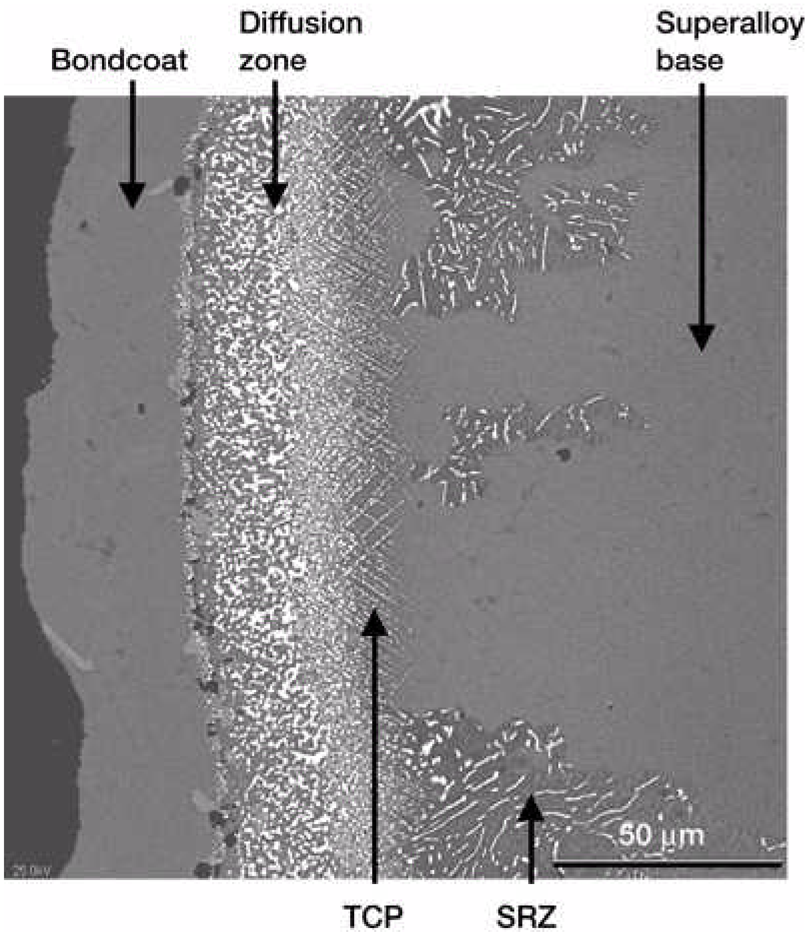
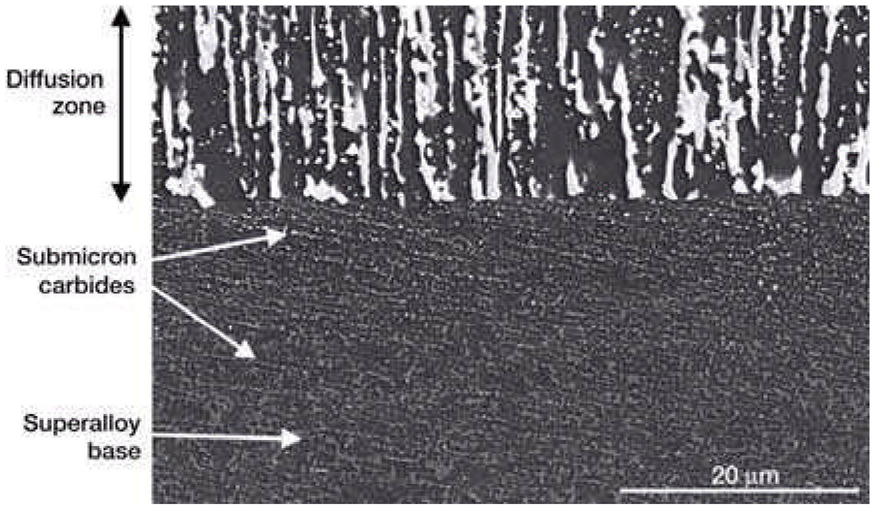
Techniques Optimized for Reducing Instabilities in Advanced Nickel-Base Superalloys for Turbine Blades



Fourth-generation alloys are susceptible to the formation of topologically close packed phases and a secondary reaction zone.

The High-Speed Research (HSR) Airfoil Alloy program developed fourth-generation single-crystal superalloys with up to an 85 °F increase in creep rupture capability over current production airfoil alloys. Recent results have been generated at the NASA Glenn Research Center on these fourth-generation alloys, but in coated form, for subsonic turbine blade applications under NASA's Ultra-Efficient Engine Technology (UEET) Program. One goal for UEET is to optimize the airfoil alloy/thermal barrier coating system for 3100 °F turbine inlet temperatures. The state-of-the art turbine blade airfoil system consists of a superalloy single crystal that provides the basic mechanical performance of the airfoil. A thermal barrier coating is used to reduce the temperature of the base superalloy, and a bondcoat is deposited between the base material and the thermal barrier coating. The bondcoat improves the oxidation and corrosion resistance of the base superalloy and improves the spallation resistance of the thermal barrier coating. A commercial platinum aluminide bondcoat was applied to the HSR-developed alloys, and a diffusion zone developed as a result of interaction between the bondcoat and the superalloy.

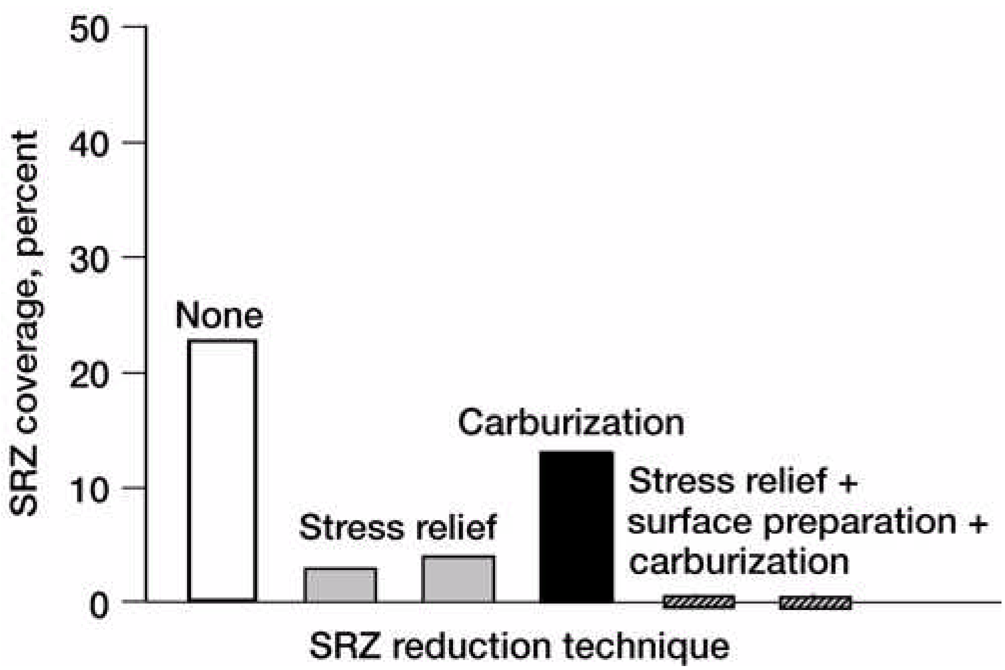


Successful carburization eliminates instabilities under the diffusion zone by forming submicron carbides and changing the local chemistry of the superalloy. Carburization is most effective when it is preceded by a stress relief heat treatment and adequate surface preparation.

Optimized strength is obtained for superalloys when the refractory element content is high and the limits of microstructural stability are approached or exceeded slightly. For fourth-generation alloys, instability leads to the formation of topologically close packed (TCP) phases, which form internally in the superalloy, and a secondary reaction zone (SRZ), which forms under the diffusion zone. There was a concern that excessive quantities of either TCP or SRZ might decrease the mechanical properties of the superalloy, with SRZ thought to be particularly detrimental and its formation unpredictable. Thus, an SRZ-reduction effort was initiated in the NASA UEET Program so that methods developed during the HSR project could be optimized further to reduce or eliminate the SRZ.

An SRZ is a three-phase constituent composed of TCP and stringers of gamma phase in a matrix of gamma prime. An incoherent grain boundary separates the SRZ from the gamma-gamma prime microstructure of the superalloy. The SRZ is believed to form as a result of local chemistry changes in the superalloy due to the application of the diffusion aluminide bondcoat. Locally high surface stresses also appear to promote the formation of the SRZ. Thus, techniques that change the local alloy chemistry or reduce surface stresses have been examined for their effectiveness in reducing SRZ. These SRZ-reduction steps are performed on the test specimen or the turbine blade before the bondcoat is applied. Stress-relief heat treatments developed at NASA Glenn have been demonstrated to reduce significantly the amount of SRZ that develops during subsequent high-temperature exposures. Stress-relief heat treatments reduce surface stresses by recrystallizing a thin surface layer of the superalloy. However, in alloys with very high propensities to form SRZ, stress relief heat treatments alone do not eliminate SRZ entirely. Thus, techniques that modify the local chemistry under the bondcoat have been emphasized and optimized successfully at Glenn. One such technique is carburization, which changes the local chemistry by forming submicron carbides near the surface of the superalloy. Detailed characterizations have demonstrated that the depth and uniform distribution of these carbides are enhanced when a stress relief treatment and an appropriate surface preparation are employed in advance of the carburization treatment. Even in alloys that have the propensity to develop a continuous SRZ layer beneath the diffusion zone, the SRZ has been completely eliminated or reduced to low, manageable levels when this combination of techniques is utilized.

Now that the techniques to mitigate SRZ have been established at Glenn, TCP phase formation is being emphasized in ongoing work under the UEET Program. The limits of stability of the fourth-generation alloys with respect to TCP phase formation are currently being defined along with high-temperature creep rupture properties. In addition, a regression model is being developed at Glenn for the prediction of the presence of TCP phase in the microstructure and SRZ under the diffusion zone. The model is based on a design-of-experiments methodology with emphasis on the potential synergistic effects of alloying elements.



The amount of secondary reaction zone (SRZ) that forms during high-temperature exposures has been significantly reduced by a stress relief heat treatment, and it has been completely eliminated when a combination of stress relief, adequate surface preparation, and subsequent carburization is used.

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