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Material characterization by deep rolling of laser deep alloyed micro-samples

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Abstract
For the development of new, metallic construction materials, laser deep alloying enables the rapid and flexible mixture of a base material with pre-deposited alloying elements. Nonetheless, post-machining of these workpieces is still a mandatory step to secure workpiece accuracy. Deep rolling processes represent an ideal possibility to smoothen and harden the surface. This paper presents an approach for short-term characterization of the mechanical properties of micro-samples resulting from a varied chemical composition produced by laser deep alloying. For this purpose, laser deep alloyed micro-samples produced with varied laser power were deep rolled under variation of the process parameters to determine the formability. The resulting plastic deformation is measured over the length of the micro-sample. The depth of the plastic deformation increases with increasing laser power in laser alloying process, indicating a higher amount of soft base material in the resulting alloy. The obtained results indicate that the deep rolling process is a suitable method to characterise the mechanical properties of laser deep alloyed micro-samples.

Plastic deformation, forming, deep rolling, additive manufacturing, laser deep alloying, micro specimens

1. Introduction

The progress in novel technologies sectors like mobility and energy requires the development of new structural materials with adapted functional properties. But the development of new materials as well as the characterisation of mechanical behaviour is a time and cost-intensive process. For further progress, a new method to characterise the properties of micro-samples in a high-throughput is required [1]. New techniques like rapid alloy prototyping [2] or laser deep alloying [3] enable fast growth in the synthesis of new structures and materials. Nonetheless, the produced materials require a characterisation of material properties and post-machining [4]. The mechanical behaviour such as the tensile strength of components strongly depends on the microstructure and the surface quality. Deducing information on material properties for micro-samples is not possible with conventional methods and therefore challenging. Mechanical surface treatments like deep rolling cause plastic deformation of surface and subsurface layers leading to an increase in hardness and compressive residual stress as well as a smoothing of the surface. The resulting plastic deformation thereby depends on the mechanical properties of the material as well as the microstructure in terms of the alloying composition and the homogeneity. Thus, it can be used to deduce material properties of deep alloyed micro-samples in an indirect but short-time approach.

This paper addresses the induced plastic deformation of laser deep alloyed and subsequently deep rolled micro-samples. The microstructure of the samples is differed by the variation of laser power in laser deep alloying process. To analyse the potential of deep rolling to characterise the mechanical properties of laser deep alloyed micro-samples, the deep rolling parameters were varied in a wide range. The resulting plastic deformation indicates a correlation to the alloying composition as a result of different laser power and thus different mixing ratio of pre-deposited alloying material and soft base material.

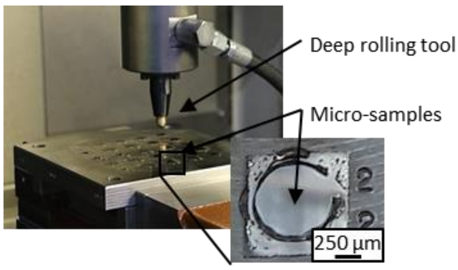

Figure 1. Experimental setup for deep rolling of micro-samples

2. Experimental setup

2.1. Laser alloying - preparation of micro-samples

Within this study, micro-samples produced by laser deep alloying were used. The base material was a conventional AISI 1015. As alloying material, an AISI 316L was pre-deposited in a total layer thickness of 0.2 mm on the base material by laser beam melting. The base and the alloying material were mixed by a disk laser Trumpf TruDisk12002 using a 3D-Scanner-Optic Trumpf PFO 3D. The laser power was varied in 5 steps of 0.25 kW from 4.50 kW to 5.50 kW to vary the energy input in the material. The modulation form and speed were kept constant. The preparation as well as the characterisation of micro-samples is described in detail in [5].

2.2. Deep rolling - characterisation of micro-samples

To investigate the mechanical behaviour of the samples, deep rolling experiments were performed. Deep rolling induces a mechanical impact by forming the workpiece material without material removal. The resulting profile is dependent on the flow behaviour of the material determined by the microstructure of the laser alloyed micro-samples.

Figure 1 shows the experimental setup for deep rolling. A hydrostatic, ceramic tool (Ecoroll HGx) ensures a constant deep rolling force F_r. By a translatory motion, a contact between tool and micro-samples is achieved resulting in a plastic deformation of surface and subsurface layers. The process parameters were varied in a wide range to determine a process window for characterization. Table 1 summarizes the applied process parameters.

Table 1. Process parameter of deep rolling process

Component	Values
Ball diameter d_b / mm	6, 13
Deep rolling pressure p_r / bar	85, 400
Feed speed v_f / mm/min	300
Lubricant	5 %-emulsion

3. Results

In this study, the plastic deformation generated by deep rolling is investigated for varying alloying composition as a result of increased laser power and thereby increased melt pool size. Figure 2 shows a resulting track generated by the deep rolling process. The characteristics of the track such as the depth, the height of the bulging as well as the width are dependent on the mechanical behaviour of the material. Figure 2 shows the topography transversal to the feed motion of the deep rolling tool and the characteristics of the resulting plastic deformation. As can be seen in the picture, the tracks show a running-in and running-out behaviour from the base material to the alloyed sample caused by the increased ratio of the surrounding soft AISI 1015 within the resulting melt pool.

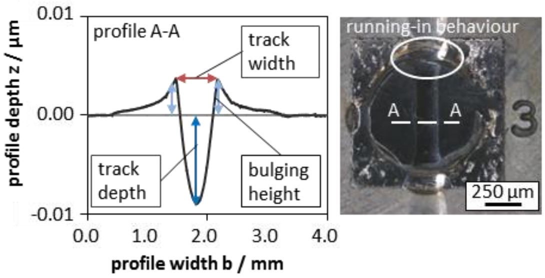

Figure 2. Exemplary plastic deformation of a laser alloyed micro-sample

By varying the deep rolling force F_r, mechanical characteristics of the material can be analysed. Plastic deformation occurs when the applied stress exceeds the yield strength of the material. In addition, high plastic deformation results in strain hardening of the material, which prevents further deformation. The inner stress state during the process thereby depends on the contact conditions of the material influenced by the chosen process parameters. To analyse the process window for a characterisation of alloying compositions of laser deep alloyed samples, the deep rolling force F_r was varied by choosing different ball diameters d_b and deep rolling pressures p_r (fig. 3). A theoretical range of deep rolling force F_r from 240 N (d_b = 6 mm, p_r = 85 bar) to 5130 N (d_b = 13 mm, p_r = 400 bar) was achieved. For all parameters, a plastic deformation was achieved indicating an exceeding of yield strength in the contact. An increase in deep rolling pressure p_r results in a more pronounced track. Despite almost constant deep rolling forces of F_r = 1130 N for a ball diameter of 6 mm and a pressure p_r = 400 bar in comparison to d_b = 13 mm and a deep rolling pressure of 85 bar, the small tool generates a deeper plastic deformation due to a higher contact pressure caused by the reduced contact area. With increasing deep rolling pressures p_r, less variation of plastic deformation can be observed. It is recommended to use lower deep rolling forces F_r to maximize the influence of microstructure.

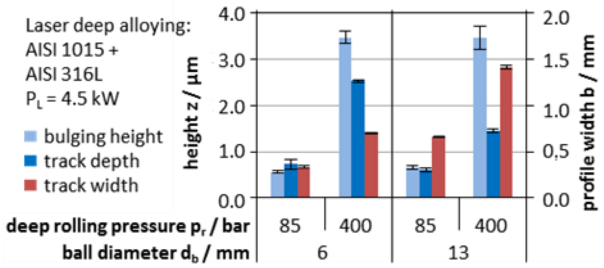

Figure 3. Induced plastic deformation under variation of load

Figure 4 shows the results for a medium force of F_r = 1130 N and a ball diameter of d_b = 13 mm. The track width is almost constant, while the track depth seems to increase with raising energy input in the material to a laser power of 5 kW, which is unexpected considering the general geometrical contact conditions. The mixing leads to an increase in depth due to an increased amount of soft base material in the micro-sample caused by a larger and deeper melt pool. Reproducibility of measurement increases as well with a higher laser power P_L. An EDX analysis of the samples is shown in [5].

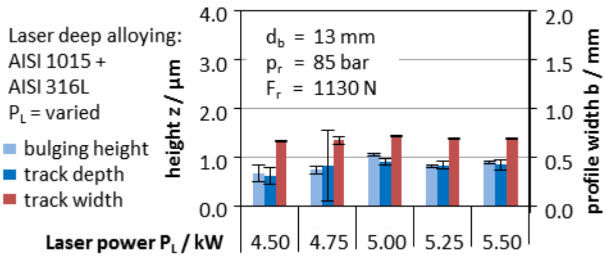

Figure 4. Induced plastic deformation in dependence of laser power P_L

4. Conclusion and outlook

This study aimed at analysing the potential of deep rolling to deduce information on the mechanical properties of laser deep alloyed micro-samples. For all deep rolling parameters, a plastic deformation can be achieved indicating an exceed of yield strength in the material. Furthermore, the results indicate a dependence of the plastic deformation induced by deep rolling from the alloying composition within the micro-sample due to the varied mixing ratio of base to alloying material as a result of varied laser power. With increasing laser power, the melt pool grows leading to a higher amount of soft base material, which results in pronounced plastic deformations.

To characterise the mechanical properties of the laser deep alloyed material dependent on the alloying composition, in further investigations the contact pressure has to be decreased in fine steps to analyse indirectly the exceed of yield strength while the mechanical impact of the deep rolling process has to be increased, e.g. by increasing the amount of contacts in the experiments, to describe the work-hardening behaviour of the material.

Acknowledgment

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