Lasers in Manufacturing Conference 2015

Using the optical measuring techniques to investigate the hot cracking susceptibility laser welded joints

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Abstract

The safety of components or constructions is of great importance in the manufacturing and processing of metallic materials. Solidification cracking as well as the weldability of materials remain still for many years a highly contentious issues, particularly with regard to the causes of the hot crack formation. Many of studies have been conducted to determine the critical condition of occurrence of the solidification cracking. In this study different digital image correlation measuring techniques in conjunction with laser diodes as the illuminating source have been employed to measure the arising strain field during the laser welding process at the surface of the workpiece directed to the laser beam in the close vicinity of the weld pool. The Controlled Tensile Weldability test (CTW) was used to apply an external tensile load during the laser beam welding in order to generate the solidification cracks. The results showed that by means of those techniques it is possible to measure the strain field without any disturbances from the intense welding light or the smoke. Additionally, the strain and the strain rate as a critical factor determining solidification crack formation can be measured and analyzed.

Keywords: solidification cracking; laser beam welding; optical measuring technique; hot cracking test.

1. Introduction

Solidification crack formation is a complex phenomenon, because it is influenced by the interplay of mechanical, thermal and metallurgical factors. From the thermo-mechanical aspect, according to Prokhorov's

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theory Prokhorov, 1956, 1962 critical strains and strain rates that occur during welding in the vicinity of the solidification front are the cause of material separation Fig. 1.

With usual measuring methods, such as inductive displacement transducers or strain gauge, experimental determination of local strain, strain rates causing hot cracks in the high temperature range and in the immediate vicinity of a weld pool is generally difficult.

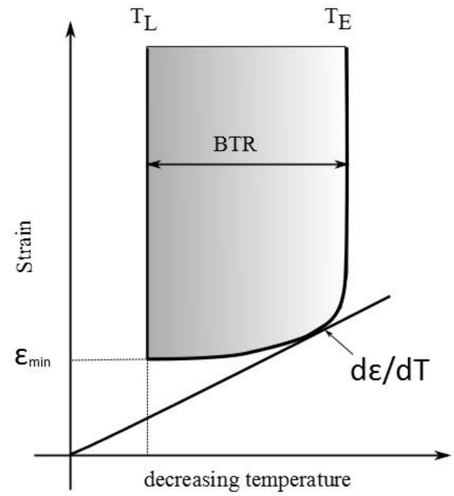

Fig. 1.The concept of brittleness temperature range (BTR) during solidification of metals in the strain-temperature regime Shankar et al., 2003

A goal-oriented optical method for determining local critical strain and strain rates is the so-called MISO (Measurement by Means of In-Situ Observation) method by Matsuda et al., 1982. This method uses a high-speed camera in combination with an optical magnifying device to record hot crack formation. The MISO method performs adequately, excepting the situations, where the difficult optical conditions (smoke, smears) in the vicinity of the weld pool along with the high magnifications lead to an increase in measurement errors. Using the MISO method, strain can be measured only at a certain point taking into account that the critical strain is location-dependent. A digital camera was used by Shibahara et al., 2012a, 2012b to measure in-situ full-field deformation distribution during welding. Quiroz et al., 2012 applied this technique to measure the strain distributions on the specimen bottom surface during bead-on-plate partial penetration laser welding conducted in the CTW test facility thus excluding the influence of laser light and plasma on the image quality. In the present study, the same external-loaded hot cracking the Controlled Tensile Weldability test was applied. The purpose of the study is to measure strain and strain rate measurement in close vicinity of the weld pool with the help of the DIC measurement technique during the hot cracking test.

2. Experimental set-up

To conduct this test, austenitic stainless steel alloy were selected. The steel was CrMnNi (1.4376). A compositional analysis of the alloy is provided in Table 1. It is well known that sulphur and phosphor can enhance the susceptibility of austenitic stainless steel to hot cracking due to their low solubility. These elements can form low melting phases that promote hot cracking. On the other hand the addition of manganese helps to prevent hot cracking by forming manganese sulphide (MnS) rather than iron sulphide Cunat, 2004.

Table 1: Chemical composition (wt-%) of the investigated material

	C	Cr	Ni	Mn	Si	P	S	N	Fe
1.4376	0.03	17.43	4.58	6.73	0.49	0.023	0.003	0.17	Bal.

To investigate the hot cracking susceptibility of this steel, the CTW test facility (shown in Fig. 2) was applied. This test allows the application of tensile strain during welding transverse to the welding direction. The maximal load capacity of the test is 500 kN. The test facility was built on a laser's table while the tensile speed was either constant or increased linearly. The tensile speed and the displacement were set by means of a CNC controller.

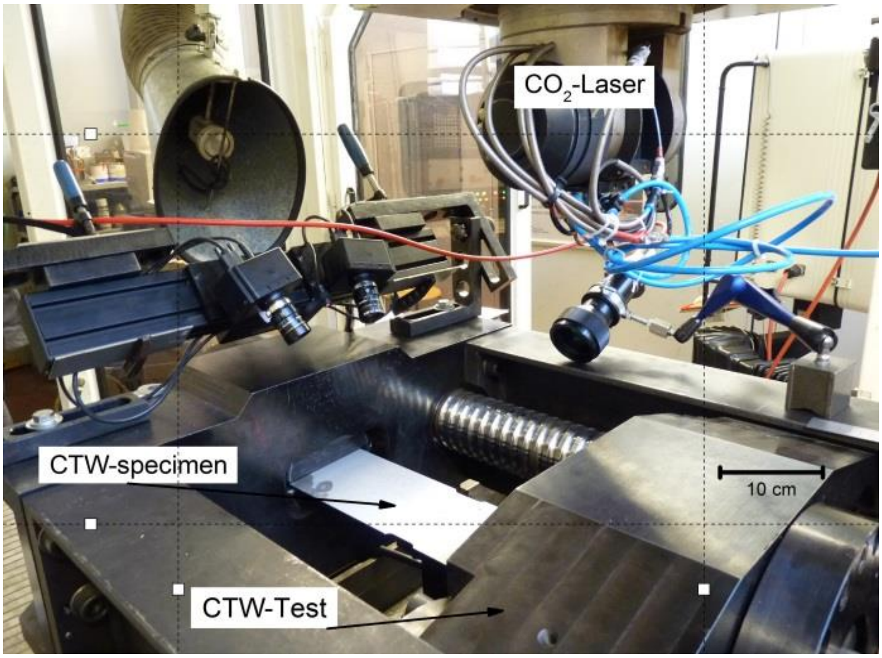

Fig. 2. CTW test facility used in conjunction with CO2 laser welding

Welding was performed with a CO_2 laser at a focal position of 0 mm and a welding speed of 1.2 m/min. The laser power was set to 2.3 kW to produce full penetration welds. The travel path of the laser was 100 mm. Shielding gas Ar/He (50/50) was applied coaxially with the weld surface. Trials were conducted by varying the tensile strain and cross-head speed while keeping the laser parameters constant. Sheets with size 120 mm x 600 mm x 1.45 mm were used as sample specimens. Laser beam welding was started at 5 mm from the specimen edge. The sheets were recessed in the center of the plate over a length of 30 mm to 110 mm in order to transmit the applied strain in this area. The specimen geometry and the schematic illustrations of the experiments are shown in Fig. 3.

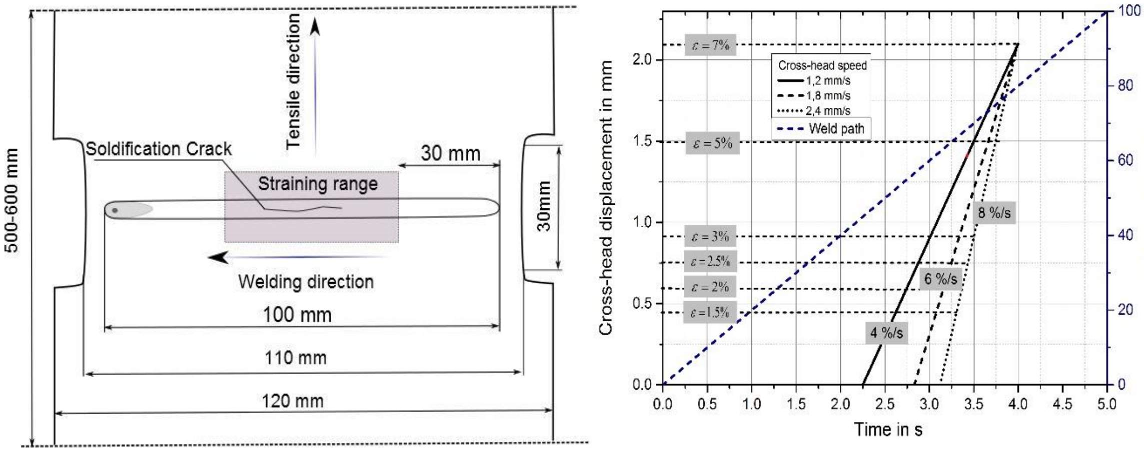

Fig. 3.The specimen geometry and a schematic illustration of the experiment

3. Results and discussion

By observing the crack-no crack behaviour and the generated crack length for each trail, the critical strain and strain rate values that are responsible for solidification cracking formation can be found. The generated crack length as a function of the applied strain and strain rate for the steel grade 1.4376 is shown in Fig. 4 the critical strain responsible for the solidification crack formation for this steel was 3.5 % and the critical strain rate was 6 %/s. At a strain of 3 % and strain rate 4 %/s, no cracks were detected. Generally, it is clearly seen that the crack length increases with increasing global applied strain.

Local strain and strain rate distribution were measured over the test time by means the DIC measurement technique and using an external laser illumination. This procedure allowed to reduce measurement without any disturbance from the intense welding light or the smoke (Fig. 5).

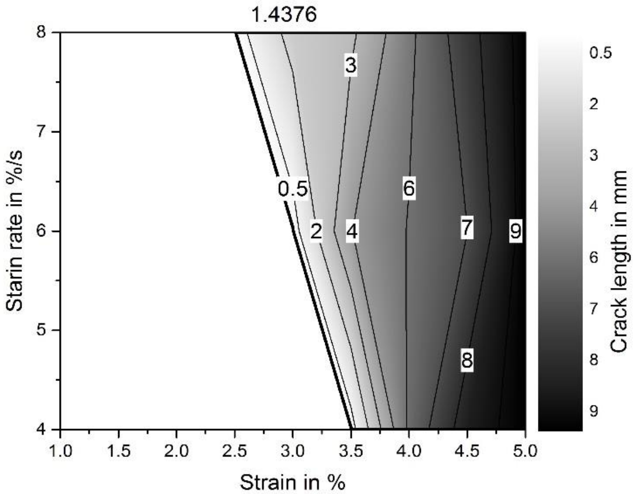

Fig. 4.Crack length as a function of the critical strain and strain rate for the steel grade 1.4376

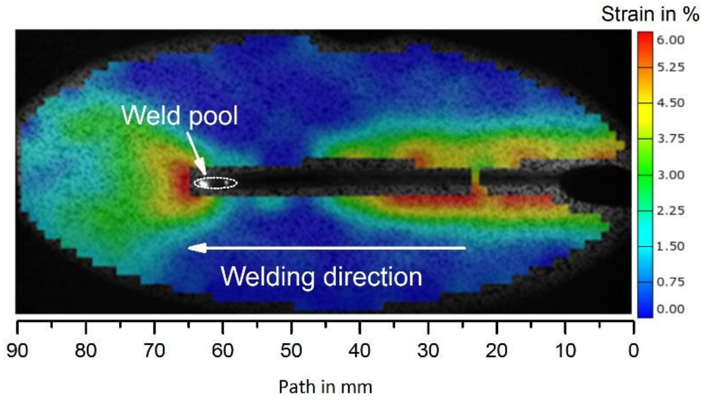

Fig. 5. Transverse strain distribution during welding at 3s, tested at a strain rate of 6%/s and at a strain 7%

The strain and strain rate evolution of three chosen points along the weld during the test (P1, P2, P3) has been analyzed. The selected points were chosen as follows, location of P1 is far enough approximately 25 - 30 mm behind the hot crack front, P2 located next to the hot crack front and P3 after the hot crack front. The time of solidification crack formation can be determined by identifying the crack front location taking into account the length of the weld pool (Fig. 6).

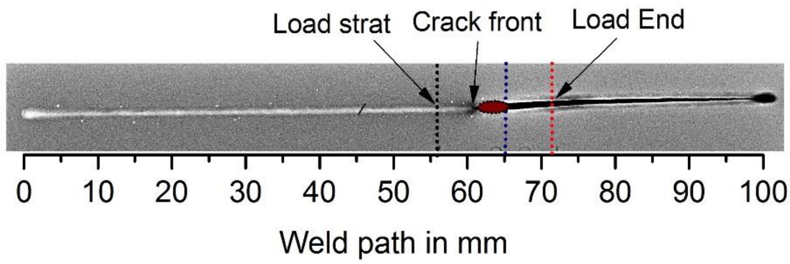

Fig. 6. Radiographic film showing centerline cracks in the CTW test specimen

Fig. 7(a) also shows the transverse strain distribution for a trial tested at global strain 5 % and strain rate 6 %/s. The local strains increase slowly at the beginning of the process, and start first to rise in the heated areas (P1 in Fig. 7 to 4.65 s). Not heated material exhibits very low strains close to zero. The measuring point P2 was placed as close as possible to the beginning point of the hot crack. In this case, the thermal expansion and the external strain are superimposed.

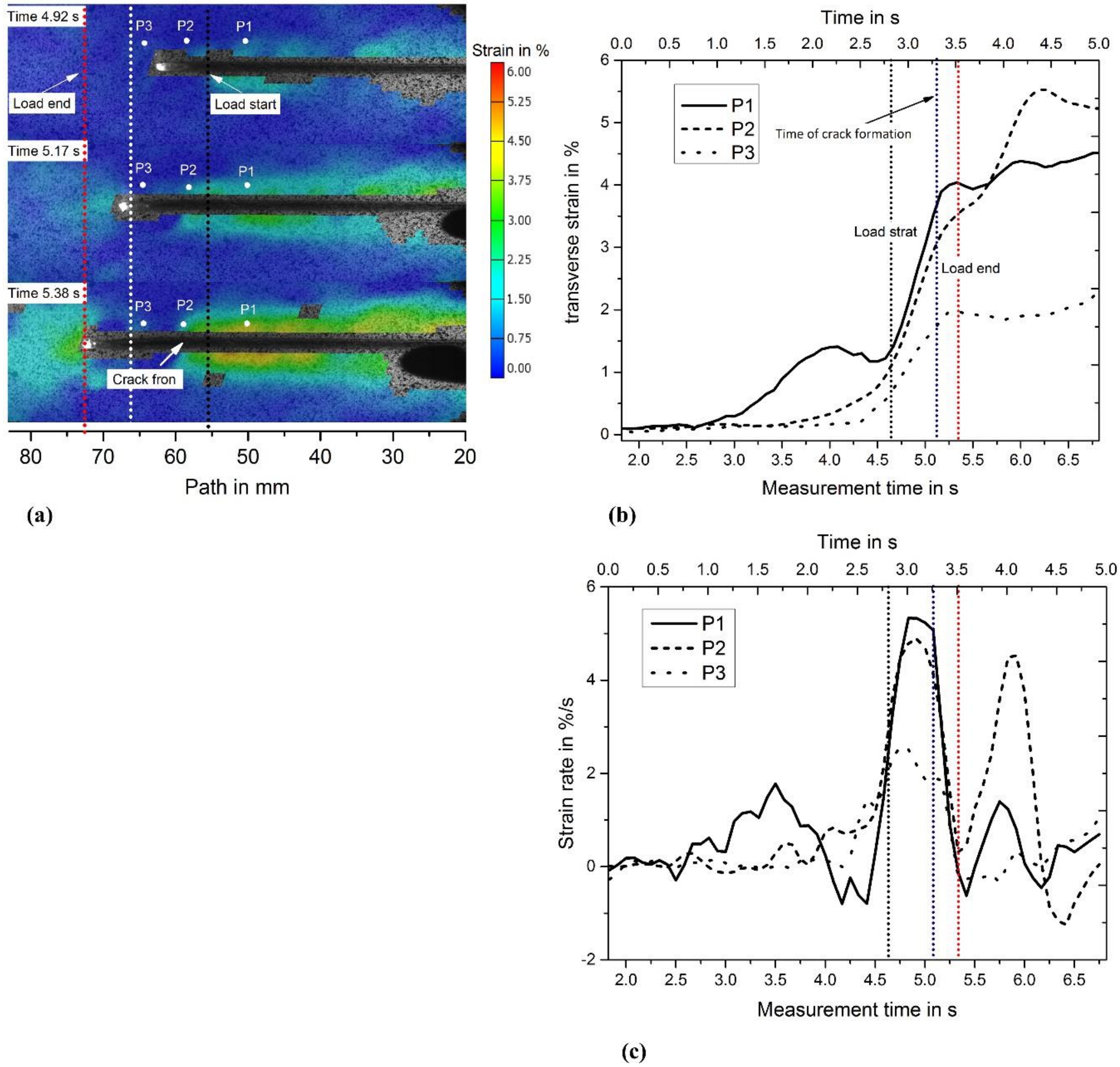

Fig. 7. (a) transverse strain distribution during the welding, (b) strain evolution of (p1,p2 and p3) over the time, (c) strain rate strain evolution of (P1,P2 and P3) over the time for the steel type 1.4376.

At this point the measured strain reaches its maximum value of 3.9% at the end of stress. According to the radiographic film of this trial, the laser location at the moment of crack formation must be approximately. at value 66 mm or 3.3 s. By referring to this time point at the measurement location P2 the measured local strain and strain rate is 3.1 %, 4.3 %/s (see the blue dotted line in the Fig. 7(a) and (c)) The measuring point P3 represents the material adjacent to the cracked weld. Again, the strain increases due to thermal expansion. Since the measuring point is next to the cracked material, the external stress has no effect here.

4. Conclusion

In this study, hot cracking susceptibility in laser beam welding was assessed for 1.4376 stainless steel by means of the CTW test. Using this test a centerline solidification crack was generated. Additionally, the Digital Image Correlation technique was applied in conjunction with an external diode laser as an illumination.

The results show that hot cracking must be expected at an external strain of 3 % and strain rate 6 %/s for the investigated material. The total crack length increases with increasing externally applied strain or strain rate.

This optical measuring system allows the measuring the local strain and strain at the surface of the workpiece directed to the laser beam in close vicinity of the weld pool. The critical local strain and strain rate which are responsible for the initiation of solidification cracking has been determined at 3.1 %, 4.3 %/s respectively.

Acknowledgements

This work was supported by the Research Association for Steel Application (FOSTA) , the Federation of Industrial Research Associations AiF, and the German Federal Ministry for Trade, Industry and Technology (BMWi Bundesministerium für Wirtschaft und Energie) (Project 17781 N, 'Development of a method for the investigation of hot cracking resistance of laser welded joints').

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