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Understanding of Inverse Coarsening of γ' precipitates in Ni-base Superalloys

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The phase decomposition process leading to precipitation of ordered γ' precipitates with high temperature stability in nickel-base superalloys enhances the operating temperature of these alloys. The higher temperatures needed by specific components in systems are either desired for basic fuel savings (fossil) or output applications (nuclear co-generation) or are required to make systems technically feasible (solar).

The additional free energy associated with the interface between γ' precipitates and the Ni matrix solution (γ) usually drives the microstructural changes with respect to the size, shape and distribution of γ' precipitates. The prolonged exposure of Ni-base superalloys at high operating temperature, along with external mechanical stress, can significantly alter the microstructure description of the optimum condition and the extended stability with respect to microstructural change has been a subject of fundamental research in last 50 years.

Although the formation of γ' precipitates usually takes place over a small range of temperature, a single nucleation event can produce a fairly broad precipitates size distribution. During high temperature service, the additional chemical driving force for diffusion of elements from small precipitates to large precipitates, due to higher curvature of smaller precipitates, eventually leads to dissipation of small precipitates. As a result, the microstructure can depart from its optimum conditions leading to degradation of mechanical properties after a prolonged exposure. Most of the published reports on coarsening are based on controlling an interface energy driven coarsening mechanism that also form the basis of newer generations of Ni-base superalloys. The possibility of an alternate coarsening mechanism has not been properly established yet with respect to stability of γ-γ' microstructure.

The coarsening mechanism, driven by elastic energy instead of interfacial energy, can substantially increase the coarsening resistance and has been mentioned in limited reports and termed as "Inverse coarsening"[1]. The elastic energy driven coarsening mechanism can have significantly different mode of microstructural change such as i) increase in the size of small precipitates at the expense of larger precipitates to produce a narrow precipitate size distribution, ii) morphological transition from non-uniform shape to more uniform shape, and iii) significant reduction in the coarsening rate after attainment of a uniform size of precipitates in the microstructure.

In the present work, multi-component high refractory element containing Ni-base superalloys with multiple generations of γ' precipitates demonstrate the inverse coarsening of precipitates when subjected to isothermal annealing at multiple elevated temperatures. Experimental observations at multiple annealing periods up to 1500 hours has shown a clear evidence of inverse coarsening mechanism where small γ' precipitates coarsen faster as compared to larger precipitates to match the size scale, followed by a unprecedented coarsening resistance. The size of lager precipitates remains almost constant, at least up to the experimental observation of 1500 hours. While the theoretical basis of a coarsening resistance has been explained by a bifurcation diagram [2] and has been demonstrated in few simpler Ni-base alloys [3,4], the experimental evidence of such long-term stability in multi-component Ni-base superalloys has not been reported elsewhere. Along with the experimental verification, phase field modeling has been attempted to reveal the multi-particle interactions during inverse coarsening of γ' precipitates.

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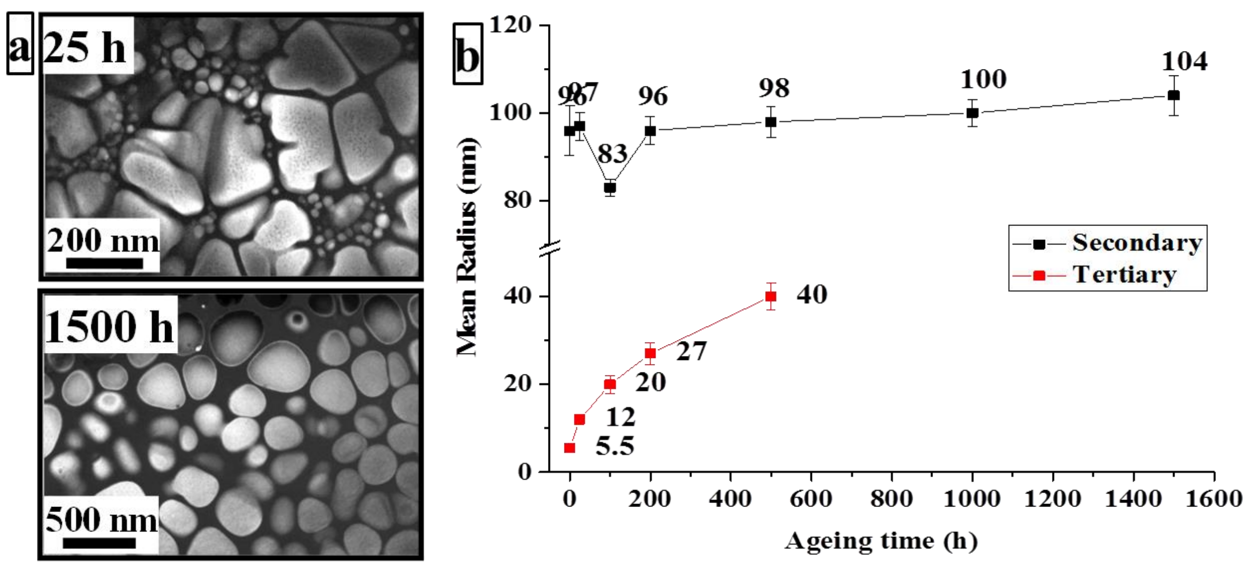

Figure 1 (a) The γ- γ' microstructure in a Ni-base superalloy subjected to isothermal annealing at an elevated temperature for 25 h. and 1500 h. (b) corresponding evolution of both (secondary and tertiary) γ' radius size upto 1500 h. of isothermal annealing.

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