SUPREME

NEWSLETTER

December 2020 | Issue Six

Foreword by Coordinator

The previous letter was published in March 2020 at the beginning of the coronavirus crisis in Europe. All project partners have obviously been impacted, some of them with significant phases of short time working since then. At our request, the European Commission agreed to extend the project by 4 months. The final date has therefore been postponed from the end of July to the end of December 2020. Thanks to this, the project could reach the majority of its initial objectives.

Like many of you, we held our plenary and technical meetings virtually and did not have the pleasure of meeting over a drink or a good meal. The T0+30 Review meeting that was to take place at TECNALIA in San Sebastian was replaced by a conference-call on March 17-18th. The T0+33 Executive Board meeting was held on May 28th and the T0+36 Review meeting on July 23rd. We were looking forward to the final meeting at GKN in Germany, but once again, the virus decided otherwise; the meeting was finally held virtually on November 24-25th.

In the last eight months, among the results obtained, we can highlight the following:

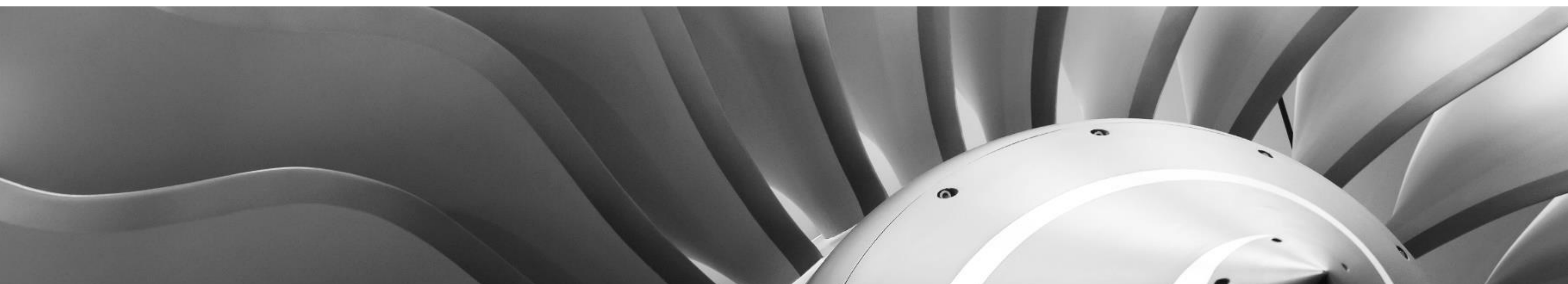
i. All the expected use-cases have been produced;
ii. Most of the objectives regarding Raw Material, Energy, Production rate and CO_2 emissions have been reached;
iii. ASL and IRIS have installed and tested successfully a monitoring system on two gas atomizers, one being equipped with a new induction heated tundish. Gas and energy consumption were measured during several atomization runs;
iv. GKN and IRIS have installed additional monitoring systems on two EOS L-PBF machines; successful test runs were performed by GKN. Printing of AM engine brackets while monitoring the gas and energy consumptions have been done successfully and KPIs calculated.
v. The SUPREME results were disseminated at the EPMA General Assembly (Apr 20), Euro PM2020 (Oct 20) and FORMNEXT2020 (Nov 20) conferences. Seven oral presentations were given at Euro PM2020 conference and eight papers have been published in the Proceedings. One talk was given at FORMNEXT2020.
vi. Four additional papers have been (or will be) published: one relative to Optimizing control for a mineral grinding circuit; one relative to Hot Isostatically Pressed Inconel 625; two on Plasma Metal Deposition of Hastelloy and 316L.

In this sixth edition of the SUPREME newsletter, EPMA inform you about the SUPREME Experts Workshop that was organized on November 26th and the results of the survey on sustainability indicators to be used in Powder Metallurgy. Demonstrators' results are described by OUTOTEC (mineral concentration step), ASL (powder production step) and GKN (L-PBF production step). Use-case production and test results are presented by DELLAS (Cutting tools), WeAre ADDITIVE (Aeronautics), MBA (Medical), IPC (Mold inserts), CRF (automotive) and TWI (Marine). Finally, the detailed presentation of the consortium continues, and ends, with EPMA.

As this is the last letter of the project, I congratulate all the project partners for the good climate of collaboration and the results achieved. I hope that we will be led to work together again in the future.

Enjoy your reading!

Dr Thierry BAFFIE
SUPREME Project Coordinator



Introduction

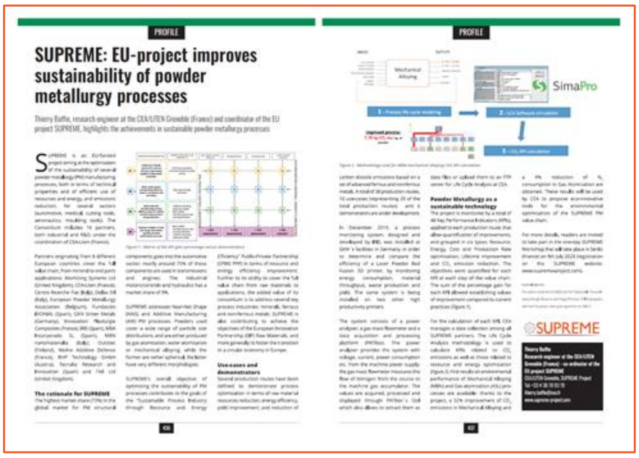
SUPREME aims at optimising powder metallurgy processes throughout the supply chain. It is focused on a combination of fast-growing industrial production routes and advanced ferrous and non-ferrous metals. By offering more integrated, flexible and sustainable processes for powder manufacturing and metallic parts fabrication, SUPREME enables the reduction of the raw material resources (minerals, metal powder, gas and water) losses while improving energy efficiency and thus carbon dioxide emissions, into sustainable processes and towards a circular economy. To achieve this goal an ambitious cross sectorial integration and optimisation between several powder metallurgy processes has been designed, concerning gas and water atomisation as well as ball milling for metal powder production, laser based additive manufacturing and near-net shape technologies for end-parts fabrication. A consortium of 16 partners has been gathered on this purpose under the coordination of the Commissariat à L'Energie Atomique et aux Energies Alternatives (CEA), France. The Project kicked off on 21 September 2017 with a meeting taking place at Brussels and ends in December 2020 having been granted a 4-months extension due to the Coronavirus mitigation plans.

The SUPREME Consortium

The SUPREME Consortium sees a mixture of organisations covering the full value chain from mineral to end parts applications: Atomising Systems Ltd (United Kingdom), CEA (France), Centro Ricerche Fiat (Italy), Dellas Srl (Italy), European Powder Metallurgy Association (Belgium), Fundación IDONIAL (Spain), GKN Sinter metals (Germany), Innovation Plasturgie Composites (France), IRIS (Spain), MBA Incorporado SL (Spain), MBNnanomaterialia (Italy), Metso Outotec (Finland), WeAre Additive Defense (France), RHP Technology GmbH (Austria), Tecnalia Research and Innovation (Spain) and TWI Ltd (United Kingdom).

Promotion

In 2020, promotion as in previous years was not really possible. With the pandemics starting in February and causing severe travelling limitations in March, almost all exhibitions where EPMA had planned to bring SUPREME materials and info, were either cancelled, or postponed and then cancelled, or changed to virtual, with much less opportunity for dissemination. Of the 10 events (exhibitions, congresses) where a promotion was initially planned, 6 were cancelled, including the World PM congress, and 4 were run online, including FORMNEXT, that had theoretically become available after the extension for the project end. The events where some information about SUPREME was given are basically EPMA online events: the EPMA General Assembly, the EPMA Euro PM2020 congress, several EPMA meetings, seminars and free webinars.
Trying to compensate for a reduced chance of direct dissemination through the usual channels, more emphasis was given to promotion via magazines and social media.
Advertisements about the Experts Training Workshop have been purchased on some technical magazines that are popular in the PM community (unfortunately inviting to join the in-person event in July that was later cancelled), and especially a 2-pages article on the web magazine Open Access Government (Figure 1) was published in April.


PROFILE

SUPREME: EU-project improves sustainability of powder metallurgy processes

Figure 1 The paper on SUPREME published on the Open Access Government web magazine.

This paper described the project especially in terms of its push towards higher sustainability PM processes and products. The OAG magazine has a very wide distribution also outside the "standard" PM audience (the total reach is more than 300000 contacts), thus this could really give more visibility to the project to normally unexposed technical and managerial figures, including also institutional stakeholders. A banner on the OAG website was also included, advertising the Workshop (the planned event in Senlis).

Concerning social media, most of the activity was carried out in LinkedIn, by EPMA, using the company page and the connected networking group. News about the project, especially concerning the Workshop, but also a sustainability survey, have been spread to the PM community, that is not limited to European fellow technical and managerial people, but also to many overseas contacts.

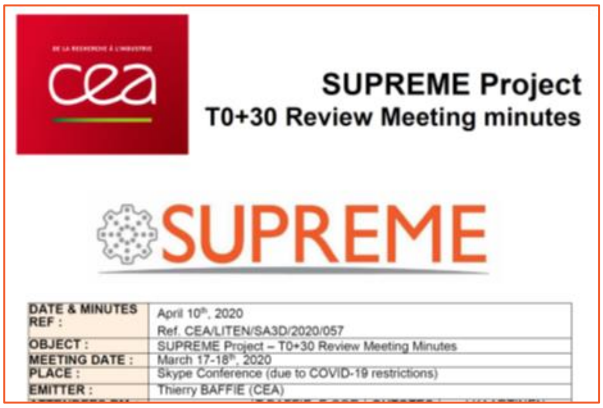
Of course, also the SUPREME Experts Training Workshop can be considered as a promotion activity, as the attendees have clearly brought information back to our contacts after the event.

SUPREME (virtual) Review Meetings

Many meetings had been planned, but the pandemic stopped most of the members activities and impacted of course also the possibility for face-to-face meetings.

A consortium meeting (T0+30) was to be held in San Sebastián (Spain) on 17-18th March 2020, but the start of travel limitations forced to transform it into a remote Steering Committee meeting with all Work Package leaders. The same happened on 23rd July, when the previously planned Final Meeting (T0+36) was transformed into an online Steering Committee meeting again after the official extension of the project to December 2020. The intermediate (T0+33) Steering Committee meeting already planned as a conference call was carried out on 28th May.

After notice of the extension, a Final Meeting for the project, including the review from the Project Officer, had initially been planned on 24-25th November in Bonn (Germany), at the GKN premises, in combination with the Experts Training Workshop planned for the next day also in Bonn. The pandemic forced to transform it as well into a virtual meeting, on the same days.


SUPREME Project
T0+30 Review Meeting minutes

SUPREME

DATE & MINUTES REF :	April 10th, 2020 Ref. CEA/LITEN/SA3D/2020/057
OBJECT :	SUPREME Project – T0+30 Review Meeting Minutes
MEETING DATE :	March 17-18th, 2020
PLACE :	Skype Conference (due to COVID-19 restrictions)
EMITTER :	Thierry BAFFIE (CEA)

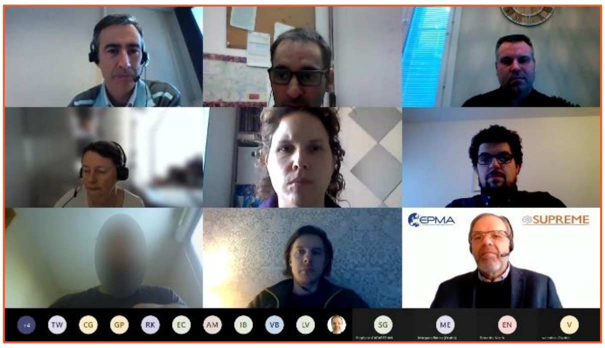
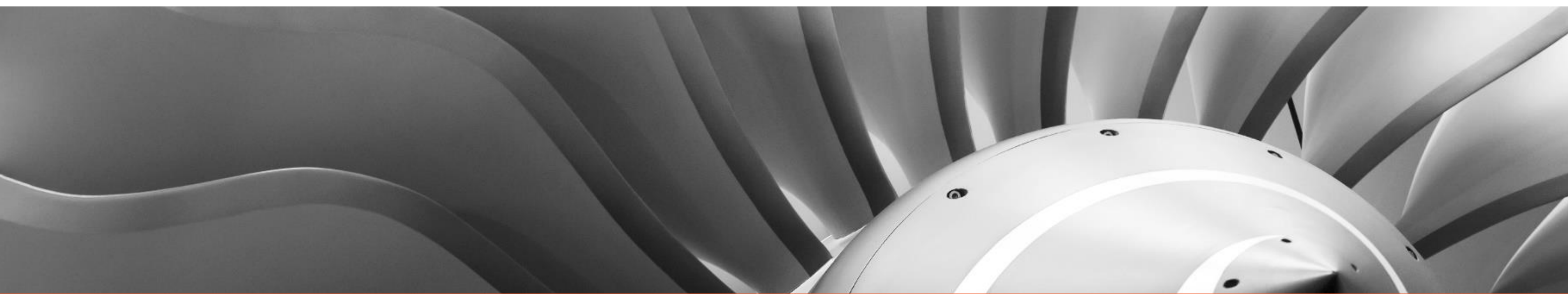


Figure 2 A screenshot from the virtual Final Meeting held on 25th November 2020.

The Final Meeting was finally held on the Microsoft Teams platform on 25th November and was attended by a large number of consortium members and by the EU Project Officer Mme Dominique Planchon. The presentations from all the Workpackages covered the whole spectrum of the activity, to illustrate all endeavours and achievements to the PO. A long and fruitful meeting that highlighted the important results obtained in terms of technical and environmental improvements in all sectors of powder metallurgy addressed.



SUPREME (virtual) Review Meetings (continued)

The PO gave useful advice on how to report everything for a better understanding by the examining bodies, and on how to disseminate and exploit further the foreground developed within SUPREME. With one more month of work yet on schedule, the Coordinator T. Baffie thanked all the partners for the constructive approach that led to a successful project implementation, and wished that there could be a chance to further collaborate in the future, for instance in the frame of another EU project.

SUPREME Experts Workshop

EPMA had organised the SUPREME Experts Workshop in Senlis (France) on 9th July, but the pandemic forced its cancellation, and the workshop was further planned for 26th November in Hotel Maritim (Bonn, Germany), in conjunction with the project Final Meeting that was to be held at GKN Bonn on 24th and 25th November. Lately, as the COVID-19 conditions were not showing any real improvement, rather an increased difficulty in travelling and an increased health risk, the final decision was to transform also this event (and the Final Meeting) into a virtual event.

The Workshop was advertised strongly on the SUPREME website, on the EPMA website and using LinkedIn. The partners also used E-Mail signatures that were thus shown to a large number of contacts during the months preceding the event.

Unfortunately, the pandemics and the changes in date and format caused a much reduced impact of some advertising actions that had been taken in the first part of 2020, also by publishing ads on specialised magazines, including a 2-page paper on SUPREME in the web magazine "Open Access Government", where the workshop was still promoted as being held in Senlis in July.

The final programme of the virtual workshop included presentations from the WP leading companies and institutes, covering the whole spectrum of the achievements obtained within the project.

Figure 3 Advertisement of the virtual SUPREME Experts Training Workshop.

Thursday 26th November 2020		
09:00 - 09:30	*Premeeting, session open for admittance*	
09:30 - 09:45	Presentation of EPMA	Bruno Vicenzi (EPMA)
09:45 - 10:15	Introduction to the SUPREME project	Dr Thierry Baffie (CEA-LITEN)
10:15 - 10:45	Efficient raw material production	Dr Jani Kaartinen (Metso Outotec)
10:45 - 11:00	*Q+A Interactive*	
11:00 - 11:15	*Coffee break*	
11:15 - 11:45	Efficient metal powder production process	Dipl. Ing. Dongjjan Zhu (GKN Sinter Metals)
11:45 - 12:15	Optimized 3D manufacturing metal processes	Dipl. Ing. Gilles Gaillard (CEA-LITEN)
12:15 - 12:30	*Q+A Interactive*	
12:30 - 14:00	*Lunch Break*	
14:00 - 14:30	Optimized near-net shape processes	Dr Iñigo Agote (Tecnalia)
14:30 - 15:00	Real-time monitoring for the optimization of industrial processes	Ioannis Kakogiannos (IRIS)
15:00 - 16:00	Use-cases & impact demonstration, Life cycle assessment & eco-innovation	Mr Tarek Sultan (WEARE ADDITIVE) and Mrs Emmanuelle Cor (CEA-LITEN)
16:00 - 16:15	*Q+A Interactive*	
16:15 - 16:30	*Coffee break*	
16:30 - 17:00	Final discussion and conclusions	Dr Thierry Baffie (CEA-LITEN)
17:00 - 17:00	End of the day	

SUPREME Experts Workshop (continued)

The lectures were also followed by a discussion and by some quizzes to verify the efficient transmission of information from the speaker to the audience. The event was hosted in the LiveWebinar platform.
The participants were about 30, and 40% of them were coming from outside the SUPREME consortium. The technical presentations given by the speakers conveyed to the audience many of the technical achievements of the project, and also their meaning in terms of better environmental performance, and understanding the areas where PM should concentrate in the future to go even further in reducing its environmental impact and being more competitive towards other mass metal parts production technologies.

Demonstrator and use-cases final results

In the following chapters, a review of all final results for the different demonstrators and use-cases is given.

Demonstrator at mineral concentration step

The resource and energy consumption reductions in mineral concentration phase focused on three main topics: ore grinding, flotation and water management at the mine site. In all these areas, the objective was to save energy, reduce the usage of fresh resources and to optimize the production without harming the quality or throughput.

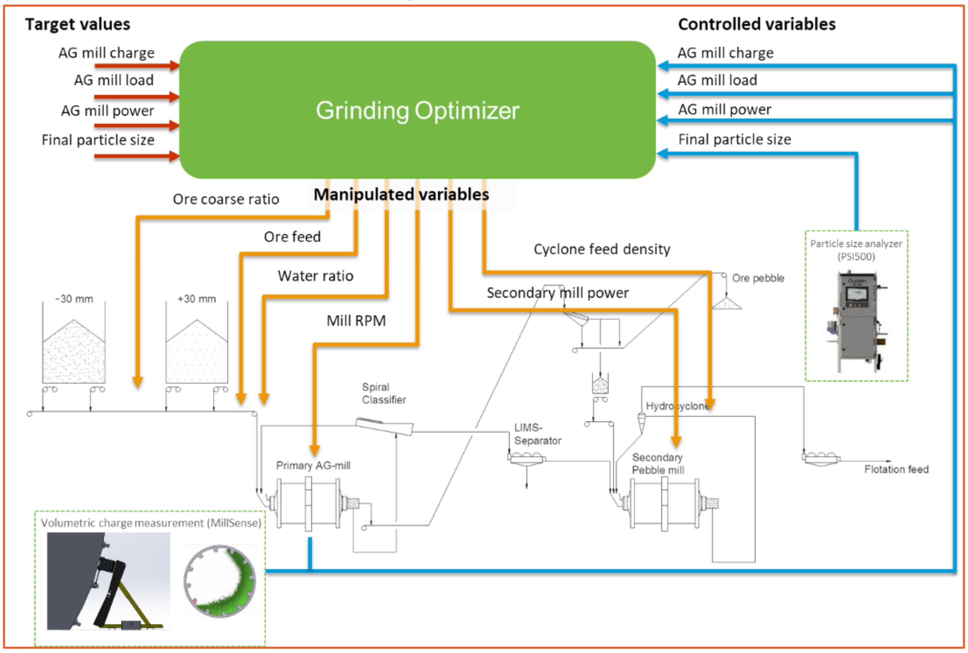


Figure 4 Structure of the grinding optimizer solution.

Grinding

The ore grinding process optimization was demonstrated on a two-stage grinding circuit at LKAB Kiruna in Sweden. Advanced instrumentation was installed on the process in the form of volumetric mill charge analysers, 3D laser scanner based particle size analyser for the ore feed and an additional slurry particle size analysis stream. The process optimization was based on model predictive controller and utilized the existing and new measurements.
The structure of the grinding optimizer solution is presented in Figure 4. A set of target values is given to the optimizer according to the current production targets. After a model identification and optimization step that is done during commissioning, the controller is able to manipulate a set of process

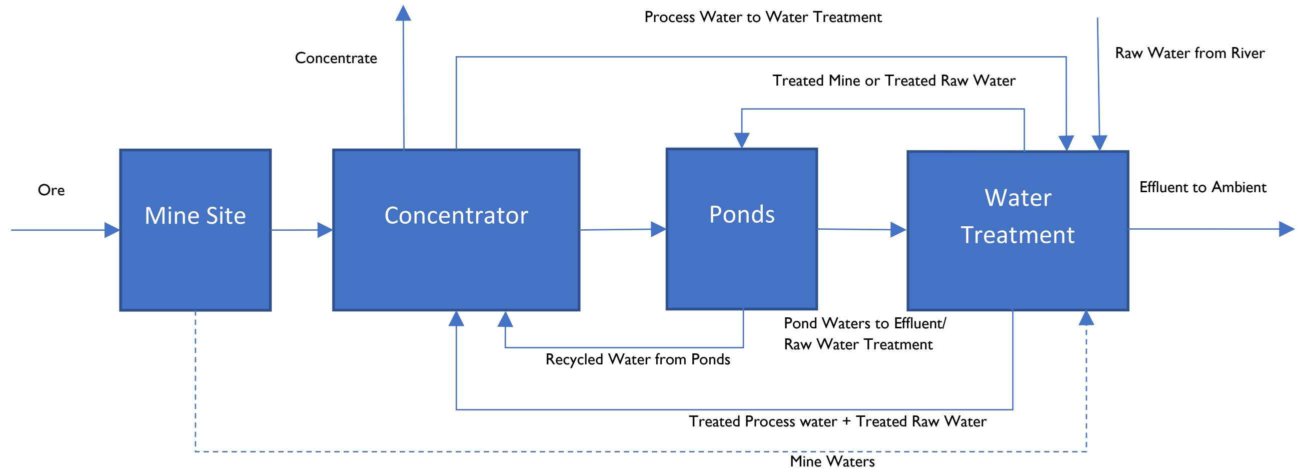


Figure 5 Water management model.

variables in order to reach the given targets in an optimal way.
Evaluation of the obtained performance was done in Spring 2020, when the grinding optimizer operation was compared to the traditional, manual control by the process operators. It turned out that the process stability was increased significantly, meaning that the variation in mill charges and particle size of the final product were clearly reduced. As a result of the increased stability, also the energy consumption and resource efficiency of the circuit were improved.

Flotation

Mineral flotation is used to separate the valuable mineral particles from the ground feed ore with the help of chemicals and air bubbles in flotation machines. In flotation improvements within the SUPREME project, the focus was on the mechanical structure of the flotation cells as well as on introducing the rotation speed control of the flotation cell rotor. In the first phase of the work, a new bubble generation approach for the flotation machines was studied, and testing was conducted. Second phase of the study related to the RPM control included initially CFD modelling of the flotation machines, and then real process testing. The test work is at the time of writing still on-going, and results are not yet available.

Water Management

In water management, the idea is to model and simulate the water flows and water storages of the whole mine site in order to optimize the water consumption quantity and water quality. In the SUPREME project, the methodology was demonstrated for the Keliber Lithium concentrator plant in Finland, where a dynamic simulation model of the water balance was developed (Figure 5). New options for the water recirculation were identified and possibilities to test flooding scenarios were implemented. Additionally, the water qualities around the site were modelled. As a result, raw water consumption reduction potential of 89% compared to the original plan was suggested. That would increase the overall water recycle rate by 4.3% at the site.

Demonstration at powder production step

As part of the SUPREME projects drive to reduce energy consumption in powder processes, an improved gas atomiser was designed and built by Atomising Systems Limited in Sheffield, UK. Getting the powder properties correct at this early stage is crucial to all of the downstream processes – additive manufacturing for example relies on flow properties. To this end, the new ASL atomiser design (the SUPREME atomiser) focuses on 3 key improvements: an improved anti-satellite system, a larger furnace, and a new induction heated tundish.

Improved anti-satellite system

This delivers powder that is extremely spherical and free flowing, building on ASL's in-house designed anti-satellite system (see Figure 6).

Larger Furnace

A larger furnace allows for more efficient refractory usage as more product can be produced for the same downtime and (on average) fewer kg of refractory materials than a smaller furnace. The SUPREME atomiser uses a 400kg furnace.

One of a kind Induction Heated Tundish

An induction heated tundish works in the same way as an induction furnace – electrical current is passed through coils contained by refractory insulator, which will then heat metal placed inside the coil.
Using this tundish allows for energy in the form of heat to be put into the tundish during pouring, allowing reduced furnace temperatures without the risk of freezing which would stop the atomising run.
This has worked successfully, allowing an average reduced melt temperature of 50°C. This in turn reduces the wear on the furnace lining, increasing its life and thereby making the system more refractory efficient.

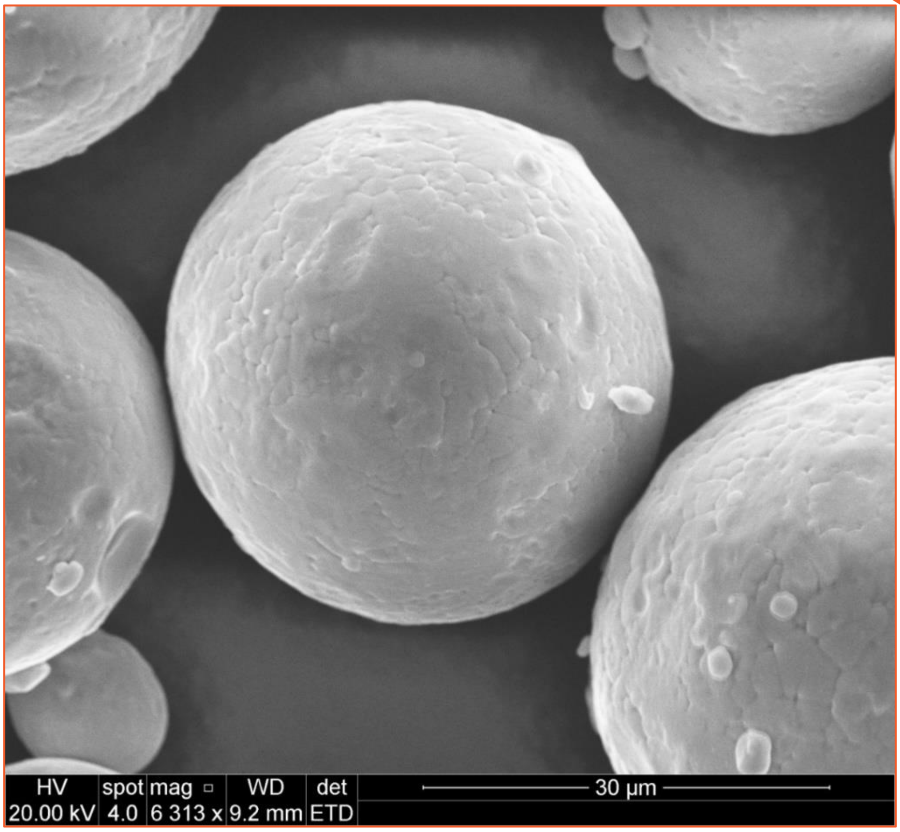


Figure 6 316L Powder from SUPREME Atomiser showing effectiveness of anti-satellite system.

Demonstration at L-PBF production step

The automotive demonstrator use case is based on an engine bracket geometry, which was provided by CRF. GKN has carried out a topology optimization considering the conventional CRF part design, developed a new material alloy (water atomized high C steel alloy) and performed a L-PBF process parameter study to achieve reliable part quality. Finally, the developed part design was produced by using single and multi-laser L-PBF systems. The part design has reached a volume reduction of 40% considering all functional boundary conditions, which were determined before by CRF (see Figure 7).
In the final automotive demonstration phase, GKN used the water atomized high carbon steel material to manufacture the conventional and topology optimized engine bracket geometry on several L-PBF systems (RENISHAW AM250HT, EOS M290 and EOS M 300 – 4), see Figure 8. Energy and gas efficiency were monitored to investigate necessary energy resources during the production process by using the monitoring hardware provided by IRIS.
The productivity ratio between the different L-PBF systems was evaluated

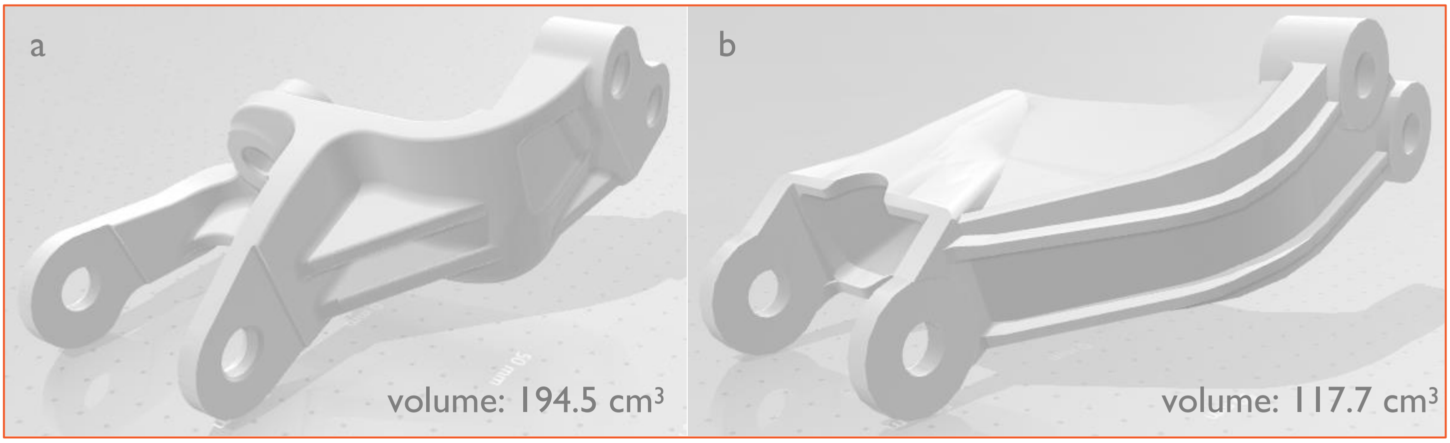


Figure 7 a) Original engine bracket (provided by CRF) and b) topology optimized engine bracket (GKN inhouse development) based on the measured actual built rates.

The achieved part quality on a single laser (EOS M290 Figure 9 left) and a multi laser system (EOS M300-4 Figure 9 right) covers the predefined boundary conditions by CRF. Density, surface roughness, mechanical properties are just a few of the necessary requirements, which were considered during the parameter development process. The application development requires suitable support structures to consist resulting internal stress, so that a reliable part production can be guaranteed.

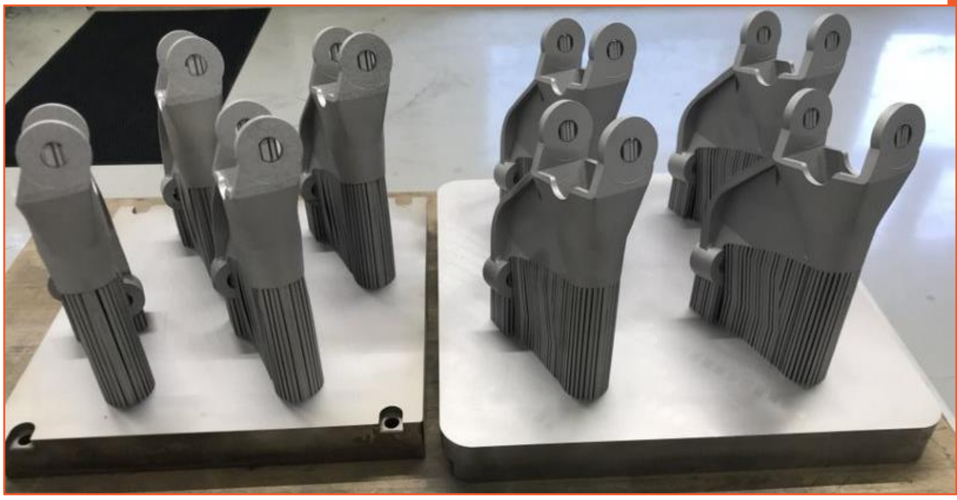


Figure 8 Topology optimized engine brackets built on EOS M 290 (left) and EOS M 300 – 4 (right)

Figure 9 L-PBF systems used during the demonstration. a) RENISHAW AM250^{HT} b) EOS M 290 and c) EOS M 300 - 4

Furthermore, an analysis of the actual build time was performed to investigate the achievable productivity by setting a process parameter and changing the hardware set up from single to multi laser systems. The achievable build time reduction of 70% indicates, that the throughput on a multi laser system can be increased significantly (Figure 10). Scan strategies like the "Full Overlap" (specific scan strategy related to EOS L-PBF systems) make an increase of productivity possible considering reliable material properties without laser stitching zones.

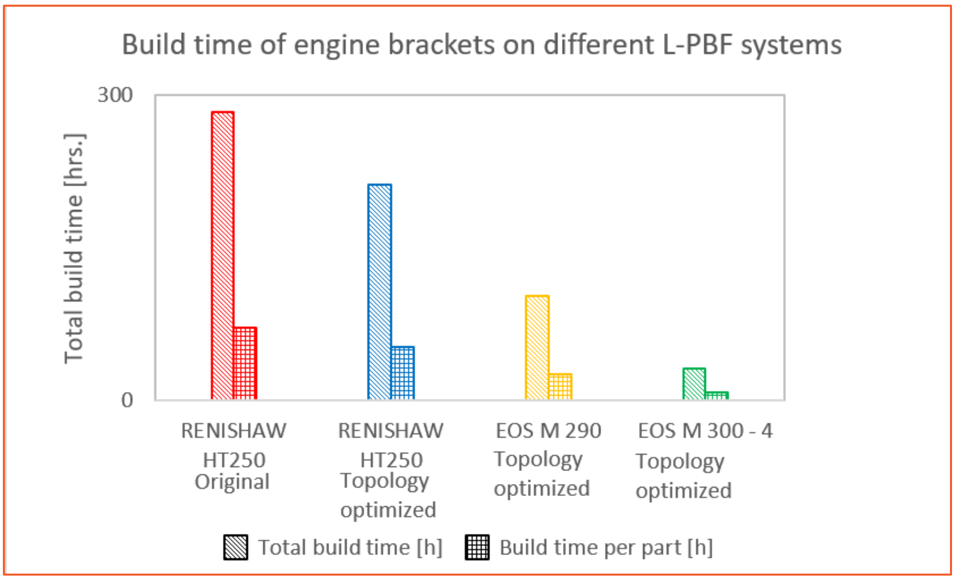


Figure 10 Build time of engine brackets on different L-PBF systems

Cutting tools use-case

The objective of the SUPREME Project was to demonstrate the savings and the advantages of using FeCuNiSnP composite cutting tools instead of Co-diamond composite ones. Using this new metallic matrix over the Cobalt matrix will allow to eliminate a harmful and toxic material (Co).

Significant improvements were expected to be demonstrated with:

- Raw material extraction savings,
- Better performance and less material waste with this new material developed in SUPREME,
- More efficient milling process for FeCuNiSnP.

DELLAS monitored the savings achieved along the value chain in SUPREME project and realized prototype tools which were assembled in a gang saw and tested in real environment to demonstrate the savings.

The task was divided into two sub-tasks:

Validation of the new material

Validation of the new material through the production of parts by cold pressing and free sintering is necessary. It's important to test the hardness, the quantity of diamonds, the diamond retentions...Then Dellas wants to be sure the gang saw blade with the new material had good cutting performance in the field.

Validation of the new process

The new production process DIM (diamond injection molding) was validated with new debinding (water vs solvent debinding) and free sintering. The "DIM tool" was tested in the field.

The project allowed demonstration, at TRL 7, of the global optimization throughout the production route of cutting tools based on FeCuNiP / diamond composite and to achieve:

i. a 35% reduction in energy use;
ii. an increase of 25% in production rate;
iii. a 33% reduction in CO_2 emissions compared to current MIM process.

A cost estimation and a market analysis (based on 8000 parts/day) of the "efficient" product was also done by DELLAS.

Validation of the new material

During the project, MBN developed a new powder (FeCuNiP alloy) suitable for MIM application in terms of density, composition and morphology using mechanical alloying process.

With the optimization of the injection process, some issues emerged for diamond tools applications:

- High Sintering Temperature (> 940°C)
- Diamond Damage due to the high temperature and long thermal treatment
- High Hardness (> 300HV, target about 250 HV)

To solve the problem MBN further refined the powder composition increasing the content of Cu and Ni in the alloy to obtain a softer matrix and modulating the low melting phase by fine-tuning the P content to lower the sintering temperature. Among the tested variants, two best candidates were produced for the DIM application, and field tests allowed to select the variant (powder V16) with most suitable properties for the target application in terms of sintering temperature (920°C), densification (>98%) and hardness (250HV).

Validation of the new process

During the project, up to 76 different feedstocks have been produced with 7 different alloy batches and 4 different binder systems. Rheological testing has been performed on most of them to evaluate the feedstock behaviour during the injection moulding process. At the end Tecnalia defined two different alternatives to the former Dellas binder (solvent soluble binder):

a) a commercial modified binder to increase the water-soluble content
b) an in-house produced binder system.

Field test

For the field test Dellas made 1100 segments with Dellas binder and powder batch V16 because it was easier to have all the equipment for this type of binder.

The 25 gang saw blades (700 segments) have been mounted on the frame (see pictures). They are working on different stones with good performances. Unfortunately, due to the Covid, Dellas was not able to do all

the tests with different customers as it would like, but the results look promising.

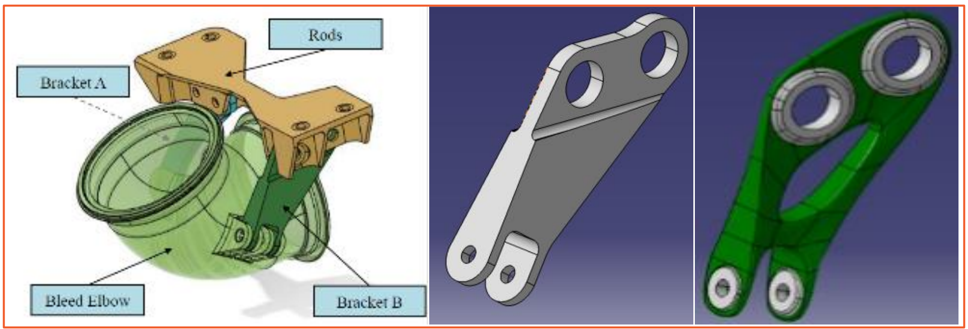
Aeronautics use-case

Use-case & business plan presentation

WeAre Additive Defense (WAAD) has selected with its end-user an Inconel 718 bracket for a plane engine bleed air supply assembly because of its high manufacturing cost by milling and its significant potential for topological optimization. The new part should have an improved performance due to a lower weight, which translates to an overall better performance in the final assembly resulting in lower fuel consumption of planes. The market volume of the use-case is estimated to 120 parts/month from 2024.

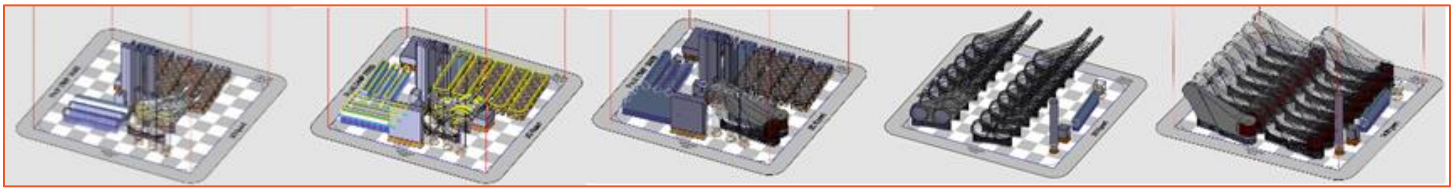
Use-case design optimization

WeAre ENGINEERING carried out the topological optimization of the use-case. The end-user delivered an assembly to study and the strain and load cases associated. Calculations were applied to the whole assembly and design optimizations done on the different parts. Finally, the highest weight reduction reached 30%.



Specimens & Use-case testing plans

To characterize Nickel base alloys (INC625 & INC718) manufactured by L-PBF process, several plates including specimens for mechanicals tests (tensile, fatigue, etc.), and non-destructive tests were produced. The results have been compared to INC718 data resulting from older qualification campaigns with the end-user. The performances of 4 different furnace heat treatments were tested to study the heat treatment post-process that is subcontracted today at high cost.



Finally, on the use-case prototype & serial plates, cut-up specimens (cut directly from the use-cases) have been inspected.
The results showed that a heat treatment for INCONEL 718 is always necessary: it requires HIP followed by solution treatment and double annealing.

Production routes
The 2 production routes done in the SUPREME project are:

- INC625-L-PBF: Manufacturing of a prototype plate with 2 use-cases with optimized design;
- INC718-L-PBF: Manufacturing of 2 prototype plates with 2 uses-cases each (1 with optimized design, 1 with original design) & 2 serial plates with maximum number of use-cases each (1 with optimized design, 1 with original design).

This project helped WAAD to study the energy consumption, carbon emissions and also productivity on a use-case for aeronautical application. The important added value is also to have a comparison between Milling & L-PBF process applied on aeronautical application.

Medical use-cases

SUPREME Project's role is to evaluate several end-user cases for the medical devices industry through modified manufacturing processes that ensure a lower environmental impact and cost reduction. Specifically, the set parameters were the improvement of at least 25% in material yield, 10% in energy yield and 10% in production rate, and at least a 30% reduction of carbon dioxide emissions.
With the help of the distribution partner, MBA, a leader in the medical and surgical technology distribution sector in Southern Europe, four end-user cases were selected and manufactured by five manufacturers: IDONIAL, TECNALIA, RHP, CEA and GKN.

- Two medical implants:
    - **Hip Arthroplasty Stem (HAS):** used to secure a hip prosthesis to the femur of the patient.
    - **Dynamic Hip Screw (DHS):** used to perform osteosynthesis in trochanteric hip fractures.
- Medical instruments:
    - **Broach handle:** used to secure the broach that is utilized to prepare the femur in hip replacement surgeries.
    - **Glenoid reamer:** used to remove bone from the glenoid cavity in shoulder replacement surgery.

Taking into consideration that these manufacturing routes are only used for small series, personalized components or in certain applications (such as

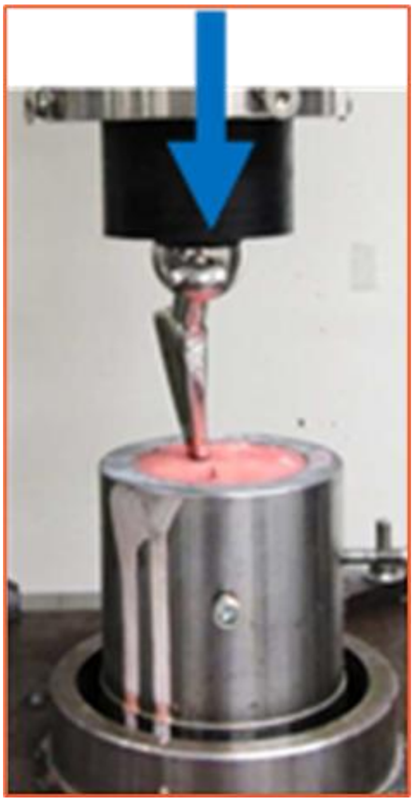


Figure 11 Fatigue test designed according to the standard for HAS.

HEMI-ARTHROPLASTY HIP STEM (HAS)	DYNAMIC HIP SCREW (DHS)	BROACH HANDLE	GLENOID
Used to fix HIP prosthesis to the proximal femur	Used to fix fractures of the proximal femur	Holds the broaches used in HIP surgery	Used to remove bone from the glenoid fossa
			
CONVENTIONNAL ROUTE: • 316L • Milling & Turning	CONVENTIONNAL ROUTE: • 316L • Milling & Turning	CONVENTIONNAL ROUTE: • 17-4PH • Milling & Turning	CONVENTIONNAL ROUTE: • 17-4PH • Milling & Turning
SUPREME ROUTES: • 316L • L-PBF	SUPREME ROUTE: • 316L • MIM	SUPREME ROUTE: • 17-4PH • L-PBF	SUPREME ROUTES: • 17-4PH • MIM & M-FDM & SLA & L-PBF & BJ

coatings), it is very interesting to study if these demonstrators are functionally valid, and hence these manufacturing processes could be considered for big-scale production and for production of other medical items.
Those manufacturers that achieved the set KPIs have provided their demonstrators for their evaluation through two validation tests: mechanical and biofunctional.
Mechanical tests have been designed and are performed at Valencia's Biomechanical Institute (IBV). Each of them has been properly defined to study each of the demonstrator's mechanical behavior considering the standard parameters they need to comply with when used in surgery.
For the **biofunctional validation**, each demonstrator is used in the surgical technique it was designed for (total hip arthroplasty, total shoulder arthroplasty and hip fracture repair surgery). Their dimensions, shape, fitting, visual impression, and functional capability are recorded considering the standards.
Given that some manufacturers included new demonstrators in the last stages of the SUPREME Project, these items are exclusively tested in dry bone by MBA's specialized team. As for the rest, they are evaluated by an orthopedic surgeon with several years of experience in shoulder and hip reconstruction techniques, who performs the mentioned surgeries using cadaveric models. These models are carefully selected to have a uniform study group in terms of age, BMI and pathologic conditions that could affect the surgeries.

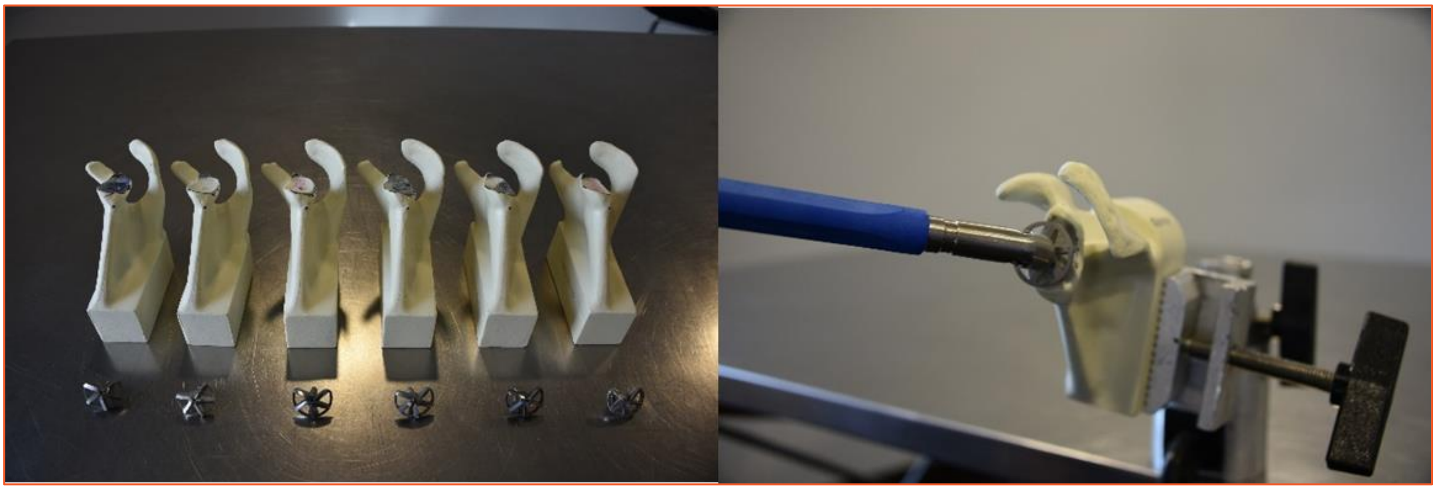
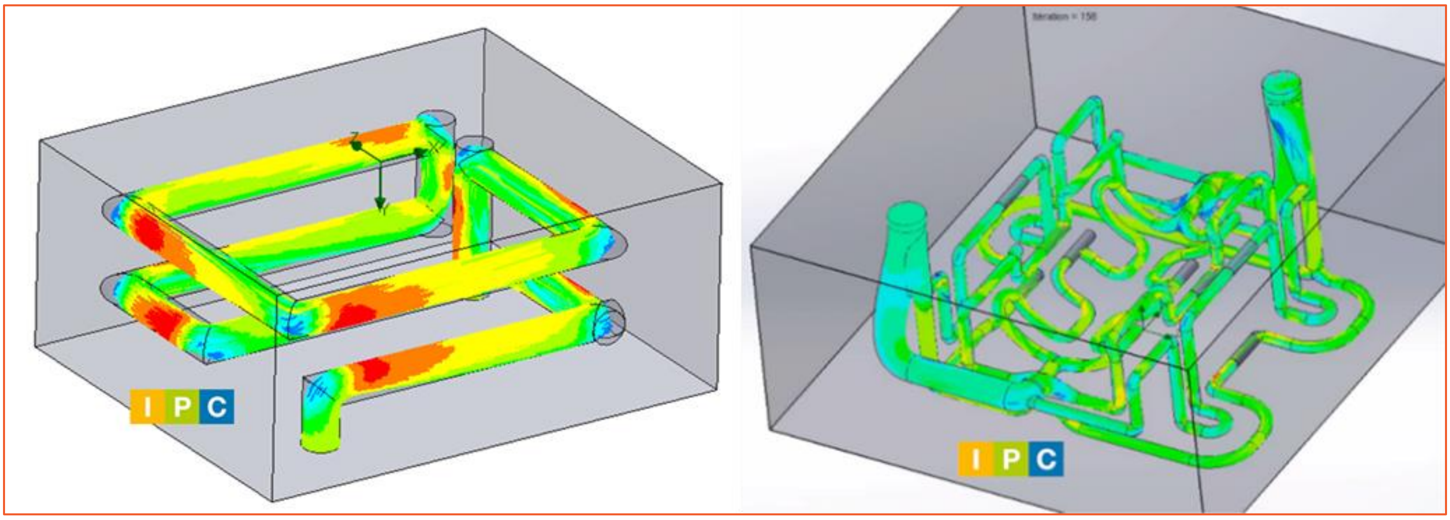


Figure 12 Biofunctional testing of Glenoid reamer demonstrator in dry bone.

Mold inserts use-case

The SUPREME project led IPC to use additive manufacturing to achieve near-net shape injection mold inserts including conformal cooling channels geometries otherwise impossible to achieve with traditional machining processes (see Figure 13). Such channels geometries obtained with Laser Powder Bed Fusion (L-PBF) helped to enhance the temperature homogeneity of the plastic part during the solidification phase, which leads to an overall reduced energy and material consumption of the injection machine electricity for heating, cooling, and



		Traditional	L40 conformal cooling
Final insert sets weight (kg)		7.200	5.527
Waste	Steel chips (kg)	4.862	2.077
	Steel powder (kg)	-	3.068 (0.660)
Energy	Electricity (kWh)	2 231	3 033
	Heat (J/kg $_{component}$)	947 754	686 254

Table 1 Environmental impact data of traditional machining VS conformal cooling

injecting, while drastically improving injection molding production rates.
While looking at the manufacturing of the inserts, the energetic and material consumption are encouraging (Table 1). The net amount of machined steel chips is less than half that consumed by traditional process, and where the powder (in red) appears high, actually 97% of it can be directly reused leaving the real loss at only less than a kilogram of powder. The overall amount of consumed steel is then 44% lower with L-PBF.
The net energy input to manufacture an insert is indeed higher, however a closer look reveals that the efficiency of direct energy input is higher for L-PBF than for traditional machining with again of 28% less calories needed per kWh input per kg of insert. Although it uses more energy, L40 in L-PBF makes better use of each kWh than machining.
As for its injection performance, under a continuous production scenario using a technical polymer, traditional cooling channel starts to yield more cumulated energy consumption after 1200 parts

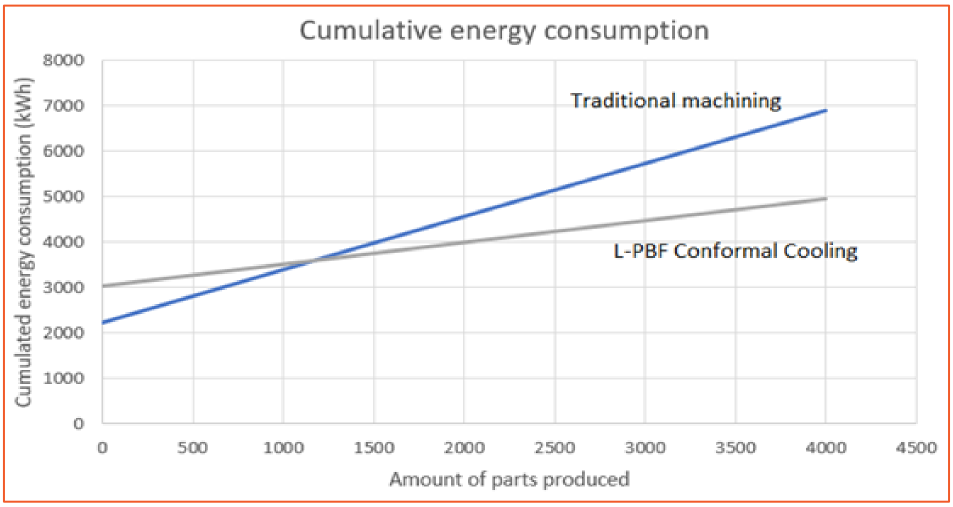


Figure 14 Cumulated energy input comparison

produced in 32h than L40, for which the same amount took only 13h to produce (see Figure 14). Conformal cooling confirmed a massive increase in productivity by over x2.3 times, all the while reducing operational energy consumption also by half for each part. The gains are substantial for an industrial application and improvements are still possible, but here are some numbers to consider :

- 59% less energy consumed per injected part
- Production rate x2.3
- Steel yield increased from 60% to 91%
- Reduction of buy-to-fly ratio by 24%

This study has been performed at IPC by Maxime Salandre, Stéphane Garabedian and Dr. Thomas Joffre with a L40 steel powder formulated by NanoSteel, commercialized by Formetrix, atomized and provided by Atomising System Ltd.

Automotive use-case

The automotive demonstrator consists of an engine bracket normally produced in cast iron without any surface hardening treatment. The new material used in SUPREME project for the demonstrator is Hard C Steel with L-PBF process, provided by GKN.
The tensile properties of the cast iron and the new material are quite similar. CRF has performed also fatigue-bending tests on the samples, with different finishing. Respect to the as-built condition, the fatigue strength at 5 million cycles in stress amplitude, with reliability of 50% (Sa(R50)) of the cast iron samples is 4% greater than the hard C steel one. With surface finishing the Hard C steel improves of 5% the Sa(R50) value respect to the as-built one. These results are encouraging.

Another important step for the introduction of a new material is to test the real component. CRF has then performed comparative bench testing between a normal production component and the demonstrator produced with the L-PBF process, see Figure 15.

The tests are still on-going, but the first results show that both solutions satisfy the product requirements for the specific bench test.

Figure 15 On the left the normal production engine bracket mounted on the bench test, on the right the GKN demonstrator on the same bench test.

Marine use-case

The SUPREME project focuses the attention on the use of advanced manufacturing processes to improve the manufacturing process efficiency and thus reduce material wastage. TWI Ltd. holding experience in the powder metallurgy (PM) manufacturing processes has successfully developed a manufacturing strategy to produce Inconel®625 (IN625) Y-shaped submarine pipe using near net shape powder metallurgy hot isostatic pressing (NNS PM HIP) technology. NNS PM HIP is an advanced manufacturing process, capable to manufacture complex-shaped parts with excellent material properties and microstructure. The process has the potential to vastly improve the "buy-to-fly" ratio of large industrial (marine, aerospace, power, aeronautical, nuclear, etc.) components (going from ~10:1 to ~2:1) when compared to a conventional manufacturing route such as casting-forging and machining. Figure 16 shows the CAD model of the submarine pipe which is currently produced using the conventional casting-forging and machining manufacturing route with a buy-to-fly ratio of 7.4:1 meaning that the current manufacturing process results in a high level of material waste with a relatively long lead time. The development of an efficient manufacturing process was

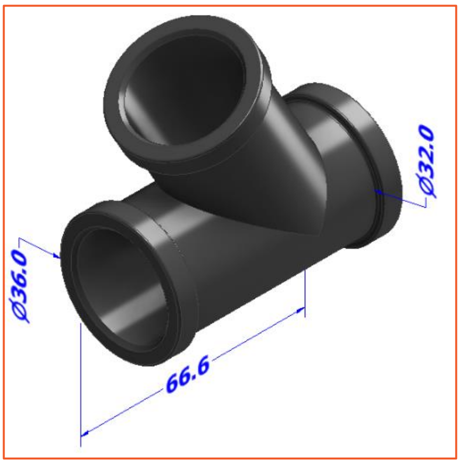


Figure 16 3D CAD representation of Y-shaped pipe.

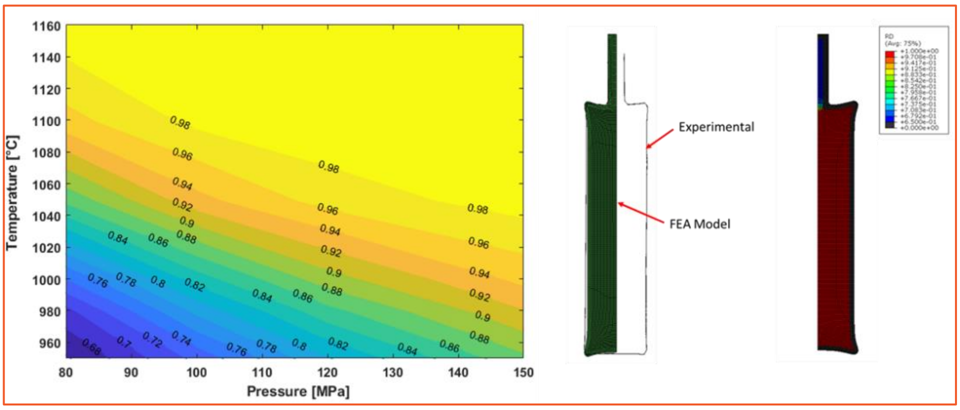


Figure 17 FEA densification map (left); geometrical accuracy and relative density calculation using a temperature of 1160°C and 120MPa (right).

led by Dr. Raja Khan (TWI), with the support of the NSIRC PhD student Alessandro Sergi, and with the collaboration of the Advanced Material Processing Laboratory (AMPLab) at the University of Birmingham. The study focused on a deep understanding of the influence of IN625 powder atomisation route and powder characteristics on the microstructure and mechanical properties of the material. Among four different powders including argon gas atomised (AGA), nitrogen gas atomised (NGA), plasma atomised (PA) and water atomised (WA) powders.

The first step of the manufacturing process consisted in the selection of the process parameters. Densification maps were built through an FEA simulation model to assess the influence of the main parameters such as temperature and pressure on the relative density of the part (Figure 17 left). Figure 17 confirms that the use of a temperature of 1160°C and pressure 120 MPa guaranteed full densification of the part.

The optimised HIP process parameters were then used to HIP the four powders. The microstructure of the four HIPed powders is reported in Figure 18. HIPed PA microstructure shows the least amount of prior particle boundaries (PPBs), while WA is characterised by the strongest presence of PPBs. The results of as-HIPed tensile properties confirm that PA powder possesses the best balance between strength and elongation, with superior properties if compared to the minimum specification of wrought IN625 (Figure 20). Thanks to its best response in terms of microstructure and mechanical properties, PA was selected for the manufacture of Y-shape pipe through NNS PM HIP.

The NNS PM HIP manufacturing process involved the design of a capsule (Figure 19), powder fill, degas, crimp, HIP and machining off the sacrificial canister to attain a net shape part geometry (Figure 21).

The prototype pipes produced during this work showed good geometrical accuracy with a reduced buy-to-fly ratio of 2.1:1 which is more than 3.5 times lower if compared to the conventional casting-forging and machining manufacturing method with a substantial reduction in CO_2 emission.

To conclude, NNS PM HIP technique has been successfully adopted to manufacture IN625 Y-shaped submarine pipe with a low buy-to-fly ratio and superior mechanical properties.

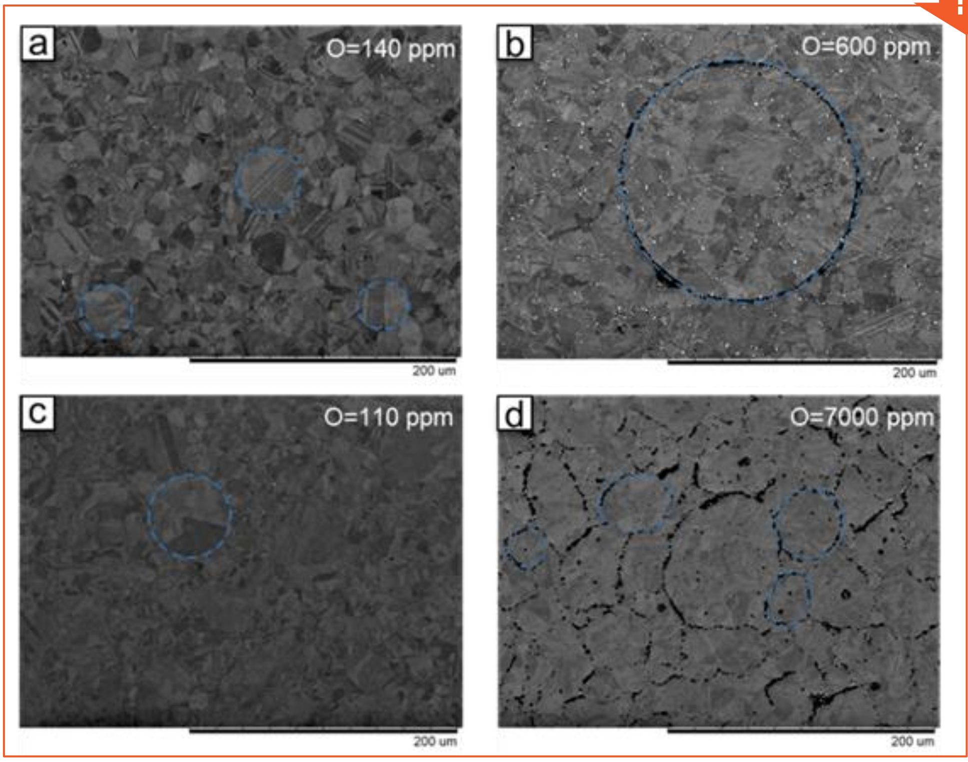


Figure 18 SEM backscattered micrographs of as-HIPed AGA (a); NGA (b); PA (c); WA(d); (PPBs highlighted in blue).

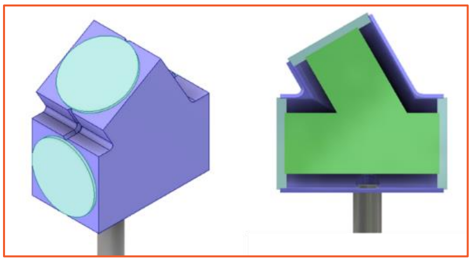


Figure 19 3D CAD drawing of the designed capsule.

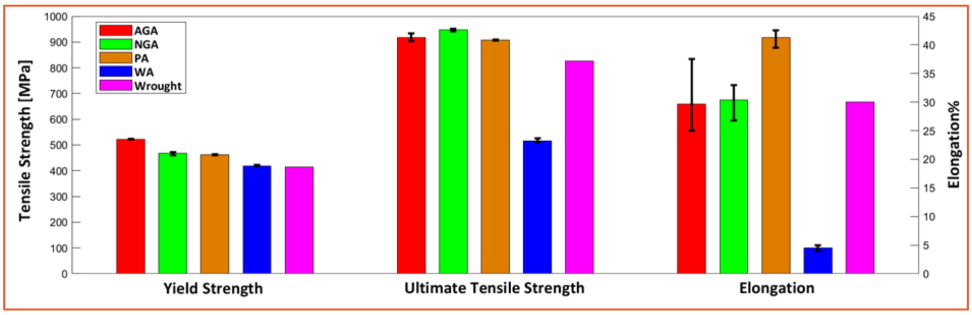


Figure 20 As-HIP Room temperature tensile properties of IN625 powders vs wrought minimum specifications.

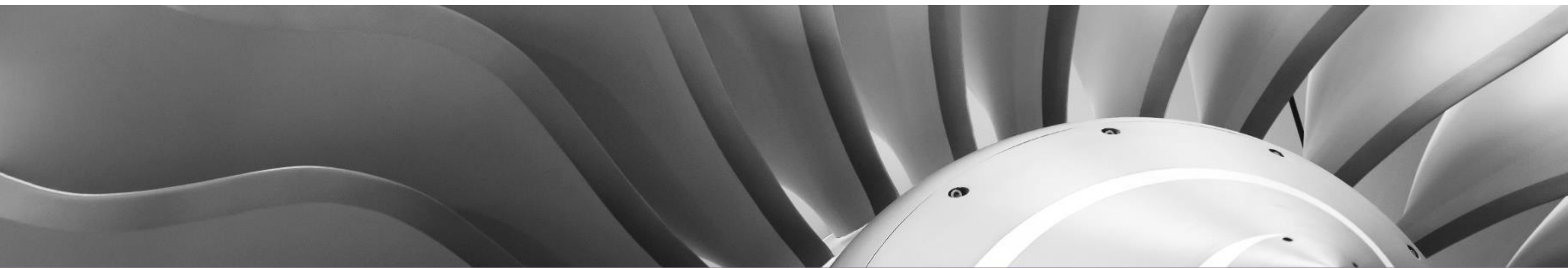


Figure 21 Submarine Y-shaped IN625 pipes produced using NNS PM HIP technique.

Meet the partners

European Powder Metallurgy Association (EPMA)

The European Powder Metallurgy Association was established in 1989 under the Belgian law (the official address is still in Brussels, while the offices are now hosted in Chantilly, France) to gather the growing European powder metallurgy community.
These are EPMA's three key missions:

- To Promote and Develop PM Technology in Europe
- To Represent the European PM Industry within Europe and Internationally
- To Develop the Future of PM

These are achieved using a variety of means including industry promotion, training & education, networking & events and technology development. EPMA serves all types of member organisations; from component, metal powder, and equipment producers to end-users, research centres, universities, and individuals who have an interest in PM.

Figure 22 Logo of the "Spotlight on PM" booklet series.

Promotion

The EPMA actively promotes the benefits of using PM technology to End User target markets through attendance, presentations and distribution of promotional literature (like the 'Introduction to' range of booklets, that covers many industry sectors, such as Conventional PM Sintering, Metal Injection Moulding, Hot Isostatic Pressing and Additive Manufacturing, and the Spotlight for PM selection of case studies) and promotional materials at selected End User trade shows, seminars and workshops.

Education & Training

The EPMA has been involved in a series of activities producing publications, videos, extensive online resources for end user designers and engineers (Design for PM, Global PM Property Database).

The EPMA holds regularly a range of seminars covering different aspects of PM Technology. These courses are particularly beneficial to technical and managerial personal looking for a more comprehensive understanding of the PM process, and for engineers and scientists with an interest in the PM process.

The EPMA Summer School, whose first edition dates back to 1998 and has now reached the 20th edition, was designed to offer participants from all parts of the EU an advanced teaching of PM's advantages and limitations by some of the leading academic and industrial personnel in Europe, giving also the opportunity to stimulate direct technical discussions by young scientists and engineers who are interested in broadening their knowledge through interaction with senior figures in the PM industry thus building their professional network.

Figure 23 Trainees at the last EPMA Summer School held in Trento in July 2019.

Recently, the PM Life activity further broadened the offer of training with even more focused courses on specific topics like Additive Manufacturing, Powders and Hard Materials, and Press&Sinter. EPMA plans to relaunch a new schedule for PM Life in 2021, including more topics and with a mixed virtual/in presence format.

YOUNG ENGINEERS D@Y

Figure 24 Logo of the last 2020 edition of the Young Engineers Day, that was a virtual event.

To stimulate and encourage young researchers in PM, EPMA created the Thesis Competition, offering financial prizes to the winners who also have the opportunity to present their work to the EPMA congress, and the Young Engineers Day, also an event normally connected to the Euro PM congresses, where students can get very introductive lessons on powder metallurgy, visit the congress exhibition, attend some of the congress sessions and events, and take part in guided tours.

Sectoral and Working Groups

The EPMA technical work can be divided into two main areas, Sectoral and Working Groups.

Six Sectoral Groups represent the main PM industry subsectors, which cover the majority of the PM industry:

- European Additive Manufacturing Group (EuroAM)
- European Functional Materials Group (EuroFM)
- European Hard Materials Group (EuroHM)
- European Hot Isostatic Pressing Group (EuroHIP)
- European Press & Sinter Group (EuroPress&Sinter)
- European Metal Injection Moulding Group (EuroMIM).

EUROPRESS&SINTER EUROFM EUROMIM EUROAM EPMI EUROHIP EUROHM EHQS

Figure 25 The six Sectoral and the two Working Groups within EPMA.

The two Working Groups cover cross-sectoral issues: the Environment, Health and Quality and Safety Group (EHQS), covering issues like chemicals management (e.g., REACh), health and safety rules, industrial standards (ISO) and sustainability (LCA, etcetera); and the European Powder Metallurgy Institutes (EPMI), gathering the main European powder metallurgy related research and education institutions and individuals.

Through the eight Sectoral and Working groups, the EPMA coordinates a range of activities designed to help the success of its members across the PM supply chain, which include:

- Benchmarking and Statistics - based on feedback from EPMA Members
- Quality Certification - advertising members' quality accreditation on the EPMA website
- International Standards - supporting the work of ISO TC119 and other standards activities.
- Contents and format of training and education events, seminars, and of the yearly congress
- Club Projects and other collaborative research projects

Technology Development

EPMA often plays a key role in the co-ordination of various government or industry funded research and development programmes, from short term specific programmes to wide ranging thematic networks running for several years. Otherwise, EPMA plays the role of disseminating partner in other projects (including SUPREME). In all cases they are designed to meet members needs and help to improve the competitiveness and capability of the European PM industry. Club Project among members are another successful tool to execute small research programmes, totally funded by a consortium of member companies, that share the results achieved by one or more research contractors (about 30 projects already completed, with more than 1 M€ raised and used).

Euro PM Congress & Exhibition

The annual Euro PM Congress & Exhibition is the pinnacle of the PM calendar in Europe, and attracts industry leaders, decision-makers, respected academics and a whole host of PM related companies and personnel from right across the supply chain to the 4-day event. Held in a different country and congress centre each year, the Euro PM Congress & Exhibition is a blend of Technical Content and Business Networking opportunities for all aspects of the PM industry. Every six years The Euro PM even becomes World PM according to the agreements with the American and Asian equivalent associations.

The Technical Programme consists normally of over 250 oral presentations selected by a Technical Programme Committee of highly reputed academics and industry figureheads from throughout Europe, on a range of Powder Metallurgy topics, including: Powder Production, Consolidation Technologies, Materials, Applications, Tools for improving PM.

The Exhibition which runs in parallel with the Congress offers an excellent opportunity for international suppliers to the PM industry to network with new and existing customers from the powder metallurgy and associated sectors.

EuroPM 2020 had to be organised virtually due to the COVID-19 pandemic; and the next edition, Euro PM2021, also initially planned in Lisbon (Portugal), has just been announced to be again a virtual event, this time including the (virtual) Exhibition, on 18-22nd October 2021. In 2022, like every sixth year, EPMA will organise the World PM: in Lyon (France), hopefully again a global, in-person, Congress&Exhibition.

Figure 26 The exhibition hall in Euro PM2019 in Maastricht.

Figure 27 Euro PM2021 will be a virtual Congress&Exhibition.

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