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Issues in numerical modeling of phase transformations in welded joint

Wiesława Piekarska[a*], Marcin Kubiak[a], Milan Żmindak[b]

[a] *Institute of Mechanics and Machine Design Foundations, Częstochowa University of Technology, Dabrowskiego 73, Częstochowa, Poland*
[b] *University of Žilina, Faculty of Mechanical Engineering, Žilina, Slovak Republic*

Abstract

This work concerns issues of mathematical modelling of phase transformations in steels during a high-speed high-power heat source welding processes. The analysis of the influence of thermal cycle parameters such as: heating rate, cooling rate and the maximal heating temperature on the kinetics of phase transformations during heating and cooling is performed. The verification of classical mathematical and numerical models of phase transformations is presented in relation to advanced welding methods using a high-speed high-power heat source on the basis of data found in the literature and experimental research.

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Keywords: phase transformations; numerical modeling; laser welding;

1. Introduction

Varying conditions of heating and cooling during the welding process result in a different structures occurring in the joint, having different mechanical properties. Changes in the microstructure of heat affected zone (HAZ), including phase transformations in solid state are the cause of significant changes in the mechanical properties of this area compared to properties of the base material [1,2]. Resultant structure in HAZ of welded steel depend majorly on thermal cycle parameters, such as: heating rate, maximal heating temperature and cooling rate. The analysis of the kinetics of phase transformation is carried out by well known mathematical models found the literature and Continuous-Cooling Transformations (CCT) diagrams. The analysis of phase transformations in classical welding methods is usually carried out for cooling process where cooling rates determine the type of final structure of the joint. The influence of maximum temperature of thermal cycle is substantially omitted in this case of steel heating, which is not a problem because maximum temperatures do not vary to a great extent [3-7].

However, in the case of advanced welding methods by using a focused high power heat sources, such as: a laser beam welding or a laser-arc hybrid welding [8] a high heating rates as well as very high and various maximum

*Corresponding author. Tel.:+48 34 325 06 99; fax: +48 34 325 06 47.
E-mail address: piekarska@imipkm.pcz.pl

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heating temperatures of steel occur [9]. Therefore, the influence of both heating rates and maximum temperatures of the thermal cycles on the kinetics of phase transformations should be taken into account during the modeling of welding process.

The paper presents issues concerning the analysis of the kinetics of phase transformations in relation to welding process using a high-speed heat source with a highly concentrated power intensity. The issue is defined, mathematical and numerical models are presented for phase transformations as well as the modification of numerical models of the prediction of phase composition in the welding process, determined on the basis of literature data and experimental research.

2. The influence of thermal cycle parameters on the kinetics of phase transformations in solid state

Heating speed has an essential impact on the temperature of the formation of austenite (Fig. 1). Start and finish temperatures of base structure transformation into austenite (Ac_1 and Ac_3) significantly increase in the case of rapid heating to the maximum temperature of thermal cycle during welding (reaching hundred K/s in the case of classical electric arc welding and even few thousands K/s in the case of laser or laser arc welding processes). This is confirmed by literature data and dilatometric research (Fig. 1). The influence of heating rate on the increase of start and finish temperatures of $\alpha \rightarrow \gamma$ transformations can be different for various steels. The increase of ΔAc_3 temperature in a function of heating rate for different steels is illustrated on Fig. 1a [10], whereas Fig. 1b presents the change of Ac_1 and Ac_3 depending on heating rates of S460 steel.

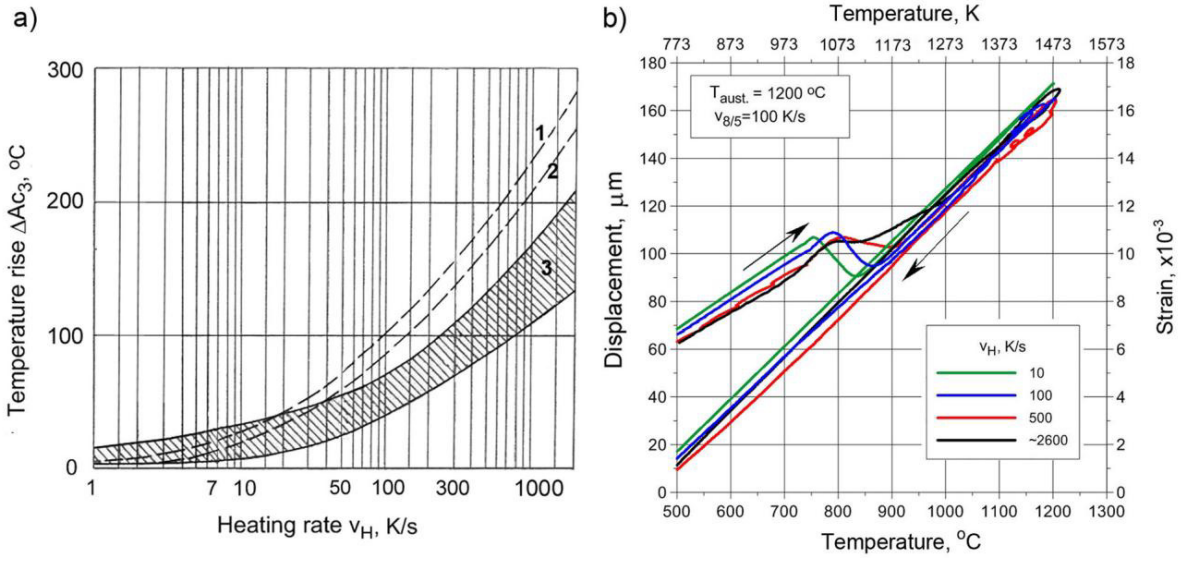

Fig. 1. a) The influence of heating rate on the increase of Ac_3 temperature: 1-structural steel (~0.4 %C), 2-alloy steel, 3-weldable, higher strength steel [10], b) dilatometric curves for S 460 steel heated by using different heating rates.

Phase transformations during cooling process and resulting changes in specific volume, and consequently the properties of the heat affected zone are dependent on cooling rates (Fig. 2a). A maximum heating temperature has also a significant effect on the kinetics of phase transformations during cooling. Research show that higher heating temperatures contribute to the formation of lower temperatures of phases initiation (Fig. 2b). Such dependence is confirmed by the results of dilatometric tests conducted by the authors of [11] for S355 high-strength steel (Fig. 3a) and DC04 steel (Fig. 3b), assuming different heating temperatures at constant conditions of heating and cooling.