FINAL ACTIVITY REPORT

CONFIDENTIAL

CONTRACT N° COOP-CT-2004-507839
Proposal number: 507839
Project acronym: RESTOOL

Project full title: Nano-composite machining tools with wear and thermal resistance

PROJECT CO-ORDINATOR : University of Nottingham.

PARTNERS :

MTM s.r.l. (Italy)
VF Stampi (Italy)
IMPT Ltd. (UK)

RTD PERFORMERS: :

Technical University of Munich (Germany)
University of Nottingham (UK)

REFERENCE PERIOD : 1 August 2004- 31 March 2007

STARTING DATE : 1 August 2004 **DURATION :** 32 MONTHS

Date of issue of this report : July 2007

PROJECT RESTOOL Final Activity Report

CONTENTS 2

PUBLISHABLE FINAL ACTIVITY REPORT

This report constitutes a progress and achievement made over 32 months comprising:

1. A short technical overview
2. Project objectives and contractors involved
3. Work performed
4. Results achieved and relation of the achievements of the project to the state-of-the-art
5. Conclusions
6. Impacts of the project on its industry or research sector
7. Final plan of using and disseminating the knowledge

1. A short technical overview

Protective coatings deem vital for endurance, performance and wear protection of modern tools. It is needless to say that an enormous number of costly replacements are performed every year in Europe to fix failing tools. The importance of wear protection for machining applications, such as drilling, turning, milling etc. is illustrated by the fact that today 40% of all the European made cutting tools are coated. It is also important to mention that the market for coated tools is rapidly growing world-wide. Unfortunately, the cost of protective coating is relatively high; this cost is passed to the consumer via the retail price; but the coated tools are still lacking the desired quality and fail to satisfy modern requirements such as fast speed of machining and cutting. (It should be noted that besides wear, such parameters as toughness, oxidation resistance, chemical stability, low friction against the material to be machined, adherence to the substrate, thermal conductivity and compatibility with the substrates, etc. define the quality of coatings.). Manufacturers express concern and try to respond to the consumer's complaints about insufficient quality of machining tools that significantly limits their applications. There is an acute need for a relatively low-cost innovative technological concept that satisfies essential marketing conditions regarding cost yet is characterised by high performance, wear resistance, reliability and endurance characteristics. One of the major problems is the use of coolants. About 40% of the machining cost represents the cost of coolants. In Germany, the cost of coolants in 1999 amounted to 1 billion EURO while in Italy it has recently reached 560 MEURO. Europe-wise, the cost of coolants has exceeded 7 billion EURO in 1999. While the machining workshops throughout Europe are predominantly SMEs, the increasing demands on productivity force them to use the tools beyond their capability. These conflicting conditions call for a new technology and new products to be more benign to modern machining operations. The novel coating materials will largely mitigate the current problems the manufacturers of machining tools are facing. The technology that will be developed in the course of the Project would largely improve the quality, compatibility, endurance and reliability of materials used in machining tools and will reduce the use of unnecessary interventions to fix degrading products. Besides that, it will decrease the use of expensive (and sometimes very toxic) substances-coolants that contaminate environment being discarded in large quantities. Compared to conventional protective coatings currently used, the new coatings will be characterised by greater hardness and toughness, better friction properties, better thermal and chemical stability and much greater wear and oxidation resistance. The results will enable the European machining industry to increase and speed up the production combined with saving of resources and should benefit health and environment.

2. Scientific and technological aim and objectives

The main goal of this Project is to develop new coating materials that may significantly help the SMEs to increase their competitiveness, with the following key objectives:

- Development of new advanced materials and a coating technology capable to replace currently used to ensure high wear protection of coated tools.
- Reduce by half the number of costly interventions to replace failing tools.
- Improve by up to 25% coating technologies for deposition on complicated surfaces.
- Reduction in the machining cost.
- Saving by up to 10% on raw materials otherwise wasted in failing tools.
- Increase competitiveness of European SMEs-tools manufacturers.

PARTNERS. Three SMEs were involved:
MTM s.r.l. (Italy) -
VF Stampi (Italy) -
IMPT Ltd. (UK) - Developer of novel and cost-effective non vacuum coating technology based on Electrostatic Spray Assisted Vapour Deposition

RTD PERFORMERS: :

Technical University of Munich (Germany)
University of Nottingham (UK)

3. Work performed

The technical work over the 32-month period (1 August 2004 to March 2007) concentrated on the tasks in the following four packages:

Work package 1: Optimised fabrication of nano-composites based on nc-TiN/SiN_x, such as nc- TiAl)N/a-Si_3N_4.

Task 1.1: Synthesis of nano-composites. The synthesis of nano-composites based on nc-$Ti_{1-x}N$/SiNx and nc-($Ti_{1-x}Al_x$)N/a-Si3N4 that has been recently developed at TUM by PACVD were further studied and optimised. The synthesis will be fully computerised minimising consumption of materials and energy. Super-hard nano-composites characterised by a wide range of values of x in nc-($Ti_{1-x}Al_x$)N/SiNx were also being synthesised. Other chromium nitride-based and titanium nitride-based nano-multilayered coatings nano-multilayered and nanocomposite coatings were synthesised by NUNI.

Task 1.2: Wear resistant of the composites. The wear resistance tests of the coatings were done in collaboration with by means of pin-on-disc at room and elevated temperature and by scratch test. The superhard nanocomposite coatings have, at room temperature, a slightly higher coefficient of friction of 0.6 ± 1 as compared to TiN (0.4 to 0.5) but, at higher temperature of 550°C the coefficient of friction of the nanocomposites decreases whereas that of TiN increases due to its oxidation instability. This is an important advantage of the nanocomposites for their application in dry machining.

Task 1.3 Primary structural characterisation. All the analytical techniques (XRD, XPS, ISS, ERD, SEM and EDX) were calibrated and routinely used for the characterization of the deposited coatings and the investigation into their properties. A problem is the relatively low availability of the ERD technique, which is important for the measurements of small impurities of light elements, because the large accelerator which is needed for such measurements is used by several research groups. A possible solution might be to allocate more funds for these measurements to be done under subcontracting elsewhere if appropriate.

Task 1.4 Thermal and mechanical characterisation. Behaviour of the nano-composites were studied during this sub-task. Thermal characterisation were carried out using thermo-gravimetry (TG) and differential scanning calorimetry (DSC). After the given treatment, the samples were be characterised by means of XRD and indentation in order to identify possible structural changes and a concomitant degradation of mechanical properties. The methodology for the investigation into the thermal behaviour of the superhard nanocomposites was further refined. The techniques described under Task 3.1 were routinely used for these studies. Whenever the quality of the coatings reaches a level where no thermally activated relaxation processes, such as self-hardening and coarsening are observed up to an annealing temperature of 1100 °C, more sensitive techniques, such as internal friction measurements would be applied. Let us emphasized, the softening upon annealing at temperature of about 600 – 750 °C, as reported by some other groups in the literature, does not occur in our coatings. This is evidently an artefact of poor quality of the coatings prepared by the other groups because we have seen such softening only in few coatings deposited by PCVD at the Chengdo Tool Research Institute. This softening was obviously due to the high content of oxygen impurities which we found in these coatings.

Workpage 2: Fabrication of coatings with improved characteristics

Task 2.1: Development of coating technology. Different coating materials which appear similar in terms of composition and crystallite size, but may differ in other important properties. For example, thermal CVD coatings have usually tensile stress which may degrade their performance, whereas those prepared by plasma PVD may suffer from a high compressive stress. The latter might appear advantageous because it causes an apparent increase of the hardness measured by the indentation technique. When such coatings are heated (e. g. during the machining operation) to 600 – 700 °C the compressive stress relaxes and the tribological properties degrade as well. For these reason, the vacuum arc deposition process seems to be promising and was used by TUM for the deposition of a selected advanced nano-composites on steel, ceramics and tungsten carbide tools. It could be further optimised by the introduction of a wide aperture source. (MTM: comparison between PVD and P CVD deposition, quality analysis). However, for the deposition of the superhard nanocomposites with a high hardness, high thermal stability and a high resistance against brittle fracture ("practical toughness") the PVD equipment required some further modifications. It is not presently quite clear, if the high resistance against brittle fracture is due mainly to the high threshold for the initiation of cracks or to a high stress intensity factor (or energy release rate). This question needs more detailed investigations. (TUM: Both, Plasma CVD as well as PVD are reasonably well developed and can be used for the deposition of standard hard coatings. The PVD (reactive sputtering) equipment with a large planar cathode operates now reliably and provides high deposition rates of up to 6 µm/hr with a good purity (see below) of the coatings. Also the prototype coating equipment with the central cylindrical magnetron cathode and turntable with planetary motion of the substrates operates very well: The deposition rate is limited to about 1 µm/hr by the relatively low power of the available power supply of 4 kW. Scaling of the deposition rate with the power density delivered to the target, which has been verified in the past months in our laboratory, makes us confident that whenever a larger power supply will be available, the deposition rate will be increased to the desirable value of 4 to 6 µm/hr also in this equipment.

However, because it is of a more fundamental scientific nature and its solution would require much more time, it was now postponed and the work concentrated on the tasks as originally planned to be done by TUM in WP 2.

The special development of the deposition techniques concentrated on the following fundamental problems:

- Improvement of the formation of the stable nanostructure by self-organization upon spinodal phase segregation,
- increase of the silicon and aluminium content in the PVD coatings and
- Investigation into the role of impurities in the coatings and improvement of the oxygen impurity content.

As these questions could be clarified, at last in principle (many further detail questions remain open), during the past 12 months, the work concentrated on the transfer of this know-how into the development of the coating technology that will be appropriate for the large-scale industrial deposition. It turned out, that for the further R& D. work which has to be done (and the work on a further improvement has to continue), let us first describe the results obtained regarding the above mentioned problems.

The measurements of internal friction showed to be much more sensitive technique for the study of the completion of the phase segregation during the deposition than the usual annealing and measurement of the hardness, toughness and crystallite size of the coatings. For example, nc-TiN/a-Si3N4, nc-TiN/a-BN, nc-TiN/a-BN/a-TiB2 as well as the industrial nc-(TiAl)N/a-Si3N4 superhard nanocomposites deposited by PVD which show a high thermal stability when only the hardness, toughness and crystallite size are measured, still show internal friction peak in the as deposited coatings. This peak vanishes after annealing in nitrogen to 650 – 700°C. Therefore we decided to

- include the internal friction measurement as a standard technique for the control of the phase segregation in the
  prototype as well as in the industrial coating equipments and

- to improve the coating technology as to minimize or – if possible – fully avoid appearance of this peak in the deposited coatings.

Nanoocomposite coatings and nano-multilayered coatings consisting of a hard ceramic phase and an amorphous phase are being considered by NUNI. The nanocomposite coatings would be deposited either directly in a single deposition process or via a two-step procedures. The two step procedures would involve the deposition of nano-multilayered coatings follow by heat treatment to form the nanocomposites. The nanocomposites and nano-multilayered coatings are being prepared using unbalanced magnetron sputter ion-plating for the fabrication of multicomponent coatings with the appropriate control of the coating stoichiometry and composition. Furthermore, the PVD method has the potential for upscaling. The microstructure of the coatings would be investigated using a combination of XRD, XPS, SEM and TEM. The hardness and mechanical properties of the nano-multilayered and nanocomposite coatings would be determined using a tribometer to compare and contrast the mechanical properties of the coatings. The cutting, drilling and machining performance of the coatings will be evaluated and compared.

IMPT and NUNI also work together to develop coatings that are suitable for dry machining at even higher temperatures, in this case high oxidation resistance coatings with a hardness of about 12 GPa would be adequate. IMPT used a novel and cost-effective non vacuum deposition technology based on Electrostatic Spray Assisted Vapour Deposition (ESAVD) to produce hard and oxidation resistance ZrO2 based coatings (e.g. YSZ) which demonstrated a a hardness of 12.6 GPa.

Task 2.2 Surface analysis. Surface investigation such as adhesion strength, layer thickness, surface topography was performed by TUM and NUNI. Environment-responsive systems were be constructed with respect to a variety of parameters. The techniques used and findings were documented in the Activity Review Report (TUM and NUNI) and Quality Manual II (NUNI).

Task 2.3 Data base creation. During this sub-task, the super-hard nano-composite coatings with thickness 4-5 μm and nanomultilayer coatings were characterised for the surface, structure, chemical composition mechanical properties. The findings and data were summarised in the activity review report and quality manuals.

Task 2.4 Pilot process. Within this sub-task the description of the pilot process of coating for cutting and drilling tools were finalised and documented in the Quality Manual. The process were further optimised by TUM in terms of impurities, phase segregation and formation of stable nanostructure, as well as the deposition temperature in order to meet the required high hardness, thermal stability and cutting performance. The samples with nano-coating were initially compared to conventional tool provided by the participating SME, MTMN, in particular regarding thermal and mechanical behaviour. Further evaluation and comparison were performed in workpackages 3 and 4.

Workpage 3: Technical evaluation of nano-composite coated tools

Task 3.1: Evaluation of the dry machining performance of tools coated with nanocomposite coatings.

(a) MTM supplied tungsten carbide tools (including inserts, miller) to TUM for coating.

(b) Coating of tools made of cemented carbide and delivered by the SME's with nc- (Ti1-xAlx)N/a-Si3N4 Coatings. TUM arranged superhard nanocomposite coatings (thickness* circa 4-5 μm) based on nc-$(Ti_{1-x}Al_x)N/a\text{-}Si_3N_4$ which have been established in WP1 and WP2 to be deposited using vacuum arc evaporation onto tools supplied by MTM.

(c) Evaluating the superhard nanocomposite coated tools for dry machining materials under the typical operating conditions as used by MTM so that the machining results and tool lifetime performance could be compared and benchmarked against conventional tools.

Task 3.2: Characterisations of coated and uncoated tools after machining tests.

NUNI provided MTM with inserts coated with nanostructured TiAlN. However, after the cutting test, the coated tools showed chipping and breakage of the cutting edge. This could possibly due to the inappropriate substrate material. Therefore, it was decided to best concentrate on the tools coated with nc-$(Ti_{1-x}Al_x)N$/a-Si_3N_4 coatings which would be more suitable with the type of substrate material and machining operation used by MTM. After machining tests on tools coated with nc-$(Ti_{1-x}Al_x)N$/a-Si_3N_4 coatings, the coated and uncoated (i.e. conventional) tools were examined by TUM and the results were related with the dry machining behaviour and tool lifetime obtained by MTM and VF Stampi.

Task 3.3 Comparison and analysis of coated tools with the conventional tools.

The machining performance and lifetime of nanocomposite coated tools against conventional tools (e.g. those from Mitsubshi).under typical operating conditions were compared to establish the advantages and limitations of nanocomposite coated tools.

Task 3.4 Technical viability of nanocomposite coated tools for machining

The machining results and lifetime of the coated tools against the conventional tools obtained from tasks 3.1 to 3.3 above helped the consortium to establish the technical viability of the various coated tools for milling and turning of steel and Ni-alloys. The cost of such coated tools were compared with conventional tools. Thus, the commercial viability of such coated tools for MTM and other SMEs could be established.

Task 3.5 Reproducibility of hard ZrO2 coatings

There is a need to develop coatings that are suitable for dry machining at even higher temperatures, in this case high oxidation resistance coatings with a hardness of about 12 GPa would be adequate. The capability of producing such coatings reproducibly would be critical. The hard and oxidation resistance ZrO2 based coatings (e.g. YSZ) produced by IMPT using the novel and cost-effective non vacuum ESAVD method in the WP1 and WP2 have demonstrated a a hardness of 12.6 GPa. In this task, IMPT has established the reproducibility of such coatings by depositing them using the deposition conditions that have been established in WP 1 and WP2, and the deposited coatings were characterised by NUNI to determine the coating microstructure, composition, hardness, adhesion, friction and wear characteristics as compared with those YSZ coatings deposited in WP1 and WP2.

Task 3.6 Evaluation results

The evaluation of the machining of coated tools and their lifetime performance against conventional tools. The evaluation of the machining of tools coated with superhard coatings [e.g. nc-$(Ti_{1-x}Al_x)N$/a-Si_3N_4] and their lifetime performance against conventional coated tools based on TiN, TiCN and TiAlN were documented in the activity review report. The technical viability of nanocomposite coated tools for machining were established and summarised in the activity review report.

The reproducibility of high temperature hard YSZ coatings has been determined and summarised in the activity review report. Based on the promising results, IMPT will explore the potential of ESAVD of hard YSZ coatings with tool coating manufacturer and coating equipment manufacturer such as Tevac for dry machining at elevated temperatures.

Workpackage 4: Economic evaluation, market trials and dissemination

Task 4.1: Market acceptance trials of coated tools

Information and knowledge on machining tests on novel nano-coated tools has been offered by MTM in collaboration with TUM and VF Stampi to other SME's and companies for market acceptance, exploitation and knowledge/technology transfer.

IMPT with the assistance of NUNI has explored the potential market for hard YSZ coated tools concept for dry machining with Tecvac and Iscar. Such relationship and exploration of the potential of the technology will continue beyond the RESTOOL project.

Task 4.2: Preparation of exploitation plan

Dissemination of the novel superhard nano-coated tools developed in the project to other SMEs by organising the following workshops to increase the awareness of the benefits and applications of the superhard nanocomposite coatings, the industrial production and coating characteristics:

a) a workshop in Ancona, Italy, 19 May 2006; and
b) a workshop in Ancona, Italy, 3 April 2007.

At the final dissemination workshop organised by MTM in Ancona on 3 April 2007, the following presentations were given by:
TUM -
NUNI -
IMPT and NUNI had jointly prepared a presentation on "Processing and Characterisation of Nanostructured Hard Coatings".

All partners involved in the discussion and finalisation of exploitation plans.

Task 4.3: Economic evaluation of nano-composites

During this task an economic evaluation had been carried out. One of the objectives of the Proposal is to significantly reduce the use of rather expensive and usually toxic coolants currently widely used Europe-wide via the substitution of conventional tools by nano-composite tools. Finally, the economic benefits, of the new coated tools as well as the cost of coating were evaluated and compared with traditionally coated tools.

Task 4.4: Training of employees

MTM, VF Stampi and IMPT employees were given the opportunity to be acquainted with the techniques for the manufacturing of nano-coating tools, and characterisation of the superhard coatings by TUM and NUNI, respectively.

IMPT has disseminated the knowledge of hard refractory $ZrO2$ based coatings to MTM and VF Stampi, and techniques for processing and characterisation of nano-coatings.

Task 4.5: Preparation of operational/quality manual

During this task the data base has been completed to retrieve best practices related to the new technology.
TUM has prepared a manual which included the description of the preparation of tools coated with superhard coatings and their engineering applications in general as well as special emphasis on dry machining.
Examples and case studies will be included with the ultimate aim to help the SME's in the future to utilize fully the advantages of such coatings. The results on machining tests obtained by MTM and VF Stampi also contributed to the Operaional/Quality manual documented by TUM.

A manual including the description of the preparation and characterisation of superhard nanomultilayer coatings and their engineering applications has been prepared by NUNI/

All partners had contributed to the preparation of final activity and management reports co-ordinated by NUNI.

4. Results achieved

(a) Superhard nanomultilayerd CrSiN and TiSiN coatings

Nano-multilayered CrSiN and TiSiN coatings have been deposited onto high speed steel using unbalanced magnetron sputter ion plating. A range of surface characterization techniques, including XRD, SEM, AFM, XPS, and tribometer has been used to determine surface topography, microstructure, compositional, layer thickness, adhesion and coating hardness. The following findings can be drawn from the study:

1) The deposited nano-multilayered coatings have a very dense structure and good coating uniformity and thickness homogeneity.
2) The hardness of the as-deposited TiSiN and CrSiN are 53.0 and 45.1GPa, Respectively
3) TiN/TiSiN coatings show higher critical failure force and scratch fracture toughness.
4) TiN/TiSiN coatings have better wear resistance and lower AE signal, indicating less total damage to the coating surface.
5) CrSiN and TiSiN have the same oxidization resistance upto 800°C in air for an hour. However, both coatings are prone to oxidization above 800°C.
6) The oxidization of Cr and Ti in coatings during the annealing treatment at 900°C is observed by XPS, which agrees well with the XRD results
5) Nano-multi-layered CrSiN and TiSiN coatings are suitable protective coatings for maching upto 800°C.

(b) Oxidation Resistance Superhard nc-TiN/a-Si_3N_4 nanocomposite coatings

The superhard nc-TiN/a-Si_3N_4 nanocomposite are more oxidation resistant than many conventional coatings including the $Ti_{1-x}Al_xN$ coating, able to withistand thermal and oxidation resistant at temperatures above 800°C as shown in Fig.1. Thus allow effective dry machining and hence avoiding the use of the coolants which could saves 20 to 30 % of the total machining costs.

This is even more pronounced for the nc-$(Ti_{1-x}Al_x)N$/a-Si_3N_4 superhard nanocomposites coatings annealed in air at 900°C for 1 hr as compared to $Ti_{1-x}Al_xN$. The thickness of the oxide on the $Ti_{1-x}Al_xN$ is about 4-times larger than that on the nc-$(Ti_{1-x}Al_x)N$/a-Si_3N_4 nanocomposite. In dry machining, where the chemical wear due to oxidation dominates, the improved oxidation resistance results in a correspondingly increase of the life-time of the tool for dry drilling of tough steel. The life-time of the drill coated with the superhard nanocomposites is about a factor of 4 longer than that of conventional $Ti_{1-x}Al_xN$ coatings and almost a factor of 20 longer as compared with the traditional TiN coatings.

The superhard nanocomposites also provide very high thermal stability. Multicomponent coatings are metastable solid solutions which undergo decomposition upon annealing to elevated temperature. For example, $(Ti_{1-x}Al_x)N$ decomposes above about 800°C into fcc-TiN and hcp-AlN. This decomposition is accompanied by a significant decrease of the hardness. The nc-$(Ti_{1-x}Al_x)N$/a-Si_3N_4 nanocomposites, however, remain stable upon annealing up to 1200°C as illustrated by Fig. 7. One can see that the decomposition and softening of the nanocomposites is hindered by the SiN_x interface up to a high temperature of 1200°C. The softening above that

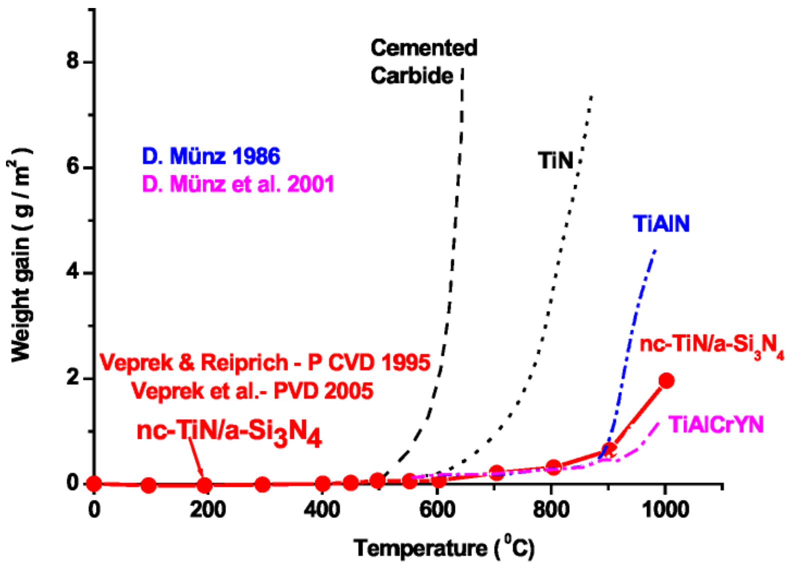


Fig. 1: Oxidation resistance of cemented carbide and various coatings [1,2]

temperature is due to diffusion of cobalt from the substrate into the coatings. Thus, the thermal stability of the coatings is higher than that of the cemented carbide, which is used for the fabrication of high-performance machining tools.

In order to achieve the high hardness enhancement, the coatings must have low concentration of oxygen impurities of less than 0.2 at. % [1]. This is possible in the state-of-the art of modern coating unites if they are operated by experienced and well-trained personnel. Therefore, care has to be exercised during the operation of the coating system.

The first superhard nanocomposites were prepared by means of plasma CVD [3,4]. The advantage of plasma CVD is its flexibility and that it provides the best conditions for the phase segregation and formation of stable nanostructure. However, it suffers of the disadvantage of difficult scaling to large, industrial equipment. For these reasons, majority of coatings on tools are prepared by physical vapour deposition. The PVD techniques can be subdivided into vacuum arc evaporation/deposition and reactive sputtering.

The advantage of the sputtering technique is a high quality of the surface of the deposited films, but this technique suffers of a relatively low deposition rates. However, the central magnetron as well as a planar one operating at a high power density of about 20 Watts/cm^2 allowed us to reach deposition rates of 5 – 6 µm/hr on stationary substrates (which is equivalent to about 1.7 – 2 µm on double rotation of the tools) [5]. Such sputter rates are already comparable with those of the vacuum arc evaporation technique.

There is a variety of industrial coating units utilizing vacuum arc. We shall limit ourselves tothe most advanced technology, which is particularly suitable for the deposition of the superhard nanocomposites. This technology uses two or more rotating cylindrical cathodes made of different materials depending on the desirable composition of the coatings. The unit equipped with two cathodes placed into the door of the vacuum chamber. This is the most advanced technology suitable for the "in house coating" [6].

(c) Application of superhard coatings for machining elaborated within the project RESTOOL

When evaluating different coatings regarding their performance one has to keep in mind that there is no single, universal, "the best" coating. The performance depends on a number of factors including pre-treatment of the tools edges prior to the deposition of coatings, post-treatment of the coated tools, such as polishing, sand blasting etc., on the type of the machining operation, machining speed, depth of cut, feed rate, material being machined etc. A coating, which performs excellently in one machining operation may fail in another one. Therefore, extensive testing is always needed in order to find the most suitable coating for a given application. For these reasons, the example to be shown hereafter should be regarded only as a rough guidance.

Within the extended period of the project RESTOOL, M.T.M. and VF Stampi conducted a large number of different machining operations (milling, turning, drilling) with different materials (different grades of steels, copper etc.) with tools coatings provided by TUM. The results are documented in three reports, and they are summarised below.

Machining conditions:

Indexable inserts: Standard indexable inserts CNMG-120408-UE6010 (TiCN-Mitsubishi) and CNMG 120404-GN IC907 (ISCAR), which are being used by M.T.M. were compared with Inserts PGN-1 20308 which were coated with "MARWIN-SI (nc-TiAlSiN)" nc-$(Ti_{1-x}Al_x)N$/a-Si_3N_4 superhard nancomposite coatings.

a) Inserts SPGN-1 20308 MARWIN-SI (nc-TiAlSiN) (RESTOOL)

CNMG-1 20408- UE6010(TiCN) (MITSUBISHI)

The life-time of the inserts coated with the superhard nanocomposites are significantly longer (55 % and 112 %, respectively) than for the standard tools from world-leading companies MITSUBITSHI (Japan) and ISCAR (Israel), which are being used in the production at M.T.M. so far. This is very encouraging, particularly if one considers the fact that the inserts coated with the superhard nanocomposites did not have chip breaker. Therefore we expect a further improvement with the other type of the chips. This will be the subject of the next series of tests. Nevertheles, already the results obtained in this first series represent a significant improvement of the economy of the machining.

Milling:

Tests performed at M.T.M.: The "life-time" of the coated tool was 4-times longer than the standard tool which is being used in the current machining operations at M.T.M (total 500 pieces can be machined with the standard tool whereas 2000 were machiened with the coated one). Considering the price of about 50 EUR per mill, machine time and personnel costs, this result represents a significant saving of the total machining costs of about 500 EUR for this single type of production.

Tests performed at VF Stampi: The significant improvement of the life-time when machining steel ISO 1.2311 and ISO 1.2083 tempered, and only a small improvement when machining steel ISO 1.1730 can be understood by the difference in the Vickers hardness (HV) of 700 for ISO 1.2311, of 495 for ISO 1.2083 tempered, and 425 for ISO 1.1730. Obviously, the superhard nanocomposite coatings show better performance when machining hard steel. Moreover, if one takes into account the fact that the tool coated with the nanocomposites has only 2 cutting edges whereas the standard one has 4, the actual improvement of the machining performance will be much higher if the same type of tools will be compared. This was not possible in the current tests because the uncoated Fraisa D10 R0 Z4 mills were not available.s

Inserts for external tourning:

All the tests are been performed using a "CNC Turning Center."
The results of the tests denote a substantial increase of the duration of the inserts equal to around 14% under normal conditions, if however the speed of cut is increased you see test 2 and 4 it is noticed that the increase of duration is almost of 65%.

Conture of milling of Copper:

We have found that the insert Restool has a light initial usury, with constant good finishing and a duration of the edge of around 40% in more. At the beginning, the Fraisa insert gets a best finishing; after that, then the edge usury very quickly with an inferior duration.

Conture of milling of steel 1.2311:

In this test we have found that the utensil Restool him usury constantly in the time with a

superior duration to the other insert.
The conventional utensil him usury quickly up to breakup if we increase the speed of cut and we work to taller values of the recommended ones while the utensil Restool is constant with a superior duration of around 60%.

Conture of milling of hard steel tempered 48-50 HRC:

In this test we have worked from immediately with superior speed of cut those recommended with a good result of finituta but above all with a duration of the edge of around him 80% superior respect the conventional utensil.

The lifetime of the drill coated with the nanocomposite coatings MARWIN G is about 63 % longer than that of the standard drill used in the production so far.

The tool coated with the superhard nanocomposites MARWIN G is superior to the standard one, which has been used in the production so far. After a time of 70 % longer than the life time of the standard tool the nanocomposite coatings still show very low wear

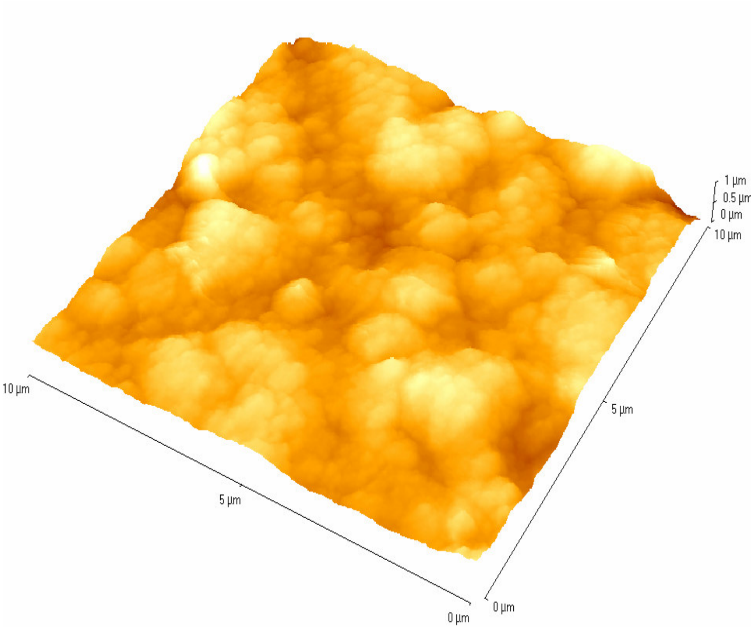
Increase in the lifetime of the insert coated with nanocomposites MARWIN G is about 59 %.

At a higher cutting speed of 280 m/min the lifetime of the standard tool strongly decreases whereas that of the tool coated with the nanocomposites MARWIN G decreases much less, and still remains longer than the lifetime of the standard tool at the lower cutting speed (see above). The lifetime of the tool coated with the nanocomposites is about 147 % longer than that of the standard tool.

(d) Refractory and oxidation resistance hard YSZ coatings

There is a need to develop coatings that are suitable for dry machining at even higher temperatures, in this case high oxidation resistance coatings with a hardness of about 12 GPa would be adequate. The capability of producing such coatings reproducibly would be critical. The hard and oxidation resistance ZrO_2 based coatings (e.g. YSZ) produced by IMPT using the novel and cost-effective non vacuum Electrostatic Spray Assisted Vapour Deposition (ESAVD) method have demonstrated a a hardness of 12.6 GPa. The reproducibility of such coatings have also been established.

Atomic force micrograph of a typical surface morphology of the 8wt%-YSZ coating deposited using ESAVD method which shows dense, uniform coatings with fine grain structure.



AFM image of ESAVD of 8wt% of YSZ

IMPT's novel and patented ESAVD coating method has demonstrated the capability of reproducing uniform and adherent YSZ coatings with adequate hardness and low mean coefficient friction, as well as low thermal conductivity and excellent thermal shock resistance, which could potential use for dry machining at elevated temperatures. Such encouraging results would allow IMPT to extend the development work beyond the RESTOOL project with potential tool manufacturers through partnership for incorporation into the ESAVD produced YSZ layers in the multilayer protective hard/superhard coatings to extend the service temperatures of the coated tools. Initial expression of interests have been received from tool manufacturers and end-users to explore such potential. This could lead onto the ultimate exploitation of the findings for potential commercial application of the ESAVD produced YSZ for the tooling market.

Conclusions

- The project has developed and provided in-depth fundamental understanding of new advanced materials and a coating technology capable to replace currently used to ensure high wear protection of coated tools.
- Potentially reduce by half the number of costly interventions to replace failing tools.
- Reduction in the machining cost.
- Saving by at least 10% on raw materials otherwise wasted in failing tools.
- Increase competitiveness of European SMEs-tools manufacturers.
- Quality Manual I (prepared by TUM) for SMEs :

  The manual describe the *Hard and Superhard Nanocomposite Coatings for Machining: Their Selection, Manufacturing and Applications*. It contains a brief description of the preparation of the coatings and a number of examples of their industrial applications for a variety of machining operations. Examples are given which show the large possibilities of increasing productivity and reducing costs, which provides a basis for an economic assessment. The manual contains also guidelines for establishing a centre for re-conditioning (stripping of the used coatings, regrinding and re-coating) of expensive tools.

- Quality Manual II (prepared by NUNI)

  This is a complimentary manual to the Quality Manual 1 by providing the fundamental aspects of superhard coatings and coating methods, as well as describing in details the various methods used for surface characterisation, mechanical testing and coating characterization of hard and superhard coatings. The specific example of processing, charcaterisation and mechanical properties of superhard coatings based on nano-multilayer structure is also presented

References

[1] S. Veprek, P. Karvankova and M. G. J. Veprek-Heijman, J. Vac. Sci. Technol. B **23,** L17 (2005).

[2] S. Veprek, M. G. J. Veprek-Heijman, P. Karvankova and J. Prochazka, Thin Solid Fims, **476,** 1 (2005)

[3] S. Veprek and S. Reiprich, Thin Solid Films **268,** 64 (1995).

[4] S. Veprek, M. G. J. Veprek-Heijman, P. Karvankova and J. Prochazka, Thin Solid Fims, **476,** 1 (2005).

[5] J. Prochazka, P. Karvankova, M. G. J. Veprek-Heijman and S. Veprek, Mater. Sci. Eng. A **384,** 102 (2004).

[6] Jilek, M., Cselle, T., Holubar, P., Morstein, M., Veprek-Heijman, M. G. J., and Veprek. S., (2004). Plasma Chem. Plasma Process. 24, 493.

Dissemination and use

The following objectives for dissemination and spreading of knowledge of RESTOOL have been achieved :

- Provide training facilities to spread knowledge added by RESTOOL inside and outside the RESTOOL.
- Devote a special effort to the external communication and knowledge dissemination to increase awareness on RESTOOL
- Provide an instrument to stimulate the transfer of research results to the industrial world, including services for SME's.
- To define a common consortium strategy for the dissemination and evaluation of the results of the joint research;
- To increase awareness on RESTOOL technology.

Individual Plans for using and disseminating the knowledge

Name of the Company	Plans for the use of knowledge	Plans for the dissemination of knowledge
MTM	RESTOOL coatings have allowed MTM to have an efficiency improvement of 25-45%, producing an improvement of the production of 7-10%. The project has led to the potential creation of a partnership between MTM and a new industrial partner (who are interested in the outputs of RESTOOL) to establish a coating service bureau/ a centre for re-conditioning of expensive tools in order to provide superhard coatings or large scale distribution in the Italian market. MTM is expected to explore a very innovative business opportunity.	Dissemination within the MTM clients. Together with FUTURO srl which has a large distribution network, it is envisaged that the RESTOOL's outputs and knowledge will continue to be widely disseminated beyond the project both nationally and internationally.
VF Stampi	The promising machining and cutting test results of the superhard coatings developed in the RESTOOL project as compared to the existing hard coatings (e.g. TiN, TiCN and TiAlN) has encouraged VF Stampi to confidently use such superhard coatings in their coated tools to increase their producitivity and efficiency, which they have demonstrated by 35-40%, and the tool life by 20%. They are ready and most willing to support MTM and FUTORO in the take up plan.	Dissemination within VF Stampi's clients and their industrial collaborators.

IMPT	Use the acquired knowledge for the further development and potential commercialization of ESAVD of refractory and oxidation resistance hard coatings for tooling markets. The knowledge and results generated from RESTOOL project has opened up the opportunity for IMPT to explore its novel and cost-effective coating technology for tooling market. Initial expression of interests have been received from tool manufacturer, and end user to explore such potential.	Dissemination within IMPT's Clients and their industrial collaborators in UK, Europe, North America and Far East.

The RESTOOL project had and would continue to contribute beyond the project for existing partners and their collaborators:

- Innovation and the creation of new knowledge;
- Access to global knowledge;
- Access to experts;
- Access to quality manual;
- Lists of references to case studies; and
- Discussion forums for problem resolution.

RESTOOL consortium welcome collaboration from academic and industrial communities. For further information, please contact the co-ordinator:

Prof. K. L. Choy
School of Mechanical, Materials and
Manufacturing Engineering
University Park
Nottingham NG7 2RD
United Kingdom
Tel/Fax: +(44)-(0)-115 951-4031
e-mail: Kwang-leong.choy@nottingham.ac.uk