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The influence of pre-heat treatment on laser welding of T-joints of workpieces made of selective laser melting steel and cold rolled stainless steel

S.V. Kuryntsev

Kazan National Research Technical University named after A.N. Tupolev – KAI (KNRTU-KAI), Russian Federation

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ABSTRACT

The details produced by additive manufacturing have limitations in sizes, if you produce large details then there are large residual stresses. It is also economically advantageous to produce complexly configured details by additive manufacturing and then weld them to rolled or wrought cheaper details. The aim of this study is to investigate the influence of pre-heat treatment on laser beam weldability of Selective Laser Welding (SLM) stainless steel to Cold Rolled (CR) stainless steel. The results of metallographic studies and mechanical tests of produced welds are presented. The results showed that the pre-heat treatment of SLM workpieces affects the welded joint strength. The laser welding mode, keyhole or conduction, affected the microstructure and microhardness of the welds.

1. Introduction

Additive manufacturing (AM) are new technologies for the production of metal parts, which over time can replace casting or stamping. It is rational to produce complexly configured details with small wall thickness by AM, for example, ventilated turbine blades, nozzles and other parts. However, currently existing Powder Bed Fusion machines have a relatively small volume of the working chamber. Due to the long production time and the residual stresses accumulation it can be easier to produce parts and weld them together. Therefore, joining AM workpieces with each other or with another metal is an important issue. It is rational to weld AM workpieces to a rolled, wrought or cast workpieces of simple geometric shapes to save the costly metal powder material

As a rule, the welded workpieces thickness is about 1 mm or less and the T-joint or overlap weld connection types are more manufacturable. Laser welding is suitable because it is necessary to weld parts with very small thickness, with the least heat input by heat conduction laser welding (HCLW) or in pulsed mode or with wobbling of laser beam [1]. Laser welding is successfully used for welding of dissimilar metals [2,3] and dissimilar steels [4–6], with both small thicknesses in the conduction or pulsed modes of laser welding and large thickness by keyhole laser welding (KHLW). One way to weld dissimilar metals is to offset the laser beam to a metal with the least thermal conductivity, as in [7]. However, the thermal conductivity of dissimilar steels does not differ so significantly [8] as the thermal conductivity of titanium and aluminum or steel and copper, so there is no need to apply beam offset or preheating of one of the workpieces.

The closest to the AM process is powder metallurgy for which laser welding is successfully used [9]. One of the first studies of laser welding of AM and wrought sheets was [10], in which the authors welded butt joints with thickness over 1 mm, did not use pre-heat treatment and used hybrid laser-arc welding. In [11] the authors compared weldability of stainless steel produced by additive manufacturing and cold rolled metal sheets with the similar chemical composition. The comparison was made by bead on plate the AM and cold rolled sheets under the same modes and comparing the results. As a rule, SLM parts (workpieces produced by AM) without heat treatment have a high level of residual stresses, resulting in cracks appearance in some samples remelted at high speeds. Also differences were found in the penetration depth and types of welding defects.

In [12] the authors describe the study of the welds of Satellite (DMD) and Nimonic (wrought) produced by autogenous laser beam welding. The Satellite samples produced by the DMD-technology were exposed to heat treatment before laser welding. Mechanical tests of the welds showed that the tensile strength of the welds is up to 800 MPa, as well as the positive effect of heat

E-mail address: kuryntsev16@mail.ru

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treatment on ductility. The mechanical and heat treatment in almost all cases is required for workpieces produced by DMD or PBF technologies [13].

Pre- and post-heat treatment has a significant effect on the microstructure and mechanical properties of welded joints [14,15]. Typically, before welding it is necessary to perform annealing at 950 – 1100 °C for 90 min followed by furnace cooling to reduce the residual stresses or to increase the mechanical properties, it is possible to perform tempering at 500–650 °C for 90 min followed by cooling in still air. In [16] the positive effect of heat treatment on the mechanical properties of samples made of PH1 stainless steel produced by PBF is described. Also, the process parameters and manufacturing strategy have a significant influence on the mechanical and surface properties and density of SLM parts [17].

As a rule, one of the problems when welding the dissimilar steels is a large amount of carbon appearing at the boundary and embrittlement of the welded joint. But in this case, the carbon content in both steels is small and the high speed of laser welding contributes to the short residence time of the weld metal in the molten state.

The first aim of this study is to identify the effect of heat treatment on the microstructure and hardness of the PH1 stainless steel produced by SLM. Secondly, determine the influence of the laser welding modes (KHLW and HCLW) on the welded joints formation and its behavior after welding. Thirdly, determine the effect of heat treatment on the weldability and the weld strength.

2. Experimental set-up

The laser machine equipped with Yb laser source was used for laser sintering; beam diameter was 100 μm at laser power 195 W and scan speed 900 mm/s for 40 μm layer. The SLM samples were produced as follows; first a 100 × 100 × 10 mm sample was produced using powder of PH1 stainless steel. Further, the resulting sample was cut by electroerosion machine (EDM) onto plates of about 1.3 mm thick (Fig. 1). After EDM cutting the samples roughness was better than that after AM, which makes it possible not to prepare samples for welding. The chemical composition of SLM PH1steel and CR 321 type stainless steel are presented in Table 1.

The cut AM samples were exposed to heat treatment under the following regimes NHT (no heat treatment), HT1 (1050 °C for 90 min followed by furnace cooling), HT2 (650 °C for 90 min followed by cooling in still air), HT3 (500 °C for 90 min followed by cooling in still air). The electric furnaces SNOL 7.2/1300 were used to carry out the heat treatment (see Table 2).

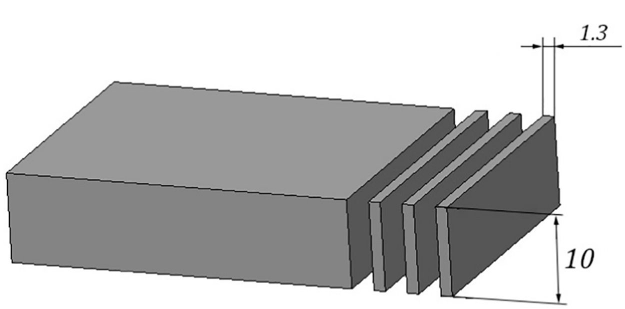

Fig. 1. The scheme of samples were cut off.

Table 2
The regimes of heat treatment and microhardness.

	Heat treatment	HV
0 NHT	No	630
1 HT1	1050 °C for 90 min followed by furnace cooling	548
2 HT2	650 °C for 90 min followed by cooling in still air	585
3 HT3	500 °C for 90 min followed by cooling in still air	724

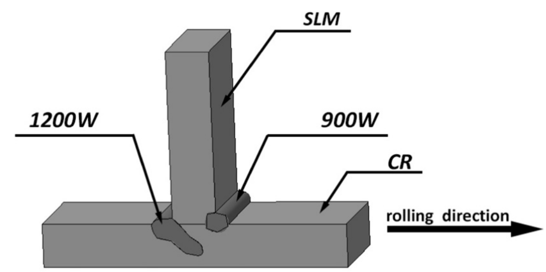

Fig. 2. Welding scheme with the indication of 900 W and 1200 W.

Table 3
Laser beam welding modes.

	Welding speed, mm/sec	Laser Power, W	Angle, ^{0}
First pass	30	900	45
Second pass	30	1200	45

SLM samples of PH1 stainless steel (100 × 10 × 1.3 mm) were welded to CR 321 stainless steel (120 × 20 × 2 mm) in the form of T-joint by laser beam. The welding scheme is shown in Fig. 2, the SLM samples were welded perpendicular to the rolling direction of CR (Fig. 2). The workpieces were sanded by sandpaper and treated with acetone before welding. The laser beam was directed between the workpieces at an angle of 45°. The welding modes are shown in Table 3.

The welding was conducted at the LS-20 of IPG – Photonics (USA) equipped with the robot KUKA KR 120 R 2700 extra HA, laser focusing head KUGLER GmbH, LK-690. The wavelength of YAG fiber laser is 1064 nm, focal length – 450 mm, laser spot diameter is 200 μm. Argon was used as a shielding gas to protect the top part of molten pool, with the purity of 99.99%; flow rate of shielding gas is 17 l/min.

Fig. 3 shows the laser welding system and the workpieces before welding. The cross sections were prepared for microstructure analysis, the reagent $CuSO_4$ 20 g, H_2O 80 ml, H_2SO_4 5 ml, HCl 100 ml was used. The samples were immerged in the etching solution and then polished with a suspension of 9 μm. Study of the microstructure was conducted using the microscope Axiovert Observer.D1m of "Carl Zeiss", metric measurements were carried out using Thixomet image analyzer. The testing machine Shimadzu AG-5kNX was used for mechanical testing (UTS); microhardness was measured by manual equipment Remet HX 1000 at a load of 100 gr. After welding the samples were cut 5 mm wide using

Table 1
Chemical composition of steels wt%.

	C	Si	Mn	S	P	Cr	Ni	Ti	Cu	Fe
321 SS	<0.12	<0.80	<2.00	<0.020	<0.035	18	10	<1.0	–	68
PH1 SS	<0.07	<1	<1%	<0.03	<0.04	15	4.5	–	3.5	75