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Effect of the Cooling Rate on the Microstructure Evolution of Haynes® 282® Ni-based Superalloy Subjected to γ′ Super-Solvus Heat Treatment

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Haynes 282 (H282) is a newly developed wrought, γ′-strengthened Ni-based superalloy, suitable for the fabrication of hot section components in aircraft and land-based gas turbines, satisfying the demand for higher operating temperatures and pressures, thus resulting in improved efficiency and environmental performance. H282's superior mechanical properties and thermal stability are established, due to its unique chemical composition permitting a standard full heat treatment (SFHT) to be applied. SFHT consists of a solution treatment (ST) at 1140°C for 2h, followed by water quenching and then a two-step precipitation treatment [1]. ST step is carefully designed, to take place above the secondary carbides' and γ′ solvus temperature (997°C), achieving significant γ matrix hardening through solid-solution strengthening. In ST of precipitation-strengthened Ni superalloys, apart from temperature and holding time, cooling rate (CR) is also of critical importance, tailoring the size, morphology, distribution, and volume fraction of γ′ phase, which is principally precipitated during the second ageing step of SFHT, at 788°C. This study assesses the effect of three different CRs from ST, namely water quenching (WQ), air cooling (AC), and furnace cooling (FC), on the microstructure evolution and attained hardness of H282.

The nominal chemical composition (wt. %) of the studied material is 20Cr, 10Co, 8.5Mo, 2.1Ti, 1.5Al, 1.5Fe, 0.3Mn, 0.15Si, 0.06C, 0.005B and balance Ni [1]. Based on this composition, the as-received H282 was solution-treated, in a reducing atmosphere, at 1140°C for 2h, followed by WQ, AC, and FC. The microstructural characterization of H282 solution treated specimens was conducted employing SEM and TEM, coupled with EDS, while their mechanical behavior was assessed via Vickers hardness test (196N).

Following ST and WQ the microstructure is characterized by an equiaxed γ matrix, consisting of primary MC and MN-type precipitates (Fig. 1), as well as nanoprecipitates, uniformly distributed within the matrix (Fig. 2) The absence of γ′ phase precipitation is also noted, strongly affecting the alloy's hardness which equals 180HV. Based on theoretical thermodynamic calculations, these precipitates are considered Mo-based borides (M_3B_2), formed during solidification [2]. ST followed by AC, led to the decoration of the γ-GBs with secondary $M_{23}C_6$ and M_6C-type carbides (Fig. 3), resulting in improved mechanical strength and creep resistance. Ultra-fine γ′ precipitates, scattered throughout the γ phase (Fig. 4), were also observed, improving H282 hardness (200HV). Finally, the solution-treated H282, subjected to FC, exhibited the highest hardness value (280HV) due to the lower CR and γ′ nucleation rate, leading to a higher volume fraction of the γ′ phase. Following ST and FC, GB serration is observed (Fig. 5) and is due to the intergranular precipitation phenomena of carbides and γ′ phase occurred during FC, contributing to the increase of hardness. As shown in Fig. 6, the γ′ phase was coarsened, possessing a complex octodendritic shape, indicative of the increased γ/γ′ mismatch, which originated a high elastic stress field, hindering the dislocation movement, thus increasing H282's hardness and strength [3].

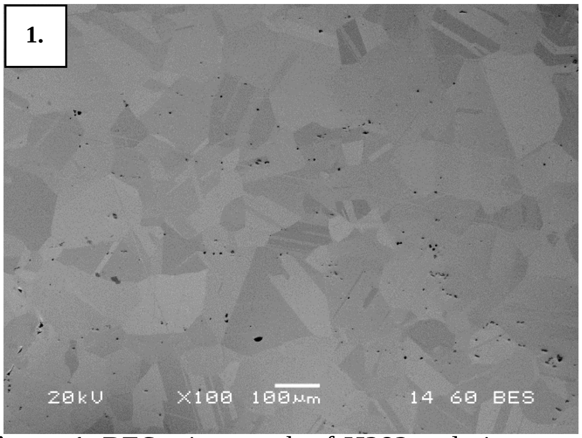

Figure 1. BES micrograph of H282, solution treated at 1140°C/2h/**WQ**, outlining the intragranular precipitation of (Ti, Mo)-based MC and TiN, throughout the γ matrix.

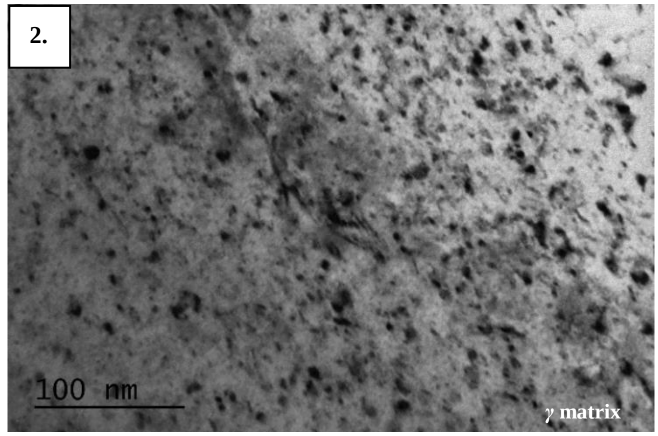

Figure 2. BF TEM image of H282, solution treated at 1140°C/2h/**WQ**, showing dense and uniform nanoprecipitation inside the γ matrix. Formation of γ' phase is not observed.

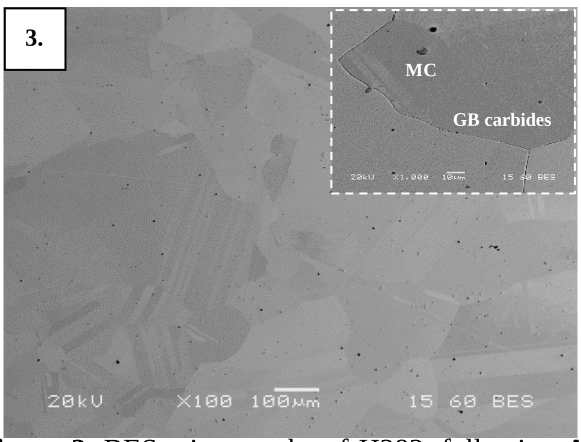

Figure 3. BES micrographs of H282, following **AC** after solution treatment at 1140°C/2h. GB (Cr, Mo)-rich $M_{23}C_6$ and Mo-rich M_6C, are formed in addition to primary MC and MN.

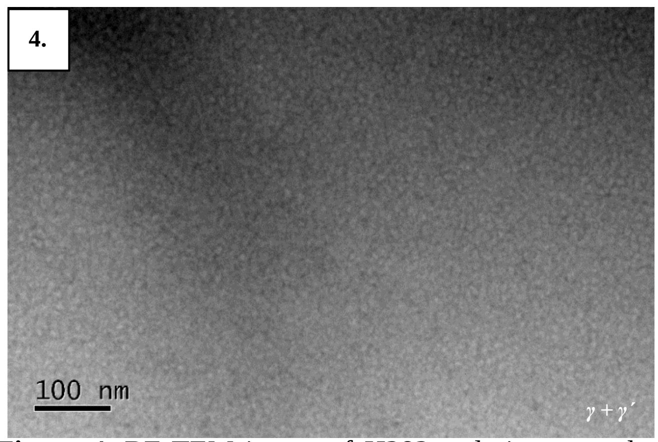

Figure 4. BF TEM image of H282, solution treated at 1140°C/2h/**AC**, illustrating the uniform dispersion of ultra-fine (6-7nm) γ' phase precipitates throughout the γ matrix.

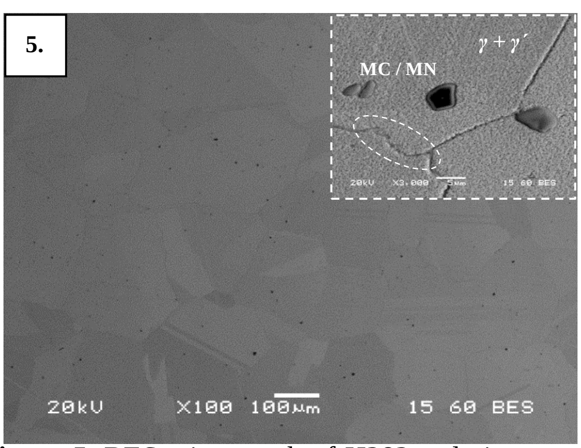

Figure 5. BES micrograph of H282, solution treated at 1140°C/2h/**FC**, showing the discrete precipitation of γ' phase. GB carbides are also coarsened, resulting in GB serration (indicated).

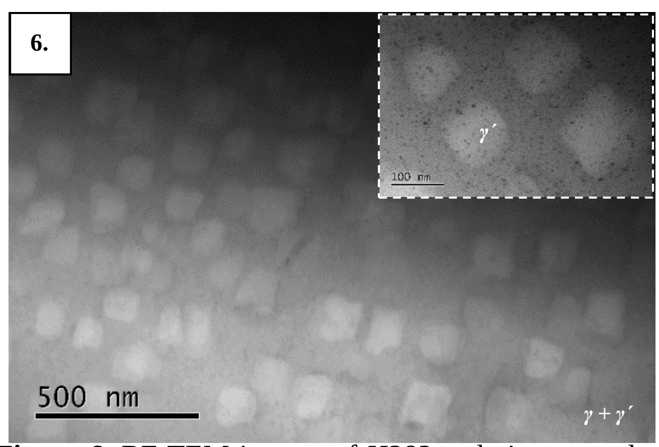

Figure 6. BF TEM images of H282, solution treated at 1140°C/2h/**FC**. Coarsened γ' precipitates (110nm), exhibiting a complex octodendritic morphology, are observed within the matrix.

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