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Austenite memory and variant selection in a novel martensitic welding alloy

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Abstract

The crystallographic orientation relationship between the reverse austenite and corresponding martensite in a new residual-stress-reducing weld metal was predicted, using the general theory of martensitic transformation, and verified experimentally. The theoretical and experimental results of this work also provided an evidence of the likelihood of austenite memory phenomenon.

Keywords: welding; residual stress; austenite memory.

1. Introduction

Austenite grains, which are generated from ferritic or martensitic grains, as a result of reheating cycle, tend to have identical crystallographic orientations to the original parent austenite. This phenomenon in steels is referred to as "austenite memory effect" and has been widely researched [1-8] since this effect can hinder grain refinement. During reheating process, austenite nuclei form and grow in triple points and/or along martensite boundaries before coalesce into large grains. The reverse austenite transformation can be diffusional or diffusion-less type [2, 8-10].

Most of investigations on the orientation of reverse austenite and martensite are based on the Kurdjumov–Sachs relationships [2, 4, 11]. However, it has been known that the true relation between austenite and martensite must be

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“irrational” [12-15]. Despite less than a few degrees difference in the irrational and Kurdjumov–Sachs orientations, the latter do not define the actual observed invariant–line between the parent and product lattices.

The phenomenological theory of martensite crystallography gives a complete description of the mathematical connection between the orientation relationship, the habit plane and the shape deformation for each plate that forms by the displacive transformation [12-19]. This theory has been used to design low transformation temperature (LTT) welding alloys capable of mitigating residual stresses in steel weldments, *e.g.* Camalloy 4 [20-25]. The theory is also been applied to study the transformation of austenite into a stress-induced martensite [26] or low temperature bainite [17, 27]. However, it appears that the validation of the above-mentioned theory and how variant selection occurs in a weld metal has not been performed to date. This is mainly due to the experimental limitations, which make the detection of sufficient retained austenite in low transformation temperature alloys very difficult if not impossible using laboratory equipment.

In this work, a novel low transformation temperature weld metal (Camalloy 4) was heat-treated to induce an adequate amount of reverse austenite, followed by Electron Backscatter Diffraction (EBSD) analysis to obtain the experimental data on the crystal orientations. The martensite crystallography theory [12-19] was then applied to examine the austenite memory effect as well as the effect of residual stress on variant selection during martensitic transformations in Camalloy 4.

2. Materials and sample preparation

Austenitic stainless steel (304L) base plates with the dimensions of 200 × 150 × 20 mm were used in this work. A 10 mm deep V-shape (60°) groove was machined along the centre of each plate. The sample plate was circumferentially welded onto a welding bench to obtain a fully constrained condition. The filler metal was a new alloy (CamAlloy 4), developed in the University of Cambridge, with high corrosion resistance and low transformation temperature.[28] The latter property makes this alloy capable of mitigating welding-induced residual stresses. The chemical composition of CamAlloy 4 is 0.01C, 13.0Cr, 6.0Ni, 1.5Mn, 0.7Si, 0.06Mo (wt.%). The preheating and interpass temperature were between 190-210 °C . The welding of each plate was completed in 8 separate passes, using gas metal arc welding with a shielding gas of 98%Ar-2%CO2. The welding current, voltage and speed were 230-295 A, 26-30 V and 65-78 cm per min, respectively.

For microstructural and electron backscatter diffraction (EBSD) investigation, a 10 mm thick cross-weld sample, perpendicular to the weld direction was removed from the centre of the welded plate by electro-discharge machining. The sample was then annealed at 600 °C for 1 hour to generate enough reversed austenite, before being ground and polished using conventional metallography procedures. The final polishing was carried out using colloidal silica for approximately 20 minutes.

3. Crystallographic characterisation and stress modeling

EBSD scans of all samples were performed in Camscan MX2600 SEM equipped with a field emission gun. The orientation images were taken at an operating voltage of 25 kV, a working distance of 30 mm and a tilt angle of 70°. The EBSD maps were acquired at a step size of 70 nm. Since the resolution of the mapping depends on the step size, a single pixel should not be counted as a grain.[29] Only the austenite and martensite grains with surface areas larger than the surface area of 5 pixels were analysed.

Fig. 1a shows the macrostructure of the weld together with the bead number and their positions. Point ‘A’ and ‘B’ show the approximate locations of EBSD analyses. In order to relate the EBSD data to the direction of residual stress at these points, a three-dimensional finite element (FE) analysis model was developed using *MSC.Marc* software.[30] Fig. 1b shows the mesh distribution in the FE Model consisting of 4200 solid brick elements and 5166 nodes in total.