SYNTHESIS REPORT

FOR PUBLICATION

CONTRACT No : Contract Number:BRECT920306

PROJECT N° :5825

TITLE : Economical Generation of Wear Resistant High Performance Layers with Laser Radiation for Development of Light Engine Components

PROJECT COORDINATOR: Fraunhofer-Institut für Lasertechnik, Germany (ILT)

PARTNERS :
1. Adam Opel AG, Germany (OPEL)
2. CETENASA, Spain (CETENASA)
3. FAGOR EDERLAN S. COOP., Spain (FAGOR)
4. Krauss Maffei Dienstleistung GmbH, Germany
5. Linde AG, TG, Germany (LINDE)
6. Schwäbische Hüttenwerke GmbH, Germany (SHW)
7. Tratamientos Termicos TTT S.A., Spain (TTT)

REFERENCE PERIOD FROM 01.12.1992 to 31.05.1996

STARTING DATE: 01.12.1992 DURATION: 42 MONTHS

PROJECT FUNDED 3Y THE EUROPEAN COMMUNITY UNDER THE BRITE/EURAM PROGRAMME

DATE: 07.04.1997

1 Title, authors and adresses

"Economical Generation of Wear Resistant High Performance Layers with Laser Radiation for Development of Light Engine Components"

Dr. K. Wissenbach, Dr. A. Gasser
Fraunhofer Institut für Lasertechnik, Steinbachstraße 15, D-52074 Aachen,
phone (++49) 241 / 8906-147 (Wissenbach), -209 (Gasser), fax -121.

Dr. H-J. Bender
Adam Opel AG, Technical Development Center Europe, 8061 Central Laboratory LBZW, Postfach 1710, D-65407 Rüsselsheim,
phone (++49) 6142/ 66-2407, fax -90759.

J.L. Perez
FAGOR EDERLAN S. COOP., Dept I+D, P.O. Box 10, E-20540 Eskoriatza,
phone (++34) 43 / 714200

Dr. R. Laag
Schäbische Huttenwerke GmbH SHW, Postfach 3280, D-73433 Aalen-Wasseralfingen,
phone (++49) 7361/50 -2235, fax -2669.

Techn. Dir. K. Jasnowsky
CETENASA, Division Laser, Poligono de Elorz sin, E-31I1O Noain-Navarra,
phone (++34) 48 / 31-2351, fax -7754.

Dr. G. Krummen,
Krauss Maffei Kunststofftechnik GmbH, Werkstofftechnik KT3W, Postfach 500340, D-80973 München, phone (++49) 89/ 8899-3449, fax -2950.

E. Munduate,
Tratamientos Termicos TTT S.A., R&D, Ctra. de Elgüieta s/n, E-20570 Bergara,
phone (++34) 43 / 76-4844, fax -5047.

J. Scholz,
Linde AG, Technische Gase, Seitnerstr. 70,82049 Höllriegelskreuth,
phone (++49) 89 / 7446-1429, fax -1659.

2 Abstract

Functional surfaces designed to withstand the imposed stress and strain are produced by means of laser surface treatment using additive materials. These layers are applied to new hollow steel camshafts (50% weight reduction in comparison with cast

iron camshafts), to aluminium brake disks (30% - 40% weight reduction in comparison with cast iron brake disks) and to extruder screws for plastic processing machines. Different layers adapted to the components are applied:

- Ledeburitic layers (layer thickness: 0,4 mm after finish grinding, hardness 650 ± 50 HV 0.3) were produced on rotary swaged hollow steel camshafts by alloying carbon into the material St 52-3 (unalloyed carbon steel, 0,16 % C).
- Wear-resistant surface layers on brake disks (AlSi alloy) were produced by alloying plasma sprayed layers into the surface. Layer thickness: 0,3 mrn after machining, hardness: 15 - 25 HRC, heat resistance: up to 400° C.
- Surface layers with a high molybdenum content were cladded on the flight lands of extruder screws. Layer thickness: 0,5 - 1 mm, layer width: 10-12 mm, Mo content: 41-63 %.

The work includes the characterization of the surface layers and the investigation of the operational properties, also in comparison with conventional processes. The layers as well as the processing technology developed in this project may be applied in many other industrial sectors as for aeronautic components, machine building components, forging, dyecasting and injection tools, road and railway vehicle components.

3 Introduction

Due to the measures to tighten emission regulations, such as the requirements for particle emission levels, the European passenger car and commercial vehicle industry requires new components for engine construction. Also the customers demand of a fuel consumption of 3 l/100km requires lighter car components and therefore with less environment contamination. To date, manufacturers have been compelled to select the materials for engine componenents and a whole range of plant construction components on the one hand in accordance with the requirements relating to the mechanical strain to which the basic material concerned is to be subjected and on the other hand in accordance with the required surface properties. A more suitable alternative, however, would be a material system consisting of a light, fully recyclable substrate material and a functional surface produced by means of an economic, environment-friendly surface-treatment process. This separation of the properties of the base material and the functional surface will enable a drastic reduction in the weight of the components. This applies in particular to components which are rotated, accelerated and decelerated, such as camshafts and brake disks, which were investigated here.

Camshafts are produced in mass production of cast iron. In the Iast years different production technologies as high pressure forming [1,2] and rotary swaging [3] ***were*** developed in order to produce hollow steel camshafts, resulting in weight reductions of up to 70% per camshaft [2]. Ledeburitic layers are known to have the best wear performance for camshafts [4], so that the rotary swaged hollow steel camshafts an a-lysed here (carbon content 0,16 mass%) have to be alloyed with carbon (up to 4 mass% C) using laser assisted processes. The cams have to be alloyed in a width of 13 mm over 360° and with a layer thickness of 0.4 mm in the finished state. The hardness of the layers should be > 50 HRC (≈ 500 HV).

The other light-weighted components related to are aluminium brake disks, which are manufactured in AlSi10. These components, which are usually manufactured in cast iron, are protected with a laser alloyed layer. This layer should have a layer thickness of 0,3 mm after machining, a hardness of 15-25 HRC and a heat resis-tance up to 400° C.

To show the broad range of applications for these laser assisted processes a different system subject to wear (worm/cylinder in plastic processing machines) involving a similar range of requirements was investigated. As the demands for plastic process-ing machines, especially extruder machines, are continuously tightened (higher out-put rate, addition of highly abrasive and corrosive components to the plastics), new protecting layers have to be developed. In this work, high Me-content layers are ap-plied to wear rings and to extruder worms segments. The layer thickness should be > 0,5 mm and the width 10- 12mm.

4 Technical description

In order to produce the different layers required for the different applications two different techniques have been applied:

1. In the case of the one-stage process (fig. 4. 1) a powder form additive is fed directly into the laser-induced melt pool via suitable supply systems.
2. In the case of the two-stage process (fig. 4.1) a preliminary coating is first applied to the surface and this is then subjected to laser radiation in a second operation.

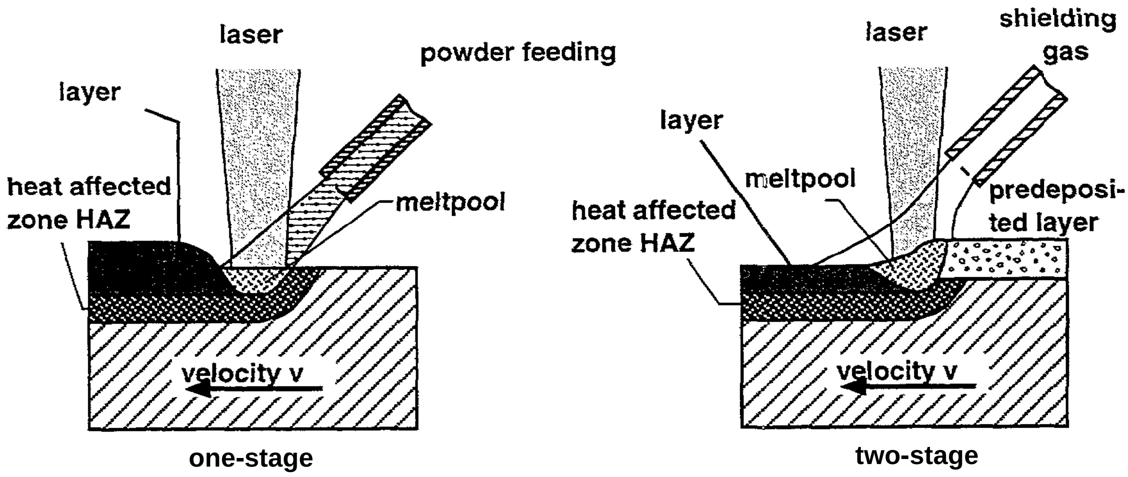

Figure 4.1: Schematic representation of the one- and two-stage process

All the layers were produced using CO_2-laser radiation (4 -7 kW). Experiments were performed on:

- low carbon steel tubes and rotary swaged camshafts (0,16 mass% C)
- flat samples and brake disks of aluminium of AlSi10
- on wear rings and extruder barrel segments of nitriding steel

The laser beam was focused either using a conventional focusing optic (Al brake disks, lens with focal lenght 127 mm) or using a beam integrating optic (camshafts and extruder worms) shown in fig. 4.2. The beam is shaped into a line form and re-imaged with an elliptic mirror. A burn-in in plexiglass showing the intensity distribution can also be seen in figure 4.2. The intensity distribution can be changed in a wide range by changing the parameters A and L (see fig. 4.2).

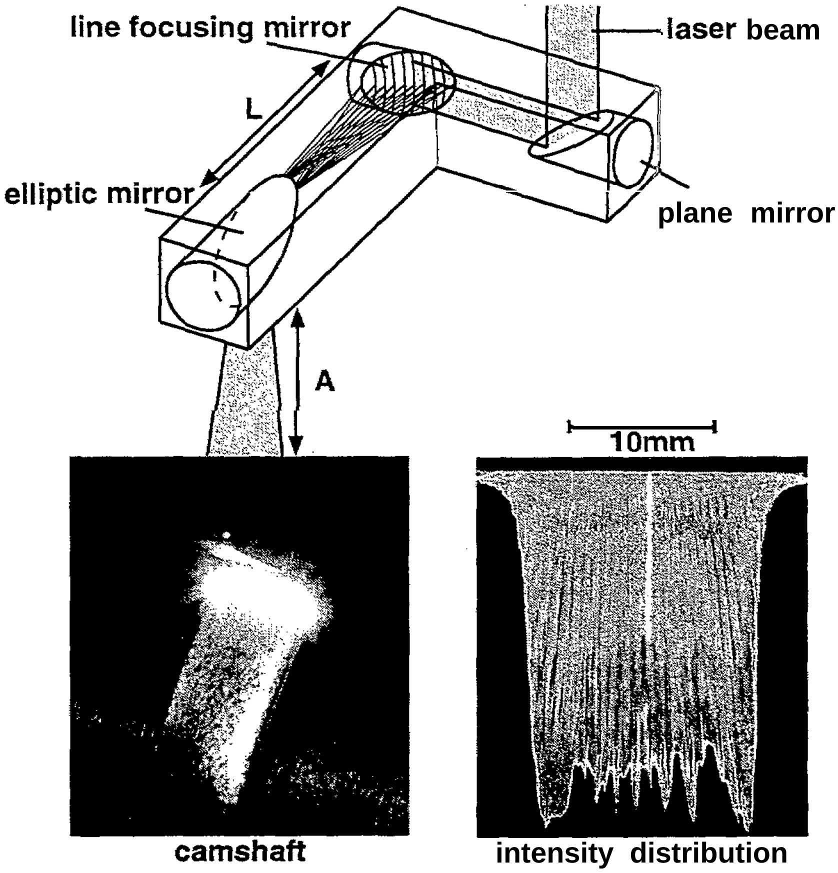

Figure **4.2:** Beam integrating optic and plexiglass burn-in

Different additive materials were applied for the different applications:

- Steel camshafts

  Graphite powder for the one-stage-process and different techniques for applying layers for the two-stage process [replacing of graphite-foils, Carboflam (oxygen-acetylene flame) layers and glue spraying with graphite powder) were tested.

- Aluminum brake disks

  Plasma sprayed layers (Ni-base and Me-base alloys, WC/Co, Cr_2O_3, Cr_2O_3/Ni5Cr) were used for the two-stage process, especially 75M0 4,25Cr 0,8B 1Fe 0,2C Ni.

- Extruders

  50%, 60% and 70% Me-alloy powder for the one- and two-stage(plasma sprayed layers,) process were tested.

The different layers were analysed (light microscopy, SEM, EDX, hardness). Wear tests were made for the aluminium brake disks and for the wear rings simulating the extruder wear performance.

5 Results

5.1 Steel camshafts

All applied techniques (one- and two-stage process) delivered ledeburitic layers. Best results were achieved with the glue spraying technique. 'I'he additive material is a liquid mixture of a binder, water and petrocoke. The mixture can be glue-sprayed to the surface by a commercial available spray gun. The workpiece is preheated to temperatures between 100-180 "C to vaporize the water and most of the binder during the spraying process. The adhesion between the sprayed layer and the base material is given by a special component of the binder which is decomposed without residues at higher temperatures. Typical layer thicknesses vary between 0,05 - 1 mm. The most important advantages of glue spraying are:

- no thermal influence of the additive material
- homogeneous layer thickness
- low binder content in the sprayed layer
- applicable to constrained positions (e. g. inner contours)
- The layer thickness was measured with a magnetic-inductive measurement device, which is capable to measure a graphite layer from 1 µm -1250 µm thickness with an accuracy of ± (1 - 3 % + 1 pm) . Figure 5.1 shows the measured layer thickness and the mean variation (average value for 11 cams) over the cam at four different positions for a spraying time of $t_s = 75$ s and a spraying distance of 200 mm to the surface of the base circle. In previous experiments an optimun thickness of 600*50 µm was found in order to alloy the steel into a depth of 0,8-1mm. Thicker layers lead to more carbon in the alloyed layer, but no formation of primary cementite was observed for layers up to 800 to 900 µm thickness. As can be seen in figure 5.1, the top of the cam shows too less thickness (position 2). Due to the fact that the camshaft is rotated with a constant number of revolutions, the velocity at the top of the cam is higher than at the base circle, leading to less layer thickness. This problem was solved by spraying the top 3 to 5 s longer than the rest of the cam.

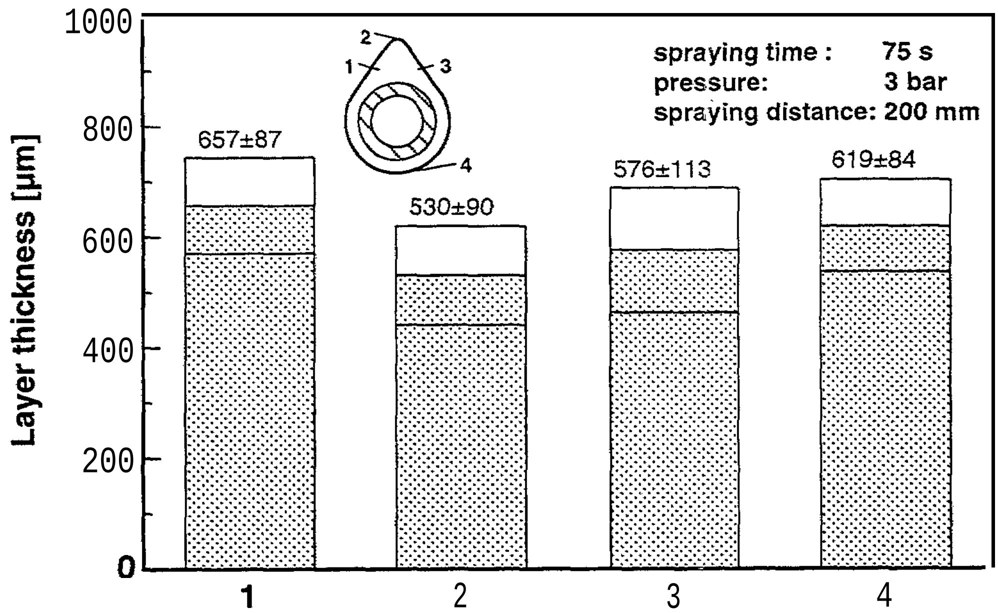

Figure 5.1: Average thickness of the glue sprayed layer on a cam at four different positions

The glue sprayed camshafts were alloyed with the optic shown in figure 4.2. The experimental setup is shown in figure 5.2.

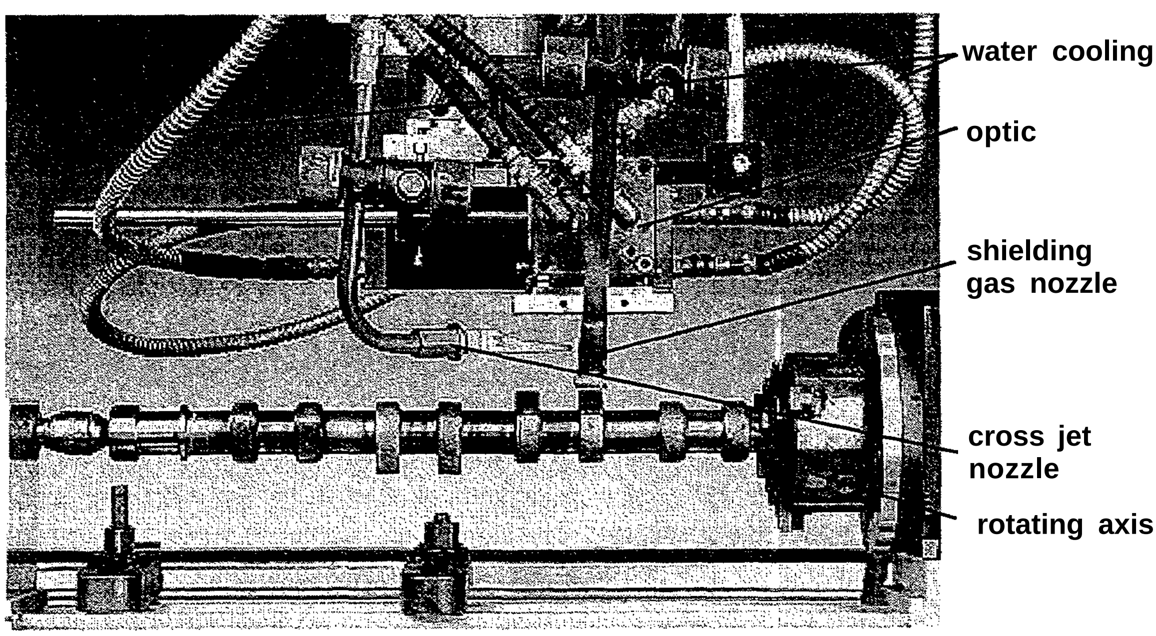

Figure 5.2: Experimental setup for alloying camshafts

A detail of the alloyed camshaft is shown in figure 5.3

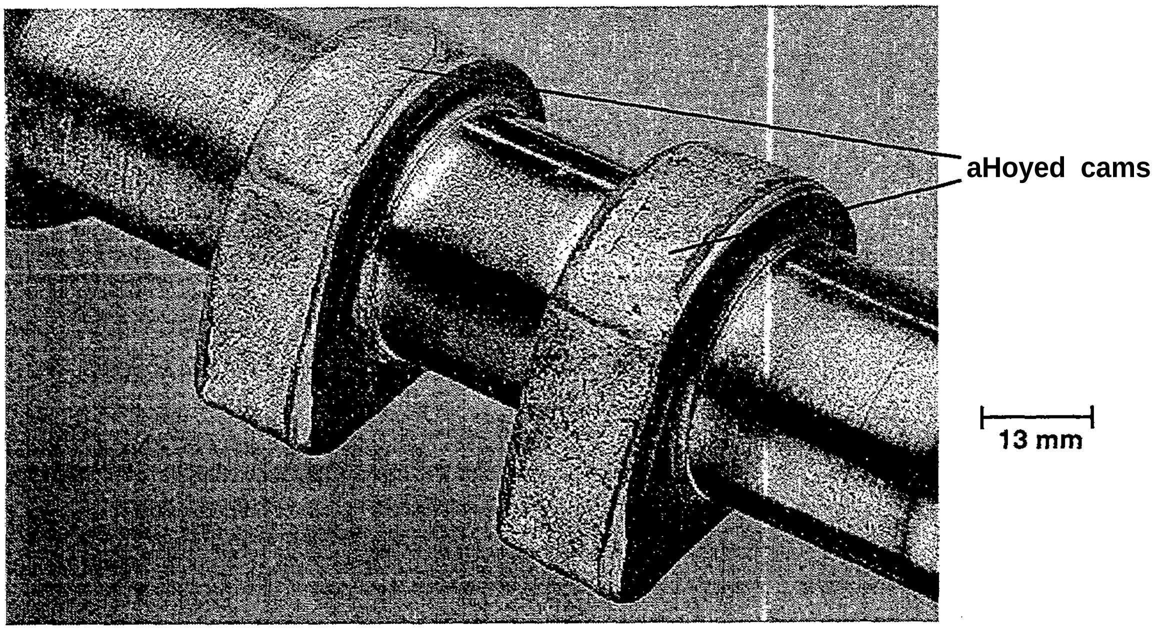

Figure 5.3: Detail of an alloyed camshaft

The cams were cut perpendicular and longitudinal in order to analyze the melting depth, the microstructure and the hardness of the layers. The melting depth was measured at several points of the longitudinal cross section, according to figure 5.4. A cross section was prepared at the angle 140°.

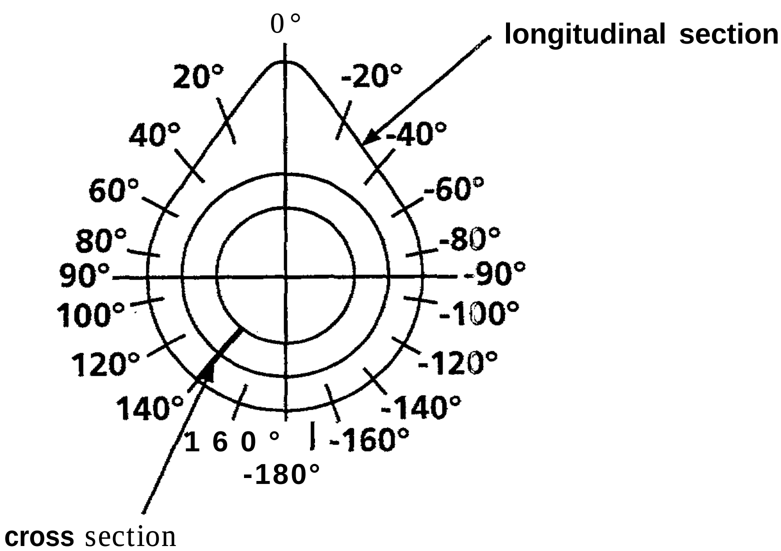

Figure 5.4: Definition of the measurement points on the longitudinal and transversal cross section of the cam

Basically four microstuctures could be identified (***figure*** 5.5) and were classified as follows:

- Microstructure (l), where the carbon content is to low to produce any ledeburite. This layer contains martensite.
- Microstructure (2), with some amount of ledeburite and the rest martensite.
- Microstructure (3), where the ledeburite content goes up to pure ledeburite
- Microstructure (4), where the cm-bon content exceeds 4,3 mass% and prymary cementite with ledeburite is observed.

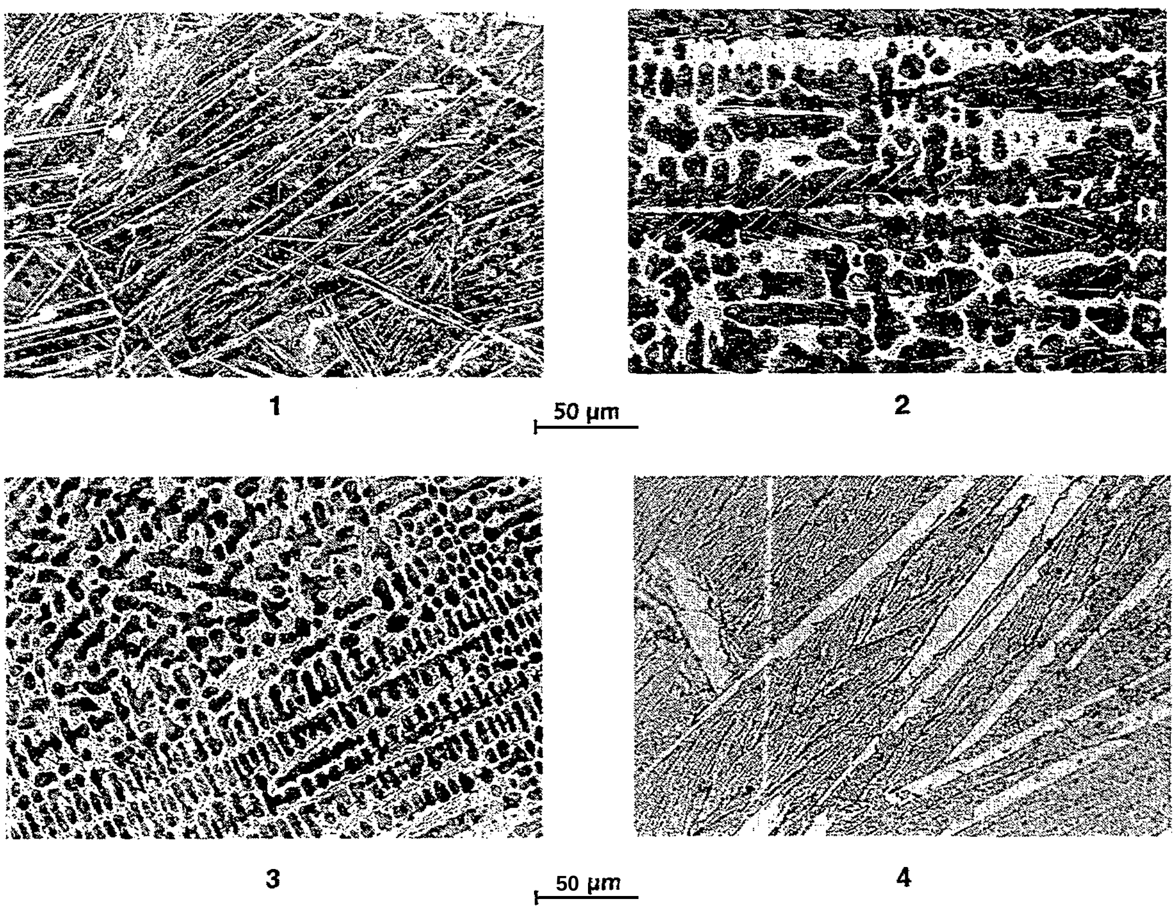

Figure 5.5: Classification of the different microstructure observed

The parameters [laser power, beam size, velocity, displacement of the beam from the rotating axis) were changed in order to produce microstructure of the type (2) and (3) all over the cam. Figure 5.6 shows the results when starting the experiments on the cams and after adapting the parameters. Figure 5.6 shows, that it is possible to alloy the whole cam with a layer thickness ≥ 0,75 mm and a microstructure (2) to (3). Figure 5.7 shows a longitudinal and a cross section of an alloyed earn as well as the microstructure produced. The average hardness for this layer is 650*50 HV 0.3.

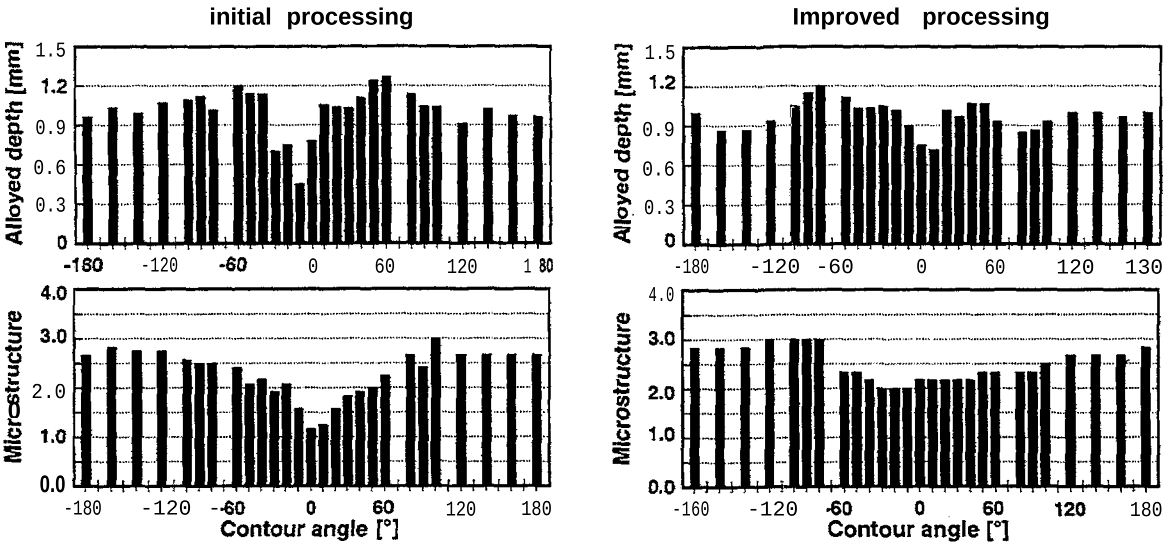

Figure 5.6: Melting depth and microstructure produced when starting the experiments and after adapting the parameters (average values)

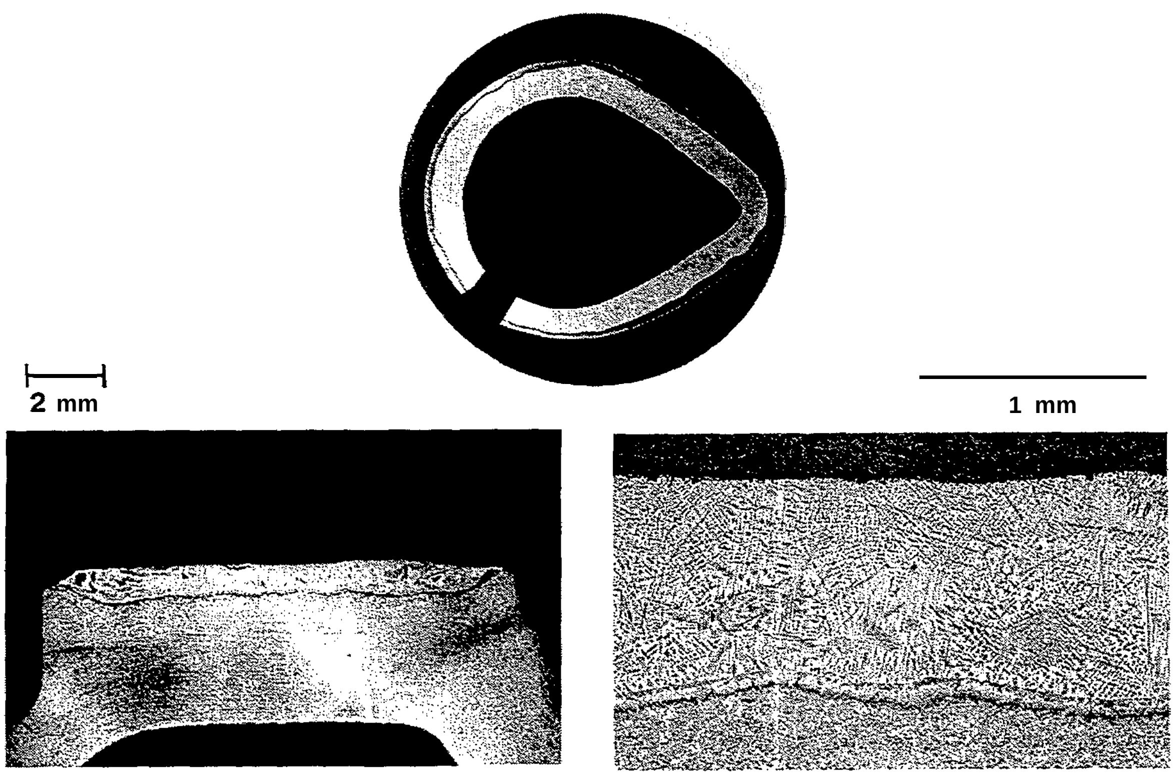

Figure 5.7: Longitudinal and cross section of an alloyed cam and corresponding microstructure

Prototype camshafts were produced and laser alloyed. After finish grinding some defects like pores, non alloyed material in the overlapped region and dimensional imperfections were observed. The dimensional imperfections are related to the rotary swaging manufacturing process and needs to be improved in order to fulfill the demands for an engine test. The porosity is not considered critically for the engine tests and the nonalloyed regions can be avoided by optimizing the handling of the camshaft. Engine tests at Opel are planned for the near future.

5.2 Aluminium Brake Disks

Brake disks of small sized, low-to-medium performance cars were manufactured in AlSi10. Best results for the laser alloying process were achieved by applying a plasma sprayed layer of 0,1 mm thickness of 75M0 4,25Cr 0,8B lFe 0,2C Ni and then alloying the sprayed layer into the aluminium with laser radiation.

Different processing techniques were used in order to reduce the distortion of the brake disks to a minimum possible:

1. Alloying the complete side of a disk, track by track, stopping at the end of each track. This strategy was working from the outside diameter to the inside diameter.
2. Alloying the complete side of a disk, using a spiral from the outside diameter to the inside diameter.
3. Alloying one track on a disk, turning the disk over and alloying another track on that side, just under the earlier alloyed track, etc. This strategy would be working from the outside diameter to the inside diameter.
4. Same strategy as in number 3 but working from the inside diameter to the outside diameter.

The best results were achieved by alloying one track on a disk, turning the disk over and then alloying another track on that side (3 and 4). With this technique a deformation of the brake disks between 0,1 - 0,2 mm was achieved. Figure 5.8 shows a laser alloyed disk and a detail of the disk.

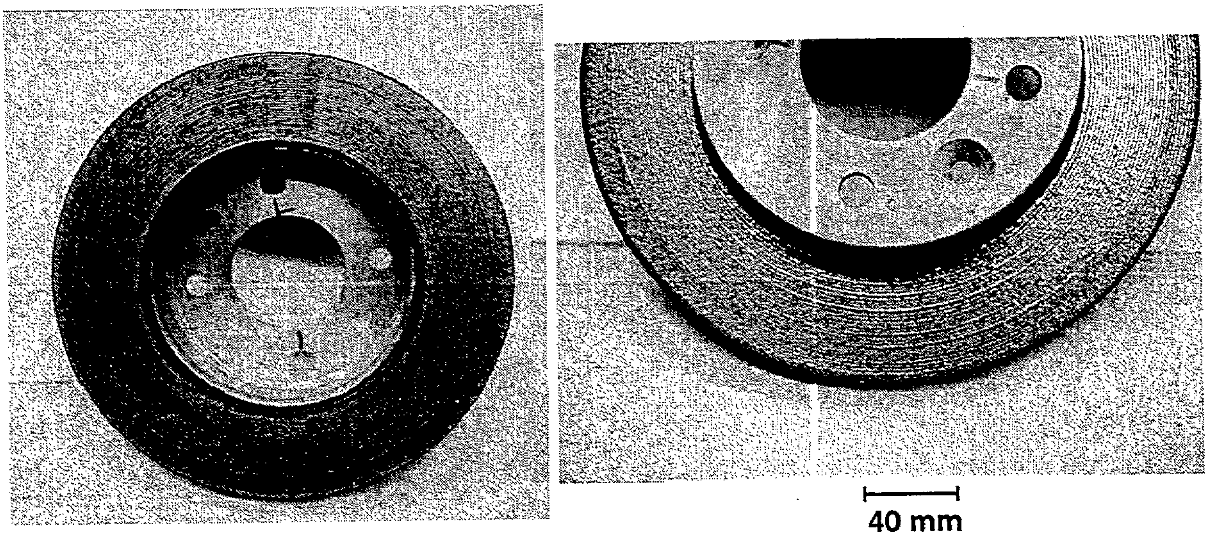

Figure 5.8: Laser alloyed Al-brake disk

Figure 5.9 shows a cross section of the alloyed layer. The alloyed layer has a thickness of approx. 0,5 mm.

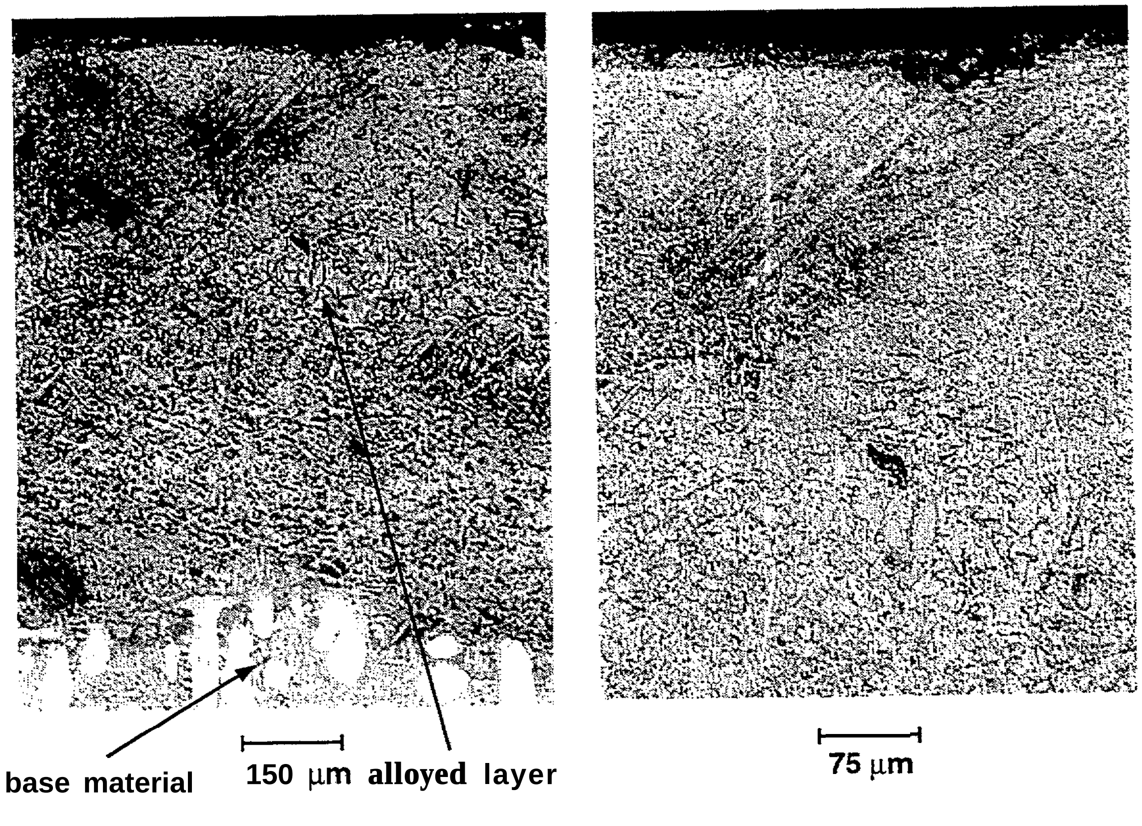

Figure 5.9: Cross section of a laser alloyed brake disk at different magnifications

The hardness of the layer shown in figure 5.9 is shown in figure 5.10. The hardness fluctuates between 200- 250 HV to a depth of 0,5 mm. This is similar to the hardness of cast iron (200 HV), and three to four times the hardness of the base material (60 HV).

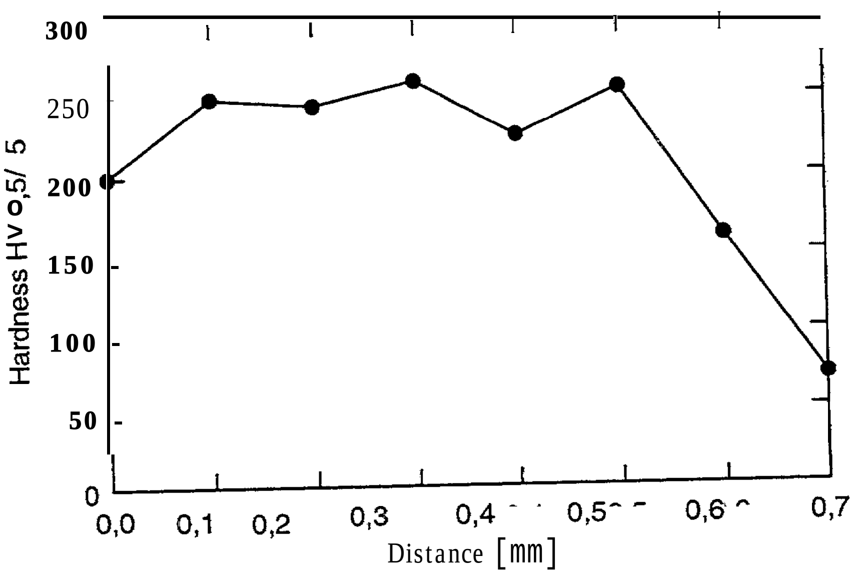

Figure 5.10: Hardness distribution for the alloyed layer shown in figure 5.9

Figure 5.11 shows a laser alloyed disk after final machining, previous to brake dynamometer tests.

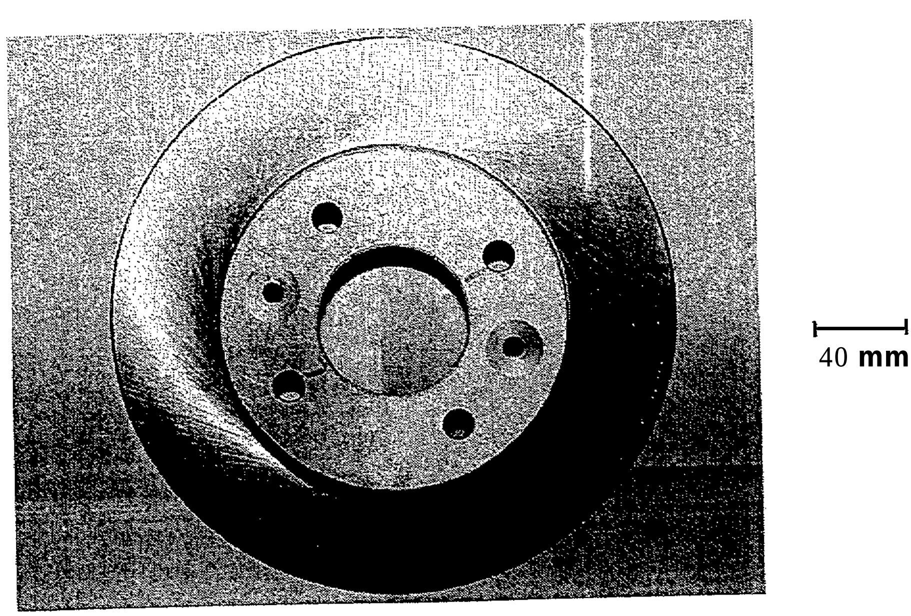

Figure 5.11: Laser alloyed disk after final machining

Application oriented tests on a brake dynamometer showed that the results are not as good as those of cast iron brake disks. Disk wear was higher than predicted by pin-on-disk tests results. This difference may be due to the fact that more alloyed layer had to be machined away for the brake tests than what was first expected. Reducing the disk deformation by changing the design of the disks (thicker rotor disks) could lead to better wear performance.

5.3 Extruders

Wear investigations were carried out on an injection moulding machine from Krauss Maffei, which had been modified to represent an annular slit tribometer [5]. Figure 5.12 shows as an example cross sections of a one-stage and two-stage layer on a wear ring with the 70 % Me-alloy.

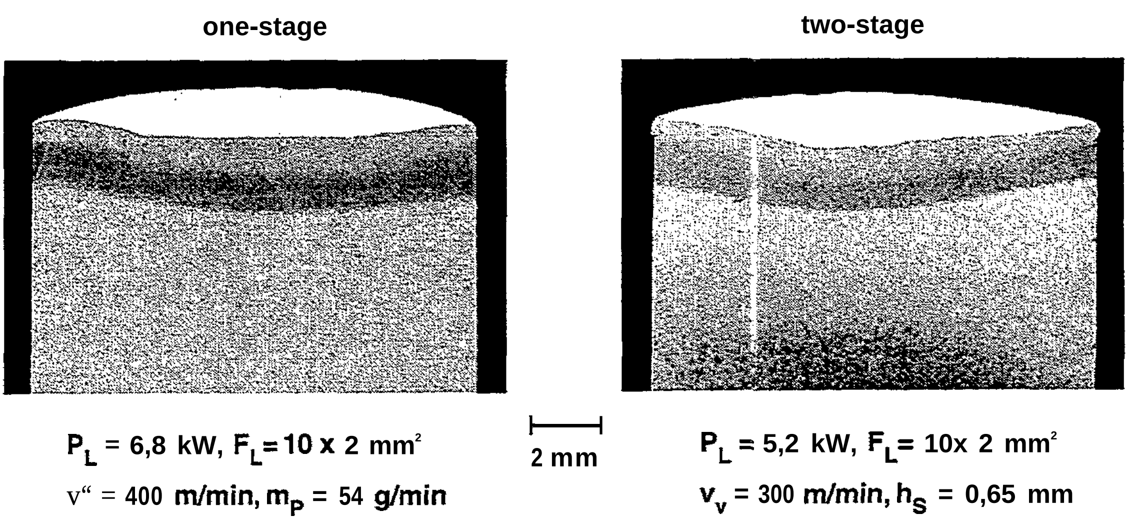

Figure 5.12: Cross section micrographs of a one- and two-stage layer (70% Mo)
P_L: laser power, FL: beam geometry, v,: velocity, m_p: powder flow rate
hs: thickness of the plasma sprayed layer

The slower velocity of the two-stage process leads to a higher heat input resulting in higher dilution. Also the microstructure are different, as shown in figure 5.13. The spheres which can be seen for the one stage process are pure molybdenum, which did not solve during the cladding process. In the two stage process almost all particles did solve due to the higher heat input necessary to remelt the plasma sprayed layer.

The shown differences between the one and two-stage process are similar in all treated samples. The resulting microstructure and hardness depend strongly on:

- the interdilution of the clad alloy with the base material
- the solving of the pure molybdenum particles

After adapting all parameters (laser power, velocity, dimensions of the beam) several wear rings were cladded with the one- and two-stage process (60 and 70% alloy).

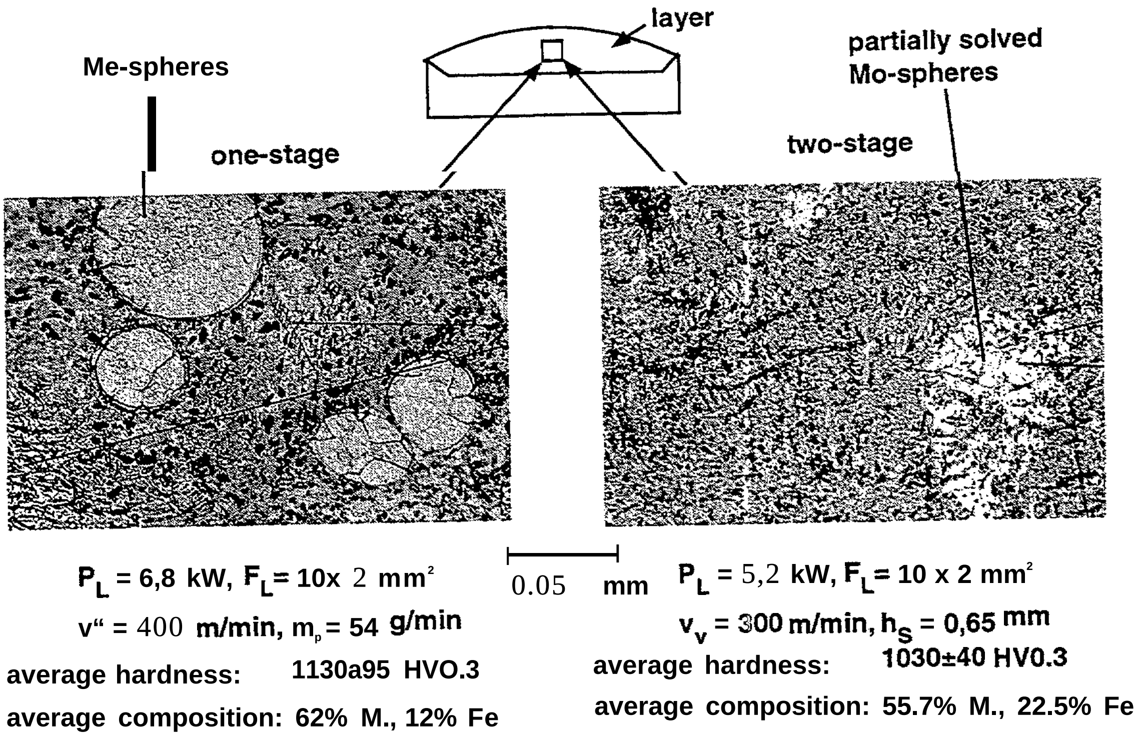

Figure 5.13: Microstructure of the layers shown in figure 5.12
P_L: laser power, FL: beam geometry, v_v: velocity, m_p: powder flow rate

The microstructures of the layers were analysed with light microscopy as well as electron microscopy (SEM, EDX). One example of a SEM micrograph is shown in figure, 5.14 for a two-stage cladded 70 % Me-layer.

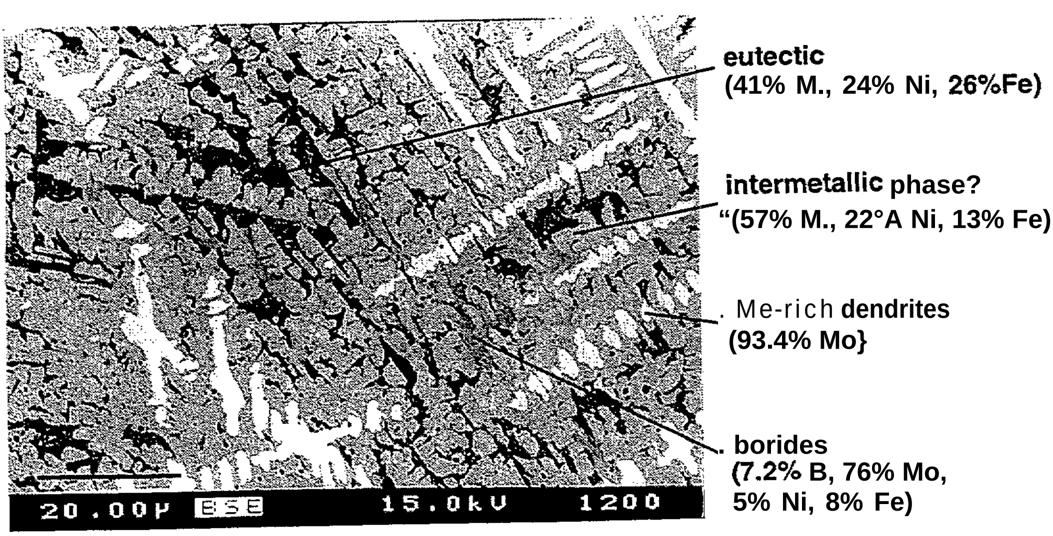

Figure 5.14: SEM micrograph for a two-stage cladded 70% Me-layer

The detected phases are rich in Molybdenum (white phase almost pure Mo (93,4%), grey phase 57 % Mo, eutectic 4170 Me). Depending on the process (one- and two stage) and on the processing parameters up to 6 different phases per layer were detected such as iron rich phases and borides (see figure 5.14). The iron content is higher for the two-stage process, as expected from the higher dilution with" the base material, see table 5.1.

iron content in mass%		
	near the surface of the layer	in the middle of the layer
one-stage process	1-13	3-21
two-stage process	6-36	16 -38

Table 5.1.: Average iron content of the layers for the one- and two-stage process (60% Mo and 70% Me-alloy)

The averaged molybdenum content for different samples were correlated with the average hardness of these samples as shown in figure 5.15.

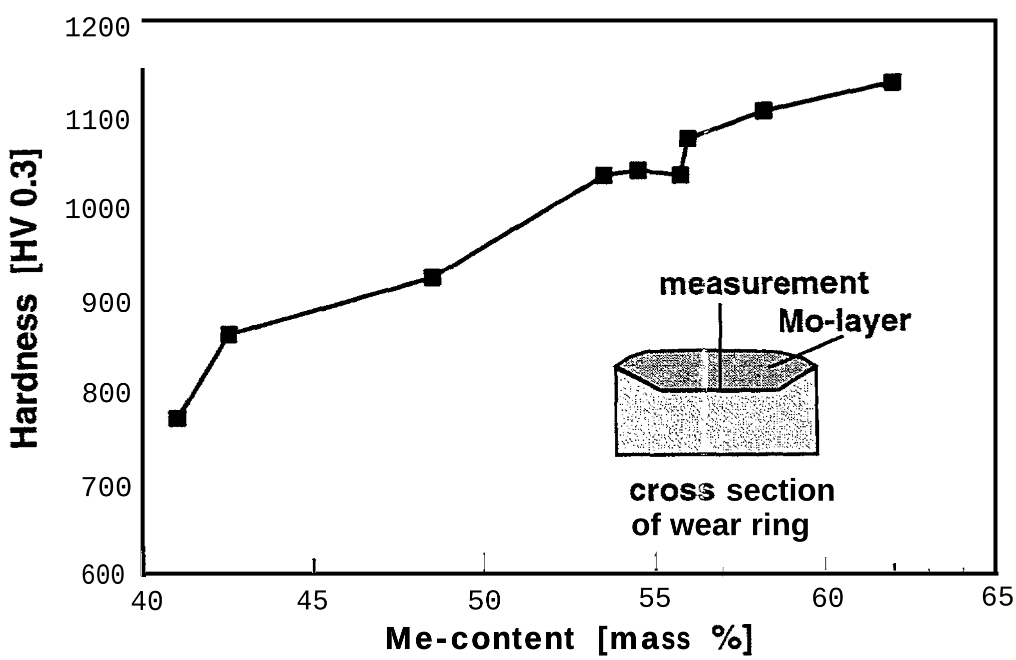

Figure 5.15: Average hardness as a function of the average Me-content of the different cladded layers (60% Mo and 70% Mo-alloy, one- and two-stage process)

The hardness depends almost linearly from the Me-content. Hardness values between 775 HV 0.3 and 1125 HV 0.3 were achieved for Me-contents between 41% and 63%, depending on the Me-content of the powder and the processing parameters.

Figure 5.16 shows a section of an extruder screw cladded with the one step process and the 70% Me-alloy, showing that the results could be transferred to real components.

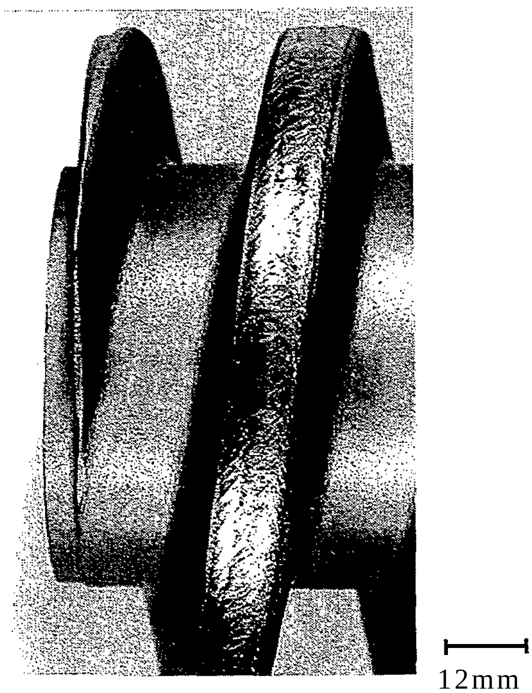

Figure 5.16: One-stage cladded part of an extruder screw

By way of summary, figure 5.17 documents the wear-performance of the investigated wear-resistant molybdenum coatings (simulation of extruder screws), as a function of the wear-path, with the following results:

. The best wear resistance is shown by a protective alloy of 70 % molybdenum content applied by the one-stage and two-stage process.

. Compared to the plasma transferred arc (PTA) clad with an 50 % molybdenum alloy, the one- and two-stage layers with a 60 % molybdenum alloy show a decidedly better wear-resistance.

. The one-stage wear-resistant layer of 60 % and 70 % molybdenum content and the two-stage wear-resistant layer of60 % and 70 % molybdenum content are similar in performance.

- The wear of the internal rings can be reduced by 40% for the 60% Mo-alloy and by 60% for the 70% Mo alloy.

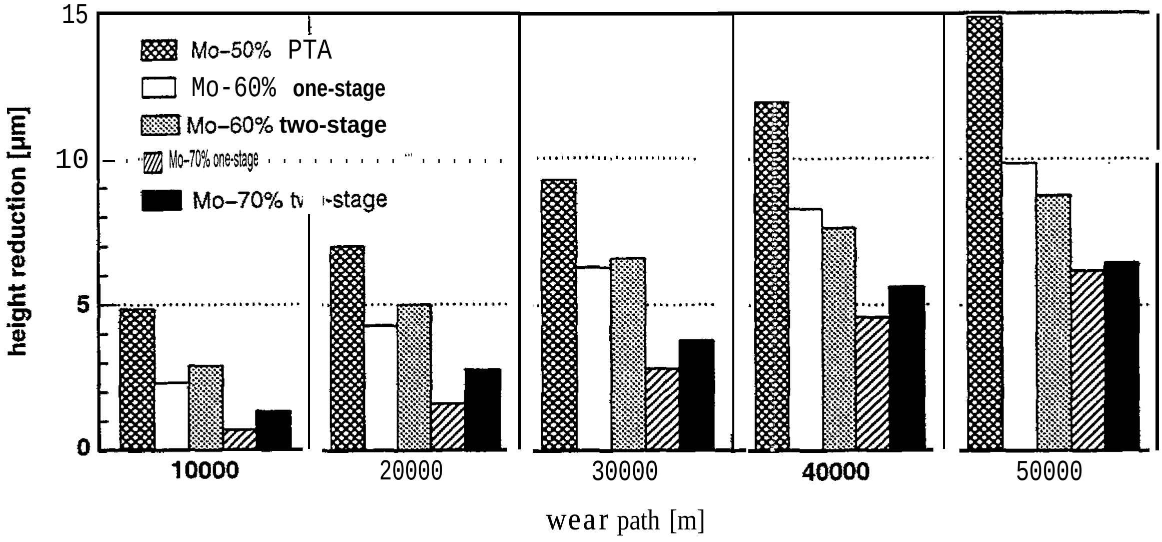

Figure 5.17: Summarizing diagram showing the performance of the wear-resistant alloyed layers investigated (internal rings)

Figure 5.18 shows the wear-performance of the external rings (extruder cylinder wear simulation) as a function of the investigated wear-protective layers of the internal rings, after a test period of 15 hours (actually achieved wear-path 50.000 meters). Compared to the external ring, which had been tested against an inner ring of PTA 50 % molybdenum, those external rings, that were tested against internal rings of one-stage applied layers of 60 % and 70 % molybdenum-alloy, as well as the two-stage layers of 70 % molybdenum-alloy show a poor wear performance.

The wear of the external ring tested against an internal ring with a two-stage layer of 60 % molybdenum-alloy on the other hand shows a clearly better wear-resistance with regard to the external ring tested against the inner ring of a PTA layer of 5070 molybdenum-alloy.

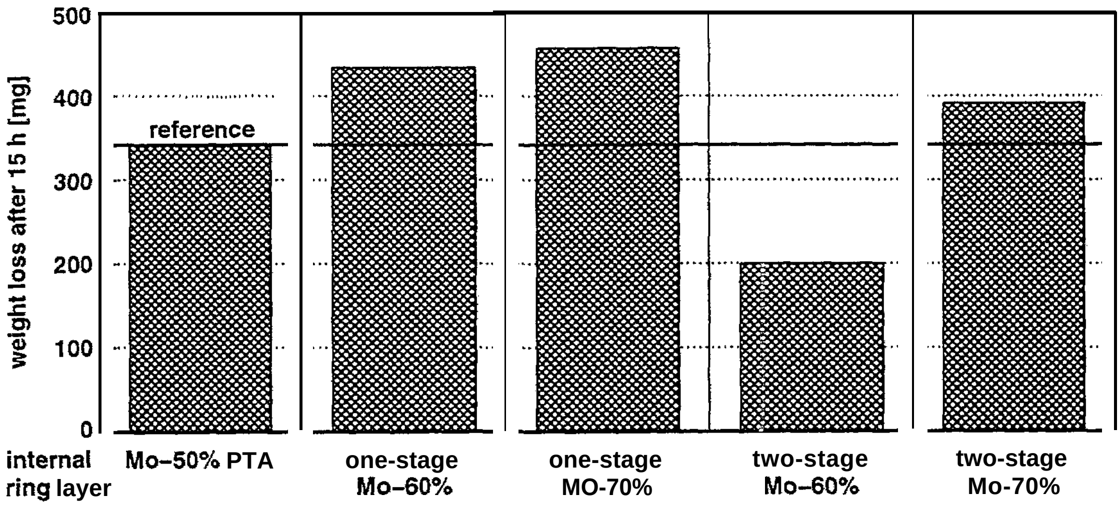

Figure 5.18: Wear on the external rings for different protective layers in the internal rings (15 h testing correspond to 50000 m wear-path lenght)

6 Conclusions

The main results that were obtained are:

6.1 Steel camshafts

A completely new rotary swaged steel camshaft was developed. The rotary swaging technology, which was originally developed for rotationally symmetrical parts, was combined with a pressing technique to achieve a non-rotationally symmetrical camshaft. The achieved weight reduction is about 50% compared to cast iron camshafts. This reduction in weight should result in a reduction in the consumption of gasoline.

A completely new technique to alloy a three dimensional part like a camshaft using a two-stage process (first: application of a carbon layer with a spraying technique, second: remelting of the layer with laser radiation) was developped.

Ledeburitic layers with a thickness of 0,4 mm after finish-grinding and a hardness of 650 ± 50 HV were achieved. The processing time for one cam is approx,. 75 s for the glue spraying and approx. 30 s for the laser alloying, using a laser power of 4 -6,4 kW (CNC controlled).

The wear performance of the camshafts has to be proved in engine tests.

6.2 Aluminium brake disks:

Production of a brake disk that was aproximately 30 to 40% lighter than current cast iron brake disks. This reduction in weight should result in a reduction in the consumption of gasoline in a vehicle.

A new technique to alloy a brake disk using a two-stage process (first application of a plasma sprayed layer of 75M0 4,25Cr 0,8B lFe 0,2C Ni, second: remelting of the layer with laser radiation) was developed.

- Alloying of aluminium brake disks using CO_2-laser radiation has been achieved, delivering alloyed layers of approx. 0,5 mm thickness and a hardness of 200-250 HV with a deformation less than 0,2 mm.

concerning laser alloyed plasma sprayed disks, both wear and crack resistance are far better than those from plasma sprayed layers only, but at present remain lower than cast iron brake disks performances.

6.3 Extruders:

- High Me-content layers for extruders were developed, containing 41-63 mass% molybdenum. The wear performance of the new laser cladded layers is up to 60% better than the plasma transferred arc (PTA) layers used at the moment in production.

The cladding technique for extruders was developed, especially the processing technique to clad tracks with a width of 12 mm and a thickness of 1 mm in one track.

7 Acknowledgments

All the participants would like to thank the support of the European Community through the BRITE/EURAM programme (Contract Number: BRE CT 920306, Proposal Number: 5825).

8 References

[1] Mücke K., Innenhochdruck-Umformen in der Serienfertigung. In: Blech, Rohre, Profile 42 (1995) 1, S.17-20.
[2] Fertigungstechnik / Neue leichte Welle. In: Wirtschaftswoche Nr. 26 (1995), S. 117.
[3] Company leaflet of SHW-GmbH, D-73414 Aalen
[4] Hamazaki M, Laser surface hardening of automotive cams. In: Welding Interna-

tional 19959 (2), S. 158-162.

[5] Montag P., Verschleißminderung an Extrudern. In: Abschlußbericht zum Forschungsthema: Verschleißschutz in Kunststoffaufbereitungsmaschinen mit neuen Werkstoffen, DKI Darmstadt, 3.11.1994, S. 46-47.