PROJECT FINAL REPORT

Grant Agreement number:	**232127**
Project acronym:	**ASPIRATE**
Project title:	**Increase of productivity, safety, greenness and cleanliness in the machining of carbon fibre reinforced composites**
Funding Scheme:	**RESEARCH FOR THE BENEFITS OF SMEs**
Period covered: from to	**from 1st June 2009 to 31st May 2011**

Name of the scientific representative of the project's co-ordinator, Title and Organisation:

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1. Final Publishable Summary report

1.1. Executive summary

Aerospace industry has been the key market for pushing this big leap towards industrial production of fibre reinforced composite components. Nowadays, the development of the production techniques and the reduction on production costs have allow wider applications in emerging markets, such as, wind energy, deep water oil platforms and transportation, as well as in more traditional scenarios like construction and civil structures or sporting goods sector.

Nevertheless, some phases of the composite products production chain present several hazards for the operator's health as well as the environment impact.

The Research for the Benefit of SMEs project, ASPIRATE, aims for giving and answer to the aforementioned drawbacks, eliminating the dust and chips completely from the working area, without affecting the operator, contributing to the cleanliness of the workpiece and maintaining the maximum flexibility of the process, as no external or peripherals.

The technology resultant from this project is based on the machining with internal chip and dust evacuation, through a hollow tool connected to a standard HSK tool-holder, a modified spindle and a suction pump attached at its rear.

The preliminary tests made on carbon and glass fibre reinforced plastics (CFRP and GFRP respectively), opened exciting application possibilities. ASPIRATE consortium involves several SMEs from these sectors, as well as, RTD actors with the experience and skills for ramping up these developments to real industrial applications.

The industrial consortium is formed by 4 SMEs from 3 European countries. All these SMEs are also intensive in R&D, as it is the case of INVENT GmbH (Braunschweig, Germany) in the design and development of aerospace components and structural applications in CFRP and GFRP, the company RHO-BEST (Innsbruck, Austria) in the development of advanced coating materials and processes, ORTZA S. Coop. (Huarte, Spain), a machine tool producer SME, with a clear target on the design and building of specialised machines for machining composite materials and finally, ZUBIOLA S. Coop. (Azkoitia, Spain), as manufacturer of special and customised cutting tools.

It is worth to mention that the beneficiary company ORTZA S. Coop. decided to leave the project in February 2011 due to the hard financial conditions this company was suffering due to the economical crisis.

After a validation process made jointly with the REA officers, it was agreed to replace ORTZA S. Coop. company by the Spanish SME company EGURKO S. Coop, which is also focusing its activity on the production of machine tools for the wood sector with high interest on the evolution of its machines to the design and production of machines for the composite industry.

The final entrance of EGURKO S. Coop. to the consortium was effective on the 15th February 2011 and it was also stated on the 1st Amendment to the contract finally signed by the REA director on May 2011.

The coordinator of the project is IDEKO-IK4, a Spanish research centre specialised on machine tools, production equipment and manufacturing processes, with a comprehensive trajectory on Framework Programmes research activities. The other RTD

is the Fraunhofer IST, with large experience also on the participation of EU funded projects.
ASPIRATE project did start on 1st June 2009 and ended on the 30th May 2011, so it has lasted a total of 24 months. In this period some key achievements have been obtained, such as the development of a complete system for the machining of CFRP materials extracting the chips and dust through the tool-holder-spindle-pump system, the design, production and testing of hollow cutting tools with brazed diamond coated inserts, as well as the corresponding validation of the system, tools and process parameters over real industrial test cases.
In the first period (Month 0 to Month 12) the consortium completed the design and implementation of the machine tool, which was ready to accomplish the machining tests. ORTZA and IDEKO beneficiaries had a key role on the developments of the machining system.
In the same way, several designs of cutting tools were designed during this first period by ZUBIOLA and IDEKO, and tested on different machining processes (trimming, cutting, drilling, pocketing) in order to find the most appropriated tool design (number of teeth, aspiration window size, substrate), pump under-pressure, and process parameters (cutting speeds, feeds, depths of cut).
The development of coating materials as well as appropriated coating processes was the joint activity performed by the Fraunhofer IST and company RHO-BEST.
During the second part of the project (Month 13 to Month 24) the consortium focused its activity on the optimization of the machine system (tool holder, spindle & vacuum pump), having it ready for accomplish the machining of different materials (CFRP and CFRG) as well as different workpieces and different cutting strategies. This activity was performed by the new partner EGURKO with the support of IDEKO research center.
Partners ZUBIOLA and IDEKO focused their activity on the development and optimization of cutting tools geometry, developing different designs according to the machining operation to be performed and the requirements of the part in terms of material to be removed, surface integrity and cutting parameters programmed.
The partners RHO-BEST and FRAUNHOFER IST continued the optimization of the diamond based coatings for avoiding the high wear rate observed on the preliminary machining trials.
Finally, the end-user beneficiary INVENT GmbH company accomplished the successful industrial validation of the internal chip extraction machining process over real parts.
More information, pictures and news from the project can be accessed through the project's website: http://www.aspirate.eu.

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1.2. Project objectives, work progress and a description of the main S&T results

The main objective of ASPIRATE was to develop an **innovative technology for machining carbon and glass fiber reinforced plastic (CFRP and GFRP) parts** based on the **internal extraction of the produced chip and dust particles through the whole machining system (cutting tool, tool holder, spindle),** avoiding all the external devices and suction pumps used nowadays, which reduce the flexibility and leave an unclean part (they do not achieve a complete chip/dust extraction), with the consequent risk for the operator's health and machine's components.
The internal chip extraction technology is based on 3 main components:

1. Hollow cutting tools suitable for machining CRFC.
2. Diamond coatings with high abrasion wear resistance,
3. Chip extraction system operating on the machine tool

The new chip and dust extraction system is rated to become a **breakthrough and a reference for machining companies in search of highly productive and human safe technologies in composite parts production**. The technological advances achieved by the end of this project will lead European countries to the head of world composites machining industry, with a qualitative jump for at least 3 years.

The specific **objectives of the project,** as they appeared on the Description of Work for the activity performed in each of the WPs, are listed below:

WP1: System Identification and Working Procedure

1. Detailed definition of the requirements of the pilot cases to test using the internal chip extraction technology, different applications and materials.
2. Real working conditions in terms of productivity, cost effectiveness, quality and accuracy from the end user point of view.
3. Definition of the main features and characteristics of the system, according to the requirements of the end users and targeted materials
4. Detailed definition of the development and testing procedure to be applied in the different phases of the project, from the preliminary flow analysis to the final implementation of the system in the machine tool.
5. Definition of the environmental and safety aspects to be introduced into the pilot system.

These first activities were accomplished during the first 6 months of the project (1st June 2009 to 1st December 2009). During the development of this first group of definition activities, the involvement of the SMEs was crucial, as the system to be developed must

fulfill the expectations of the participating SMEs and also should give a cost effective and quality response to the requirements established by the market.
As an example of the activity performed in this WP, the next tables show the process parameter data for different cutting processes defined by AIRBUS for the production of composite components. This information was provided by beneficiary company INVENT GmbH along with the tentative industrial parts to be used for the validation of this innovative cutting process, as it can be seen in Figures 1, Figure 2 and Figure 3 below:

Process	***Tools***	***Parameters***
Drilling	SHM twist drill 85°-100°	v_c = 50 - 100 m/min f = 0,02 - 0,08 mm
Countersinking	HM countersink or spotfacer	n = 800 - 1200 1/min f = 0,05 - 0,2 mm
	PCD countersink or spotfacer	n = 1200 - 2400 1/min f = 0,1 - 0,3 mm
Reaming	SHM or HM machine reamer	v_c = 10 - 25 m/min f = 0,1 - 0,2 mm

Process	***Tools***	***Parameters***
Milling	HM, PCD, diamond coated multi blade end mills	v_c = 150 - 800 m/min v_f depending on axial and radial thickness

Process	***Tool***	***Parameters***
Side milling	PCD end mill 3-5 cutting edges diameter: 8 mm	v_c = 300 m/min spindle speed = 3100 1/min v_f = 400 mm/min axial depth = 4 mm radial depth = 8 mm

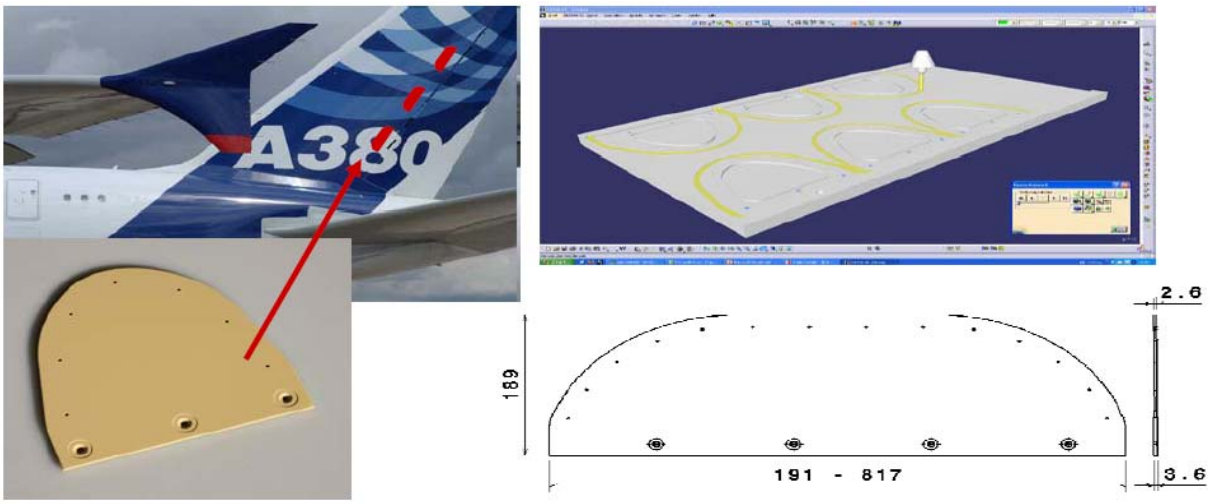

Figure 1.- Cut-out panel (AIRBUS A380), provided by INVENT GmbH

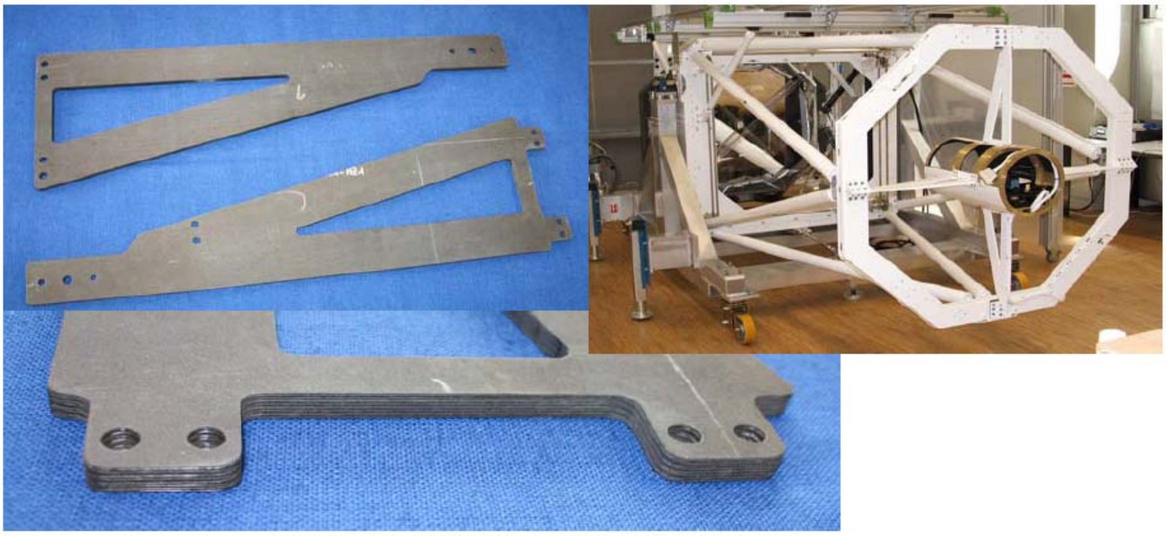

Figure 2.- SUNRISE telescope

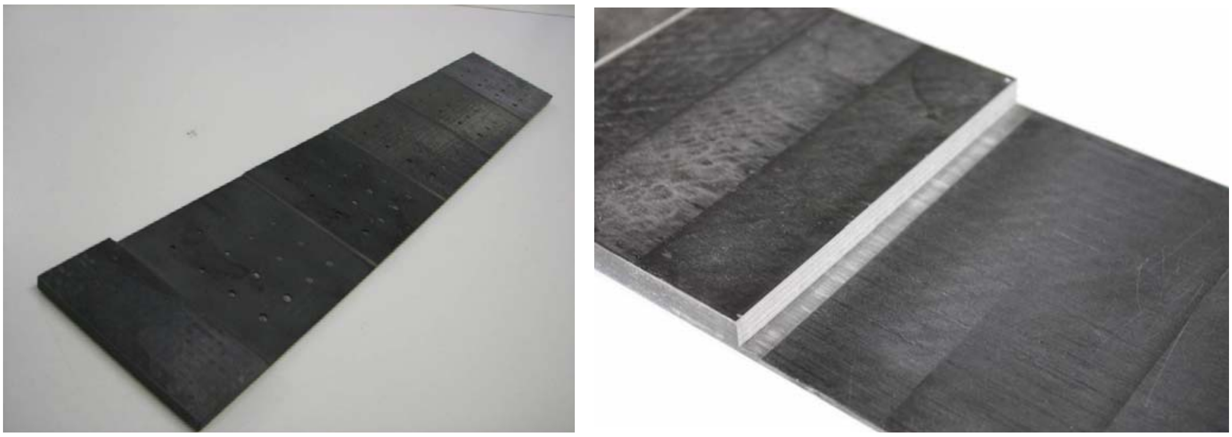

Figure 3.- Step wedge part: complete view (left); detail view of the steps (right)

WP2 Pilot System Development

The objectives defined for this WP were oriented to develop the core elements that will make up the internal chip extraction technology, making it feasible to be applied on industrial scenarios:

- A new **electro-spindle** able to integrate the internal chip extraction technology. As well as the technological breakthrough for chip extraction, power, stability, rotational speed and accuracy will be key factors for the success of the new spindle.
- The selection and testing of different suction systems will be run in this WorkPackage. The variables will be determined and the design of the whole machine system will be realized to maximize the efficiency of the suction system.
- A control system to monitor the chip extraction process preventing chip jam and possible damages in workpiece and tool. This control system must response to any disturbance with an appropriate action.

Once the development of the single elements is made, all of them would be integrated in the pilot system for the final validation of the whole system

The characteristics of the spindle are summarized next:

1) Tool holding is by an elastic ER32 collet.
2) Machining Refrigeration. No refrigeration is foreseen as most aerospace companies do not permit cooling in the machining of Fibre Reinforced Composites.
3) Power and speed have been established in order to be able to reach the values of cutting parameters, according to cutting speed, feed rate, cutting sections, part material specific cutting forces etc...
4) Internal spindle bore. An internal bore, diameter 10 mm goes through the spindle. Internal bore has been designed without any direction or section changes in order to facilitate internal air+chip+dust flow.
5) Stiffness requirements. Elements and materials, alloyed steel with Ni Cr and Mo as main alloy elements , has been selected to stand cutting forces, torque and power, despite the loss of material section due to the internal bore.
6) Rear end of spindle has been modified, including a 10º conical end slope, to better connect it to suction pump by means of a rotary joint.

In order to achieve a cost effective system, by means of low equipment cost, good maintainability, reliability and availability, prototypes based on commercial vacuum pumps have been selected in this WorkPackage.
The initially selected vacuum pumps were chosen with the main goal of incorporating the most suitable equipment for the internal chip aspiration process,
Main characteristics of prototypes were:

1) High or lower under pressure values. 0.42-0.84 bar
2) Compact system design or high volume and footprint dimensions. 175-80 cm

The finally selected suction equipment and its characteristics, is represented in the next table:

Model **P22-1.** Catalogue characteristics	
Power	7.5Kw
Maximal under-pressure	0.42 bar
Tank volume	175 l
Dimensions	165x83x80 cm^3

In the new Control System, aspiration pump is connected to PLC`s digital Input/Output module and to CNC. The CNC can command the aspiration pump as well as the machine tool itself , indeed CNC is always aware of the state of the aspiration pump.

Operator is now able to control the aspiration system in two ways

1. Manual mode machine. Operator directly switches on/off the vacuum pump by means of a push located in the machine tool panel control.
2. Automatic mode. Aspiration system can be activated or deactivated in machining programs by an auxiliary function M59, for switching on and M60 for switching off

In next figure, all elements taking part in the control process of aspiration system in both automatic and manual mode are shown:

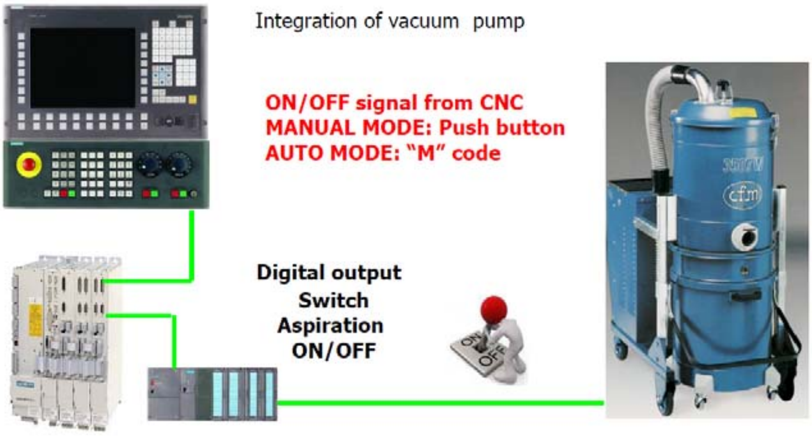

Figure 4 Integration of vacuum pump control

The task on WP2 finalised with the integration of the complete system: spindle, tool holder, vacuum pump and control system.
After the initial System validation tests, the final Pilot System has been used in all machining tests for Aspirate project. Next pictures show different Pilot System elements during internal aspiration machining tests.

Figure 5 Pilot System including the Aspiration Pump. Aspiration Pump is connected to spindle rear by flexible tube and to machine tool CNC by electric cord

Figure 6 Modified machine spindle with a HSK50-F hydraulic chuck holding a steel tube PCD aspiration tool.

<u>WP3 Cutting tool development</u>

Being the cutting tool one of the most critical technologies to be developed regarding the internal chip aspiration process, the research and development activities in this workpackage were focused on the following issues:

- Development of hollow cutting tools for internal chip extraction during machining.
- A new cutting tool geometry to enhance the performance of the abrasion protection coatings of the cutting edges. The cutting geometry and the coating should be adapted to the type of fiber of the material and its orientation.
- Development of anti-adhesive coating for the internal surface of the hollow shaft of the tool based on Ni and Cr layers with PTFE microcapsules.

Several approaches were defined on the design and fabrication of these hollow cutting tools:

- Adapting and improving steel tube PCD teeth internal aspiration tools to Reinforced Composite materials.
- Developing a new concept for internal aspiration tools. Solid Carbide suitable for internal aspiration machining of composites

Different tool prototypes have been proved to find the best characteristics for both types of aspiration tools. Finally the optimised prototypes of hollow cutting tools have been designed, produced and tested.

The next page shows different designs and approaches followed on the design and manufacturing of these hollow cutting tools:

	*Figure 7 General view of tool showing teeth, aspiration windows and 10º axial angle.*
	*Figure 8 Solid Carbide tool after diamond coating*
	*Figure 9 PCD teeth are joined to the steel tube by means of soldering*

The WP3 has performed also an extensive activity in the research and development of optimum coating materials and technologies to be applied both to the cutting edges, for improving tool life and resistance to wear, as well as for coating the internal bore of the spindle tube, in order to avoid any chips and dust jamming, which could endanger the safety of the process.

Diamond coatings of 8 µm thickness have been deposited onto cemented carbide tools with 0.5 µm SiC interlayer made with Silane and Methane precursors and with different deposition parameters. Closed diamond films were observed

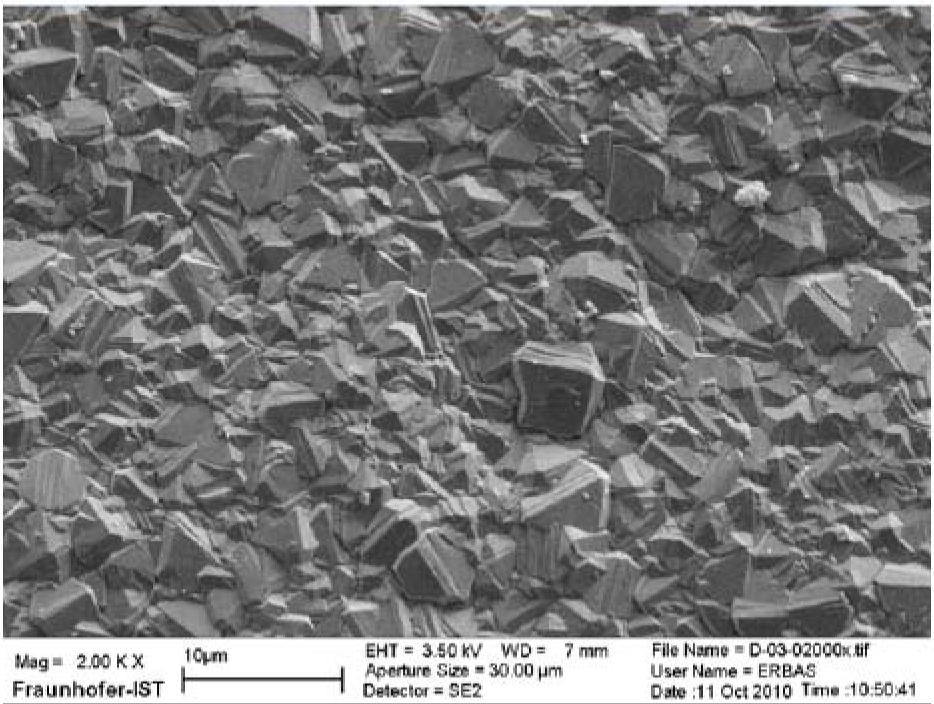

Figure 10 SEM image of diamond film on-top of SiC interlayer

WP4 Cutting Strategy

The main objective and activities within WP4 were oriented to the development of HSC cutting technology with internal chip evacuation for machining FRP composites. This includes the definition of process parameters matching internal chip removal and dry technology, based on the elaboration of necessary basic knowledge about chip formation, tribological conditions and safety aspects. In that sense, it has been researched how the cutting parameters, cutting tool geometry and cutting strategy affect the quality of the machined part and the wear of the cutting tool.

Further on, the development of advanced machining strategies, e.g. circular milling processes, contouring and five-axis machining, with regard to technological, ecological and cost effectiveness (material removal rate, processing time and cutting tool consumption) has been also core activity of this work package.

Figure 11. The influence of the cutting edges geometry on the size and shape of the chip and dust has been analysed on this WP4

WP5 Technology transfer and Industrial Validation

The objective of this task was the application, at the maximum possible level, of the developed machining system on industrial scenarios.

The validation has been performed on the pilot system set up in IDEKO facilities, but working under the industrial conditions stated by INVENT as the end user. ZUBIOLA did provide the necessary cutting tools for the different industrial applications tests.

The results of this WP has permitted to evaluate the developed technology against the traditional processes under the productive terms (cutting speed, cutting feed, tool life, MRR, accuracy) quantified previously in WP1 by INVENT.

It has been also analysed the operator's health hazards due to the evacuated chips, as well as safety issues regarding machine, part, fixture, cutting tool and process with the new technology.

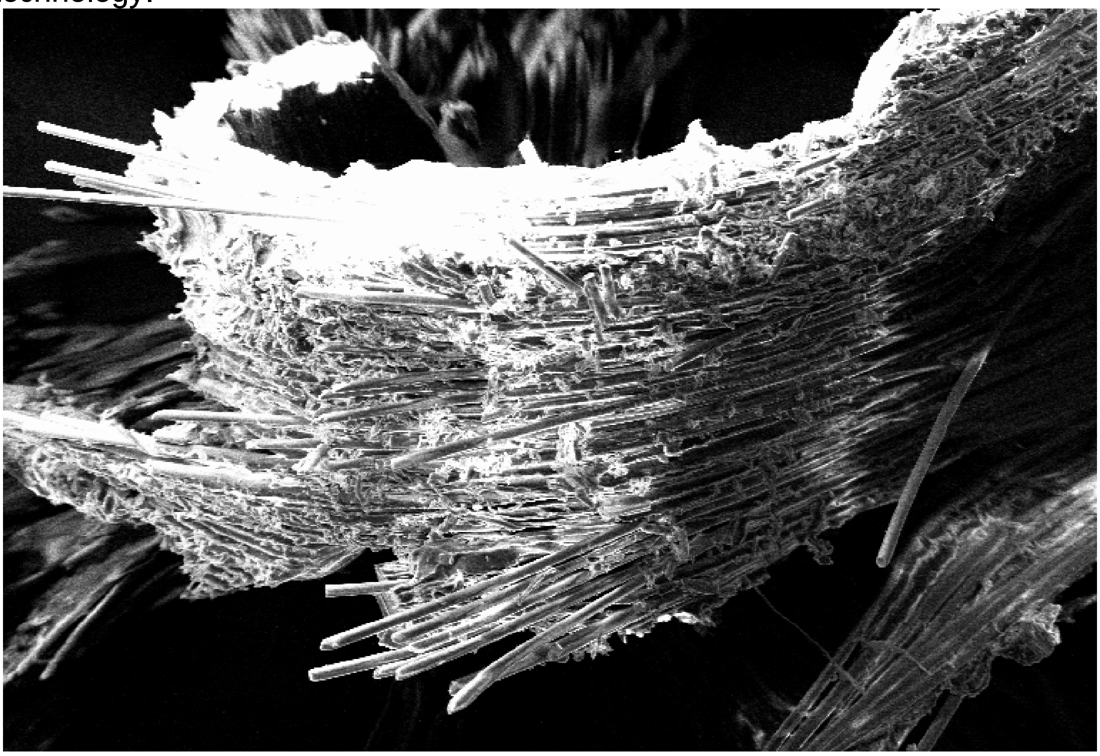

Figure 12 Cut carbon fibre splintered into 5-6 micron fibrils

1.3. Potential Impact and Dissemination Activities

Besides the activities on presenting the project results made by the project partners in their own facilities, by means of posters and presentations to customers, the consortium has made several actions for disseminating the project outcomes:

- **JEC Fair 2011**: During the last 29th to 31st March 2011, the results obtained on the ASPIRATE project were presented at a Boot on the prestigious JEC Composites fair in Paris. The JEC fair is the most important event related with composites manufacturing held in Europe.
  During this fair, many companies interested in our aspiration machining technology came to the boot for requesting information.

- **International Innovation Journal**: In April 2011 an interview and a description of the main project results were published in a 3 pages report within the April issue of the International Innovation journal. This journal is being distributed to more than 30.000 readers in Europe, USA and Japan. Many industrial, European Commission officers, scientists and academic people receive this journal regularly.

- **CFK Stade Valley Convention**: ASPIRATE consortium decided to present also the results of the project on the CFK Stade Convention, which was held on the 6th, 7th and 8th June 2011 at the Stade Convention, a composites centred event celebrated in the city of Stade (Germany).

Regarding Exploitation issues, the consortium has prepared the PUDF ("Plan for Using and Disseminating the Foreground") report. In this document they have been identified several potential industrially exploitable results, the markets where these results will be presented, the targeted industrial sectors and the time to market.

1.4 Project Website

As soon as the project started, it was set up a project website under the address http://www.aspirate.eu, where the general public and interested companies can find information on the project activities, dissemination, partners, achievements, etc.

In this website it has been set up also an information repository which is only accessible to registered partners. In this private area of the website the partners of the consortium can interchange information about the technical activity and results obtained in the WorkPackages.

Dissemination activities have been also published on the project's website (posters, papers, interviews, videos, etc). Next page shows some pictures representative of the project website:


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Presentation
The main objective of ASPIRATE is to develop an innovative technology for machining carbon and glass fibre reinforced plastic (CFRP and GFRP) parts based on the internal extraction of the produced chip and dust particles through the whole machining system (cutting tool, tool holder, spindle), avoiding all the external devices and suction pumps used nowadays, which reduce the flexibility and leave an unclean part (they do not achieve a complete chip/dust extraction), with the consequent risk for the operator's health and machine's components.
The basic idea of the project has been conceived by the Spanish machine tool manufacturer ORTZA to equip their machines with a new technology to solve the problematic machining of fibre-reinforced composites. The three critical components for the success of this development are the hollow cutting tools (to be developed by the SME ZUBIOLA), the diamond coatings for machining abrasive composite materials (to be developed by SME RHO-BEST) and the design of the chip extraction system, which will be developed by RTDs Fraunhofer IST and IDEKO. The SME company INVENT GmbH, as an aerospace end user, will assess and validate the developed technologies in each of the target potential applications and will provide a technology transfer by the end of the project. Spain, Germany and Austria will be represented in the consortium, providing a higher impact of the breakthrough in Europe.
The new chip and dust extraction system is rated to become a breakthrough and a reference for machining companies in search of highly productive and human safe technologies in producing reinforced composite components. The technological advances achieved by the end of this project will lead European countries to the head of world composites machining industry, with a qualitative jump for at least 3 years.


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Partners
Main actors involved in the development of the Aspirate Project are the companies listed below:
ideko
ρ-BeSt coating
Fraunhofer IST
INVENT
EGURKO
ZUBIOLA


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RHO-BEST GmbH
Rho-BeSt coating GmbH was founded in 1996 with core-business area of diamond coating for different applications based on a new, own-developed and patented coating technology. Industrial mass production is established since 2000 especially for wear protection of tools for machining graphite, aluminium and aluminium alloys as well as fibre-reinforced composites. Beside production rho-BeSt is performing research in interdisciplinary fields like wear and friction of NCD-coatings:
Development of NCD-layers/interlayers for machining of new materials and composites
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High international level of collaboration reflects the success of rho-BeSt nano-crystalline diamond (NCD) und ultra-nano-crystalline diamond (UNCD) material
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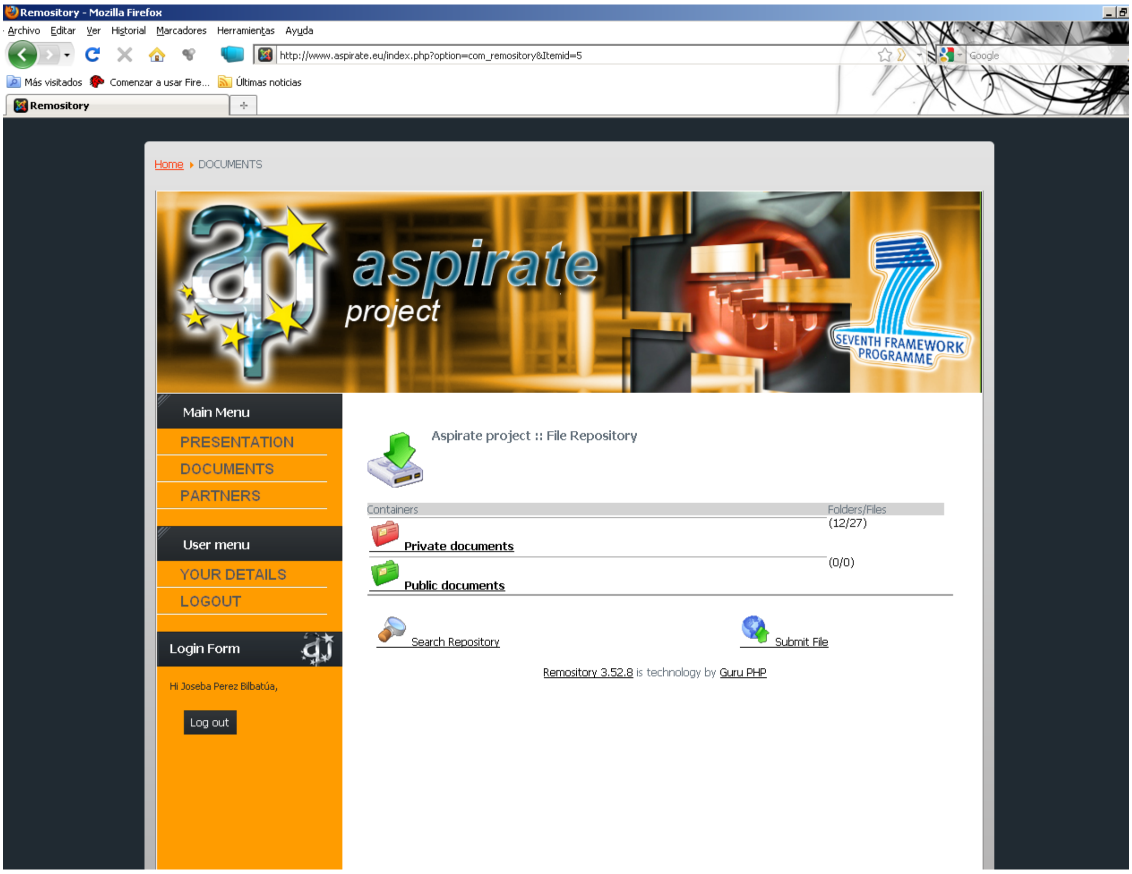
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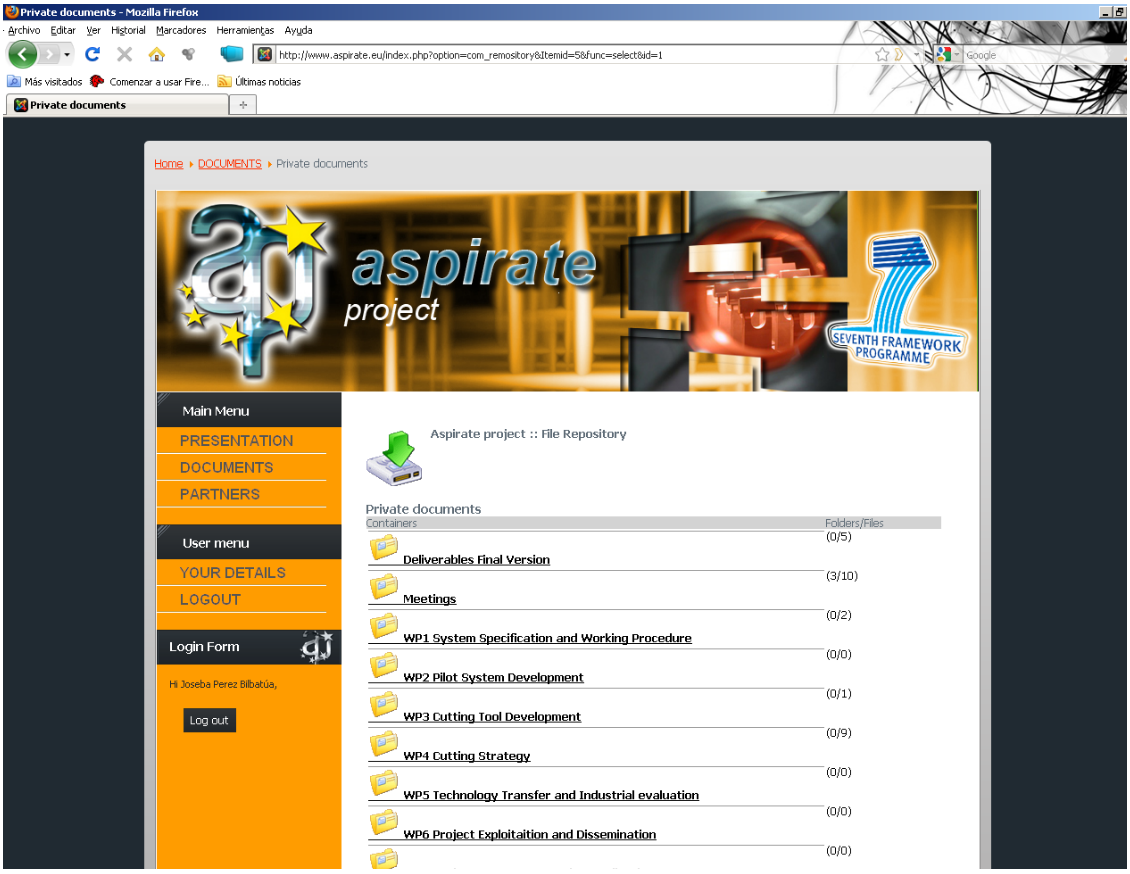
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Deliverables Final Version (0/5)
Meetings (3/10)
WP1 System Specification and Working Procedure (0/2)
WP2 Pilot System Development (0/0)
WP3 Cutting Tool Development (0/1)
WP4 Cutting Strategy (0/9)
WP5 Technology Transfer and Industrial evaluation (0/0)
WP6 Project Exploitaition and Dissemination (0/0)
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Short Description: Deliverable D1.1. Definition of system specifications
Submitted By: iferreres
Submitted On: 04 Mar 2010
File Size: 674.76 Kb
D1.2 ASPIRATE Final version.pdf
Short Description: D1.2. Results of preliminary tests with the extraction system
Submitted By: iferreres
Submitted On: 04 Mar 2010
File Size: 832.88 Kb
Deliverable D2.1 Final Version
Submitted By: jperez
Submitted On: 30 Mar 2010
File Size: 132.94 Kb

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Use and dissemination of foreground

Section A (public)

A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?

Section A (public)

A2 LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date	Place	Type of Audience	Size of audience	Countries addressed
1	Poster	Ideko	JEC show composites	29.-31.3.2011	Paris, France	Visitors of composites fair, mainly business	29 000 visitors of the fair	International, fair visitors came from 100 countries
2	Conference	Ideko	CFK-Valley Stade Convention	7.6.2011	Stade, Germany	People from science and industry, interested in CFRP	430	Germany, 20 % of the visitors were international
3	Magazine	Ideko	International Innovation	(to be published)	-	Government, policy and academic communities	30 000 subscribers	Europe, INCO countries

Section B (Confidential or public: confidential information to be marked clearly)

Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.
The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

Part B2

Type of Exploitable Foreground	Description Of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Design of aspiration tool	YES		Tools for CFRP machining, tools for Al/Mg machining	Aerospace, automotive	2011 (CFRP tools), 2013 (Al/Mg tools)	-	Zubiola (owner)
General advancement of knowledge	Deposition process for silicon interlayer-diamond tool coating	YES		Diamond coating for cemented carbide tools	Aerospace, automotive, mold and die making	2013	-	Rho-BeSt (owner), Fraunhofer IST (technology transfer)
Commercial exploitation of R&D results	Design of machine tool with chip aspiration	YES		Machine tool for CFRP machining	Aerospace, automotive	2012	-	Egurko (owner), Ideko (technology transfer)
General advancement of knowledge	CFRP cutting process with and without aspiration tools	YES		Improving efficiency and safety of CFRP production	Aerospace, automotive	2011	-	Invent (owner), Ideko (technology transfer)