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PROJECT FINAL REPORT

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Project acronym: EFFIPRO

Project title: Energy Efficient Manufacturing Process of Engineering Materials

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4.1 Final publishable summary report

4.1.1.- EXECUTIVE SUMMARY

Today's industrial PM processes present long processing times and important energy consumption. Field Assisted Sintering Technologies (FAST) have emerged as novel processes to produce sintered parts via application of an external electrical current. The current application shortens significantly the sintering time, saving energy and thereby making this process good candidate for sintering nano-structured metallic composites and engineering metallic materials. However current FAST technologies mostly need to be carried out under controlled atmosphere and present further important drawbacks for industrial implementation (e g. low productivity, high equipment cost).

The aim of the *EFFIPRO* project was to develop and implement at pilot plant scale a novel Hybrid Electrical Resistance Sintering (HERS) technology. This is a two steps sintering process in which the sequential application of two different electrical fields is used: activation step and sintering step.

The process is based on the passage of an electric current exclusively through the powders which act as a short circuit resistance and is heated up instantaneously due to Joule effect (the use of dielectric dies forces the current to pass exclusively across the powder mass). This direct heating of the material (instead indirect heating of conventional furnaces, through convection and radiation phenomena) allows a very efficient sintering process. This process enables to sinter materials in few seconds compared to the tens of hours required in a conventional sintering process and allows great flexibility to produce small batches of parts. The process is conducted in the air is (without the need for protective atmospheres) so it can be easily integrated in current production lines.

The technology has been studied at fundamental level and a pilot plant scale equipment has been designed and built. As a result the technology has been protected by means of a patent application: *EP16382069*.

Higher performances metallic composites (based on hard metals: WC-Co) and engineering metallic materials have been obtained using this technology. The new technology shortens notably the processing time and is capable to produce materials with enhanced properties (hardness and toughness), mainly due to the novel finer microstructures that are obtained. In addition, the use of this process will bring significant energy consumption reduction in the sintering process.

The technology has been validated in the cutting tool sector: the production of three different tools (prototypes) has been carried out: a turning insert, a drill head and a drill. These tools have been tested under industrial environment: the insert and the drill head in machining of Fe based material for automotive parts and the drill for Ti/CRFP stacks machining in aerospace. Although further validation tests are needed, it has been found that the behaviour of the tools is similar or slightly better than that observed for conventional tools: the wear appreciated in the tools is equal or smaller than in commercial tools. In addition, the surface quality of the machined parts using EFFIPRO tools was found to be excellent.

4.1.2.- SUMMARY DESCRIPTION OF PROJECT CONTEXT AND OBJECTIVES

The P/M process is near-net or net-shape manufacturing process that combines the features of shape making technology for powder compaction with the development of final material and design properties (physical and mechanical) during subsequent densification or consolidation process (e.g. sintering). It is critical to recognise this interrelationship at the outset of the design process because **a subtle change in the manufacturing process can cause a significant change in material properties**.

Objective:

The aim of EFFIPRO was to **develop and implement at pilot plan scale a novel Hybrid Electrical Resistance Sintering (HERS) Technology**, using the sequential combination of an activation step and a sintering step

The main objective of EFFIPRO was to **develop and implement at pilot plan scale a novel Hybrid Electrical Resistance Sintering (HERS) Technology**, using the sequential combination of an activation step and a sintering step, to obtain nanostructured materials with improved performance, durability and lower cost. The technology has been validated in the cutting tools industry where tools with better properties and longer lifetime will be obtained using a highly efficient process. The impact of the new developed

The achievement of this objective has had a clear impact in different fields:

Impact in the manufacturing time:

Today's industrial PM processes present **long processing times** (from several hours to few days). Field Assisted sintering technologies (FAST) have emerged as novel processes to produce sintered parts via application of an **external electrical current**. The EFFIPRO technology shortens significantly the sintering time not only compared to conventional PM processes but also compared to typical FAST processes, such as SPS. In addition, unlike SPS or other pulsed current waveform FAST techniques, EFFIPRO processes is conducted in the air, without the need for protective atmosphere (typical FAST processes need to be carried out under controlled atmosphere, hence presenting important drawbacks for industrial implementation e g. low productivity, high equipment cost.

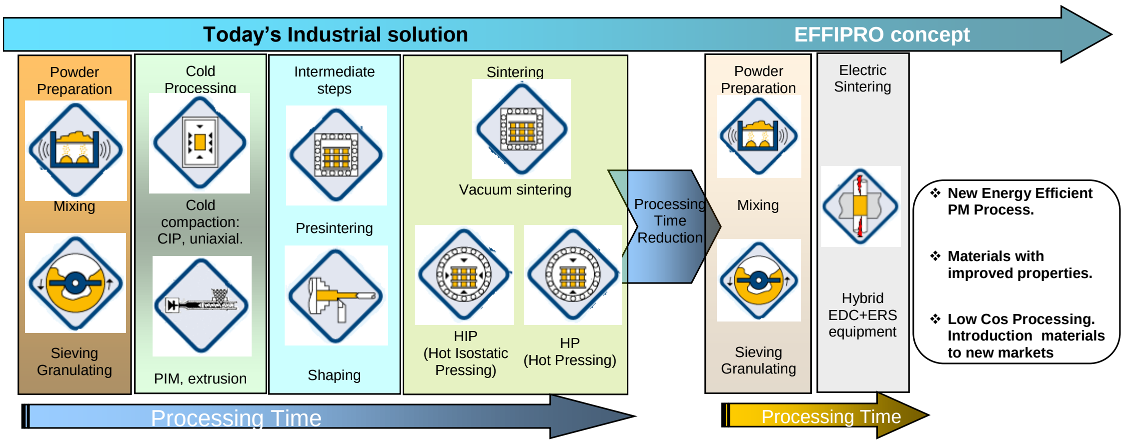


Figure 1: *EFFIPRO Project concept*

Figure 1 show how the EFFIPRO process is expected to impact in the PM parts manufacturing time. It can be seen that the sintering step of the PM parts manufacturing process is substituted by the EFFIPRO process, reducing drastically the processing time.

The EFFIPRO technology will clearly impact in the in the PM parts manufacturing time and the simplicity to be implemented in existing parts production chains.

Impact in the energy consumption:

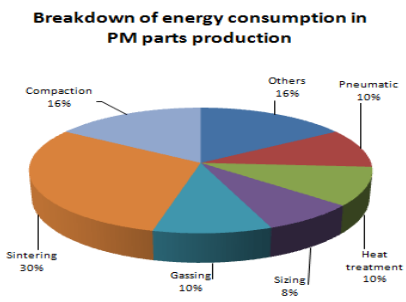


Figure 2*: Energy Consumption in PM parts production.*

Today's PM industrial processes present important energy consumption, especially during the sintering steps: The highest consumption, about 50% is related to sintering step (see figure *2*). Because "energy" is "power" multiplied by "time", a shortening of the sintering cycle time leads to lower energy costs. Due to the speed of the new process and the effectiveness of the energy used (the current directly affects the part being processed) it will have a positive impact in the **energy consumption** during the sintering process in small series production.

Impact the flexibility of the manufacturing process

The current PM market and parts producers are moving towards customized and personalised production, meaning that industries should face small production series and very frequent change of the part configuration (materials, geometry,…). HERS technology is perfect to respond to the new market trends due to the very simple equipment configuration and the fact that one part is obtained per sintering shot (no need to use big furnaces at full capacity to make the process competitive), making EFFIPRO process very flexible and excellent for small series and customised parts.

Impact of materials with improved properties:

This technique will revolutionise microstructure control in hard metals and allow for properties not reachable by conventional processing routes It will clearly help in obtaining new types of microstructure via processing, essentially generating nanostructures with "cleaner" grain boundaries. The features of the technology (speed, lower sintering temperatures and fast cooling) will allow nanostructures to be obtained that would be impossible to obtain by means of conventional sintering technologies. This will allow the avoidance of sintering aids and will clearly improve the mechanical properties of the materials.

The process will produce new microstructures allowing the generation of parts with improved properties, such as hardness; toughness, wear resistance the hard materials.

In order to achieve the main objective other partial goals and topics has been investigated during the project:

Scientific objectives:

- ❖ Understanding of the fundamentals of the hybrid Electrical current assisted sintering technology.
- ❖ Development of nanostructured materials with tailored properties.
- ❖ Understanding the link between the processing condition-microstructure-mechanical properties.
- ❖ To master the microstructure of parts.

Technical objectives:

- ❖ Development, design and set up the new concept of Hybrid electrical current assisted sintering equipment: with tailor-made electrical features in order to control (i) the uniformity of the microstructures, (ii) the grain size, (iii) the homogeneity of parts, and to enable the production of complex shapes.
- ❖ Implementation of this knowledge-based technology in the industry at pilot plant scale.
- ❖ Development of advanced hard metals, with nano size structures (<200nm), longer durability (2 times higher) and higher toughness without hardness amortisation 30% and improvement in the hardness.

In order to accomplish the project tasks and activities a well-balanced consortium has been formed. The core group of the EFFIPRO project is composed of 8 partners belonging coming from 6 countries: Germany, France, Greece, United Kingdom, Denmark and Spain.

***Table 1:** Description of the consortium and role of each partner.*

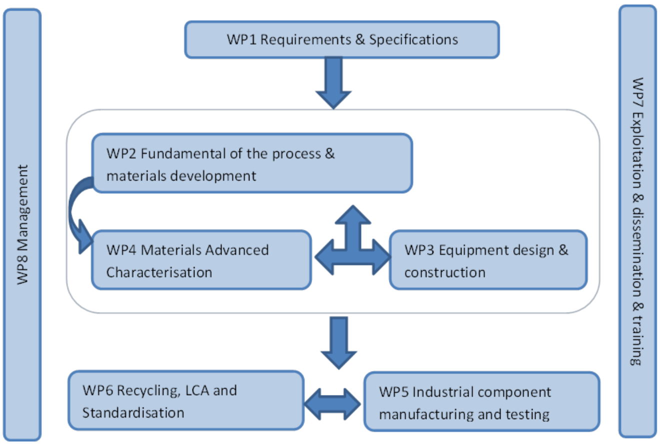
Participant	Country	Profile	Key expertise	Role in the project
Fundación TECNALIA Research & Innovation (TECNALIA)	Spain	RES	Private R&D Institute focused on materials	Coordinator of the project. Development of the sintering technology and; design and construction of the pilot plant scale equipment. LCA and environmental analysis of the process
Universidad de Sevilla (USE)	Spain	RES	University with expertise in powder metallurgy and electrical resistance sintering process	Study the fundamentals of the new sintering technology, including the simulation of the process. Characterisation of the obtained parts.
Fraunhofer Institut Fertigungstechnik und Angewandte Materialforschung, Institutsteil Pulvermetallurgie und Verbundwerkstoffe Dresden (FRAUNHOFER)	Germany	RES	Fraunhofer Institute for Manufacturing and Advanced Materials develops new sintered and composite materials and offers innovative powder metallurgy technologies	Benchmark of the technology using SPS process. Advanced characterisation of the samples and prototypes developed during the project.
MIRTEC, S.A. (MIRTEC)	Greece	IND	Ceramic synthesis and processing methods.	Design and development of ceramics dies for the new sintering process. Manufacturing of the dies to obtained the prototypes.
KYOCERA UNIMERCO, Ltd (UNIMERCO)	Denmark	IND	Design and production of standard and customized tools for the business segments of wood, metals, composites and the food industry	Specification of the cutting tools. Design of cutting tools. Manufacturing of the industrial prototypes

Participant	Country	Profile	Key expertise	Role in the project
Aleaciones de Metales Sinterizados S.A. (AMES)	Spain	IND	PM parts producer for automotive sector. Strong know-how in equipment design and construction	Pilot plant equipment developer. End user of the tools to machine parts for automotive
European Powder Metallurgy Association (EPMA)	United Kingdom	OTH	As association strong links with the main PM players	Responsible of the dissemination of the results.
Airbus Group Innovations (AIRBUS)	France	IND	Corporate research facilities of AIRBUS. Provides worldclass capabilities in aeronautics, defence and space	End user of the tool to machine parts for aerospace sector: specifications of the pats to be machined and validation of the tool at industrial environment.

The consortium gathers companies and research institutions so that to cover all competences needed for the project. It covers the whole value chain of the hard metals tools manufacturing process, paying especial attention in the technology developers (AMES, MIRTEC; TECNALIA). The tools manufacturing process and requirements is well covered by one of the leading tooling manufacturer worldwide (KYOCERA UNIMERCO). Two different end users validate the quality of the parts obtained by the development technology in two different industrial fields: automotive (AMES) and Aerospace (AIRBUS).

__Description of work__

The *EFFIPRO* project is focused on the development of Electric current assisted technology to produce high performance hard materials at a competitive production cost. The work has been divided into 8 Work Packages (WP).



WP1 Requirements & Specifications: This task defined the basic requirements of the final components or prototypes (end users) and the specifications of the Hybrid Electrical Resistance Sintering process

WP2 Fundamentals of Electrical Current Assisted Technology: The fundamentals of the technology were deeply studied at lab scale. The relationship between the processing conditions-microstructure and mechanical properties has been established. This WP will include the development of the materials (hard metals and candidate formulations to substitute hard metals) and deep understanding between processing conditions-microstructure and mechanical properties and pre-pilot plant scale analysis. Benchmarking samples were obtained by other manufacturing techniques (conventional powder metallurgy and SPS). The development of the ceramic dies was also carried out.

WP3 Equipment Design and Construction: The design and construction of the industrial scale equipment was carried out in this task. The results obtained with lab scale equipments in WP2 allowed the proper design and construction of the industrial scale equipment. Beside the equipment itself the implementation of the equipment in the production chain was studied in this WP: process control devices, in situ monitoring, etc.

WP4 Materials Advanced Characterisation: Micro and Nano characterisation of the materials was carried out. Advanced characterisation techniques were used: Scanning Electron microscopy (HR-SEM and EDX) and Transmission electron microscope (TEM) in order to determine the grain size; X ray diffraction, nano indentation, fracture toughness.

WP5 Industrial Component Manufacturing and testing: Process scale-up and component prototyping was carried out by the manufacturing industrial partners; while the end users performed "in –service" testing and evaluation of the cutting tools for the selected automotive and aeronautic machining operations.

WP6 Recycling, LCA and Standardisation: Techno-economic analysis together with environmental assessment of the manufacturing process was carried out. This included product Life Cycle Analysis (LCA) according to ISO 14040/44 and the ILCD handbook. The whole chain was supported by sophisticated modelling tools. The efficiency of the new process in terms of cost machinery, energy saving, reduction of waste, etc was also studied. Safety issues was specifically treated in every step of the project: equipment manufacturing, raw materials handling (fulfilling the REACH legislation), equipment use, etc. Recycling issues were also addressed so that all the produced part will be recycled after their utilisation.

WP7 Exploitation & Dissemination: The exploitation of the results obtained results were done according to the consortium agreement. EPMA was responsible of the dissemination and training activities for the spreading of the outputs of the project through conferences, workshops and seminars. All partners took part in IPR and exploitation issues managed by UNIMERCO. A business plan was also developed within this WP.

WP8 Project Management: The aim of this WP is to maintain the project on track from the technical and financial point of view.

4.1.3.- DESCRIPTION OF THE MAIN S&T RESULTS/FOREGROUNDS

WP1. Requirements and Specifications

The objectives of this WP are:

- To accurately define the specifications of the materials and parts according to industrial applications foreseen.
- To select the prototypes/components and the drawings
- To select the criteria and type of tests for characterizing and benchmarking the materials and parts made thereof.
- To define the requirements of the EDC+ERS equipment and tools (dies, punches etc)
- Main partners involved will be cutting tool manufacturers, end users and equipment developers but all other partners will contribute at a lower level bringing their expertise where it is necessary.

Main Results:

- Requirements of the parts to be machined:

  In order to validate the products of the technology which is being developed in this project, appropriate components have been selected by the end users (AMES and AIRBUS) as test cases from two industrial sectors which are at the forefront of the use of the cutting tool bits and inserts to be produced.

  Each of the components chosen, one from the aeronautical and one from the automotive industry, have been picked as involving processes which are widely representative of the kinds of machining operations to be applied.

  From the automotive sector a sintered low alloy steel part, approximately cylindrical in shape, has been selected. The production of this part requires finish machining operations including both turning and drilling, and therefore involving two types of cutting element which will both be produced using the technology developed in the project. The machining of this part involves a significant consumption of cutting tools due to the large amount of material removed at each pass. The object therefore is to reduce the import of the cost of cutting tools and of the cost of the machining operations on the overall cost of production of the part.

  Production of the aeronautical part requires the drilling of a bimaterial join (Ti6Al4V + CFRP) where both the cost of the operation, due to the very large number of holes to be drilled, together with the quality of the interface between both material components, are of great significance.

  The characteristics of the machined materials have been established as well as typical machining conditions. The following table shows the type of the parts to be machined, their characteristics and the current machining conditions.

- Identification of the prototypes to be developed in the project.

Based on the requirements of the end-users, AMES and AIRBUS, cutting tools used in today's machining process have been identified and selected.

Depending on the machining operation and the material to be machined, different type of tools and geometries are currently used. Three different cutting tools were selected to evaluate the developed material in three different machining operations (see figure 3):

1. Turning of the outer diameter of an iron based alloy of a parking-position lock component for automotive applications.
2. Drilling of a dead end boring of an iron based alloy of a parking-position lock component for automotive applications.
3. Drilling of a composite stack made of CFRP (carbon Fiber Reinforced Polymer) and Ti-6Al-4V for aeronautic applications.

The selection of the raw materials (powder composition, particles size,…) of which the cutting tool will be manufactured, has been done; and the requirements of the cutting tools established. This will allow comparing the developed material with the requirements and with commercially used cutting tool materials.

A B C

***Figure 3**: Selected prototypes: A) Prototype No1 insert for turning operations, B) prototype No2 drill head to drill a dead end boring and C) prototype No 3 a drill to drill composite material for aeronautic sector.*

The material selected for each of the prototypes and the requirements of the materials are described in the table 2:

***Table 2:** Requirements of the material*

	K10Type or similar Hardmetal: Turning tool for automotive and Drill for Aerospace	**K30Type or similar Hardmetal:** Drill bit for automotive machining
Chemical Composition	WC-6Co	WC-10Co
Hardness (HV10)	1800 ± 50	1600 ± 50
Porosity	<A02, B02	<A02, B02
K1c	8 MPa $m^{-0.5}$	9 MPa $m^{-0.5}$
Grains size	< 800 nm	< 800 nm
Microstructure	Uniform Carbide and Binder distribution, no third phases like carbon or mixed carbides (eta)	Uniform Carbide and Binder distribution, no third phases like carbon or mixed carbides (eta)

- Identification of pilot plant scale requirements:

  During this task the requirements of the pilot plant scale equipment (including the ceramic dies) were established. These requirements are strongly influenced by the material chemical composition (electrical properties) to be sintered and the size of the prototype.

  The basic requirements of the new sintering equipment were identified. These include the electrical module characteristics, mechanical load application unit features and the ceramic die requirements.

This data was crucial to design and manufacturing of the pilot plant scale equipment.

Concerning the ceramic dies, the key properties have been identified and preliminary values established. A number of ceramic candidates were also been proposed. The objective regarding the ceramic mould was to identify which are the key properties that the ceramic must have. Using those properties an investigation for ceramic materials and their characterisation was carried out in WP2.

- Requirements of the ceramic dies:

  Ceramic materials should combine special Physical, Thermal, Mechanical and Electrical properties, thus considerably limiting the number of candidate materials used for HERS dies. The key properties of the ceramics to be used as dies in the HERS process were identified.

***Table 3**: Requirements of the ceramic.*

Property	Requirement
1 Physical	
Density (g/cc)	---
Porosity (%)	<30%
2 Mechanical	
Flexural Strength MOR (MPa)	>50
Fracture Toughness (Mpa $m^{0,5}$)	>1.5
Stiffness-Yougn Modulus (GPa)	<200
3 Thermal	
TC (W/mºC)	<30
CTE (x 10-6/ºC)	<4
Max. Service Temperature (ºC)	>1000
4 Electrical	
Electrical resistivity (Ωm)	$>10^9$

WP2. Fundamentals of electrical Current Assisted Technology

The objectives of this WP are:

- To understand the fundamentals of the technology and development of materials at lab scale. To establish a relation between processing conditions-microstructure and mechanical properties.
- This WP will include the development of the materials and deep understanding between processing conditions-microstructure and mechanical properties.
- Benchmarking: samples with the same compositions will be obtained by other manufacturing techniques. Benchmarking of the technology: well-known material will be produced by hybrid current technology and their properties will be compared with commercially available products.
- The development of the ceramic dies and machining assessment of the obtained samples.
- Production of samples for characterisation in WP4.
- Simulation of the process to allow minimising the experimental trials during the process optimisation.
- Development of numerical models to aid the industrial scale equipment design and manufacturing.

Main Results:

- Selection of the raw material:
  Different powders were studied due to the fact that the selected powders at the beginning of the project were not suitable for the ERS technology. Powders from several suppliers were tested. Finally the most appropriate powder was selected for the project development.

- Understanding the fundamentals of the process:

A very comprehensive test matrix was performed to cover most of the processing parameters and identify how the sintering conditions affect the material microstructure and final properties. This study ended up with the definition of the optimum sintering parameters window for each powder composition. These conditions were use during the up-scaling process.

- Selection of the ceramic dies:

  Ceramic die plays a critical role in the HERS sintering process. For an efficient HERS process the die needs to be electrically insulating (to force all the current circulate across the powder), have good thermal insulating properties (low thermal conductivity to avoid heat leaks and the need of cooling), be resistant to thermal shock, have adequate mechanical strength and wear resistance (to increase their life), have adequate roughness for de-moulding, exhibit good machinability, be chemically inert, among the main characteristics.

  Different ceramic materials were developed and tested. Eventually 2 ceramics were selected for the dies manufacturing for HERS process. The most appropriate ceramic manufacturing process was also selected among: slip casting, uniaxial pressing extrusion and Cold isostatic pressing (CIP).

- Benchmarking

  A comparison between the HRES process and two other sintering processes was carried out (conventional sinter-hip and SPS).

- Simulation: development of the numerical model

  A model of the HERS process was developed which consider a mechanical and a thermal action on the powder mass. The mechanical action rules powder mass plastic straining depending on the pressure and temperature present in any point of the model. A creep law is governing this action. The thermal action predicts heat flow depending on thermal loss due to temperature gradients and heat generation due to Joule effect. At any moment and location in the powder mass, material properties are varied according to the considered point local temperature and density. Figure 4 shows and example of the temperature distribution and variation during the sintering process.

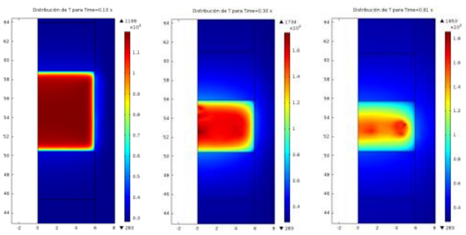


***Figure 4**: Temperature distribution in the sintering at different sintering stages.*

  The model was successfully implemented in a commercial Finite Element Software, after fixing several problems and predicts the sample temperature, porosity and stresses during the sintering process.

<u>WP3. Equipment design and Construction</u>

The objectives of this WP are:

- Design and manufacturing a pilot plant scale HERS equipment
- Design and manufacturing of ceramic dies for the prototypes processing.

- ❖ Design of the whole production line to allow a continuous production of parts using the developed technology.
- ❖ Installation of the pilot plant scale equipment in the industrial partners' facilities and Training.

Main Results:

- ➢ Design and manufacturing of ceramic dies for prototypes production:

  After the knowledge gained in the previous tasks the design of the dies to obtained the prototypes was successfully done: dimension, tolerances, size,… were defined to be able to produce the three tools defined in the project.

  Being aware of the importance of the dies two different materials were used to manufacture the prototype dies. Two die per prototype configuration were obtained. Figure 5 shows an example of some off the obtained dies with each material.

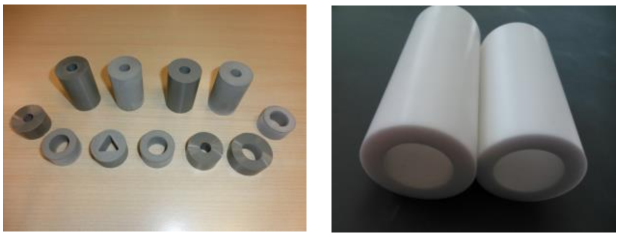


Figure 5*: Example of the ceramic dies obtained for the prototypes production.*

- ➢ Design and manufacturing of HERS equipment:

  The hybrid electrical resistance sintering (HERS) equipment is divided in three main parts: the electrical unit, the mechanical unit and the automatic production unit.

  Design of the electrical Unit: the electrical unit of the equipment has two different stages: the activation step and the sintering step. Based on the output from the previous task the dimensioning of the electrical part and the most appropriate activation method (in terms of electrical powder and current type) were selected.

  Design of the mechanical Unit: according to the required maximum load and the load application rate the most appropriate pressing system was designed and built. This press should be able to give the required load and have an adequate response time to allow an appropriate sintering process.

  Design of the automatic production line: The automatic system consists in the automatic powder feeding, automatic samples ejection from the mould and a pick and place system with a digital balance that makes possible to perform a preliminary quality control of the sintered part just after it has been manufactured without stopping the production.

  Figure 6 show the pilot plant scale equipment with all the parts described above.

***Figure 6**: HERS pilot plant scale equipment.*

In addition to the selection of the most adequate mechanical and electrical units, their design and construction; the software control system of the process was created. The process control system is one of the key features that ensures a successful and reliable sintering conditions. The process lasts only few seconds and many different phenomena and steps occur in such limited timeframe. Therefore and accurate control and response time of the devices is a must. The electrical two steps (activation and sintering) occur sequentially and the load is also applied during the process. Therefore a proper commutation and synchronisation of the different steps should be ensured. A specific software control was created to control, monitor and store all process parameters at every millisecond of the process.

The manufacturing of the pilot plant scale equipment was successfully done (including the production line). The equipment is fully automated: automatic powder filling and samples ejection system. A robot takes the samples and control the weight to ensure that the part has been done according to the required powder mass. Therefore the equipment can operate without the need of personnel.

WP4 Materials advanced characterisation

The objectives of this WP are:

- ❖ To characterise the materials at macro, micro and nano scale.
- ❖ To assist in the ceramics selection for the dies.
- ❖ To compare of the properties of HERS, SPS and sinter-hip samples.
- ❖ To help in the understanding of the fundamentals of HERS process.
- ❖ Evaluation of the prototypes after testing.

Main Results:

- Characterisation of the starting powders:

  The starting materials for the experimental investigations were characterised by chemical, microstructural and powder characterisation methods. Many different properties were assessed in the powders: apparent density, flowability, chemical composition (especially O and C content), electrical resistivity, thermal conductivity, particle size, particle size distribution, microstructure. The obtained properties allowed having accurate information about the powders quality and selecting those powders that fulfil with the requirements for the HERS process and the industrial use of the powders. Figure 7 shoes and example of the spherical shape of the used WC-Co powders

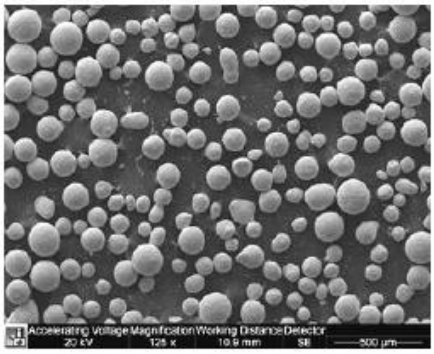


Figure 7: *Particle shape of the WC-Co powders.*

- Characterisation of the ceramic materials:

  The required electrical and thermal properties of the developed ceramic materials used in HERS processing were measured. In particular three key properties were studied in the ceramics: Thermal conductivity, Electrical resistivity and Coefficient of thermal expansion. This analysis allowed to select the most promising materials for the dies.

- Hard materials structural advanced characterisation:

  A comprehensive characterisation of HERS samples was done regarding microstructure, mechanical and magnetic properties. The obtained values were compared to conventionally obtained hardmetals. The following figures and tables illustrate the properties assessment and the comparison with commercial material.

  An example of the micro structure can be found in figure 8: it can be seen that EFFIPRO samples present finer grain size than Sinter-HIP samples.

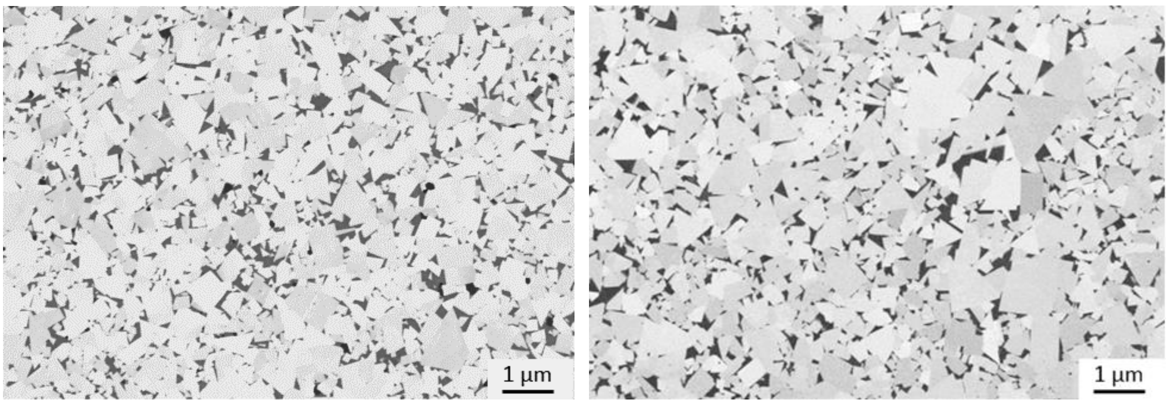


Figure 8: *HRSEM images of polished and ion-etched cross sections of ERS/WC6Co (Left) and Sinter HIP material (Right).*

Crystal grain size was estimated by the linear intercepts method (based on DIN EN 623-3). The measured lengths of intercepts for WC give a WC-grain size of about 274nm for HERS and 326nm for the conventional process (**¡Error! No se encuentra el origen de la referencia.**). The reason for this very low grain growth are the very short processing time and very fast cooling rate during the ERS process. The size of the Co phase is similar in the conventional and HERS processes.

Table 4: *Comparison of phase sizes of differently processed hardmetal WC6Co*

Process	*Phase*	*Length of intercepts (nm)*			*Number of measured regions*
		d_{10}	$\mathbf{d_{50}}$	d_{90}	
HERS	WC	73	**196**	441	934
	Co	28	**73**	218	310
Sinter-HIP	WC	89	**233**	528	932
	Co	28	**77**	195	417

Comparing these results with previous literature, grain size obtained in HERS samples is similar to the one reported by Spark Plasma Sintering of nanocrystalline powders. It is important to take into account that in the present work submicron powders were used instead of nanometric ones. The very low grain growth observed during processing opens the possibility of nano-crystalline hard metals.

Materials obtained by HERS (6 and 10 % Co) presented higher hardness compared to conventional materials obtained by Sinter-HIP (see **¡Error! No se encuentra el origen de la referencia.**5). A hardness increase of the 5 % was observed for the 6 % Co and and increase of the 8 % for the 10 % Co.

Table 5: *Summary of properties of differently processed hard metals*

Compo-sition	*Process*	*Density (g/cm^3)*	*Hardness HV30*	*Fracture toughness K_{1C} (MPa√m)*	*H_C (Oe)*	*M_S (10^{-7} $T{*}m^3{*}kg^{-1}$)*	*Co binder composition (wt%) W*	*Co binder composition (wt%) C*
WC6Co	HERS	14.7	1960±15	9.6±0.5	470	101	9.8	0.04
	Sinter-HIP	14.8	1860±15	9.5±0.5	385	103	8.8	0.03
WC10Co	HERS	14.3	1750±20	10.3±0.5	420	150	9.0	0.14
	Sinter-HIP	14.4	1620±15	10.2±0.5	320	154	13.9	~0

In HERS materials, a small variation of the hardness was observed between the core and the surface of the samples, presenting a small increase of the hardness at the surface. This phenomenon is not completely clear at the moment. This can be linked to a slightly higher grain size observed at the core of the samples. Samples are heated by Joule's effect during HERS and the temperature at the core of the samples is slightly higher than at the surface. This longer time at high temperature can produce a very small increase in grain size. Another possible explanation is the migration of Co from the core of the samples; this migration can produce small micro-porosity and the local decrease of the hardness. However, not significant variations in the Co content were observed.

Fracture toughness (K1c) reveals similar behaviour for the differently processed samples (conventional and HERS) with values in the range of 9-10 MPa m0.5 (see **¡Error! No se encuentra el origen de la referencia.**). It is known that fracture toughness decreases with increasing hardness in conventional composites, whereas the increase of hardness in nano-structured composites does not further reduce their bulk fracture toughness. The very short processing time used in HERS (in the orders of few seconds) helps controlling the grain growth and thus obtaining finer microstructures. It is believed that this reduction in grain size increases the hardness but maintaining the fracture toughness constant. The microstructural characterisation of the WC–Co hardmetals is often performed using magnetic measurements. By measuring the magnetic saturation MS or the coercivity HC, it is possible to obtain an approximation of the WC grain size, cobalt content and even determine the presence of additional phases. Generally, an increase of coercivity is observed with a decrease in WC grain size. The comparison of the measured HC values of HERS with Sinter-HIP samples confirms the reduction in grain size observed in HERS materials. The measured MS values (**¡Error! No se encuentra el origen de la referencia.**) suggest, that all samples are near the lower C limit, as it is presented in **¡Error! No se encuentra el origen de la referencia.**.

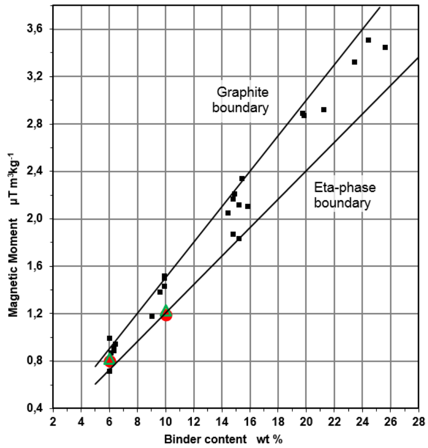


***Figure 9**: Magnetic moment of different WC/Co hardmetals plotted against Co content compared with the values of the fabricated samples (ERS ●, Sinter-HIP ▲)*

- Characterisation of the virgin Prototypes:

The HERS prototypes reveal very fine microstructures with WC-grain sizes of below 300nm. These fine microstructures cause hardness`s with HV30 > 1700 and high coercivities of HERS prototypes. After the process optimization the Co-distribution is nearly constant across the bulk sample resulting in acceptable microhardness distribution.

The chemical analysis revealed acceptable oxygen and carbon content in the prototypes.

Fracture toughness (K1c) obtained using the Palmqvist method reveals similar behaviour of the HERS prototypes compared to conventionally sintered or SPSed references, with values around 10 MPa $m^{0.5}$.

The following two tables illustrate the compliance of the obtained properties with the specifications. It can be observed that all the specified properties have been achieved except the hardness value for prototype No3 which is slightly lower than the required value (but it is needed to take into account that 10 % of Co was used instead of 6 %).

***Table 6:** Properties of PROTOTYPE No1 and No3*

	REQUIREMENT	EFFIPRO PROTOTYPE No1	EFFIPRO PROTOTYPE No3
Hardness (HV10)	1800 ± 50	1880± 13	1778± 17
Porosity	<A02, B02	<A02, B02	<A02, B02
K1c	8 MPa $m^{-0.5}$	9.4± 0.3	10.3± 0.2
Grain size	< 800 nm	330nm	330nm
Microstructure	Uniform Carbide and Binder distribution, no third phases like carbon or mixed carbides (eta)	Uniform Carbide and Binder distribution, no third phases like carbon or mixed carbides (eta)	Uniform Carbide and Binder distribution, no third phases like carbon or mixed carbides (eta)

***Table 7:** Properties of PROTOTYPE No2*

	REQUIREMENT	EFFIPRO PROTOTYPE No2
Hardness (HV10)	1600 ± 50	1728± 15
Porosity	<A02, B02	<A02, B02
K1c	9 MPa $m^{-0.5}$	10.4± 0.2
Grain size	< 800 nm	330nm
Microstructure	Uniform Carbide and Binder distribution, no third	Uniform Carbide and Binder distribution, no

	phases like carbon or mixed carbides (eta)	third phases like carbon or mixed carbides (eta)

WP5 Industrial components manufacturing and testing

The objectives of this WP are:

- The industrial implementation and validation at pilot plant scale of the newly developed processes.
- Production of blanks by HERS process.
- Production of the tools and their testing by the end-user

Main Results:

- Installation of the pilot plant scale equipment:

  The pilot plant equipment was installed in the facilities of AMES in Barcelona. The machine has automatic dossing and pick and place system for a continuous operation.

- Manufacturing of the blanks:

  The blanks for the prototypes manufacturing were produced at AMES and the final machining was performed at UNIM.

  In order to find the optimized parameters for the manufacturing of the blanks, several sets of parameters were used including: applied pressure and intensity, sintering time, cooling time, and the powder chamber (mass). A total of 147 references were tested and about 545 blanks were manufactured, more than 5 sets of punches and about 30 kg of each of the two compositions of WC-Co were used. For every new reference developed, a small sample was characterized (density, microstructure, hardness and toughness. Figure 10 shows an example of the blank used for prototype No1 production.

Figure10. *Blank for prototype No 1 with edm'ed internal hole.*

- Tools production:

  Once the blanks were manufactured, the tools were produced form those blanks. As described earlier, 3 different tools (prototypes) were produced: insert, drill bit and a drill.

  Prototype No1: in order to obtain the insert, the blank was grinded using diamond grinding wheel. After grinding of the inserts was finished, the cutting edges were rounded to a pre-established radius. Figure 11 show a photograph of the prototype No1.

Figure11. *Prototype No 1.*

Prototype No2: The blanks were flat ground to prepare them for brazing. The shank of the drill was made of a standard hardmetal grade. After brazing, the whole drill had to be externally ground. The next step was to grind the drill blank in a CNC grinding machine that had been programmed according to the desired final tool geometry. Figure 12 show a photograph of the prototype No2.

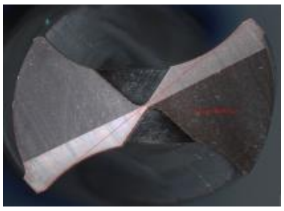


Figure 12: *Prototype No 2: left: Drill head front picture. Right complete tool (brazed head to the shank)*

Prototype No3: The manufacturing procedure was the same as described above for the prototype No 2 drill. There are some additional steps involved due the long L/D ratio of this tool and the tool geometry. Figure 13 show a photograph of the prototype No3.

Figure 13: *Prototype No 3.*

The three prototypes were successfully produced.

- In service testing and subsequent characterisation of the tools:

Prototype No1:

The first prototype is an insert that it was used to machine the outer diameter (turning operation) of the parking-position lock from an automatic transmission shown in figure 14, a low alloy steel.

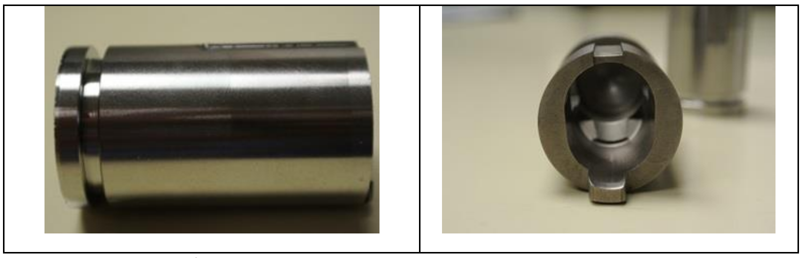


Figure 14: *parking-position lock from an automatic transmission to be machined showing the two areas where turning, prototype No1 (right picture) and drilling prototype No2 (left picture) is done.*

This prototype No1 tested at AMES, showed better behaviour than conventional tools (when the same tool geometry and size is used, see Figure 15 and Figure16). The quality of the machined parts (roughness) is similar whatever tool is used.

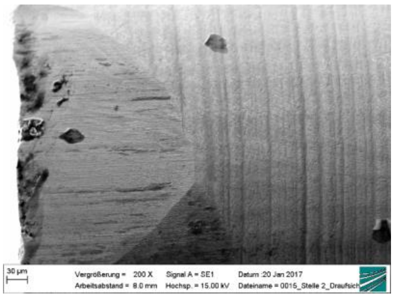


Figure15. *SEM picture, edge of conventional tool after testing*

Figure16*. SEM picture, edge of EFFIPRO tool after testing*

The quantitative analysis of the tool wear is shown in the table 8. It can be appreciated that the wear in EFFIPRO tool is smaller than that observed in commercial tools.

Table 8: *Comparison of tools obtained with conventional material and EFFIPRO material*

	Initial measurements/mm	Final measurement/mm	# parts	Wear %	Wear average
EFFIPRO tool	30,242	30,321	15	0,53	0,42
	30,246	30,262	5	0,32	
Commercial flat tool	30,214	30,268	5	1,08	0,95
	30,214	30,255	5	0,82	

Prototype No2:

Prototype 2 is a drilling head designed to drill the same part that was turned using prototype No1 (see figure 14 right). The drill head manufactured by the EFFIPRO process was brazed to a standard hardmetal grade shank.

Lab tests of the tool carried out at UNIMERCO revealed a good behaviour of the tool. The tools withstand all machining tests without breaks at the joining interface. The development of the edge radius (figure 17.) during drilling of several holes is presented in table 8. The measured values demonstrate nearly no development of wear during the machining.

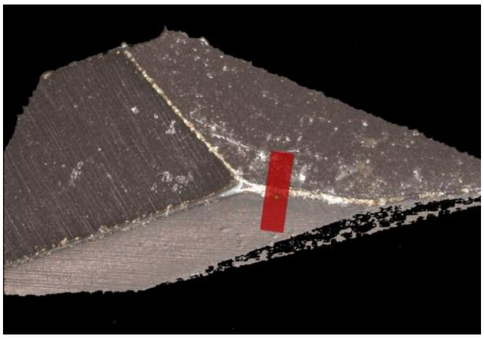


Figure 17. *Measured edge of the drilling head after machining of different holes.*

Table 9: *Measured development of the edge radius during drilling.*

Number of drilled hole	Measured radius of the functional edge of the EFFIPRO tool in µm
1	20.1
2	21.4
3	20.8
5	20.9
10	22.1
15	20.5
20	19.9
25	17.3
30	19.1

During the field tests the tool failed prematurely from the brazed interface between the tool head and the stem. Usually, the contact surface between both parts (head and stem) is not flat like the EFFIPRO tools. The interface is reinforced with two pins that fit the drill head to increase the resistance to the torsion stresses. Therefore, it has not been possible to evaluate prototype No2 behavior under industrial environment.

Prototype No3:

Prototype No3 is a drilling designed to drill holes in CFRP/TA6V stacks for aeronautic applications. AIRBUS was the responsible of the field tests of this tool.

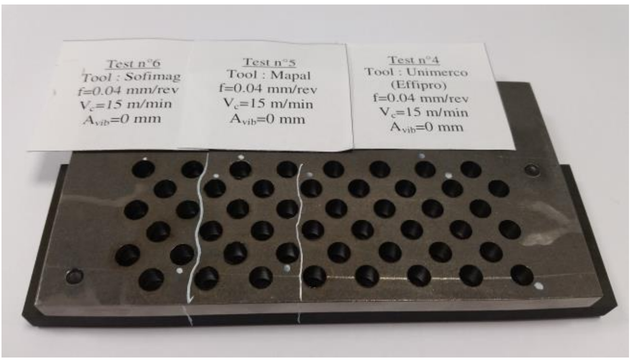


Figure18. *CFRP/TA6V stacks used to drill the holes.*

Testing at AIRBUS of prototype No3 was very promising. Testing in dry conditions was performed to the EFFIPRO tools compared to 2 different conventional tools (standard tool and another commercial tool). Better results in terms of wear resistance (see **¡Error! No se encuentra el origen de la referencia.**19) and durability of the tool were observed with the EFFIPRO tools.

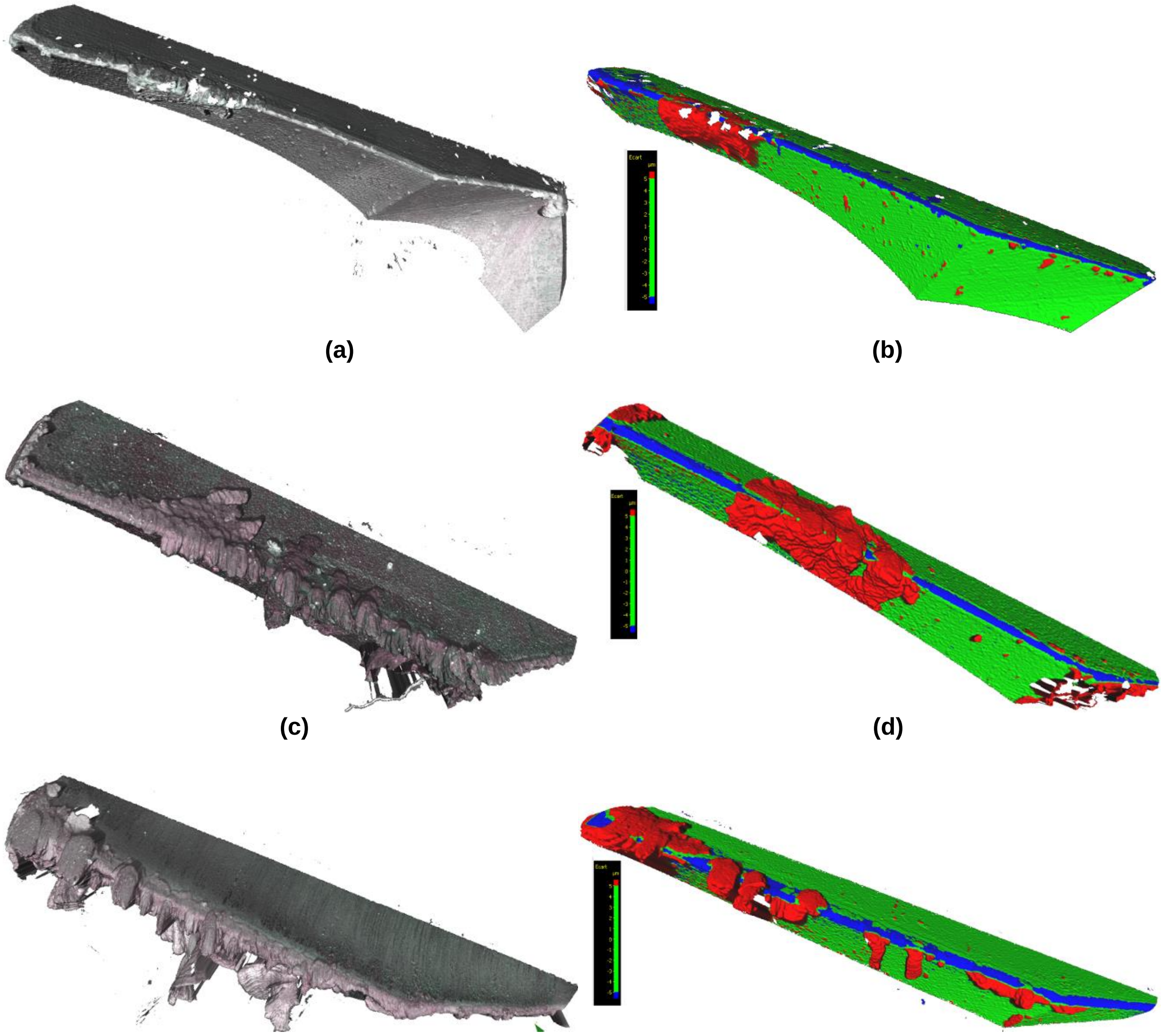


Figure 19 *:Evolution of the cutting tool: EFFIPRO Tool (a-b), Standard tool(c-d) and other commercial tool (e-fol) for 27 holes drilled in CFRP/TA6V under dry conditions: (a) one cutting edge of the EFFIPRO tool, (b) Superimposition of the new and worn cutting edge of EFFIPRO tool, (c) one cutting edge of the Standard tool, (d) Superimposition of the new and worn cutting edge of Standard tool, (e) one cutting edge of the other commercial tool, (f) Superimposition of the new and worn cutting edge of other commercial tool.*

By looking at Figure , two tool wear mechanisms are exhibited for the three cutting tools:

- A loss of material due the abrasion phenomenon of CFRP (in blue on the figure)
- A sticking of titanium on the cutting tool (in red on the figure)

No main differences are observed between the three cutting tool, but lower addition in the EFFIPRO tool.

Ranking was established between the three tools (**¡Error! No se encuentra el origen de la referencia.**10). The lower final number means the better performance.

Table 10: *Results of drilling tests in CFRP/TA6V*

Rank	EFFIPRO TOOL	STANDARD TOOL	OTHER COMMERCIAL TOOL
Axial Force	2	1	3
Torque	1	3	2
Temperature	1	3	2
Diameter	2	3	1
Roughness	1	3	2
Tool wear	1	2	3
TOTAL	**8**	**15**	**13**

The best tool among the three tools is the EFFIPRO tool.

The test campaign was repeated using vibration assistance and it improved the performance of the tools. EFFIPRO tools are promising compared to conventional tools in dry conditions but tests with lubrication are needed to fully characterize the EFFIPRO materials

WP6 Recycling, LCA & Standardisation

This work package has three main objectives:

- To quantify and analyse the environmental impacts from the new process with the help of the LCA- (Life Cycle Assessment) Methodology according to ISO 14040:2009, 14044:2006 and International Reference Life Cycle Data System (ILCD) Handbook. Quantify and analyse environmental impacts according to ISO 14040:2009 / 14044:2006 LCA Methodology
- Standardise the process according to European standards. Definition and collection of relevant European standards related to Safety and Electromagnetic compatibility (EMC).
- Definition and collection of relevant European standards related to nanoparticles.
- Recycling and re-using the material produced in the process and tools after their life.

Main Results:

- Environmental Impact Analysis:

  In order to evaluate the environmental impact, LCA methodology was applied to the technology developed within EFFIPRO and compared to the conventional process.

  Life Cycle Assessment (LCA) was carried out as a tool to analyse and evaluate environmental impacts caused by products throughout their life cycle (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). Life cycle assessment is the only method that assesses the environmental impacts of a product or activity (a system of products) over its entire life cycle. Main characteristics of the LCA for EFFIPRO are:

  - LCA presents results for 12 alternatives: 3 different tools (turning tool insert, drilling head and drilling tool) made by 2 different alternatives (traditional and EFFIPRO processes) and considering 2 different scenarios (production of a large number of tools and production of one tool).
  - 10 LCA environmental impact categories have been quantified and analysed including the contribution to climate change, ozone layer depletion potential, primary energy consumption, etc.

  LCA results show that the environmental impacts of EFFIPRO process are much lower than the traditional' s when producing less than 70 tools. The energy consumed during the machining of the tools in EFFIPRO conditions this result. The process for the fabrication of the blanks was not optimized and an important machining stage is needed to obtain the final tools. Optimizing the fabrication of the blanks, EFFIPRO will be adequate for the fabrication of a higher number of tools from the environmental point of view.

  It is important to know that there is no a lineal relationship between the impact and the number of tools produce in traditional technology. In the traditional process, all the pieces are introduced in the same furnace, for that reason, the impact depends on the number of tools per cycle in the furnace and it depends on a lot of factors, not only the capacity of the equipment. Because of that, 12 different alternatives have been analysed in order to provide a very complete view of the variability of the results depending on the assumptions taken. The 12 alternatives consisted on 3 types of tools (turning tool insert, drilling head and drilling tool), assessed by 2 different processes (traditional and EFFIPRO) and in

2 different scenarios (production of a large number of tools and production of one tool). The creation of scenarios allowed providing relevant information in the comparative study, allowing understanding until which number of tools EFFIPRO sintering process is more energy and environmentally efficiency than traditional process.

Results show that the new process has associate lower environmental impacts compared with traditional process when producing less than 70 tools. This is mainly because the energy consumption in EFFIPRO sintering process is lower than in traditional process in the production of individual units. However, in the production of more than 70 tools, traditional process seems to have a better energy and environmental performance because it takes more advantage from the furnace. In other words, the variation of the energy consumption of a traditional furnace with respect of the number of tools produced is not very high.

In addition to the LCD analysis some Key performance indicators were identified and evaluated. Indicators and targets are important tools to guide, measure, monitor and improve progress. The framework includes a list of key performance indicators (KPIs) defined according to the critical parameters identified for EFFIPRO project. The KPIs aim to measure the performance of the EFFIPRO process in comparison with a traditional sintering process. The comparison allows the quantification of the improvements of the new process in terms of cost, energy use, process time, use of resources, etc.

The evaluation of the indicators presents the following conclusions for the EFFIPRO process:

- In energy and environmental terms EFFIPRO technology is more efficient until the production of 70 tools. This result is mainly conditioned by the machining of the tools.
- In terms of the speed of the process, EFFIPRO technology is faster than traditional until the production of small series of tools. Again the long time that the machining requires conditions this result.
- In economical terms, EFFIPRO tools are more profitable than traditional´ s until the production of 40 tools if the same selling price is considered. Less energy in machining and material requirements will help to improve this result.

Several EFFIPRO project objectives are successfully reflected in the results of the indicators framework. EFFIPRO is more energy efficient, more profitable and the process is faster than traditional process when producing little number of tools. Further research is needed in order to improve this results but it can be concluded that project developments provide relevant, valuable and promising developments to the sintering processes.

➢ Standardisation:

Within the EFFIPRO project a new technology was developed and materials with new characteristics were obtained. For that reason, the possibility of creating new standards or modifying existing ones was considered for the following fields:

- New standards for the characterization/testing of new materials (hard metals)
- New standards related to the equipment
- New standards related to the new technology and processing route

- New standards about specific tooling

The survey carried out at European and worldwide standards/directives level in relation to the above topics resulted that all the possible field requiring standards are well covered by current standards and directives. Therefore there was no found need to create new standards or modify existing ones, such as: ISO/TC 119 Powder Metallurgy (in particular under Sub –Committee 4 Sampling and testing methods for hardmetals. This SC4 is very active and currently some standards are under review).

- Recycling:

The materials used in EFFIPRO project belong to commercial hard metal family. Their composition is formed by WC and two different metallic binder compositions: 6% Co and 10% Co. These two compositions are commercial materials and the recyclability issues have been already developed at industrial scale. Therefore, within EFFIPRO a review of already existing different recycling process for hard metals was done. The EFFIPRO project has not developed any new recycling process.

There are different methods for the recycling of hard metals: the physical, the chemical and the metallurgical. Physical method involves crushing and milling the sintered product, until it reaches the target particle size. It can then be employed as coated or loose abrasive. Chemical reclamation is in principle simpler, since it treats the reclaim material as if it were ore concentrate, putting it through almost the entire chemical process to produce powdered raw material of the highest quality. The metallurgical normally describes the so-called zinc process, which produces intermediate results. From the economic point of view, the physical process is less expensive but the quality of the final products is very low. Zinc process can be an alternative from the economic point of view b ut main drawbacks are the lack of purity and the difficulty of maintaining good grain-size distribution. For that reason, zinc recycled materials are not used for high quality hardmetal parts in a large percentage.

Bearing in mind all this information, for hard metals not very contaminated as produced in EFFIPRO after testing, the zinc process seems to be the best alternative for recycling.

WP7 Dissemination and exploitation of project results

This work package has three main objectives:

- To ensure the maximum impact of EFFIPRO project through effective dissemination of the project results and to develop a structure to assure the continuity of EFFIPRO after the project end.
- To assure a successful exploitation and to establish the basis for the market uptake of EFFIPRO through a strategic and business-oriented commercialization plan including dedicated business models and the appropriated IPR management for the knowledge generated during the project.

Main Results:

- Dissemination:

  Due to IPR issues and allow a proper protection of the results (patenting) before disclosing sensible information dissemination activities have been limited until the patents have been applied. Nevertheless, thanks wide network and numerous evented organised by EPMA (European Powder Metallurgy Association), several dissemination activities have been carried out: conferences, congress, fairs, magazines, newsletter, training courses,…

- Exploitation:

  During the last stages of the project especial efforts have been done to set up an exploitation plan and establish an exploitation road-map of the key exploitable results generated in the project. Four different exploitable results have been generated:

  1. Hybrid Electrical Resistance Sintering Equipment
  2. Hybrid Electrical Resistance Sintering Process/Technology
  3. Development of advanced dies and ceramic materials
  4. Improved Cutting Tools UNIMERCO

  Two patents have been applied to protect two of them. The other two will be protected through “Trade Secret”.

  Result number 3 (ceramic materials) is already being exploited directly (commercialisation of powders) by one of the partners of the project). Results 1 and 2 will be exploited indirectly by means of a technology transfer or licencing of the technology to a Third party.

WP8 Project Management

The coordinator and the partners involved in project management have normally dealt with all the day to day administrative aspects:

- Management of funding
- Distribution of information from the EC to the consortium
- Organisation of consortium progress review meetings
- Preparation of periodic report
- Distribution of project reports and further deliverables to the EC
- Resolving of problems occurring between the partners during the project

More in detail, management activities are listed:

Website of the project www.effipro.org with the update information of the project. The website is divided in two different areas, one for public dissemination of the project and, the second one, only for project members.

Organization of progress project meetings (KOM, 6 months, 12 months, 18 months and 24 months, 30 months, and final meeting (40 months)

Preparation of the official reporting documents.

Distribution of the funding between partners.

4.1.4.- POTENTIAL IMPACT- DISSEMINAITON ACTIVITIES-EXPLOITATION RESUTLS

Potential Impact:

This project will increase the competitiveness of European powder metallurgy companies. General market for the Hybrid ERS technology/equipment is Powder sector (equipment and parts manufacturers). With this new technology is possible to perform the sintering of any conductive powder (metals and composites) and it opens a large market. Powder Metallurgy is the general market for the Hybrid ERS equipment and technology. Inside PM, specific markets are the

- cutting, drilling and mining tool sector.- This sector is also important for the Advanced Cutting Tools developed within the EFFIPRO project (exploitable result)
- automotive industry
- aerospace industry
- Other markets

Ceramic dies and materials developed within EFFIPRO, in addition to the HERS technology, can be used in the advanced ceramics sector for extreme conditions.

The impact of the project for the partners is the following:

UNIMERCO will benefit from the project because a new manufacturing process will allow producing customized tools with reduced lead time and improved performance (lifetime and properties).

MIRTEC has developed a new generation of advanced ceramics, not only appropriate to be used as dies in the HERS process, but also for high temperature and dielectric applications.

AMES, as technology developer and end user will get several benefits from the project: first of all it is co-owner of the technology /equipment development, and hence it is very interested in the exploitation of the technology (technology transfer to a Third party), as PM parts producer will get the benefit of using the new technology to produce some of the components they currently produced using conventional PM processes. Last but not least as end user will benefit from the new generation of cutting tools developed in the project.

AIRBUS as end user will benefit from the new tools to machine titanium based alloys, CFRP and stacks made of Ti-CFRP.

Dissemination Activities

The dissemination activities have been divided in two different categories:

- General Dissemination: where the audience is the general public.
- Industrial and Scientific dissemination, where the targets are specific communities.

- General dissemination: A public website was set up at the start of the Project and regularly updated with the Project's progress and public results, following an editorial plan that will define the expected contribution of partners. The website will remain active for at least 5 years after the completion of the

Project. Therefore, the Project will have a public area where the main public progress and outcomes of the Project will be available to the scientific community and the general public, and a private section for the Consortium. An introductory leaflet and a poster for the general public and the expert audience were created. A brochure has been issued every six months to provide information about the current status of the Project.

Leaflet and Poster/Roller Banner: The Leaflet and Poster/Roller Banner has been used by Consortium members at their dissemination events. The EPMA has kept revise the leaflet and poster updated along the project.

Website: The *EFFIPRO* Website (www.effipro.org) has been developed with a public and a private area. The public page contains information about the Project, links to the Consortium members' websites, an area for news, documents such as scientific papers, research and also a 'Contact Us' page.

- Dissemination to the scientific and industrial community: Partners have participated and disseminate their work in relevant conferences and congress and in scientific journals.

  Participation in Congress and Conferences: participation in the main 3 powder metallurgy events that were held during the project lifetime:

  1. Euro PM2014, 21-24 Sept 2014 in Salzburg, Austria. 1 scientific article.
  2. Euro PM2015, 4-7 October 2015 in Reims, France.: 1 scientific article.
  3. World PM2017 12-15 October 2017 in Hamburg, Germany: 3 technical contributions, an EFFIPRO stand and the End Users workshop were presented at the event.

The Project has also been presented in the following sectorial and working groups:

- European Hard Materials Sectorial Group (EHMG)
- European Structural Parts Group (ESPG)
- European Metal Injection Moulding Group (EuroMIM)
- European Powder Metallurgy Group (EPHG)
- European Additive Manufacturing Group (EAMG)
- European Powder Metallurgy Academic Network (PMRADNET)
- Research Education and Training Working Group (RET).

All of the above groups are coordinated by the EPMA. Special presentations given in smaller committees' like the PM sectorial Groups listed above where a higher interactivity is possible between the Consortium partners and the participants. This enabled an enhanced dissemination of the technology by focusing on some aspects of the Project, which may be of interest to the sectorial group. Furthermore, the EPMA will ensure the visibility of the Project in its other events like the two day short course (up to 2 per year).

Participation in other events:

- The International Conference on the Science of Hard Materials
- International Conference on Sintering

- Powder Metallurgy World Congress and Exhibition
- The International Conference on the Science of Hard Materials (ICSHM13)
- Hagener Symposium Pulvermetallurgie (D)
- International Conference on Powder Metallurgy & Particulate Materials (US)

Training activities: Training activities have been identified as a way of disseminating results. Dissemination of EFFIPRO in two different levels was carried out:

1) A first 'Introductory Level' in the form of a Summer School for ca. 50 young students (Master Level) and engineers (less than 35 years old), where the background and the potential of the technology was addressed. This is a long term dissemination strategy since these 'future high potentials' will bring with them the *EFFIPRO* knowledge to their companies and universities. This will ensure a successful penetration of the *EFFIPRO* technology within the scientific and industrial community. A Summer School is organised every year where the *EFFIPRO* Project has been presented: overall in 3 Summer Schools.
2) A second 'Experts and End Users level' in the form of a Training Workshop at the end of the Project for senior scientists and industrials on possible dedicated subjects: thie waorkshop was held during the world PM 2017 conference.

Exploitation of the results:

The project has generated 4 exploitable results:

1 Hybrid Electrical Resistance Sintering Equipment

2 Hybrid Electrical Resistance Sintering Process/Technology

3 Development of advanced dies and ceramic materials

4 Improved Cutting Tools UNIMERCO

During the last stages of the project an exploitation plan and establish an exploitation and a road-map for the exploitation of the key exploitable results has been set up.

Results 2 and 3 are protected through two: one for the technology and the other for the developed new ceramics Results 1 and 4 will be protected through "Trade Secret".

Result number 3 (ceramic materials) is already being exploited directly (commercialisation of powders) by one of the partners of the project). Results 1 and 2 will be exploited indirectly by means of a technology transfer or licencing of the technology to a Third party.

4.1.5.- PROJECT WEBSITE

www.effipro.org