Journal of Constructional Steel Research 114 (2015) 305–313

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Welding of stainless steel using defocused laser beam

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ARTICLE INFO

Article history:
Received 20 May 2015
Received in revised form 30 July 2015
Accepted 1 August 2015
Available online xxxx

Keywords:
Laser welding
Defocused laser beam
Austenitic stainless steel
Microstructure

ABSTRACT

Type 321 stainless steel has a wide range of applications, including welded constructions. Common arc welding has disadvantages because of low speed and higher heat input that result in significant residual stresses and strains. The alternative to arc welding is laser welding that allows elimination of these negative effects. The results of research on welding of stainless steel with a defocused laser beam are presented and discussed in this paper. It was assumed that the use of defocused laser beam would increase volume of the weld pool that in turn would reduce requirements for preparation of edges and the gap between workpieces. Attention was mainly paid to metallurgical processes of the weld pool formation, depending on the welding conditions. Microhardness of the selected sample was measured, 2D-imaging, metallographic studies, quantitative evaluation of phase components of various zones of the weld pool were conducted. The obtained results prove that the use of the defocused beam allows obtaining quality welded joints, and this technique has also positive influence on the stability of the keyhole, and on the phase composition of the weld metal.

1. Introduction

Currently stainless steels of austenitic, martensitic, duplex grades are widely used in many industries [1,2]. Requirements to reduce weight and increase performance of constructions cause use of more expensive steels of the above grades [3,4]. Corrosion-resistant austenitic steels are extensively used in manufacture of welded components and structures for various purposes [5]. Most common arc welding is mainly used, which has a number of disadvantages for these steels: high coefficient of heat input, low speed, and large heat-affected zone [5,6]. All these factors lead to high level of residual stress, thermal deformations, use of thermal and mechanical treatment after welding, and reduction of corrosion resistance of the weld metal [1,7–9].

Laser welding has several advantages when compared to arc welding: low coefficient of heat input, ability to provide high welding speed, which has positive effect on reducing deformation of welded structures [10]. Besides, high cooling rates provided by laser welding have positive influence on metallurgical processes that affect the phase composition of the weld metal, which determines its performance properties [6,8]. Due to unique properties laser and laser-arc welding are actively used for welding of dissimilar materials [11]. However, there are high requirements to preparation of the weld groove for welding and stability of the gap, if they are not complied with, then the keyhole will be unstable, leading to formation of defects, loss of the weld joint quality [9].

The authors [12] carried out mechanical studies of welded joints of wrought and SLM-technology of steel blanks produced by laser-arc welding, and it was found that selecting certain parameters makes it possible to obtain a satisfactory weld.

K. Kadoi et al. [13] found out that the speed of laser welding of 310S type stainless steel affects the speed and direction of dendrite growth during crystallization, which in turn affects resistance against formation of solidification cracks. Chao Fang et al. [14] conducted a study of mechanical properties of the compounds from 316LN steel, obtained by laser-arc welding in 10 passes. Some of welding passes were obtained by use of a defocused laser beam, which had positive effect on filling of the weld pool of upper passes.

The paper [15] describes an experiment on hybrid welding of 9Cr1Mo stainless steel with grooving and use of cold and hot filler material; three sources of heat and impact of the coefficient ratio of depth to width of the weld bead on the propensity to hot cracking are considered. The authors conclude that the hot wire allows obtaining a welded joint without solidification cracks at a higher coefficient ratio of depth to width of the deposited bead.

The authors [16] study weldability of 17–4 PH martensitic stainless steel, and the following facts were found out: the welding speed does not have significant effect on the depth of the melted through material, but significantly affects formation of pores (10 mm/s, 20 mm/s, 30 mm/s), i.e. the higher the speed the less pores. The shielding gas has significant influence on stability of the keyhole, a gas with a lower molecular weight, higher thermal conductivity generates less plasma, which also significantly influences the porosity.

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http://dx.doi.org/10.1016/j.jcsr.2015.08.004

Table 1
Chemical composition of a specimen, wt %.

C	Si	Mn	S	P	Cr	Ni	Ti	As	Cu
<0.12	<0.80	<2.00	<0.020	<0.035	17.0–19.0	9.0–11.0	<1.00	–	–

Evaluation of dependence of residual stress on the heat input during laser welding is represented in the paper of Wei Liu et al. [17]. The authors concluded that the rate reduction increases the amount of welding heat input, with other parameters being equal, resulting in increased residual stress. This is also consistent with the mathematical model of this process.

Use of defocused laser beam for sealing run of the root is considered in the paper [18]. The authors investigate T-joints obtained by laser welding on the one side with melting through the entire thickness and sealing run on the opposite side. Depending on the welding conditions there are defects on the reverse side in the form of undercuts, lack of penetration and others, to neutralize them sealing run of the root can be used by use of the defocused laser beam for the purpose of remelting defective areas, which will lead to smoothing of undercuts and other defects. 3 kW laser power, 45^0 beam angle, 1.5 m/min welding speed, and different (20, 25, 30, 35, 40, 45, 50 mm) focal lengths are applied for sealing run weld test. The authors conclude that the sealing run of T-joint may be effected by the defocused laser beam, which will provide a greater weld pool, and it will allow to remelt the defects, get a smooth surface, and compensate the lack of penetration in some modes where it is necessary.

All the specified works relate in this or that way to experimental studies performed in this paper, they relate to increase of heat input during welding by defocused beam, and affect of welding conditions on the pore formation, stability of keyhole, metallurgical processes in welding and so on.

This paper describes experimental studies on welding of 321 type stainless steel by use of defocused laser beam, it is anticipated that this will increase the weld pool volume, which in turn will reduce requirements to the gap between the welded workpieces, preparation of edges. Bigger volumes of the weld pool at the same welding speeds will lead to reduction in solidification rate, which is likely to affect the phase composition of the weld metal.

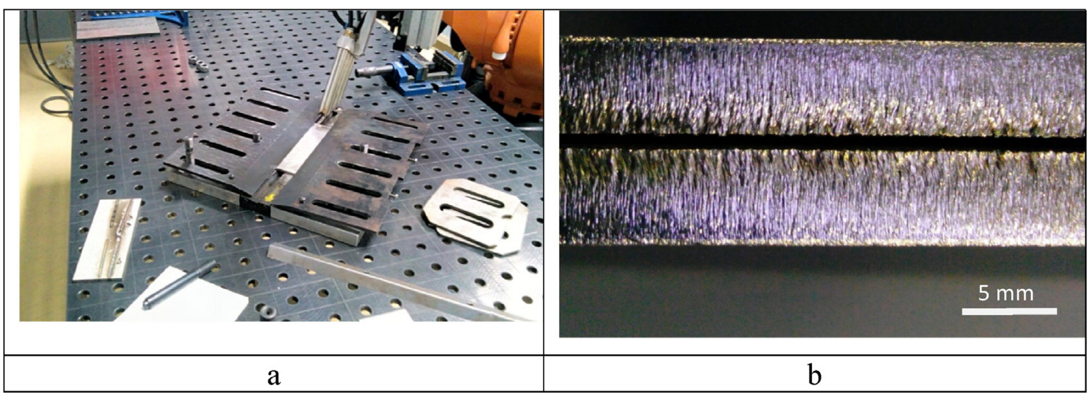

Fig. 1. a — Photo of workpieces before welding and b — quality of edge surfaces before welding.

Bead width, mm	1,69	1,53	1,62	1,37	2,00	2,30	2,50	2,61	3,25
Focus distance, mm	0	+ 5	+10	+ 15	+ 20	+ 25	+ 30	+ 35	+ 40

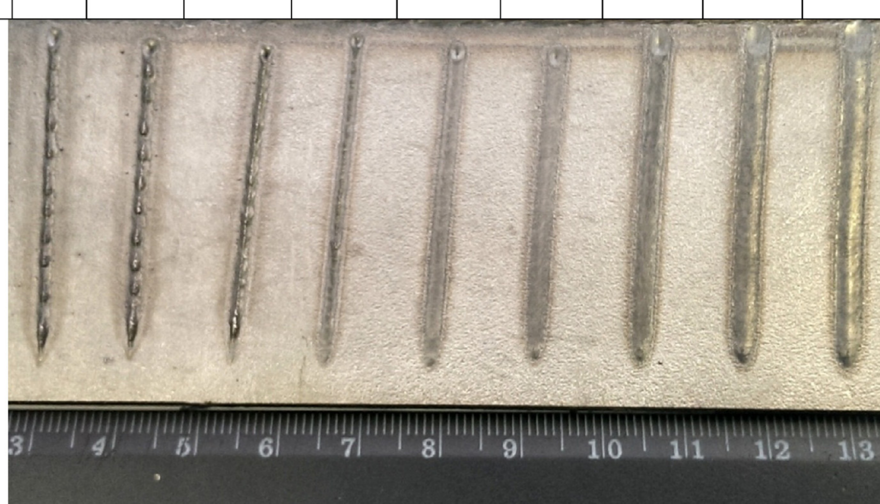

Fig. 2. Bead-on-plate test, welding speed 20 mm/s, laser power 1 kW.