Dry Metal Forming Open Access Journal

Fast Manuscript Track

Edited by Frank Vollertsen
Available online at elib.suub.uni-bremen.de

www.drymetalforming.de

Dry Met. Forming OAJ FMT 1 (2015) 134–136
Received 28 September 2015; published 04 November 2015

Laser generated cooling channel in a forming tool

Hannes Freiße*[1], Malte Stroth[1], Thomas Seefeld[1] and Frank Vollertsen[1,2]

[1]BIAS - Bremer Institut für angewandte Strahltechnik GmbH, Klagenfurter Str. 2, D-28359 Bremen, Germany
[2]University of Bremen, Bibliothekstr. 1, D-28359 Bremen, Germany

Abstract

In this work a cooling channel was additively manufactured by direct laser deposition and was integrated in the drawing die of a deep drawing tool. The drawing die has a circular form and it is applicable to form cups with a diameter of 30 mm. The cross section of the cooling channel has a pentagonal form. Two ports were drilled into the drawing die to realize the inlet and outlet of the cooling water. The function of the cooling effect was tested and measured by thermal imaging.

Keywords: additive manufacturing, aluminum bronze, direct laser deposition, dry metal forming, cooling channel

1 Introduction

After the presentation of an additively manufactured deep drawing tool [1], this work investigated the generation of a cooling channel in the forming tool by the additive manufacturing technique.

Besides the lubrication the temperature of the tool surface has a significant influence on the forming process [2]. In general, forming processes can be classified according to the global temperature of the material in cold forming and hot forming subject to the recrystallization temperature of the material. In addition, not only the workpiece but also the forming tool can be tempered. Depending on the application, a cooling or heating is deployed. Furthermore, it has to be distinguished where the temperature is measured or applied. This could be globally for the whole forming process and the environment or it could be just locally applied at a defined area of the tool or of the workpiece.

The local temperature in the forming process caused by friction and plastic work dissipating could be derivated by measuring the thermoelectric voltage [3]. In a globally tempered vacuum environment deep drawing of high strength sheet metals difficult-to-deform under normal temperature was enabled at high temperatures. A drawing ratio of 1.94 was reached [4]. By the application of locally heated drawing dies and blankholder with simultaneous cooling of the punch the drawing ratio of the aluminum alloy AW-6016-T4 could be increased by 65 % [5]. The same technique improved the formability of a magnesium alloy MgAl3Zn. In this process the formed cup was additionally cooled directly after the forming process. The drawing ratio was increased from 2.1 to 5 [6]. Inductive heating of the drawing die and sheet out of steel 1.4301 could increase the drawing ratio from 1.85 at room temperature to 2.46 at 350 °C [7]. For highly-stressed components for the automotive industry, the formed components are directly quenched in the forming tool. The high cooling rates could be realized by applying cooling channels in the forming tool. These cooling channels were drilled into the forming tool [8].

Nowadays, drilled straight bores around the tool cavity are applied to realize the cooling channels. This manufacturing technique caused some problems regarding an optimal cooling effect. So, for example parting planes, ejector pins or cores had to be applied. To realize cooling channels even for complex geometries the drilling operation can be costly, both in time and money. Complex cooling channels can be manufactured more efficiently by additive manufacturing [9]. An additive manufacturing method is the direct laser deposition process. Today this process is applied for industrial production for example for coatings or for repairing applications [10].

In this work an approach is presented to integrate a cooling channel by using the direct laser deposition process as an additive manufacturing technique. The cooling channel was laser generated into the drawing die of a deep drawing tool. Thermal imaging was deployed to prove the function regarding the cooling time.

*E-mail address of corresponding author: freisse@bias.de

2 Experimental details

2.1 Experimental set-up

For the experiments a Trumpf HL4006D lamped pump Nd:YAG laser was deployed. The laser spot diameter was 1.2 mm and laser power of 500 W was used. The cladding speed was 500 mm/min. A turntable machine enabled the rotational movement of the substrate. As it is commonly applied by prior investigations for welding copper [11], the head was tilted by 8° to protect the laser head against back reflection. To feed the cladding powder into the process zone the pneumatic powder feeder GTV MF-PF-2/2 was integrated in the system. The feeding gas was Argon and 7.5 l/min was used. The powder supply was coaxial with a three jet powder nozzle. The powder feed rate amounted to 5 g/min. For the direct laser deposition process gas atomized powder out of aluminum bronze named CW305G with the chemical composition of CuAl10Fe1 was used. The particle size was in a range from 45 µm to 125 µm. The drawing die was additively manufactured on a substrate out of aluminum bronze CW307G with the chemical composition of CuAl10Ni5Fe4. The dimension of the substrate was 70 x 70 x 12 mm³.

2.2 Laser generating of the cooling channel

To integrate the cooling channel into the drawing die a welding sequence was developed. So the workpiece being produced was classified in four different zones (Fig. 1). At first the inner and outer ring were generated on the substrate in the welding position PA. Secondly the cover of the cooling channel was laser deposited in the welding position PB. So sloping walls in form of rings were realized welded into a form of a pentagonal. Finally the fillings and the top layers were produced in the welding position PA.

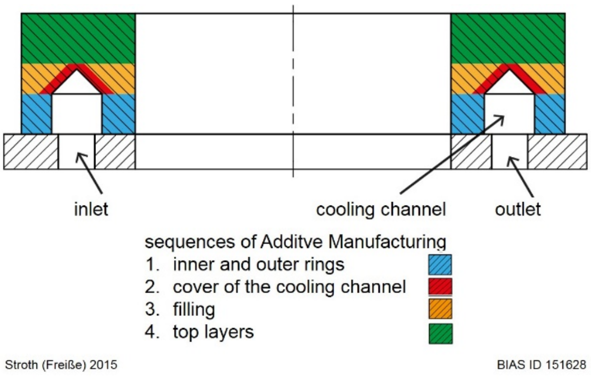

Fig. 1: Build-up zones of the drawing die with an integrated cooling channel

The inlet and outlet for the cooling water as well the final dimensions of the drawing die were milled afterwards.

2.3 Nondestructive testing of the cooling channel

A radiography was applied by the 3D X-ray machine Phonix v/tomex/x from the company GE.

The thermal imaging of the cooling effect was made by using the thermal camera Jenoptik VarioCAM. For the recording and controlling the software InfraTec IBRIS 3 professional was deployed. Before the thermal imaging, the drawing die was tempered on the one hand by the inlet of hot water with a temperature of 74 °C or on the other hand by cool water with a temperature of 21 °C. These water temperatures were also used for thermal imaging of the warming or cooling effect of the drawing die. To receive a reproducible and uniform emissivity the drawing die was painted black. The coefficient of emissivity was assumed to be 0.96.

3 Results and discussion

Fig. 2 is showing the drawing die with an integrated cooling channel additively manufactured by direct laser deposition.

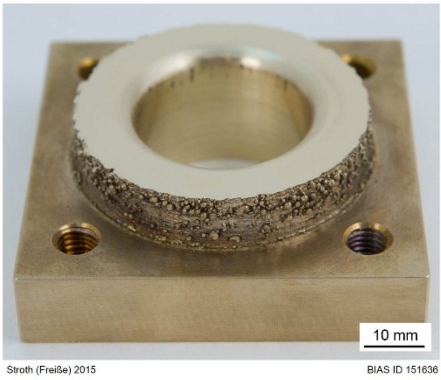

Fig. 2 Laser generated drawing die with an integrated cooling channel

The existence of the cooling channel in the drawing die could be examined by the X-ray imaging. An X-ray image in horizontal perspective is given in Fig. 3. The inner diameter of the cooling channel amounted to 38 mm and the outer diameter was 47 mm.

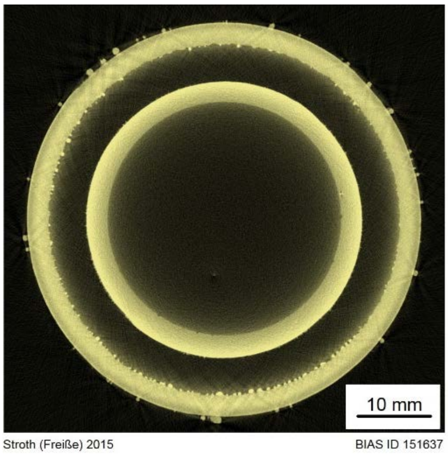

Fig. 3 X-ray image of the integrated cooling channel in horizontal perspective

Fig. 4 is showing an X-ray image of the integrated cooling channel in vertical perspective. No imperfections were detected. A thermal distortion of the cooling channel and the drawing die was visible. The cooling channel had a width of 4.5 mm and a height of 4 mm. The thickness of the top layers was 5.2 mm.

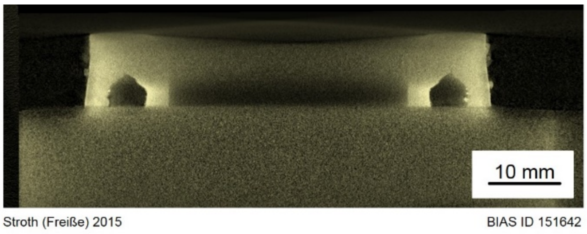

Fig. 4 X-ray image of the integrated cooling channel in vertical perspective

In Fig. 5 the thermal imaging of the cooling effect is illustrated. The tightness of the cooling channel was demonstrated. The cooling rates were measured at the inside of the drawing die in the area of the inlet of the tempered water. A cooling rate of 1.4 K/s was determined. The heating rate was 0.9 K/s. The temperature difference between the inlet and outlet was 15 K during the cooling as well during the heating.

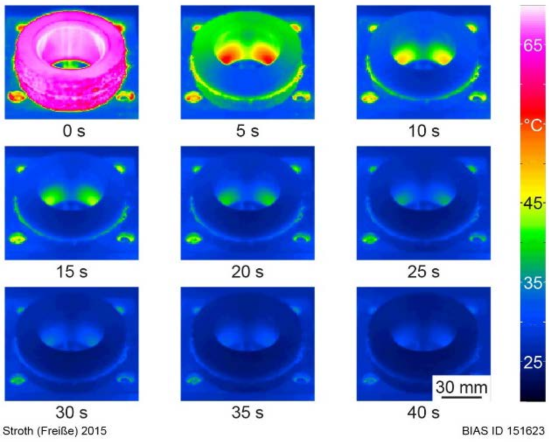

Fig. 5 Thermal imaging of the cooling effect

4 Summary

The aim of this work was to integrate a cooling channel in a drawing die by additive manufacturing. Therefore the direct laser deposition was applied. The additive manufacturing of the cooling channel and the geometry of the drawing die was realized in the welding position PA. The cover of the cooling channel was closed by welding in the position PB. So the cooling channel had a pentagonal form. Applying the 3D X-ray imaging the existence and the geometry of the cooling channel could be shown. The cooling and heating rate was measured by thermal imaging. Within the first ten seconds the most efficient cooling effect was observed. The tightness of the cooling channel was evaluated.

Acknowledgment

This work was supported by Deutsche Forschungsgemeinschaft (DFG) within priority programme 1676 (Se1435/2-1).

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