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A Comparative TEM Study of Nanoprecipitate Formation in Waspaloy® Welds

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Ni-based superalloys represent a class of high performance alloys extensively applied in the aerospace industry, where combination of superior mechanical properties, improved surface stability and high creep and fatigue resistance, are prerequisites. Waspaloy® is a wrought, *γ΄* strengthened Ni-based superalloy, suitable for fabrication of hot section components in gas turbine and jet engines, mainly as blade and disc material. Hence, efficient commercial application of Waspaloy® requires the use of welding, not only during manufacturing of new complex components, but also during repair of service-damaged parts [1]. This paper presents a TEM investigation of the microstructural evolution of Waspaloy®, following Gas Tungsten Arc (GTA) and Electron Beam (EB) welding. The nanoscale characterization of *γ΄* intermetallic phase provided is of great importance, as its composition, morphology, spatial and size distribution strongly affect the properties, which enable the application of Waspaloy® in demanding high-temperature service conditions.

The nominal chemical composition (wt. %) of the studied material is 19.5Cr, 13.5Co, 4.2Mo, 3.0Ti, 1.4Al, 1.0Fe, 0.06C, 0.05Zr, 0.006B and balance Ni. Based on this composition, Waspaloy® sheets were welded in the solution-annealed condition. The welding parameters, employed for GTA and EB welds, are listed in Table 1. The post-weld heat treatment (PWHT), which was applied to both Waspaloy® welds, is covered within the AMS 5544J specification and is as follows: a solution treatment at 996°C for 2h, followed by air-cooling, and then a two-step age-hardening treatment, at 843°C for 4h (stabilization) and at 760°C for 16h (precipitation), both followed by air-cooling. The microstructure finally obtained, consists of an FCC *γ* matrix strengthened by solid solution and finely dispersed *γ΄* precipitates ($Ni_3(Al,Ti)$), as well as primary Ti-rich MC-type and secondary Cr-rich $M_{23}C_6$-type carbides.

The present study highlighted the combined effect of both welding processes and PWHT on the microstructural evolution of Waspaloy®, and more specifically on the formation and precipitation characteristics of *γ΄* nanoparticles. SEM examination indicated the influence of GTA and EB welding parameters on the fusion zone microstructures. The lower heat input and higher cooling rate of EB weld led to a considerably finer and fully columnar *γ* dendritic structure, compared to that of GTA weld (Figs. 1, 2). Following welding processes, combined with the PWHT, spherical *γ΄* precipitates performed a duplex distribution in both GTAW and EBW fusion zones (Figs. 3, 4). Coarser (secondary) and finer (tertiary) *γ΄* nanoparticles precipitated out during the cooling from solution heat treatment, while their optimal size was obtained during the subsequent ageing step of the PWHT. As far as GTA weld is concerned, TEM examination coupled with EDS spot-microanalyses revealed excessive epitaxial nucleation of Cr-rich carbides on the surface of secondary *γ΄* phase precipitates (Fig. 3) [2].

References:

[1] HJ Penkalla et al., Materials Chemistry and Physics **81** (2003), p. 417.
[2] A Alexandratou acknowledges the General Secretariat for Research and Technology (GSRT) and the Hellenic Foundation for Research and Innovation (HFRI) for the financial support.

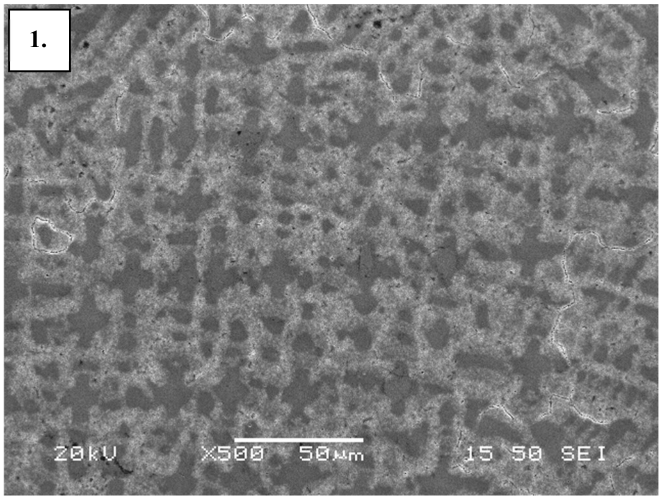

Figure 1. SEM-SEI micrograph of Waspaloy® GTA welded fusion zone, outlining the development of a cruciform, randomly oriented, γ dendritic microstructure and the existence of solidification grain boundaries (SGBs).

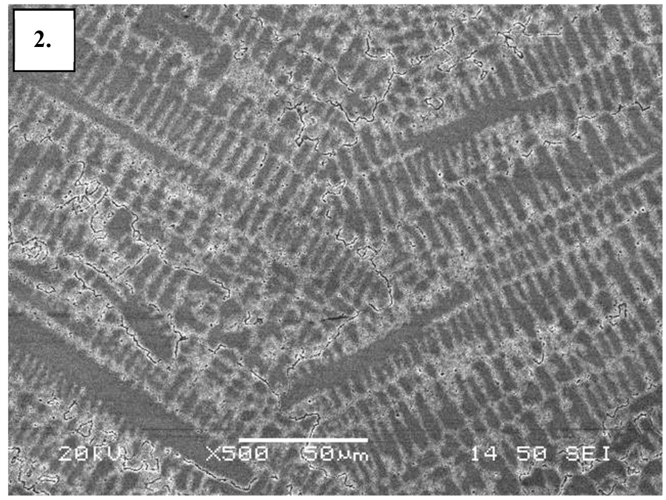

Figure 2. SEM-SEI micrograph of Waspaloy® EB welded fusion zone, showing the growth of a fine columnar γ dendritic structure, oriented to the weld center. Solidification grain and sub-grain boundaries (SSGBs) are also observed.

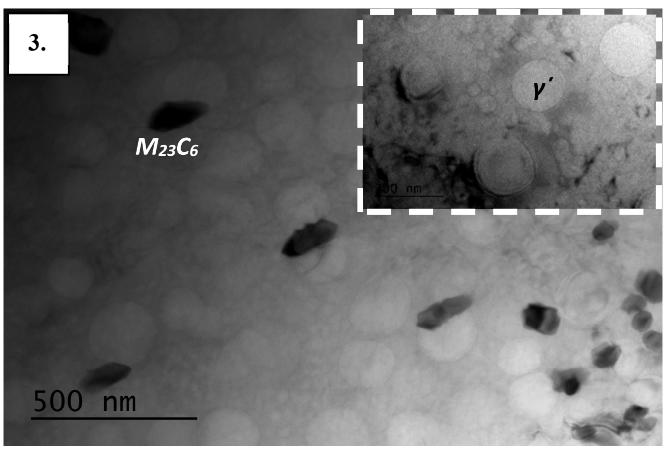

Figure 3. BF TEM micrographs of the GTA welded Waspaloy® fusion zone, showing the bimodal size distribution of γ´ phase within the γ matrix. The heterogeneous nucleation of Cr-rich $M_{23}C_6$ carbides on the secondary γ´ precipitates is also illustrated.

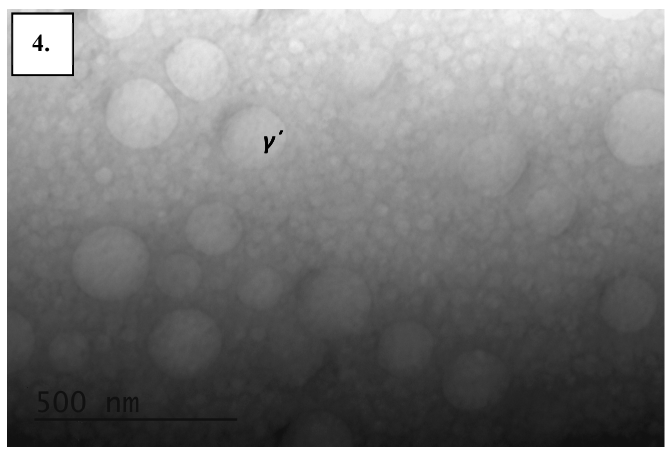

Figure 4. BF TEM micrograph of the fusion zone of EB welded Waspaloy®, illustrating a bimodal distribution of finely dispersed, spherical γ´ precipitates within the γ matrix. The coarser γ´ nanoprecipitates are about 170 nm, while the finer are 40 nm.

Table 1. Welding parameters used for GTAW and EBW.

Parameter	GTAW	EBW
Current	80 A	80 mA
Voltage	14 V	50 kV
Travel Speed	Manual	165 cm/min
Shielding Gas	Argon	Vacuum
Filler Metal	Waspaloy®	None (autogenous)