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A novel procedure to account for high temperature gradients in an induction dilatometer sample during rapid heating

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Abstract

Investigations of the length changes upon heating and cooling due to thermal expansion alone or its combination with phase transformations are often investigated using dilatometry. In dilatometric measurements with high heating rates a large longitudinal temperature gradient within the sample hinders an accurate investigation of the physical effects. In this study we examine the longitudinal temperature gradient and its effect on the measured length change for a wide range of heating rates. Maximum temperature differences of 160 °C for a maximum temperature of 570 °C within the sample are measured. A correction method based on a numerical model of the dilatometric experiment is developed and tested. The presented method allows an accurate and flexible method for correcting the interfered length change and exact interpretation of dilatometric data for high heating rates and complex time temperature profiles.

Keywords: Dilatometer, Induction heating, Phase transformations, Heat equation, Temperature gradient, Longitudinal end effect

1. Introduction

In many modern heat treatment processes, like contact heating for press hardening [1], induction hardening [2] or laser hardening [3] very high heating rates up to 10 000 °C/s are occurring. These high heating rates are influencing the microstructural development and the resulting mechanical properties of the material. The investigation and detailed understanding of phase transformation during rapid heat treatment of steels is of great importance to improve their performance.

Dilatometry is an established technique to precisely measure the dimensional change of a metallic specimen due to a temperature change. It does not only provide information about the thermal expansion, if solid-solid phase transformations with a detectable specific volume change are present dilatometry also provides a tool for in-situ investigations of these processes. [4, 5, 6, 7, 8, 9, 10]

Fig. 1 shows the schematic setup of a common push-rod dilatometer (DIL 805 by TA Instruments in this case). The specimen is held between two push rods usually made of fused silica or alumina. One of the push rods is fixed, the other is connected to a linear variable differential transformer (LVDT) and transmits the dilatation of the specimen. The specimen is placed in the center of a induction coil, allowing high heating rates. The coil incorporates a second perforated coil for gas quenching. Temperature is controlled by a Pt-$Pt_{90}Rh_{10}$ thermocouple (type S) spot welded on the center of the specimen. To avoid possible oxidation the complete measurement setup is enclosed by a vacuum chamber.

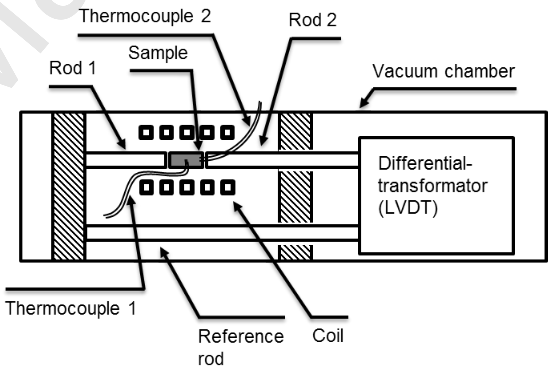

Figure 1: Set-up of the dilatometer measurement unit. Thermocouple 1 measured the temperature in the center and controls the process, thermocouple 2 measures the temperature at the end of the sample

With the described setup dilatometric measurements with high heating and cooling rates are possible. But this setup also introduces some errors. Often a temperature gradient from the center of the specimen to its end is observed [8, 11, 12, 13]. Kop et al. [13] reported that the temperature difference between the center of the specimen and the end remain within 10 K for low heating and cooling rates. For higher heating rates the temperature inhomogeneity is increasing as indicated by Mohapatra et al. [8].

This longitudinal temperature gradient is usually attributed to heat conducted from the specimen to the not inductively heated push rods [8, 12]. Because of this temperature gradient direct conversion of the measured length change is not feasible. Prevention of the longitudinal temperature gradient is difficult if not impossible. One solution to decrease the temperature

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