Materials and Design 121 (2017) 11–23

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

A novel arc heat treatment technique for producing graded microstructures through controlled temperature gradients

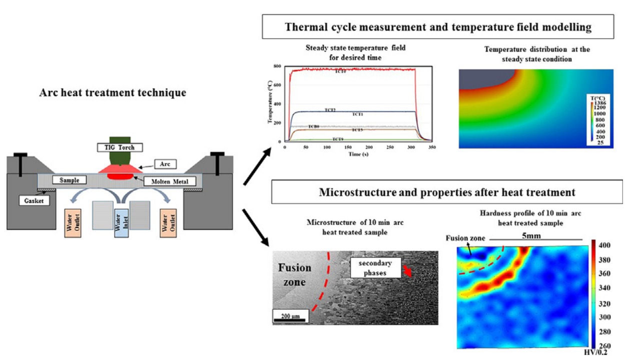
Vahid A Hosseini [a,b,*], Leif Karlsson [a], Kjell Hurtig [a], Isabelle Choquet [a], Dirk Engelberg [c], Matthew J. Roy [d], Chamara Kumara [a]

[a] Department of Engineering Science, University West, SE-461 86 Trollhättan, Sweden
[b] Innovatum AB., Trollhättan, SE-461 29 Trollhättan, Sweden
[c] School of Materials, The University of Manchester, Manchester M13 9PL, UK
[d] School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, Manchester M13 9PL, UK

HIGHLIGHTS

- A new heat treatment technique was introduced for the physical simulation of materials processing using a stationary arc.
- Steady state temperature distributions can be achieved and maintained, for different holding times.
- The technique can be used to simulate conventional heat treatment, welding, multi-step heat treatments, and etc.
- Arc heat treatment was successfully applied on a super duplex stainless steel and temperature distribution was modelled.
- The alloy showed the formation of secondary phases and microstructure sensitization in the temperature range 850–950 °C.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 January 2017
Received in revised form 7 February 2017
Accepted 14 February 2017
Available online xxxx

Keywords:
Stationary arc
Heat treatment
Graded microstructure
Super duplex stainless steels
Physical simulation
Welding

ABSTRACT

This paper introduces a novel arc heat treatment technique to produce samples with graded microstructures through the application of controlled temperature gradients. Steady state temperature distributions within the sample can be achieved and maintained, for times ranging from a few seconds to several hours. The technique reduces the number of samples needed to characterize the response of a material to thermal treatments, and can consequently be used as a physical simulator for materials processing. The technique is suitable for conventional heat treatment analogues, welding simulations, multi-step heat treatments, and heat treatments with controlled heating and cooling rates. To demonstrate this technique, a super duplex stainless steel was treated with a stationary TIG arc, to confirm the relationship between generated steady-state temperature fields, microstructure development, hardness, and sensitization to corrosion. Metallographic imaging and hardness mapping provided information about graded microstructures, confirming the formation of secondary phases and microstructure sensitization in the temperature range 850–950 °C. Modelling of temperature distributions and thermodynamic calculations of phase stabilities were used to simulate microstructure development and associated welding cycles.

* Corresponding author at: Department of Engineering Science, University West, SE-461 86 Trollhättan, Sweden.
E-mail addresses: vahid.hosseini@hv.se (V.A. Hosseini), leif.karlsson@hv.se (L. Karlsson), kjell.hurtig@hv.se (K. Hurtig), isabelle.choquet@hv.se (I. Choquet), d.engelberg@manchester.ac.uk (D. Engelberg), matthew.roy@manchester.ac.uk (M.J. Roy), chamara.sandun@hv.se (C. Kumara).

http://dx.doi.org/10.1016/j.matdes.2017.02.042
0264-1275/© 2017 Published by Elsevier Ltd.

1. Introduction

The outcome of a heat treatment (HT) is dependent on knowledge about the combined effects of time and temperature on the microstructure of an alloy. This information is usually summarized in time-temperature transformation (TTT) and continuous cooling transformation (CCT) diagrams. The conventional way to produce TTT and CCT diagrams is to heat treat a large number of samples, with each point in TTT diagrams representative of an experiment performed at a specific time and temperature. The method is time consuming and it is impossible to cover all temperatures, even though the Avrami equation has been shown to be able to extrapolate or interpolate to areas in TTT diagrams without any experimental data [1,2]. Conventional heat treatment methods also fail to simulate welding cycles, because heating and cooling rates during welding are normally faster than furnace responses.

Physical simulation tools provide new possibilities for simulating heat treatment of materials, with the ability to generate microstructure close to real material processing conditions [3]. The DSI Systems Gleeble thermal-mechanical-simulator, for example, is widely used in simulation of weld heat affected zones [4,5], and is also capable of applying thermo-mechanical treatments on samples [3,6]. These simulators, however, are expensive and applied temperature gradients are often quite different to those experienced in real welding due to how heat is applied.

Another technique to produce welding thermal cycles in a controlled manner was introduced by remelting a plate with several bead-on-plate tungsten inert gas (TIG) welding passes. Hosseini et al. [7–9] applied this method to investigate the effect of multiple thermal cycles on the microstructure and corrosion resistance of a super duplex stainless steel (SDSS). A graded microstructure was formed in the heat affected zone (HAZ) after applying up to four TIG passes. The technique provided data about the kinetics of nitrogen loss in the weld zone and the evolution of nitride and sigma phase contents in the HAZ. It was possible to investigate the evolution of microstructures produced over a wide range of peak temperatures (melting point to room temperature). However, the technique could only be used for continuous cooling and the number of runs was limited due to the distortion of the plate [7–9]. Compared to a typical Gleeble equipment, it produced real welding temperature gradients and relevant graded microstructures.

Another method to physically simulate weld metal and HAZ was introduced by Glickstein et al. [10]. They applied a stationary TIG arc on a stationary plate to investigate the welding parameters for Alloy 600. The plate was fixed, but no backing plate or coolant was used. In this work, thermal cycles were recorded and the evolution of the weld pool was studied for arc times up to 10 s. Glickstein et al. [11] also modelled the evolution of heat affected zone (HAZ) width with arc exposure time using the same experimental method. No microstructural investigations were performed on the fusion zone and HAZ. A stationary arc was also employed to investigate the evolution of weld pools in other studies [12]. Hertzman et al. [13] used a stationary arc to investigate the nitrogen absorption and desorption kinetics in duplex stainless steels. A stationary arc has also been used as a part of a calorimetry device to calculate the arc efficiency of the TIG welding process [14].

This paper introduces a novel arc heat treatment technique, in which a wide range of temperatures can be produced simultaneously in a single sample for selected holding times ranging from a few seconds to several hours. A SDSS was chosen as a pilot material to evaluate the technique, since changes in the ferrite/austenite balance and precipitation of secondary phases are strongly dependent on the applied thermal cycles and of great importance for resulting properties for this group of alloys [15–18]. The focus of the present study is on the characteristics and possible applications of this arc heat treatment technique, which can be used to generate a wide range of thermal cycles and graded microstructures. The paper first introduces the arc heat treatment technique with possible applications, modelling of the temperature distribution in the arc heat treated sample, followed by characterization of the arc heat treated SDSS sample. Finally, the correlation between microstructures predicted by thermodynamic calculations, measured and modelled temperature fields, hardness and observed microstructure is discussed.

2. Materials and methods

The present section is aimed at describing the procedure of the arc heat treatment technique. Moreover, the modelling of temperature distribution in the arc heat treated sample is explained and finally the methods used to characterize the graded microstructure are detailed in this section.

2.1. Experimental setup and heat treatment technique

The schematic setup of the arc heat treatment device is illustrated in Fig. 1. A disc was bolted to the top of a chamber containing circulating water. The concept of the present design was to impose symmetric heat extraction of the center of the disc during arc heating. Water cooling was started an hour before the experiment to have a stable

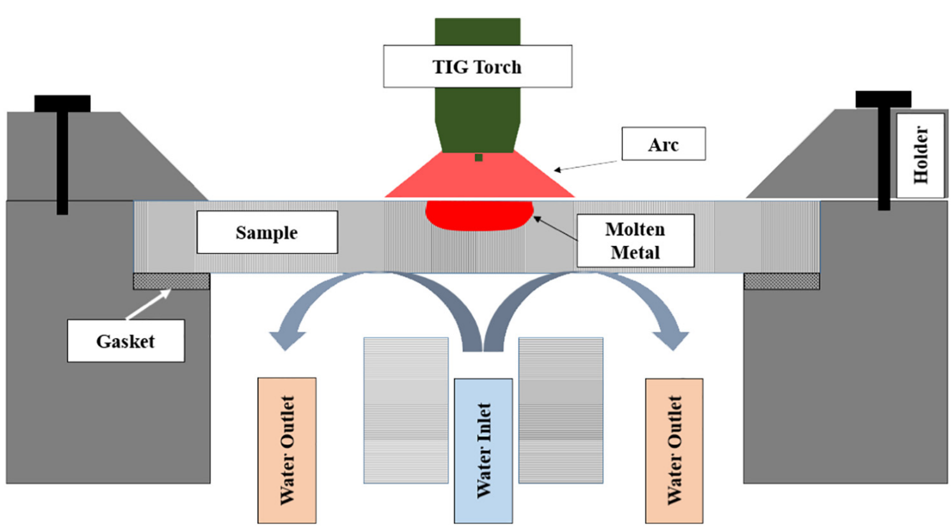


Fig. 1. Schematic illustration of the arc heat treatment method. The arc is applied on top of the water-cooled disc.