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Process-limiting Factors and Characteristics of Laser-based Micro Welding

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Abstract

In this study the process of laser-based micro welding was examined using the example of ultra-thin stainless steel foils with total welding depths of 50 µm and 100 µm. For this purpose, focal diameters between 20 µm and 200 µm were applied to the work piece using scanning units with various image scales as well as a single-mode and a multi-mode laser with different fiber core diameters. In order to generate full penetration welds, the process windows were determined applying a power level up to 500 W as well as feeding rates up to 6 m/s. A relational expression concerning related power was defined in order to characterize and predict the lower process boundary. By means of high speed recordings the dependencies of process boundaries with respect to melt pool behavior have been clarified. Furthermore a changeover of welding regime within the process window was revealed and described dependent on the focal diameter.

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Keywords: laser; micro welding; ultra-thin foils; process boundary; remote

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1. Introduction

When work piece dimensions are reduced to micro scale, typical scaling effects occur (Vollertsen et al., 2007). For instance, the distortion comparatively increases nonlinearly with decreasing thickness of the work piece (Thomy et al., 2010). Due to the short laser/material interaction time during micro welding and the large surface in comparison to the volume of the work piece, the melt cools down and solidifies very quickly. Additionally, in micro scales the adhesion force between melt and base material and the cohesion force in the liquid phase dominate the gravitation (Wautelet, 2001).

When these scaling effects become significant during welding, then the process is different from common macro welding and can be defined as micro welding. In Vollertsen et al. (2007), a dimension threshold of the work piece of < 200 µm is defined. This is according to the empirically found threshold between 100 µm and 200 µm of the author during laser welding of metal foils.

Nowadays a broad range of lasers are available in terms of beam quality and power output. The beam quality determines the resulting focal diameter. In micro welding the above-mentioned scaling effects extend the applicable aspect ratio which is defined by the ratio of focal diameter to welding depth resp. work piece thickness. Thus, also bigger focal diameters of multi-mode lasers can be used achieving aspect ratios of < 0.4 (Patschger, 2013). The maximum power output of the applied laser entails the range of process velocity. In combination with fast scanning units process velocities in the range of several m/s are possible. It is known that at higher feeding rates melt pool instabilities such as grooving and/or humping occur.

2. Test design and test arrangement

In order to determine the laser micro welding process, ultra-thin (≤ 100 µm) stainless steel (AISI 304) foils served as specimens. Applications in micro welding are frequently jointed in a lap weld (Qin, 2010). For this reason, the foils were welded in an overlapping joint. The feeding rate was raised at a given laser power until an incomplete penetration resulted. Thereby, a process window could be determined (Fig. 1(a)). This step was iterated by increasing the laser power incrementally. If only results of the lower process boundary nearby an incomplete penetration were used, this method of approach leads to the following definition: The welding depth *s* is in accordance with the foil thickness and then defined by it.

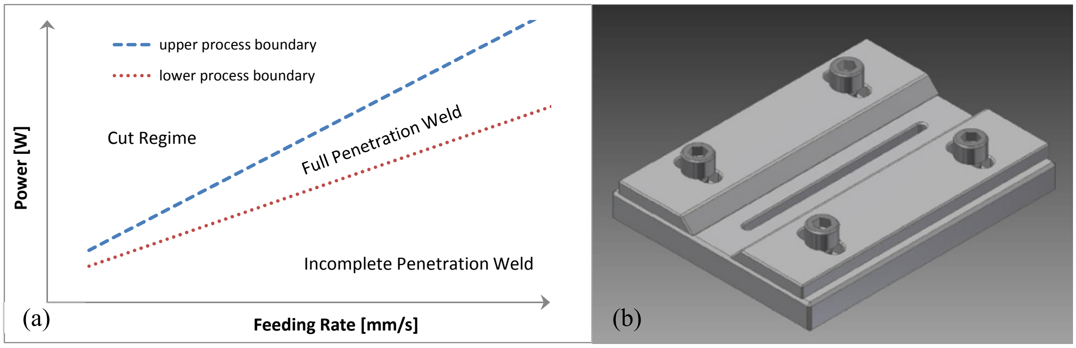

Fig. 1. (a) Simplified scheme of welding process boundaries; (b) clamping fixture.

Two different laser sources were used in this study in order to provide a broad range of focal diameters. The first laser source is a ROFIN multi-mode fiber laser which was coupled to a RAYLASE scanning unit. As a second laser source an SPI single-mode fiber laser combined with a SCANLAB scanning unit was chosen. Various objectives and collimation units were used. In combination with different beam properties of the laser sources, focal diameters between 25 µm and 204 have been obtained.