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Remote laser cutting of open cell foams – Processes for the factory of the future

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It is well known that the global climate change is the largest challenge for the society of the 21st century. For managing the resulting consequences, innovative materials become more and more important. Open cell metal foam contributes promising solutions to light-weight design, battery applications and renewable energy harvesting. Still, challenges are present concerning the cutting into a defined shape. Remote laser cutting offers a solution for decreasing the production costs as well as the needed component accuracy. Our investigations reveal that this technique has a high potential concerning cutting speed of open cell aluminum foam, which was increased by more than 500% compared to state-of-the-art laser separation. Furthermore, different material thicknesses up to 20 mm were investigated. Additionally, the limit of the possible contour wall width was decreased to less than the size of one pore. This paper offers insight into the viability of remote laser cutting in overcoming the challenges dealing with mechanical milling or grinding. Investigating the process concerning thermal stress input as well as particle attachments will be the next steps in the future.

Keywords: Laser; Remote; Cutting; Open cell foam; Steel

1. Introduction

In the last several years, innovative materials such as open cell metal foams deliver the opportunity to be the solution for upcoming challenges in light-weight design [1]. For pushing the possibilities, open cell foams were utilized in various fields of application such as heat exchangers, battery systems or medical implants [2–11]. Note that manufacturing open cell metal foam into a define shape is still challenging due to the utilization of mechanical processes like milling or grinding, as shown in Fig. 1 [9]. An innovative approach in overcoming these challenges is the application of laser technology [12].

Laser technology is a new approach for cutting metal foam due to the fact that it is a wear-free and highly flexible process [13]. Several experiments were carried out using laser fusion cutting [14,15]. This is an established separation technique in various fields of industrial applications. The basic principle is well known as the laser beam is absorbed at the surface of the material and melts the entire bulk at once. A coaxial high pressure gas stream (for example N_2, Ar, or air) ejects the molten material to the bottom side of the specimen [12]. Due to melting the entire bulk in the cut kerf at once, a thermal stress is induced. Consequently, several investigations dealt with induced thermal stress into the foam material in order to determine and evaluate the cutting parameters as well as the geometry of the contour [13]. Additionally, the property of the open cell structure decreases combustion of the process gas. Nevertheless, dross attachments as well as thermal stress are the biggest challenges that have to be investigated in more detail.

Therefore, several investigations concerning laser fusion cutting of open-cell metal foam were carried out. Nevertheless, meld attachments as well as the possible thicknesses, still limits the possibilities. In conclusion, laser cutting possesses the ability to increase the cutting speed and the quality of the parts generated from foam material [16–18].

In order to overcome those limitations a novel laser cutting technology was implemented and successfully tested [19–21]. Our previous investigations showed that remote cutting is a

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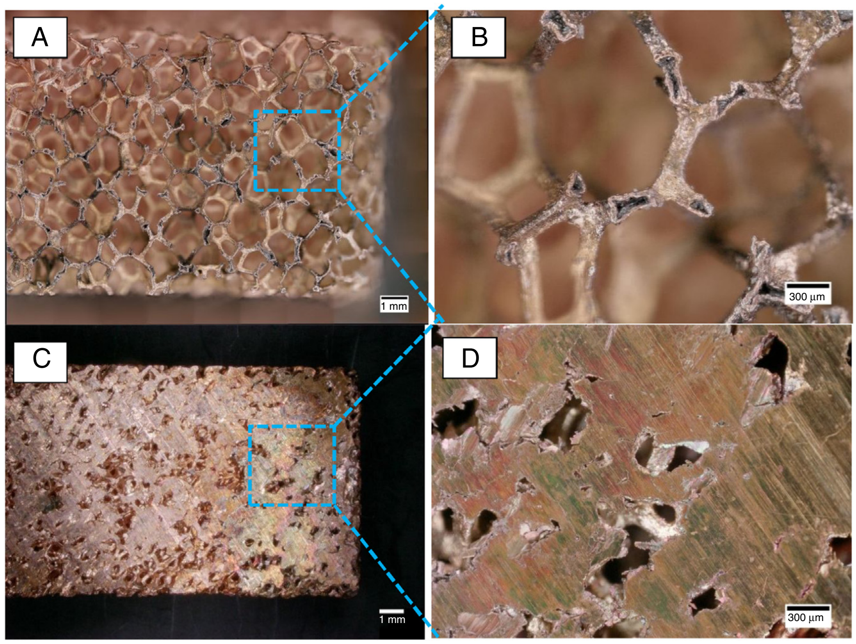

Fig. 1. Microscopic investigation of the smearing effect: metal foam before (A, B) and after mechanical machining (C, D); loss of cellular behavior through surface defects.

promising approach in sizing with laser. Moreover, it has the possibility to reduce the thermal induced stress. Furthermore, the open cell structure will be kept as well as the preferred contour outline. The investigation verifies the novel remote laser cutting technique for open cell foams. Relevant core themes of the research are achievable separation velocity, edge geometry, achievable component tolerances and minimal wall thickness.

The second section will give an introduction into the experimental setup. Explaining the basic principle of remote laser cutting as well as the methodology are the major subjects in the section. A special focus is put on the imaging process and how it can be used for getting reliable results. The third section focusses on material characterization and cutting process parameters. Finally, the fourth section illustrates the results regarding the four major core themes.

2. Experimental setup

Since the basic physical principle is not generally known, this section will describe remote laser cutting in more detail. The laser beam is absorbed at the surface and melts only a small volume of the irradiated area. Next to the molten part, a small amount of material is vaporized, shown in Fig. 2. This vapor is called steam cavity and consists of a high pressure, which ejects the molten material. For achieving the steam cavity in the cut kerf, a high intensity of the laser beam is required. It is known that this could be achieved by using small spot sizes in the focal plane. The cut kerf is created in a gradual ablation. Moreover, the melt and vapor is ejected to the top side of the specimen. Consequently, small spot sizes (Øspot < 100 µm) at large working distances require a high beam parameter product (BBP). Accordingly, a single mode fiber laser was utilized for the following investigations [22].

The word "remote" in the sense of laser cutting describes the beam manipulation system, which focuses and deflects the laser radiation. Hence, the beam gets deflected over mirrors, which are attached on highly dynamic galvanometric drives. Typically, a larger distance (up to 650 mm) to the material surface is adjusted than other laser cutting technologies (0.5–1.5 mm). Summarizing the different separations techniques, the basic principle of the remote laser cutting and fusion cutting is illustrated in Fig. 2.

Laser remote cutting as an alternative separation technique for metal foams will be discussed in terms of four main criteria; achievable cutting speed, edge shape, thermal damage and oxygen distribution. Due to the fact that the laser beam is deflected by mirrors, cutting speeds of up to 1200 m/min are possible. Furthermore, stepwise ablation of the material during remote cutting offers an opportunity to manipulate specific process parameter (idle time between cycles, cross jet pressure, scan velocity). Moreover, optimizing these can reduce the thermal damage zone.

As already mentioned, for the remote laser cutting technique high brilliant beam sources are indispensable. For the following investigations, a single mode fiber laser with a maximum output power of 5000 W is utilized. Due to the fact that the beam size has a significant influence on the spot size, a collimator with a focal length of 200 mm is used [18]. As a beam manipulation system a scanner with an aperture of 20 mm and a focal lens (340 mm focal length) was considered. The results of the optical components are measured with a laser beam diagnostic system and shows spot value of 61 µm.

In this report, open cell foam out of steel-316L and aluminum were investigated. The foams were provided from the companies "Mayser" (aluminum foam) and "Alantum" (steel 316L foam). Table 1 presents the most important material parameters.