UCRL-CONF-209248

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January 27, 2005

2005 TMS Annual Meeting and Exhibition
San Francisco, CA, United States
February 13, 2005 through February 17, 2005

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TMS Letters **TMS (The Minerals, Metals & Materials Society), 2005**

Effect of Stress Mitigation on Precipitation Kinetics of Alloy 22 Welds

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Subject Categories: Nuclear Materials, Surface Modification and Coatings, Intermetallics, Characterization

Abstract

Understanding the phase stability of Alloy 22 (N06022) is important since the precipitation of tetrahedrally close-packed (TCP) phases over time has been known to adversely affect corrosion and mechanical properties. Prior observations have shown that these phases precipitate during the welding process. After welding, residual stresses due to the solidification and cooling from temperature remain. When the weld cannot be stress-relieved by solution annealing, the application of commercially available stress-mitigation processes such as low plasticity burnishing (LPB) and laser shock peening (LSP) may be used to produce near-surface compressive stresses. This study involved examination of cross-sectional samples of aged 1.25" thick welds of Alloy 22 plates using electron backscatter diffraction (EBSD) for TCP identification and micrograph analysis for TCP quantification. Precipitation in both the as-welded and LSP weld was observed primarily in inter-dendritic regions whilst precipitation in the LPB weld was in both inter- and intra-dendritic regions.

Introduction

Alloy 22 (UNS N06022) is a nickel-based alloy that has been selected as the candidate material for the outer barrier of the nuclear waste containers for the proposed geologic repository at Yucca Mountain, Nevada [1]. This was primarily due to its excellent resistance to corrosion [2-5]. However, since Alloy 22 welds are known to form potentially detrimental tetrahedrally close packed (TCP) phases upon solidification [6], examining the effect of stress mitigation techniques on TCP stability is important. In this work, the cross section of 1.25" thick prototypical welds are investigated in as-welded (ASW), low plasticity burnished (LPB), and laser shock peened (LSP) conditions. Specimens were studied at three different stages of aging (as-received, aged 50 hours at 700°C, and aged 500 hours at 700°C) to determine the effects of stress mitigation on TCP phase stability.

Experimental Method

Three sets of specimens were cut from 1.25" thick plate Alloy 22 single-V welds (ERNICRMO-10). Each set was comprised of one ASW, one LPB, and one LSP specimen. Two sets were aged in an air furnace at 700°C, one set for 50 hours and the other set for 500 hours, and subsequently water quenched. After metallographic preparation, images were collected using an FEI Company Quanta 200 scanning electron microscope (SEM) in backscatter mode for TCP phase quantification, and individual precipitates were studied using electron backscatter diffraction (EBSD) [7] for TCP phase identification.

Due to the compositional differences between the TCP phases and the weld matrix [6], a backscatter electron detector is best suited for imaging the TCP phases. Under these imaging conditions the TCP phases appear brighter, and applying a threshold to the images allows for TCP phase volume fraction quantification. Forty images were collected for each specimen within the top 4mm of the weld and subsequently analyzed for TCP phase volume fraction.

Three TCP phases have been observed to form in Alloy 22 welds, μ, σ and P [6]. Since each of these phases have different crystal symmetries, it is possible to identify the TCP phases present in the welds through diffraction. To achieve this, EBSD patterns were captured from thirty TCP particles in each specimen (selected at random) by manual placement of a collimated electron beam on each particle. These captured patterns were then indexed to identify the phases using a TexSEM Laboratories OIM 4 system.

Results

In Table I, the effect of the aging on TCP phase volume fraction is listed. It can be seen that in the as-received and 50 hour specimens, the effects of stress mitigation are negligible and the volume fractions of all the specimens were less than 0.15%. However in the specimens aged for 500 hours, the volume fractions increased significantly, with the LPB specimen containing approximately 20% higher TCP volume fraction than the ASW and LSP specimens. This can be attributed to a substantially higher TCP phase content in the top 1mm of the weld, as seen in the last row of Table I. Figure 1 shows typical images from all the specimens aged at 500 hours. While TCP phases decorate inter-dentritic regions (primarily between secondary dendrites) in all three, they also decorate what appear to be deformation bands in the LPB specimen that do not exist in the other two (ASW and LSP) specimens.

The types of TCP phases present in the aged specimens are listed in Table II, and it is evident that the P phase is the most prevalent. It should be noted that in this analysis, diffraction patterns could not be obtained from the smaller TCP phases (smaller than 0.5μm in diameter), and these were labeled as unidentified. Table II then quantifies the distribution of the coarser TCP phases. It can be observed that of the coarser particles, none of the observed TCP phases are σ and the stress mitigation decreased the relative amount of μ.

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Acknowledgements

Michael M. McGregor and Robert G. Erler are gratefully acknowledged for their assistance in sample treatment and preparation. This work was performed under the auspices of the U. S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract N W-7405-Eng-48. This work is supported by the Office of Civilian Radioactive Waste Management (OCRWM), U.S. Department of Energy.

Table I. Effect of Stress Mitigation and Aging at 700°C on TCP Phase Volume Fraction

Aging Times	0 Hours at 700°C			50 Hours at 700°C			500 Hours at 700°C		
Mitigation Condition	None	Burnished	Peened	None	Burnished	Peened	None	Burnished	Peened
Volume Fraction (%)	0.09	0.10	0.13	0.09	0.14	0.13	4.92	6.53	5.40
Vol. Frac. in top 1mm(%)	0.10	0.11	0.15	0.06	0.12	0.13	6.18	8.78	5.95

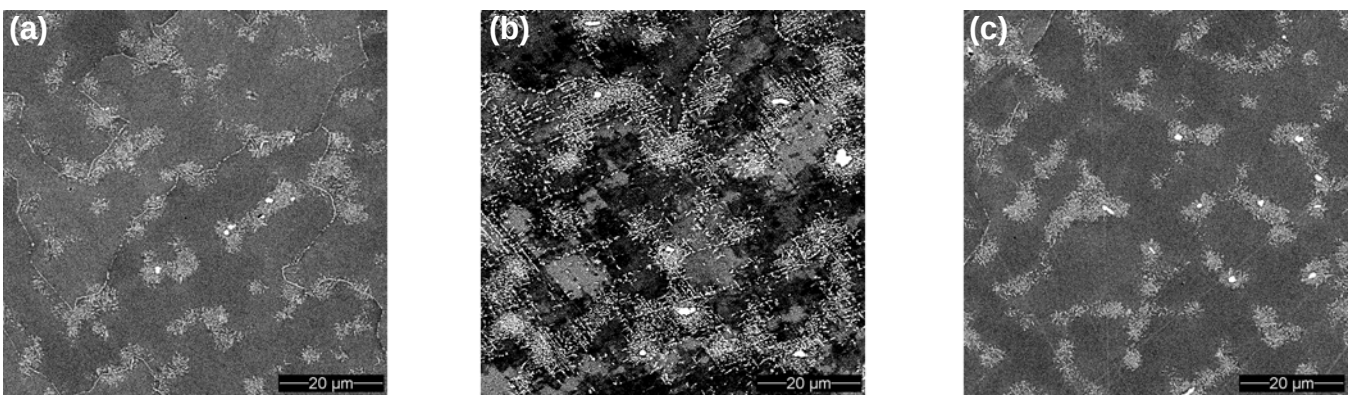

Figure 1. Cross-sectional backscattered electron micrographs of (a) untreated, (b) low plasticity burnished, and (c) laser shock peened Alloy 22 welds aged for 500 hours at 700°C. Micrographs were obtained within 1mm of the top of the weld.

Table II. Effect of Stress Mitigation and Aging at 700°C on TCP Phase Types

Stress Mitigation Treatment	Aging Time @ 700C (hr)	TCP Phase Fraction (%)			
		P	μ	σ	Unidentified
None	50	49.29	23.47	0.00	27.24
None	500	37.69	27.04	0.00	35.26
Burnished	50	51.52	17.13	0.00	31.35
Burnished	500	47.78	1.74	0.00	50.47
Peened	50	59.46	9.90	0.00	30.64
Peened	500	51.42	8.55	0.00	40.03