Marine Structures 44 (2015) 232–253

Contents lists available at ScienceDirect

Marine Structures

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

Prediction of residual stresses induced by low transformation temperature weld wires and its validation using the contour method

Ramy Gadallah [a, *], Seiichiro Tsutsumi [b], Kazuo Hiraoka [b], Hidekazu Murakawa [b]

[a] *Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[b] *Joining and Welding Research Institute, Osaka University, 11-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan*

ARTICLE INFO

Article history:
Received 14 April 2015
Received in revised form 11 August 2015
Accepted 11 October 2015
Available online 31 October 2015

Keywords:
Contour method
Simulated contour method
LTT weld wires
Compressive residual stresses
Martensitic transformation start temperature
FEM

ABSTRACT

Welding residual stresses are one of the main factors influencing the engineering properties of welded structures, and should be taken into account during designing and manufacturing products such as ships, bridges, etc. Recently, both computational and experimental methods play a significant role for providing residual stresses. The contour method (CM) became one of the most powerful techniques that can provide measurement of residual stresses normal to a plane of interest. In this method a component is cut at any plane of interest. Displacements normal to the cut surface are measured and then processed. Using the Thermal–Elastic–Plastic Finite Element Method (TEP-FEM), residual stresses after welding can be predicted. As well as, the elastic FEM can be used to reproduce residual stresses from measured longitudinal displacements in the CM.

The main objective of this paper is to evaluate the effectiveness of different low transformation temperature (LTT) weld wires using TEP-FEM and the CM. In the simulation part, a computational approach is developed to numerically simulate both of welding and the CM. In the TEP-FEM, phase transformation is considered for LTT welds, additionally volume change and variation of mechanical properties with temperature are considered. In the simulated CM, welded specimens to be measured are replaced by TEP-FE models. Then the procedure of the CM is examined before applying it to real measurements. The simulated CM successfully

* Corresponding author. Tel./fax: +81 6 6879 8645.
E-mail address: gadallah@jwri.osaka-u.ac.jp (R. Gadallah).

http://dx.doi.org/10.1016/j.marstruc.2015.10.002
0951-8339/

predicted how the CM would reconstruct the residual stresses if applied experimentally. In the experimental part, welding is conducted using conventional and various LTT weld wires. Longitudinal residual stresses produced due to welding are measured using the CM. The results of TEP-FE simulation and the CM show the effectiveness of the different LTT weld wires in introducing compressive stresses in the weld. It is also observed that the applied LTT weld wires, which have almost the same martensitic transformation start temperatures, do not show big difference in the induced compressive residual stresses in the weld metal.

1. Introduction

Controlling the induced residual stresses are most common concerns in welding of high strength steels. Kannengiesser et al. described that the safety of welded high strength steel structures demands for the precise knowledge of the distributions of the residual stresses that is induced due to welding, which greatly influence the crack resistance and the service load [1]. Murakawa et al. mentioned that residual stresses are of concern because they are often on the order of the material yield stress and hence lessen the service loads that can safely be borne by the structure, in case of static loading and fatigue [2]. Altenkirch et al. reported that a reduction in the maximum endurable load of a component is due to the superposition of the in-service tensile loads with the induced welding residual stresses especially when these stresses are tensile [3]. Thus, the additional tensile residual stresses weaken the fatigue performance of welded joints as described by Ohta et al. [4]. Hence, how to control and reduce welding tensile residual stresses or even to introduce compressive stresses to the weld is a vital task both in designing structures and welding processes.

Various mechanical as well as thermal in situ and post-weld treatment methods and combinations of these methods are available for application during or after welding process in order to reduce detrimental tensile residual stresses or to generate compressive stresses. Murakawa et al. discussed that number of mitigation techniques have been proposed for reducing tensile welding residual stresses such as post weld heat treatment, shot peening, modification of the structural configuration and implementation of the thermal tensioning technique [5]. In the same context, Miki and Anami mentioned that diverse fatigue strength improvement methods have been proposed and some of these methods have been applied for real steel structures, such as TIG-dressing, peening and grinding [6]. Altenkirch et al. addressed that it is appropriate to directly generate beneficial residual stresses (i.e. compressive residual stresses) during the welding process, in which the post-weld treatments are cost intensive and time consuming or even impractical due to the complexity of large or inaccessible welded joints as in case of ship building or pressure pipe welded components [3]. Barsoum and Gustafsson reported that the fatigue strength can be improved if the crack keeps closed during the fatigue loading and this can occur when compressive residual stresses are introduced to the component [7]. Bhatti et al. stated that considerable reduction in tensile welding residual stresses as well as an improvement in fatigue strength can be achieved by using low transformation temperature (LTT) weld wires instead of conventional wires [8].

Ota et al. explained a technique that can induce compressive residual stresses in welds by exploiting the phase transformation expansion due to austenite to martensite phase transformation [9]. Darcis et al. mentioned that, in these LTT alloys, martensitic phase transformation in an unconstrained specimen starts at about 180 °C and completes at room temperature [10]. Whilst normal steel alloys that used in weld fillers have phase transformation temperatures around 400 °C–600 °C [10]. Thomas and Liu reported that martensite has a lower density than austenite and therefore there is a 4–5% increase in martensite volume due to the austenite to martensite phase transformation [11]. Based on the use of LTT alloys, martensitic phase transformation causes compressive residual stresses at ambient