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Reduced wear and adhesion forces by laser dispersing of ceramics

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Abstract

Laser dispersing offers a great potential to fabricate layers or tracks with tailored properties threat duce abrasive or adhesive wear at the surface of highly stressed components. Different ceramic powder materials like aluminum nitride, aluminum oxide and titanium carbide have been embedded in the surface of tool steels using laser dispersing. The created layers were investigated regarding their elemental composition, dimension, particle distribution and hardness curve.

Keywords: processes; tool wear; surface treatment; dispersing; ceramics; zirconium oxide; aluminum nitride; titanium carbide; laser

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1. Introduction

Realising energy saving applications is an important issue to be considered in the auto, aircraft and aerospace industries today, the companies try continuously to increase the usage of lightweight parts in their vehicles, because this is a efficient method to increase the conservation of non-renewable resources. Due to this, conventional steel parts have been replaced more and more with weight-optimised parts made of forgeable aluminum alloys. These alloys are particularly suitable because they have similar strength values compared to medium-strength steels and a beneficial formability. Directly compared to steel parts, these aluminum parts can achieve a weight reduction up to 50 % and improve the corrosive behavior [1]. Beside the advantages, forging of aluminum alloys effects an increased abrasive and adhesive wear at the surface of forming tools, especially the adhesive wear has a big impact towards the forming procedure [2]. Conventional applications of wear reduction are not always able to reduce the high abrasive and adhesive wear sufficiently.

Higher performance can be reached with laser-dispersed layers to increase the life cycle of wear charged consumables [3]. These functional layers, composed of the tool materials as matrix and embedded ceramics as reinforcement, enable adjustable properties for highly stressed components [4]. The combination of both the advantageous tribological characteristics of ceramics (such as high hardness, high corrosive resistance and wear resistance) and the toughness of metals is the reason for the increased performance. Furthermore, reduced friction can be reached if the material pairings are optimised regarding their chemical affinity. These optimised wear

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properties and the reduced adhesion forces as a result of using aluminum nitride (AlN) particles tshall improve the wear resistance of aluminum forging dies.

One more process to consider aside from the common dispersing procedure is the combination of laser cladding and laser dispersing. Thus, the generation of ceramic-reinforced structures can be realised. In the field of printing and stamping technology of paper materials, there are multiple conditions to which a tool is subjected. For example, on inking rollers abrasive wear occurs due to the direct contact of the printing components with the paper materials. Additionally, the cleaning of the inking rollers uses aggressive chemical products which lead to corrosion on the tool surface. In contrast to completely coated tool surfaces, wear-resistant cutting lines for paper stamping, cutting or perforating applications are of substantial interest to the paper processing industries. For accurate cutting quality, high demands are made on the tools. An essential part of these cutting tools is fabricated under adoption of etching techniques. The desired cutting line geometry is masked and the excessive volume is etched so that often only 5 % of the basic material volume remains.

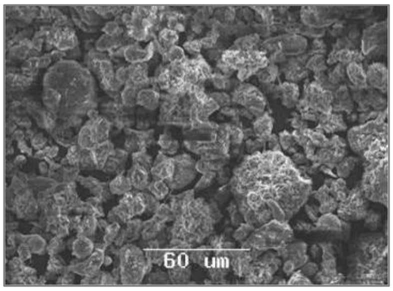
Generative laser cladding of cutting lines obviates the etching process and allows a resource-conserving and cost-saving process. The cutting line can be built up by using powder filler material which is supplied by a powder feeder and focussed by a coaxial powder nozzle. In order to generate metal-ceramic composite cutting lines, two different powders, the matrix material and the ceramic constituent, have to be transported to the processing zone where the materials are melted by laser radiation.

2. Experimental Part

2.1. Alminum forging tools

Non spherical AlN ceramic particles are used in the investigations; due to their minor affinity towards aluminum they shall reduce adhesion forces and improve the wear properties at the surface of aluminum forging dies. Wettability tests have shown that the affinity is decreased with increased temperature. Furthermore, high percentages of magnesium in the aluminum alloy can decrease the wettability [5].

The median particle diameter D_{50} is 55µm, and due to the milling procedure during their production the particles show a rough surface (Fig. 1). With the help of cross sections, SEM- and EDX-analysis, the particles have been investigated to increase the knowledge of the present elemental composition and microstructure.



aluminum nitride powder:

- average particle size: 50 - 60 µm
- elemental analysis:

N: 33.17 %
C: 0.01 %
Fe: 0.0027 %
O: 0.5 %
Al: balance

Fig. 1. SEM-picture and elemental analysis of AlN powder material used in the dispersing investigations

The texture of the investigated particles is not homogeneous because pores in various sizes are distributed over the grain (Fig. 2). An SEM analysis using the back scattering mode detected a consistent spread of elements inside the particles. Micro hardness measurements, placed directly in single particles, have shown a Vickers hardness between 1000 and 1300 $HV_{0.1}$. Additionally, a combination of steel and titanium powders is added to the AlN powder to improve layer forming and the embedding of the dispersed ceramic particles.

A standard 1.2714 tool steel, which is typically used in forging dies, is utilized as the substrate material for the dispersing investigations.

The material is annealed without any prior heat treatment and a fiber guided 4 kW Nd:YAG laser is adapted to a 3-axis test bench. This apparatus is used for manipulation of the substrate and optical system. The integration of a real time temperature control system is optional to increase the process stability if necessary.

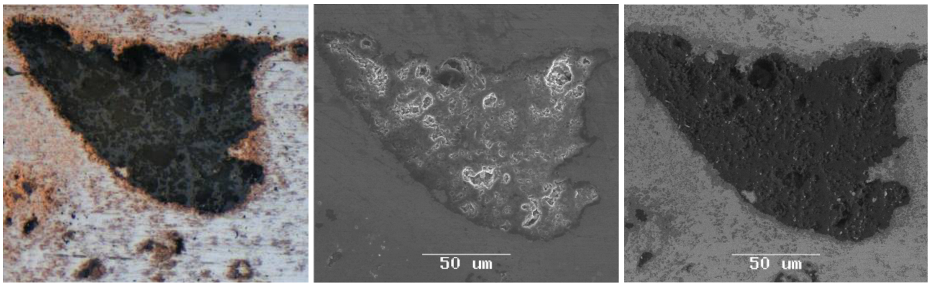


Fig. 2. different investigations of embedded AlN powder particle to identify the heterogeneous structure, detected using an optical microscope (left); middle) SEM-picture; right) back scattering picture

2.1.1. Single Tracks

To prove the principle of creating dispersed layers using AlN ceramic particles, single tracks have been dispersed under variation of laser power, feed rate, defocusing and powder feeding parameters. The powder feeding parameters define mass rate and ratio of powders as well as transport gas velocity. Regarding the feed rate, the investigations have shown that particularly slow feed rates (0.15 m/min) lead to sufficient results (Fig. 3). Using less laser power leads to a small, mainly cladding similar structure with dispersed AlN-ceramics. Higher laser power levels lead to a reduction of finer grain fraction percentage in the particle distribution and increased percentage of larger, agglomerated AlN particles. The investigations pointed out that using a feed rate of 0.15 m/min and a laser power P_L = 650 W leads to a dispersed track with constant particle distribution, a width of 2.6 mm and a dispersing depth of 0.65 mm. Due to the heterogeneous size range of particles in the used AlN powder, there is a increased number of bigger AlN particles.

A maximum dispersing depth of 1.1 mm could be reached using 1000 W laser power, even though percentage distribution and regularity of the embedded ceramics is not optimal.

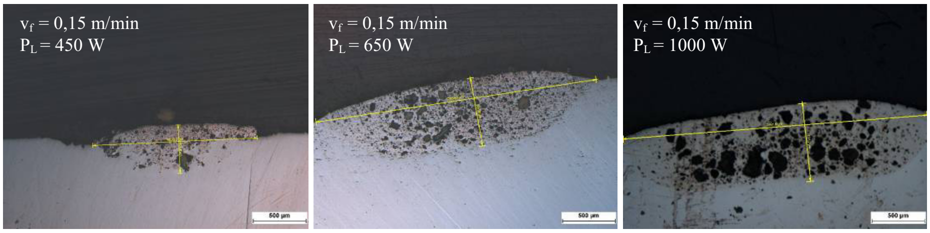


Fig. 3. overwiew of cross section of single laser dispersed tracks with dispersed AlN particles produced with varied laser power with 1.2714 steel substrate

Investigations concerning the impact of laser power and feed rate towards width and depth of dispersed tracks have shown that the width depends exponentially from the used laser power, while a prior linear behaviour could be detected for the dispersing depth. Different feed rates have a minor impact on the track dimensions, especially on the width. Up to 550 W the track depth is comparable and independent from the feed rate, with increasing laser power the track depth for the different feed rates diverges. Principally, the depth is reduced if there is an increased percentage of ceramic particles inside the dispersed tracks or the feed rate is higher than 0.4 m/min.

Hardness measurements through the layer compound, incipient at the top of the dispersed layer, have shown that the hardness level in the matrix of the dispersed area is higher than in the substrate material (Fig. 4). With increasing laser power the hardness decreases close to values of the substrate hardness. Also, the heat affected zone moves into the substrate, while the hardness increases. Finally, the hardness converges towards the level of the substrate material (250 $HV_{0.5}$).

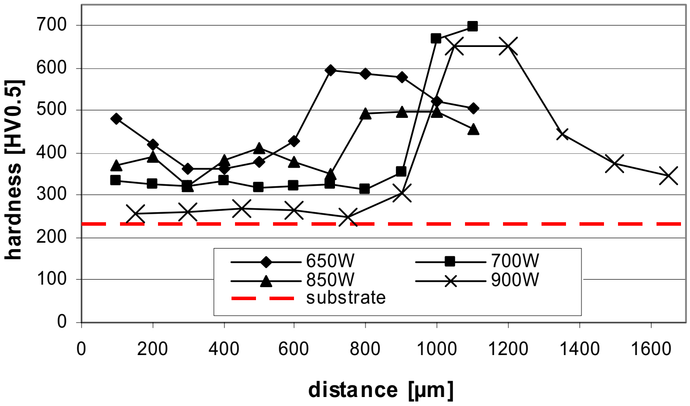


Fig. 4. hardness curve of dispersed layers produced with varied laser power in dependence of the distance to the layer surface

2.1.2. Dispersed Areas

When changing from single dispersed tracks to dispersed surfaces, different conditions of heat conduction should be considered. Due to this the working parameters and the welding strategy need to be fitted towards the new environmental conditions. However, the principal behaviour of the dispersed layer compound is comparable with the detected behaviour of single tracks. If the laser power chosen is too small then no material-close connection between layer and substrate is formed, beyond that the dispersed tracks have the predominant character of a cladding layer (Fig. 5a).

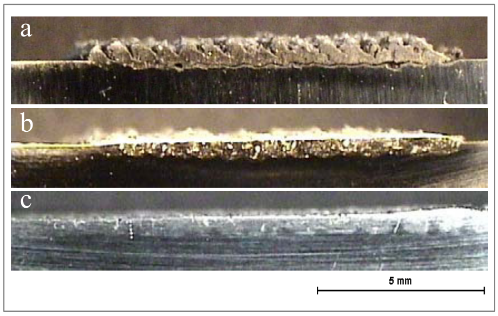


Fig. 5. Overview of cross section of laser dispersed surfaces with AlN particles using different process parameters

If the process parameters are adjusted correctly, a dispersed layer with constant distributed AlN particles can be achieved (Fig. 5b, shiny particles). In Fig. 5c a dispersed layer with minor ceramic particle density is shown, as a result of undervalued powder feeding parameters. Something else to note is the hardness in the dispersed areas. Compared with the characteristic of the dispersed tracks, the hardness in the matrix material of the dispersed layer is up to 400 $HV_{0.5}$ higher. An explanation for this phenomenon could be a phase with golden colour which was detected using an optical microscope (figure 2, left). The phase is spread inside the matrix material of the investigated dispersed areas and as seam around the embedded ceramic particles. This phase was detected as well in the dispersed track, however in less percentage and just in the low and middle laser power range. Initial investigations of the “golden phase” using EDX-analysis have supported the hypothesis of being titanium nitride. Definite conclusions can not be made yet, since the EDX-analysis is not the most suitable measurement procedure to determine the exact nitrogen percentage. This is caused by the presence of titanium which has a characteristic peak at nearly the same energy of nitrogen; due to this an explicit classification of the measured values is not possible. However, the investigations will be continued with more applicable characterisation techniques like WDX or XRD.

2.2. Cutting lines

In order to produce cutting lines with minimised wear, a combined process of laser cladding and layer dispersing has been designed.

Thick substrate materials, instead of thin tool sheets, have been used to determine suitable parameters. Research started with austenitic chromium nickel steel and heat-treatable steel respectively as substrate materials. As matrix material a material similar to the substrate should be used?, hence, an austenitic chromium nickel steel powder with particle diameters from 45 µm - 90 µm has been applied. Ceramic particles for a reinforcement of the matrix material have been used in different conditions: microparticles with particle sizes > 1 mm, agglomerated nanoparticle powder with agglomerate sizes of about 10 µm and primary particles of about 100 nm.

In Fig. 6, two cross-sections of laser-cladded dispersion lines are presented. The left picture shows a dispersed line consisting of an austenitic chromium nickel steel and 5 wt-% of titanium carbide particles with particle sizes from 22.5 µm to 45 µm. This line is fully connected to the substrate material with no pores, cracks or other defects in it. The ceramic particles are allocated homogeneously across the whole section. The cladded dispersion line in the right picture has been generated with a powder mixture of the steel mentioned before and titanium carbide with a ceramic fraction of 21.5 wt-%. With the exception of a small notch on the left side of the laser cladded line it shows no defects just as the former line.

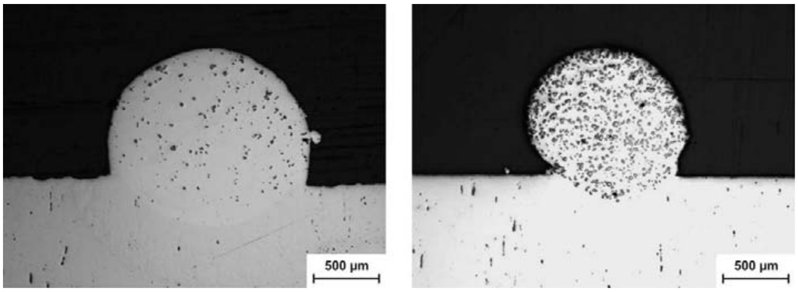


Fig. 6. cross-section polishes of laser-cladded dispersion lines, matrix material: austenitic chromium nickel steel, ceramic particles: 5 wt-% of titanium carbide (left picture) and 21.5 wt-% of titanium carbide (right picture)

3. Conclusion and Outlook

A procedure to create a metal-ceramic layer compound using laser dispersing with AlN powder material has been shown. Dispersed tracks and areas have been produced and investigated regarding dimension, microstructure, elemental analysis and micro hardness. A constant particle distribution over the profile of the dispersed layer has been achieved. Without any subsequent heat treatment, a hardness of 800 $HV_{0.5}$ has been reached in the compound matrix material but the presence of titanium nitride still needs to be approved. Titanium nitride is an established wear protection coating, e.g. for aluminum drillers, and a positive effect towards the adhesive wear properties of the dispersed surface can be expected [6].

Further investigations will test the performance of the metal-ceramic layer compound in extensive aluminum forging and wear tests. With ring compression and wettability tests using the sessile drop procedure, the friction and adhesive properties of the composite will be determined. The wear analysis will be supported by an additional simulation to help discover the required optimisations and to determine a “closed loop” between planning, testing and improvement sequence.

Metal-ceramic composite layers and cutting lines have been generated using powdery metallic and ceramic filler materials. Microscopic analysis of these composite layers revealed a homogeneous distribution of the particles in the laser-treated area. Using oxide ceramics as reinforcing constituent, the addition of wettability agents like titanium powder is potentially necessary to receive satisfying results concerning the distribution of the particles and their penetration depth in the matrix or substrate material. Further work adresses the generation of cutting lines on thin sheets instead of thick substrate materials. The geometry of these cutting lines has to be completed in subsequent sharpening and grinding processes.

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