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Laser beam welding in vacuum of dissimilar metals for surgery instruments

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Abstract

Laser beam welding under vacuum to weld the austenitic stainless steel X20Cr13 to the martensitic stainless steel X5CrNi18-10 has been investigated. The objective of this study was to determine process parameters to produce a full penetration joint and to examine weld quality and mechanical properties. It could be demonstrated that a 3 mm depth joint could be realized with very good mechanical properties and without any imperfections by using only 450 W beam power.

Keywords: laser beam welding in vacuum; stainless steel; welding of dissimimilar metals

1. Introduction

Laser welding is an established process in many industries. Due to the high quality of the weld, the process is also increasingly used in medical technology (Löffler, 2013). Another important advantage of laser beam welding is the high-power density in the focused beam, which allows narrow weld seams with small heat affected zones and a high depth to width ratio (Gerhards et. al., 2016). The high cooling rates favor a fine structure which often leads to an improvement of mechanical properties. On the other hand, these high temperatures gradients lead to increased martensitic formation, especially with carbon rich steels, which can lead to high hardness (Beretta et. al., 2007). If the stresses, due to high hardness are higher than the material strength, hardening cracks are the results. Challenges emerge when welding two materials which have dif-

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ferent physical and metallurgical properties such as thermal conductivity, melting point or lattice structure. In the case of excessively high differences between the melting points or deviating lattice structures, intermetallic phases can occur (Otten, 2015). The position of the laser beam determines significantly the composition of the weld seam and thus the mechanical-technological properties (Otten, 2016). The laser beam welding in vacuum is currently investigated as an alternative to conventional laser beam welding and electron beam welding in recent years, particularly through the research group Reisgen at the Institute of Welding Technology and Joining Technology at RWTH Aachen University (Jakobs, 2015), (Reisgen, 2016), (Turner, 2016). One of the main advantages is, that due to the considerable increase in cycle efficiency, the beam power can be reduced significantly. While on atmosphere normally beam powers of 3-4 kW are used, the applied beam powers discussed in this series of tests were less than 500 W. Another benefit regarding the weld seam quality is the stabilization of the keyhole based on the reduce ambient pressure, which limits or even avoids pores. *Fig. 1*. shows a direct comparison between laser welding at atmosphere and in a reduced ambient pressure. Where in *Fig. 1*. a) the typical plasma plume and an increased spatter formation can be detected, the plume in *Fig. 1*. c) is reduced and more stable. Spatters arise only isolated. The right pictures show the corresponding cross-sections. The weld profile is more parallel-sided and increased in depth, the formation of the nailhead is reduced and pores can be avoided.

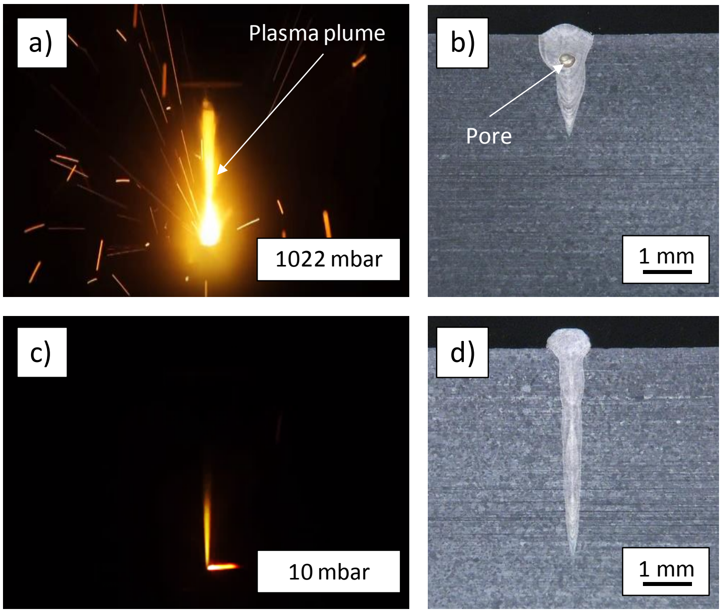

Fig. 1. Comparison between conventional laser beam welding at atmosphere a)-b) and a reduced ambient pressure of 10 mbar c)-d) with a 500 W Single Mode Fiber Laser at a welding speed of 20 mm/s in stainless steel (1.4301).

In this paper, laser beam welding in vacuum of a martensite-austenite connection is to be described. The compound is used in surgical instruments, e.g. a curettage where the shaft consists of an austenitic stainless steel and the tool of a martensitic stainless steel.

2. Experimental Procedure

The welding tests were carried out in a 40 l vacuum chamber at a pressure of 10 mbar with a Yb:YAG disc laser (TruDisc 16002) with a maximum power output of 16 kW. The combination of a 200 µm fiber and an imaging ratio (ff: 300 / fc: 200) of 1.5 lead to a spot diameter of about 300 µm.

The beam position of the samples discussed in this paper was always exactly cantered on the gap. The materials used are the austenitic stainless steel 1.4301 (X5CrNi18-10) and the martensitic stainless steel 1.4021 (X20Cr13). The cylindrical material was cut into samples with the size Ø 6x55 mm. The front surfaces were machined and cleaned with acetone before welding. During the welding process, the samples were rotated through 400 degree including up and down slopes. After welding, the samples were prepared for metallographic examination.

3. Results

A stereomicroscopic image and a macro-section of the weld are shown in Fig. 1. a)-b). The welding parameter were identified in pre-trials on plates to ensure a depth of minimum 3.2 mm. The applied welding configuration was 450 W beam power with a feed rate of 20 mm/s without pre-heating. The beam was focused on the surface.

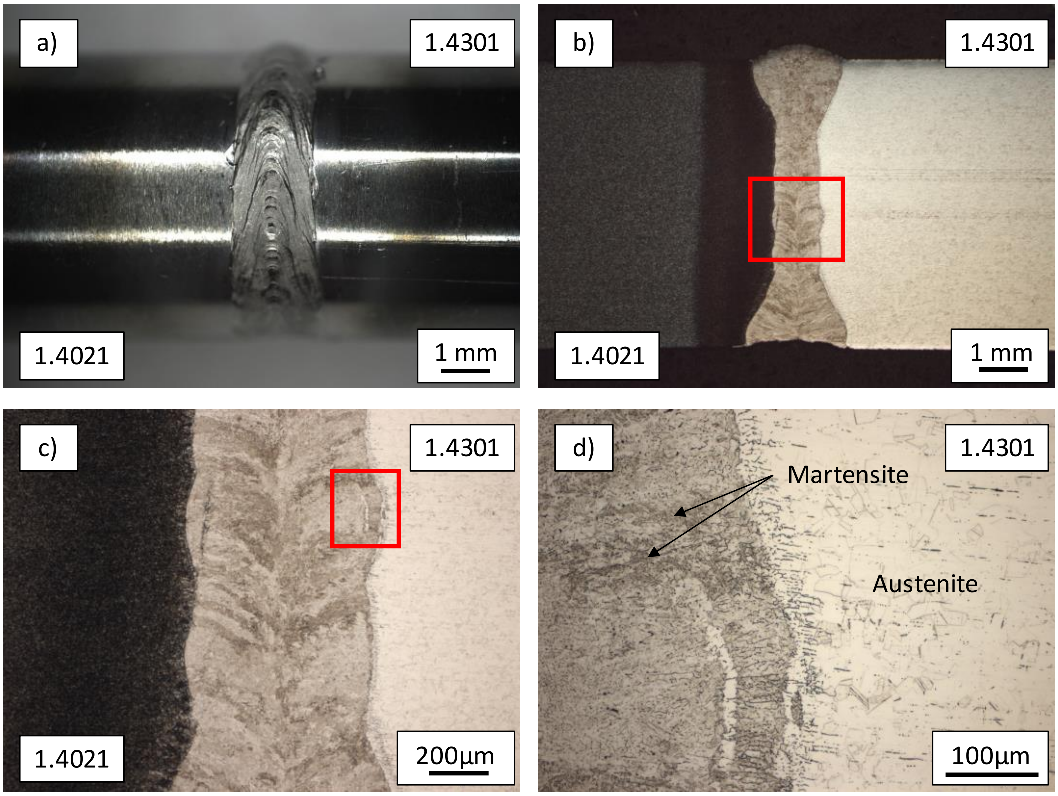

Fig. 2. a) Welding bead; b) macro-section, c) macro-section in detail; d) micro-section

Due to the low-pressure atmosphere tempering colors could be avoided, the image in *Fig. 2*. a) shows the weld seam without any cleaning afterwards. In the macro-section (*Fig. 2*. b)) demonstrate a full penetration without any pores or hardening cracks. The appearance of the bead with the so-called nail head is typical for laser beam welding with keyhole. The fine acicular structure of the martenisite is clearly visible in the seam. Fig. 1. c)-d).

Fig. 3 shows the microhardness profiles of a typical weld seam without pre-heating. The maximum hardness values were in the heat-affected zone (HAZ) of X20Cr13 steel. This can be explained by the highest temperature gradient which occur close to the fusion line. From this point a decrease in hardness in correlation with the increasing distance from the weld can be observed. Typical for chromium-containing steel is that the structure of the heat-affected zone consists almost mainly of non-tempered martensite. This can be observed independent of the cooling rate during welding.

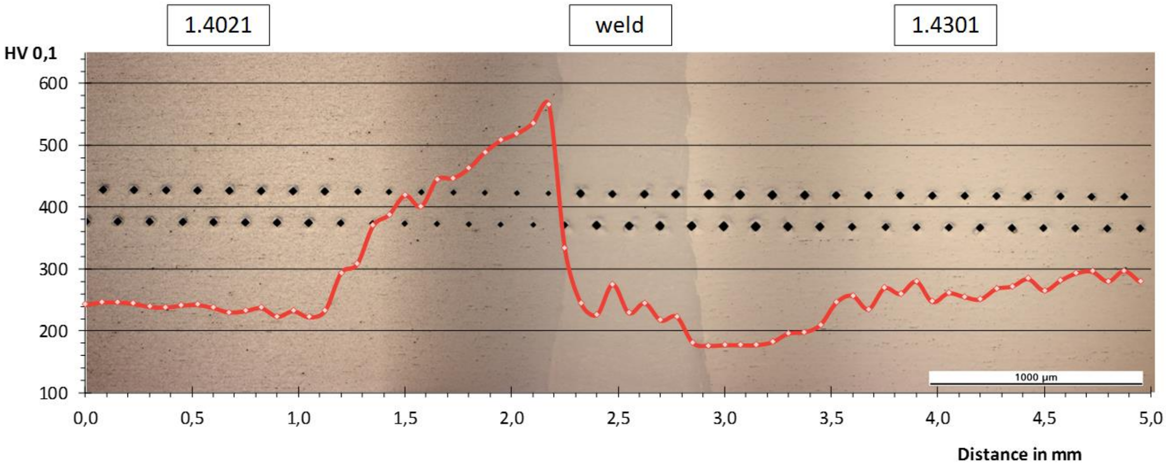

Fig. 3. Hardness measurement HV0.1

The hardness profile of the weld seam shows a continuous increase towards X20Cr13. In the seam are areas with the pronounced acicular structure of the martenisite and cellular austenite *Fig. 2*. d). Depending of the measurement location different hardness values arise. The HAZ towards X5CrNi18-10 shows a decrease of hardness, which can be explained by grain growth during the cooling phase.

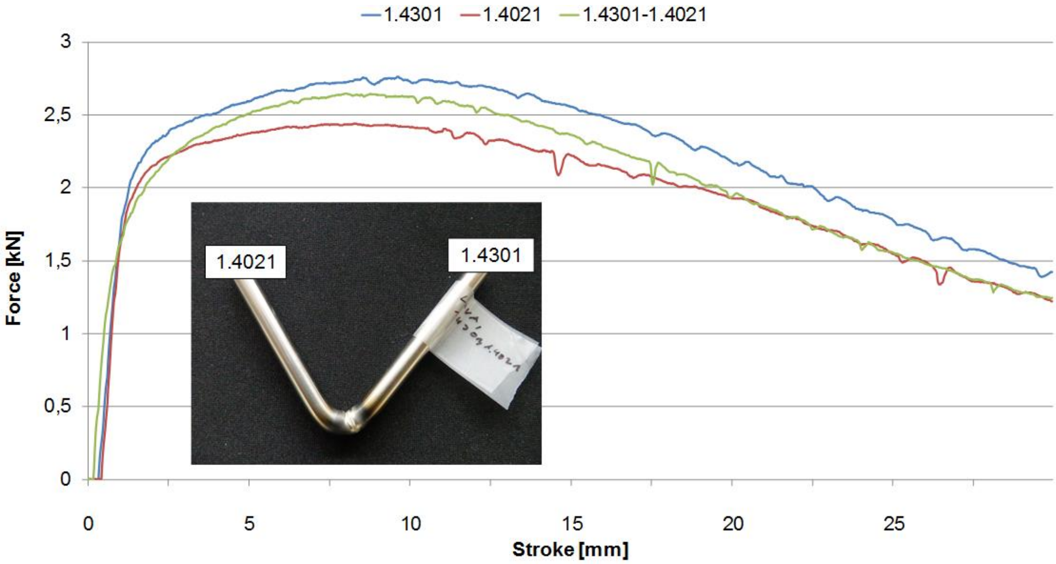

Fig. 4. Results of the three-point bending test of the base material and the composite materials.

Surgical instruments are mainly loaded by bending stresses. To evaluate the deformability behavior three-point bending tests were performed, where the plunger was placed on the weld. *Fig. 4* shows the results of the bending test. The highest bending strength can be detected with X5CrNi18-10 base material and the lowest with X20Cr13. The composite materials are located between the base materials. With increasing stroke length (bending angle) the deformation behavior is growing like X20Cr13. The good weld seam quality and the narrow heat-affected zone results in excellent deformability behavior, despite the high hardness values.

4. Conclusion

Sound welds in dissimilar stainless steel could be realized by laser beam welding under vacuum. The energy input could be reduced significantly compared to laser beam welding at atmosphere. The applied vacuum level of 10 mbar in combination with a minimal inert gas flow protection of the laser aperture safety prevents tempering colors of the process zone. Furthermore, pores can be avoided completely due to the low-pressure atmosphere. It also reduces the cooling rate and therefore the hardness of the martensite. All those effects result in good mechanical properties even without further heat treatment.

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