A Novel Technique for Studying of Phase Transformations
Part I: Single Sensor DTA, Development and Verification

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Introduction

Phase transformations during welding determine the final microstructure of welded joints and hence their mechanical and in-service properties. These phase transformations are also critically connected to the weldability of structural alloys. The available experimental methods for studying of phase transformations have limited applicability in welding conditions.

A novel Single Sensor Differential Thermal Analysis (SS-DTA) technique has been recently developed at the Ohio State University. This technique allows investigating the solid-liquid and solid-state phase transformations during actual processing by welding and other thermo-mechanical applications. The SS-DTA has tremendous application potential in development of new alloys, welding consumables, and welding procedures.

Technical Approach

The SS-DTA is based on digital acquisition of weld thermal data and analytical or numerical modeling of a reference thermal history. The temperature difference between the measured and the reference thermal histories is plotted as a function of the temperature to reveal the heat of reaction effects that accompany the individual phase transformations.

The accuracy and reliability of SS-DTA is verifyied by comparison to the classic DTA and dilatometry, by measuring the solidification temperatures of pure metals and eutectic alloys, and by determinig the feromagnetic/paramagnetic transition temperature in feromagnetic metals. The response time of various thermocouples is also evaluated.

Results and Discussion

The comparison to the classic DTA has proven that SS-DTA has equal accuracy in determining the starting temperatures and better resolution in measuring the finishing temperatures of phase transformations and structural changes. These investigations covered: 1) the decomposition of austenite and the magnetic transition in steels HSLA 65 and P91, and in Armco Iron; 2) the precipitaion of cementite in Armco Iron and of an intermetallic phase in a Ni-base consumable.

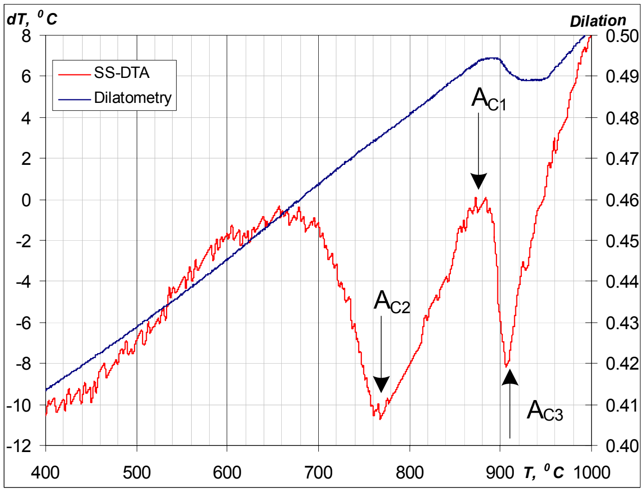

Figure 1: Comparison of SS-DTA to dilatometry. A_{C2}, A_{C1} and A_{C3} in Armco Iron, heating rate 57 ^{0}C/s.

The comparison of SS-DTA to dilatometry has shown that SS-DTA has equal acuracy and superior sensitivity to the typical welding soild-state phase transformation. This comparison included: 1) the ferrite-austenite transformation in Armco Iron (**Figure 1**) and the martensite reversion in high-chromium powerplant steels, in supermartensitic, and in cold worked austenitic stainless steels during heating; 2) the delta-ferrite to austenite and the austenite to primaty ferrite, acicular ferrite, bainite, and martensite transformations in a range of steels and wled metals during cooling.

The high sensitivity of SS-DTA to the heat effect of magnetic transition allowed estimating the response times of type K and R thermocouples in the case of direct contact with metal surface. This parameter determines the reliability of thermocouple measurements during welding, but there is no data about it for the case of direct contact with metals. The response times were evaluated by measuring the magnetic transition temperatures in Nickel 200 and Armco Iron.

The measurements of the solidification temperatures of Lead and Aluminum confirmed that the SS-DTA is very sensitive to the release of latent heat of fusion and to eutectic solidification caused by the presence of impurities in the tested metal. The in-situ application of SS-DTA during GTAW of the Al-Mg alloy 5454 revealed formation of eutectic phase resulring from significant supercooling of the solidifying weld.

Conclusions

The newly developed technique for single sensor differential thermal analysis combines the high sensitivity and accuracy of the classic DTA with the applicability in actual processing conditions. It can be used as a superiour alternative of the dilatometric analysis in welding simulation experiments.

The SS-DTA is applicable for studying the whole range of solid-liquid and solid-state phase transformations and structural changes occuring during welding and other thermal and thermo-mechanical processing applications. This technique provides valuable research tool for the materials developing, producing, and processing companies, and for the research and educational institutions.