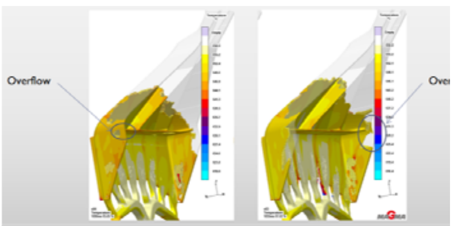


Figure 7: Filling simulation with SCMg parameters. Determination of air entrapments.

Figure 8: Examples of obtained parts with the new overflows

A good correlation has been obtained by adjusting simulation parameters to SCMg process.

5. Define the monitoring equipment.

Construct and install the monitoring Squeeze Casting process equipment. New high speed temperature sensors combined with pressure and contact sensors in direct contact with the injected metal.

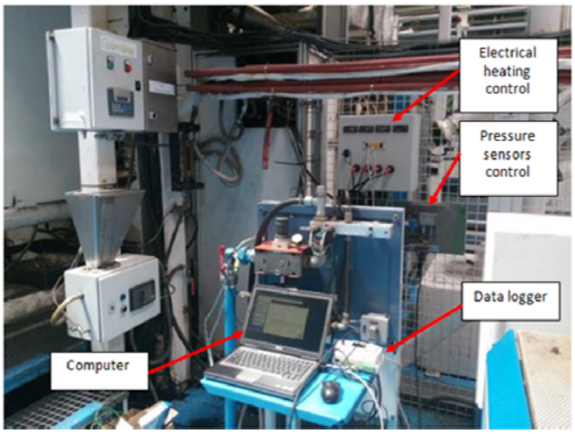


Figure 9: Detail of some of the monitoring and control equipment.

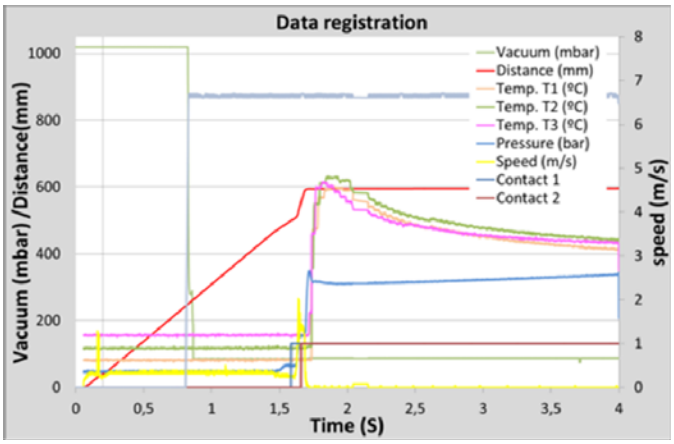


Figure 10: Example of a data registration with advanced sensors

6. Define the key production parameters.

	Mg SQUEEZE CASTING	Mg HPDC
Temperatures (°C)	Ingot at the preheating unit: 215 Mold: 300 Alloy in furnace: 690	Ingot at the preheating unit: 215 Mold: 200-250 Alloy in furnace: 680
Specific pressure (bar)	650 - 1200	< 700
Heating and/or cooling conditions	Oil tempering of die + lubricator	Oil tempering of die + lubricator
Cycle time	57	60
Plunger speed (m/s)	0.5 - 2	≈ 10

	THERMAL TREATMENT
	T4
Temperature (°C)	350-400
Time (h)	4 - 10
Quenching	Air - Water

Figure 11: Key production parameters employed for SCMg process

7. Develop of thermal treatment for Mg Squeeze casted parts.

Taking into account the microstructure evolution analyzed in GAI laboratory, the parameters for the T4 Thermal Treatment were selected. Porosity, hardness and microstructure were assessed as an early evaluation of the treatment success before an overall study was carried out by FORD, as it can be observed below

AVERAGE MICROHARDNESS (HV500g)	
AM60B	49.2
AM60B + T4	53.9
AZ91D	67.3
AZ91D + T6	88.1

Figure 12: Hardness test comparative results

8. Determination of the final mechanical and material properties.

RX analysis:

	HPDC				
	1	2	3	4	5
1	4	3	4	4	4
2	2	2	3	4	4
3					
4					1
5	2	2	2	1	2
6	2	3	3	3	3
7	4	3	3	2	3
8	2	3	3	3	4
9	4	4	3	4	3
10	4	4	4	4	4
11	4	4	4	4	4
12	2	3	3	3	4
13	4	4	3	4	4

HPDC

	HPDC + Vacuum				
	24	25	26	27	28
1	2	3	3	2	3
2			1		
3					
4					
5	2	2	3	3	3
6		2	2		2
7	1	2		1	
8	2	2	2	1	2
9	3		2	3	4
10	3	3	3	2	2
11	3	3	2	4	3
12	2	2	1	2	3
13		1	3	1	3

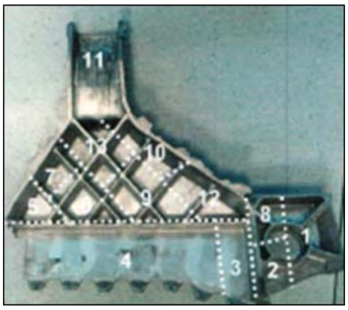
HPDC + Vacuum

	(2,3 m/s)				
	A1	A2	A3	A4	A5
1			1		
2					
3					
4	2		3		
5					
6	2	2	2	3	3
7		2	2	3	3
8	2				
9	3	2	3	4	3
10					
11					
12					
13	2				

Squeeze Casting

	Squeeze Casting 2A (Vacío)					
	P1	P2	P3	P4	P5	P6
1	1	1	1		1	2
2	1	2	2	2	2	1
3						
4	2	1	2		2	1
5						
6	2	1	1	3	2	2
7						
8	3	2	3	3	3	2
9		1		2		
10						
11						
12				1	1	2
13						

SCMg + Vacuum



SCMg benefit
- Porosity almost eliminated
- Enabler for heat treatment

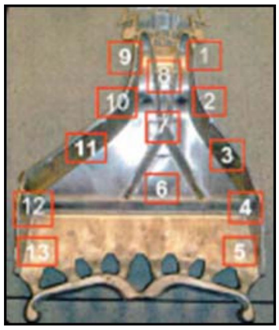


Figure 13: Determination of porosity in the different parts and areas

An unrivalled low porosity (compared to state-of-the-art Vacuum-HPDC) has been obtained with the new process.

Tensile test:

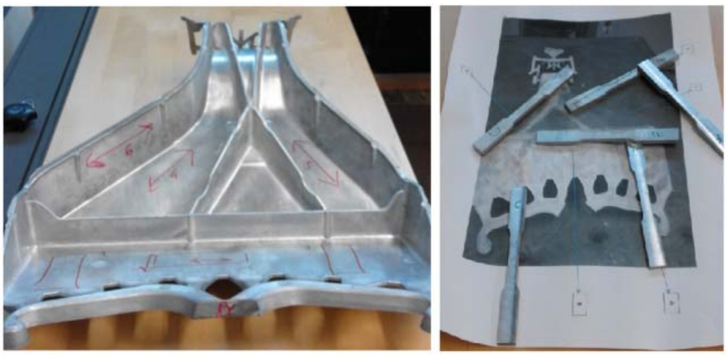


Figure 14: Tensile test bar extraction from SCMg part.

SCMg material without heat treatment shows improved mechanical properties compared to HPDC material. A significant improvement is being introduced by T4 heat treatment of SCMg parts: Elongation to fracture practically is doubled and hardening behavior is improved, enabling more widespread and homogeneous plastic deformation in crash load cases.

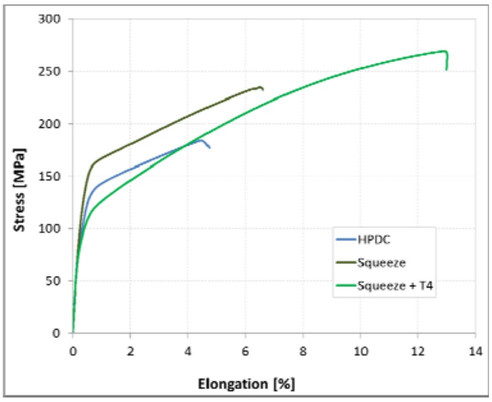


Figure 15: Comparison between obtained properties for HPDC, squeeze and Squeeze + T4 AM60B alloy. Curves obtained by casted test specimens

Penetration tests:

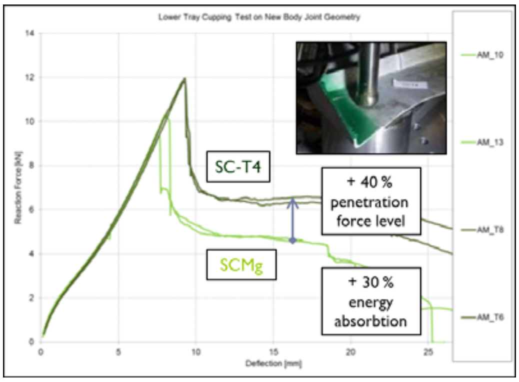


Figure 16: Penetration test results AM60B SC vs. SC-T4 cast part

Penetration test results show a clear advantage for the new SCMg process with T4 thermal treatment, delivering a 40 % increase of the average penetration force level and 30 % improved energy absorption.

Axial (static load) tests:

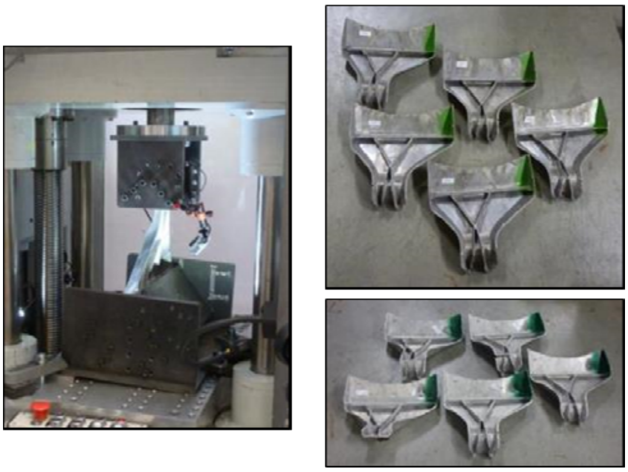


Figure 17: Equipment (left) and samples (AM60 + AM60-T4) of axial tests

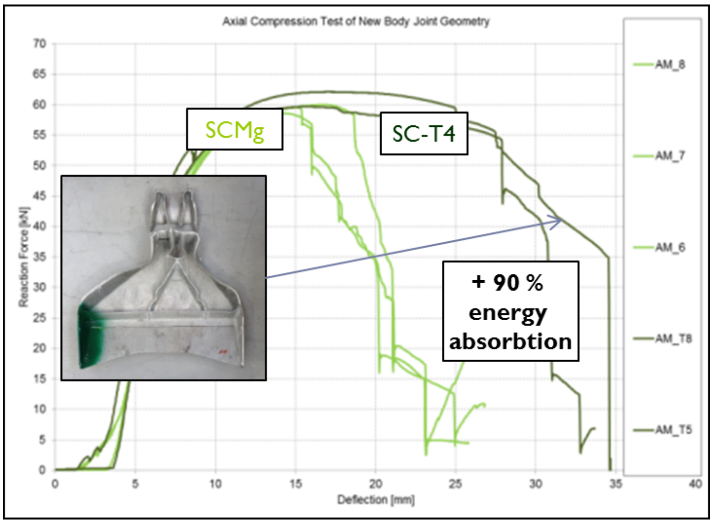


Figure 18: Example of obtained results with a SCMg with and without T4 heat treatment

In the axial tests the new SCMg process with a T4 thermal treatment demonstrated the potential to highly increase the absorption energy (up to 90 %).

9. <u>Improve simulation process to obtain a better accuracy of prediction results.</u>

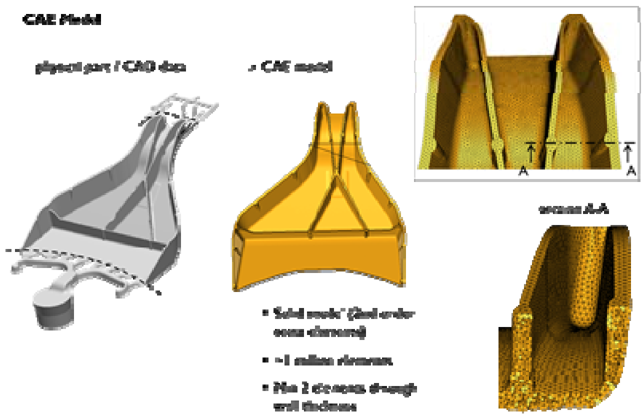


Figure 19: CAE model of final Body Joint demonstrator

To obtain a better accuracy of prediction results for complex shaped cast parts, dominated by inhomogeneous wall thickness distributions and geometrical intersections, a solid element modeling approach has been developed to suit crash simulation requirements. Geometry is captured by a minimum of two 2nd-order elements across the wall thickness, resulting in a model size of 1 Mio elements for typical SCMg components. Advanced numerical methods were applied to ensure acceptable CPU run times in crash simulation. Local properties affecting crash performance (e.g. flow length, porosity) are mapped to the crash simulation model, using casting simulation results.

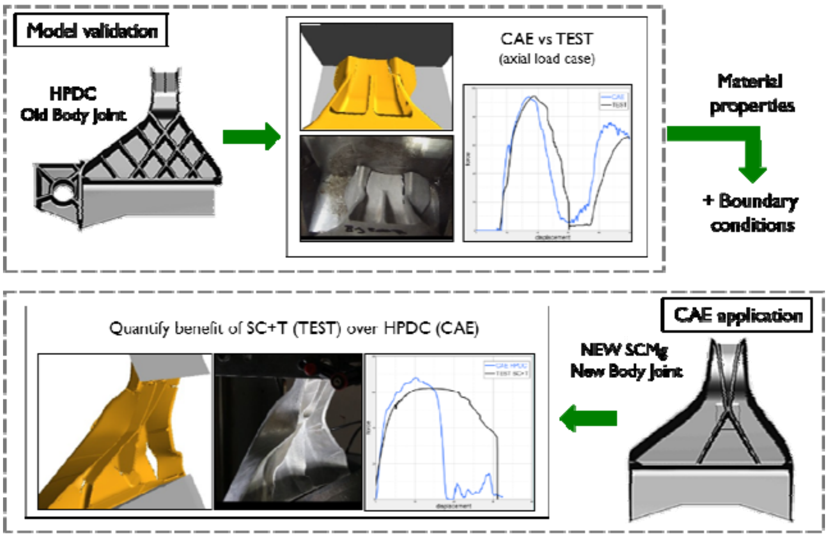


Figure 20: CAE Loop – Validation of material cards & boundary conditions → Simulation of New BJ performance under axial test conditions

The new solid element modeling method was used to accurately model the so-called Old Body Joint, reference geometry for the new SCMg demonstrator component and produced by GAI with AM60B material in the HPDC process. After calibrating HPDC material properties and axial test boundary conditions for the reference part, the behavior of the New Body Joint geometry with HPDC material was simulated to compare with SCMg test results.

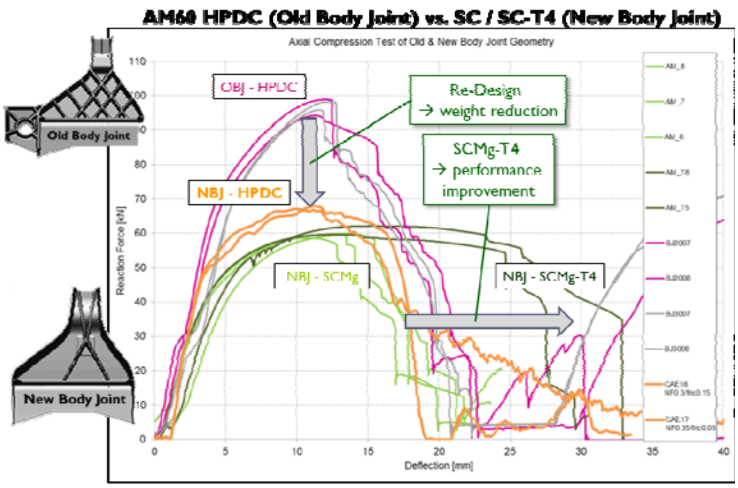


Figure 21: Axial tests – Comparison of Old BJ and New BJ results w/ and w/o heat treatment

As a result of the re-design process the New Body Joint with HPDC material shows lower peak forces, fulfilling the re-design requirements. Comparing the New Body Joint produced by the HPDC process (CAE results) with SCMg parts (test results), there is little difference, similar consistency of results and only slightly lower peak forces of the SCMg parts.

In contrast to that the New Body Joint SCMg-T4 parts show much extended deformation to failure, resulting in very smooth energy absorption (40 – 80 % improvement). Compared to HPDC Old BJ parts, the new SCMg-T4 process and New BJ geometry show lower weight (- 16 %) at comparable energy absorption due to the much extended deformation capability, demonstrating the high potential of the new SCMg-T4 process.

10. Cost estimation:

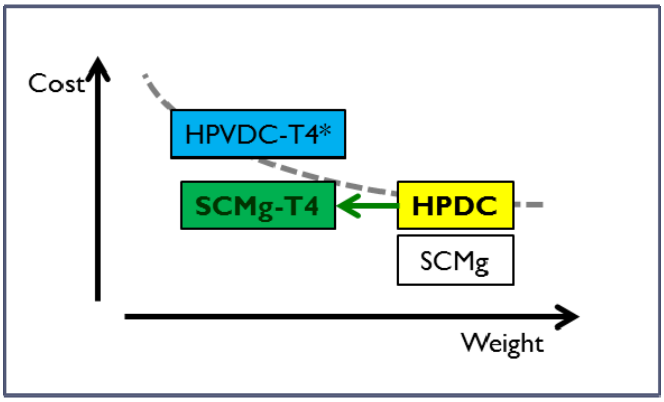
- ✓ Production cell. → *INCREASE*
- ✓ Process control. → *INCREASE*
- ✓ Energy costs. → *INCREASE*
- ✓ Safety requirements. → *SAME*
- ✓ Die life. → *IMPROVED BY 20%*
- ✓ Scrap rate. → *IMPROVED BY 25%*

Cost Estimation			
		High Pressure Die Casting	Squeeze Casting
Material			
Raw Material	Ingots	=	=
Molten Temperature	HPDC 680ºC SQ 690ºC	=	↑
Protective Gases	SO2	=	=
Die			
Manufacture			↑
Tooling Life		↓	↑↑
Process			
Machine	Same machine for both processes	=	=
Yield		=	=
Cycle time		=	=

Figure 22: Cost estimation summary table.

Final economic evaluation	HPDC	Vacuum HPDC + T4	SCMg + T4
Difference (%)	Base	+6%	+ 0,20%

Figure 23: Estimation of economic impact of SCMG with the standard and Vacuum HPDC+T4



*** = hypothetical data, technology not established yet**

Figure 24: Cost-weight potential of the different casting process

- Summary: Determination of real performance indicators of the developed equipment and compare it with the theoretical approach provided at the design and simulation phase (productivity, energy savings, efficiency and quality).

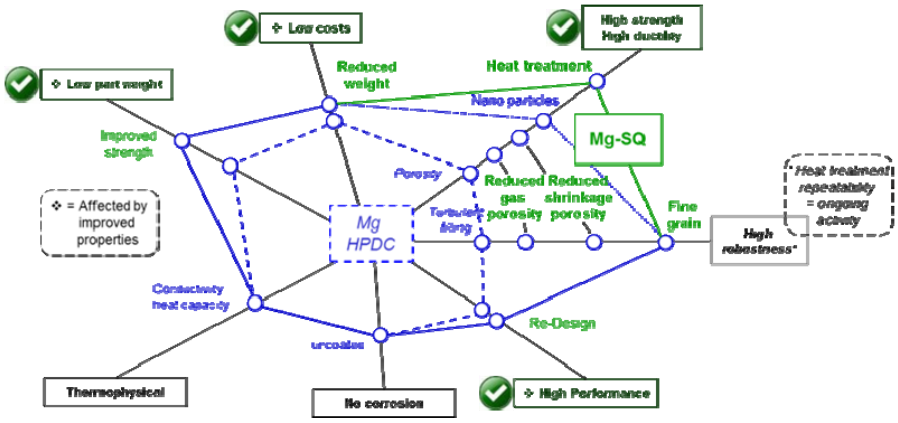


Figure 25: Global comparison of metrics and targets for Mg HPDC vs. the new SCMg process

Comparing the state-of-the-art HPDC process for AM60 material with the new SCMg process with T4 heat treatment, the new SCMg-T4 process successfully has met the expectations and proven the potential to deliver superior results:

- ✓ Unique performance potential (w/ heat treatment)
- ✓ Low weight (CO2, vehicle performance, downsizing)
- ✓ Unrivalled low porosity (even compared to state-of-the-art vacuum HPDC)
- ✓ High strength + high ductility
- ✓ Attractive cost-benefit ratio

Aluminium parts for the automotive and wind power sector produced by low pressure squeeze process (LPSC)

A similar technical concept, to the one for the SCMg technology, has been used for the development and evaluation of the new LPSC technology (Figure 26). In a multidisciplinary approach (but in this case three demonstrator components) have been designed, produced and evaluated using state-of-the-art methods and advanced technologies.

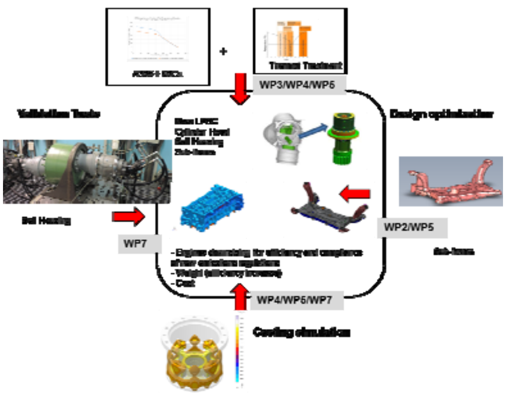


Figure 26: EFEVE project concept for the development of LPSC aluminum based components.

1. Definition of the demonstrators

3 demonstrators have been selected to compare the results of the new developed process.

• Cylinder Head (automotive): Engine Cylinder Heads are facing a critical development point, the always increasing demands for efficiency and the compliance of new emissions regulations are pushing the engine designers towards downsizing components which, in the specific case of Cylinder Heads, result in higher operating temperatures and pressures. These conditions require the current aluminium alloys static and dynamic mechanical properties at room and elevated temperatures to be increased in order for the component not to fail prematurely. New Aluminum based Cylinder Head produced by the innovative LPSC process has been the proposal to achieved new engines requirements. The final demonstrator component selected for material and process development is an aluminium alloy petrol engine Cylinder Head currently cast using the conventional Low Pressure casting process (FORD 2.0L/2.3/2.5L family).

• Bell Housing (wind power): The interest is to investigate the technical and economical improvements that could be achieved with the new LPSC process for aluminium based alloys and to evaluate the application of this technology to the Wind Turbine and in the future to replicate it to the Construction Equipment industry. The final objective is to introduce in this kind of components aluminium instead of the standard cast iron in order to reduce the cost and weight of components so increase the efficiency of the turbine, improve installation and maintenance. Not only the weight but also the machining process times thus consequently the cost. The final demonstrator component selected for process development and performance evaluation has been a cast iron Bell Housing from BONFIGLIOLI's range of existing designs, providing:

- Multi-dimensional part features (thin & thick wall)
- Multiple load cases (bending, pull)
- Mid-size dimensions of part and tool set, allowing efficient production and reduced machining costs
- Straightforward technology transfer to a other wind component cast parts

• Sub-frame (automotive): The EFEVE reference part has been a C-Car Sub-frame. Design space and component requirements provided by FORD, and development of the geometry and of the LPSC process performed by NEMAK. For mass-produced cars the current solution for Sub-frames is steel sheet design. Starting point is the state-of-the-art HPDC process, currently standard process for the production of light metal Sub-frames. The project objective is to overcome the shortcomings of this technology.

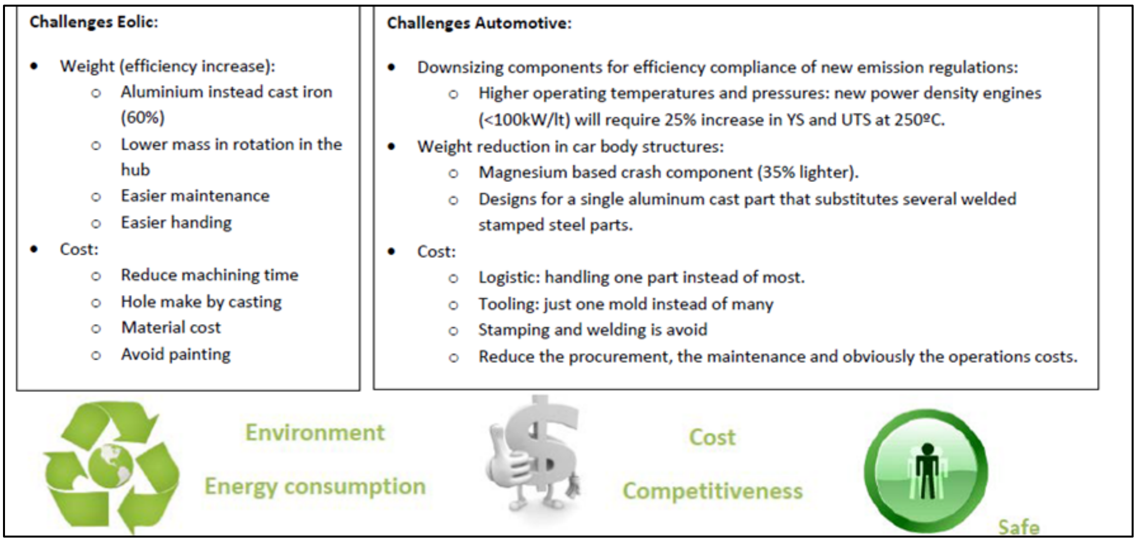


Figure 27: Requirements analysis of the selected three demo components

2. Definition of the equipment needed for the new process

Low pressure squeeze casting (LPSC) is an efficient enhancement of the low pressure casting process. This process combines the advantages of squeeze casting as well as LPDC by adding a squeeze process to the LPDC process. Therefore the mould has to be equipped with a squeeze mechanism, the machine has to be upgraded with a machine to mold connector unit and the squeezing steps have to be integrated into the casting and cooling control software

.

The first stage has been to validate the new process variables and materials defined at lab scale in a pilot level industrial environment (Nemak – Mexico) and to establish if current casting cells can be modified to accommodate the new LPSC process moulds to produce experimental castings and also to verify if the required enhancements in mechanical properties comply with the targets stated in the project. For this purpose, current prototype equipment (GIMA cast machine) located at Nemak's has been adapted to work with an accordingly modified mould. All the required modifications to the casting equipment required to perform the pilot scale industrial trials have been analyzed and become feasible. Process variables, critical characteristics and special considerations have been identified and resolved.

According to engineering concepts– which are based on results and conclusions from trial castings at NEMAK/Mexico – the assembly of the LPSC equipment demonstrator started and finished at FILL. A new casting machine generation has been established with the LOW PRESSUTE CASTER W. This type of machine comprises on the one hand improvements in

- Safety engineering
- Maintenance-friendly machine
- Frequency controlled hydraulics
- New Control system

and on the other hand an extension of the hydraulic system for supporting squeeze casting moulds.

Figure 28: LPSC demonstrator based on a LOW PRESSURE CASTER W by FILL

3. Define the dies for the demonstrator

Three dies has been developed by BRAMBILLA for the demonstration of the LPSC technology. The first mould, an existing Cylidner Mould, has been modified and adjusted according to the needs of the new LPSC process.
Based on this experience and acquired knowledge other two new molds have been developed. A mould for a new Bell Housing desing, and a very complex mould for a new aluminium Sub-frame concept.

4. Casting Simulation:

The simulation has been basic to check the good correlation between simulation and real parts and to improve the designs for the dies.

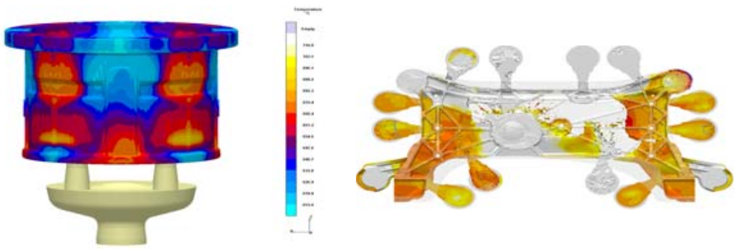


Figure 29: Simulation: geometries, filling and porosity.

The correlation has been obtained by adjusting simulation parameters to LPSC process.

5. Define the key production parameters

Key production parameters have been defined for each one of the demonstrators. For the cylinder head casting parameter technically remained the same with the addition of the squeeze step. For the wind power sector part, baseline casting and processing parameters were established and will require fine tuning for the mass production stage. In the case of the structural component these parameters will be developed in the near future.

6. Develop of thermal treatments for Al SCLP casted parts

Thermal treatment has been selected that presents a good combination of mechanical properties and is economically affordable, as the maintenance periods are not too long. It is based in a solution heat treating, water quenching and artificial ageing. These parameters were optimized according to the component operational conditions, i.e. high temperature stability for cylinder heads, high room temperature resistance for the wind power and structural component applications. There still are room for improvement once the products are tested in real conditions and feedback on the part performance is collected and analyzed.

7. Determination of the final mechanical and physical material properties

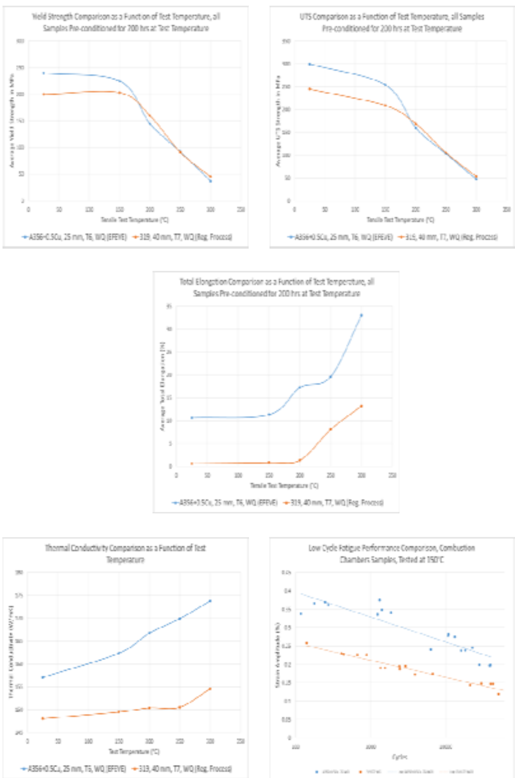


Figure 30: Mechanical and physical properties of LPSC Aluminium material.

Despite the fact that static mechanical properties at elevated temperatures fall at the same levels, the increased elongation (ductility) translates in a better LCF results. This will certainly reflect in a better components performance.

8. Corrosion

It was shown from the corrosion resistance behaviour that the aluminium cast studied has the capabilities of replacing the coated steel components. The alloy shows overall good corrosion behaviour and appear to be able to resist 15 years operative life.

9. Cost estimation:

- ✓ Production cell. → SAME
- ✓ Process control. → SAME
- ✓ Energy costs. → SAME
- ✓ Safety requirements. → SAME
- ✓ Die life. → SAME
- ✓ Scrap rate. → IMPROVED by 15%

- Summary: Determination of real performance indicators of the developed equipment and compare it with the theoretical approach provided at the design and simulation phase.

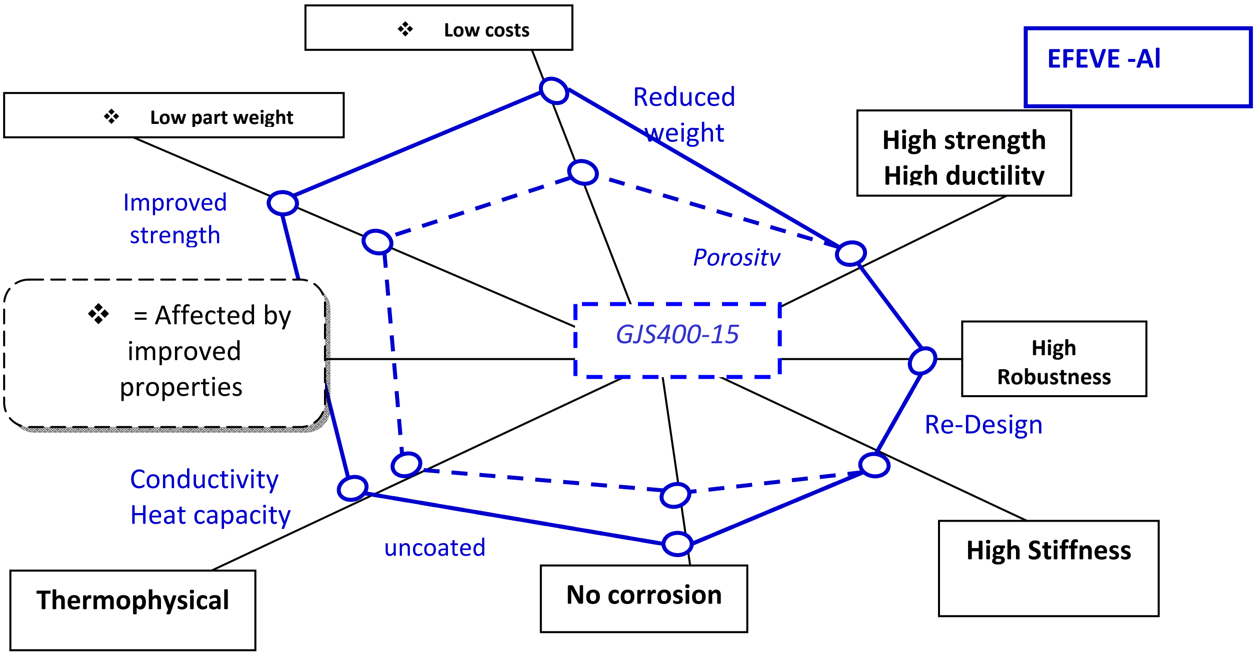


Figure 31: Global comparison of metrics and targets for GJS400 cast vs. the new Al LPSC process.

In the case of the cylinder head, the main characteristics improvement came from the squeeze device utilization. Higher mechanical properties and fatigue life were achieved thanks to the mould improved cooling conditions and the fact that squeezing prolongs the liquid alloy contact with the mould delivering higher solidification rates that translate into better mechanical performance.

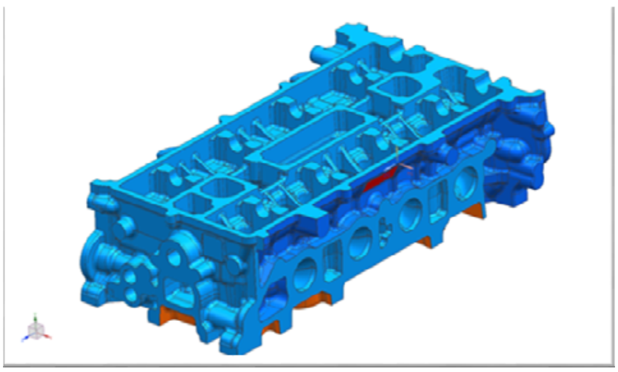


Figure 32: Automotive powertrain Aluminium LPSC demo, Cylinder Head.

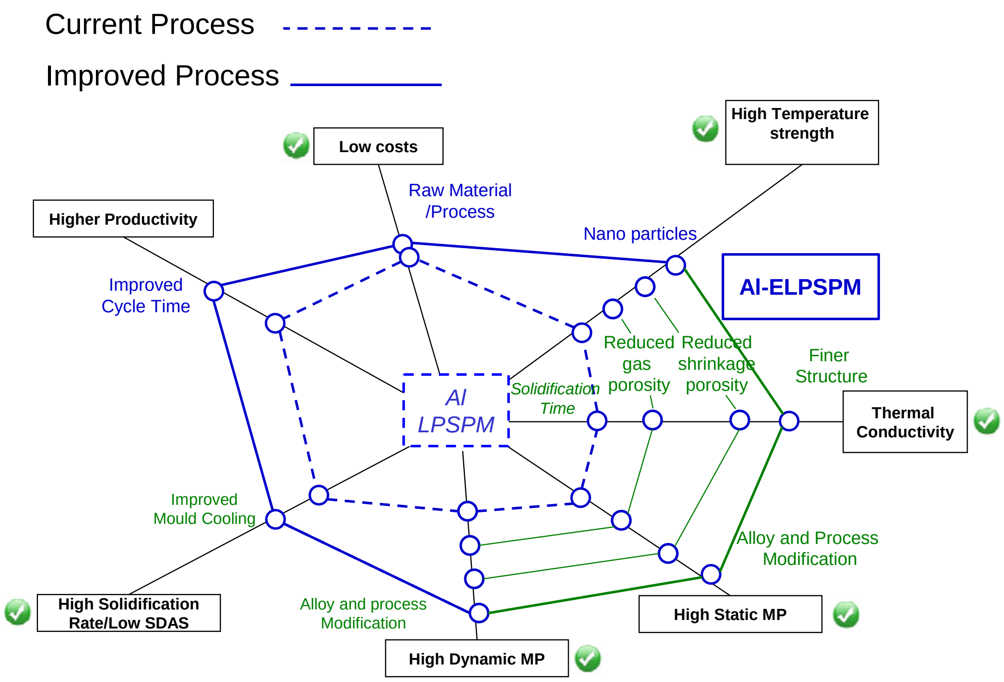


Figure 33: Global comparison of metrics and targets Al LPSPM cast vs. the new enhance LPSC process.

For the structural component, the proposed design was able to withstand the working loads and forces proposed by the OEM. FEA analyses showed that the the proposed aluminium alloy is capable of delivering the performance required with approximately 3 kg less than the original stamped steel design. Process development will continue to produce this parts aiming to validate its compliance in bench tests. The introduction of such a component to the market, using this low cost process and the ability to heat treat the parts to fine tune its properties, will be a major enabler for the weight reduction targets that OEM's are currently pursuing.

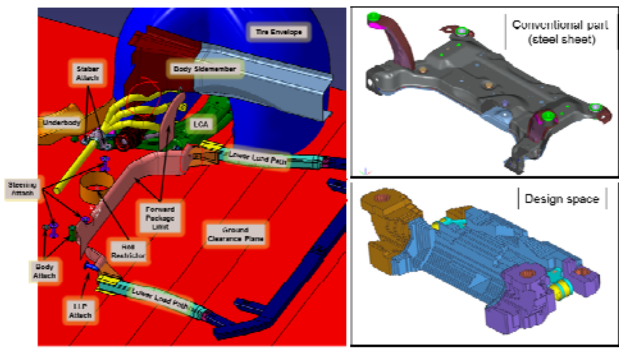
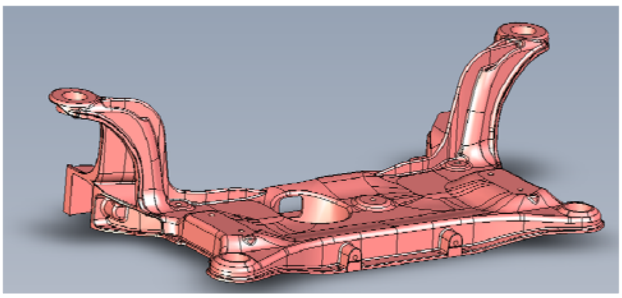


Figure 34: C-Car Fron Sub-frame package Details



Part Basic Information	
Material	AlSi7Cu0.5Mg0.4
Heat Treatment	T6
Volume (mm³)	3,911,639.96
Mass (kg)	10.56

Figure 35: Automotive structural Aluminium LPSC demo, Sub-frame.

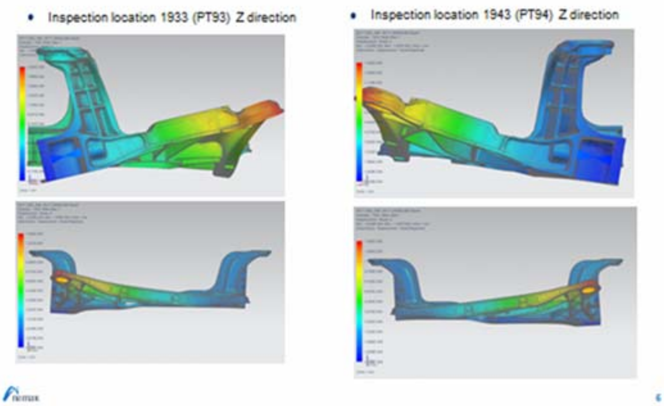


Figure 36: FEA results, Stiffness analysis and optimization

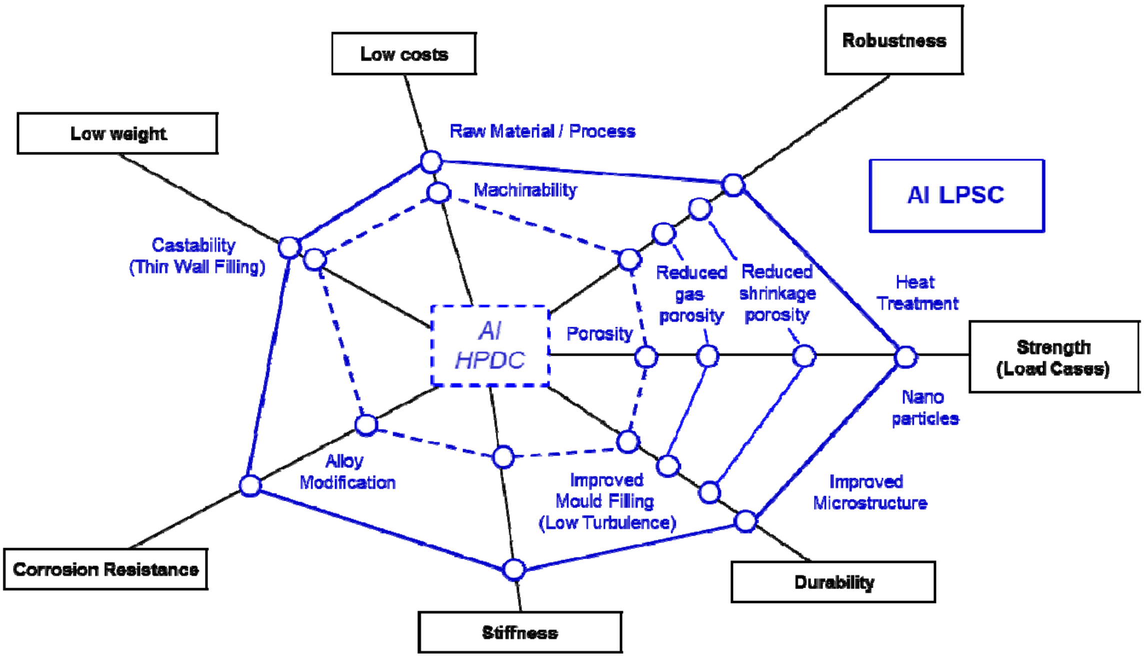


Figure 37: Global comparison of targets for AL HPDC vs. the new Al LPSC process

Life cycle assessment (LCA), life cycle cost (LCC) and thermoeconomic analysis (TA) of the new EFEVE technologies

Two objectives were set regarding the designing and developing of tools and methodology for the optimal development of the Life Cycle studies according to the involved processes. In addition, developing a sound and transparent assessment in terms of environmental impacts, cost effectiveness and energy savings through life cycle studies (LCA and LCC). Moreover, the aim of the TA is to develop global energy and exergy balances, as well as to calculate the TA parameters of all involved processes, comparing the new technology developed in the EFEVE project with conventional technology frequently used for producing similar products.

Finally, all results were integrated and assessed in a holistic optimization to provide diagnosis and advisory feedback. As main outcome, it can be said that a Holistic Life Cycle Approach (HLA) methodology was provided in order analysing the life cycle of the materials involved in the EFEVE project, considering the evaluation of different scenarios of the use phase, recycling and disposal from three different points of view: environmental, exergetic and economic for making decisions.

1. Life Cycle Studies

Regarding the Mg technology, the LCA/LCC results concerning the generic Mg body joint through SCMg revealed that the metal production technology stage has a significant influence on the environmental performance characteristics, in particular, in the CO2 eq. emission indicator. As the Mg production conducts higher environmental implications when compared to the Al (conventional), which is due to the large amounts of raw materials and energy in the beginning of the life of the product. Nevertheless, for the rest of studied environmental indicators (acidification, photochemical oxidation, human toxicity and eutrophication) the SCMg technology has lower impact in the Mg component when compared to the Al base case (conventional HPDC).

Thus, taking advantage on the car weight reduction caused by using a lighter metal, which has serious influence in fuel consumptions and consequently in decreasing the CO2 eq. emissions, the type o technology used for obtaining the Mg alloy is a critical decision to achieve that CO2 eq. emissions can be offset much earlier than the lifetime of the car (assumed as 200 000 km). In fact, if considering an improved Mg production technology with higher energy and material savings and CO2 eq. emission reductions (generated by the use of an alternative cover gas), environmental benefits in terms of CO2 eq. during the whole lifetime of the car are obtained.

2. Thermoeconomic Analysis

In this project, the TA methodology was applied to processes that are not normally assessed with this kind of analysis. it will allow to develop different scenarios for other operating strategies. The conventional approach of this analysis had to be adapted according to the requirements of every process and new application opportunities are been established in the field of TA and energy optimization for further research.

Regarding the generic body joint, the same demonstrator has lower weight when it is made with Mg instead of Al because of the density difference. Therefore, less amount of metal must be melted to obtain one part and less electricity is consumed. The unit exergy cost of the product is mainly generated in the melting furnace and in the squeeze process and it is similar in both processes (Conventional HPDC: 1.3108 vs lab-scale SCMg: 1.3112). In the HPDC, the greatest contribution is due to the melting stage. On the other hand, with Mg alloys, the melting furnace uses electricity instead of natural gas, reducing its unit exergy cost. However, the casting stage contribution is higher in the SCMg process, compensating each other.

Regarding the other demonstrators, every manufacturing process has different exergy yield, irreversibility and TA parameters because the mould injected is different. Depending on its shape, every demonstrator needs to be manufactured in a mould with different gating system and number of cores. Its final weight is different, as well as the amount of metal molten for producing one part, complicating the comparison between them. In both modes, the same energy consumptions per kg melted or injected are considered in the holding furnace and in the injection machine. Applying the new technique, the final product has been improved and the process does not have greater resources consumption. Even though from a strict TA viewpoint, the new methodology is similar as the conventional one, important improvements are expected to be achieved during the use stage, and therefore, results are favorable so far.

3. Holistic Optimization

The holistic optimization is based on three different pillars: Holistic Life Cycle Approach (HLA), the ELCA, and economic evaluation.

In this light, under the HLA methodology proposed, CIRCE has provided several loop-closed system solutions considering various scenarios of beginning of life and end-of-life with minimum environmental-economical impacts in the whole life cycle of the product. Similar LCA results were obtained for the Al automotive components (Cylinder Head and Car sub-frame) manufactured through the LPSC technology. This is, the improvement of the conventional Al cast process technology (hybrid LPSC machine) allows manufacturing lighter cars generating fuel savings and consequently CO2 eq. emissions. Regarding the wind turbine component, similar advantages from environmental/economical point of view were also obtained. Results show that the amount of kilometres that should be driven to compensate the additional exergy consumed during the manufacturing process depends on the car's characteristics, the amount of Al replaced and the efficiency of the manufacturing processes. In the most optimistic situation analysed, the car only needs to move about 45000 km to compensate the manufacturing process inefficiencies. On the other hand, the most pessimistic result indicates that the lifetime of the car is not enough for compensating the initial exergy consumption.

The exergy approach of this section was constituted by an Exergy Life Cycle Assessment. This section quantifies the amount of exergy required to obtain components of a car when they are made of Al or Mg through the HPDC and SCMg processes respectively, from ore to the final product. Furthermore, during the use stage of these parts, it is compared the exergy savings if Mg is used instead of Al because of the weight reduction in the car structure. Results of this study show that Mg components frequently require more exergy to be manufactured than Al components. However due to the density difference, a car weights less if its structure is made of Mg instead of Al and therefore, exergy savings are obtaining during the use stage. The additional exergy consumed during the manufacturing stage could be compensated during the use stage, and that is the target of this study.

Regarding the last pillar of this holistic diagnosis, the economic assessment developed in this document was divided into two different parts: On the one hand, the generic body joint production was analysed when it is manufactured with Al (HPDC process) and with Mg (SCMg). On the other hand, the other three demonstrators were analysed when they are made with the LPSC technology.

Regarding the generic body joint, one kilogram of Mg is more expensive than one kg of Al, but because of their density, a Mg component is lighter than the same component if it is made of Al. Considering the weight reduction in the car and the fuel savings as a consequence of this replacement, the Net Present Value, the Internal Rate of Return and the Pay-back period were calculated based on the fuel prices in different European countries. Results indicate that according to all these economic criteria, the investment is very profitable.

On the other hand, similar methodology was applied in the other three demonstrators. The investment incurred to manufacture the automotive components, considering that the traditional material used in those structures is steel, was compared to the savings obtaining due to the car weight reduction. It was considered that the weight of these Al parts is 50 % lower and their costs are 60-80 % greater than the same structures made with steel. The same economic parameters as before were calculated and all of them indicate that the investment is recommended.

The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

1.- Introduction

We strongly believe that the output of this project will have a huge impact on the markets were the developed products will be utilized. In the case of the automotive industry the gains on weight reduction and mechanical properties improvements, translated into better part performance will get us a step closer to a full aluminium/magnesium vehicle that will allow CO2 emissions and efficiency targets. The wind power sector will also benefit from the low weight and high structural stability of aluminium alloys, making the manufacture and maintenance operations of these components easier and at a fraction of the cost.

EFEVE project has developed applications in two main operational areas: Magnesium Squeeze Casting and Aluminium Low Pressure Die Casting. Derived from those two areas, some applications have been identified; some of them are single stand-alone applications. The EFEVE project provides two essential application building blocks or business areas that can significantly improve casting applications on Magnesium or Aluminium and enable new services for foundry market (Figure 38). Additionally, other services related to both new technologies could represent offerings in the form of consultancy or R&D services for target markets. Three offerings will be used in this first iteration:

1. Magnesium Squeeze Casting process
2. Aluminium Low Pressure Squeeze Casting process
3. Other services: Nano-reinforced alloys (in magnesium and aluminium); Nano-reinforced sand cores, etc.

The idea is depicted in the figure below (Figure 38).

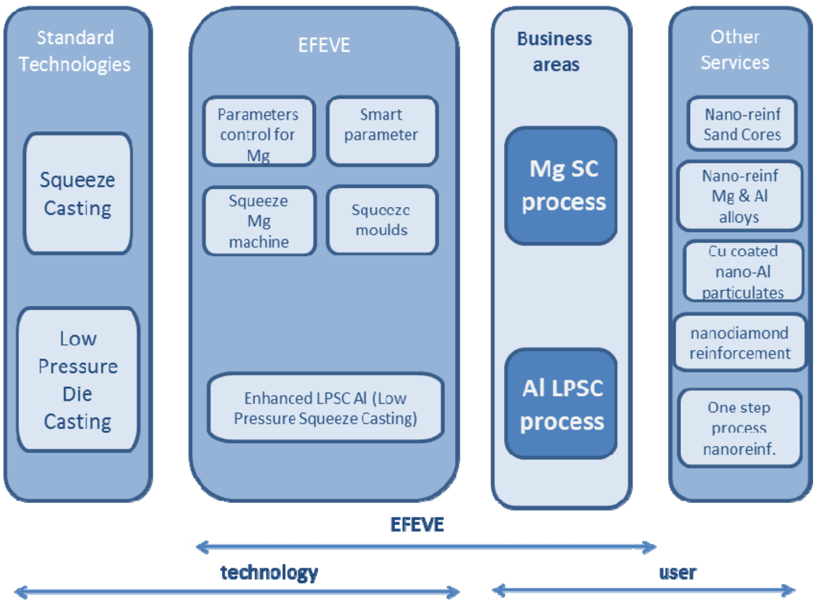


Figure 38: EFEVE Business applications

On the far left are the basic, state of the art technologies that are widely available and that are reused within the EFEVE project. The second rectangle depicts the EFEVE's main results in both areas, Aluminium and Magnesium. On the far right in Figure 38, the main business areas that can be supported by casting manufacturers or nanotechnology providers are detailed.

2.- Main dissemination activities

A focused dissemination strategy has been implemented in order to ensure effective collaboration both within the project and with communities external to it, as well as to raise awareness of the project objectives and achievements, so as to maximise its impact and encourage acceptance of EFEVE results by the targeted stakeholders.

In more detail, the objectives of the dissemination have been:

- To raise public awareness about the project, its expected results and progress within defined target groups using effective communication means and tools;
- To exchange experience with projects and groups working in the domain of casting processes and lightweight materials and components in order to join efforts, minimize duplication and maximize potential;
- To significantly influence foundry customers belonging to the key industrial sectors involved into the project (Automotive and Wind Power Generation) and to all other industrial sectors demanding similar parts, assets and components;
- To disseminate the fundamental knowledge, the methodologies and technologies developed during the project;
- To pave the way for a successful commercial and non-commercial exploitation of the project outcomes.

The project dissemination activities have included: participation to conferences and trade shows, workshops, scientific papers, articles, posters, and the creation of the project logo and the project website in order to reach the largest number of professionals and lay audience, to outline the project aims and to enhance public awareness of EFEVE progress.

In general, dissemination events and activities organised by or to which the EFEVE team has taken part can be divided into the following categories:

- Scientific and EC conferences in the field of new production technologies, materials, and nanotechnology
- Trade shows and events related to the foundry, automotive and wind power sectors
- Workshops aimed at reaching relevant stakeholders and decision makers.

A selection of the most relevant dissemination activities made is reported below, divided in the aforementioned categories.

<u>2.1 Scientific and EC conferences in the field of new production technologies, materials, and nanotechnology</u>

EFEVE progress and results achieved in the definition and the development of manufacturing technologies for light alloys with nano element have been presented at scientific conferences such as:

- *11th International Conference Advanced Carbon Nanostructures 2013 – ACNS' 2013* (Saint-Petersburg - Russian Federation, July 01-05, 2013)
- *16th European Conference on Composite Materials – ECCM16* (Sevilla - Spain, June 22-26, 2014);
- *VIII International Conference on Mechanochemistry and Mechanical Alloying – INCOME* 2014 (Krakow - Poland, June 22-26, 2014)
- *XII International Conference on Nanostructured Materials - NANO 2014* (Moscow - Russian Federation, July 13-18, 2014)
- *15th Trends in Nanotechnology International Conference – TNT2014* (Barcelona - Spain, October 27-31, 2014)
- *12th International Conference Advanced Carbon NanoStructures - ACNS' 2015 (*Saint-Petersburg - Russian Federation*, June 29 – July 07, 2015)*
- *XI Congreso Nacional de materiales compuestos - MATCOMP 2015* (Mostoles - Spain, July 06-08, 2015)
- *Third International Conference on Advanced Complex Inorganic Nanomaterials* - ACIN 2015 (Namur - Belgium, July 13-17, 2015)
- *16th Trends in Nanotechnology International Conference – TNT2015* (Toulouse - France, September 07-11, 2015)
- *European Congress and Exhibition on Advanced Materials and Processes - EUROMAT 2015* (Warsaw - Poland, September 20-24, 2015)
- *72nd World Foundry Congress – WFC 2016* (Nagoya - Japan, May 21-25, 2016).

The results of the investigation on the environmental performance of the generic body-joint (*automotive component*) manufactured using magnesium alloy have been presented at the *10th Conference on Sustainable Development of Energy, Water and Environment Systems - SDEWES 2015* (Dubrovnik – Croatia, September 27 – October 2, 2015) instead.

EFEVE project has been presented also at several events organized or supported by the European Commission with the aim of bringing together nanotechnologies and advanced materials community, as well as relevant actors from manufacturing and process industry and technology domains from all over Europe, in order to identify priorities and strategies crucial to strengthen the European industrial innovation ecosystem. The main events attended have been:

- *Euronanoforum 2013* (Dublin - Ireland, June 18-20, 2013)
- *NanotechItaly 2013* (Venice - Italy, November 27-29, 2013)
- *Industrial Technologies 2014* (Athens - Greece, April 9-11, 2014)
- *Let's Conference* (Bologna - Italy, September 29 - October 1, 2014)
- *NanotechItaly 2014* (Venice - Italy, November 26-28, 2015)
- *Euronanoforum 2015* (Riga - Latvia, June 10-12, 2015)
- *NanotechItaly 2015* (Bologna - Italy, November 25-27, 2015)
- *Industrial Technologies 2016* (Amsterdam - Netherlands, June 22-24, 2016).

Figure 39 – a) EFEVE project poster at Industrial Technologies Conference 2014 (Athens, 09-11/04/2014); b) EFEVE project poster awarded during the Gala dinner of the same conference; c) EFEVE project poster at EuroNanoForum 2015 conference (Riga, 10-12/06/2015)

2.2 Trade shows and events related to the foundry, automotive and wind power sectors

In order to reach foundry customers and relevant actors belonging to automotive and wind power generation sectors, as well as all other industrial sectors demanding similar parts, assets and components, EEVE project activities and progress have been presented also at relevant trade shows and events such as:

- *71th World Foundry Congress* (Bilbao - Spain, May 19-24, 2014)
- *WindEnergy exhibition* (Hamburg - Germany, September 23-26, 2014)
- *Automotive CAE Grand Challenge 2015* (Hanau - Germany, March 31 - April 01, 2015)
- *GIFA Trade Fair* (Dusseldorf - Germany, June 16-20, 2015)

The participation of the project partners to these events has been intended as a way to promote EFEVE results in a strongly industrial and not only scientific domain, in order to further the exploitation potential, having indeed had an impact on possible interest.

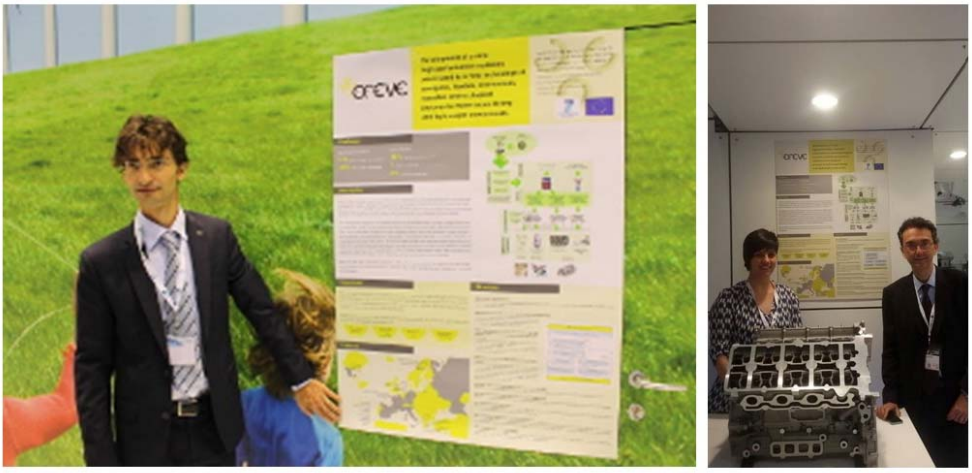


Figure 40 – a) EFEVE poster displayed at Bonfiglioli Riduttori booth during the WindEnergy exhibition 2014 (Hamburg, 23-26/09/2014); b) EFEVE poster displayed at Modelleria Brambilla booth during the GIFA trade fair 2015 (Dusseldorf, 16-20/06/2015)

2.3 Workshops aimed at reaching relevant stakeholders and decision makers

EFEVE Project has been presented also on the occasion of several workshops aimed both at creating synergies among various EC funded projects in order to capitalize on the respective results achieved, and at informing policy makers about the project contribution towards expected EC sustainable production targets. During these events, the main project achievements and results have been presented, and further themes to be investigated in order to take the best advantages from the work done have been proposed and discussed.

Among these events, it is worth to mention:

- *Impact Workshops for the Factories of the Future Public-Private Partnership Projects* (Brussels - Belgium, editions: 2013, 2014, 2015, 2016)
- *"Bringing Nanotechnology Research into the European Production Industry" Workshop at LET's conference* (Bologna - Italy, October 1, 2014), organized in collaboration with PLAST4FUTURE and FLEXICAST FP7 projects.
- *EFEVE workshop at GIFA Fair* (Dusseldorf - Germany, June 16, 2015)
- *Bienal Española de Máquina Herramienta - BEMH* (Bilbao - Spain, June 2, 2016), organized in collaboration with TOP-REF (FP7), NIWE (FP7), TASIO (H2020) and Indus3es (H2020) projects
- *ERTRAC-EUCAR Innovation Demonstration Day* (Brussels - Belgium, June 14, 2016).

Figure 41 – a &b) EFEVE project at 71st World Foundry Congress (Bilbao, 19-24/05/2014); c) EFEVE workshop at GIFA Fair 2015 (Dusseldorf, 16-20/06/2015)

3 Main dissemination material

3.1 EFEVE project logo

EFEVE project logo has been created in order to assure to the project an attractive visual identity, and to foster its immediate observer recognition. The adopted graphics and the colours have been intended to communicate the main concept of the project: from the

Figure 42 – EFEVE project logo

title in black representing the industrial sector, to the three green icons representing both the three sectors initially involved into the project, and the new eco process that will be developed under it.

3.2 EFEVE project website and social profiles

To ensure maximum visibility to EFEVE objectives and results, it has been set up a project website registered in the “eu” domain and with an intuitive URL to increase hit rates: http://www.efeve.eu/. The public website has several sections devoted to illustrate the project contents, the partners and the main dissemination activities done to external visitors, as well as a link allowing accessing the collaborative space used for partnership internal communication and project management.

A Facebook page (https://www.facebook.com/Efeveproject) and a LinkedIn group (https://www.linkedin.com/groups/8210803/profile) have been published, maintained and restyled periodically to increase the attraction effect.

3.3 EFEVE poster and leaflet

Several versions of project poster and leaflet, highlighting EFEVE results gradually achieved, have been prepared, displayed and/or distributed both at partner premises and in occasion of conferences and events. All the versions have been made available on the project website.

Figure 43 – EFEVE project posters

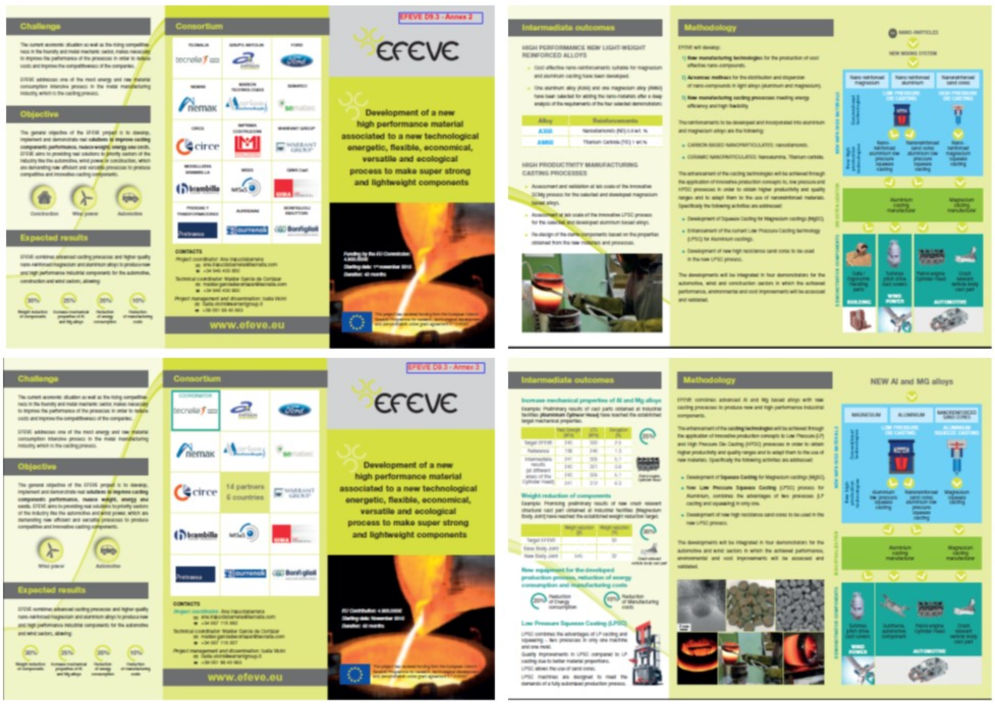


Figure 44 – EFEVE project leaflets

4.- Key exploitable results

The key exploitable results that have been selected for providing a general overview of their key advantages are described as follows:

Enhanced LPSC Al (Low Pressure Squeeze Casting)

Current low pressure casting process produce parts with low mechanical properties at critical areas when compared with gravity processes. The new process LPSC in aluminium aims to reduce/eliminate this disadvantage. When combined with the benefits of non-turbulent filling this process could be preferred to produce high output/performance cylinder heads and chassis parts for the automotive industry. If the enhanced low pressure casting process can combine the benefits of low pressure counter gravity quiescent filling with high casting integrity only obtained (today) by gravity fast solidification processes, could represent a new alternative to comply with new engine and chassis design performance standards. If the result is positive, this new process could be the preferred process to produce high output Diesel and Petrol cylinder heads in a market of approximately 40 Million engines worldwide.

The main sectors that can take advantage of its marketing uptake are: the automotive and the wind power sectors. Both market segments could be addressed: windmills' and cars' parts manufacturers and OEMs. The potential impact of this new process could range from 3% to 4% of the global market in the aluminium casting industry for the automotive sector and as for the wind sector could range from 0.5% to 1% in the short term.

Squeeze Mg machine, Squeeze moulds and Mg Sq Cast process

The New Squeeze Casting Process will be technically competitive due to the better mechanical properties obtained in the injected parts and the possibility of customizing the final properties of injected parts by specific thermal treatments. It also permits to apply welding techniques, in order to obtain complex parts / multi-material parts. It increases robustness of Magnesium casting technologies by means of laminar filling. It represents a unique method to obtain high quality aluminium and magnesium parts wieldable.

The main sector that can take advantage of its marketing uptake is the automotive sector, for both market segments: cars' parts manufacturers and OEMs. The potential impact of this new process could range from 3% to 4% of the global market in the magnesium casting industry for the automotive sector.

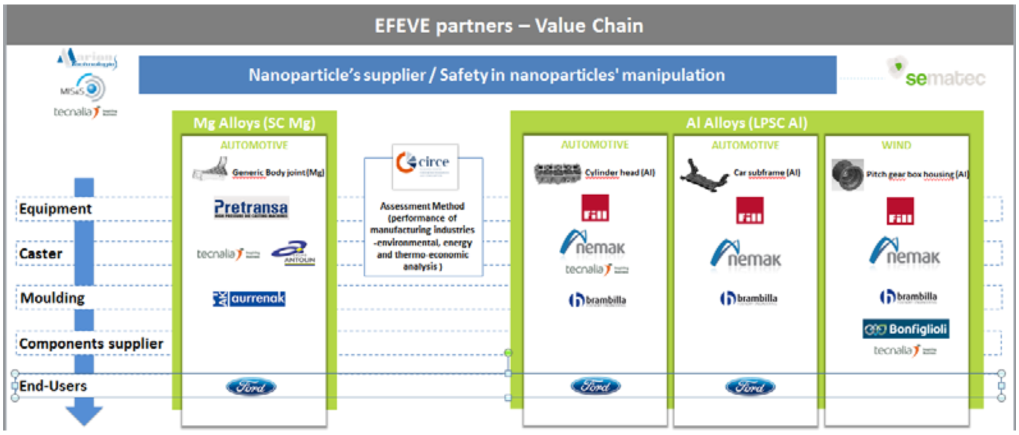
It is also clear that cooperation between companies, interdisciplinary teams dedicated to a common goal deliver outstanding results that at the end translates to a better life quality for all of us. This type of collaboration needs to continue to be promoted by governments worldwide to unleash the full potential of the scientific and technical community in the pursue of a better world.

5.- The address of the project public website and relevant contact details

EFEVE project website: http://www.efeve.eu/

EFEVE Consortium and relevant contact details

No.	Beneficiary Name	Country	Website	Contact
1	FUNDACION TECNALIA RESEARCH & INNOVATION	Spain	http://www.tecnalia.com/	Mrs Ane Irazustabarrena
2	GRUPO ANTOLIN-INGENIERIA SA	Spain	http://www.grupoantolin.com/	Mr Diego Val Andrés
3	FORD-WERKE GMBH	Germany	http://www.ford.com/	Mr Ulrich Weiss
4	NEMAK SA	Mexico	http://www.nemak.com/	Dr. Jose Talamantes
5	MARION TECHNOLOGIES S.A.	France	http://www.mariontechnologies.com/	Mr. Joseph Antoine Sarrias
6	SEMATEC SERVICIOS MEDIOAMBIENTALES Y TECNICOS SA	Spain	http://www.sematec.es/	Mr. Paul Minguez
7	FUNDACION CIRCE	Spain	http://www.fcirce.es/	Mr Andres LLombart
8	IMPRIMA COSTRUZIONI SRL	Italy	http://imprimacontrolling.com/	n.a. *(Participation ended)*
9	WARRANT GROUP S.R.L.	Italy	http://www.warrantgroup.eu/	Mrs Isella Vicini
10	MODELLERIA BRAMBILLA	Italy	http://brambilla.it/	Mr Gabriele Bonfiglioli
11	NAT. UNIV. OF SCIENCE AND TECH. "MISIS"	Russia	http://en.misis.ru/	Mr. Vladimir Popov
12	GIMA CAST GMBH	Germany	n.a.	n.a. *(Participation ended)*
13	PRENSAS Y TRANSFORMACIONES SA	Spain	n.a.	n.a. *(Participation ended)*
14	AURRENAK S COOP	Spain	http://www.aurrenak.com/en/	Mr Ignacio Mtnez. de la Pera
15	BONFIGLIOLI RIDUTTORI SPA	Italy	http://www.bonfiglioli.com/en/	Mr Andrea Torcelli
16	PRETRANSA DIECASTING S.L	Spain	http://www.pretransadiecasting.com/en/	Mr Verland Pacheco
17	FILL GESELLSCHAFT MBH	Austria	http://www.fill.co.at/	Mr Harald Sehrschön


EFEVE partners – Value Chain
Nanoparticle's supplier / Safety in nanoparticles' manipulation
Mg Alloys (SC Mg)
Al Alloys (LPSC Al)
AUTOMOTIVE
WIND
Generic Body joint (Mg)
Cylinder head (Al)
Car subframe (Al)
Pitch gear box housing (Al)
Assessment Method (performance of manufacturing industries -environmental, energy and thermo-economic analysis)
Equipment
Caster
Moulding
Components supplier
End-Users