PART I

Processing

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RECENT DEVELOPMENTS IN LASER SURFACE TREATMENT

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ABSTRACT

Some unrelated examples are given where progress has been made in laser surface treatment in the last few years. These are large scale transformation hardening, reproducible surface melting of cast iron, surface alloying with a reaction with the surrounding atmosphere, fundamental studies of solidification and evaporation cleaning.

INTRODUCTION

Developments in laser technology and in manipulating techniques as well as computer technology have resulted in systems being available for a wide range of surface treatments. The highly localized heat source enables non equilibrium conditions to be achieved. Required microstructures can be produced, enabling tailor making of components with desired surface properties. The types of surface treatment can be subdivided into the classes surface modification, solid state (eg martensitic transformation) and surface melting as shown in Table I.

TABLE I: Types of Surface Heat Treatment

Treatments without melting	Treatments with melting
Rapid homogenization	Simple melting (finer structure, supersaturation)
Transformation hardening (Martensitic transformation)	Refinement by evaporation of impurities Surface alloying Injecting particles into surface (Alloy hard metals)
Surface annealing	Cladding (thick hard metal coatings)

Each of the applications relies on the specific features of laser treatment ie rapid heating and homogenization and subsequent self quenching. In transformation hardening the rapid quench produces a martensitic structure in the surface which improves wear and fatigue behaviour. In other applications the desired properties are achieved by homogenization of the surface layer by producing a single phase or finely divided microstructure (eg corrosion) or by surface softening (eg increasing ductility for thread rolling) or by changing the composition of the surface or by dispersion/precipitation hardening (eg internal oxidation or nitriding).

Some applications of lasers are discussed in the following with examples of where new developments have recently taken place either in the handling enabling better reproducibility and higher quality of existing techniques or in new applications.

SOLID STATE TRANSFORMATIONS

Laser hardening has been used successfully to harden a variety of steels [1,2,3], see Table II.

TABLE II: Materials and components hardened by lasers in commercial processes

Component	Material
Steering Gear Housing	Ferritic malleable iron
Camshafts and Camfollowers	Ferritic, pearlitic and bainitic SG iron
Mineral Sieves	Bainitic SG iron
Motor Blocks and Cylinders	Cast iron
Motor Shaft Splines	AISI 1050 steel
Cutting Blades	AISI 1050 steel
Firing Zone Cutout Cams	AISI 4340 steel
Electric Razor Cutter Combs	0.7 % C steel

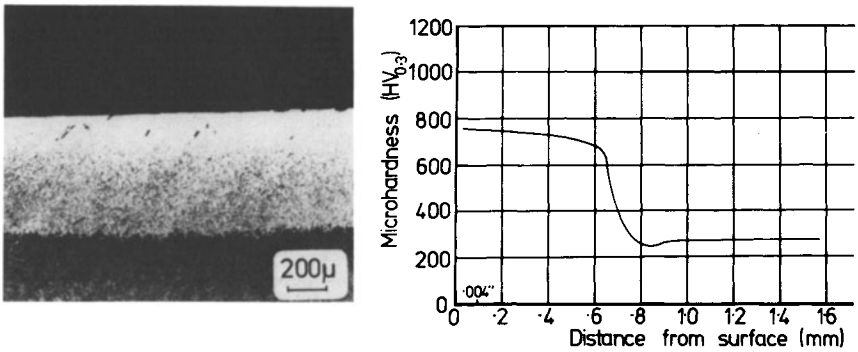

Fig. 1: Typical micrograph with corresponding hardness profile, En8 (1.0503, AISI 1043)

A typical micrograph is shown in Fig. 1, together with the corresponding hardness profile. The effort in recent times has been devoted to harden reproducibly large surfaces without overlapping effects which can lead to tensile residual stresses and possibly cracking. One method of reducing the cracking problem is to increase the effective track front so that instead of a narrow track a wide strip is treated. This can be achieved by beam shaping eg via beam integrators, wobbling mirrors or more elegantly with slit shaped beams, as is available in the Heraeus laser. A typical laser system is shown in Fig. 2. The table is capable of supporting components up to 100 kg in weight.

A problem of laser hardening in production has been the variable absorption by the workpiece. To overcome this colloidal graphite coating has been used thus enabling a very high degree of reproducibility as demonstrated by Dausinger [4] who hardened and tested 40.000 set screws. A further development has been the treatment of very large components, see Fig. 3. Such components could not be treated previously and inherently suitable materials had to be used. Laser hardening is not required over the whole surface - a supporting hardened surface is produced. This reduces total wear.

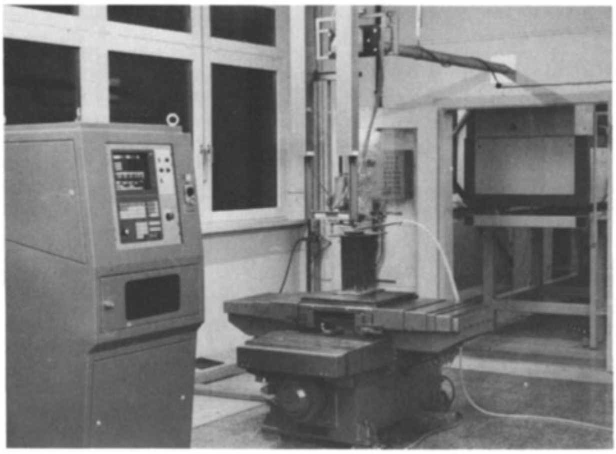

Fig. 2: 5 kW Heraeus Laser and Manipulator
Computer control of five translations/
rotations possible

Fig. 3: Laser hardened diesel cylinders
750 mm id., MAN München photograph

Another form of solid state transformation is homogenization and retention of the homogenized phase on rapid cooling. An example of this is the production of a homogeneous surface on Zircalloy thereby preventing selective corrosion by the dispersed phase. The laser treatment produces very thin layers without distortion unlike other methods. The hardness and strength in depth is retained.

The advances in the field of transformation hardening have been therefore in the reproducibility of the treatment, size of components treated and range of applications.

LASER MELTING

Laser melting of metallic surfaces enables a rapid and directional solidification of the liquid phase [5]. Depending on the composition and melting conditions different solidification morphologies are obtained [6]. A progressively finer and finer structure and ultimately amorphous solidification is observed with increasing quench rate. Two examples of this, iron-boron and iron-carbon-silicon alloys are given to demonstrate the principle.

Iron-Boron Alloys

It is now possible to devise a solidification map showing the structure produced as a function of composition and solidification rate for a constant temperature gradient (Fig. 4,5).

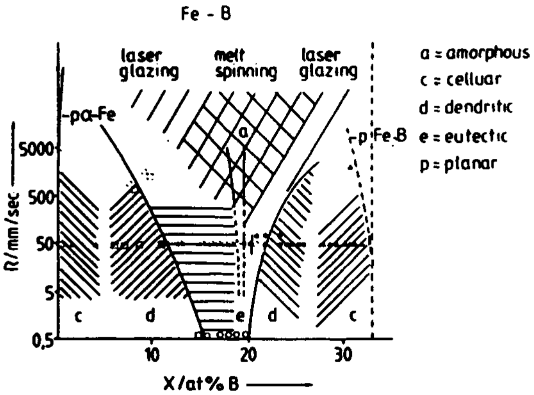

Fig. 4: Solidification map

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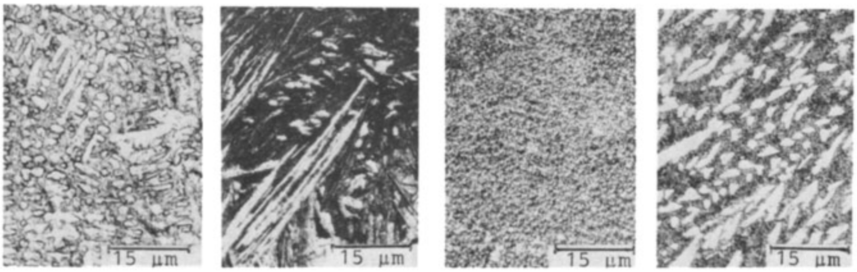

Fig. 5: Microstructure from which Fig. 4 was constructed
a) dendritic b) acicular eutectic
c) $Fe_{23}B_6$ d) Fe_2B dendrites + eutectic

On the iron rich side the limited solubility of boron in iron is hardly increased by rapid quenching. At low boron contents the structure is cellular; on increasing the amount of boron a transition to first dendritic, then feathery and acicular eutectics is observed. Within a composition range of 19-20,5% B $Fe_{23}B_6$ appears. Still higher boron contents result in a reappearance of dendritic and cellular structures, this time the primary phase is Fe_2B. The effect of increasing the quenching rate is to displace the boundary between the various structures. At sufficiently high rates amorphous solidification is observed. In the transition region metastable Fe_3B is observed.

Iron-Carbon-Silicon Alloys

If the composition is maintained constant and the solidification velocity and thermal gradient varied, different microstructures can be produced. Fig. 6 shows the variation of solidification mode with temperature gradient and solidification velocity for the alloy Fe3.5%C2%Si. It can be seen that a change in the G/R-ratio leads to macrostructural changes whereas changes in the quenching rate modify the degree of refinement.

Improvements to laser and manipulative devices has enabled a better control of the microstructures obtained and hence properties.

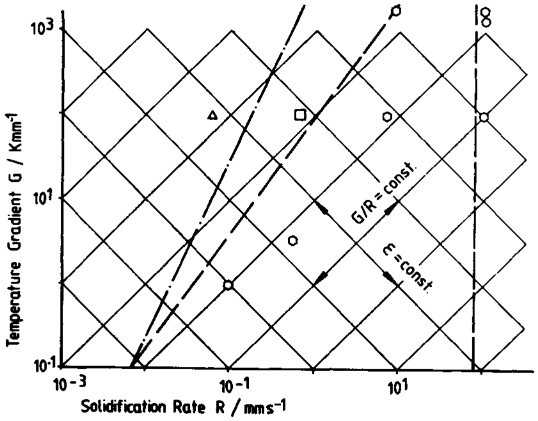

Fig. 6: Variation of the solidification mode
□ cellular ○ planar, single phase
○ dendritic △ planar, two phase

Surface Melting of Cast Iron

Surface melting of iron base alloys has been carried out successively in the past. It was shown that non metallic inclusions in the surface layer of steels could be rendered harmless by surface melting when they reprecipitated in an extremely fine form or even evaporated. The rolling wear fatigue properties could thus be improved dramatically [6].

Surface remelting of cast iron components for the automobile industry (Fig. 7,8) has now been optimized to a high degree and better service properties have been observed. Laser treatment is distortion free and can produce shiny, crack and pore free surfaces with a roughness of typically ± 5 µm. This high quality was only possible by specifying the nature, composition and microstructures of the cast iron, for example the quantity, size and morphology of graphite. Elements which affect the hardenability must be known to enable a proper choice of the laser parameters. Irons containing only traces of Cr, Mo, Ni etc. can be remelted crack free without preheating while with 1 to 2% of the alloying elements they must be preheated to 300 - 400°C. Some elements from the moulding sand are also found in the surface regions of a casting and can cause pores or affect the plasma formation.

Control of these parameters has lead to laser treated components with a life four times longer than hitherto with TIG, chill cast iron or ZrO_2 plates [7].

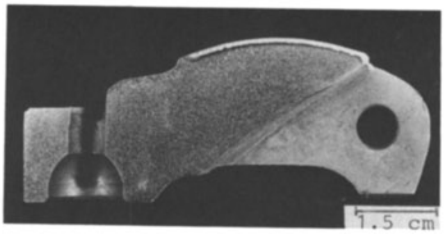

Fig. 7: Camfollower

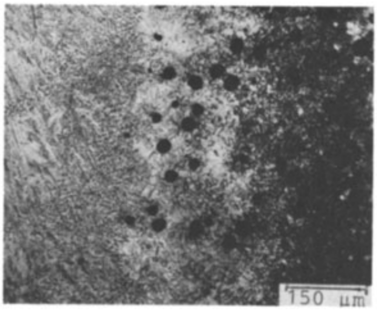

Fig. 8: Microstructure of above camfollower

SURFACE MELTING WITH BASEOUS ALLOYING

Internal Oxidation of Silver Base Contact Alloys

Silver base contact alloys are normally produced using powder metallurgical techniques. The requirement is an alloy contact which on the one side can be soldered but on the other contains oxide to prevent welding during switching. Such oxides make soldering difficult. Recent work has shown that it is possible to cause a surface to react with the surrounding atmosphere by heating it with a laser. This has been exploited for carburizing iron base alloys and carburizing and nitriding of titanium alloys. In this present application the laser is used to heat the surface in oxygen thus inducing internal oxidation.

Fig. 9 shows an X-ray microprobe distribution map for Sn in an AgSn alloy. The tin is homogeneously distributed in the matrix and in the surface the tin level is generally low but peaks are observed associated with the formation of tin oxide [8].

Internal oxidation is a very interesting extension of gas alloying with some promising technical applications.

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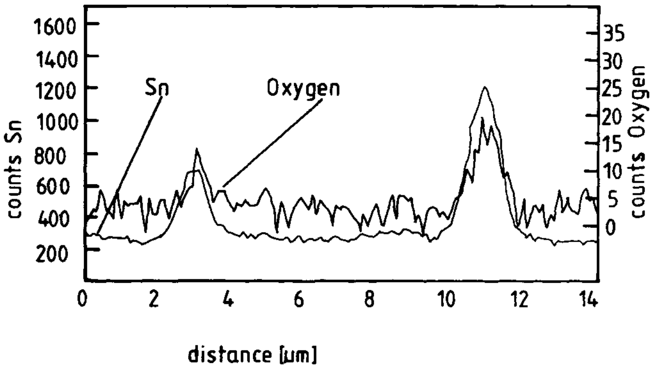

Fig. 9: An X-ray microprobe line scan across the surface

Gas Alloying of Titanium

Reactive metals, e.g. titanium, zirconium, aluminium, magnesium form compounds when melted in a reactive atmosphere. Such compounds are usually very hard and hence it is possible by a laser surface treatment to produce hard surface layers. Fig. 10 shows a titanium specimen, surface melted in a nitrogen/argon mixture with a typical roughness of a few microns. The homogeneity of the layer is shown in Fig. 11. The hardness values obtained depend on the quantity of nitride and hence interaction time.

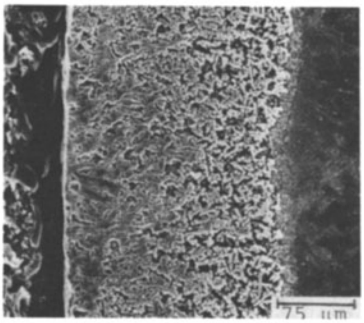

Fig. 10:
Surface melted titanium

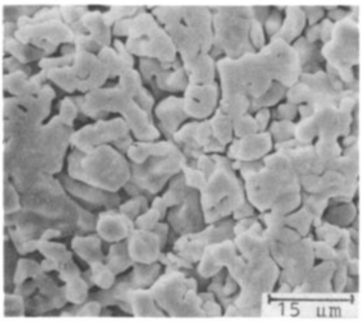

Fig. 11:
Homogeneity of the layer

Surface nitriding of titanium can be considered to have passed the development stage. There are numerous possible applications, where the wear, hardness or corrosion can be improved [9]. Nitriding of titanium is only one possible form of gas alloying - carburizing and carbo-nitriding of titanium is

