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### Laser treatment of alloys

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# ***1*** Introduction

In 1917 Einstein formulated the basic concepts of stimulated emission [1] that evolved to the introduction of the laser, standing for “Light Amplification by Stimulated Emission of Radiation”. The principle of a laser is to excite atoms to a high energy level and in order to have an inversion in population with respect to an intermediate level. When radiation interacts with the excited atom with the frequency that corresponds to the energy difference between the higher energy state of the atom and the intermediate state with inverse population, it produces a radiation with the same phase as the incident radiation. This radiation is amplified with a resonance cavity to get a coherent beam. Another unique property of a laser beam is the high degree of monochromaticity that allows efficient focusing. (replaced from Chapter 3.13 1<sup>st</sup> paragraph). It took more than 40 years before the first operational laser was built by Maiman [2,3] at the Hughes Research Laboratories in California. After this invention, the world was turned into a true laser rush that inspired both the scientific community and the entertainment industry. Already in 1964, the James Bond movie *Goldfinger* shows a giant fictional laser that is supposed to cut thick metal plates. The Bond set uses a scaled-up prop that suggests the original 1960 ruby-crystal laser, completed with external flash lamps and a red beam. This was one of the early public demonstrations of a laser cutting process, and even though, it was a special effect, it already suggested the potential impact of lasers in industry. The high power laser-based industry became a reality much later. It became widely spread around the world and turned into an economically important activity with increasing investments and applications every year.

The surface condition of a component is usually the most important engineering factor. Almost inevitably the outer surface of a work-piece is subjected to wear and corrosion while it is in use. To an increasing degree, therefore, the search is for surface modification techniques, which can increase the wear resistance of materials. Unfortunately, there exists an almost bewildering choice of surface treatments that cover a wide range of thickness. The choice has to be such that the surface treatment does not impair, too much, the properties of the substrate for which it was originally chosen; that is to say, it should not reduce the load bearing capabilities, for example. This aspect of the substrate has been overlooked frequently in surface engineering with emphasis rather on the protective coating itself. Equally, the surface treatment chosen should be suitably related to the problem to be solved. If a thin protective layer may do the job, it does not make much sense in concentrating on processing of a thick layer on top of a substrate. It is worth noting here that wear resistance is a property, not of

## Chapter 1

materials but of systems, since the material of the work-piece always wears against some other medium. It is its relation to its environment – e.g. lubrication, speed of sliding/rotation - that determines the wear resistance of the material in a given construction. As a general rule, wear is determined by the interplay of two opposing properties: ductility and hardness.

Surface modifications can be grouped into two categories:

Processes for the deposition of a coating or protective layer, like polymeric coating, electroplating, galvanization, physical vapor deposition techniques, plasma deposition, laser cladding among others.

Processes that promote only modifications of the original microstructure. These processes are achieved by changing the chemical composition of a surface, as it is the case of carburizing, nitriding, boriding and laser alloying; or transforming the microstructure of a surface, as for example by shot peening, induction hardening, laser hardening, laser surface remelting, etc...

In this thesis two high-power laser techniques are used for the surface engineering of metallic alloys [4]:

*Laser cladding*, which allows the deposition of thick resistant metallic by a melting process fusing a special alloy onto a weaker substrate.

*Laser hardening*, which produces wear resistant tracks by microstructural transformations, i.e. a laser beam scans across a component without melting. For instance, in steels or ferrous alloys a temperature above 1200 °C should be avoided.

This thesis focuses on the application of these laser processes, the observation of microstructure formation, residual stresses and some aspects of the mechanical properties of laser surface engineered ferrous alloys. It is divided as follows:

The basic principles of the microscopy techniques and mechanical tests used in this thesis are briefly described in *Chapter 2*.

In *Chapter 3*, the application of the laser hardening process on gray cast iron, a material that is widely used in engineering components, is investigated based on the observations of microstructure transformations. Furthermore, the optimization of the laser cladding process with the coaxial and the side setups are performed by a semi-empirical approach that is based on a graded method experiment. The processes are characterized aiming at processing maps for the most efficient application of the technique. Furthermore, the Nd:Yag laser energy distribution of the setup used in this thesis is characterized in terms of focus distance.

The influence of the process parameters and alloys on the microstructure of laser deposited clad layers is thoroughly investigated in *Chapter 4* by means of EBSD microscopy techniques. Effects of beam velocity on grain coarsening and texture are discussed and presented as distribution orientation figures and pole figures.

A drawback of the laser cladding is the high tensile residual stresses that may be created in the coatings due to the melting followed by resolidification of the layer and provoke degradation of the coating mechanical properties, or even may provoke cracking of the layer during deposition. To investigate this problem, lab and synchrotron X-ray diffraction techniques were applied in *Chapter 5* to determine the stress distribution and stress tensors in clad layers. Some solutions for the cracking of the coatings are proposed based on the deposition mode of the tracks and the use of the martensitic alloys.

Finally, in *Chapter 6*, the wear properties of Co-based alloy claddings are tested by dry sliding in a range of temperatures that span from the room to typical automotive engine application temperatures. The oxidative wear mechanisms active in different regimes is also discussed.

In summary; this work contributes to a deeper understanding of laser processing technology and its potential applications. Laser processing can provide unique challenges and opportunities based on high spatial precision, reproducibility and automatic control.

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## References

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