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Influence of hot isostatic pressing temperature on microstructure and tensile properties of a nickel-based superalloy powder

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A high strength high γ' fraction nickel-based superalloy powder RR 1000 has been hot isotatically pressed (HIPed) at different temperatures. Microstructural analysis and assessment of the tensile properties were performed on these samples. It was found that HIP led to the formation of $(Hf,Zr)O_2$ particles on prior particle boundaries (PPBs) which were not present in the as-received powder. It is suggested that the oxides are formed by the diffusion of Hf and Zr from the interior of powder particles to the particle surfaces where oxygen level is usually high. When different HIP temperatures were used, no obvious effect on oxide size and distribution was observed but there was an effect on the microstructure and tensile properties. Thus, HIPing at super-solvus temperatures reduced the density of PPBs over the density observed in samples HIPed at sub-solvus temperatures by making grains within the original powder particles grow beyond the precipitates on PPBs, resulting in larger grains with serrated boundaries. Slow cooling from HIPing temperatures also led to the formation of irregular-shaped γ'. The 0.2% yield strengths at room temperature and at 700 °C were found to decrease with increase of HIP temperature but the high temperature ultimate tensile strengths and elongation increased considerably. Increasing HIPing temperature from sub-solvus to super-solvus temperatures also led to the transition of fracture mode from interparticle debonding to transgranular fracture mode.

1. Introduction

The demand for improved jet engine efficiency and performance has resulted in the continued development of high strength polycrystalline superalloys. Concurrent with the increase in strength is a significant decrease in conventional hot workability complicated by extensive segregation in the cast ingots. The decrease in workability adversely affects the overall component cost and the ability to achieve the desired properties. This has spurred the development of powder metallurgy (PM) techniques for producing components of highly alloyed compositions to achieve the desired microstructures, properties, and cost effectiveness. One of the most common PM techniques is hot isostatic pressing (HIPing) which enables production of fully consolidated product with homogeneous microstructure. So far, HIPing has been used to consolidate advanced nickel-based powder superalloys such as Rene 95 [1,2], Astroloy [3–5], APK1 [6], UDIMET 720 [7], UDIMET 720LI [8], EP741NP [9], Inconel 718 [10–12] and FGH4096 [13]. Although some of the as-HIPed nickel-based superalloys such as Astroloy were reported to show comparable mechanical properties to their extruded+forged counterpart [5], most of the directly HIPed nickel-based superalloys were found to suffer from the presence of prior particle boundaries (PPBs) which are particularly detrimental to mechanical properties such as low cycle fatigue, high temperature ductility and stress rupture properties [1–4,7–11]. The formation of PPBs is generally believed to be associated with the powder particle contamination by either oxygen or carbon or nitrogen which usually leads to the formation of oxides, carbides or oxy-carbides decorating at PPBs and impeding grain boundaries from moving beyond PPBs [1–12].

Many attempts have been made to reduce or eliminate PPBs. Decreasing either oxygen or carbon level was reported to decrease PPBs by reducing PPB precipitate decoration [6,10,14]. Increasing HIPing temperature is believed to be another method to reduce PPBs by promoting the grain boundaries to move beyond PPBs but this usually leads to coarsening of microstructure [7]. Exerting post-HIP high temperature solution treatment was reported to dissolve carbides at PPBs and thus to disrupt PPBs [10]. Gessinger et al. [3,4,15] suggested that the addition of strong carbide formers such as Ta or Hf may promote stable carbide

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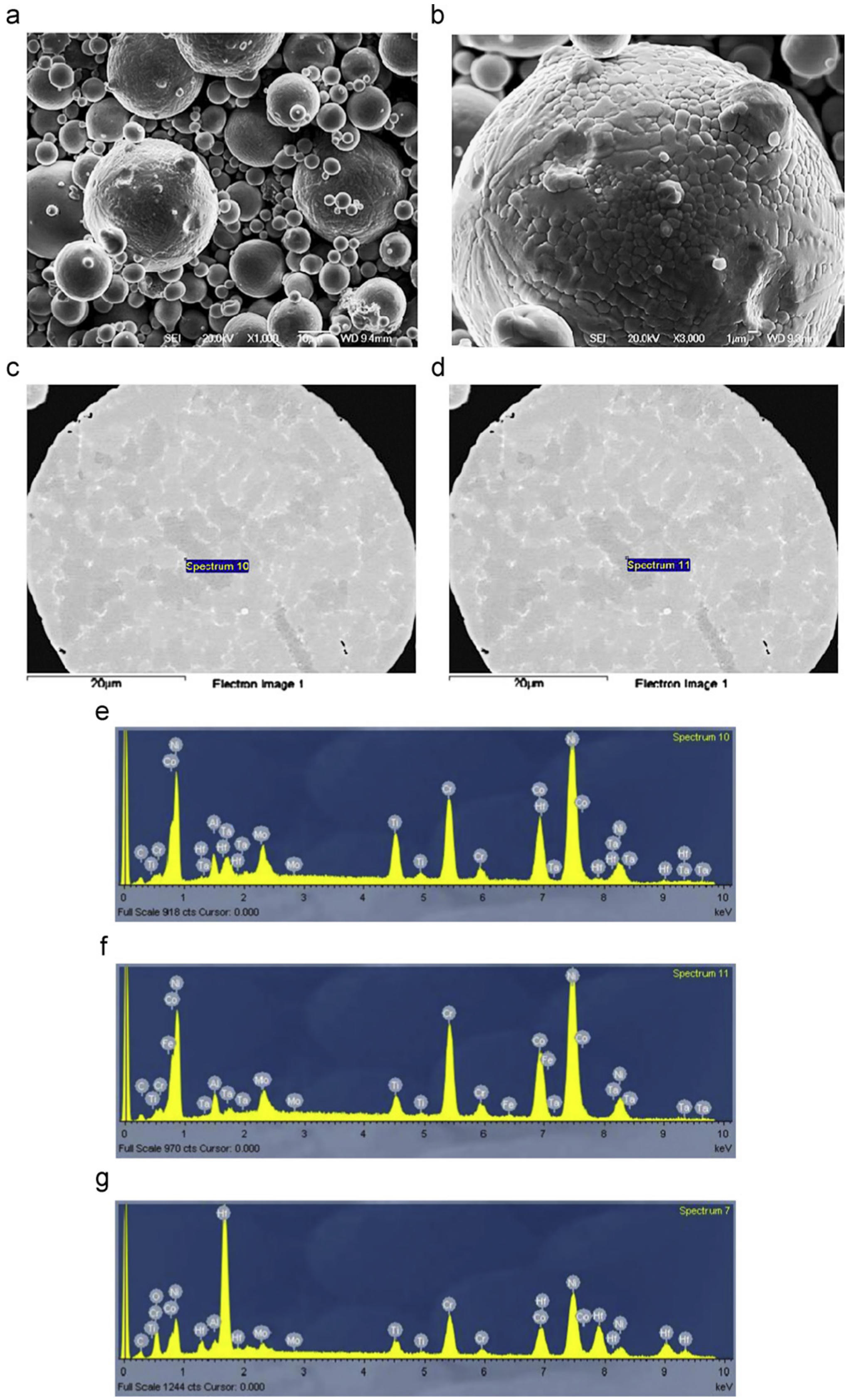

Fig. 1. Secondary electron SEM micrographs showing (a) the powder particle size and distribution, (b) the detailed particle surface structure; Back scattered SEM images showing (c) an interdendritc region and (d) the matrix next to the interdendritic region for EDX analysis; EDX analyses results showing the compositions of (e) the interdendritic region, (f) the adjacent matrix and (g) a precipitate shown in (c) indicated by the red arrow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)