Phase Transformation Monitoring of Incoloy 800H GTAW Spot Weldment

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Abstract

A spot weldment of Incoloy 800H was produced by GTAW process. During cooling phase transformation of the weldment was monitored by newly developed technique for single sensor differential thermal analysis. The SS-DTA technique used in this study was developed based on linear piece-wise approximation analysis. Cooling curve from approximation and actual were compared. Precipitates along grain boundary were detected by this technique and compared with microstructure analysis. The results showed that this technique was possible for monitoring of phase transformation of this Ni-base alloy.

***Keywords**: GTAW, Phase Transformation, Precipitates*

1 Introduction

In engineering application for high strength and high temperature services, the Incoloy 800H is one of the candidate materials for this application [1]-[2] It is a solid solution strengthening alloy [3] which has good high temperature oxidation resistance [4]-[6]. However, since this material has high Cr and Ni as well as small amount of C and Ti, precipitation reaction could occur during welding and post weld heat treatment. $Cr_{23}C_6$ is one of the reactions that could form [3], [6], and [7]. This chromium carbine forms along grain boundary that could affect corrosion properties as well as weldability of the alloy during fabrication and services. Strain-age cracking is one of the problems for fabrication of this alloy due to high Cr promotes precipitate free zone and Ni with Ti that could promote formation of γ' [8]-[10]. This could occur during both post weld heat treatment and during service condition. With this prospective problem, it would be benefit if the formation of precipitate such as $Cr_{23}C_6$ and γ' can be determined or monitored during fabrication and post weld heat treatment as well as during service. By taking advantage of newly developed technique for In-situ phase transformation so call SS-DTA [11]-[12], it could be used to monitor during welding phase transformation of this alloy. In this study, a new variation in calculation or algorithm of SS-DTA was developed for determination of any precipitates form during cooling of welding of Incoloy 800H. Any indication from SS-DTA technique was compared and confirmed with microstructure analysis.

2 Experimental Methodology

2.1 *SS-DTA Technique*

This technique is the adapted classical DTA technique which is based on the difference between measured values of temperature and reference temperature. In the SS-DTA, the reference temperature is derived from an estimation of data which, in this study, was linear-piece wise method. The length of linear-piece was a set of data to be determined for a set of single, average, values. This was plotted as a reference curve of temperature. Therefore, to make this technique to be more accurate, it is required high sampling rate of the actual data. In this study 2 kHz was the frequency used for acquiring data points. A segment for linear-piece wise was 1.5 seconds for each segment. The length of each segment also affects the sensitivity of the analysis. Cooling curve of actual data and reference data were then plotted and determined for difference. In case of phase transformation or precipitation occur, the difference in temperature among actual and reference curve is shown against temperature in which it is the temperature that any transformation occurred.

2.2 *Material*

Incoloy 800H was selected since it could form TiC during solidification [3] with nominal composition shown in Table 1. However, as with other types of Ni-based alloys, $Cr_{23}C_6$ could also form along grain boundary. γ' could also form if the material expose to high temperature for long time.

Table 1 : nominal composition of Incoloy 800H [3]

	C	Cr	Fe	Mn	Ni	Si	Al	Other
800H	0.05-0.1	19-23	Bal.	1.50	30-35	1.0	0.15-0.6	Ti 0.15-0.60

2.3 *Spot GTAW*

A series of spot GTAW with pulse current was applied to the specimen with size of 10 mm x 20 mm x 12 mm. The welding parameters were set as shown in Table 2. A welding torch was fixed for preset arc length. Three sets of thermocouple were welded into the sample as shown in Figure 1. The thermocouple T1, T2, and T3 were welded at approximately same distance from the weld pool as the spare parts among them in case of failure from melting due to the heat from welding.

Table 2 : Spot GTAW Parameters

Parameters	Values
Welding Current • Background • Peak	20A 80A
Welding Voltage • Background • Peak	 10.8V 13.2V
Electrode Size	2.4 mm
Shielding Gas	Argon
Shielding Gas Flow	12 Litre/min

Then a series of welding were produced on the specimen until the temperature measured reached 1200°C. While the specimen cooling down to room temperature, a data acquisition was operated to collect temperature profile of each set of thermocouple. This was repeated on the same specimen for 10 times in order to determine the effect of repair welding.

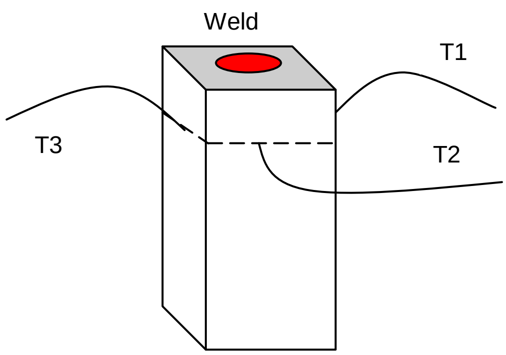


Figure 1 : Experimental Setup

2.4 *Microstructure Analysis*

After the analysis of SS – DTA to determine if any possible transformation or precipitate could occur, the specimen was then cut for cross section through the area of thermocouples were welded. This was in order to analysis the microstructure in the areas that were determined for precipitation occurred.

The microstructure specimen was grinded, polished, and etched to reveal the microstructure of the welded Incoloy 800H. Etching solution was selected based on ASTM E407 which was 20ml of HNO_3 and 60ml of HCl.

An optical microscope brand Carl Zeiss Model Axiovert 40 MAT with digital camera Canon A640 was used for taking micrographs of the welded Specimen.

3 Experimental Results

3.1 *Data from SS-DTA*

The data collected from the welding of each cycle of GTAW was shown in Figure 2, Figure 3 and Figure 4 for 1st, 3rd, and 10th replication of the welding consecutively. As can be seen in the Figures that some of temperature curves were not completed, this was due to melting of thermocouples and could not be used for measuring temperature any more. According to Figure 2 the 1st trial of spot GTA welding, there was no transformation or precipitate occurred. Temperature 1 showed temperature drop at around 25 seconds after welding. This resulted from detachment caused by fusion of a thermocouple. Therefore other channels were used for analysis.

The experiment was continued until the 3rd of spot GTAW trial, some reactions were picked up at temperatures about 950°C – 1050°C and 550 °C - 650 °C as shown in Figure 3. However, only channel 2 of temperature profile (Delta T Graph 2) showed strong reaction while channel 3 showed some of the reaction in which it could be mixed with noise signal. The reaction picked up from channel 2 was strong giving delta T of about +/- 8 °C at temperatures about 950°C – 1050°C. This delta T was caused by heat transfer due to the reaction that occurred during formation of phase or precipitates in this case. This heat caused fluctuation of temperature at the temperature reaction occurred as picked up and shown on delta T.

These effects were picked up from this point to the 10th trial as shown in Figure 4. However, the reaction at high temperature was minimized while the reaction at lower temperature was stronger from +/- 2 °C to +/- 4 °C. Therefore, the reaction at high temperature decreased but the reaction at low temeperature increased. With this experiment, the effect of multipass or repair welding was demonstrated.

3.2 *Microstructure*

Micrograph of welded Incoloy 800H were shown in Figure 5. As can be seen, the microstructure of welded Incoloy 800H showed austenite phase with twin in some area. At higher magnification, precipitates of Cr23C6 were formed along grain boundaries. This showed the evidence in Figure 6. In addition, γ′ precipitates were also formed at the grain interior as shown in Figure 7.

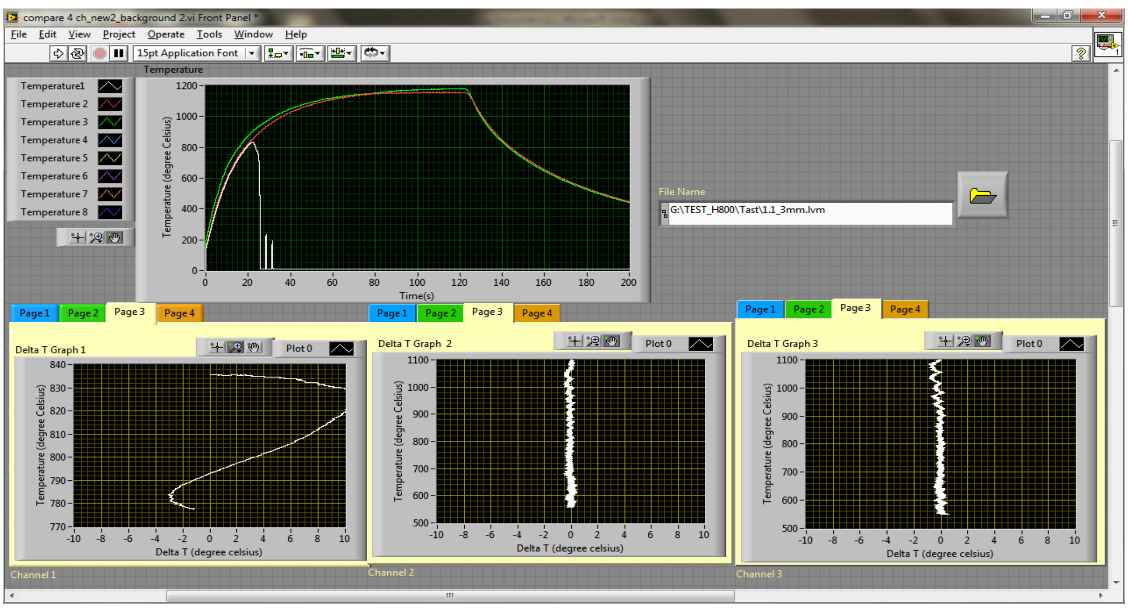


Figure 2: 1st trial of GTAW spot

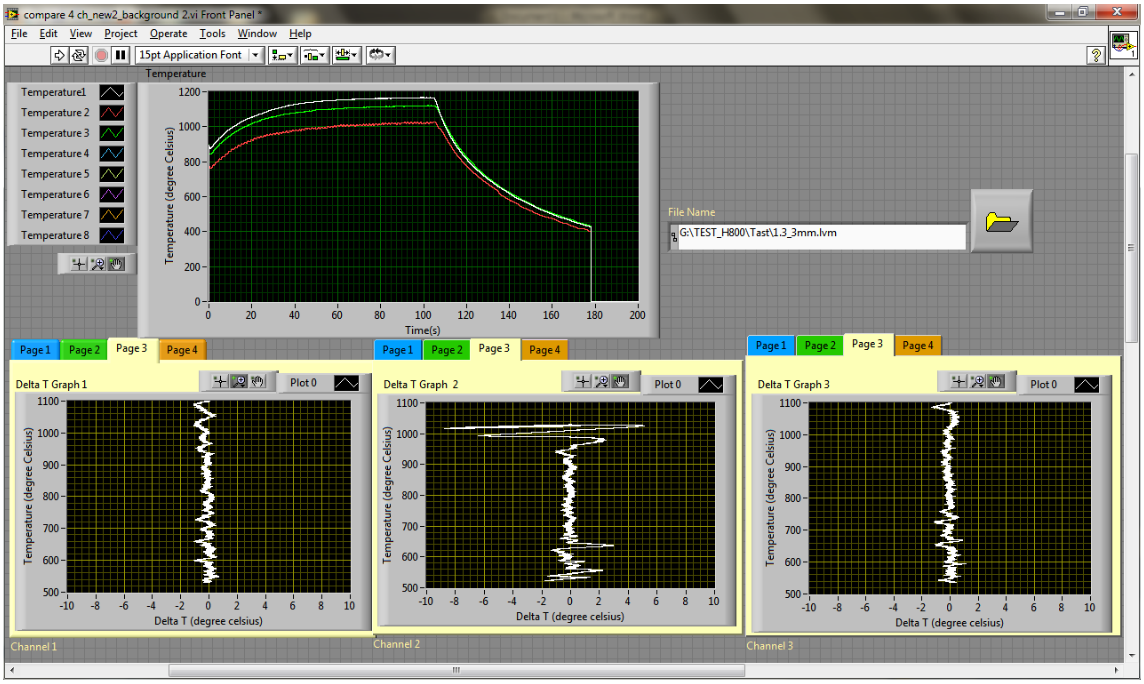


Figure 3: 3rd trial of GTAW spot

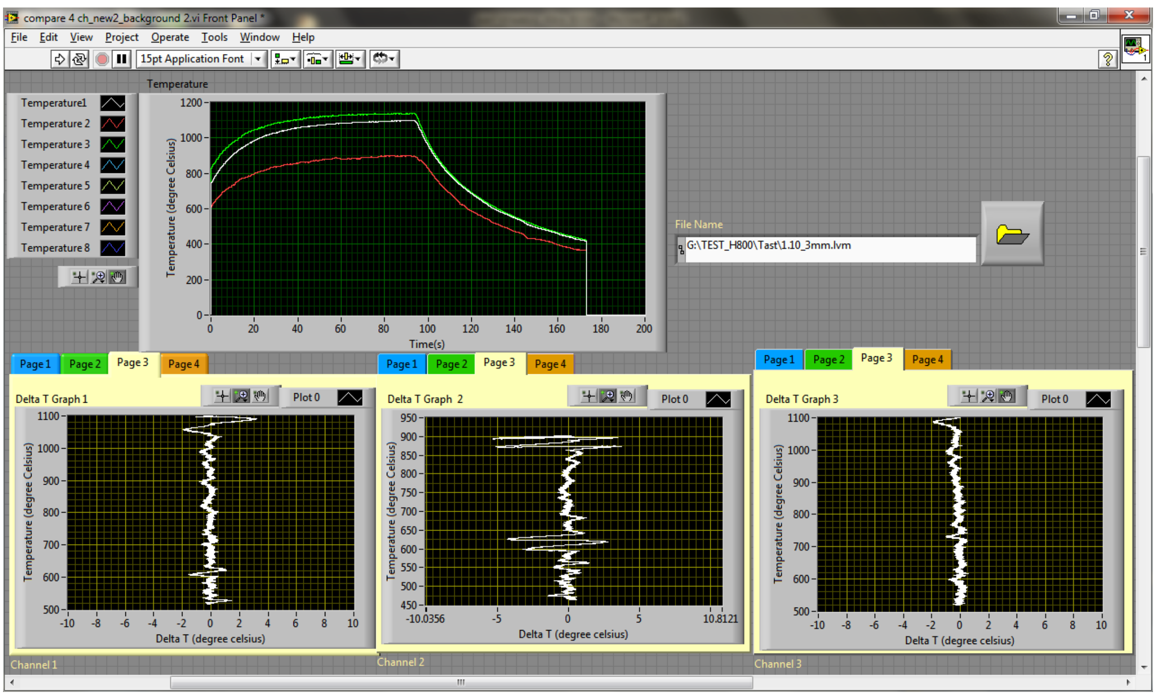
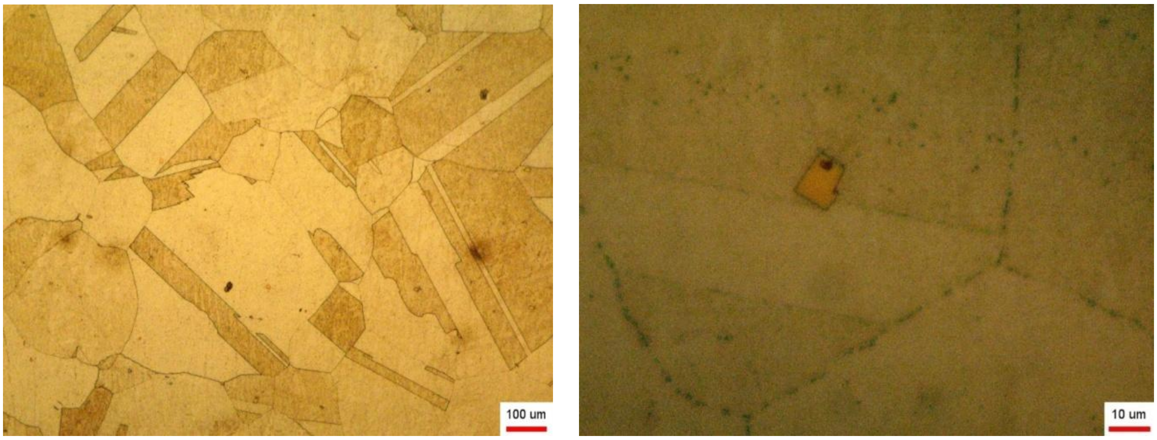


Figure 4: 10th trial of GTAW spot

4 Discussion

According to the SS-DTA data, there would be precipitates formed at the temperature around 950^{o}C – 1050^{o}C. This was believed to be γ' since this phase precipitates at this temperature [9]. The micrograph was shown in Figure 7. This precipitates were formed during welding and formed at the early stage of repaired weld (as simulated as following trial of GTAW spot). However, it was faded away and had less reaction as shown in the 10th trial of spot weld as the delta T for temperature difference was lessen.



(a) **(b)**

Figure 5: Microstructure of welded Incoloy 800H (total 10 trials) (a) low magnification (b) higher magnification

In contrast, $Cr_{23}C_6$ phase was believed to form at the later stage of repaired welding. From the SS-DTA data, it was formed around temperature of 550 ^{o}C - 650 ^{o}C. The effect of reaction was stronger as the number of repaired weld proceeded. The micrograph of this phase was shown in Figure 6 which similar to what was found by Lee H.Y. et. al [13]. Precipitates were formed along grain boundaries and consumed Cr making it to be susceptible for corrosion [14]. The formation of $Cr_{23}C_6$ would affect the susceptibility for reheat cracking in HSLA [15] steel or strain-age cracking in Ni-base alloy [10].

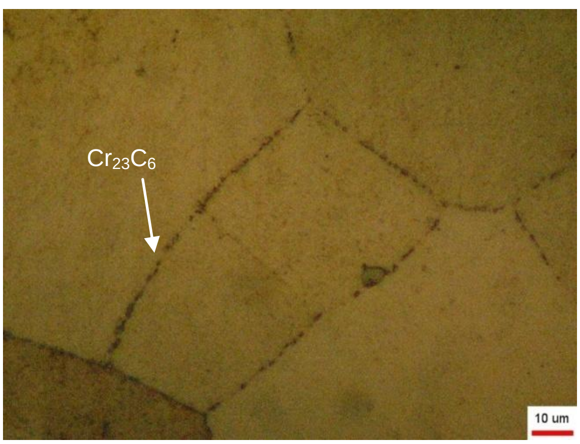


Figure 6: $Cr_{23}C_6$ precipitates formed like chains along grain boundaries.

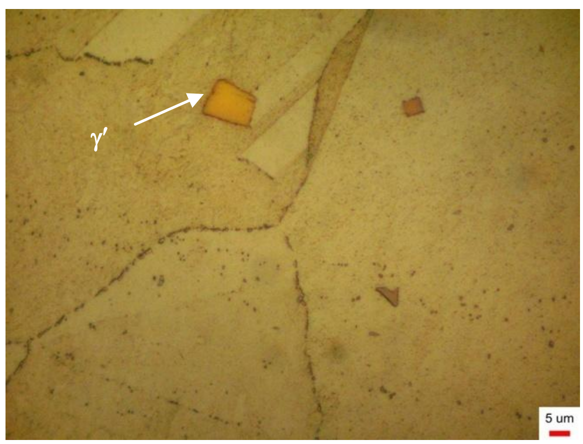


Figure 7: γ' precipitates (arrowed) located intragranular in some areas

5 Conclusion

- SS-DTA could be used for identification of reaction that could occur during welding.
- A variation of SS-DTA technique using linear-piece wise mathematical could be used for SS-DTA.
- Multiple phase transformations or precipitation could be detected using this SS-DTA technique.
- Multiple-time welding during repaired welding could affect the microstructure change of the weldment.
- Further study could be done for identification of precipitates found by this SS-DTA technique.

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