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Industrial Paper

Increasing the process window of copper welding applications by adapting the power density distribution

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Abstract

The demand for copper welding applications is increasing due to the rising electrification of motor vehicles. For these applications, it is well known that for infrared lasers relatively high travel speeds combined with a good to very good beam quality is necessary. While good welding results can be achieved, often the available laser power limits the penetration depth. In addition, there may be limitations with regard to the handling system, which might not reach the necessary travel speeds. Therefore, the lower boundary of the process window is often a practical limitation.
This paper shows that copper welding tasks can also be carried out at travel speeds below 5m/min using an adapted power density distribution. The advantages of the adapted power density distributions compared to a standard TopHat distribution are shown by means of high-speed footage, cross sections and evaluations of the weld seam surfaces.

Keywords: Laser Welding; Copper; Process behavior

1. Introduction

Copper is a material characterized by high thermal conductivity and electrical conductivity. These thermophilically properties are particularly useful for electrical applications, for example for motors, batteries and current collectors. In addition, the material is used especially for heat dissipation applications. Heat exchangers and solar collectors are worth mentioning here. In the manufacture of copper components, lasers are the tool of choice for producing material-bound, non-detachable connections with high electrical and thermal conductivity properties. The laser tool enables a high degree of automation and high process speeds, thus achieving high productivity. The challenge in laser material processing of copper is the low absorptance of the material at industrial wavelengths of 1 µm. In the solid state, this absorption is approx. 5 %. In the molten state, the absorptance increases to approx. 14 %, see Fig. 1. As a result, when the molten phase is reached, more energy in the form of heat is suddenly introduced into the interaction zone. It should also be mentioned that the thermal conductivity of copper in the molten state decreases abruptly, see Fig. 2. This leads to an accumulation of heat in the interaction zone.

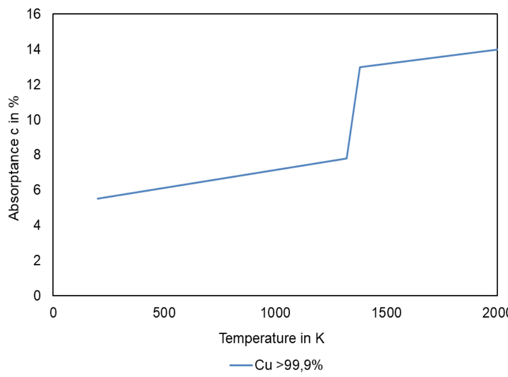

Fig. 1. Temperature depended Absorption for a wavelength of 1µm, Engler (2015), Blom et al. (2003).

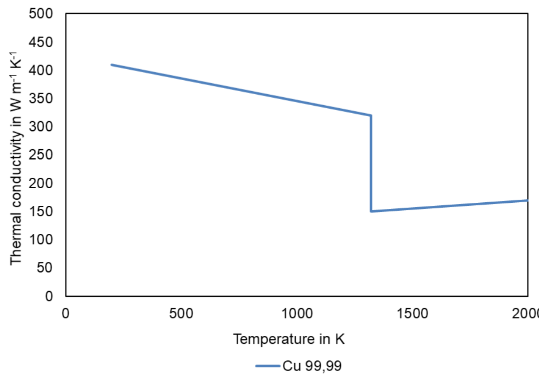

Fig. 2. Thermal conductivity of Cu, Cargan (2010), Pottlacher (1999).

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The consequence of these material-specific properties is an unstable process behavior, which is accompanied by increased spatter formation, ejections and poor seam appearance. Especially at welding speeds below 6 m/min, an increased process instability can be expected Heider (2018). However, these spatters should be avoided in contacting applications as they can cause short circuits and thus destroy the component or assembly.

In order to avoid process instabilities such as spatter and ejections, the positive influence of the adjustable ring mode laser (ARM) has already been demonstrated for different materials. This laser system uses a core-ring fiber, whereby the power between core and ring can be adjusted independently of each other. The impact of the ARM laser was demonstrated for steel materials by Wang et al. (2020) and Mohammadpour et al (2019). It has also been shown that the welding process could be significantly stabilized in the lap joint of galvanized steel sheets and thus melt ejections were reduced Kallage (2017). The present publication shows the first results on the influence of the ARM laser when welding Cu-ETP in the lap joint configuration. Further findings on welding of copper materials will follow.

2. Experiential Setup

2.1. Material

Cu-ETP using a sheet thickness of 0,5mm and 2mm were used for demonstrating the positive influence of the ARM laser.

2.2. System

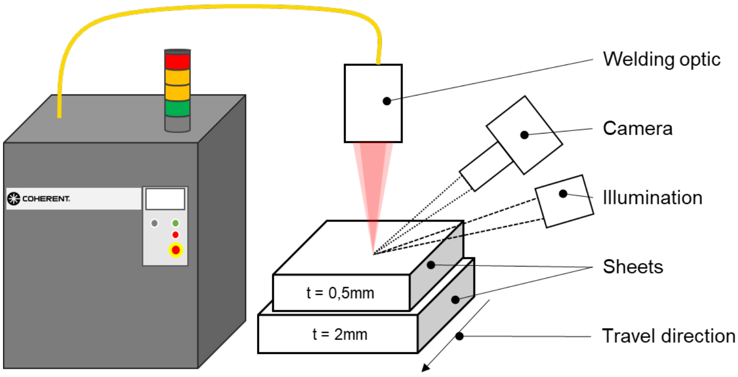

Fig. 3. Schematic experimental setup.

For the experimental investigations, a 10 kW Coherent ARM laser with a core diameter of 70 µm and an outer ring diameter of 180 µm was used. The wavelength amounts to 1070 nm for core and ring. The imaging optics (Optoscand) has a magnification of 1,5. For the reference process, a standard laser fiber laser (wavelength of 1070 nm) with a beam diameter of around 300 µm was used. No inert gas was applied for the experiments. A Photron camera with a 12 x Navitar lens was implemented for process observation. A diode emitting in the red wavelength range was utilized to illuminate the process zone. The schematic experimental setup can be seen in Fig. 3.

3. Results

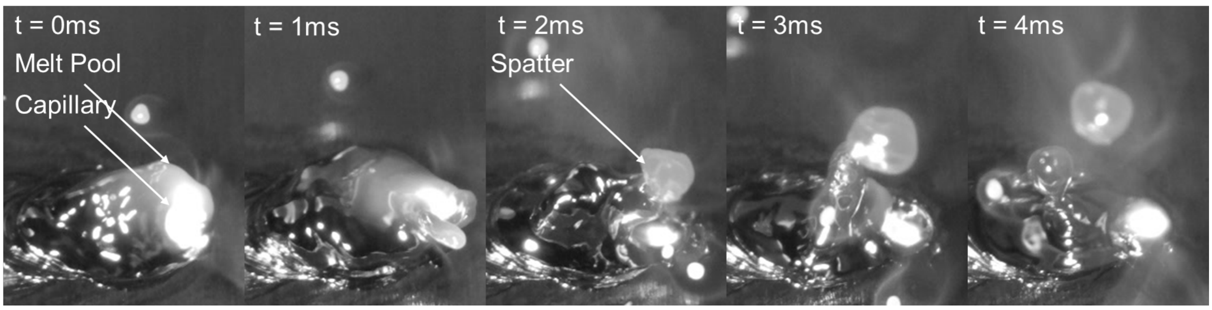

Fig. 4. Reference process, v = 6 m/min, process observation using high speed camera.

As already known from the state of the art, an unstable vapor capillary and a very unstable molten pool can be observed when welding with a standard laser at a speed of 6 m/min. This characteristic behavior is shown in Fig. 4. It can be seen how the melt pool behind the capillary moves against the travel direction. At t = 2 ms, spatters detach themselves and are accelerated upwards in vertical direction. At t = 4 ms a new melt droplet can be seen on the backside of the capillary.

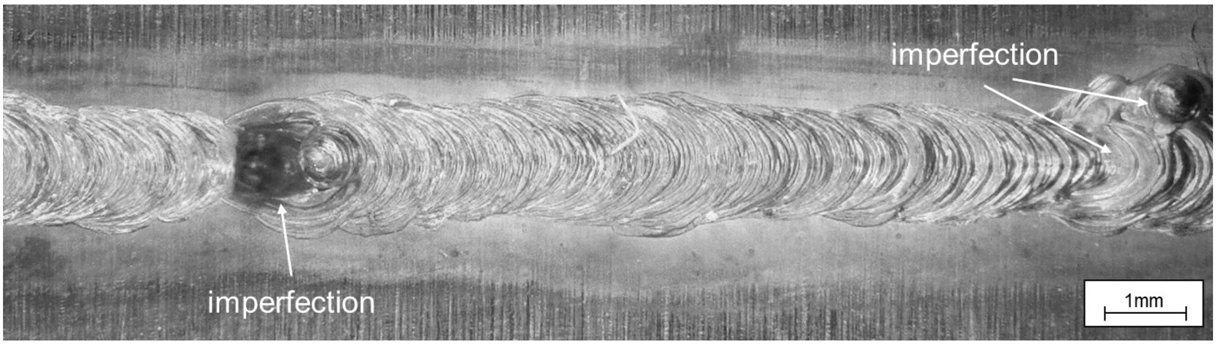

Fig. 5. Reference process, v = 6 m/min, weld surface.

The result of this process behavior is an uneven weld surface, which is characterized by defects in the form of holes and melt adhesion. The corresponding seam surface is shown in Fig. 5. It can be assumed that spatter formation will increase as the welding speed is further reduced and the surface quality of the weld seam will further deteriorate.

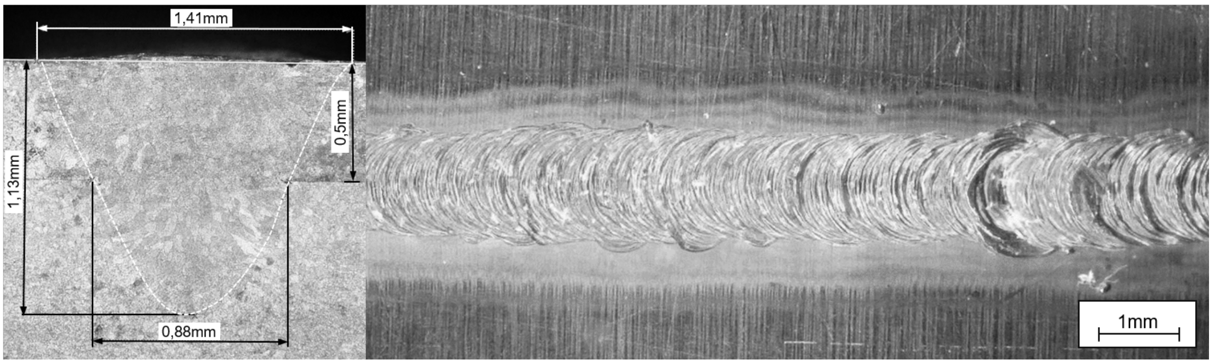

Fig. 6. ARM laser, v = 5 m/min, cross section and weld surface.

Using the ARM laser, it was possible to produce a flawless weld seam at a welding speed of 5 m/min. On the basis of the cross section (see Fig. 6), a weld seam width of 0,88 mm was determined at the joint between the upper and lower sheet. This width is 76 % greater than the thickness of the upper sheet. It can be assumed that the requirement regarding the permissible current density at the weld seam is thus fulfilled. Furthermore, a welding depth of 1,13 mm was determined. The seam surface does not show any imperfections like spatters or holes. Therefore, it can be stated that applying the ARM laser at low welding speeds (v = 5 m/min) good weld seams with very good seam quality are achievable.

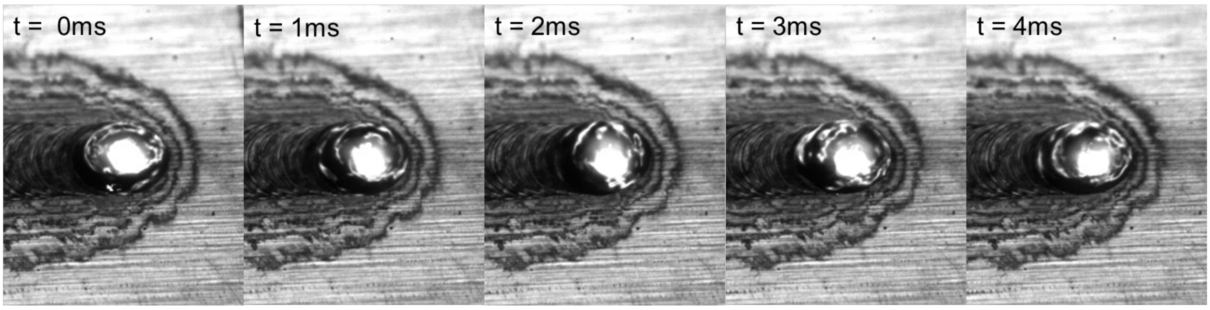

Fig. 7. ARM laser, v = 3 m/min, process observation using high speed camera.

Using a welding speed of 3 m/min, a process area was determined in which a stable capillary with a very calm melt pool is present. From the sequence of images (see Fig. 7), it can also be seen that the melt pool slightly bulges around the capillary. However, no characteristic chaotic movement of the melt pool can be seen.

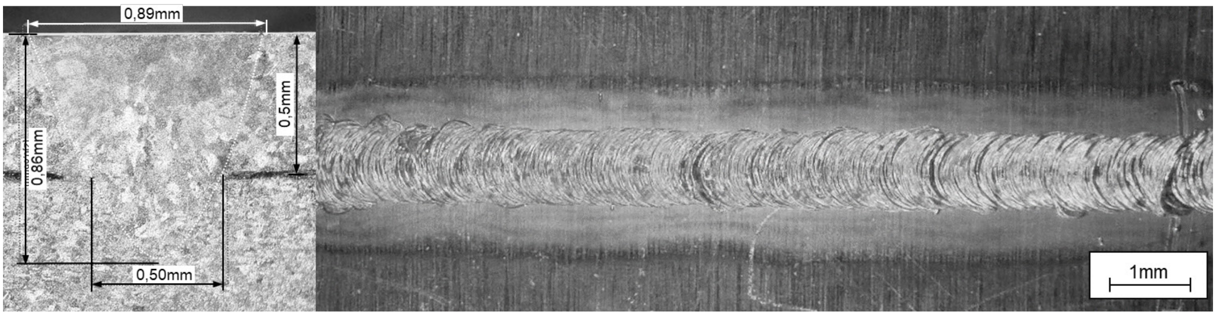

Fig. 8. ARM laser, v = 3 m/min, cross section and weld surface.

The calm melt pool formation about the stable capillary can also be seen in the high quality of the weld surface (see Fig. 8). The cross section shows that a welding depth of 0,86 mm was achieved. Around the joint, a weld seam width of 0,5 mm was determined, which corresponds exactly to the sheet thickness of the upper joining partner. However, it can be assumed that the width is too narrow for possible contact tasks.

At this point, it should be noted that this process regime occurs in a very small range of setting variables. A transfer to other sheet thicknesses and joint arrangements is planned. Nevertheless, this result shows that the process areas can be shifted to lower travel speeds without the presence of spatters and holes. These imperfections would occur when using standard fiber lasers.

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