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Evaluation and optimization of the bonding behavior between substrate and coating processed by laser cladding

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Abstract

The laser cladding process can be found in many different industrial applications. A lot of different material combinations were observed in recent years. For the application of laser cladded coatings in highly loaded areas, such as forming tool surfaces, the bonding characteristics between substrate and coating have to be evaluated and optimized. A special testing device is developed to measure the adhesive tensile strength of standardized laser cladded samples. To improve mechanical properties of the coating system within the process window, process parameters are tested and optimized by applying the design of experiment method. Results are presented from an iron based and a nickel based coating material on two different steel substrates.

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Keywords: laser cladding; adhesive tensile strength; bonding; design of experiment method

1. Introduction

The laser cladding process is known under different nomenclatures like Laser Metal Deposition (LMD), Direct Metal Deposition (DMD), Selective Laser Cladding (SLC), Direct Laser Cladding (DLC), Laser Rapid Manufacturing (LRM) and some others. Regardless of different process variants, the main principle - using a laser beam to melt a welding filler material on a substrate under protective atmosphere - is common to all. By computerized numerical control coatings and different geometrical shapes can be achieved. Typical technical applications are the generative manufacturing or repairing of turbine blades (Toyserkani et al. 2005, p.19), medical applications such as manufacturing of implant structures (Kumar et al. 2014), wear protection layers for mining and oil field equipment and also tool components for pressure die casting (Nowotny et al. 2010) and forming

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applications (Behrens et al. 2014). The deep drawing process of advanced and ultra high strength steels in the automotive industry is challenging for the tooling components that produce car body parts. New tooling solutions are needed to meet the requirements regarding tool wear, tribological surface condition, short time of manufacturing, the possibilities of flexible design changes and a cost effective production. New approaches also need to rethink solutions offered by the conventional toolmaking, leading to new processes and innovative manufacturing techniques. A possible solution is offered by the laser cladding process for active tool surfaces in the field of sheet metal forming. Klocke et al. (2014) is showing concepts for deep drawing tools combining the laser cladding process with local geometrical optimizations of highly stressed surface areas. In addition to the tribological surface properties, the consideration of the mechanical properties of the laser coatings is inevitable in this special field of application because of the stress loads of the tool in partial areas of the drawing radius and the blank holder. To find the optimum parameter setting within the process window of such laser cladded coatings specific evaluation methods are needed to quantify the coatings properties for tooling applications. Witzel et al. (2011) focused on a relation between process parameters, the microstructure and the ultimate tensile strength (UTS) of laser cladded Inconel bulk material. Through this investigation a coherence between process parameters and UTS was shown. Also Köhler et al. (2012) showed the effects on fatigue strength of laser coated samples. Nevertheless, using this process as coating technology, with typical coating thicknesses of 0,5 – 3,0mm, it is also very important to look at the interface zone between coating and substrate. A special testing device was developed and built up in order to measure the quality attribute adhesive tensile strength. The measured adhesive tensile strength and hardness values of the coatings are defined as quality attributes by applying the design of experiment method.

2. Experimental Setup

2.1. Equipment

All welding samples are laser cladded on a Trumpf DMD 505 laser cell. This machine is equipped with a 3,2kW CO2 laser source and a powder feeder to apply the coating material which is typical gas atomized with a particle size between 50 – 150µm. Fig. 1 is showing the process principle and an example of a partially cladded 3D geometry.

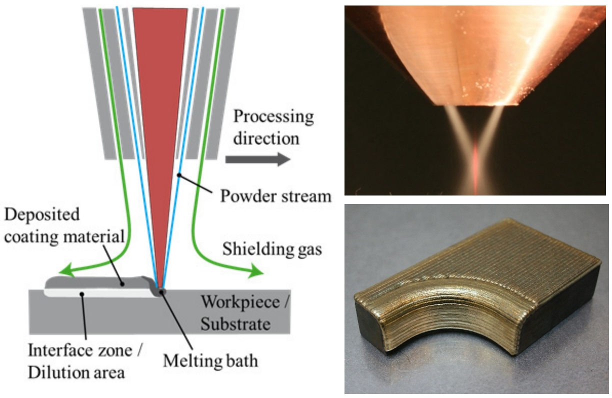

Fig. 1. Schematic process principle – laser cladding (left); welding optics (top right); tool surface coated with Cu85 (bottom right).

Tryouts of a new substrate/coating combination are done on a standardized flat sample as seen in Fig 2. Usually lines are welded at the beginning to find a first parameter set for a specific aspect ratio of the clad geometry. In a next step first areas are coated with different parameters in a single and multi-layer technique. This first steps are based on operator experience and the trial-and-error method. The main target in this phase is to eliminate typical failure modes like cracks, pores and the delamination defects of the coating. After a rough definition of the process