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Additive Manufacturing of a deep drawing tool

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Abstract

A new approach to establish sustainable production technology in metal forming is to avoid lubricants. This new green technology is called dry metal forming. In this work laser surface technology by means of laser cladding and remelting was used to asses the surface properties by varying process parameters. Furthermore, the cladding process was applied for additive manufacturing. The target was the generation of a deep drawing tool to form circular cups out of 1.4301 high alloy steel with an inner diameter of 30 mm. Different build-up strategies were tested to realize the near net shape geometry of the tool. Parameter set for the deposition process was investigated. The generated forming tool was successfully deployed to form circular cups.

direct powder deposition, additive manufacturing, deep drawing tool

1. Introduction

Usually lubricants are used in metal forming to reduce friction between workpieces and forming tools, to decrease wear and to prevent corrosion. For further production processes like coating or welding a cleaning process is necessary. Dry metal forming by means of reducing the demand of lubricants is a vision to integrate new green technology for mass production for sustainable use of materials and resources [Vol14]. Approaches to realize dry metal forming were presented by measuring and controlling thermoelectric voltage, current and temperature [Tro15] or by selective oxidation of the tool surfaces [Wul15]. In this work laser surface technology by means of laser cladding and remelting is used to adapt tool surfaces for dry metal forming.

Laser cladding is industrially deployed for surface technology [Koe12] and widespread used for maintenance, repair and overhall (MRO) technologies [Wag08]. Using laser cladding to generate surfaces out

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of aluminum bronze for forming tools was presented bei [Sch10]. Aluminum bronze is a copper alloy with aluminum as the main alloying component whereby the hardness increases and the malleability is not impaired. This material was firstly documented scientifically 1856 in France [Mei00].

In this work we varied different laser cladding process parameters to analyze the influence on the tribological behavior. Furthermore, the additive manufacturing of a deep drawing tool out of aluminum bronze by direct metal deposition is presented. The tool was applied to form circular cups out of 1.4301.

2. Laser cladding and tribological testing

A 4 kW Trumpf HL4006D lamped pump Nd:YAG laser and the laser processing head Precitec YC50 with coaxial powder supply were integrated in the experimental set-up. The pneumatic powder feeder GTV MF-PF-2/2 supported the cladding material into the process zone by using 7.5 l/min argon gas. Argon gas was also used as shielding gas provided in the center with 16 l/min and coaxial with 8 l/min. Using 4 kW and a spot diameter of 2.5 mm resulted in a laser power intensity of 840 W/mm². Gas atomized aluminum bronze with a chemical composition CuAl10Fe1 was used as coating material. A fine powder with a particle size from 5 µm to 53 µm and a coarse powder with a particle size from 45 µm to 125 µm were applied. The powder feed rate amounted to 20 g/min. Both aluminum bronze substrate CuAl10Ni5Fe4 and cold work steel 1.2379 acted as substrate material. The process speed was varied from 0.5 m/min to 2 m/min. Furthermore, the cladded tracks were post processed by laser remelting.

The integrity of the clads was determined by metallographic cross sections. Undesirable pores or cracks were not detected in the cross sections of all specimens. Fig. 1 shows a metallurgical cross section.

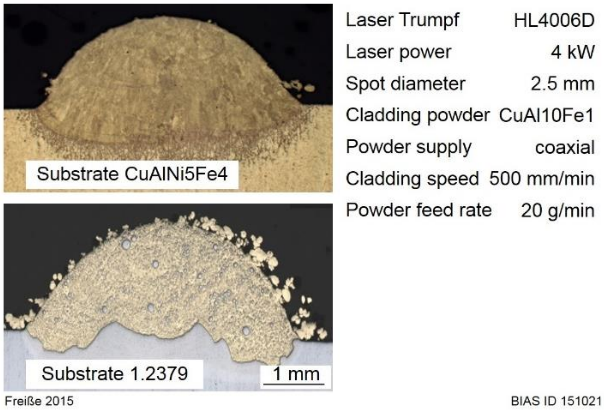

Fig. 1. Metallographic cross sections of laser cladded tracks on two different substrates

In a dry oscillating ball-on-plate test the tribological behavior of the clads against the high alloy austenitic steel 1.4301 with a hardness of 242 HV0.5 was investigated. The normal force was 10 N and the mean speed amounted to 10 mm/s. The test lasted 24 h. Coefficient of friction transient measurement data of clads are exemplary given in Fig. 2 (a). The results of the average of friction coefficients for every variation of the clads are summarized in Fig. 2 (b). It became apparent that the tribological behavior of the clads could neither significantly be varied nor improved by variation of the powder particle size, the process speed or by applying a post-process laser remelting treatment. The friction coefficient was particularly influenced by the substrate material. The deposited tracks on aluminum bronze substrate showed a lower friction coefficient from 0.23 to 0.28. The friction coefficients of clads on steel substrate amounted to a range from 0.58 to 0.78.

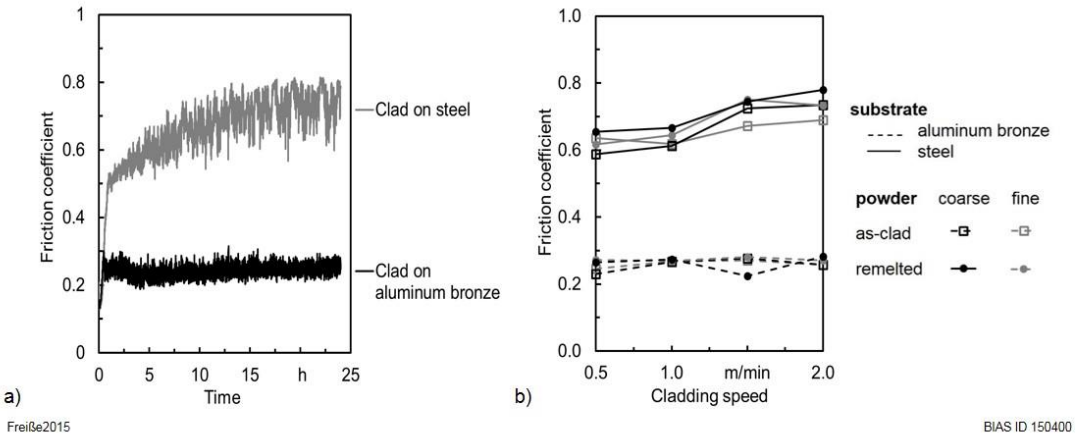

Fig. 2. Friction coefficient. a) Exemplary transient measurement data and b) average friction coefficient for the modified surfaces

In order to achieve a low friction coefficient, the influence of the steel substrate on the properties of the aluminum bronze clad should be avoided. So the approach was developed to manufacture the entire deep drawing tool out of aluminum bronze by direct metal deposition.

3. Additive manufacturing process

Direct metal deposition was used to generate the near net shape geometries of the punch, the blank holder and the drawing die. The final dimensions of the tool were realized by milling. The as-deposited and milled tool parts are illustrated in Fig. 3.

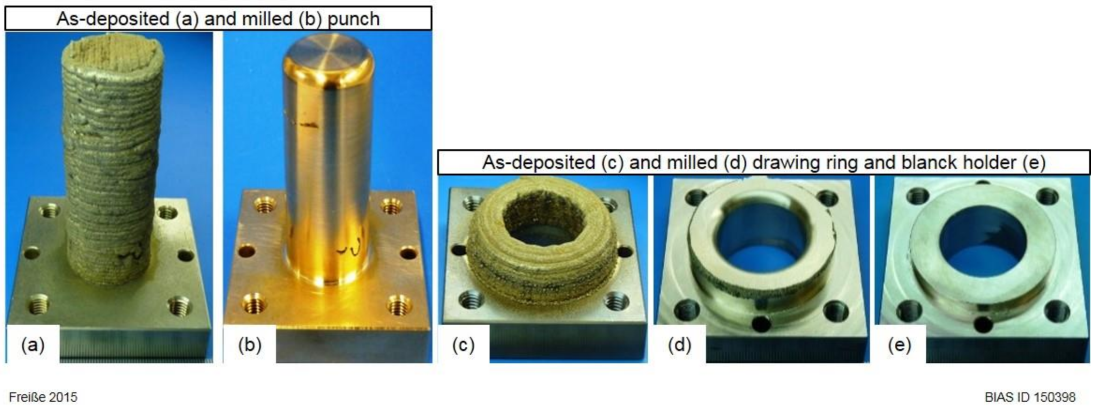

Fig. 3. Additively manufactured and milled deep drawing tool

The height of the punch was 70 mm and the diameter was 30 mm. Laser power of 2.5 kW was used and the depositing speed was 0.5 m/min. The powder feed rate amounted to 20 g/min. The process parameters led to a hight of the cladded tracks of 1 mm and a width of 3.8 mm. For adjusting the layers in vertical direction, an increment of 0.75 mm was used and the overlapping increment in horizontal direction amounted to 2 mm. The catchment efficiency of the powder material was around 70 %. The geometry was realized by depositing the inner filling by linear arranged tracks and the outer boundary by depositing rings. The drawing die and the blankholder were generated by deploying horizontal and vertical arranged rings. A metallurgical cross section of the punch was prepared. Smaller pores with diameters up to 50 µm were detected. No cracks were observed. Within the hardness measurements, an average value of 186.6 HV0.5 with standard deviation of 9.8 HV0.5 was determined. The hardness was homogeneously distributed in the punch. Three measurement lines were deployed. Fig. 4 is showing the hardness distribution in the punch.

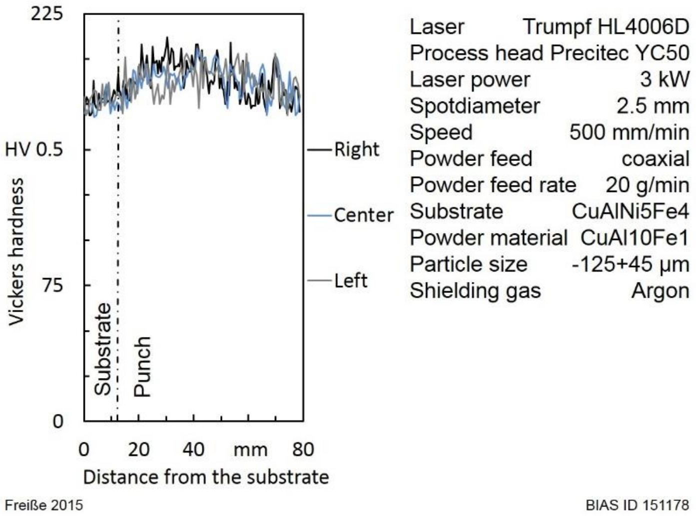

Fig. 4 Hardness distribution in the punch

The tool was used to form circular cups with an inner diameter of 30 mm by applying a drawing ration of 1.73. Compression tension testing machine Zwick Roell Z250 was used to realize the motion of the deep drawing process by using a deep drawing device. The experimental set up is given in Fig. 5. The forming speed amounted to 10 mm/s. By adjusting the suspension travel of four helical compression springs a blankholder force of 2.9 kN was applied.

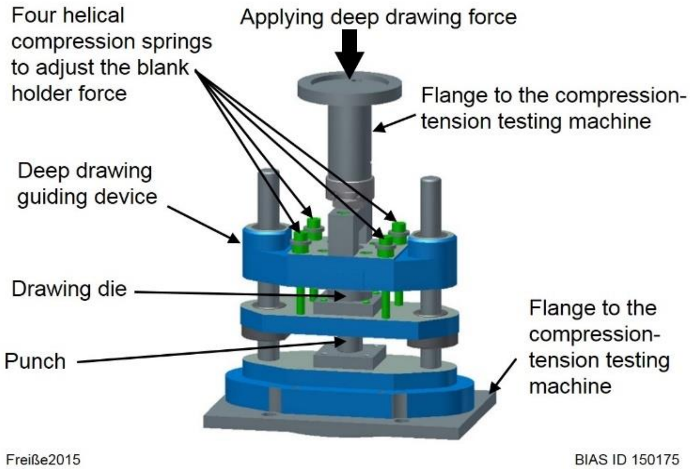

Fig. 5. Experimental set-up for the deep drawing test

Fig. 6 shows the results of the deep drawing test with and without lubricant and an example of a dry formed cup. The material was high alloyed steel 1.4301 with a sheet thickness of 0.5 mm. In the case of using lubricant an average of the maximum punch force of 26.4 kN with a standard deviation of 0.95 kN was measured. Within the dry forming process the average of the maximum punch force was 27.73 kN with a standard deviation of 0.88 kN. No cup base fractures and no wrinkle formation were observed.

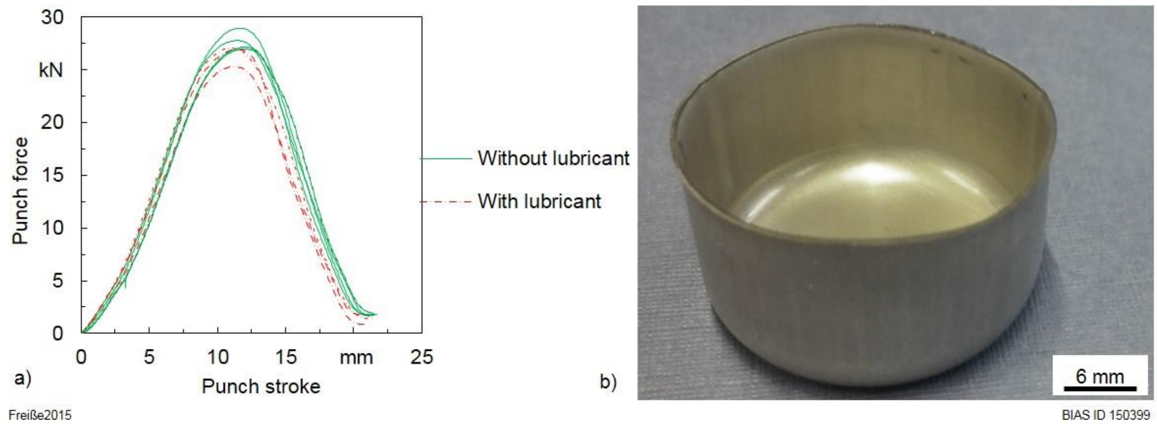

Fig. 6. Results of the deep drawing test with and without lubricant (a) and example of a dry formed cup (b)

4. Summary

The work shows the results of tribological investigations on laser cladded aluminum bronze for dry metal forming. With the performed experiments, it was possible to note that the tribological behaviour of the clads could not be modify by using different powder grain sizes, cladding speed or by applying post process laser remelting. However, the results of friction coefficient were shifted to higher values about 38 % when steel acted as substrate material instead of aluminum bronze. So the approach was developed to use the laser cladding process for generating the whole deep drawing tool out of aluminum bronze. The near net shape geometries of the punch, the blank holder and the drawing die were additively manufactured and applied for deep drawing. The cups were formed with and without lubrication. In the case of lubricant-free forming the average of the maximum punch force was about 5 % higher compared to the results of the lubricated forming process. However, the forming tool had low wear resistance and it is not yet applicable for industrial mass production.

Acknowledgements

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