Laser melt injection of ceramic particles in metals
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Chapter 1

Introduction

Properties of materials can be classified from different viewpoints, for example, mechanical (strength), chemical (corrosion resistance) and economical (costs). An important question in materials science and engineering is how to exploit the advantageous properties of materials, without being hampered by the disadvantageous properties. In general, the answer lies in modifying materials by tailoring the structure, or combining two or more complementary materials. A nice example where advantages of material properties are exploited, lies in the field of surface science and engineering. The different requirements of surface properties of components, in comparison with bulk properties, led to the emergence of and developments in this field. Cost reduction and increasing the useful lifetime of structural components have given an impetus to both applied and fundamental research.

The field of surface engineering covers a wide range of surface modifications, for example the production of coatings. Surface science and engineering embraces the different processing methods, structures and properties of the surfaces as well as methods to analyze these. Linking processing, microstructure and properties is, like in materials science, the ultimate challenge in surface engineering. However, an obvious route is to optimize the surface properties after a certain processing route by varying certain processing parameters. In our approach, knowledge of the microstructure is essential to understand the general consequences of surface processing on the surface properties. This understanding may then be applied on different materials systems, processing methods and property requirements. In this thesis, the
main emphasis lies on processing and resulting microstructure; nevertheless, also an attempt is made to couple the properties to the microstructure.

The topic that is investigated is aimed at improving the surface properties, as wear resistance and hardness, of light-weighted metals by using high-power lasers. There are several different laser surface treatments, ranging from laser heating and subsequent cooling of the surface to a full coverage of the surface of a substrate by a coating. Laser treatments can be positioned accurately, however treating larger surface areas may be complicated and time consuming by the limiting spot size of the laser beam. Laser surface treatments are therefore especially suitable for treatment of complex shaped workpieces and samples that are only locally exposed to friction and wear (for example sprocket wheels and pistons).

In this work the Laser Melt Injection (LMI) process is used to improve the surface properties. In this process a high-power laser locally melts the surface layer of a metal workpiece, while simultaneously solid second phase ceramic particles are injected into the melt pool. After the laser beam passes the melt pool rapidly resolidifies and the particles are trapped in the top layer of the surface. In other words, the process creates a Metal-Matrix Composite (MMC) layer, only in the top layer of a workpiece.

Two different material systems are investigated: SiC particles in Al and WC particles in Ti-6Al-4V. In both systems the particles react with the substrate material to form new phases, both at the particle/matrix interface in the form of reaction layers and in the resolidified melt pool between the particles. The commercially pure Al substrate is chosen as a model system, the commercial Ti-6Al-4V alloy as a system that is often used in applications (for example aerospace and off-shore industry). From a laser treatment point of view, these two substrate materials are very different. Al has a very high reflectivity for laser light (~ 90%), which makes Al a difficult metal to melt. The reflectivity of Ti is lower, and therefore it is easier to create a melt pool in Ti-6Al-4V. The consequences of this difference will be elaborately discussed in this thesis.

For both systems a process parameter study, i.e. laser and powder flow parameters, is carried out carefully to obtain suitable process parameters and to understand the influence of changing these parameters. In the case of SiC particle injection into Al, a simple model is developed to understand the influence of the oxide skin that is present on the Al melt pool. This model exists of two parts: penetration of a particle through a surface layer and a moving
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particle in liquid. Special attention is paid to the microstructure of the produced MMC layers of both systems. Electron microscopy is used to analyze and identify the different phases in the coatings. In addition, information of the crystallographic orientations of the reaction layers with respect to the particles is obtained. Furthermore, tensile tests on the MMC layers are performed. The deformation behavior is observed during in-situ tensile tests. Crack nucleation and propagation in the layers are studied to pin down the weakest spots in the coatings. Besides this, the hardness of the different phases present in the WC<sub>p</sub>/Ti-6Al-4V is measured by nano-indentations.

In chapter 2, the laser melt injection is described in more detail. In this chapter, various microscopy techniques as well as mechanical testing techniques are briefly explained. At the end of chapter 2 an example is given of the cooling rate dependence of the metastable phase formation during laser processing. In chapter 3, laser processing and the microstructure of SiC particle injection into Al are presented. The laser processing of WC particles in Ti-6Al-4V and the resulted microstructures are discussed in chapter 4. In chapter 5, mechanical test results for both material systems are presented.