FINAL ACTIVITY REPORT

Contract number COOP-CT-2004-508710-FORBEST

Proposal number 508710 (call identifier FP6-2002-SME-1)

Acronym ForBeST

Title Increased Service Lifetime of Forging Tools by Combined Surface Treatments

Project co-ordinator Fraunhofer Institute for Production Technology IPT, Germany

Partners	**Country**	**Shortcut**
A. BENEVENUTA & C. S.p.A.	Italy	BENE
DMF Werkzeugbau GmbH	Germany	DMF
Forjaco - Aco Forjado, Lda.	Portugal	FAF
Rasche Umformtechnik GmbH & Co KG	Germany	RAS
KLF - ZVL MTK spol. s.r.o.	Slovakia	MTK
National Institute for Laser, Plasma and Radiation Physics	Romania	ILPP
Fraunhofer Institute for Production Technology IPT	Germany	IPT

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Contents

1 Abstract

Nitriding of forging dies is a well known technology to extend the lifetime of the dies due to a higher wear resistance. A good approach to improve the wear resistance is to combine laser alloying or laser dispersing with a subsequently nitriding or nitrocarburising process. Main innovation of this surface treatment technology was the investigation on new material compositions regarding the additives in connection with the base material. Both the influence of laser treated and subsequently nitrided as well as subsequently nitrided and "Combined Magnetron Sputtering and Ion Implantation (CMSII)" treated areas near surface were investigated. The surface layer properties and the increase of the dies' lifetime were of outstanding interest.
The Project "Increased Service Lifetime of Forging Tools by Combined Surface Treatments – ForBeST" was divided into three phases: research, development and validation. In addition management activities attended the project during its entire duration.

1.1 Research

The basic research was done using samples with a simple geometry which were analysed by metallographic research.
Wear resistant layers on samples were made by laser alloying/dispersing during basic research and process layout. Different additive materials (TiC, WC-Co, MoC etc.) were tested with the objective to generate layers with good properties (high penetration depth, no cracks, even distribution of the particles, reduced abrasion). The laser treatment was followed by plasma nitriding or nitrocarburising with and without "Combined Magnetron Sputtering and Ion Implantation (CMSII)". The main objective of these processes was to reduce the adhesion of samples/dies during the forging application.
The optimum process parameters for each technology and the combined treatment were defined as the results of this phase (figure 1).

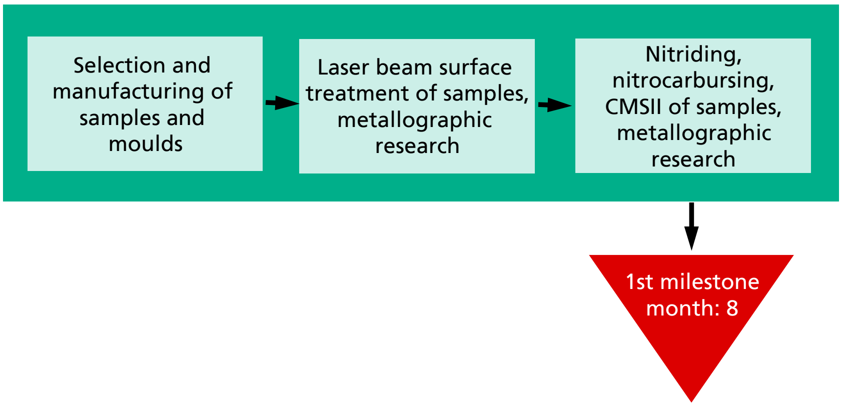


Figure 1: Research, Project "ForBeST"

1.2 Development

The process parameters defined in the research phase were adapted to selected dies/moulds. This selection was done by the industrial partners in co-operation with the RTD performers. The moulds which are forging and aluminium die casting moulds were applied under real conditions in the companies of the industrial partners. A comparison with conventionally treated moulds was ensured in this way. The process parameters of combined surface treatments of new moulds were continuously optimised. For this optimisation the results of done applications were used.
The processing parameters were adjusted depending on the forging and die casting applications. A close loop was established between the transfer of results to moulds, optimisation of the nitriding process, investigations on operational properties and identification of the wear mechanisms (figure 2). The output of this phase was used for the comparison with conventionally treated moulds of the industrial partners.

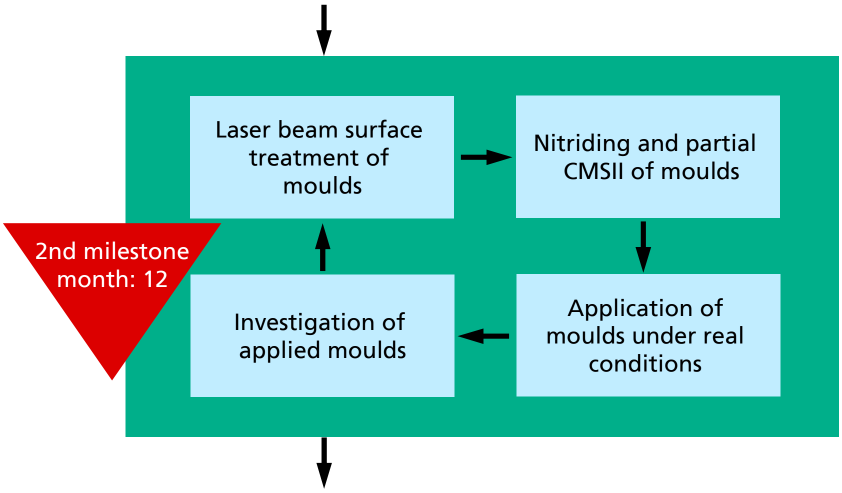


Figure 2: Development, Project "ForBeST"

1.3 Validation

The surface treatments and their combination were assessed in this phase. The obtained results and the potential of the combined treatment were evaluated (figure 3). A plan concerning the exploitation of the results was set up and the knowledge about the increase of moulds' lifetime was disseminated. The assessment of the results included technical properties and economical aspects. The "Technology Implementation Plan" and the "Plan for Using and Disseminating Knowledge" were output of this phase.

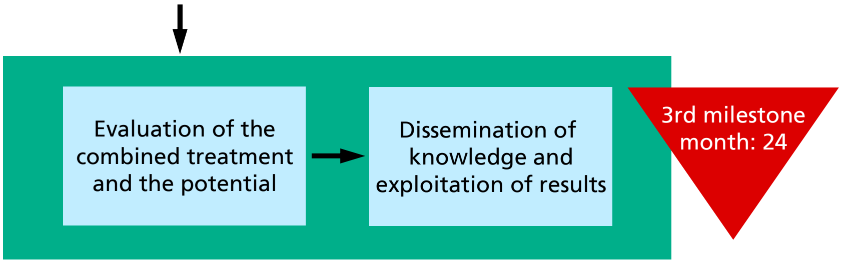


Figure 3: Validation, Project "ForBeST"

1.4 Management

The project management ensured that the planned and arranged project activities correlate with each other (figure 4).
Three milestones were defined in the workflow. The first milestone was defined after finishing the research tasks and before treatment of dies/moulds. The criterium for assessment were optimised surface layers against abrasion and sticking effects.

The second milestone was defined after the first test of the dies under industrial conditions and the investigation as well as assessment of these dies. The process parameters were optimised depending on the results of the assessment.
The final meeting, including a presentation of the final reports, marked the third milestone.

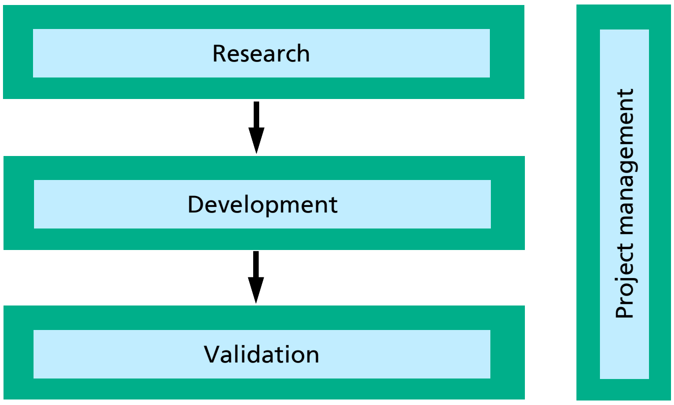


Figure 4: Validation, Project "ForBeST"

2 Project objectives

The European forging and aluminium die casting industry, which is dominated by small and medium sized enterprises (SMEs), has to reduce its production costs to stay competitive against similar companies from outside Europe.
For this reason the general objective of the Project "ForBeST" is to reduce the manufacturing costs of products. This aim can be realised by a longer lifetime of forging and aluminium die casting moulds. By this the forging and die casting enterprises have not only to manufacture less moulds, but also the machining down times are significantly reduced. There are less production stops due to a change of moulds.
The surface of forging and die casting moulds is subjected to temperatures between 200 and 800 °C in operation as well as enormous pressure and friction. Because of that circumstance, the failure of these dies is caused by mechanical and thermal wear in up to 70% of all cases. The objective of the project activities is therefore to develop high wear resistant surface layers by combining laser alloying/dispersing and plasma nitriding/ nitrocarburising. In addition dies are coated with TiN/TiAlN by "Combined Magnetron Sputtering and Ion Implantation (CMSII)".

At the beginning of the project duration the expectation was an increase of 100% of moulds' lifetime. In cause of a 100% increase the overall costs per produced piece will decreased by at least 20%. The improved quality of the manufactured products due to the higher wear resistance of the moulds is an additional expected benefit.

3 Progress report

3.1 Summary of the objectives for each work package

The objectives for each work package can be summarised as follows according to the "Description of Work" and the decisions made by the project consortium in the Kick-off Meeting:

Work package 1 – Manufacturing of samples and moulds

- Selection of moulds (material, geometry, number of moulds)
- Selection of samples (material, geometry, number of samples)
- Agreement regarding heat treatment (hardness characteristic)
- Production and provision of samples
- Production and provision of moulds

Work package 2 – Laser surface treatment (laser alloying/dispersing) of samples

- Implementation of an one-step laser alloying/dispersing process
- Testing parameters for laser alloying/dispersing
- Definition of the additive materials and their mass flow
- Analyses of laser treated samples (surface roughness, layer geometry, hardness characteristic, definition of carbides)

Work package 3 – Nitriding, Nitrocarburising and Combined Magnetron Sputtering Ion Implantation (CMSII) of samples

- Testing nitriding parameters (temperature, duration, pressure and gas composition)
- Characterisation of the hardness profiles and penetration depths
- Provision of the process layout for nitrocarburising
- Deposition of a thin hard layer (material TiN or TiAlN) on the nitrided layer by Combined Magnetron Sputtering and Ion Implantation (CMSII)
- Analyses of treated samples for the identification of the layer characteristics

Work package 4 – Laser surface treatment of moulds (transfer of results)

- Coding CNC programs
- Transfer of results from WP 2 to the selected moulds
- Definition of process strategy with the intention to reduce distortion and the formation of cracks
- Investigations on the following process parameters: laser power, feed rate of laser beam, size and position of laser beam
- Provision of laser alloyed/dispersed moulds

Work package 5 – Nitriding of moulds (transfer of results)

- Surface finishing of selected moulds
- Plasma nitriding of the selected moulds
- Transfer of the first results from the real tests to the following nitriding processes
- Consideration of the penetration depth and treatment time

Work package 6 – Application of combined treated moulds

- Application of moulds under real conditions
- Definition of the most effective surface treatment technology in consideration of costs
- Mould tests in steps to realise iteration loops
- Economic consideration

Work package 7 – Analyses of applied moulds

- Investigations of the applied moulds with the objective to specify the present wear mechanisms
- Cutting of selected moulds and metallographical investigations concerning the following aspects:
  - Structure of the alloyed area
  - Presence of nitrides
  - Cracks and their initiation points
  - Surface quality and dimensional differences

Work package 8 – Evaluation of the combined treatment and the potential of the technology

- Quantification of the success of the combined surface treatment
- Analyses of the reached results (work packages 4 - 7)
  Viewpoints:
  - Quality/stability of the combined treatment technology
  - Advantages and disadvantages of different layer structures
  - Reproducibility of the treatment
  - Economic consideration (combined and conventional surface treatment)

- Further potential applications
- Technology transfer to industrial companies

Work package 9 – Provision of a plan "Use and dissemination of knowledge"

- Provision of a plan which includes the use and dissemination of knowledge and results
- The Plan shall include the following articles:
  - Potential markets for the combined surface treatments
  - Activities and responsible partners
  - Suitable material combinations and surface treatments
  - Making the results available to industrial users
  - Time schedules

Work package 10 – Project management

- Project management of the Project "ForBeST" in consideration of the time schedule and the objectives
- Support of communication
- Provision of reports

3.2 Technical progress

Work package 1 – Manufacturing of samples and moulds

Forging and aluminium die casting moulds were selected by the industrial partners in co-operation with the RTD performers in the Kick-off Meeting and succeeding meetings. The steels 1.2365 (X32CrMoV3-3); 1.2343 (X38CrMoV5-1) and 1.2344 (X40CrMoV5-1) were defined as base materials at the same time. The properties of the steels 1.2343 and 1.2344 can be assessed as similar. Moreover the parameters of the heat treatments were defined (surface hardnesses between 48 HRC and 50 HRC). Fraunhofer IPT provided heat treated samples (diameter 80 mm; thickness 10 mm) made of the mentioned base materials.

The moulds' complexity levels more precisely the geometries were very different. The moulds with a lower complexity level from the companies DMF and RAS were decided to treat first. The moulds with a higher complexity level belonging to the companies BENE, FAF, MTK should be treated subsequently.

A list of the selected moulds from all partners is given:

Figure 5: Mould "DMF"

• Identification	"048 Teileinsatz FS – DMF"
• Type of mould	Insert of an aluminium die casting mould
• Application	Die casting parts for the automotive industry
• Mould steel	1.2343 (X38CrMoV5-1)
• Heat treatment	Quenched and tempered (50 ± 2 HRC)
• Maximal dimension	Approximate 70 mm
• Applied material during the die casting process	AlSi9Cu3(Fe)

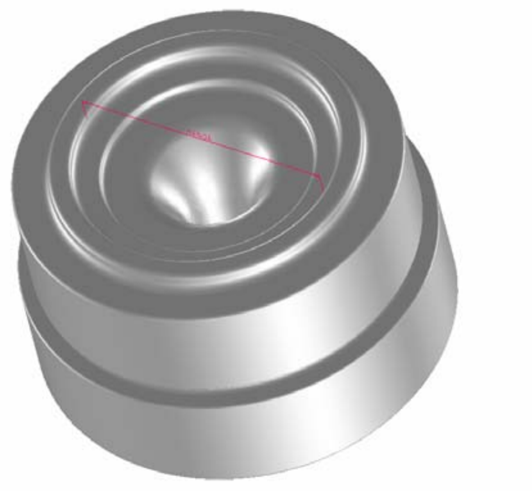


Figure 6: Mould "RAS"

• Identification	"Untergesenk Vorform – Rasche"
• Type of mould	Forging mould, blank mould, lower part

• Application	Forging parts for the automotive industry
• Mould steel	1.2365 (X32CrMoV3-3)
• Heat treatment	Quenched and tempered (48 - 50 HRC)
• Maximal dimension	Approximate 140 mm
• Applied material during the forging process	46MnVS3 (steel 1.1305)

Figure 7: Mould "MTK"

• Identification	Forging mould – "Mould MTK"
• Type of mould	Forging mould, lower part
• Application	Flange for the automotive industry
• Mould steel	1.2343 (X38CrMoV5-1)
• Heat treatment	Quenched and tempered (48 HRC)
• Dimensions	Diameter 270 mm, thickness 75 mm
• Applied material during the forging process	S 355 J2G3 EN 10025+A1 (steel 1.0572)

Figure 8: Mould "BENE"

Identification	Forging mould – "Mould BENE"
Type of mould	Forging mould, upper and lower part
Application	Shift-fork (freight vehicle)
Mould steel	1.2344 (X40CrMoV5-1)
Heat treatment	Quenched and tempered (46 HRC)
Dimensions	280 * 190 * 110 mm³

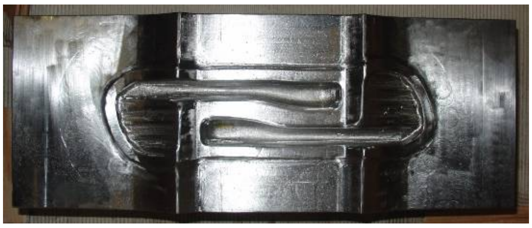


Figure 9: Mould "FAF"

Identification	Forging mould – "Mould FAF"
Type of mould	Forging mould, upper and lower part
Application	Pedals (motor scooter)
Mould Steel	1.2344 (X40CrMoV5-1)
Heat treatment	Quenched and tempered (49 - 50 HRC)
Dimensions	400 * 140 * 100 mm³
Applied material during the forging process	C35 EN 10083-2 (steel 1.0501)

In addition DMF Werkzeugbau GmbH selected ejector pins for a feasibility study. It should be investigated, if parts with a low volume can be laser treated without dimensional deviation. The selected ejector pins can be characterised as follows:

Figure 10: Ejector pins – DMF

Identification	Ejector pins "Pins – DMF"
Type of mould	Ejector pins of an aluminium die casting mould
Application	Ejector pins for die casting moulds

Pin material	1.2343 (X38CrMoV5-1)
Heat treatment	Quenched and tempered (45 HRC)
Dimensions	length 79.68 mm, diameter in the functional area approx. 3.6 mm
Applied material during the die casting process	AlSi9Cu3(Fe)

Work package 2 – Laser surface treatment (laser alloying/dispersing) of samples

The processes laser alloying and laser dispersing were implemented in line with this work package. Therefore a box (1500 * 1500 * 1500 mm^3) was built to protect the process operators and the entire machine shop against the laser radiation and powder contamination (powder particle size 20 - 60 µm). Fraunhofer IPT applies Nd:YAG-lasers and high power diode lasers (laser power up to 3 kW) in line with surface treatment techniques. These laser systems have similar wavelengths (800 - 1064 nm) and resulting the absorption of laser radiation in the moulds'/parts' surface varies ± 10%. Within the Project "ForBeST" a fiber-coupled Nd:YAG-laser with a maximum laser power of 3 kW as well as a direct high power diode laser was applied by the Fraunhofer IPT. The results presented that is better to apply a Nd:YAG-laser for laser alloying/dispersing processes. Nd:YAG-lasers have rotation-symmetric foci which is required for the definition and realisation of paths on the surface of complex moulds. The high power diode laser, which are available at Fraunhofer IPT have non-rotation-symmetric foci.
The powder conveyer (Sulzer Metco, TWIN-10-C) was modified for application of different powders from two containers into the process area.
During the test series the heat treated samples (diameter 80 mm, thickness 10mm) were laser alloyed/dispersed with the additive materials titanium carbide (TiC) and tungsten carbide cobalt 88-12 (WC-Co 88-12) in an area of 20 * 40 mm^2. The additive material tungsten carbide cobalt (WC-Co) was used for the laser alloying process. WC-Co is blown in the molten area near surface of a mould/part and molten itself by the laser radiation. After solidification WC-Co is held in the area near surface. The additive material titanium carbide (TiC) was used for the process laser dispersing. In contrast with laser alloying the particles are not molten during the laser treatment. The TiC particles are even dispersed in the areas near surface after the solidification of the base material. The difference bases on the chemical stabilities of the materials TiC and WC-Co.

The following figure 11 presents the implementation of the laser alloying/dispersing process:

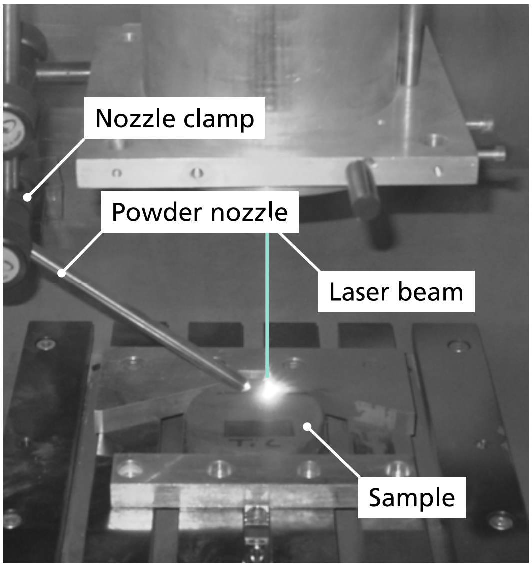


Figure 11: Laser alloying of a sample

After test series and the subsequent analyses (light microscopy etc.) the optimised parameters for geometrical defined tracks and a low surface roughness were defined as follows:

• Laser power	1500 W
• Feed rate	500 mm/min
• Focal length	200 mm
• Focus diameter	2 mm
• Hatch distance	1 mm
• Inert gas	argon
• Laser System	Nd:YAG-laser

The light microscopy of samples presented a penetration depth reached by laser radiation of approx. 1.5 mm, as shown in figure 12. This figure presents a typical structure of a laser alloyed sample made of the base material 1.2365 (X32CrMoV3-3) and laser dispersed with the additive material TiC.

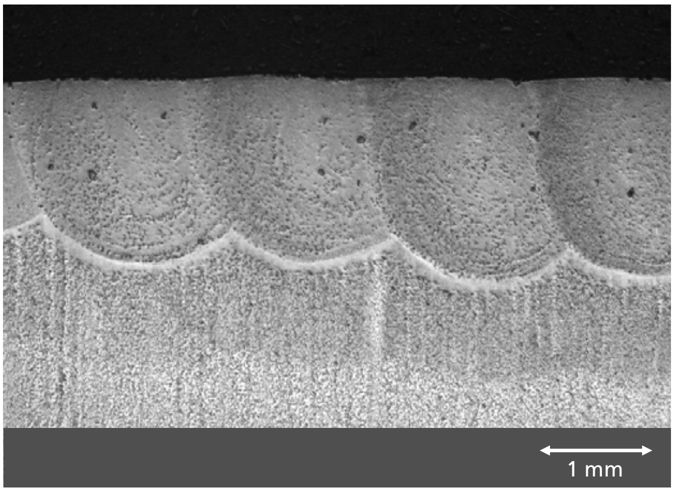


Figure 12: Structure of a laser dispersed sample (base material 1.2365; additive material TiC)

Fraunhofer IPT investigated the influence of the laser power and feed rate on the penetration depth of carbides. The aim of these investigations was an optimisation of the process parameters laser power and feed rate. The used samples had been made of steel 1.2365 (X32CrMoV3-3).
The penetration depth of the carbides was analysed. The penetration depth of the element tungsten was investigated regarding laser alloying and the element titanium concerning laser dispersing by an energy dispersive X-ray linescan analyses (EDX linescan analyses) (figures 13 and 14).

Characterisation

- Base material 1.2365
- Hatch distance 1 mm
- Laser power1 500 W
- Additive material TiC
- Feed rate TiC 0.4 g/min

Results of the linescan

- Ratio of TiC near surface
  - 1.51 mass-%
  - 1.73 atom-%
- Ratio of TiC in a depth of 0.5 mm
  - 1.8 mass-%
  - 2.06 atom-%

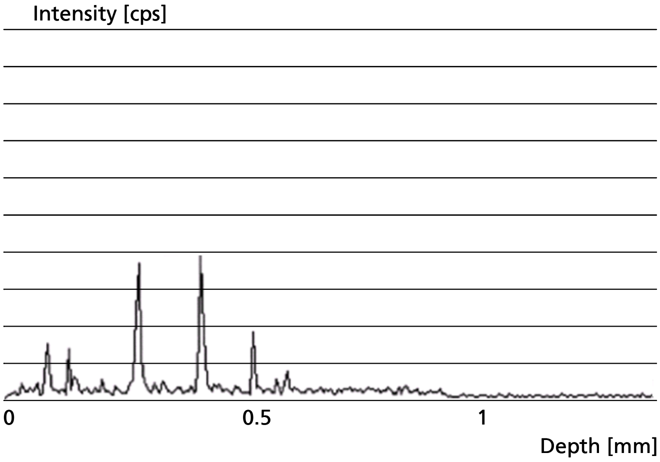


Figure 13: EDX linescan analysis – Laser dispersed sample (additive material TiC)

Characterisation

- Base material 1.2365
- Hatch distance 1 mm
- Laser Power 1 500 W
- Additive material WC-Co
- Feed rate WC-Co 0.9 g/min

Results of the linescan

- Ratio of W near surface
  - 9.57 mass-%
  - 3.02 atom-%
- Ratio of W in a depth of 0.5 mm
  - 7.84 mass-%
  - 2.46 atom-%

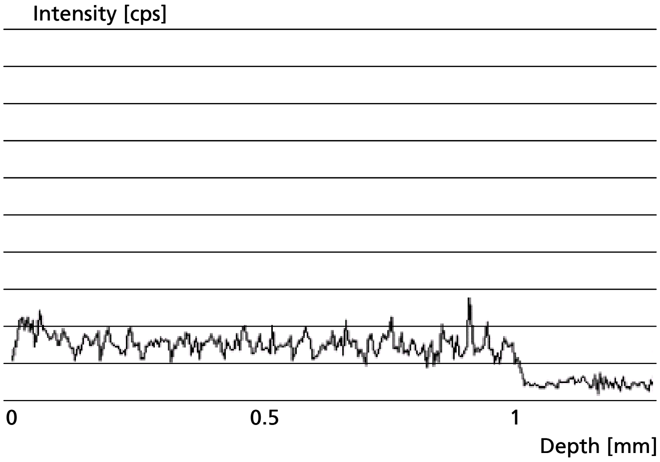


Figure 14: EDX linescan analysis – Laser alloyed sample (additive material WC-Co)

Fraunhofer IPT investigated the distribution of the elements tungsten (W) and titanium (Ti) in the areas near surface by energy dispersive X-ray mappings (EDX mappings). Laser alloyed (additive material WC-Co) and laser dispersed (additive material TiC) samples (base material steel 1.2365) were metallographically prepared and the distribution of the elements W and Ti were taken by EDX mapping. The penetration depth of the elements tungsten and titanium was about 1 mm (figure 15) and confirmed the results of the EDX linescan analyses. The distribution of all elements and carbides respectively is even in the areas near the surface.

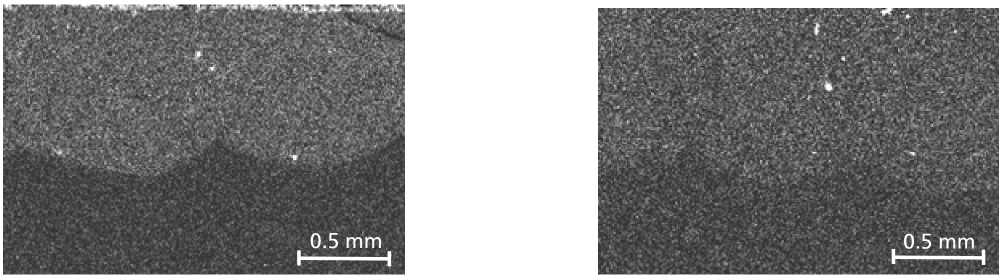


Figure 15: Distribution of the element W after laser alloying (left) and Ti after laser dispersing (right) of steel 1.2365

In addition to the EDX analyses the penetration depth of the carbides was investigated by hardness characterisation. The hardness of the samples, laser alloyed with the additive material WC-Co and laser dispersed with the additive material TiC, presents a carbide penetration depth of approx. 1 mm (figure 16). The obtained depths concerning all treated samples (base materials 1.2343, 1.2344, 1.2365; as well as additive materials WC-Co, TiC) are approx. 1 mm.

The hardness was always increased from approx. 550 HV0.1 up to approx. 650 HV0.1 in the areas near surface.

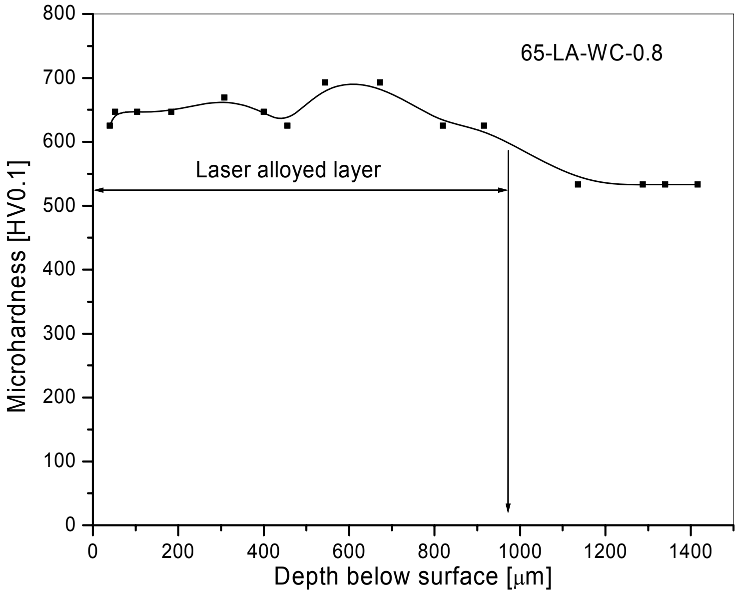
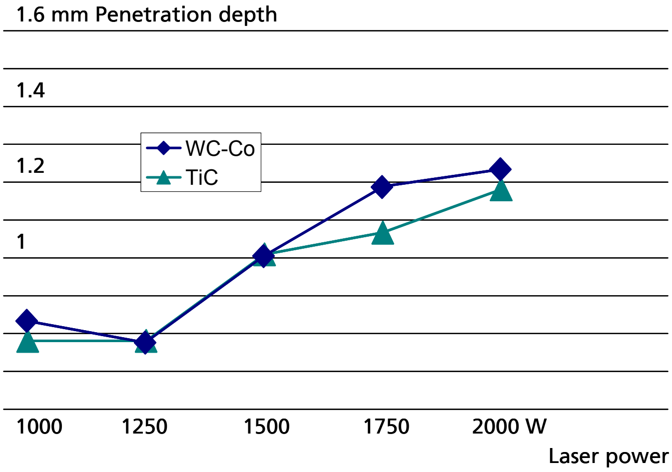


Figure 16: Hardness characteristic (base material 1.2365; additive material WC-Co)

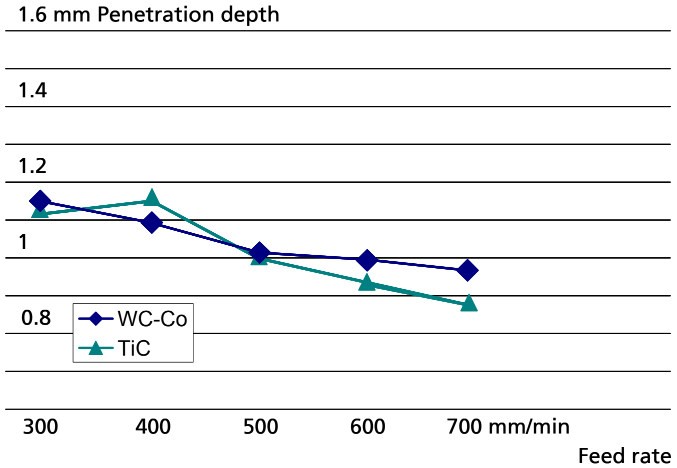
The laser power was varied between 1000 and 2000 W (increment 250 W) and the penetration depth of the elements W and Ti measured. In both cases an increased penetration depth up to approx. 1.2 mm could be reached by increasing the laser power (figure 17). But at the same time with increasing laser power and by this increasing energy input into the areas near surface resulting residual stresses will grow. Therefore the maximum laser power for alloying/dispersing of real moulds was restricted by 1500 W (penetration depth 1mm).



Laser power	1000 - 2000 W (varied)
Feed rate	500 mm/min
Focal length	200 mm
Focus diameter	2 mm
Hatch distance	1 mm
Inert gas	argon
Laser System	Nd:YAG-laser

Figure 17: Influence of the laser power on the penetration depth of carbides (base material steel 1.2365)

The feed rate was varied between 300 and 700 mm/min (increment 100 mm/min). The penetration depth of the elements W and Ti was measured by EDX linescan analyses. An increased penetration depth of all carbides up to approx. 1.1 mm could be realised by decreasing the feed rate (figure 18). Similar to the laser power with decreasing feed rate the energy input into the mould's areas near surface increases resulting in residual stresses. The minimum feed rate for laser alloying/dispersing of real moulds was defined as 500 mm/min (penetration depth 1 mm) to avoid as far as possible stresses.



Feed rate	300 - 700 mm/min (varied)
Laser power	1500 W
Focal length	200 mm
Focus diameter	2 mm
Hatch distance	1 mm
Inert gas	argon
Laser System	Nd:YAG-laser

Figure 18: Influence of the feed rate on the penetration depth of carbides (base material steel 1.2365)

Fraunhofer IPT implemented a Pin-on-Disc Test to investigate the influence of the additive materials on abrasion. Therefore samples which have been laser alloyed/dispersed with different additives were stressed by a sample fastener with a defined mass (7.1 N) on a rotating standard polishing disc. The samples rotated in defined 90° per each rotation of the disc to achieve a regular removal during the Pin-on-Disc Test.
The abrasive disc (SiC paper, grain size P 240) turned opposite in comparison with the samples' rotating direction. The applied medium water cooled down and evacuates abrasion particles. The defined polishing time was observed by using a stopwatch. The total polishing time was 10 min per sample. The test was interrupted each 2 min. The weight of the samples was defined and in addition the abrasive paper changed. By this the comparability of each single polishing cycle was ensured. The difference between the measured sample weight and the start weight is represented in a diagram against the measuring time. The mentioned weight difference is defined "weight reduction [g]".

Parameters Pin-on-Disc Test:

Rotation speed disc	600 R/min
Rotation speed sample fastener	3 R/min
Sample speed	4.1 m/s
Stress on each sample	7.1 N
Abrasive paper	SiC, grain size P 240
Medium Applied	Water
Polishing time	2 min (total polishing time 10 min)

Unalloyed and laser alloyed/dispersed samples made of steels 1.2365 and 1.2343 were applied in line with the Pin-on-Disc Test. The additive materials molybdenum carbide (MoC), vanadium carbide (VC), titanium carbide (TiC) and tungsten carbide cobalt 88-12 (WC-Co 88-12) were used during laser alloying/dispersing. The laser treatment parameters were kept constant (work package 2). A finishing process (surface grinding) followed the laser treatment. Finally the samples were plasma nitrided.
With the additive materials titanium carbide (TiC) and tungsten carbide cobalt (WC-Co) a clear reduction of abrasion as shown in figures 19 and 20 was obtained. The samples alloyed/dispersed with molybdenum carbide (MoC) or vanadium carbide (VC) led to a minor reduction of the abrasion or an increase in comparison with the unalloyed samples. These results were achieved for both 1.2365 and 1.2343 steels.

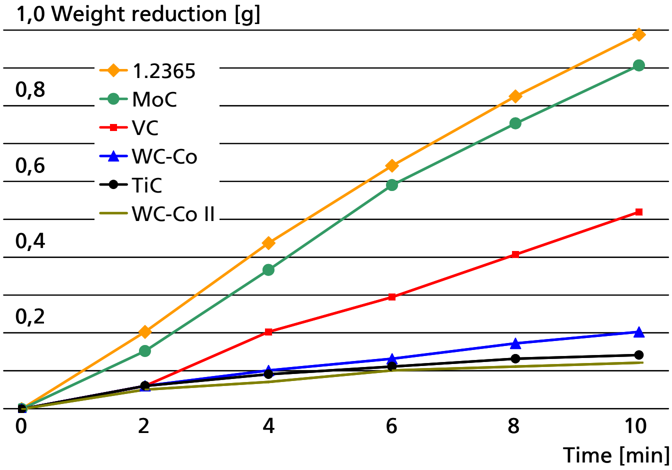


Figure 19: Results – Pin-on-Disc Test (base material 1.2365)

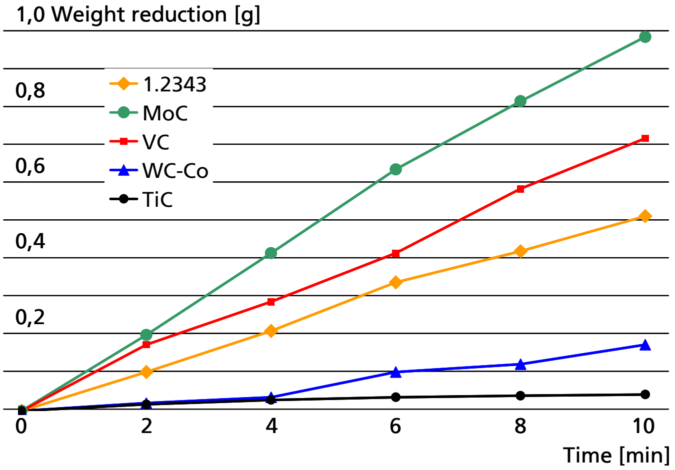


Figure 20: Results – Pin-on-Disc Test (base material 1.2343)

The consortium decided to laser disperse the moulds in line with the Project "ForBeST" with the additive material TiC due to the results obtained in this work package.

Work package 3 – Nitriding, Nitrocarburising and Combined Magnetron Sputtering Ion Implantation (CMSII) of samples

The National Institute for Laser, Plasma and Radiation Physics and the Fraunhofer IPT selected in co-operation the samples' dimension for the laser treatment and the succeeding nitriding process.
Taking into account the load to which the surface layer is subjected during the forging operation and the experience with the conventional plasma nitriding of forging tools, a case depth of about 0.3 mm was considered to be a good choice for the first set of experiments. This case depth was obtained by plasma nitriding at 550 °C for 20 hours. The treatment atmosphere contained 75% H_2 + 25% N_2 and the working pressure was 400 Pa.

Investigations on samples made of steel 1.2365 and laser dispersed with TiC

The depth profile of the microhardness for a steel 1.2365 sample laser dispersed with TiC and plasma nitrided at the above mentioned parameters is shown in figure 21.

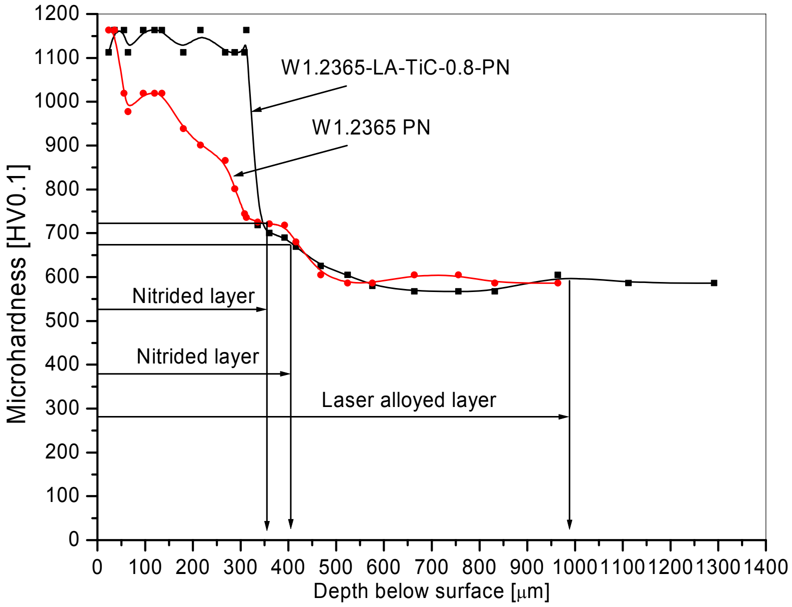


Figure 21: Microhardness characterisation of a sample made of steel 1.2365, laser dispersed with TiC and non-alloyed treated by plasma nitriding

For comparison, the microhardness profile was determined in a region out of the dispersed zone. This profile corresponds to the plasma nitriding of steel 1.2365 steel without any dispersing. The case depth of the nitrided layer is approx. 0.40 mm. It can be clearly seen the increase in hardness for the dispersed layer in comparison with non-dispersed zone. The micrograph of the plasma nitrided layer in the laser dispersed zone is shown in figure 22. The reagent used was NITAL 2%. In figure 23 the compound layer obtained by plasma nitriding of the laser dispersed zone is shown. The thickness of this compound layer is approx. 10 µm. In comparison, the compound layer produced by plasma nitriding at the same process parameters on steel 1.2365 is only 3 - 4 µm. In addition to the increase in hardness, the increase in the compound layer thickness is another beneficial effect of the combined laser dispersing and plasma nitriding treatment.

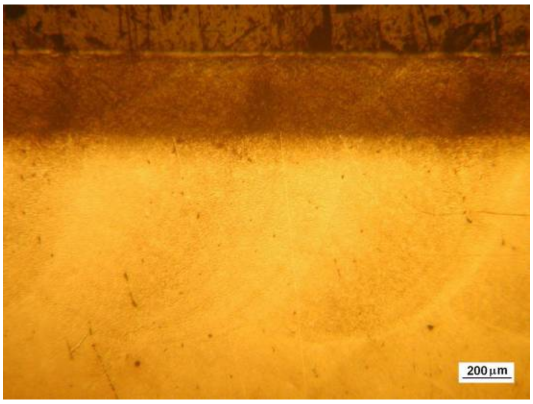


Figure 22: The micrograph of the surface layer produced by combined treatment on steel 1.2365

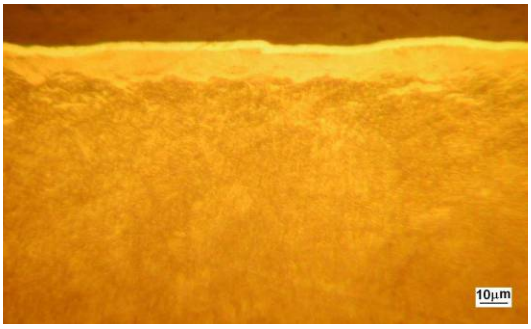


Figure 23: The compound layer produced by plasma nitriding on laser dispersing area

In order to protect the compound layer during the metallographic preparation, a nickel layer was electrochemically deposited on the sample before mounting in bakelite. As far as concern the depth of the diffusion zone shows a value of approx. 360 µm, which corresponds quite well with that indicated by the microhardness profile.

Investigations on samples made of steel 1.2365 and laser alloyed with WC-Co
Similar investigation has been carried out with samples laser alloyed with WC-Co. The plasma nitriding parameters were the same in comparison with laser dispersed (additive material TiC) samples. The depth profile of the microhardness for a steel 1.2365 sample laser alloyed with WC-Co and plasma nitrided is shown in figure 24. In this case, the increase in hardness due to the laser alloying can be clearly seen. The hardness of the nitrided layer in the laser alloyed zone is higher than that produced by plasma nitriding on the same sample at the same process parameters, but in a non-alloyed zone. The increase in hardness at the level of 600 - 650 HV0.1 can be seen for all the

depth of the laser alloyed zone. This can bring a significant contribution to the increase of the lifetime of the forging tools. On the other hand, the depth of the diffusion zone is less in the laser alloyed zone in comparison with that obtained in the non-alloyed zone. This effect can be seen in figures 25 and 26, where the transition between the alloyed and non-alloyed zones is shown for WC-Co and TiC alloyed samples. In the case of TiC dispersing this difference in case depth does not appears very well in the microhardness depth profile (figure 24) because the TiC alloying itself did not induce a significant increase in hardness. The case depth and the hardness of the nitrided layer is correlated with the percentages of the nitride formers alloying elements like Cr, W, Ti, Mo, Al, V. The hardness increases with increasing the percentages of these alloying elements, but at the same time, the diffusion coefficient of the nitrogen decreases and consequently the case depth decreases for the same treatment time. This observation is in a good agreement with the chemical composition depth profile measured for steel 1.2344 steel alloyed with WC-Co and TiC. In that case the concentration of the W in the alloyed layer was 9.5 wt.% and the corresponding concentration of Ti was only 0.9 wt.%. Of course, the steel is different but the alloying conditions were very similar, so similar concentrations of W and Ti are expected in the steel 1.2365 as well.

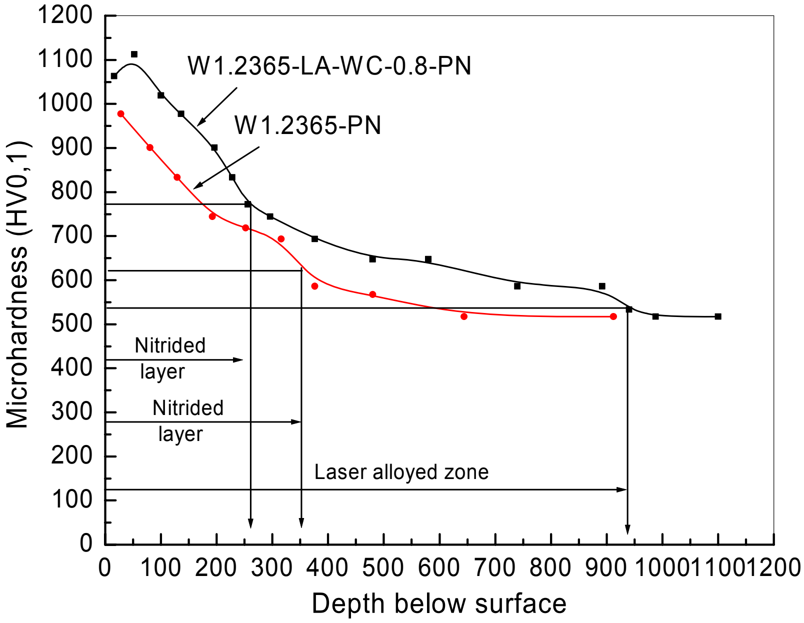


Figure 24: Microhardness characterisation of a sample made of steel 1.2365, laser alloyed with WC-Co and non-alloyed treated by plasma nitriding

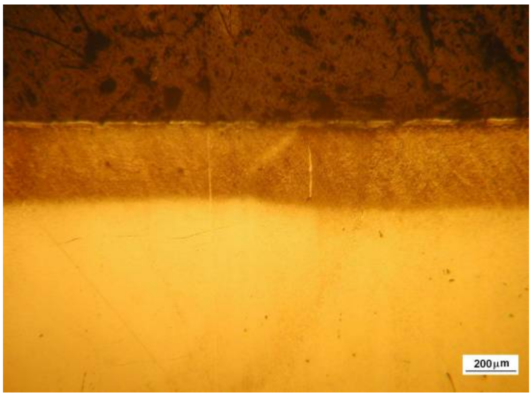


Figure 25: Transition between the alloyed and non-alloyed areas for steel 1.2365 laser alloyed with WC-Co

Figure 26: Transition between the dispersed and non-dispersed areas for steel 1.2365 laser dispersed with TiC

Typical micrograph of a plasma nitrided laser alloyed layer is shown in figure 27. The compound layer is of approx. 10 µm and the diffusion zone is approx. 250 µm, in good accordance with the microhardness profile.
The case depth for the plasma nitriding of the WC-Co laser alloyed steel 1.2365 steel is approx. 0.25 mm, while under the same treatment conditions the case depth for the dispersing with TiC is approx. 0.35 mm. This is agreement with the above mentioned comment concerning the concentrations of W and Ti in the laser alloyed zone.

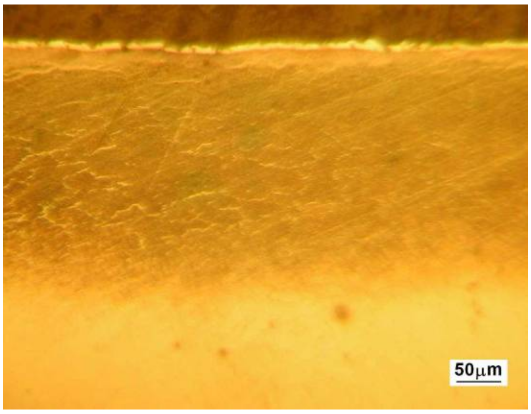


Figure 27: Micrograph of the surface layer produced on steel 1.2365 by combined treatment (laser alloying with WC-Co and plasma nitriding)

Investigations on samples made of steel 1.2344 and laser dispersed with TiC

The steel 1.2344 steel samples laser dispersed with TiC were plasma nitrided at the same process parameters as the samples from steel 1.2365. The microhardness profiles for the laser alloyed zone and non-alloyed zone are shown in figure 28.

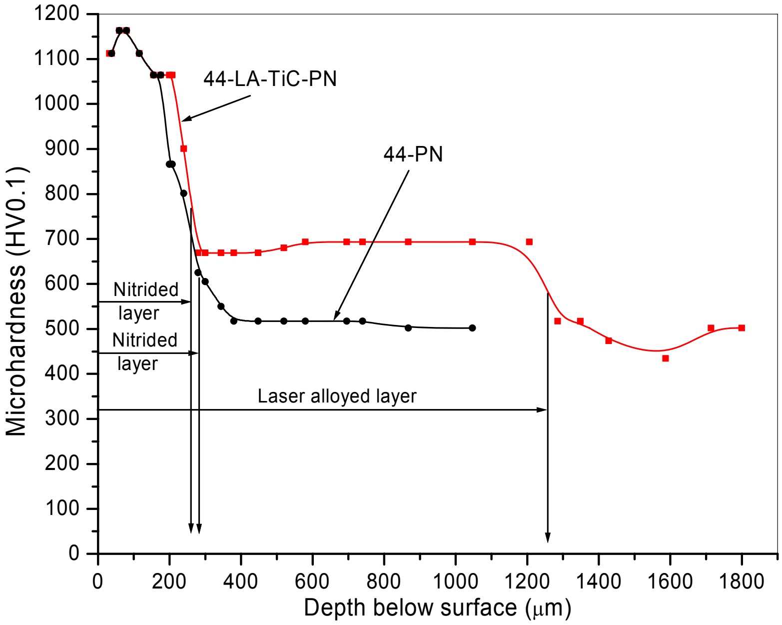


Figure 28: Microhardness characterisation of a sample made of steel 1.2344, laser dispersed with TiC and non-dispersed treated by plasma nitriding

As it can be seen, there is no significant difference in the case depth of the nitrided layer obtained for laser dispersed and non-alloyed zones. Metallographic examinations indicated a depth of the diffusion zones of 230 µm for dispersed area and 240 µm for non-alloyed area. As far as concern the compound layer the thickness is 3 - 6 µm for alloyed area and 6 - 9 µm for non-alloyed area. In contrast with the steel 1.2365, for steel 1.2344 the thickness of the compound layer obtained by plasma nitriding seems to decrease for the laser dispersed zones with TiC. There is no an explanation for this phenomenon so far. It is important to mention the increase in hardness of up to 690 HV0.1 produced by laser dispersing, which appears below the nitrided region. This is expected to lead to a significant increase in the fatigue resistance of the surface layer produced by combined treatment. The core hardness is of 502 - 517 HV0.1.

Another observation is a slight decrease in hardness up to 473 - 443 HV0.1 for a depth of approx. 0.35 mm below the dispersed zone. Then the hardness increases to the normal core hardness. This decrease correspond the thermal affected region below the dispersed zone, which can be seen in the micrograph shown in figure 29. An explanation for the existence of this zone might be the following: during the laser dispersing process, the temperature of the surface layer decreases from the alloying temperature to the tempering temperature of the steel. Due to the fast cooling and to dispersing process the hardness does not decrease. At the same time, somewhere below the dispersed layer, the temperature might exceed the tempering temperature and the cooling rate might not be high enough. Consequently, a de-quenching and a decrease in hardness might occur in that region.

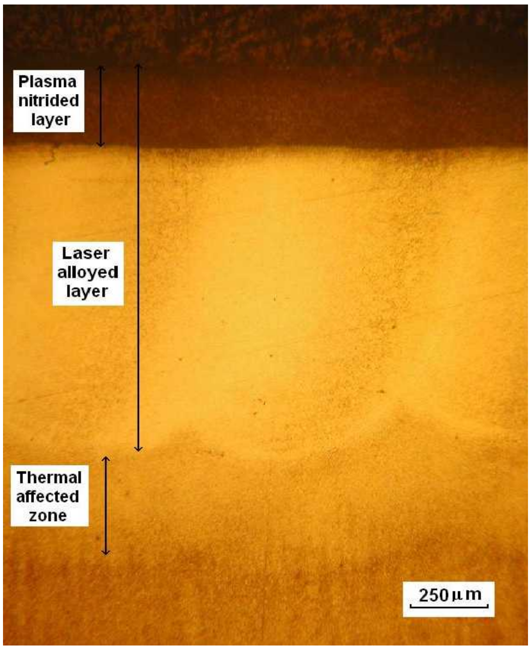


Figure 29: Micrograph of sample made of steel 1.2344, treated by laser dispersing and plasma nitriding

Investigations on samples made of steel 1.2344 and laser alloyed with WC-Co

The reached results and knowledge during the investigations on samples made of steel 1.2344 and laser alloyed with WC-Co are conform to the results reached by investigations on the steel 1.2365. Because of that circumstance, the achieved results and knowledge are mentioned in the chapter "Investigations on samples made of steel 1.2365 and laser alloyed with WC-Co".

Coating of laser alloyed/dispersed and plasma nitrided samples by Combined Magnetron Sputtering and Ion Implantation (CMSII)

Samples of steel 1.2365 treated by laser alloying/dispersing with WC-Co/TiC and plasma nitriding were coated by nc-Ti2N/nc-TiN using the Combined Magnetron Sputtering and Ion Implantation (CMSII) technique. After plasma nitriding, the samples ware lightly polished, ultrasonically cleaned in two baths using trichloroethylene and acetone and then coated with nc-Ti2N/nc-TiN nanocomposite layer. After coating, the samples have been sectioned perpendicular to the treated surface, Ni coated to prevent the edge rounding and distraction of the surface layer, mounted in bakelite and polished with SiC paper and diamond paste up to 1 µm. 2% Nital reagent was used to reveal the structure of the surface layer. The micrograph of the nc-Ti2N/nc-TiN coating deposited on plasma nitrided surface of steel 1.2365 steel without laser alloying is shown in figure 30. The same coating deposited on the steel 1.2365, but after WC-Co laser alloying and plasma nitrided is also shown in figure 30.

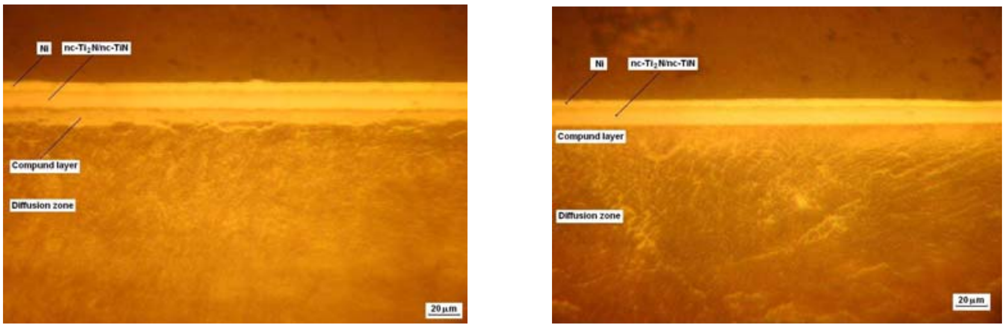


Figure 30: Optical micrograph of a nc-Ti$_2$N/nc-TiN nanocomposite coating deposited on plasma nitrided steel 1.2365 substrate (left side); Optical micrograph of a nc-Ti2N/nc-TiN nanocomposite coating deposited on plasma nitrided and laser dispersed with WC-Co steel 1.2365 substrate (right side)

The thickness of the coating was 12 µm and the hardness was approx. 2000 HV0.04. The adhesion between hard coating and plasma nitrided layer was good for both laser alloyed and non-alloyed surfaces. The thickness of the compound layer produced by plasma nitriding on laser alloyed surface was of 12 - 15 µm in comparison with only 6 - 8 µm produced on non-alloyed surface. This can be seen by examining figure 30. From the erosion viewpoint this is a positive result. Similar results have been obtained with steel 1.2365 laser dispersed with TiC.

Work package 4 – Laser surface treatment of moulds (transfer of results)

Taking into account the results obtained in work package 2 the selected forging and aluminium die casting moulds of the industrial partners were successively laser treated. Failing with a larger number of moulds the project partners decided to focus exclusively on laser dispersing with the additive material TiC as the best results within the Pin-on-disc Test had been achieved at this. For laser dispersing the following process parameters were applied in general:

• Laser System	Nd:YAG-laser
• Laser power	1500 W
• Feed rate	500 mm/min
• Focal length	200 mm
• Focus diameter	2 mm
• Hatch distance	1 mm
• Inert gas	argon

The moulds with a lower complexity level (moulds of the companies DMF and RAS) were laser dispersed first. 2 Moulds "DMF" and 3 Moulds "RAS" were laser treated in the course of the project duration. Subsequent the dies with a higher complexity level from the companies BENE (2 upper and 2 lower parts), FAF (2 upper and 2 lower parts) and MTK (2 lower parts) were dispersed at Fraunhofer IPT in the Project "ForBeST".
An adapted CNC program was coded for each mould before laser dispersing. In addition clamps were constructed and manufactured for the connection with the used 5-axis clamping system.

Figure 31: Laser dispersing – Mould "DMF"

Figure 32: Laser dispersing – Mould "RAS"

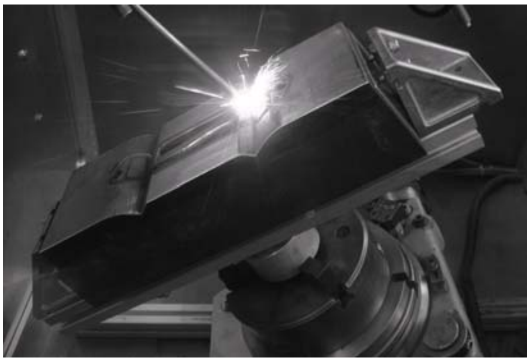


Figure 33: Laser dispersing – Mould "FAF"

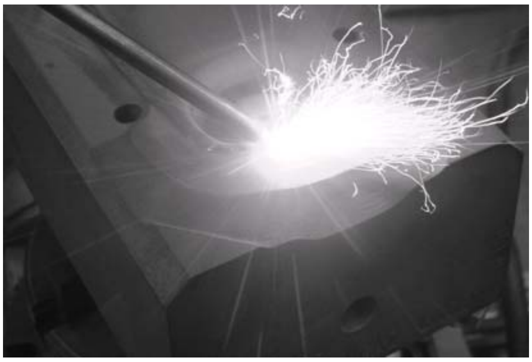


Figure 34: Laser dispersing – Mould "BENE"


Figure 35: Laser dispersing – Mould "MTK"

All moulds were heated up by a Bunsen burner before the laser process.
The measured basic temperatures were approx. 90 °C. Additional heat energy was provided into the areas near surface by using a non-focused laser beam immediately before the laser dispersing.
Within the first laser treatment of the Moulds RAS and MTK large areas of the surface have been laser dispersed. Because of the huge thermal load and the dispersed carbides residual stresses arise during solidification and cooling which led to the appearance of cracks. In the case of the Mould "RAS" 8 cracks

formed on the 1st laser dispersed mould (figure 36) respectively one crack in the 1st Mould "MTK".

Figure 36: Formed cracks – 1st Mould "RAS"

The applied measures to prevent crack formation in line with the 2nd and partial 3rd iteration loops were new maching strategies and a reduction of the laser treated areas. In the case of the Mould "RAS" therefore the feed direction of the coded concentrical ring path was changed after each 2nd path. In addition the laser treated areas of the Moulds "RAS" and "MTK" were reduced as presented in figures 37 and 38.

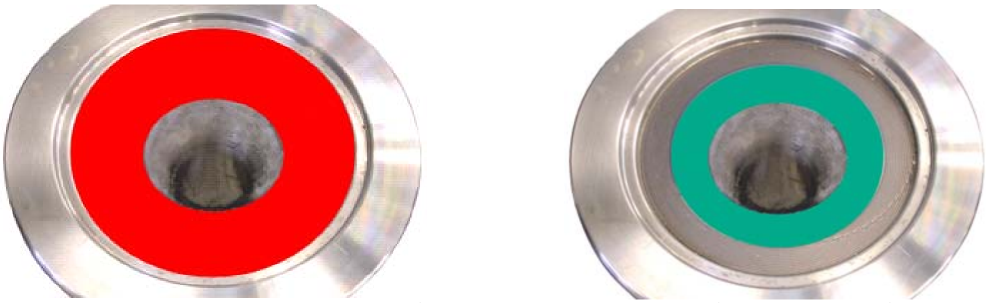


Figure 37: Laser dispersed areas of the Mould "RAS" – Left side: area of the 1st mould, right side: reduced area of the 2nd and 3rd mould

Figure 38: Laser dispersed areas of the Mould "MTK" – Left side: area of the 1st mould, right side: reduced area of the 2nd mould

With these new machining strategies applied on reduced laser treated areas the formation of cracks could be completely eliminated.

As mentioned before Fraunhofer IPT carried out furthermore additional investigations on laser dispersing of ejector pins. The Ejector pins of an aluminium die casting had been provided by DMF Werkzeugbau GmbH, Germany. The objective of the laser treatment was the reduction of abrasion on the technical surface. Unfortunately a laser dispersing of the ejector pins with required dimensional accuracy (figure 39) was not successful. Because of the small dimensions of the ejector pins the energy input was not precisely controllable in spite of a focal spot geometry 0.2 mm diameter. The resulting residual stresses led to intense deformations. The laser and optical systems of Fraunhofer IPT are designed for a treatment of dies/moulds and parts with large dimensions.

Fraunhofer IPT and DMF Werkzeugbau decided to coat the ejector pins by nc-Ti2N/nc-TiN using the Combined Magnetron Sputtering and Ion Implantation (CMSII) technique without a prior laser treatment.

Figure 39: Deformation in the functional area after laser treatment – Ejector pins "DMF"

Work package 5 – Nitriding of moulds (transfer of results)

Plasma nitriding of the Moulds "RAS"

The selected moulds were sent back to the industrial enterprises for surface finishing. After that the moulds were sent for nitriding to the National Institute for Laser, Plasma and Radiation Physics, Romania.

The provided dies by Rasche Company are shown in figure 40. They are relative big dies with a weight of approx. 48 kg. The steel was steel 1.2365, treated at a hardness of approx. 48 HRC (T_{quench} = 1,030 °C, $T_{temp\ 1}$ = 590 °C, $T_{temp\ 2}$ = 570 °C).

Two lots of dies were treated by combined laser dispersing and plasma nitriding. The first lot was one die with the cracking problems. The second lot was composed of two dies which were treated by laser dispersing with improved technology. The surface of the dies was inspected by a magnifier (4 x) before plasma nitriding. One of the dies was without cracks. At the other one, one very small crack was detected.

The dies were plasma nitrided at the optimized parameters: T = 540 °C, P = 400 Pa, t = 20 h, Q = 20 N*l/h (figure 41). A picture of the forging dies after the combined treatment (laser dispersing + plasma nitriding) is shown in figure 42.

Figure 40: Dies "RAS" provided for combined treatment

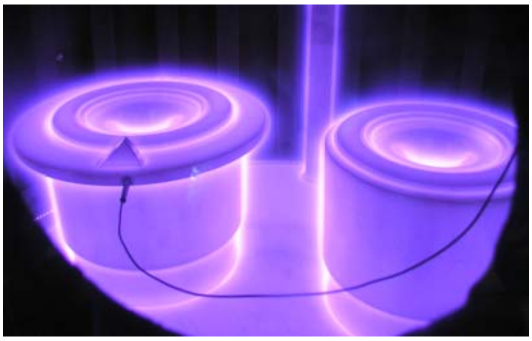


Figure 41: Dies "RAS" during plasma nitriding

Figure 42: Dies "RAS" after plasma nitriding

A very good surface can be seen on the die without cracks (figure 43), while the crack is visible at the other die (figure 44). The die hardness of the laser dispersed and non-dispersed surface areas was measured before and after plasma nitriding by using a MIC 10 portable hardness tester produced by Krautkramer GmbH (figure 45). The instrument uses Vickers penetration with indentation evaluation by Ultrasonic Contact Impedance (UCI) method under load. The results are shown in figures 46 and 47 for the real die and for a steel 1.2365 sample which was treated in the same load with the dies.

Figure 43: Surface of the Die "RAS" without cracks

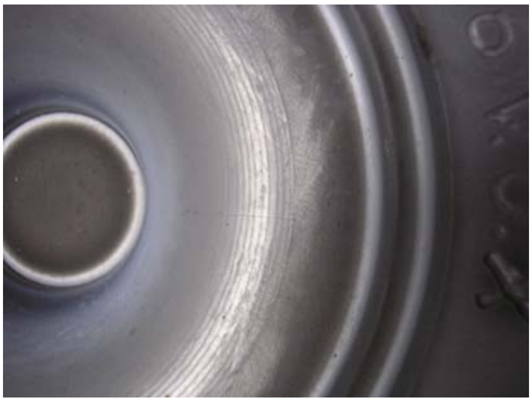


Figure 44: Surface of the Die "RAS" with one crack

Figure 45: MIC 10 Krautkramer hardness tester

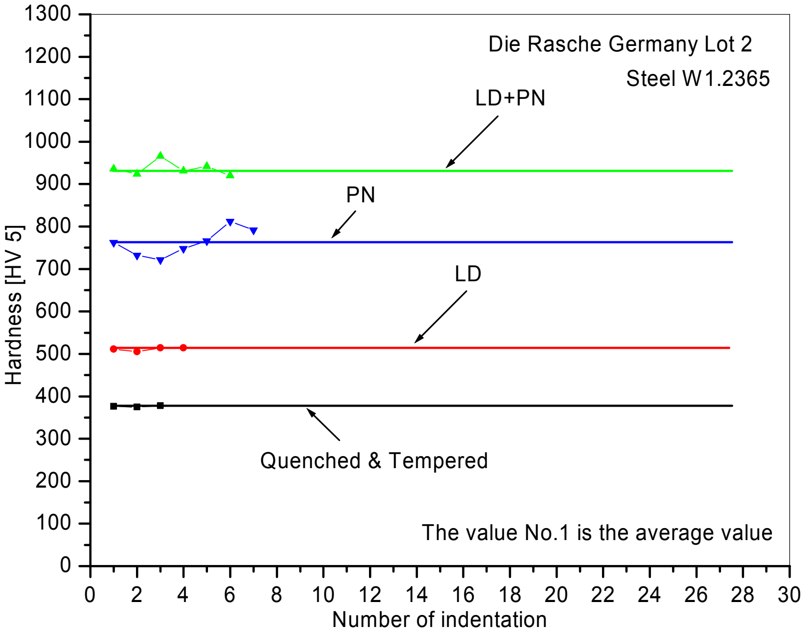


Figure 46: The hardness of a Die "RAS", measured on quenched and tempered, laser dispersed (LD), plasma nitrided (PN) and LD+PD surface areas.

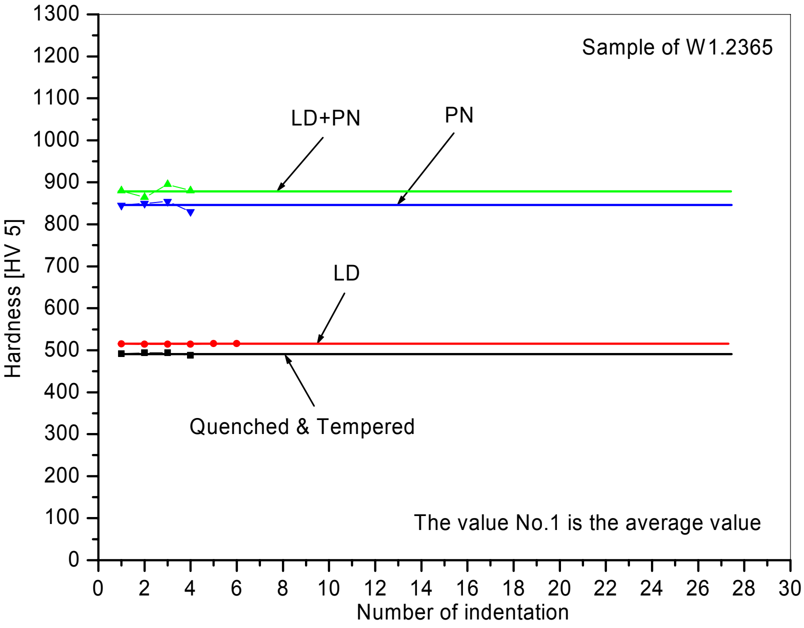


Figure 47: The hardness of a sample made of steel 1.2365 and treated in the same batch with the Die "RAS", measured on quenched and tempered, laser dispersed (LD), plasma nitrided (PN) and LD+PD surface areas

The following diagrams show the hardness values for a number of indentations and their average value. The hardness was measured for four types of surfaces obtained as a result of various treatments: quenching and tempering (Q+T), laser dispersing with TiC (LD), plasma nitriding (PN) and combined treatment (LD+PD). As it can be seen the hardness of the (Q+T) die is smaller than that of sample, but after LD a similar value (approx. 520 HV) is obtained. An increase in hardness up to approx. 900 HV is produced by combined treatment on both die and sample surfaces. The microhardness profiles for surfaces treated by plasma nitrided and combined treatment are shown in figure 48.

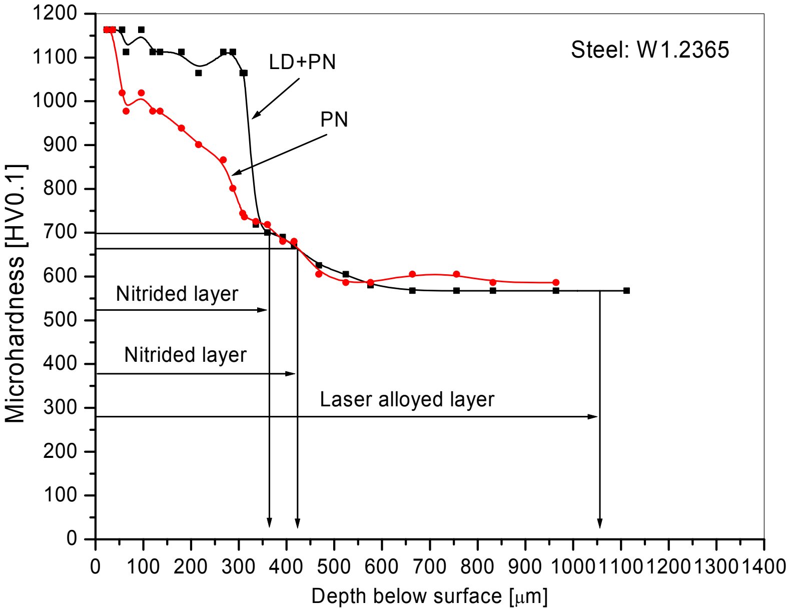


Figure 48: The microhardness profiles for steel 1.2365 treated by plasma nitriding and combined treatment (LD+PN) together with the Die "RAS"

As it can be seen, within the nitrided layer the hardness of the laser dispersed zone is higher than that corresponding to non laser treated, but out of nitrided layer there is no significant difference.

Plasma nitriding of the Moulds "MTK"

The KLF-ZVL MTK spol. Company provided for testing the die shown in figure 49. It is made of steel 1.2343 steel and it is treated to 48 HRC. This means a quenching temperature of 1,000 - 1,030 °C and two tempering treatments to 550 - 650 °C. One die with a weight of 23 kg was treated as Lot 1 and another one as Lot 2.

The plasma nitriding parameters were those obtained during the optimization process, namely: T = 540 °C, P = 400 Pa, t = 20 h and Q = 20 N*l/h. The second die during and after plasma nitriding is shown in figures 50 and 51.

The hardness of the die was measured before and after plasma nitriding in laser dispersed and non-laser dispersed zones.

Figure 49: Die "MTK" provided for testing the combined treatment

These zones are indicated in figure 49 and the hardness values in table 1. As it can be seen there is no significant improve in hardness as a result of laser dispersing only. The average value is approx. 500 HV. By plasma nitriding, the hardness increased on both laser dispersed and non-laser dispersed areas to a value of approx. 920 HV. A slightly higher value of approx. 970 HV appears in zone 1. No cracks have been detected on die surface. The microhardness profiles for surfaces treated by plasma nitrided and combined treatment are shown in table 1.

Hardness HV5									
Zone 1		Zone 2		Zone 3		Zone 4		Zone 5	
Before PN	After PN	Before PN	After PN	Before PN	After PN	Before PN	After PN	Before PN	After PN
491	970	565	922	473	918	484	917	524	900
460	980	492	920	511	910	505	915	540	890
520	980	512	934	485	901	552	921	552	893
489	952	467	940	470	922	528	930	530	910
560	978								
530	987								

Table 1: The hardness (HV5) of the Die "MTK" (Lot 2) before and after plasma nitriding

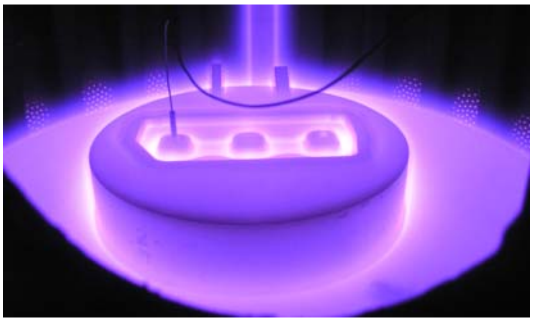


Figure 50: Die "MTK" during plasma nitriding

Figure 51: Die "MTK" after plasma nitriding

Plasma nitriding of the Moulds "FAF"

Forjaco – Aco Forjado, Lda, Portugal provided for testing the combined treatment the dies shown in figure 52 made of steel 1.2344 steel. Two lots of two dies each have been treated.

The treatment parameters for plasma nitriding were: T = 530 °C, P = 146.65 Pa, t = 20 h and Q = 20 N*l/h. The dies during and after plasma nitriding are shown in figures 53 and 54.

The hardness of the dies was measured before and after plasma nitriding in laser dispersed and non-laser dispersed zones (figure 52). The results are shown in figures 55 and 56. Dispersion of the values is mainly due to the relative high roughness of the surface dies.

The hardness of quenched and tempered surface is in the range of 500 - 550 HV and this hardness increases by laser dispersing to 650 - 700 HV. Further increase in hardness to 900 - 1,000 HV is obtained by plasma nitriding for both laser dispersed and non laser treated zones. Although the hardness of the non laser treated zones seems to be a little bit higher than that for laser dispersed zones, the influence of the sub-nitrided layer with a hardness of 650 - 700 HV is expected to be very important in increasing the fatigue resistance of the forging dies. No cracks have been detected on die surface.

Figure 52: The Die "FAF" (upper and lower part) provided for testing the combined treatment

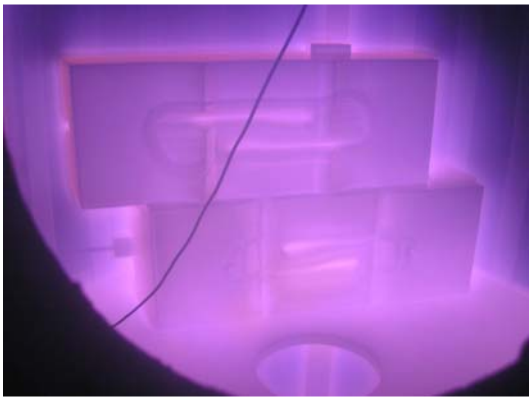


Figure 53: Die "FAF" during plasma nitriding

Figure 54: Die "FAF" after plasma nitriding

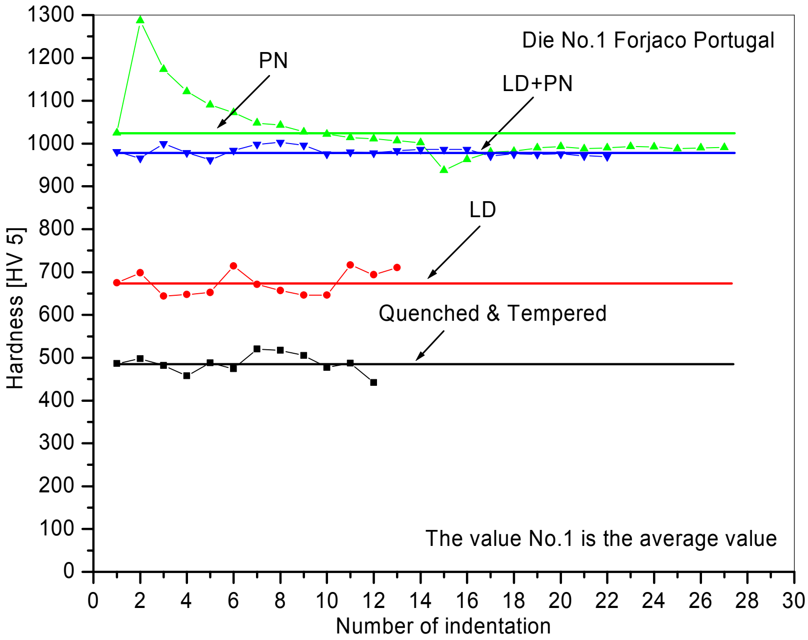


Figure 55: The hardness of a 1st Die "FAF", measured on quenched and tempered, laser dispersed (LD), plasma nitrided (PN) and LD+PD surface areas

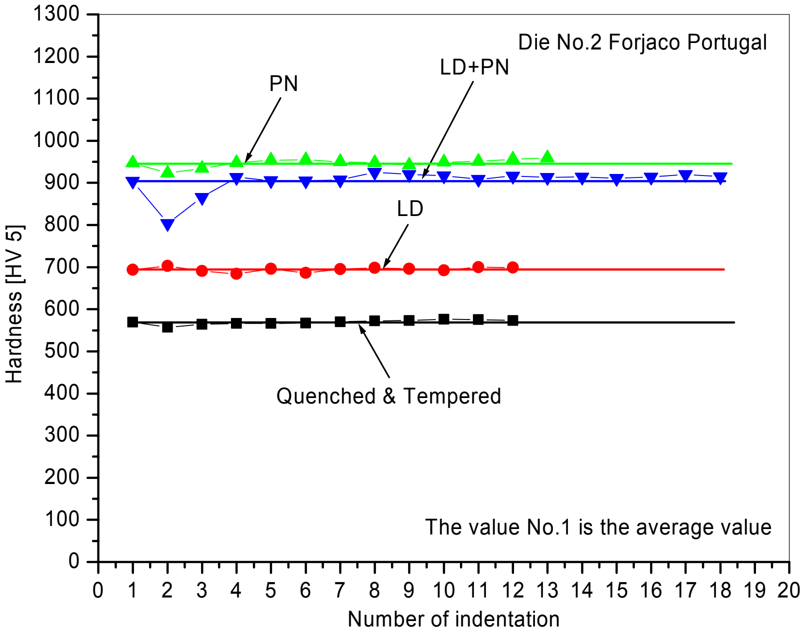


Figure 56: The hardness of a 2nd Die "FAF", measured on quenched and tempered, laser dispersed (LD), plasma nitrided (PN) and LD+PD surface areas

<u>Plasma nitriding of the Moulds "BENE"</u>

A. BENEVENUTA & C. S.p.A., Italy, provided for testing the combined treatment two dies made of steel 1.2344 steel (figure 57). One lot of two dies has been treated. The dies after plasma nitriding treatment are shown in figure 58. The treatment parameters for plasma nitriding were: T = 540 °C, P = 533.28 PA, t = 20 h and Q = 20 N*l/h. No cracks have been detected on die surface. The hardness of the dies was measured before and after plasma nitriding in laser dispersed and non-laser dispersed zones according to the marked zones (figure 57). Two sets of measurements were carried out on each die. The results are shown in figures 59 and 60.

Figure 57: Die "BENE" (upper and lower part) provided for testing the combined treatment

Figure 58: Die "BENE" after plasma nitriding

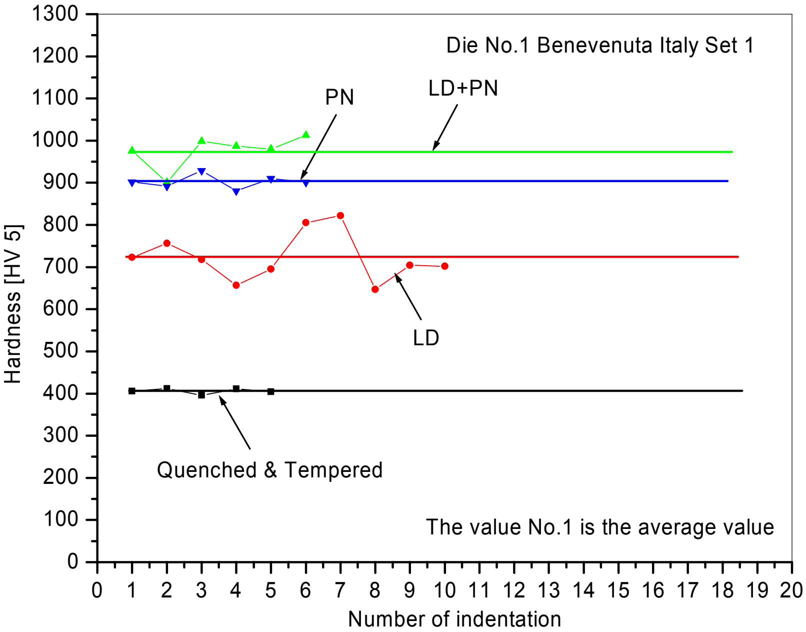


Figure 59: The hardness of a 1st Die "BENE", measured on quenched and tempered, laser dispersed (LD), plasma nitrided (PN) and LD+PD surface areas

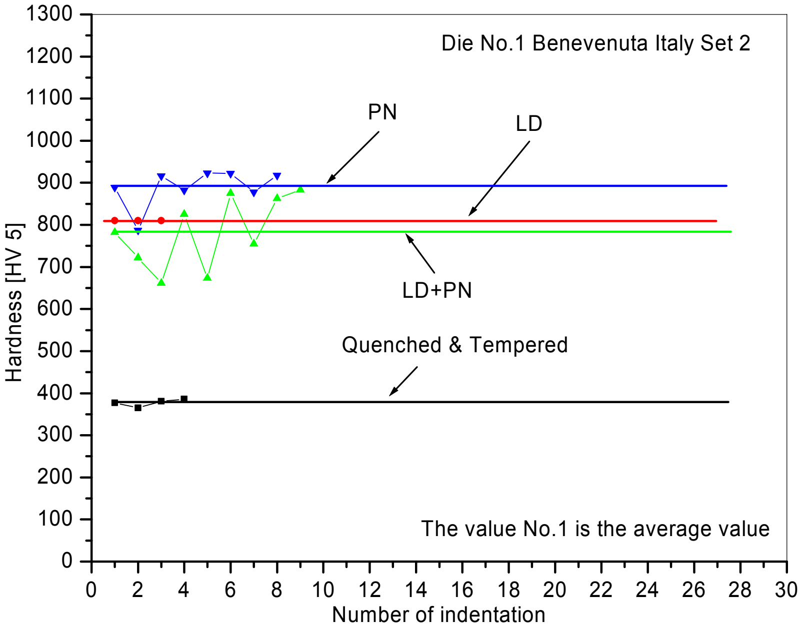


Figure 60: The hardness of a 2nd Die "BENE", measured on quenched and tempered, laser dispersed (LD), plasma nitrided (PN) and LD+PD surface areas

Further increase in hardness to 840 - 920 HV is obtained by plasma nitriding on non laser treated zones, while combined treatment (LD+PN) produces a hardness of 940 - 970 HV. For one set of measurement this hardness was in the range of 650 - 850 HV, but this might be caused by the high roughness of the surface. The microhardness profiles for plasma nitrided laser dispersed and non-laser dispersed areas are shown in figure 61.

Unfortunately, the sample accompanying the dies during the plasma nitriding process was one provided by IPT for the research phase of the project. The core hardness of that sample was approx. 500 HV. The core hardness of the dies "BENE" was in the range of 370 - 400 HV. It seems that the tempering temperature for the real dies was higher than that used for samples. Consequently, the information obtained by investigation of the samples after plasma nitriding is not fully relevant for the real layer existing on the dies. This fact is available for all the dies treated by combined treatment. The only existing information on the dies is the hardness measured with the portable tester. No cracks have been detected on die surface.

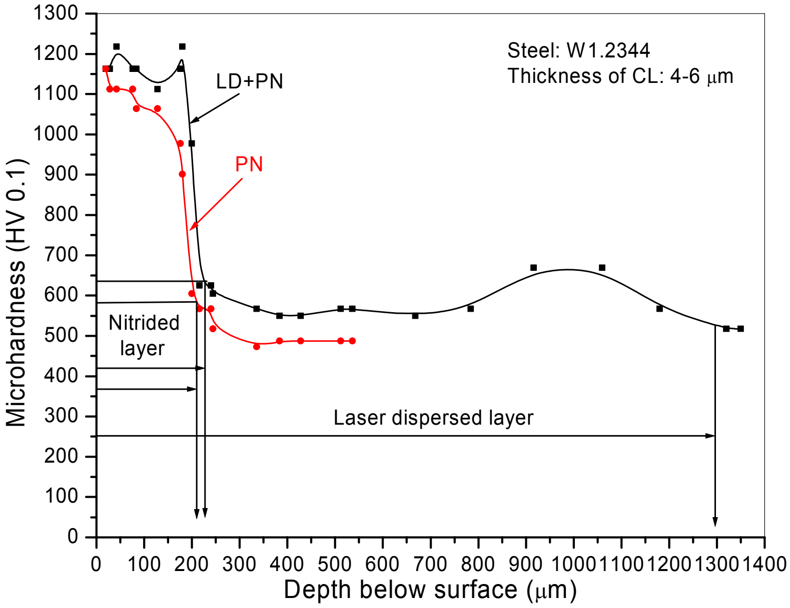


Figure 61: The microhardness profiles for steel 1.2344 treated by plasma nitriding and combined treatment (LD+PN) together – Dies "BENE"

<u>Plasma nitriding of the Moulds "DMF"</u>

The DMF Werkzeugbau GmbH, Germany provided for testing the combined treatment the two dies shown in figure 62. They have been made of steel 1.2343 steel and quenched as well as tempered (50 ± 2 HRC).

The plasma nitriding parameters were those obtained during the optimization process, namely: T = 540 °C, P = 400 Pa, t = 20 h and Q = 20 N*l/h.

Figure 62: Dies "DMF" after plasma nitriding

For the second stage of the project, DMF Werkzeugbau, provided for testing a number of 10 ejectors used in molding process. These ejectors were coated with two types of hard layers and the results will be presented in the next section of this report.

A summary of the hardness values obtained for the three types of steel used by our industrial partners is given in table 2.

Treatment	Hardness HV5			
	Rasche W1.2365	KLF-ZVL MTK W1.2343	Forjaco W1.2344	A. Benevenuta W1.2344
Q+T (core)	370	480 – 550	500 – 550	370 – 400
LD	510	480 – 550	650 – 700	720 – 800
PN	760	900 – 980	940 – 1,000	840 – 920
LD+PN	940	900 – 980	900 – 970	940 – 970

Table 2: Hardness of the forging dies obtained for various treatments

By analyzing the results shown in table 2, the following comments can be made:

(i) The companies use dies with different core hardness. Dies "RAS" and "BENE" were tempered at high temperature (600 - 620 °C). By this way the toughness of the core is increased and the wear protection is insured by surface treatment. The risk for cracking is reduced due to the lower internal stress. KLF-ZVL MTK and Forjaco use dies with higher core hardness (tempering temperature approx. 550 °C) and by this way the core hardness can partially insure the wear protection as well.

(ii) The core hardness affects the final hardness after plasma nitriding, if only this treatment is applied for wear protection. The Dies "RAS" and "BENE" have a lower hardness after plasma nitriding (760 - 920 HV) in comparison with Dies "MTK" and "FAF" (900 - 1,000 HV).

(iii) As a result of laser dispersing the surface hardness increases by approx. 150 HV for dies "RAS" and "FAF" and practically there is no hardness increase for the Die "MTK". A spectacular increase in hardness of 350 - 400 HV occurred for the die made of steel 1.2344 steel at A. BENEVENUTA.

(iv) As far as concern Combined Treatment (LD+PN) an increase in hardness up to (900 - 980 HV) occurred for all dies, no matter of type of steel and manufacturing procedure.

Development of CMSII technology for producing high temperature resistant thin coatings

Combined Magnetron Sputtering and Ion Implantation (CMSII) is a high energy ion assisted deposition process where a high voltage pulse discharge is superposed over the magnetron sputtering. A schematic representation of this process is shown in figure 63.

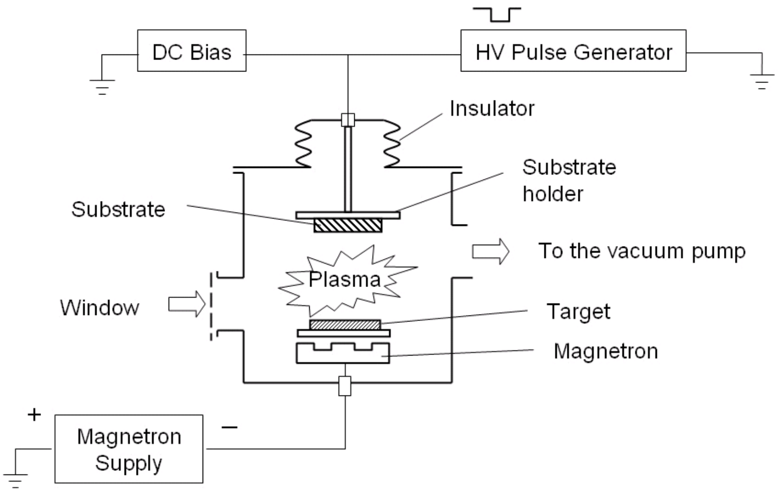


Figure 63: Schematic diagram of the CMSII equipment

The treatment chamber is similar to conventional magnetron sputtering except that the insulation system of the load was designed for 100 kV. Typically, pulses of 20 to 70 kV with a width of approx. 20 µs and a frequency of 10 - 50 Hz are applied to the load. The plasma ions are accelerated during the high voltage pulses and strike initially the substrate and then the layer itself during its growing with energies of tens of keV. As a result of this periodical ion bombardment the following effects occur:

- A stress relief at the interface and within the layer. Due to this effect, layers with a thickness of 10 - 50 µm have been produced.
- A featureless, extremely dense, pore free nano-structure is produced. The typical columnar structure of TiN does not exist any more. TEM analyses have shown crystallites with a size of less than 10 nm.
- A significant enlargement (up to 5 - 8 µm) of the layer-substrate interface resulting into a strong adhesion between the layer and the substrate. For conventional magnetron sputtering this interface is of approx. 1µm.

- A high densification of the layer. Using a titanium magnetron target, nc-Ti2N/nc-TiN nanocomposite layers with a hardness of 25 - 40 GPa have been obtained.

The nc-Ti2N/nc-TiN coating is stable up to 550 °C. It has a very good abrasion and corrosion resistance. In the framework of this project a new type of coating, based on W-Ti-Si-C system was produced and investigated. The magnetron targets of 77 mm in diameter and 2.8 mm thickness were obtained from powders by using specific methods for powder metallurgy. Two types of targets with different SiC content were obtained. The compositions of the targets, designed as target A and B, are given in the table 3.

Target	Composition (wt.%)				
	WC	TiC	TaC+NbC	Co	SiC
A	76.4	4.8	4.8	9.0	5.0
B	72.5	4.5	4.5	8.5	10.0

Table 3: The chemical composition of the targets

Typical deposition conditions were: magnetron current intensity – 1.6 A, working gas – Ar, deposition pressure – 6.6*10-3 mbar, high voltage pulse amplitude – 35 kV, pulse duration – 20 µs and frequency 25 Hz. Austenitic stainless steel (10TiNiCr180) and plain carbon steel (C45) samples of 30x25x3 mm were used as substrates in the preliminary experiments.
The coatings produced with targets A and B were designed as coating A and coating B respectively. The deposition time in both cases was 1 hour. The coatings B exhibited a poor adhesion to the steel substrates, but this problem was solved by introducing an intermediate Ti layer between the coating and substrate. Molybdenum interlayer was successfully used as well. The microhardness measured with various loads and the thickness of the coatings, determined from metallographic examination is shown in table 4.

Coating	Thickness (µm)	HV 0.05	HV 0.1	HV 0.2
A	9	2,250	1,500	1,050
B	14 (including the interlayer)	~ 3,500	2,600	1,700

Table 4: The coatings microhardness and the thickness

The phase composition and the chemical composition of the coatings were investigated by X-Ray Diffraction (XRD) and Optical Glow Discharge Spectrometry (OGDS) techniques respectively. The results are shown in figures 64 and 65.

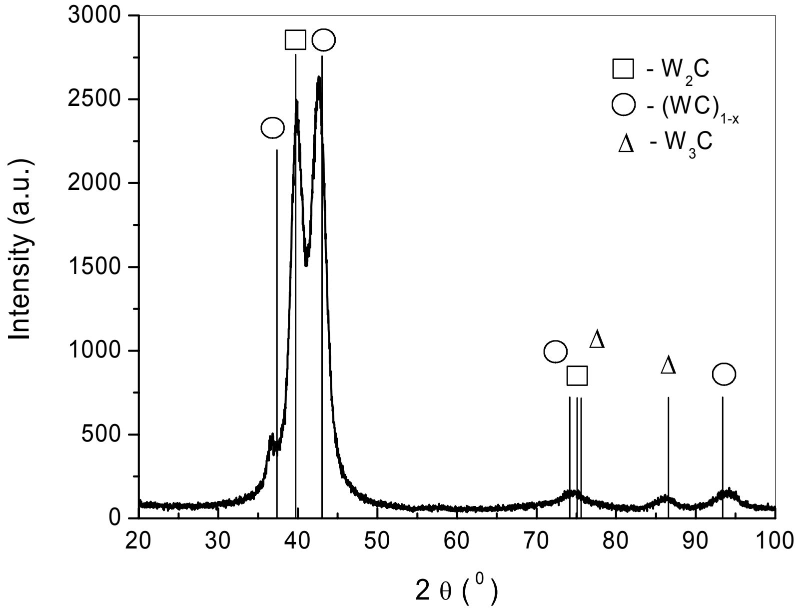


Figure 64: XRD patterns for A coating

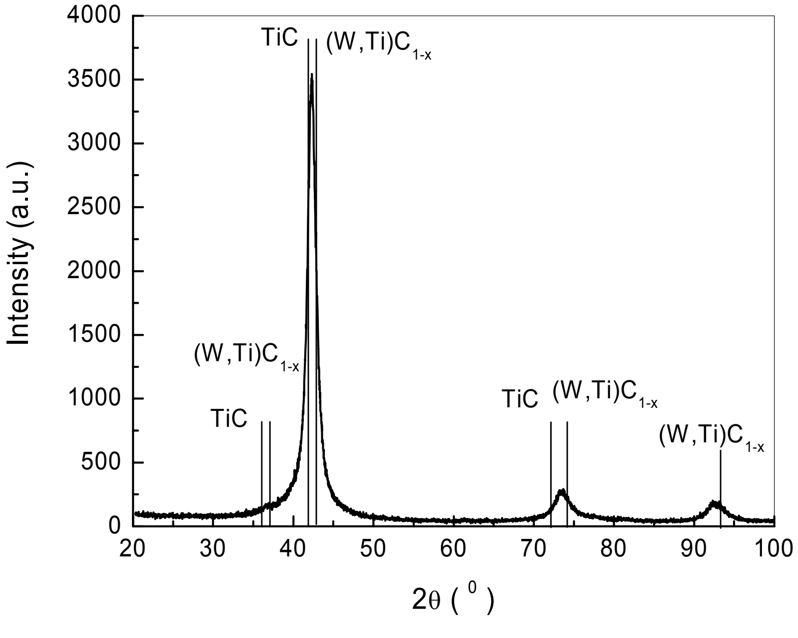


Figure 65: XRD patterns for B coating

As it can be seen, no diffraction lines of the substrate (α-Fe) were identified. The coating produced with target A (with 5% SiC) shows diffraction lines of tungsten carbides. The lines of W_2C and W_3C phases are clearly identified.

Although these carbides are unstable, they are usually observed for W-C coating deposition. Diffraction lines for β-WC(1-x), a non-stoichiometric phase, have been also identified. As it has been already reported in the literature this phase represents a transitional stage of the transformation WC→ β-$WC_{(1-x)}$→ W_2C→ W_3C→W. The SiC or other compound has no contribution on the diffraction pattern of the coating A. Sample B revealed a different XRD pattern. The diffraction peaks for (W, Ti)C_{1-x} multiphase compound were identified. As the atomic radius of Co is similar with that of W (1,35 Å) and close to the Ti atomic radius (1.40 Å) it is possible that some of the Co atoms to be included in the (W, Ti)C_{1-x} compound. On the other hand, due to the comparable atomic radius of these three elements, the increase of microhardness for the coating B in comparison with the coating A, cannot be explained by the solid solution hardening effect caused by the solubility of Co in the W-Ti-C system. It might be due to the finer structure of the coating B.

The depth profiles for the concentrations of the coating constituents are shown in figures 66 and 67.

As it can be seen in figure 66 the distribution of the elements across the layer is relative uniform excepted W and Ti. The Ti concentration appears to be higher in the inner region of the coating than in the outer part. This feature is probably due to the higher sputtering yield of Ti at the target level comparatively with W. This leads to an "enrichment" of the W concentration at the target surface resulting in a higher concentration of the W in the outer region of the coating. For both coatings the Co content (about 12,5 wt. %) is higher than in the target (8.5-9 wt.%). This might be also explained by the preferential sputtering effect. The Ti interlayer deposited to improve the adhesion of the coating, with a thickness of about 5 µm can be clearly identified in figure 67.

As the SEM investigations revealed, the surface roughness of the coating B is significant lower than that of the coating A (figures 68 and 69). This might be associated with the structure of the coating B which is based on the complex phase (W, Ti)C_{1-x}. This surface characteristic suggests that the finer structure of the coating B could be responsible for the higher microhardness. A cross section of the coating is shown in figure 70. It can be seen the featureless extremely dense structure. Below the (W, Ti)C_{1-x} coating there is the intermediate Ti layer which improves the addition between (W, Ti)C_{1-x} and the substrate.

The change of the coatings hardness during a thermal heating cycle has been investigated. Samples made of stainless steel, plain carbon steel, and titanium, coated with A and B layers were subjected to several heating cycles in air, at temperatures of 250, 350, 550, 650, 750, and 920°C using an electric furnace. Samples coated with nc-Ti2N/nc-TiN, with an initial microhardness of 2,900 HV0.1 were used as a reference.

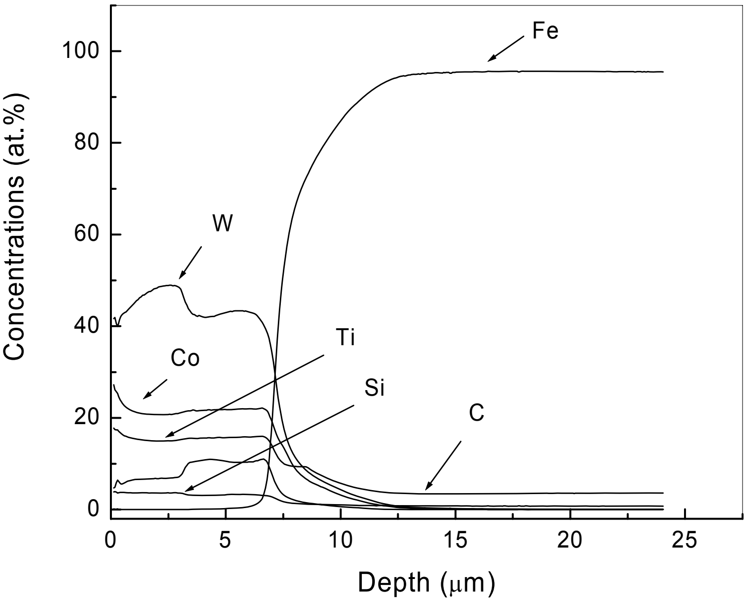


Figure 66: Elemental depth profile for A coating

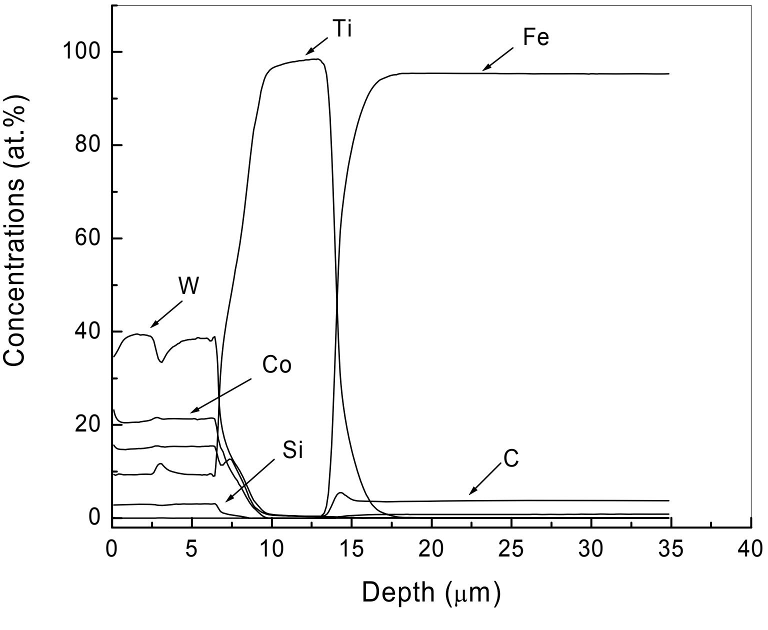


Figure 67: Elemental depth profile for B coating

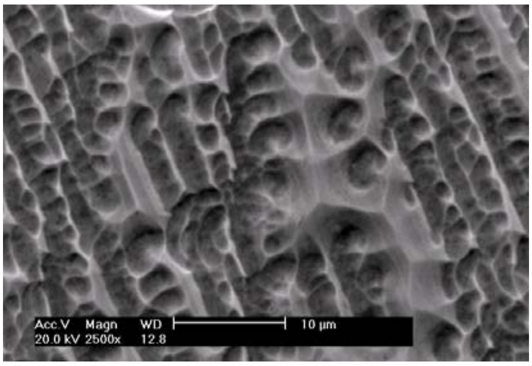


Figure 68: SEM images of the surface of the A coating

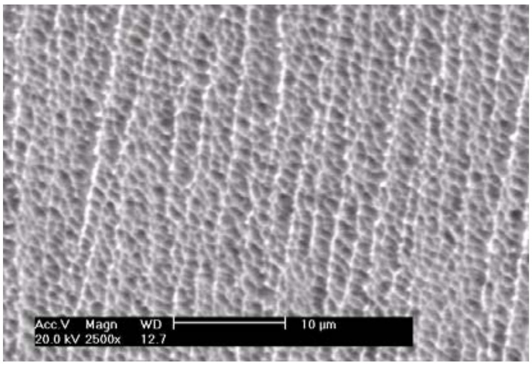


Figure 69: SEM images of the surface of the B coating

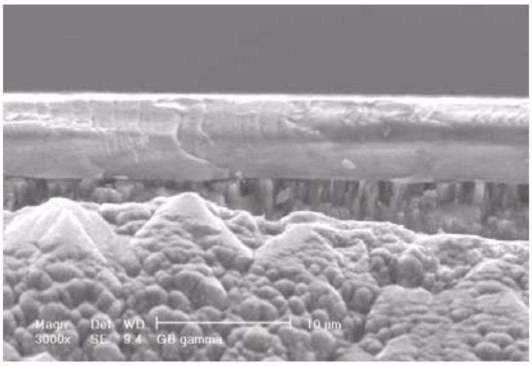


Figure 70: SEM cross section of the (W,Ti)C_{1-x} coating

Each cycle consisted in heating to the testing temperature, an exposure for 15 min, followed by cooling in air to the room temperature. After each cycle, the microhardness was measured, the samples surfaces were carefully inspected and then the same samples were heated up to the next test temperature. The change of coating microhardness during the thermal stability test is shown in the figure 71. Both A and B coatings revealed no change in hardness after heating up at the temperatures below 550 °C. With increasing the temperature up to 920 °C the hardness decreases gradually, but the

coating B remains always harder than the coating A. No significant influence of the substrate has been detected in this test, although at 920 °C the coating A has been delaminated from Ti and stainless steel substrates. Under the same conditions, the coating B maintained its integrity on all substrates.
The reference nanocomposite coating nc-Ti2N/nc-TiN deposited by the same technique revealed a similar behavior at the thermal stability test, excepted with a slight increase in hardness after annealing at 550 °C. After heating up at 920 °C the hardness of the nc-Ti2N/nc-TiN reference coating decreased to 400 HV 0.05 (13% of the initial value) whiles the hardness of the coating B remained at approx. 900 HV0.05 (27 % of the initial value).

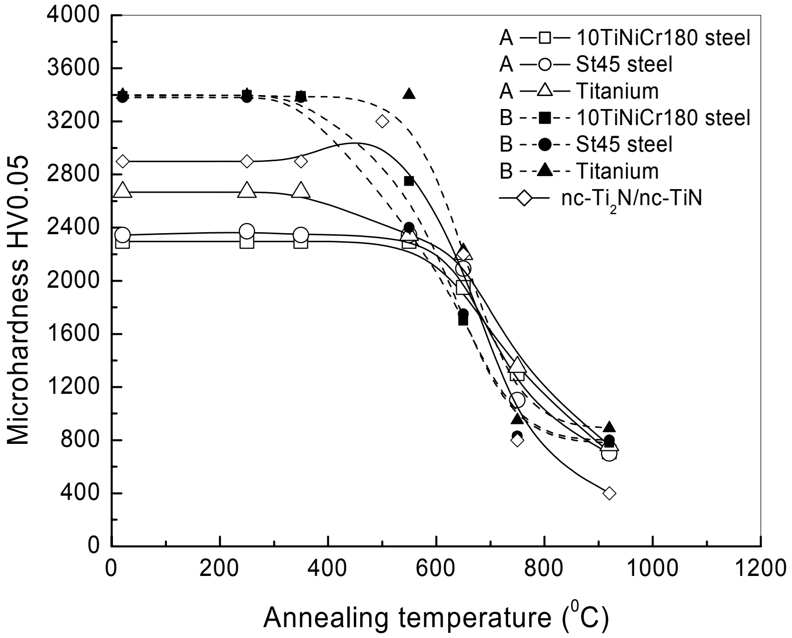


Figure 71: The evolution of coatings microhardness as a function of annealing temperature (solid line A coating, dash line B coating)

As it was mentioned in the previous section, DMF Werkzeugbau GmbH, Germany proposed for testing a number of 10 ejectors made of steel 1.2343. They are part of a molding die. Seven ejectors were coated with nc-Ti2N/nc-TiN nanocomposite layer and three with (W,Ti)C_{1-x} structure produced with the target B. Six of these ejectors are shown in figure 72. The coating characteristics are shown in table 5. The (W, Ti)C_{1-x} is hard, has a good resistance at high temperature, but it is quite brittle. This is why only 3 ejectors were coated with this type of layer. This is the first application. On the other hand, there is a good experience in working with nc-Ti2N/nc-TiN coating.

Figure 72: Ejectors coated with (W, Ti)C_{1-x} layer (3 Off on the left side) and with nc-Ti2N/ nc-TiN nanocomposite layer (3 Off on the right side)

Type of coating	Coated components	Coating Thickness (µm)	Coating hardness	
			HV 0.04	HV 0.1
nc-Ti_2N/nc-TiN	- 3 small ejectors - 4 large ejectors	6.5 ± 0.5	1,861; 1,861	1,407; 1,339
(W, Ti)C_{1-x}	- 3 small ejectors	3.5 ± 0.5	3,517; 3,116	901, 744, 866

Table 5: Hard layer characteristics for the coated ejectors

Work package 6 – Application of combined treated moulds

Application of Moulds "DMF"

The 2 Moulds "DMF" (inserts) were applied in an aluminium die casting process (figure 73). The objective was manufacturing die casting parts for the automotive industry. The used material during the aluminium die casting process was AlSi9Cu3(Fe). The lifetime of conventionally treated inserts (liquid nitriding) had been 5.000 parts.

Regarding the moulds combined treated with laser dispersing and nitriding, almost no abrasion was visible after 5.000 die casting cycles (figure 74). Furthermore no cracks appeared in a visual inspection. The lifetime criteria have not been reached yet. The inserts will be applied in line with the production of replacement parts in future (smaller batch sizes). DMF Werkzeugbau GmbH, Germany estimates that the lifetime of the Moulds "DMF" will be approx. 10.000 die casting parts. In this case the increase of lifetime is about 100%.

Figure 73: Mould "DMF"
during its application

Figure 74: Mould "DMF" after
5.000 die casting cycles

Further on the ejector pins coated in the Project "ForBeST" are assembled in an aluminium die casting mould. Ejector pins are always used in moulds/dies which are applied for the manufacturing of parts in large batch sizes (injection moulding dies, forging moulds, die casting mould etc).
The applied material during the aluminium die casting process is AlSi9Cu3(Fe). 6.000 aluminium parts have been casted by using the coated ejector pins. A lower percentage of aluminium adherence could be achieved. The pins' lifetime criteria have not been reached yet. The increase of lifetime is approx. 3% (date December 1, 2006). It is not possible to estimate pins' lifetime at present. A further application of the ejector pins will be realised in the course of the next weeks (January/February 2007). All partners will be informed about the analyses of the pins after its application and the required investigations.

Application of Moulds "RAS"
In case of RAS 3 moulds were combined treated by the National Institute for Laser, Plasma and Radiation Physics and Fraunhofer IPT. The applied material in the forging process was 46MnVS3 (steel 1.1305). The lifetime of the 1st applied mould could not be increased, because of crack formation during laser treatment. The same lifetime of 1.700 parts in comparison with conventionally

treated moulds (liquid nitriding) was reached. Less surface roughness existed after 1.700 forging cycles (detailed results are discussed in the chapter "analyses of applied moulds").
The partners decided to realise further iteration loops. These additional applications have not been finished yet. The 2nd and 3rd combined treated Moulds "RAS" will be applied in the beginning of the year 2007.

Application of Moulds "MTK"

2 Moulds "MTK" were treated in line with the Project "ForBeST". The 1st Mould "MTK" (forging mould) was applied for the production of flanges for the automotive industry. The applied material during the forging process was S 355 J2G3 EN 10025+A1 (steel 1.0572).
Max. 1.250 forging parts could be forged by an application of a conventionally treated mould (liquid nitriding). 3.340 parts were forged by using the 1st Mould "MTK" in the enterprise KLF-ZVL MTK. The increase of the lifetime was approx. 300%. Together with MTK as well as the other partners it was decided to realise further iteration loops. The application of the 2nd Mould "MTK" will be realised in the first months of the year 2007. KLF-ZVL MTK estimates that the lifetime of the 2nd Mould "MTK" will be at least the same in comparison with the 1st Mould "MTK".

Application of Moulds "FAF"

In 2 iteration loops 4 mould parts (2 upper parts and 2 lower parts) were combined treated during the project duration (figure 75). The 2 Moulds "FAF" were applied during forging processes in the enterprise Forjaco - Aco Forjado, Lda., Portugal (figure 76). The applied material was C35 EN 10083-2 (steel 1.0501). The forging products were pedals (figure 77).
Approx. 4.000 parts were forged by using conventionally treated moulds (quenching and tempering) in the past. In addition a gas nitrided mould was tested (layer thickness 0,2 mm; hardness 1000 - 1100 HV 0,1). 6.000 parts could be forged by using this mould.
With the combined treated moulds a lifetime of 10.800 forging parts for the 1st Mould "FAF" and 11.000 forging parts for the 2nd Mould "FAF" could be achieved. In comparison to conventionally treated moulds moulds a reproducable increase in lifetime of about 275% was obtained.

Figure 75: Applied 1st Mould "FAF" (fig., front) and 2nd Mould "FAF" before its application (fig., back)

Figure 76: 1st Mould "FAF" during its application

Figure 77: Forging product "FAF" (Pedal)

Application of Moulds "BENE"

For BENE 2 upper and 2 lower mould parts were combined treated in 2 iteration loops in line with the Project "ForBeST" (figure 78). Both moulds were applied in the enterprise A. BENEVENUTA & C. S.p.A., Italy. The moulds were used for the manufacturing of shift-forks (freight vehicle).

The 1st Mould "BENE" was applied in 12.000 forging cycles. That accords with a lifetime increase of 100% in comparison with a conventionally treated (gas nitriding, thickness of the nitrided layer 0.2 mm) mould. The enterprise A. BENEVENUTA tested also forging moulds which were only gas nitrided in a time consuming gas nitriding process (thickness of the nitrided layer 0.5 mm). 12.000 forging cycles could be achieved in line with the application of this mould (figures 79 and 80).

A. BENEVENUTA decided to laser treat (Fraunhofer IPT) and afterwards to gas nitride (thickness of the nitrided layer 0.5 mm) one mould in the enterprise itself during a further iteration loop. This mould was applied and 17.000 parts were forged. Lifetime of the Mould "BENE" could be increased 142% in comparison with a conventionally gas nitrided Mould "BENE" (thickness of the nitrided layer 0.2 mm).

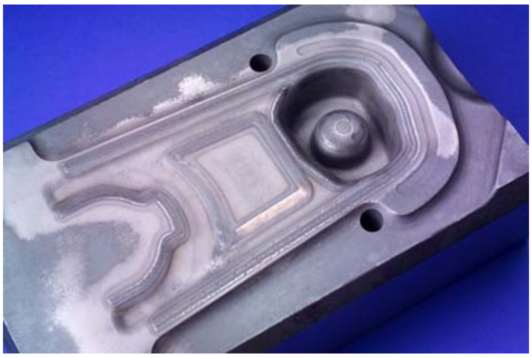


Figure 78: Laserdispersed Mould "BENE" before its application

Figure 79: Applied lower part of the 1st Mould "BENE" (after 3rd polishing)

Figure 80: Applied upper part of the 1st Mould "BENE" (after 3rd polishing)

Work package 7 – Analyses of applied moulds

The analyses of applied moulds contained both a technical investigation on the moulds as well as an assessment of the economic efficiency of the combined treatment.

Technical investigations on applied moulds

In order to extend the lifetime of the forging and aluminium die casting moulds the wear resistance of the moulds should be increased by developing highly wear-resistant surface layers. The lifetime of hot processing moulds is limited by specially defined lifetime criteria (crack formation, dimension deviations etc.)
In application the surfaces of hot processing moulds are subjected to temperatures between 200-800 °C as well as enormous pressure and friction. The failure of forging tools is caused up to 70% by mechanical or thermal wear. One of the main objectives of the Project "ForBeST" was to provide an outstanding wear resistance, a good oxidation resistance at elevated

temperatures and a low coefficient of sticking associated with a high fatigue resistance.
Typical wear mechanisms for forging and die casting moulds are shown in figure 81.

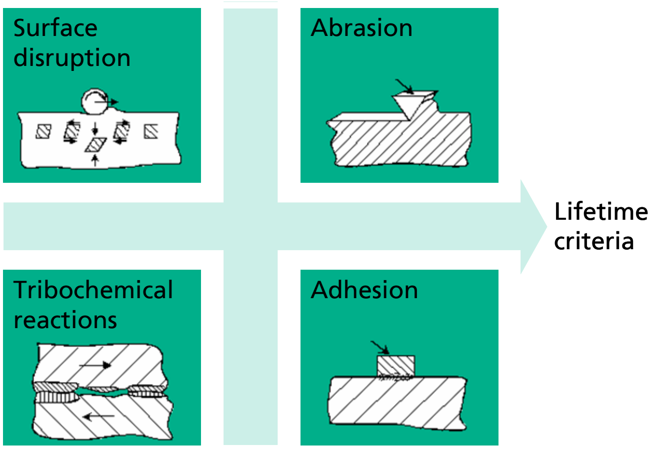


Figure 81: Wear mechanisms

The requirements on a mould material and surface properties can be extrapolated from the existing strains as follow:

- High strength
- High toughness
- High surface hardness
- Thermal resistance
- Thermal shock resistance
- Chemical resistance

⇨ High wear resistance

The results of the investigations on the laser dispersed and plasma nitrided areas near surface accord to the results achieved concerning the treated samples (figure 82). As the industrial partners insisted on a revision of their moulds for further application a metallographical analyses of the areas near surface was impossible. Therefore the investigations focussed on a visual inspection of the mould surface, particularly the worn-out areas and the surface roughness.

Figure 82: Micrograph of a part made of steel 1.2344, treated by laser dispersing and plasma nitriding

By analysing the applied forging and aluminium die casting moulds the wear mechanisms adhesion and abrasion could be determined as main influence which limit primarily lifetime of processing moulds. Adhesion prevails in aluminium die casting processes.
The analyses of the surface quality (surface roughness) of conventionally treated/combined treated and applied moulds resulted in all cases surface quality was increased (same amount of forging cycles). In figure 83 the surface of a conventionally treated (liquid nitriding) mould and the surface of the 1st Mould "RAS" after 1.700 forging cycles is shown. As surface quality is also a lifetime criteria for advanced products, the reduced surface roughness allows a prolonged lifecycle of forging moulds.

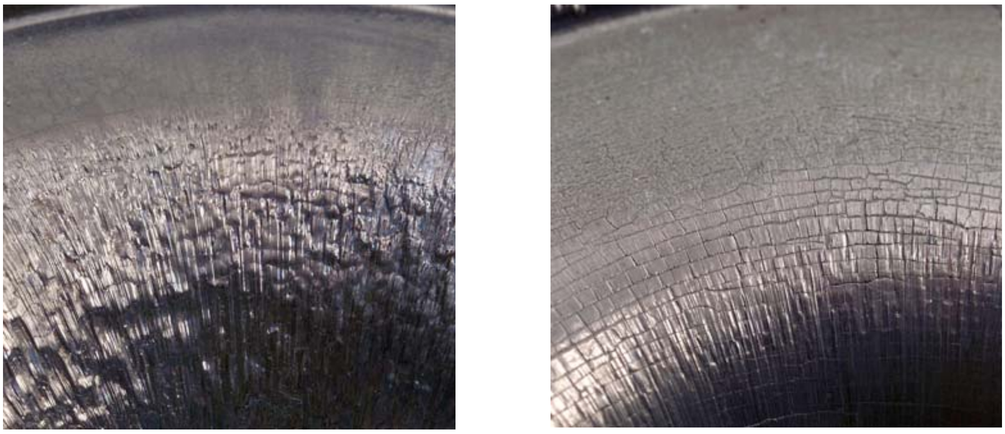


Figure 83: Surface of a worn out Mould "RAS" (1.700 forging cycles) which was liquid nitrided (left side); surface of the combined treated Mould 1 "RAS" after the same lifetime (right side)

Economic efficiency of the combined treatment

Fraunhofer IPT evaluated the economic efficiency of the combined treatment (laser alloying/dispersing combined with plasma nitriding). The evaluation based on the following mathematical calculation (figures 84 - 87):

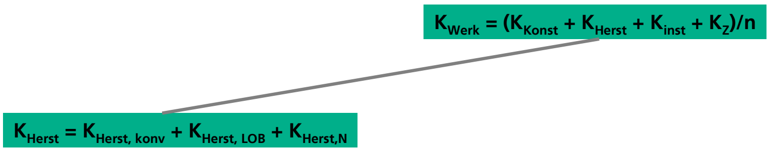
Calculation of tool costs relating to lot size

$$K_{Werk} = (K_{Konst} + K_{Herst} + K_{inst} + K_{Z})/n$$

- K_{Werk} **= tool costs relating to lot size**
- K_{Konst} **= tool design costs**
- K_{Herst} **= tool manufacturing costs**
- K_{Inst} **= maintenance costs**
- K_{z} **= imputed interest**
- n **= number of produced parts** (variable)

Figure 84: Economic efficiency (I/IV)

Calculation of tool costs relating to lot size



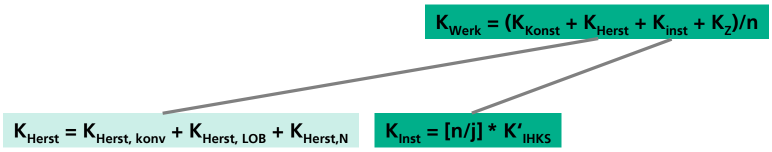
$K_{Werk} = (K_{Konst} + K_{Herst} + K_{inst} + K_Z)/n$

$K_{Herst} = K_{Herst,\ konv} + K_{Herst,\ LOB} + K_{Herst,N}$

- K_{Herst} = tool manufacturing costs
- $K_{Herst,\ konv}$ = toll manufacturing costs for conventional tools
- $K_{Herst,\ LOB}$ = laser treatment costs
- $K_{Herst,\ N}$ = nitration costs

Figure 85: Economic efficiency (II/IV)

Calculation of tool costs relating to lot size



$K_{Werk} = (K_{Konst} + K_{Herst} + K_{inst} + K_Z)/n$

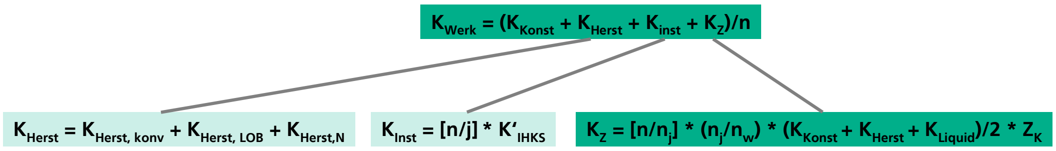
$K_{Herst} = K_{Herst,\ konv} + K_{Herst,\ LOB} + K_{Herst,N}$

$K_{Inst} = [n/j] * K'_{IHKS}$

- K_{Inst} = maintenance costs
- n = number of produced parts (variable)
- j = maintenance intermittent
- K'_{IHKS} = maintenance cost rate

Figure 86: Economic efficiency (III/IV)

Calculation of tool costs relating to lot size



$K_{Werk} = (K_{Konst} + K_{Herst} + K_{inst} + K_Z)/n$

$K_{Herst} = K_{Herst,\ konv} + K_{Herst,\ LOB} + K_{Herst,N}$

$K_{Inst} = [n/j] * K'_{IHKS}$

$K_Z = [n/n_j] * (n_j/n_w) * (K_{Konst} + K_{Herst} + K_{Liquid})/2 * Z_K$

- K_Z = imputed interest
- n = number of produced parts (variable)
- n_j = lot size per annum
- n_w = total lot size per tool
- K_{Konst} = tool design costs
- K_{Herst} = tool manufacturing cots
- K_{Liquid} = liquidity revenue
- Z_K = imputed interest rate

Figure 87: Economic efficiency (IV/IV)

For the estimation of the economic efficiency specific data of each industrial partner was required. For confidential reasons specific data of the industrial partners are not published in this report. The results of the estimation regarding the economic efficiency are presented in figure 88.

	Lifetime (conventional)			**Combined surface treatment**			
	Quenching/ tempering	Liquid nitriding	Gas nitriding	Lifetime	Costs (*)	Increase of lifetime	Cost advantage (**)
DMF Werkzeugbau		5.000		10.000	245 € (1 piece)	100%	9%
					57 € (5 pieces)		
Forjaco	4.000		6.000	11.000	445 € (1 piece)	275%	56%
					125 € (5 pieces)		
A. BENEVENUTA			6.000 (12.000)	17.000	449 € (1 piece)	142%	28%
					129 € (5 pieces)		
KLF-ZVL MTK		1.250		3.340	331 € (1 piece)	300%	58%
					92 € (5 pieces)		
Rasche Umformtechnik		1.700		🟨	266 € (1 piece)		
					078 € (5 pieces)		

🟨 Data required
(*) Supposed hourly rate 50 €/h
(**) Relating to max. lifetime (combined surface treatment)

Figure 88: Economic efficiency – estimation

Work package 9 – Provision of a plan "Use and dissemination of knowledge"

The use and dissemination of knowledge is described in the 6th chapter of this report as well as in the Management Report, Project "ForBeST".

Work package 10 – Project management

The co-ordinator Fraunhofer IPT introduced the Commission requirements which exist in connection with the Project "ForBeST" to the project partners in the beginning of the project. The providing of the Financial Statements, the reporting guidelines and the associated time schedules were presented. The different kinds of costs and the completion of the Financial Statements in detail were matters of particular interest. The partners were asked to provide Financial Statements (at the end of the 1st and 2nd project year). In addition audit certificates had to be prepared for the entire project duration at the end of the project.

Fraunhofer IPT provided Activity Reports, Management Reports, Summary Financial Tables and Cost Budget Follow Up Tables to the address of the European Commission as well as of all project partners at the end of each reporting period.

The co-ordinator Fraunhofer IPT supported always an interchange of information about the project’s progress, to make decisions and to find solutions concerning the subtasks between all project partners and the European Commission.

3.3 Planned activities and actual work accomplished

Each work package as well as objective was categorised with a percentage of fulfilment in order to give an overview of the work accomplished:

Progress categories

100%	Tasks are already finished
75%	Tasks are still in progress and almost finished
50%	Tasks are full in progress
25%	Tasks have started in near history
0%	Tasks have not started yet

Work package 1

100%	Selection of moulds
100%	Selection of samples
100%	Agreement regarding heat treatment
100%	Production and provision of samples
100%	Production and provision of moulds

Work package 2

100%	Implementation of an one-step laser alloying/dispersing process
100%	Testing parameters for laser alloying/dispersing
100%	Definition of the additive materials and their mass flow
100%	Analyses of laser treated samples

Work package 3

100%	Testing nitriding parameters
100%	Characterisation of the hardness profiles and penetration depths
100%	Provision of the process layout for nitrocarburising
100%	Deposition of a TiN or TiAlN layer on samples by CMSII
100%	Analyses of treated samples for the identification of the layer characteristics

Work package 4

100%	Coding CNC programs
100%	Transfer of results from WP 2 to the selected moulds
100%	Definition of process strategy with the intention to reduce distortion and the formation of cracks
100%	Investigations on process parameters defined
100%	Provision of laser alloyed/dispersed moulds

Work package 5

100%	Surface finishing of selected moulds

100% Plasma nitriding of the moulds selected
100% Transfer of the first results from the real tests to the following nitriding processes
100% Consideration of the penetration depth and treatment time

Work package 6
100% Application of moulds under real conditions
100% Definition of the most effective surface treatment technology
100% Mould tests in steps to realise iteration loops
100% Economic consideration

Work package 7
100% Investigations on moulds applied
100% Cutting of selected moulds and metallographical investigations

Work package 8
100% Quantification of the success of the combined surface treatment
100% Analyses of the reached results (work packages 4 - 7)

Work package 9
100% Provision of a plan which includes the use and dissemination of knowledge and results

Work package 10
100% Project management of the Project "ForBeST" in consideration of the time schedule and the objectives
100% Support of communication
100% Provision of reports

4 List of deliverables

Work packages	**Deliverables**
1	Provision of selected samples (months 1 - 3)
1	Provision of selected moulds (months 2 - 6)
2	Samples laser alloyed/dispersed (months 2 - 6)
2	Optimised process parameters (laser alloying/dispersing) (months 5 - 7)
3	Samples plasma nitrided and sputtered by Combined Magnetron Sputtering and Ion Implantation (CMSII) (months 2 - 7)
3	Optimised process parameters (plasma nitriding and CMSII) (months 4 - 8)
	1st MILESTONE
4	Laser alloyed/dispersed moulds (months 9 - 16)
5	Moulds nitrided with optimum parameters (months 10 - 17)
6	Application of combined treated moulds under real conditions in the enterprises of the industrial partners (months 11 - 20)
7	Report on mould’s lifetime and wear mechanisms (months 12 - 21)
	2nd MILESTONE (after 1st iteration loop)
8	Quantified success of combined surface treatments (months 21 - 22)
9	Plan for use and dissemination of knowledge (months 6 - 24)
10	Co-ordinated project activities, documentation (months 1 - 24)
	3rd MILESTONE

5 Management and co-ordination aspects

5.1 Performance of the consortium

The interactions between all partners including the RTD performers were/are effective concerning the communication and co-operation. No problems encountered during the entire project duration.

5.2 Used and scheduled person months

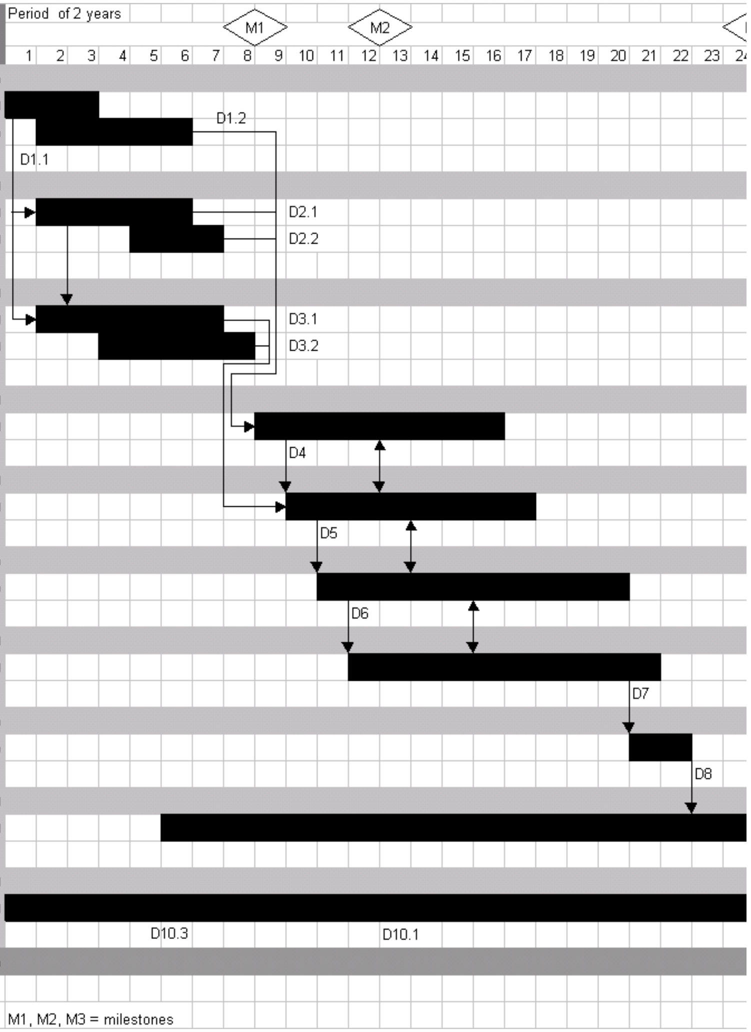
The used person months do not exceedingly differ from the scheduled person month status. The workplan and the Final Management Report, Project "ForBeST" includes more detailed information.

5.3 Workplan

All project activities in the Project "ForBeST" based on the workplan introduced in the "Description of work".
Almost all project activities were in time. There was a delay regarding the work packages 6 and 7. This circumstance was a result of long shipping durations of the samples and moulds between the project partners. The duration of shipping parcels took between Portugal and Germany approx. 14 days. The time required for shippings between Germany and Romania was nearly the same.

WORKPLAN, Project "ForBeST"

MANPOWER ForBeST (in person-months)		BENE	DMF	FAF	RAS	MTK	IPT	ILPP	TOTALS
		I	D	P	D	SK	D	RO	
WP 1	**Manufacturing of samples and test tools**	1,50	1,00	2,25	2,50	1,50	0,00	0,00	**9,75**
1.1	Production of samples	0,25		0,25	0,25	0,25			**1,00**
1.2	Production of test tools	1,50	1,00	2,25	2,50	1,50			**8,75**
WP 2	**Laser surface treatment of samples / metallographic research**	0,00	0,00	0,00	0,00	0,00	12,50	0,00	**12,50**
2.1	Basic research						8,00		**8,00**
2.2	Analysis of laser treated samples						4,50		**4,50**
WP 3	**Nitriding/Nitrocarburising/CMSII of samples / metallographic research**	0,50	0,00	0,00	0,00	0,00	0,00	20,00	**20,50**
3.1	Basic research	0,50						15,00	**15,50**
3.2	Analysis of the treated samples							5,00	**5,00**
WP 4	**Transfer of laser surface treatment to test tools**	0,00	1,00	0,00	0,00	0,00	6,00	0,00	**7,00**
4.1	Transfer of laser surface treatment to test tools		1,00				6,00		**7,00**
WP 5	**Nitriding/Nitrocarburising/CMSII of test tools**	1,00	0,00	0,00	0,00	0,00	0,00	15,00	**16,00**
5.1	Nitriding/Nitrocarburising/CMSII of test tools	1,00						15,00	**16,00**
WP 6	**Real tests of laser treated tools**	5,50	0,00	6,25	6,00	6,00	0,00	3,00	**26,75**
6.1	Real test of laser treated tools	5,50		6,25	6,00	6,00		3,00	**26,75**
WP 7	**Investigation of used tools**	1,50	1,50	2,00	2,00	2,00	4,00	2,00	**15,00**
7.1	Investigation of used tools	1,50	1,50	2,00	2,00	2,00	4,00	2,00	**15,00**
WP 8	**Assessment of technology combination and investigation of potential**	0,75	0,75	0,75	0,75	0,75	1,50	1,00	**6,25**
8.1	Assessment of technology combination and investigation of potential	0,75	0,75	0,75	0,75	0,75	1,50	1,00	**6,25**
WP 9	**Dissemination of knowledge and exploitation of results**	2,00	2,00	0,50	0,50	0,50	3,00	1,00	**9,50**
9.1	Dissemination of knowledge and exploitation of results	2,00	2,00	0,50	0,50	0,50	3,00	1,00	**9,50**
WP 10	**Project management (including documentation)**	1,00	1,00	1,00	1,00	1,00	3,00	1,00	**9,00**
10.1	Project management (including documentation)	1,00	1,00	1,00	1,00	1,00	3,00	1,00	**9,00**
TOTAL MANPOWER (in person-months)		**13,75**	**7,25**	**12,75**	**12,75**	**11,75**	**30,00**	**43,00**	**132,25**



M1, M2, M3 = milestones

5.4 List of meetings

The meetings listed below were held during the entire project duration (November 1, 2004 to October 31, 2006)

Subject	Date	Location
Kick-off Meeting	November 24, 2004	at Fraunhofer IPT, Germany
6-month Meeting	May 11, 2005	at Fraunhofer IPT, Germany
12-month Meeting	November 17, 2005	at Fraunhofer IPT, Germany
Final Meeting	October 26, 2006	at Fraunhofer IPT, Germany

The 18-month Meeting was replaced by bilateral workshops between the co-ordinator Fraunhofer IPT and the individual partners according to the wishes of the industrial partners. The objective of this procedure was to investigate the applied moulds and to analyse a mould application in the companies. The bilateral workshops are listed below in this chapter.

Participants in the Kick-off Meeting
Dr. Ruset, National Institute for Laser, Plasma and Radiation Physics
Mrs. Spaethe, DMF Werkzeugbau GmbH
Mr. Märker, DMF Werkzeugbau GmbH
Mr. Urban, KLF-ZVL MTK spol. s.r.o.
Mr. Smatana, KLF-ZVL MTK spol. s.r.o.
Mr. Duchovic, KLF-ZVL MTK spol. s.r.o.
Mr. Bausch, Fraunhofer IPT
Mr. Castell-Codesal, Fraunhofer IPT
Mr. Gläser, Fraunhofer IPT

Participants in the 6-month Meeting
Dr. Ruset, National Institute for Laser, Plasma and Radiation Physics
Mrs. Spaethe, DMF Werkzeugbau GmbH
Mr. Baruth, Rasche Umformtechnik GmbH & Co KG
Mr. Marietti, A. BENEVENUTA & C. S.p.A.
Mr. Smatana, KLF-ZVL MTK spol. s.r.o.
Mr. Duchovic, KLF-ZVL MTK spol. s.r.o.
Mr. Bausch, Fraunhofer IPT
Mr. Gläser, Fraunhofer IPT

Participants in the 12-month Meeting
Dr. Ruset, National Institute for Laser, Plasma and Radiation Physics
Mr. Smatana, KLF-ZVL MTK spol. s.r.o.
Mr. Duchovic, KLF-ZVL MTK spol. s.r.o.
Mr. Tennigkeit, Rasche Umformtechnik GmbH & Co KG
Mr. Bausch, Fraunhofer IPT
Mr. Gläser, Fraunhofer IPT

Participants in the Final Meeting
Dr. Ruset, National Institute for Laser, Plasma and Radiation Physics
Dr. Grigore, National Institute for Laser, Plasma and Radiation Physics
Mr. Pflitsch, Rasche Umformtechnik GmbH & Co KG
Mr. Tennigkeit, Rasche Umformtechnik GmbH & Co KG
Mr. Marietti, A. BENEVENUTA & C. S.p.A.
Mr. Zuzcak, KLF-ZVL MTK spol. s.r.o.
Mr. Smatana, KLF-ZVL MTK spol. s.r.o.
Mr. Sensel, KLF-ZVL MTK spol. s.r.o.
Mr. Duchovic, KLF-ZVL MTK spol. s.r.o.
Mr. Bausch, Fraunhofer IPT
Mr. Gläser, Fraunhofer IPT

In addition the following meetings were held as workshops participating the co-ordinator Fraunhofer IPT and an industrial partner:

Industrial partner	**Date**	**Location**
RAS	March 8, 2005	at Rasche Umformtechnik, GmbH & Co KG, Germany
DMF	April 5, 2005	at DMF Werkzeugbau GmbH, Germany
FAF	July 5, 2005	at Forjaco - Aco Forjado, Lda., Portugal
RAS	January 23, 2006	at Rasche Umformtechnik, GmbH & Co KG, Germany
MTK	June 16, 2006	at KLF-ZVL MTK spol. s.r.o., Slovakia
FAF	June 22, 2006	at Forjaco - Aco Forjado, Lda., Portugal
BENE	July 18, 2006	at A. BENEVENUTA & C. S.p.A., Italy
RAS	July 26, 2006	at Rasche Umformtechnik, GmbH & Co KG, Germany
DMF	July 27, 2006	at DMF Werkzeugbau GmbH, Germany
ILPP	August 4, 2006	at the National Institute for Laser, Plasma and Radiation Physics, Romania

Moreover contact between the RTD performers and all partners was regularly realised on the phone and via email. The intention was to interchange information about the project’s progress, to make decisions and to find solutions concerning the subtasks.

6 Use and dissemination of knowledge

6.1 Direct applications and benefit

The main benefit of the Project "ForBeST" is the development of the combined process laser alloying/dispersing and plasma nitriding/nitrocarburising.
It is possible to increase the lifetime of forging and die casting moulds 100% - 300% by using this technique. The superordinated objective is to reduce the manufacturing costs of products. This aim can be realised by a longer lifetime of moulds. The forging and die casting enterprises need to manufacture less moulds and the non-productive times are significantly reduced (less production stops) (figure 89).
The RTD performers, the Institute for Laser, Plasma and Radiation Physics and the Fraunhofer IPT presented all process parameters for the laser treatment and the nitriding process during the Final Meeting. Industrial Partners plan to laser treat and nitrate their moulds by themselves in future (DMF Werkzeugbau GmbH, Germany; KLF-ZVL MTK spol. s.r.o., Slovakia). Other partners asked for a qualification of "Job shops" for an external surface treatment of their moulds (A. BENEVENUTA & C. S.p.A., Italy; Rasche Umformtechnik GmbH & Co KG). The enterprise Forjaco - Aco Forjado, Lda. will consider all economic facts in the course of the next weeks. Forjaco will enquire about a "Job shop" in Portugal.
The RTD performers, the Institute for Laser, Plasma and Radiation Physics and the Fraunhofer IPT will use the reached knowledge and results during the project duration for an acquisition of new projects. The intention will be to realise a further development of the technology. In addition the RTD performers will use the project results in line with the university/academic education.
The co-ordinator Fraunhofer IPT verifies a support of a technology transfer of the combined surface treatments to each enterprise resp. a qualification of "Job Shops" possibly in form of a succeeding project. Therefore the European Commission will be contacted. The Fraunhofer IPT will inform the project partners about existing possibilities. If applicable, Fraunhofer IPT will send a pre-proposal regarding a continued project to the address of each project partner.

- Direct implementation of results in the industrial enterprises (maybe via "Job shops")
- Presentation at exhibitions and fairs
- Offering new technologies
- Increasing of knowledge and market expansion
- Comparison with conventional methods
- Expanding business activities by adding Europe-wide contacts
- Market analyses

Figure 89: Benefits for the enterprises, Project "ForBeST"

6.2 Protection of the results

No results were developed in the course of the project "ForBeST" which shall be protected by a patent. If further research take place in the enterprises, the individual enterprise will protect the obtained knowledge by a patent. In detail new process strategies or material combinations may be patented by an industrial enterprise.

6.3 Recipients of disseminated information

The project deliverables and the technology were, are and will be presented in line with fairs, exhibitions and colloquiums as well as in professional journals. In this way potential new appliers of the combined surface treatments and appliers of treated moulds are informed with the assistance of the enterprises and institutes involved in this project. The intention is to convince new appliers of using the technology ("Job Shops") and of applying treated forging and aluminium die casting moulds (large-/medium-/small-sized forging or mould making enterprises). One objective for the RTD performers is to look for further applications using hot processing moulds and to transfer the results reached in this project to new applications. In this way a further development of the combined treatment technology can be realised.

6.4 Exploitation and dissemination strategy

Achieved results and knowledge in the Project "ForBeST" were published in professional journals and presented in colloquiums. No specific technological data were published. The rights of the industrial partners involved in the project were protected in this way.

The results of the mould applications and investigations of the treated moulds were published as follows:

1) C. Ruset, E. Grigore, T. Gläser, S. Bausch: »Combined treatments – a way to improve surface performances«, The fifth International Edition of Romanian Conference on Advanced Materials, Bucharest-Magurele, Romania, Sep. 11-14, 2006

2) C. Ruset, E. Grigore, X. Li , H. Dong: »Combined magnetron sputtering and ion implantation, a new method for depositing thick hard nanocomposite coatings«, Proceedings of the Int. Conf. on Surface Coatings and Nanostructured Materials, Aveiro, Portugal, Sept. 7-9, 2005

3) E. Grigore, M. Chivu, C. Coman, H. Dong, X. Li,
C. Ruset: »High temperature resistant coatings deposited by Combined Magnetron Sputtering and Ion Implantation«, Tenth International Conference on Plasma Surface Engineering, Garmisch-Partenkirchen, Germany, Sept. 10-15, 2006

4) E. Grigore, C. Ruset, K. Short, D. Hoeft, H. Dong, X. Y. Li, T. Bell: »In situ investigation of the internal stress within the nc-Ti2N/nc-TiN nanocomposite coatings produced by a combined magnetron sputtering and ion implantation method«, Surface and Coatings Technology, vol. 200, p. 744-747, 2005

5) Glaeser, T.: Standzeitverlängerung von Werkzeugen und Formen durch Laserlegieren/-dispergieren und Nitrieren, VDWF im Dialog, Magazin des Verbands Deutscher Werkzeug- und Formenbauer e. V., Ausgabe 03/2006, Schwendi, 2006

6) Glaeser, T.: Standzeiterhöhung von Schmiede- und Druckgießwerkzeugen durch Laserlegieren/-dispergieren und Nitrieren, Laser Magazin, Ausgabe 03/2006, Bad Nenndorf, 2006

The RTD performers can and will apply its experience in the further development of the combined treatment technology in the course of the next months (approx. 6 - 12 months). New industrial, bilateral projects will be implemented (approx. 6 months). The intention will be to find optimum solutions for particular applications and needs of industrial enterprises (small- and medium-sized enterprises).
The Fraunhofer IPT is always present in relevant fairs, exhibitions and colloquiums to expose new developments. The IPT has an experience of 25 years in the execution of projects with the European industry, the dissemination of the research results and the transfer of technologies to SMEs across Europe. Fraunhofer IPT will use and disseminate achieved knowledge and results in the Project "ForBeST" in the course of the next 1 - 12 months.

The Project "ForBeST" and its contents, investigations and deliverables were presented in the following fairs, exhibitions and colloquiums in the past. The presentations were made by the co-ordinator Fraunhofer IPT, the National Institute for Laser, Plasma and Radiation Physics or one of the industrial enterprises:

- Aachen Machine Tool Colloquium AWK'05 (June 2 - 3, 2005, Aachen)
- LASER 2005 World of Photonics (June 12 - 16, 2005, Munich)
- 5th International Colloquium "Werkzeugbau mit Zukunft" (November 29, 2005, Wiesbaden)
- EuroMold 2005 (November 30 - December 3, 2005, Frankfurt on the Main)
- Hannover Messe 2006 (April 24 - 28, 2006, Hannover)
- 6th International Colloquium "Werkzeugbau mit Zukunft" (September 26 - 27, 2006, Aachen)
- EuroMold 2006 (November 29 - December 2, 2006, Frankfurt on the Main)

The Project "ForBeST" was presented in discussions with potential appliers, exhibits and via flyers.

7 Summary of the activities and major achievements

Forging and aluminium die casting moulds are subject to different types of wear during application, primarily abrasion wear and adhesive wear. The investigated combined surface treatment technique (laser alloying/dispersing and plasma nitriding) allows an efficient modification of moulds' edge layer with almost no distortion. Investigations on the surface treatment technique and an increase of mould's lifetime were matters of particular interest.

On this account Fraunhofer IPT initialised the CRAFT Project "Increased Lifetime of Forging Tools by Combined Surface Treatments – ForBeST" (contract number COOP-CT-2004-508710) in cooperation with one research establishment and five industrial users from five European countries. The project was supported in the sixth framework programme of the European Commission.

The National Institute for Laser, Plasma and Radiation Physics (Bucharest, Romania) and the Fraunhofer IPT were involved in this project as research establishments. The following enterprises participated as end users, too:

- A. BENEVENUTA & C. S.p.A. (Turin, Italy)
- DMF Werkzeugbau GmbH (Nohra near Weimar, Germany)
- Forjaco - Aco Forjado, Lda. (Anadia, Portugal)

- Rasche Umformtechnik GmbH & Co. KG (Plettenberg, Germany)
- KLF - ZVL MTK spol. s.r.o. (Martin, Slovakia)

For an increase of the lifetime and efficiency of forging and aluminium die casting moulds the surface treatment techniques laser alloying/dipersing and plasma nitriding were combined in a two-step combined surface treatment. Laser alloying/dispersing primarily countervails against abrasion wear. A nitrided layer protects the mould surface against adhesive wear.
Fraunhofer IPT laser disperses selected forging and aluminium die casting moulds, which belong to the industrial partners. Following plasma nitriding took place at the National Institute for Laser, Plasma and Radiation Physics in Romania. For the investigation on the behaviour during application and lifetime the participating enterprises applied the combined treated moulds under real conditions. The combined surface treatment was iteratively optimised. The moulds' lifetime could finally be increased 100 - 300%. The end users have access to extensive knowledge regarding the surface treatment techniques and layer systems as well as their characteristics during different stresses now.

8 ANNEXES

Please, find attached the minutes of the project meetings and a CD-ROM with all required electronic data.