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Applying laser dispersion and laser ablation to generate functional layers for deep drawing tools

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Abstract

Avoiding lubricants in forming processes would reduce the demand of minimal oil in production processes. Cleaning processes would not be necessary any more. This would offer the possibility to optimize the cost efficiency of the process chain. However, forming without lubrication would lead to a significant change in the tribological system. So, new approaches for tool surfaces must be developed to ensure process reliability in dry metal forming. In this work a laser generated tool surface is presented to form high alloy steel without lubrication. Laser dispersion is applied to inject spherical fused tungsten carbide particles into the surface of the aluminum bronze substrate. Afterwards, ultra-short pulse laser is deployed to ablate the matrix of the metal matrix composite (MMC). Subsequently, the hard particles stand out of the matrix with a defined depression and form a supporting plateau, which is in direct contact with the sheet material during the forming process.

Keywords: laser dispersion; laser ablation; forming technology

1. Introduction

Forming is a material und energy efficient process for industrial mass production [Neu06]. Nowadays lubricants are still applied to protect the tools against wear. Avoiding lubricants would improve forming processes regarding ecological und economical aspects. However, higher loads are resulting in forming without lubrication and higher wear will normally occur. So, new tool surfaces must be developed to

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withstand the higher loads and to reduce wear in dry metal forming [Vol14]. Approaches were presented by modifying ta-C and a-C:H coated tools by a laser based smoothing for deep drawing of aluminum sheets [Ste17] or by oxidized tool surfaces with α-Fe_2O_3 layers for deep drawing of high strength sheet metal [Yil17]. Dry metal forming of high alloy steel was presented by using aluminum bronze as tool material [Fre16]. For increasing the wear resistance, the tool surface can be reinforced by hard particles [Fre16a]. The chemical composition and/or the micro geometry can be adapted to influence the tribological behavior. The micro geometry of a surface can be modified by laser ablation in a very precise way [Kun16]. For testing the tribological behavior different testing methods are applied. To investigate the friction coefficient of the tool surface for sheet metal forming, strip drawing test are often used [Kir12].

In this work, a new tool surface for dry metal forming is presented. Hard particles are injected into the surface by laser dispersion. The matrix of the metal matrix composite (MMC) is partly removed by laser ablation. In consequence, the hard particle stood out of the surface and formed a supporting plateau which is in direct contact with the sheet material.

2. Experimental set-up

The experimental set-up included a 4 kW Trumpf HL4006D lamped pump Nd:YAG laser. A fiber optic cable with a diameter of 600 µm was used to transmit radiation to the Precitec YC50 cladding head where the laser beam was collimated and focused. The laser spot diameter was 6 mm. Argon shielding gas was provided in the center with 16 l/min and coaxial with 8 l/min. The pneumatic powder feeder GTV MF-PF-2/2 was integrated in the system to feed the cladding powder into the process zone by using 8 l/min argon gas. The eroding machine AGIE evolution 2 was applied to machine the target geometry of the strip drawing jaws. The hard particle content was determined on the metallographic cross sections in binary pictures.

Aluminum bronze with a chemical composition of CuAl10Ni5Fe4 acted as substrate material. The dimensions of the substrates were 10 x 21 x 30 mm³. Spherical fused tungsten carbide (SFTC) particles from the company Oerlikon Metco were deployed. The particle grain size was in a range from 45 µm to 106 µm. In Table 1 the process parameters, equipment and material of the laser dispersion process are given.

Table 1. Process parameters, equipment and material of the laser dispersion process

Laser	Trumpf HL4006D	Substrate	CuAl10Ni5Fe4
Wavelength	1064 nm	Dimensions	10 x 21 x 30 mm³
Fiber diameter	600 µm	Particles	SFTC
Collimation length	200 mm	Particle size	-106+45 µm
Focusing length	200 mm	Powder feeding rate	25 g/min
Spot diameter	6 mm	Feeding gas	Argon
Laser power	3 kW	Feeding gas flow rate	8 l/min
Shielding gas	Argon	Process head	Precitec YC50
Centric flow rate	16 l/min	Travel speed	300 mm/min
Coaxial flow rate	8 l/min	Overlapping degree	40%

The hardness of the spherical fused tungsten carbides (SFTC) amounted to 3.500 HV. Figures 1 shows scanning electron microscopy (SEM) images of the hard particles. The powder shows a good flow behavior because of the spherical form. The melting temperature of these particles is 1100 °C. The melting temperature of the bronze matrix is 1050 °C to 1080 °C.

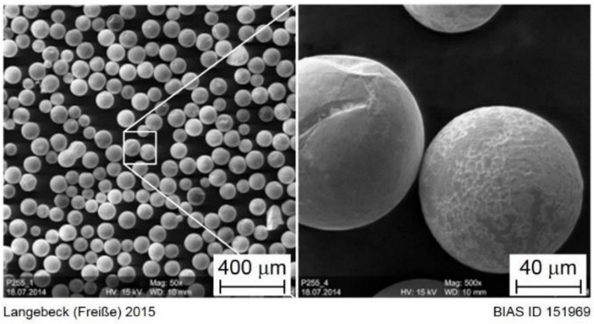

Fig. 1. Scanning microscopy (SEM) images of the hard particles

For laser ablation, the picosecond laser Trumpf Micro5050 was applied. The Xiton Harmonic Box (XHB) was applied to convert the fundamental wavelength of 1030 nm to the wavelength of 515 nm. The spot diameter was 29.4 µm and the fluence set to 0.77 J/cm². The scanner hurrySCAN®II 14 was used to control the movement of the laser beam in x- and y-directions. For positioning the substrate in z-direction the linear thrust unit ISEL LES 5 was used. The positional accuracy was ± 0.02 mm. The scanning speed was 2 m/s and the repetition rate was 200 kHz. Hence the overlapping degree of the laser ablated points in the feed direction was 70%. The overlapping degree of the tracks was also adjusted to 70%. No shielding gas was applied. The equipment and the process parameters of the laser ablation process are picted in Table 2. The ablation depths were measured by using the laser scanning microscope Keyence VK-9700.

Table 2. Equipment and process parameters for laser ablation

Laser	Trumpf TruMiro5050	Repetition rate	200 kHz
Wavelength converter	Xiton Box	Pulse duration	< 10 ps
Converted wavelength	515 nm	Scanner	Scanlab hurryscan II 14
Focusing length	196 mm	Scanning speed	< 15 m/s
Focus diameter	29.4 µm	Scan field	120 x 120 mm²
Fluence	2 J/cm² to 4 J/cm²	Linear axis	ISEL LES 5
Average power	30 W	Position accuracy	± 0.02 mm

The tribological behavior was tested by a strip drawing test, see Figure 2. The sheet material was out of high alloy steel 1.4301 with a thickness of 0.5 mm. The contact pressure was adjusted to 2.5 MPa. The strip drawing apparatus was installed in a compression-tension testing machine Zwick Roell Z250. The strip drawing force sensor with a max. testing load of 5 kN and a measurement uncertainty of ± 10 N was used to measure the tension force Ft. The normal force Fn was measured by the sensor Kistler 9217A. This sensor had a max. testing load of 500 N and a measurement uncertainty of ± 1% of the current measuring value. The friction coefficient µ was calculated by the equation (1):

$$\mu = \frac{Ft}{2 \cdot Fn} \tag{1}$$

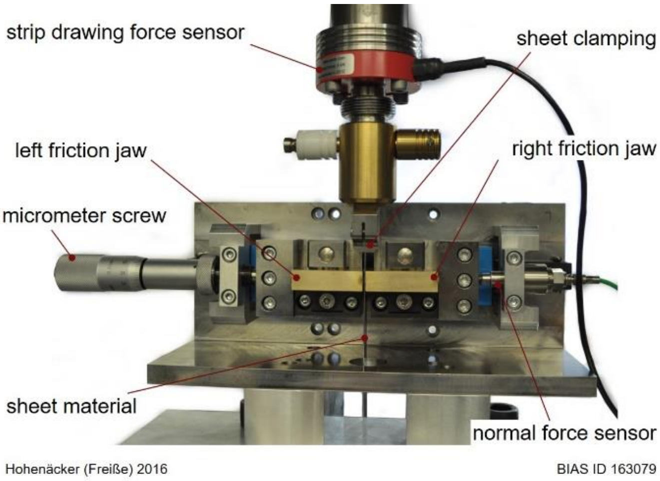

Fig. 2. Strip drawing apparatus the investigate the friction coefficient

3. Results

The influence of the laser power on the track geometry is given in Figure 3. Doubling of the laser power led to an increase of the width by 33% and of the depth by 75%. The width of the tracks was used to set a defined overlapping degree of the laser dispersed tracks.

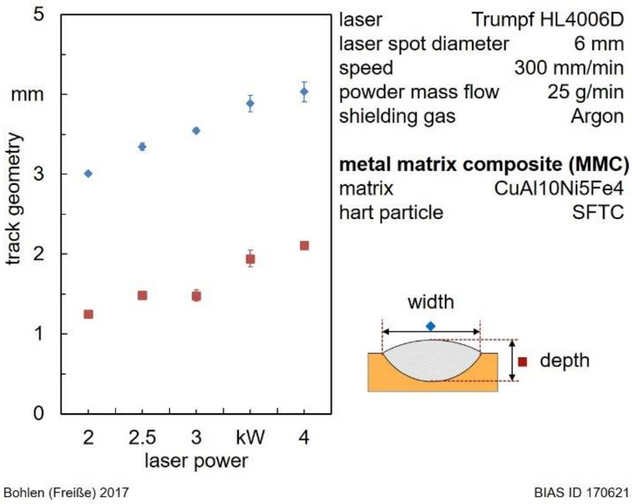

Fig. 3. Influence of the laser power on the track geometry

Figure 4 is showing the influence of the laser power on the hard particle content and on the powder catchment efficiency in laser dispersing of six tracks with an overlapping degree of 40%. By applying higher laser power, the powder catchment efficiency was increasing. However, a lower hard particle content was received. It is assumed that this was caused by the larger melting pool volume. Using laser power higher than 3 kW resulted in an undesirable dissolving of the SFTC.

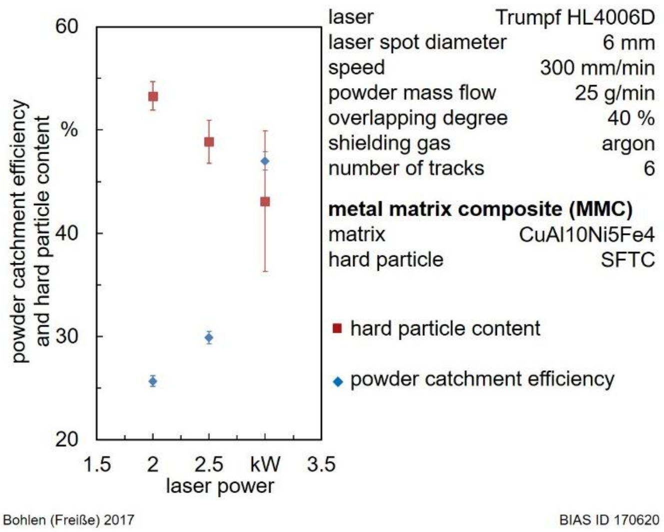

Fig. 4. Hard particle content and powder catchment efficiency as a function of the laser power

Two laser dispersed tracks were deposited on the strip drawing jaws. The dimensions of the strip drawing jaw substrate, the laser dispersed surface, the finished eroded shape and a metallographic cross section are given in Figure 5.

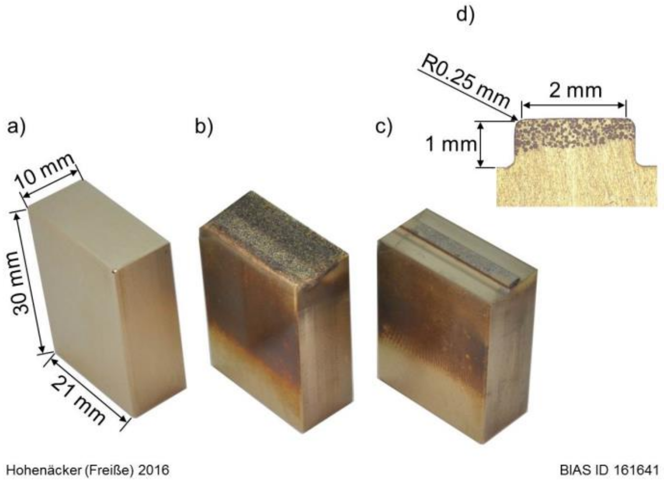

Fig. 5. Laser generated MMC surface on a strip drawing jaw. a) dimensions of the strip drawing jaw substrate, b) laser dispersed surface, c) finished eroded shape shown in overview and d) in metallographic cross section

By applying the laser ablation, the matrix of the composite material is removed more than the hard particles, see Figure 6. So, the hard particles stood out of the surface a formed a supporting plateau which is in direct contact with the sheet material during the deep drawing process. The distance between the plateau out of hard particles and the matrix is called depression.

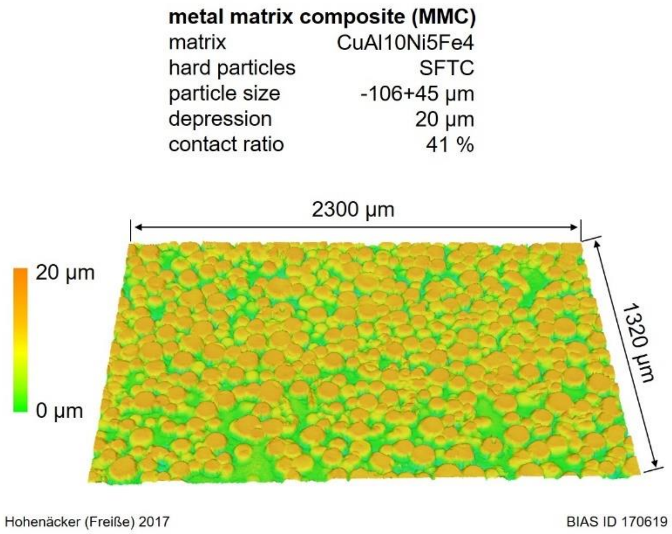

Fig. 6. Overview picture of the laser ablated MMC tool surface with a supporting plateau out of hard particles which is in direct contact with the sheet material

The ablation of the hard particles is undesirable. The laser ablation ratio was defined to evaluate the efficiency of the ablation process, see Figure 7. A higher laser ablation ratio means higher efficiency in producing a supporting plateau out of hard particles.

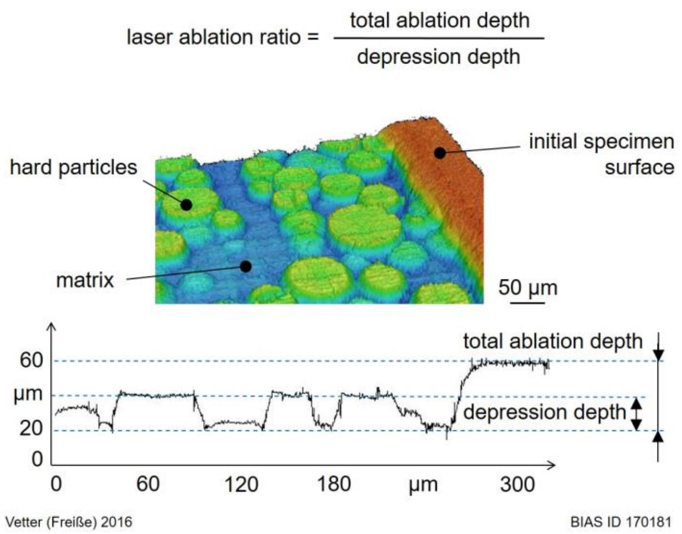

Fig. 7. Definition of the laser ablation ratio

Figure 8 is showing the laser ablation ratio as a function of the fluence. Higher fluence led to a higher total ablation depth and higher depression depth. However, the ablation ratio could be increased about 15% by decreasing the fluence by 50%.

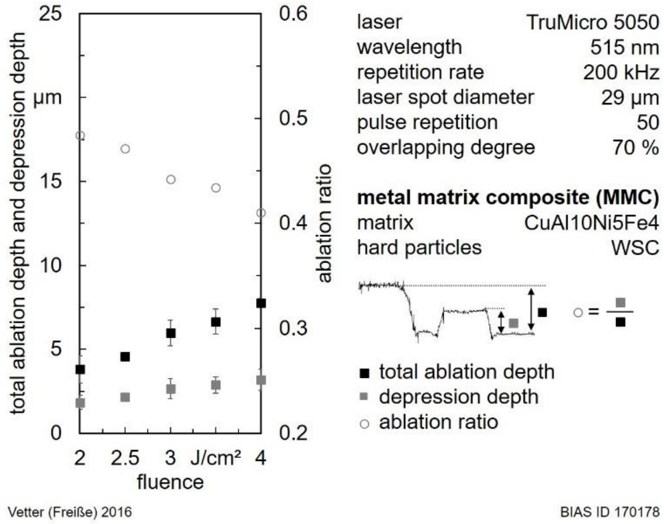

Fig. 8. Laser ablation ratio as a function of the fluence

The tribological behavior of this novel tool surface was tested with and without lubrication, see Figure 9. Lubricated strip drawing resulted in lower friction coefficient compared to dry sliding. The friction coefficient is increasing in lubricated sliding by applying higher depression. This can be traced back of a temporary breakdown of the lubricating film caused by the oversized lubricant pockets. No influence of the depression on the friction coefficient was investigated in dry sliding.

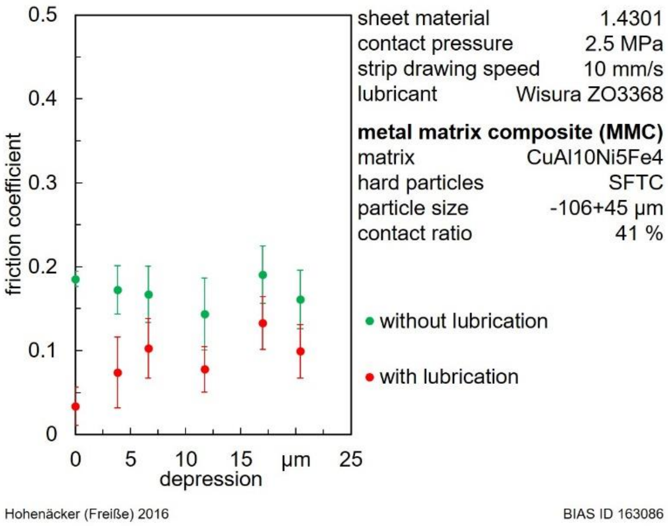

Fig. 9. Influence of the depression on the friction coefficient in a strip drawing test with and without lubrication

4. Conclusion

A novel laser generated tool surface for sheet metal forming reinforced with hard particles is presented. Hard particles are injected into the surface by laser dispersion. The melting temperature of the spherical fused tungsten carbides and the aluminum bronze are close to each other. Undesirable dissolving of the particles can occur by applying higher laser power. Lower laser power resulted in smaller track volume. This led to a decrease of the powder catchment efficiency and to an increase of the particle content. The maximum hard particle content amounted to 53%. By applying laser ablation on the MMC surface, it was shown that the matrix was ablated more than the hard particle. This effect could be increased by using lower fluences.

Acknowledgements

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