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Stabilizing Additively Manufactured Superalloys at High Temperatures

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Abstract : The control of properties and material behavior by implementing thermal-mechanical processes is based on mechanical deformation and annealing according to a precise schedule that will produce a unique and stable combination of grain structure, dislocation substructure, texture, and dispersion of precipitated phases. The authors recently developed a thermal-mechanical technique to stabilize the microstructure of additively manufactured nickel-based superalloys even after exposure to high temperatures. However, the mechanism(s) that controls this stability is still under investigation. Laser peening (LP), also called laser shock peening (LSP), is a shock based (50 ns duration) post-processing technique used for extending performance levels and improving service life of critical components by developing deep levels of plastic deformation, thereby generating high density of dislocations and inducing compressive residual stresses in the surface and deep subsurface of components. These compressive residual stresses are usually accompanied with an increase in hardness and enhance the material's resistance to surface-related failures such as creep, fatigue, contact damage, and stress corrosion cracking. While the LP process enhances the life span and durability of the material, the induced compressive residual stresses relax at high temperatures (>0.5Tm, where Tm is the absolute melting temperature), limiting the applicability of the technology. At temperatures above 0.5Tm, the compressive residual stresses relax, and yield strength begins to drop dramatically. The principal reason is the increasing rate of solid-state diffusion, which affects both the dislocations and the microstructural barriers. Dislocation configurations commonly recover by mechanisms such as climbing and recombining rapidly at high temperatures. Furthermore, precipitates coarsen, and grains grow; virtually all of the available microstructural barriers become ineffective.Our results indicate that by using “cyclic” treatments with sequential LP and annealing steps, the compressive stresses survive, and the microstructure is stable after exposure to temperatures exceeding 0.5Tm for a long period of time. When the laser peening process is combined with annealing, dislocations formed as a result of LPand precipitates formed during annealing have a complex interaction that provides further stability at high temperatures. From a scientific point of view, this research lays the groundwork for studying a variety of physical, materials science, and mechanical engineering concepts. This research could lead to metals operating at higher sustained temperatures enabling improved system efficiencies. The strengthening of metals by a variety of means (alloying, work hardening, and other processes) has been of interest for a wide range of applications. However, the mechanistic understanding of the often complex processes of interactionsbetween dislocations with solute atoms and with precipitates during plastic deformation have largely remained scattered in the literature. In this research, the elucidation of the actual mechanisms involved in the novel cyclic LP/annealing processes as a scientific pursuit is investigated through parallel studies of dislocation theory and the implementation of advanced experimental tools. The results of this research help with the validation of a novel laser processing technique for high temperature applications. This will greatly expand the applications of the laser peening technology originally devised only for temperatures lower than half of the melting temperature.

Keywords : laser shock peening, mechanical properties, indentation, high temperature stability
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