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Influence of Alloying Elements on Laser in Vacuum (LaVa) Welding of Nickel-Based Alloys

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Abstract

Nickel-based alloys have good resistance to corrosion and/or high temperatures and are therefore used in chemical industry, aviation and power generation. The development of suitable welding parameters for a specific welding task requires resources such as workpieces, personnel and above all time. The understanding of the influence of alloying elements on the seam geometry can reduce these resource requirements. The aim of this work is to determine the influence of alloy constituents on the seam geometry during laser beam welding in vacuum (LaVa) of nickel-based alloys with a seam depth of up to 15 mm at a power of 6 kW. Lava is investigated in order to exploit the advantages of vacuum known from electron beam welding, such as process stability and the higher welding depth at lower system costs.

Keywords: laser in vacuum; nickel-based alloys; weld seam geometry

1. Introduction

The resistance of nickel-based alloys to corrosion and high temperatures has long been the reason for their use for example in chemical industry, aviation and power generation. The development of suitable welding parameters for a specific welding task requires resources such as workpieces, personnel and above all time. The understanding of the influence of alloying elements on the seam geometry can reduce these resource requirements. The aim of this work is to determine the influence of alloy constituents on the seam geometry during laser beam welding in vacuum of nickel-based alloys with a seam depth of up to 10 mm at a beam power of 6 kW. For this purpose, investigations were carried out on the nickel-based alloy Inconel 718, pure nickel, pure iron and S355JR. In order to determine the influence of the working pressure on the seam geometry two working pressures of 100 mbar and 10 mbar were investigated.

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Laser beam welding in vacuum allows a significant reduction of metal vapor during the process and leads therefore so lower vapor density in the capillary. Just some of the advantages compared to laser welding on atmosphere are reduced losses due to absorption of laser power in metal vapor, increasing seam depth and decreasing seam width (Turner).

2. Materials and Methods

The investigation includes four materials: pure iron, Fe 99.8 % (DIN IEC 60404-1); pure nickel, Ni 99.2 % (2.4066, DIN 17740); Inconel 718 (2.4668, NiCr19Fe19Nb5Mo3, DIN 17744); S355JR (1.0045, DIN EN 10025). The chemical composition of the investigated materials is determined by optical emission spectrometry (OES) at Welding and Joining Institute (ISF) RWTH Aachen University (Table 1). The pure iron and pure nickel materials show few impurities. The used Inconel 718 is within the valid range of DIN 17744 and offers with 53.4 % nickel a good comparison between the pure materials. The tests were executed as bead on plate welds with a welding velocity of 30 mm/s and a beam power of 6 kW (Table 2) generated by a 16 kW multi-mode disc-laser (Trumpf 16002) with a spot size of 300 µm, a focal length of 300 mm and a wavelength of 1030 µm. To consider the influence of the focal position on the seam geometry the test pattern was performed with surface focus and 20 mm over- and sub-focusing. The test series A and B differ in the working pressure of 10 mbar and 100 mbar and corresponding to that the shielding gas flow of 4 respectively 18 liters per minute of Argon 4.6 (DIN EN ISO 14175). The gas flow in this case is used to regulate the working pressure. To represent the average seam geometry three cross sections of each weld seam were measured. In addition to the seam depth and the seam width (on the workpiece surface) the melted area was also measured.

Table 1. Chemical composition of investigated materials determined by OES at Welding and Joining Institute (ISF) RWTH Aachen University

	Ni	**Fe**	**Cr**	**Nb**	**Mo**	**Ti**	**Al**	**Co**	**Mn**	**Si**	**C**
pure iron	0.023	99.8	0.015	0.001	0.005	0.001	0.008	0.005	0.024	0.007	0.009
pure nickel	99.2	0.089	0.016	0.015	0.001	0.016	0.021	0.006	0.241	0.143	0.037
Inconel 718	53.4	18.13	18.03	5.35	3.05	1.08	0.467	0.142	0.074	0.043	0.02
S355JR	0.018	97.7	0.156	0.022	0.005	0.013	0.039	0.005	1.568	0.353	0.04

Table 2. Test parameters for test series A and B

	series A	**series B**
working pressure [mbar]	100	10
shielding gas Argon 4.6 [l/min]	18	4
welding velocity v_s [mm/s]	30	30
beam power P [kW]	6	6
focal position [mm] (related to workpiece surface)	-20 / 0 / +20	-20 / 0 / +20

3. Results

The highest seam depth of 10.24 mm was detected in Inconel 718 at surface focus with a working pressure of 10 mbar (Figure 1). The weld seams with a working pressure of 10 mbar are generally slightly deeper than with 100 mbar. A probable reason is the reduced vapor pressure at lower working pressures (Honig, Zhang). Inconel 718 has the highest seam depth for both investigated working pressures and focal positions, whereas pure nickel has always the lowest seam depth. Compared to Inconel 718 pure nickel reaches up to 2.5 mm lower seam depths. Even with 20 mm over- or sub-focusing the seam depth of Inconel 718 is up to 1 mm higher than for the iron materials and up to four times deeper as for pure nickel. This can as well be explained by different vapor pressures; the high fractions of, compared to nickel, lower evaporating chromium and iron in Inconel 718 lead to higher evaporation rates and therefore to deeper seams.

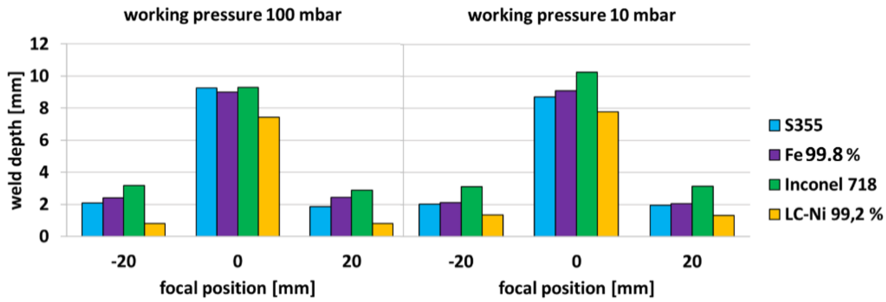

Fig. 1. Weld depths of investigated cross sections at working pressure of 100 mbar (left) and 10 mbar (right)

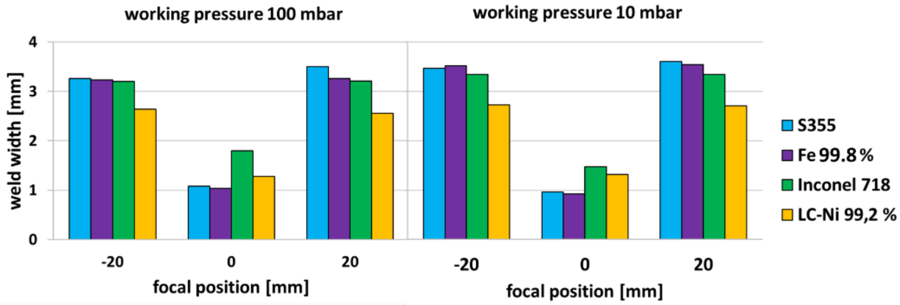

Fig. 2. Weld widths of investigated cross sections at working pressure of 100 mbar (left) and 10 mbar (right)

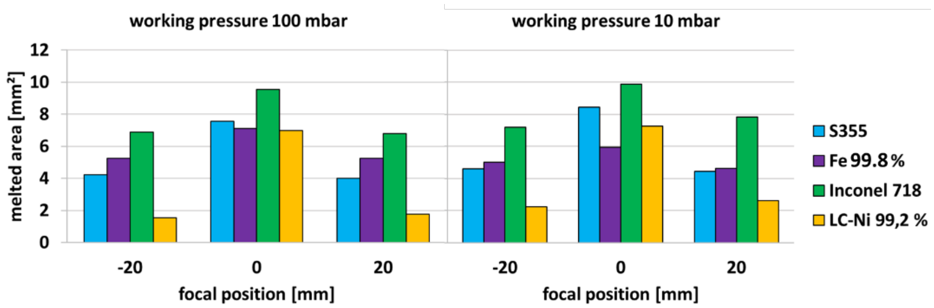

Fig. 3. Melted area of investigated cross sections at working pressure of 100 mbar (left) and 10 mbar (right)

Opposite effects can be found for the iron materials; the weld depth of S355JR and pure iron is quite similar between each other for both working pressures. Considering the seam width at surface focus the same effects can be observed for the iron materials, whereas in this case pure iron has the lowest values of all (Figure 2). For over- and sub-focusing the seam width of pure nickel is smaller than that of Inconel 718, but, in contrast to the seam depth, the iron materials show generally higher values than the nickel materials. The difference between the investigated working pressures is very low.

Looking at the melted area of the investigated materials, Inconel 718 has the highest values, which is connected to the high seam depth (Figure 3). The opposite applies to pure nickel; according to the low seam depth and width, the melted area is comparatively small. Both the nickel materials as well as S355JR show generally slightly higher values for 10 mbar working pressure. In contrast to this the melted area of pure iron is smaller for 10 mbar working pressure for all focal positions. The values of melted areas of the iron materials for over- and sub-focussing differ with up to 21 % at 100 mbar, whereas the deviation is close to zero for 10 mbar. However, for 10 mbar working pressure at surface focus S355 shows 12 % more melted material than for 100 mbar, which is expressed by distinct bulging (Figure 4). Bulging also occurs in the pure iron at 10 mbar, but the melted area is even smaller than with 100 mbar. In return, the seam width at the workpiece surface and in the upper half of the seam depth is smaller. Both nickel materials show no bulging, but a nail-like seam geometry.

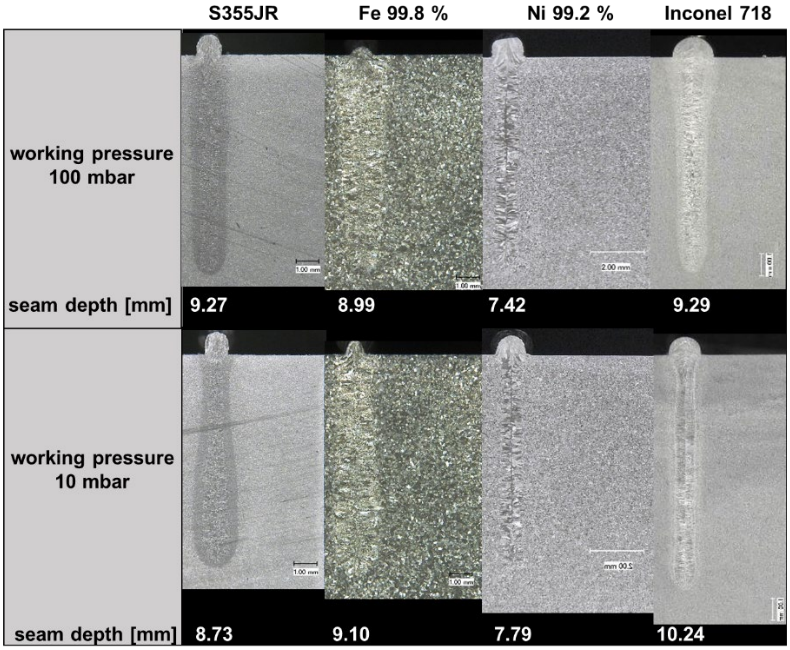

Fig. 4. Cross sections of selected weld seams at surface focus with working pressure 100 mbar (top) and 10 mbar (bottom)

A possible reason for the different seam geometries is the dynamic of the melt pool, the capillary and the vapor plume. Investigations of the capillary show dynamic wave movement in the capillary walls (Chongbunwatana, Li, Pang). The varied working pressure influences the vapor pressure and the surface tension of the melt around the capillary. Therefore, the reflexion of the beam at the melt surface and the energy distribution inside the capillary is influenced as well, which leads to different weld seam geometries.

4. Conclusion

The influence of alloying elements during laser beam welding in vacuum was investigated for selected nickel and iron materials at a working pressure of 100 mbar and 10 mbar. The weld seam geometry can be specifically influenced by changing the working pressure only; even in a small range between 100 mbar and 10 mbar. Both the weld depth as well as the weld width at the workpiece surface and the melted area can be influenced. High fractions of, compared to nickel, lower evaporating chromium and iron in Inconel 718 lead to higher evaporation rates and therefore to higher seam depths in relation to the other investigated materials. Distinct bulging can be created in the iron materials by reduction of the working pressure. Further investigation of the melt surface and the vapor capillary could generate new insights about the different seam geometries in the iron and nickel materials.

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References

Chongbunwatana, K.: Simulation of vapour keyhole and weld pool dynamicsduring laser beam welding. Prod. Eng. Res. Devel. (2014), pp. 499–511.

Honig, R. E., Kramer, D. A.: Vapor Pressure Data for the Solid and Liquid Elements. RCA Review, Vol. 30 (1969), No. 2, pp. 285–305.

Turner, C. et al.: Laser beam welding under vacuum of high grade materials, Weld World (2016) 60:403–413.

Li, S. et al.: Effects of welding parameters on weld geometryduring high-power laser welding of thick plate, Int J Adv Manuf Technol (2015) 79:177–182.

Pang, S. et al.: Dynamic characteristics and mechanisms of compressible metallicvapor plume behaviors in transient keyhole during deeppenetration fiber laser welding. Appl. Phys. A (2016) 122:702.

Zhang, Y., et al: Corrected Values for Boiling Points and Enthalpies of Vaporization of Elements in Handbooks. J. Chem. Eng. Data, 56 (2011), pp. 328–337.