

## A Novel Technique for Studying of Phase Transformations Part II: Single Sensor DTA, Range of Applications

*Boian T. Alexandrov and John C. Lippold  
Welding and Joining Metallurgy Group, the Ohio State University*

### Introduction

Part I of this publication gives a general description of the newly developed technique for Single Sensor Differential Thermal Analysis (SS-DTA), of the approaches used in its verification, and of its sensitivity to various phase transformations and structural changes. Part II presents the range of applications of the SS-DTA in terms of structural alloys and welding consumables, phase transformations and microstructural changes, weldability and fabricability studies. This technique provides an effective and inexpensive tool for determining the phase transformation temperatures during both actual and simulated processing, and for developing and testing of procedures for welding and other thermal/thermo-mechanical applications.

### Technical Approach

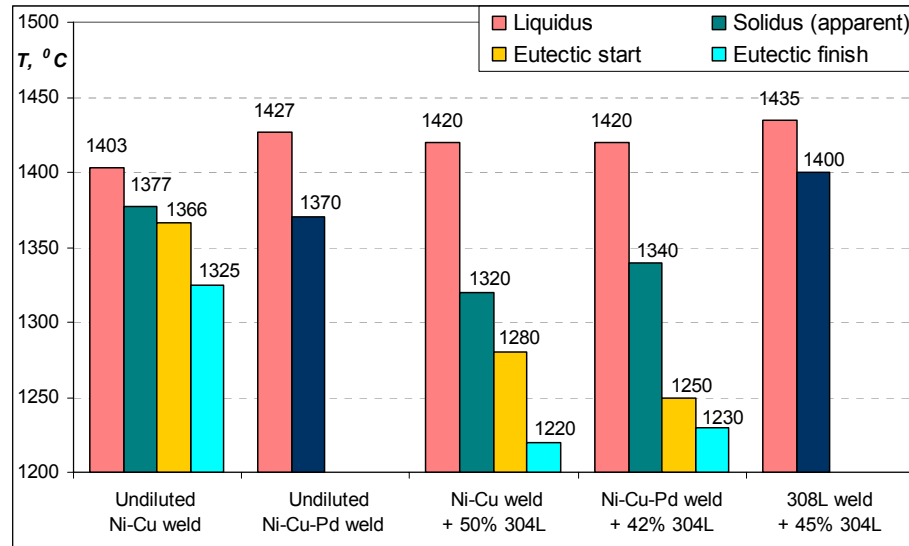
The technical approach used in this investigation was designed to explore the range of applicability of the SS-DTA technique. The studied materials included: 1) carbon, HSLA, power plant, martensitic, supermartensitic, and austenitic stainless steels; 2) Ni-base, aluminum, and titanium alloys; 3) covered electrodes and consumable electrode wires. The SS-DTA was applied during SMAW, GTAW, FSW, and PWHT, during thermo-mechanical simulations, and button melting experiments. The whole range of weld phase transformations was investigated including solidification, solid-state transformations, precipitation reactions, and recrystallization. Light microscopy, SEM, EDS, and microhardness measurements were used for phase and microconstituent identification.

### Results and Discussion

The development of SS-DTA technique allowed the in-situ investigation of the weld metal solidification behavior and solid state phase transformations. This provided a solution to the problem of constructing in-situ continuous cooling transformation (CCT) diagrams for the originally solidified weld metal. In the past, weld metal phase transformations were studied by reheating weld samples in thermal simulators. Using SS-DTA, in-situ CCT diagrams were developed for the weld metal of E6010 and E10018 covered electrodes. Such diagrams help the welding engineer in determining the operational window of heat inputs that would provide optimal combination of microstructural constituents in the weld metal.

The SS-DTA was employed in the development stage of experimental Ni-Cu and Ni-Cu-Pd SMA consumables for determining of their solidification ranges, **Figure 1**. Effects of eutectic solidification were found that corresponded well to the nil-strength temperature of

these welds. The in-situ determined solidification ranges in four high alloy austenitic stainless steels coincided very well with the solidification cracking temperature ranges measured by Varestraint test.



**Figure 1:** Solidification ranges in experimental SMAW consumables compared to E308L-15

The solidification behavior, precipitation reactions, and solid state phase transformations in some Ni-base consumables and in Ti 6-4 alloy were investigated using specially developed button-melting technique. The later allowed melting small quantities of the investigated alloy and closely reproducing the cooling conditions of GTAW.

The martensite-to-austenite transformation in supermartensitic steel and in steel P 91 was studied during actual welding, PWHT, and simulation of weld thermal histories. Accurate determining of the  $A_{C1}$  temperature in these steels is required to avoid reformation of fresh martensite upon cooling after PWHT.

The reversion of martensite, recrystallization and precipitation were investigated in cold worked steel 304L during furnace heating and simulation of weld thermal histories. The thermal range of recrystallization in cold worked Nickel 200 was also measured.

## Conclusions

The technique for single sensor differential thermal analysis has a wide range of potential applications in studying the phase and microstructural changes that occur during processing of structural alloys. Typical examples of such applications are alloy and consumable development, weldability studies, development and testing of procedures for welding and postweld heat treatment.