# Numerical simulation of austenite retention in triplex stainless steel weld metals†

**SAIDA Kazuyoshi*, ARATA Hayata*, OGIWARA Hiroyuki*, NISHIMOTO Kazutoshi***

**KEY WORDS**: (Triplex stainless steel) (Retained austenite) (Kinetics) (Solidification mode) (Segregation) (Numerical simulation) (Martensitic transformation) (Ferritic-austenitic transformation)

## 1. Introduction

Triplex stainless steel, which consists of ferritic, austenitic and martensitic phases, is one of the most hopeful welding consumables applied to preheat-free welding of HT980 [1]. It has been shown that the amount of retained austenite in the triplex stainless steel weld metal should be controlled in an optimal range in order to obtain sufficient joint properties of HT980 welds. In the present study, the kinetics of austenite retention was examined and the amount of retained austenite was predicted for the various weld metal compositions and welding conditions in order to obtain basic information on the applicability of such triplex stainless steel welding consumables to the preheat-free welding of HT980.

## 2. Materials and Experimental Procedures

Twenty-three kinds of nominally 13mass%Cr-7mass%Ni triplex stainless steels with varying amounts of Ni and C were used for the base metal. In order to obtain the triplex stainless steel weld metals, gas tungsten arc melt-run welding (GTAW) was conducted using the following welding conditions: arc current 120 A, arc voltage 14 V and welding speed 1.67-10.0 mm/s. The amount of retained austenite in the base and weld metals was measured by X-ray diffraction analysis using the 5 peaks method.

## 3. Kinetic Approach to Retention of Austenite

"*Retained austenite*" is an austenitic phase that does not transform to a martensitic phase upon cooling from a high temperature (austenitic region). Therefore, the retention of austenite is a complementary event to the martensitic transformation. Assuming that the retention of austenite is governed by the chemical composition in that location prior to the martensitic transformation, the retention kinetics of austenite arise from the non-uniform distribution of alloying elements due to microsegregation. Austenite is finally retained in a particular location if the $M_s$ temperature in that locationis below RT. Microsegregation behaviour in the weld metal was computed using a theoretical model in which is below RT. Microsegregation behaviour in the weld metal was computed using a theoretical model in which solidification segregation and subsequent desegregation of alloying elements during the welding process were simulated. Four types of solidification modes (A, AF, FA and F modes) were considered in calculating the solidification segregation, and the ferritic-austenitic transformation in the solid was also considered in calculating the desegregation of alloying elements during cooling after solidification. Assuming that the morphology of a dendritic cell is basically a hexagonal prism as illustrated in **Fig. 1**, the model analysed here used one-dimensional diffusion in a rectangular triangle. Solidification proceeds one-dimensionally from a cell core to a cell boundary. The distribution of solute elements was calculated using the finite differential method scheme considering the moving boundaries.

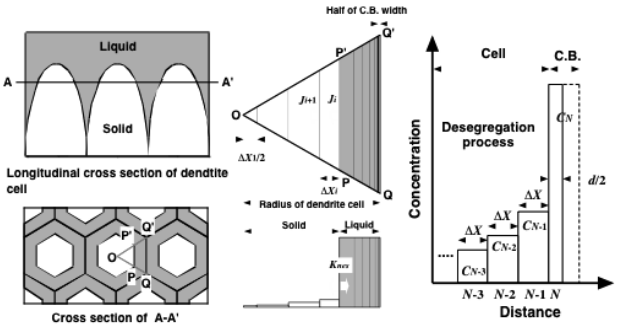


**Fig. 1** Schematic illustration of analysis model

In the present study, the $M_s$ and $M_f$ temperatures of triplex stainless steels was assumed to be expressed by (unit: K): (1)

$$M_s = 1263 - 26[\mathrm{Mn}] - 53[\mathrm{Ni}] - 32[\mathrm{Cr}] - 18[\mathrm{Mo}] - 97[\mathrm{C}][\mathrm{Cr}]$$

$$M_f = M_s - 100$$

**Figure 2** illustrates the distribution of the $M_s$ and $M_f$ temperatures in a dendritic cell calculated from the solute concentrations. Austenite is retained in the

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* Dept. of Materials & Manufacturing Science. Graduate School of Eng., Osaka University, Osaka, Japan

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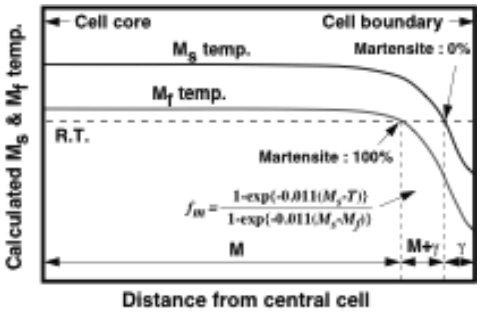



**Fig. 2** Concept of retention kinetics of austenite based on distribution of $M_s$ and $M_f$ temperatures

location where the $M_s$ temperature in that location drops below RT, and some amount of austenite is retained in the transformed martensite at locations where RT is situated between the $M_s$ and $M_f$ temperatures. The fraction of martensite transformed $f_m$ at temperature $T$ (between $M_s$ and $M_f$) can be expressed by:

$$f_m = \frac{1 - \exp\{-0.011(M_s - T)\}}{1 - \exp\{-0.011(M_s - M_f)\}} \quad (2)$$

The distribution of solute elements, Cr, Ni, Mo, Mn and C was calculated for pseudo-binary systems. The material constants employed for the calculation were taken from references and computed using *Thermo-Calc*. Three kinds of solidification/cooling rates were determined from the measured thermal cycles during GTAW while varying the welding velocity from 1.67, to 5.0 and 10.0 mm/s.

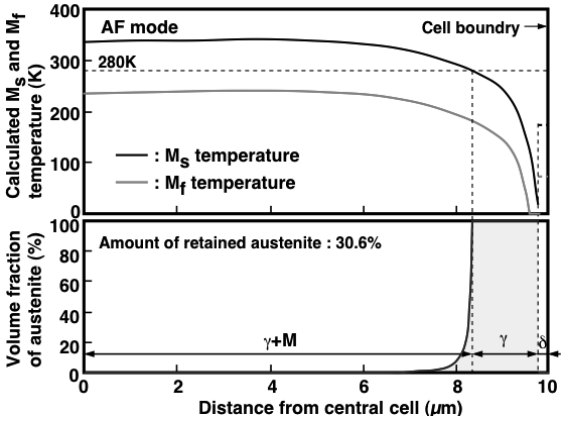
## 4. Analysis Results for retained Austenite

*Distribution of $M_s$ and $M_f$ Temperatures in Dendritic Cell*

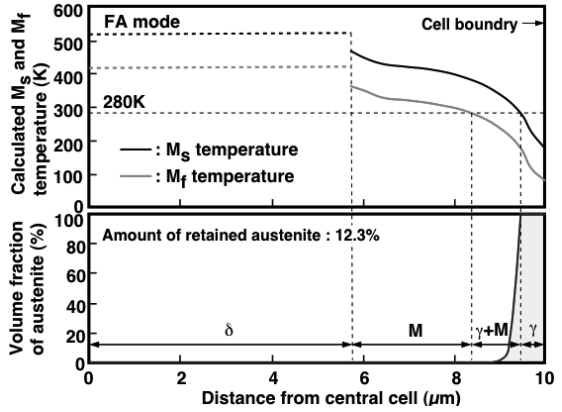
**Figure 3**(a) and (b) show the distributions of the $M_s$ and $M_f$ temperatures and the volume fraction of retained austenite in a dendritic cell calculated for the weld metals C1 (AF mode) and A2 (FA mode), respectively. In the case of weld metal C1, the $M_s$ and $M_f$ temperatures also drop toward a cell boundary, however, a ferritic phase (δ) exists at a cell boundary. Retained austenite remains adjacent to a ferritic phase, and a cell core corresponds to austenitic+martensitic phases (γ+M). The amount of retained austenite in the weld metal is calculated as 31.1%. In the case of weld metal A2 (FA mode), the $M_s$ and $M_f$ temperatures once again decrease toward a cell boundary. A ferritic phase (δ) exists inside a cell, and a martensitic phase is formed adjacent to a ferritic phase. A cell boundary corresponds to retained austenite. The amount of retained austenite in the weld metal is calculated as 12.3%.

*Validity of Retention Kinetics of Austenite in Weld Metal*

In order to validate the retention kinetics of austenite proposed in the present study, calculated amounts of retained austenite were compared with measured values. **Figure 4** shows the relationship between the calculated and measured amounts of retained austenite in the weld metal with varying alloy compositions. There is a good agreement between them for all solidification modes. It follows that the retention of austenite in the triplex stainless steels weld metal at differing alloy compositions and welding conditions can be quantitatively predicted by the present numerical analysis.




(a) AF mode




(b) FA mode

**Fig. 3** Calculated distribution of $M_s$ and $M_f$ temperatures in dendritic cell

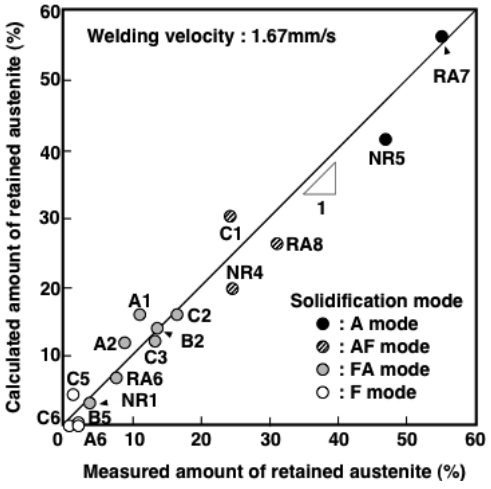



**Fig. 4** Comparison of amount of retained austenite between calculated results and measured ones

## 5. Conclusions

The results obtained may be summarised as follows;

(1) The retention kinetics of austenite were formulated with regard to the various solidification modes, the ferritic-austenitic and martensitic transformations in the solid, assuming that austenite retention arose from the non-uniform distribution of alloying elements due to microsegregation.

(2) The $M_s$ and $M_f$ temperatures dropped near a cell boundary. The calculated amounts of retained austenite in the weld metal increased with an increase in the Ni and C contents in steels (and with a decrease in cooling rate during welding).

(3) The calculated amounts of retained austenite in weld metals were approximately consistent with measured ones at any alloy composition and welding velocity. It followed that the retention of austenite in the triplex stainless steel weld metals at differing alloy compositions and welding conditions could be quantitatively predicted by the present numerical analysis.

## References

[1] K. Saida, K. Nishimoto, K. Ogawa, S. Okaguchi and K. Fujiwara: 'Proposal of Welding Consumable of Triplex Stainless Steel for Ultra High-Strength Steel', Sci. & Technol. Welding & Joining, 15-3 (2010), p.185