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OFIENGINE

Development of the new thermal spraying equipment and technology for production of components for marine transport engines

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Publishable executive summary

Project Objectives

The main objective of the project consists on the development of a new thermal spray equipment for the production of components for marine transport application. This technology should allow the manufacturing of marine engine components with improved technical and service characteristics.

List of contractors:

Partic. Role	Partic. No.	Participant name	Participant short name	Country	Date enter project	Date exit project
CO	1	FOUNDATION INASMET-Tecnalia	INA	SP	1	36
CR	2	Centre National de la Recherche Scientifique	CNRS	FR	1	36
CR	3	PyroGenesis S.A.	PGS	GR	1	36
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CR	5	JAVICAN S.L.	JAV	SP	1	36
CR	6	ARAIN SAL	ARA	SP	1	36
CR	7	KANTER S.A.	KAN	SP	1	36

Co-ordination Activities

The Project is co-ordinated by IGNACIO FAGOAGA.

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Work Performed

As scheduled in the DoW, Work packages (WP) 1, 2, 3, 4, 5, 6 and 7 have been performed during the duration of the project. According to the scheduled activities the following fields have been developed:

End user needs

With base on the information collected during the kick-off meeting held in INA as well as on further inputs from the partners via e-mail and several phone communications, the deliverables 1.1 and 1.2 were prepared by the task leaders, KAN and INA, respectively. The same collected all the needs and suggestions coming from the industrial partners and outlined the most relevant information related to the specification on coating properties, powders materials and process parameters to be employed during the project.

Design of the OFI equipment

As a first approach, a comprehensive screening test was performed to establish a suitable parameter window to process carbide based materials according to the requirements of the industrial partners in terms of feed stock powders of interest and the expected coating properties. The information collected during this initial project stage offered the basis for the design and manufacture of a new OFI gun prototype, which has been already validated for the deposition of high quality cermet type coatings.

Beside the spray gun as main component, there are other 4 different peripheral modules that were designed and/or adapted to fulfil the overall requirements of the new OFI system. These are the main controller, the chiller unit, the gas lines (including the modular controllers) and the powder feeder.

Manufacturing and testing of the OFI equipment

The new gun prototype was manufactured and tested according to the design developed in a previous stage of the project. The process parameters were newly screened and validated to establish the optimal parameter window for those targeted cermet type powders. The results arising from this second screening test completed the information required for the development of the control algorithm and hardware for all control units.

Concerning the peripheral modules, the cooling system was scaled-up and a new powder feeder was purchased and integrated into the system. The manufacture of the main control console, the gas lines and their controllers has been finished and all the modules have been integrated into the new OFI system. The software to control and monitor the spraying process was developed and tested with the new OFI spray installation.

Start-up of the new OFI installation

Following the manufacture of the different core modules specially designed during the project for the OFI prototype (i.e. main control console and gas lines) and their integration with the remaining system peripherals (i.e. power source, water chiller, powder feeder and exhaust system), the entire installation was finally brought into service during this last reporting period. Due to different imperfections in the software/hardware configurations, some minor adjustments were required to ensure the proper communication between the different modules. For this reason, this task was prolonged 6 month beyond the scheduled due date (end 2008). To validate the new OFI spray installation, the process parameters were newly screened and contrasted with the parameter window previously optimised for the targeted cermet type powders.

Development of cermet type coatings

There are at least 7 different mean process parameters that have to be optimised in close correlation to the gun configuration. It includes five gas flow rates, the stand-off distance to the substrate and the powder feeding rate. The process gases include basically oxygen, methane, argon as plasma gas, nitrogen as auxiliary plasma gas and the carrier gas. In a first approach, a broad parameter window was screened and optimized using the initial gun configuration. The optimisation was performed with base on the resulting coating microstructure and hardness. In a further step, a narrower selection of samples was investigated under x-ray analysis to evaluate the extent of decarburization of the feedstock material.

The results achieved in this first screening test offered the basis for the further optimisation of the OFI gun. The developed gun prototype was then manufactured and validated with base on the results newly achieved with a WC-17Co powder. The optimised parameter window proved to be also useful for the deposition of high quality Cr_3C_2-NiCr type coatings and further WC based powders as WC-12Co and WC-10Co-4Cr.

Development of amorphous/nanostructured type coatings

One commercial HVOF powder from The NanoSteel™ Company with a particle size distribution of +15 to -53 µm was investigated, SHS7574. This is a Super Hard Steel (SHS) powder material which has been designed for the conventional HVOF systems of the third generation like the DJH and the Tafa JP5000. In principle, the corrosion resistance of the resulting coatings uses to be superior to that of conventional Austenitic Stainless Steel and Nickel Base Superalloys such as Hastelloy 625 in extreme corrosive environments. The process parameters were optimised for the gun configuration validated for cermet type coatings and the resulting coatings characterised in terms of their microstructure and wear performance.

Development of metallic coatings

Even tough out of the scope of the work plan scheduled in WP1, some reference Ni/Co-based coatings were exemplary developed.

Development of Fe-based cermet coatings

Some attempts have been done to develop a new family of cost effective coatings combining the properties of the well performing WC-type cermets and the high corrosion resistant of cheaper nanostructured steel coatings. The approach followed consisted on a mixture of two commercial feedstock materials in the gun, adjusting the feeding rate of each material to tailor the coating microstructure. Additionally, BPE International provided to the consortium an experimental cermet powder manufactured using a novel concept. The same consists on particles having a corrosion resistant metal core (typically 316L) and a hard ceramic shell (typically Al_2O_3). A first screening test was accomplished to validate the spray ability of this experimental powder.

Development of reference coatings by HVOF

Based on their year long experience on the deposition of deposition of thermal spray layers, PyroGenesis developed the process parameters for the deposition of the targeted powder materials with the DJH2700 system. This is a HVOF system of the last generation from Sulzer Metco, which is operated with propane as fuel.

Manufacturing, characterization and installation of marine engine components

This activity was started earlier than scheduled. Three different demonstrators were manufactured following the specifications collected in WP1, i.e. piston crown, piston pin and valve spindle. The piston crown was coated with an anti-adherent Cr_3C_2-NiCr_based layer using the new OFI prototype and sent to the end user (client from KANTER). The piston pin and the valve spindle were coated with WC-17Co and Cr_3C_2-NiCr layers, respectively. Following the specifications of WP1, both components had to be finished to achieve the desired surface quality. Only the surface finishing achieved on the piston pin fulfilled the specifications, and thus, only this component was sent to the end user. A significant amount of resources were allocated for the optimisation of the surface finishing procedure for the valve spindle. Nevertheless, the further optimisation of the surface quality beyond the threshold achieved during the project, demands the implementation of special skills and equipments not available within the consortium. Additionally, three different demonstrators were manufactured and sent to the respective end users for their integration (clients from INASMET outside the consortium), i.e. turbine socket, stern-tube component and piston rings for small engines.

In order to guarantee the quality of the coating, a control sample was prepared for each demonstrator manufactured during the project. The same were characterised and validated with the results previously achieved on button samples.

Functional evaluation of the marine engine components

Since the expected service life of the coated components overpass in many years the project duration (> 4 years), it was not be possible to assess the functional performance of the demonstrators which are currently under testing. Until the project conclusion, any feedback from the end users was received. Nevertheless, with the aim of guaranteeing the quality of the components in mass scale production, the consortium re-oriented the focus of the work on the development of product acceptance standards for all those overlay coatings of interest. In addition, a significant amount of resources was employed to develop special control samples with specific dimensional features relevant for the most demanding applications (i.e. steam sealing coatings for valve spindles). The lasts will be employed by the end user (KANTER so far) for either the homologation of new coating service suppliers or internal quality management issues.

Mathematical Modelling

The modelling task has been divided in four sub-tasks corresponding to the various sub-processes of the system comprising the whole stage of the process, i.e.: plasma formation, combustion, expansion of the flame in the barrel and in the ambient air. The work performed during the project was related to modelling of: 1) the formation of the Argon plasma in the d.c. plasma torch; 2) the mixing of the fuel (CH_4) and oxidant (O_2) gases with the high temperature plasma jet (Ar), ignition of the diffusion flame in the pressurized combustion chamber and development of the flow in the laval nozzle; 3) the mixing of the plasma-flame jet flow with the ambient gas; 4) the injection, cinematic and thermal behaviour of powder particles in the gas flow.

Process optimisation

In relation to the optimization of the OFI process, it should be underlined that the optimization of the system was carried out in parallel with the modelling tasks. The simulation results helped to improve the design of different gun modules in an early stage of the project, i.e. gas injector for auxiliary gas (N_2) and fuel.

Additionally, two experimental measurement campaigns with in-flight particle diagnostic systems were accomplished to validate the numerical results of the simulation and further optimise the process parameter window for WC-Co type materials. The first campaign dealt with a parametric study for gas flow rates and nozzle geometry and yielded to the design of a new converging diverging nozzle design. The second campaign was focused on the investigation of the effect of the last modifications suggested with base on the simulation results aimed to further improve the combustion chamber and powder injection module.

Achieved results

At the beginning of the project, the consortium agreed to focus the work on the development of an OFI prototype for the production of novel WC-Co and Cr_3C_2-NiCr based coatings to asses the wear and corrosion protection needs of three main diesel engines components: valve spindles, piston crowns and piston pins. In addition, as fourth case study, it was proposed to develop a wear resistant coating able to withstand the deformation of the piston rings during their installation. As a first approach, this coating should consist on an amorphous/ nanostructured steel coating, using commercial powders as feedstock material. A second approach consisted on the development of this wear resistant layer using an experimental cermet powder to be provided by the project partner BPE.

The design of the OFI spray system has been accomplished following a modular concept. The peripheral installations (i.e. cooling system, powder feeder and gas lines) were carefully designed/selected and manufactured to fulfil the technical requirements of the new gun prototype and ensure the operation of the system in a safe and reproducible way. Each module is managed by its own controller using a common electronic board deign and communicates to the main control unit through a BUS connection. All the modules can be easily exchanged and up-dated, thus allowing the continuous modification and up-date of the whole spray system with relatively low investment costs and short down times. The electronic line diagrams of the developed circuit boards were done available for the consortium. The system is compatible with all standards, regulations and laws currently in force in EG, so that it will conform to a CE Certificate (to be pursued after the project conclusion).

The control software has been developed following an user friendly concept, which will allow the operation of the system under different levels of access, i.e. full access as process designer or “engineer modus”, limited access as basic operator, visitor, etc. In general the system will allow the specification of Set Points, the monitoring of Present Values, selection of gas lines, plasma parameters and powder feeder parameters, execution of calibration procedures, development and management of safety protocols, printing, recording and file saving. The installation and Setup procedures of the entire OFI system, as well as the functional procedures that must be followed to make a coating job, have been finished and are available for the consortium. The new OFI installation has been thus successfully brought into service.

In agreement to the specifications collected at the beginning of the project, the new gun prototype was manufactured and validated for the development of high quality cermet type and amorphous/nanostructured steel coatings. Nevertheless, the same also features a flexible modular design which should offer the possibility to tailor the gun configuration for materials with the most different chemical and physical nature. The corresponding technical drafts have been finished and are now available for the consortium. In terms of the process productivity, it was demonstrated that the OFI system is able to deposit standard WC-Co materials with a deposition efficiency of around 60%. This represents an advantage to the currently available high velocity spray systems and could be traduced in a reduction of the productions costs of at least 20%.

Three of the demonstrators scheduled in WP1 for marine engines have been manufactured, i.e. piston crown, piston pin and valve spindle. Two of them, i.e. the piston with coated crown and the piston pin, sent to the end users for installation and are currently under testing. Additionally, INASMET had the opportunity to explore the potential of the OFI system for the manufacture of three further components which used to be normally coated by HVOF, i.e. turbine socket, stern-tube component and piston rings for small engines. The last have been sent to the end users (clients from INASMET) and are currently under testing.

A set of quality standards has been developed for the most relevant overlay coatings for the marine engine sector and collected in product acceptance datasheets. In addition, special control samples were designed with specific dimensional features relevant for the most demanding applications (i.e. steam sealing coatings for valve spindles). The lasts will be employed by the end user (KANTER so far) for either the homologation of new coating service suppliers or internal quality management issues.

During the first half of the project, most of the work related to the optimisation of the different gun components was performed following year long empirical observations. Each change accomplished in the gun design has been validated with base on the resulting coating quality and the observed system performance at the corresponding process parameters. Nevertheless, this procedure is not only cost intensive but also inefficient. For this reason, the development of the gun design was further accomplished with the help of the results arising from the modelling tasks performed.

In relation to the mathematical modelling of the system, a model for the plasma formation in the plasma torch has been developed. The same gives realistic steady-state temperature results in agreement with the temperature levels found in the literature and with reasonable CPU time. The predicted thermal efficiency is quite realistic. The model was used to obtain the velocity, temperature, pressure and chemical composition fields of the gas mixture at the combustion chamber inlet. According to the simulations, the level of temperature of the plasma gas after its mixing with the Nitrogen gas is lower than 5,000 K. As the chemical species (Ar, N_2) are not dissociated or ionized at this temperature, it was decided to use the classical chemical reaction schemes found in the literature to model the combustion process.

A second step consisted on the development of a model to simulate the mixing of the fuel (CH_4) and oxidant (O_2) gases with the high temperature plasma jet (Ar), the ignition of the gas mixture in the combustion chamber and the development of the flow in the Laval nozzle. In this second part, a fast chemistry model following the Eddy Concept Model was used to model a one step chemical reaction with a few numbers of species. Due to large gradients of temperature, pressure and density, the numerical scheme is stiff and the convergence is quite long to obtain. It could be stated that:

- Even if the temperature level seems to be slightly over-estimated by the model (about 3,000 K) it is in the same range than the predicted results of the literature dealing with HVOF processes;
- The predicted pressure is in good agreement with the pressure measurements done with new OFI prototype;
- The predicted flow structure (velocity, pressure, temperature, chemical composition) shows that the design of different parts of the system can be improved. Indeed, in the original configuration of the system, the auxiliary N_2 gas was injected through a single injector. The predictions showed that it had a strong tendency to deflect the plasma jet and made it asymmetrical. Consequently, the injection of N_2 gas was modified by using four injectors equally distributed along the plasma torch periphery. This made it possible to improve the mixing of plasma and auxiliary gases. The same kind of modification has been done for the fuel injector distribution. As the different gas injectors are now equally distributed, the flow is quasi-symmetrical. Also, these modifications made it possible to adopt a 2-D axi-symmetric geometry as the flow is now quasi-symmetrical; this allowed reducing the CPU time for the calculations presented in this report that involved both the internal and external fields of the system.
- The velocity, temperature and pressure fields at nozzle can be used to predict the plasma-flame jet development in the atmosphere.

According to the predicted results from the third simulation step dealing with the mixing of the plasma-flame jet flow with the ambient gas, the gas jet velocity (250 m/s) and temperature (180 K) are slightly increased by the adding of a plasma source. This increase can be explained by a better mixing of the fuel and oxidant thanks to a higher turbulence level reached with the plasma source and the higher temperature of the ignition flow that favours the appearance of the methyl radical. The predictions showed a rather good agreement with the measured external gas flow temperature and the photographs done of the shock waves.

The last simulation step dealt with the prediction of the injection and the cinematic and thermal behaviour of particles in the flame. A particle melting model was implemented in the CFD code fluent. The model was validated by in-flight particle measurements on WC-17Co particles. Particle velocity and particle spray width are well predicted by the model but their temperature and melted fraction are underestimated, about 280 K for the temperature. This discrepancy is probably due to the assumptions of uniform temperature in the particles that is not valid due to their important porosities. Nevertheless, this assumption is usually adopted in HVOF modelling. It can be therefore stated, that the developed model gives good trends.