Project no. 017788

SEFUCO

High Performance Self-Lubricated Multifunctional Coating for Demanding Industrial Applications

Instrument **Co-operative Research Project (CRAFT)**

Thematic Priority

Final Activity Report

Period covered: from **30.5.2005** to **29.6.2007** Date of preparation: **14.1.2008**

Start date of project: **30.5.2005** Duration: **25 Months**

Project coordinator **Pertti Lintunen**
Project coordinator organisation **VTT** Revision **Final**

Executive summary

The reliability of large industrial fields such as energy plants, process industry and transport are dependent on the functioning of critical components. In particular, safety critical components in heavy engineering, such as bearings, seals, shafts, barrels, rolls, etc. face material sticking problems. Conventional lubrication oils often cannot be used due to process environment, temperature or impurities. Self-lubricating, wear -resistant coatings are available, but only for specific applications. A broader solution is needed; this is why the SEFUCO project was set up.

The SEFUCO consortium is made up of two Research Performers and six SMEs from Western and Northern Europe with the aim to improve coating performance for demanding industrial applications. The goal of the project is to enhance the safety and reliable use of critical components. It will also prevent people from being exposed to hazardous waste due to chemical leaks caused by sticking and tribology problems. Tribology is the science and technology of friction, lubrication, and wear. In addition to powder production and thermal spraying, tribology represents one of the three technology areas of the SEFUCO project.

Novel powder production techniques open possibilities for innovative powder compositions and tailored coating solutions. Meanwhile, thermal spray methods have been well established to produce wear -resistant coatings for components. For instance, a space organisation has been investigating the use of thermally sprayed (TS) coatings with the addition of solid lubricants (SL). Universities, institutes, automobile and electronic manufacturers have all done specific research on the same topic. However, tailored coatings including solid lubricants are not yet commercially available.

Thermal spray techniques are coating processes which involve spraying melted (or heated) materials onto a surface. The energy to heat the feedstock is supplied by either electrical (plasma or arc) or chemical means (combustion flame). Coating quality is usually assessed by measuring its porosity, oxide content, bond strength and surface roughness. Generally, the coating quality increases proportionally with particle velocities. The heated materials are typically fed through an insulated tube to the sprayer, where they may be atomised before being expelled through a nozzle.

The control starts from the coating material processing. At first the consortium discussed about their needs for their applications. Material compositions were tailored according to the application. After that started the powder manufacturing and the optimisation of powder processing parameters to get acceptable quality for the spray powders. When the powder quality was in sufficient level the products were sent to thermal spray tests. The SEFUCO consortium started optimising spray coating processes, especially HVOF (high velocity oxyfuel), for spraying powders containing solid lubricant materials, adapting them to different application environments. Furthermore, the consortium was undertaking tribological tests to determine tribological, wear and corrosion properties of the coatings containing solid lubricants. Controlling the whole manufacturing route from powder to coating allowed for the tailoring of the coating composition according to each application.

The main technical objectives of the project are:

- Stability testing of solid lubricants during powder manufacturing processes and during the thermal spraying process.
- Development of manufacturing technology for multicomponent powder containing solid lubricant (SL) for thermal spraying.

- Thermal spraying and optimisation of spraying process for SL containing powders, evaluation and characterisation of manufactured coatings.
- Determination of tribological, wear and corrosion properties of coatings

A combination of novel powder manufacturing and HVOF coating technology will be achieved with co-operation of different European SME's. The project gives an opportunity to combine these two different technologies. The technological and economical chain is formed by powder manufacturers TL Beteiligungs GMBH (AU), Millidyne Oy (FI), HVOF coating manufacturers Kuopion Konepaja Oy (FI) and Scana Offshore Vestby As (NO), and the industrial end-users, JS Oy Pietarsaari (FI) and Eaton-Hydrowa (NL). The SME contractors of the project are introduced shortly in the following.

Scana Offshore Vestby AS (until 31.05 2006 name was **Brødrene Johnsen As)** is mechanical engineering company in Norway. They are also specialised for coating manufacturing and mechanical pre- and post-treatments. Main customers for the company are from the field of off-shore industry, but also erosion/corrosion solutions for high wear components are provided. BRJ has provided reference coatings and post-treatments for coatings in this project. BRJ is aiming to obtain direct benefits by having new, innovative, self-lubricated coating for it's product line, and by this way strengthen it's competence on it's market area.

TL Beteiligungs GMBH is a small company specialised for raw material producing, and equipment selling in the field of metallic coatings, including overwelding and thermal spraying. The core competence of the company is raw material manufacturing, including metallic powders for thermal spraying and PTA-welding, metallic wires for arc spraying and flame spraying, and ceramic products (powders and rods). Their benefits will be new, innovative product for themselves, as well as new clients from the thermal spray companies, and indirectly also from end users.

JS Oy Pietarsaari, the main company profile for JS is the maintenance and repair of the valves. This includes field assembling as well as new component manufacturing in the company's machine shop. The company has continuously grown and broadens to the new areas of demanding equipment. JS has very good relationships for many of it's clients and can by this way offer wide range of potential field cases for coating properties testing in true applications. JS is aiming to obtain direct benefits by widening its product range to be able to offer valve's with longer life time and more reliable use.

Millidyne Oy is a SME research and development company, specialized in advanced surface treatment technologies. The company was established in 1998, currently employing a staff of about 10 people. Millidyne’s business strategy is based on customer oriented product development, coating raw material sales and technology transfer. Millidyne has also been several years involved with ceramic powder research and development and has its own powder production facilities in operation at the end of January 2004. Millidyne is participating in the project as a powder producer and developer and powder-processing specialist. Millidyne will benefit from the project with new powder products for thermally sprayed specialty, self-lubricating coatings.

Kuopion Konepaja Oy is an innovative thermal spray company from Finland, who is run by it's managing director Mr. Risto Finne. Company has manufactured thermal spray coatings over 10 years starting from flame spray and fused coatings. Latest investment was full automated HVOF cell with articular robot. KKP will obtain direct benefits by having new, innovative, self-lubricated coating for it's product line, and by this way strengthen it's competence on it's market area.

In this project there is one non-SME company, so called large enduser **Eaton-Hydrowa B.V.** The company classifies its business into four distinct segments, which are, by size: Fluid Power, Industrial & Commercial Controls, Automotive and Truck. Company has gained expert knowledge and expertise in the field of hydraulic cylinders destined for most divergent projects, well established all over the world. The role of the HYDROWA in the project will be an end user for the developed coatings. HYDROWA produces hydraulic cylinders for coating experiments and conduct field tests with these components. Their will benefit from project with new, low friction coating for their hydraulic components.

There are two RTD partners involved in the project. ***VTT Technical Research Centre of Finland***, located in Tampere and Espoo, is the project co-ordinator. VTT is a national impartial organisation that carries out technical and techno-economic research and development work. VTT is the largest research organisation in the Nordic countries. As an RTD performer VTT expects no post project exploitation benefits. Contribution of VTT to the project are processing of powders with agglomeration and SHS- technique, evaluation and feasibility of solid lubricants applicable in the project, optimisation of powder processing parameters for solid lubricant containing powders, evaluation of powder microstructure and adjusting the particle size distribution suitable for thermal spraying, optimisation of thermal spray process for solid lubricant containing coatings, evaluation of coating composition and microstructure and also assisting in field test of coated test specimens or components.

TNO the Netherlands Organisation for Applied Scientific Research has primary task of supporting industry, the government, and other groups in technological innovation and to assist client in solving problems. Many industrial clients are small and medium enterprises (SME). TNO maintains close contact with basic research institutions, both at home and abroad in order to translate the most up-to-date technologies and insights into practical applications. In this project TNO have researches from the group of tribology science. TNO, as an RTD partner, will not share any IPR or exploitation benefits generated by this project. Contribution of TNO to the project is evaluation and feasibility of solid lubricant compounds applicable in the project, evaluation of the solid lubricants stability, tribological testing of SL containing coatings (wear tests, measurements for coefficient of friction, corrosion tests), and also assisting in field test of coated test specimens or components.

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1. Project objectives and main achievements

The project objectives and main achievements of the project are presented ion the following.

1.1 Objective

The SEFUCO project aims for developing a self-lubricating, low friction and low wear coating capable to work under non-lubricated conditions. Novel powder structures manufactured by advanced powder production processes and optimisation of thermal spray process are the methods to achieve the goal.

1.2 Work performed

A short overview of performed work done in the SEFUCO project by SME and RTD partners is presented in table 1.

Table 1. Overview of contractors involved in different work packages.

Work Package	SME's involved	RTD's involved
WP1 Survey of solid lubricants	All SME's: giving background information of requirements of different applications	TNO&VTT: performing the literature survey of different SL's
WP2 Stability testing of solid lubricants	MILLIDYNE: test of SL's stability during agglomeration	VTT: stability of SL during SHS and agglomeration, thermal spray tests TNO: literature survey
WP3 Powder manufacturing for TS	MILLIDYNE: providing own powders, manufacturing of experimental powders for coatings, expertises in agglomeration sharing their knowledge with consortium SCANA: providing powders for coatings KKP: providing powders for coatings TLB: providing powders & rods for coatings	VTT: powder manufacturing, by agglomeration and by SHS technique, characterisation of powders
WP4 Coating optimisation	JS: substrate preparation for coatings HYDROWA: test component for coatings SCANA: coating manufacturing and optimisation, grinding of coatings KKP: coating manufacturing and optimisation, grinding of coatings TLB: coating manufacturing and optimisation	VTT: coating manufacturing and optimisation, characterisation of coatings
WP5 Tribological testing	HYDROWA: providing their testing facilities for testing of rods, testing the coated rods	TNO: measurements of COF, performing wear tests and corrosion tests

The work started from the coating material processing. At first the consortium discussed about their needs for their applications. Material compositions were tailored according to the application. After that started the powder manufacturing and the optimisation of powder processing parameters to get acceptable quality for the spray powders. When the powder quality was in sufficient level the products were sent to thermal spray tests. The SEFUCO consortium started optimising spray coating processes, especially HVOF (high velocity oxyfuel), for spraying powders containing solid lubricant materials, adapting them to different

application environments. Furthermore, the consortium was undertaking tribological tests to determine tribological, wear and corrosion properties of the coatings containing solid lubricants. After the quality of powders and coatings were approved to be sufficient, coatings were sent to tribological testing. Testing of coating were extensive: wear resistance of coatings was tested with abrasive wear tests, coefficient of friction (COF) was measured at three different temperatures (room temperature, 300°C and 400°C) and corrosion resistance was measured with two different methods.

1.3 Main achievements

Main achievements are presented in the following divided into 3 technology areas present in the project.

On the powder processing site one of the main achievements was the successful creation of powder for thermal spraying where three alloying elements were integrated into each powder particle. Innovative powder solutions consist of a hard carbide phase, metal matrix phase and solid lubricant additions, some of them alloyed in a nanostructured scale. Powder had good flowing properties which is beneficial for the coating process. Powder manufacturing parameters were adjusted so that it gave directly the suitable particle size for thermal spraying process. Thermal spray powders should have certain particle size otherwise coating quality will not come acceptable.

Thermal spraying of these experimental powders developed in this project gave good coating quality. Solid lubricant additions are very sensitive for thermal loads and could easily decompose or even evaporate during the coating process. It was possible to manufacture coatings were added solid lubricant did not decompose during the spraying process. Compared to same type of coatings without solid lubricant additions the successful coatings performed well under abrasive wear tests. And also compared to commercial available coatings the results from coating properties were encouraging. Still in some cases solid lubricant additions were decomposed. Therefore further research work is needed to fully understand the phenomena occurring during powder processing and thermal spraying

After the quality of powders and coatings were approved to be sufficient, coatings were sent to tribological testing. Testing of coating were extensive: wear resistance of coatings was tested with abrasive wear tests, coefficient of friction (COF) was measured at three different temperatures (room temperature, 300°C and 400°C) and corrosion resistance was measured with two different methods. Solid lubricant additions did reduce the wear resistance of the coatings slightly. That was expected on the basis of literature survey. The friction properties of coatings were not much better compared to coatings without solid lubricants. This is mainly due to the surface roughness of the coatings which has very strong effect on friction properties. Grinding of coatings containing solid lubricant may cause in some cases pull-outs onto the coatings surface and therefore leave surface too rough. In friction tests surfaces are sliding against each other and in such tests the surface quality has very important role. Although friction tests performed during this 2 years project did not give clear evidence of reduction for COF, lot of knowledge was created and disseminated within the consortium. Next step would be finding out certain applications and test methods where this kind of coatings would give better results compared to traditional ones.

1.4 List of milestones

Milestones of the project are presented in the table 2. The Milestone 1 was completed and the gathered information was used for selection of solid lubricants (Milestone 2) to be studied more detailed. Multicomponental powders containing solid lubricant have been produced (Milestone 3). Powders performed properly in thermal spraying process. Milestone 5 was partly achieved. Some of the coatings had composition as planned (as in powders). In some cases the solid lubricants were not present in the coating (although present in the powder). This was not due to the quality of the spraying technology, it is more question of the physical properties of added solid lubricant. Milestone 6 was demonstrated succesfully with some of the coating compositions. At high temperature tests the friction COF values were above 0.3 (COF= coefficient of friction).

Table 2: Milestones List

No.	Milestone name	WP no.	Due date	Actual delivery date	Assessment criteria
1	Generation of sufficient data from properties of different solid lubricants	1	Month 6	21.12.2005 (D2)	Sufficient report accepted by partners
2	Selection from different solid lubricants (SL) the most promising alternatives for the three different applications	1&2	Month 6	21.12.2005 (D1&D2) Evaluation of SL's stability will continue.	SL withstand the powder processing and thermal spraying without decomposing
3	Multicomponent powder where all alloying elements are integrated into each powder particle. Successful powders for thermal spraying.	3	Month 6	14.6.2006 (D4.2)	Powder acceptable for TS
4	Interim report and Interim plan for using and disseminating knowledge	6	Month 12	13.7.2006	Acceptance by EC & partners
5	Parameter window for optimal coating containing SL determined. Manufacturing of coating which meets the requirements.	4	Month 20	Results reported 16.10.2006 (D8), 15.2.2007 (D11.2)	Acceptance by partners
6	Demonstration of SL coated components with low friction ($\mu<0.3$, dry) properties	5	Month 25	Results reported 13.7.2007 (D14)	Acceptance by partners
7	Final report	6	Month 25	Report 9.11.2008	Acceptance by EC & partners

2 Impact of the project to its SME and RTD partners

Following results of the project can be exploited:

1. **Modified coating materials (powders)**, which can be used in demanding applications against wear and friction problems at higher temperatures than room temperatures. At least 2-3 new exploitable compositions are created from the results created during the project. Knowledge for manufacturing these powder compositions was created during the project. Benefits of these tailored compositions are suitability to certain application and reliability of components functionality. This result has main impact on Millidyne.

2. **New, self-lubricating coatings**, which can be applied to substrate with acceptable properties. Parameters for spraying these coatings have been developed and evaluated during the project. These novel coatings can be applied to components of customers of thermal spray companies. This result has an impact on SCANA AS, KKP and TLB.

3. **New component coated with self-lubricating coatings,** which can be used in applications working e.g. under high temperatures, pressures, adhesive wear conditions. This result has impact on HYDROWA, JS and TLB.

3 Dissemination and use

Route to exploitation will utilise the supply chain shown in figure 1 where each partner has clear role to play in the supply chain. Raw material producers Millidyne and TLB will get patentable ideas for novel powders. Thermal spraying companies SCANA, KKP and also TLB will get novel coatings and spraying parameters for them. End-users Hydrowa and JS will get new products for their customers.

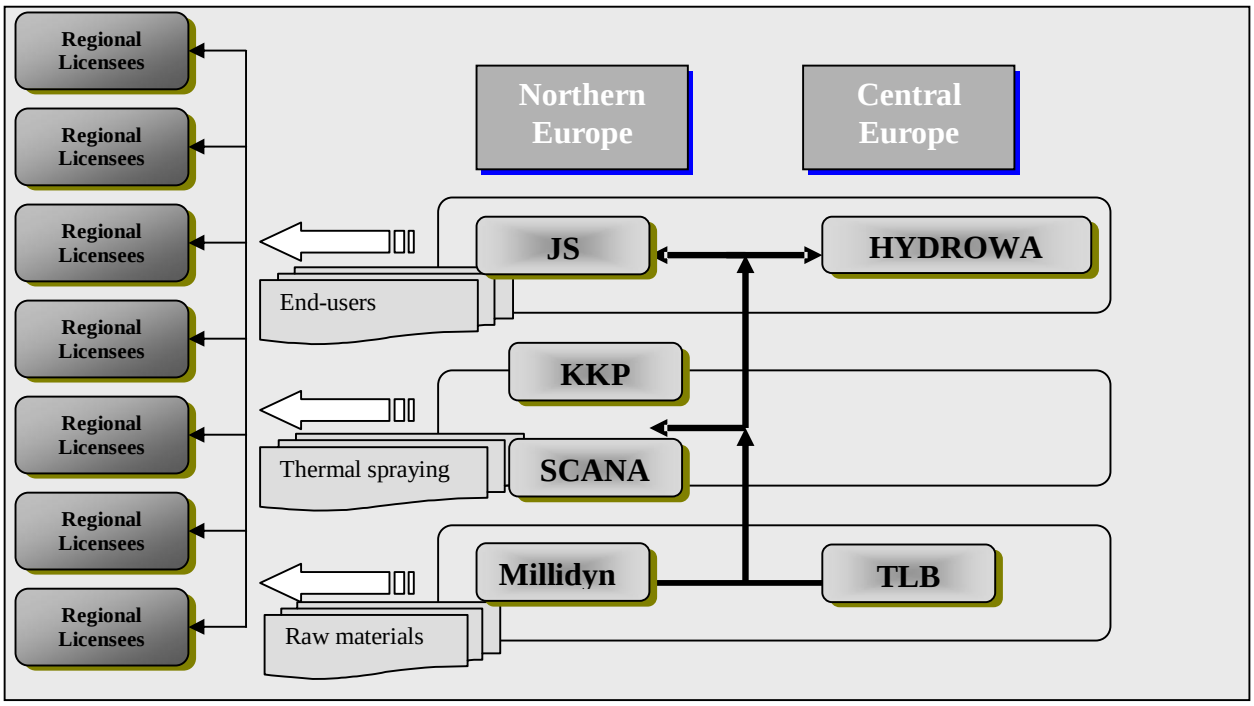

Figure 1.Exploitation route

Partners will play an active role in technology transfer and marketing contact with potential customers. Partners are already currently very active in fairs and exhibitions, and will actively disseminate the results during the project as well as afterwards. Project website has an internal part, where only project partners are allowed to login. All important data obtained from the project including all published reports and newsletters will be put on the project website. External part of the website, will be constantly updated with information related to the project and its results. Participants are currently active in the national workgroups hold by IAGs, and in those activities direct link for other coating manufacturers and end users are able to form. Active

IAGs in this content are The Technology Industries of Finland, DVS - German Welding Society, and GTS Gemeinschaft Thermisches Spritzen e.V. (Association of Thermal Sprayers).
Past and future activities in dissemination of knowledge of SEFUCO project is presented in the following table 3. So far Ulla Kanerva gave an oral presentation on the project results in ITSC 2007 in Peking. More detailed dissemination plan will be discussed in the beginning of the year 2008. There are still long-term tests ongoing at Hydrowa and these results will be discussed within consortium before making decisions. All results planned to be published should be accepted by exploitation committee formed within consortium (chairman for the committee Jari Knuuttila). There will be direct dissemination of knowledge for customers of contractors of the SEFUCO project via email or phone discussions.

Table 3. Dissemination of knowledge.

Planned Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
2006	http://sefuco.vtt.fi (www pages opened 4/2006	General public		Worldwide	All
2007	International Thermal Spray Conference and Exposition (ITSC 2007)Peking, China 14-16.5.2007	Research /Industrial users	global	around 300	VTT etc.
2008	Publications / Posters	Research / General public			VTT etc.
2008	International Thermal Spray Conference and Exposition (ITSC 2008), Maastricht, The Netherlands, 2-4.6.2008	Research /Industrial users	global	around 300	VTT etc