Industries of the Future-West Virginia

Preventing Solidification Defects in Large Superalloy Castings used in Advanced Electric Power Systems

Co-Funded By:
STAC

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Project Summary:
The rapidly growing need for clean, reliable, and affordable power across the United States has led to increasing demand for high-efficiency gas turbines. To improve energy efficiency, reduce operating cost, and lower emissions, gas turbines are operated at high temperatures: each 5° F increase in firing temperature results in a 1% increase in combined-cycle efficiency. Temperature limits are determined by the capability of the materials used for components such as turbine wheels and buckets to withstand the severe stresses associated with high-speed operation at high temperatures. Currently, Fe-Ni-base superalloys are used for these components in the latest generation of combined-cycle gas turbines. Improvement of these alloys has been identified by the U.S. Department of Energy as a critical enabling technology for high efficiency coal gasification-based power generation as well as natural gas fired power plants.

The ability to apply alloys used in aircraft engines, which operate at higher temperatures, to large-diameter power generation turbines has been limited by difficulties in producing the much larger (5x to 100x heavier) ingots that are needed. For example, Inconel 718 (IN-718) is being targeted for the next generation GE H-class turbine that would require a maximum wheel operating temperature of about 1200 F. However, materials suppliers have been unable to reliably produce defect-free IN-718 VAR ingots in diameters larger than about 30 inches, as the slower cooling rate of the larger ingots during solidification dramatically increases compositional inhomogeneity in the final product, leading to the formation of macrosegregation defects such as freckle (black spots rich in low melting-point compounds) and center segregation.

This project is a key step toward enabling the reliable commercial production of IN-718 castings large enough for current and future generations of gas turbines. Use of IN-718 in GE H-Class turbine discs enables firing temperatures 200 F higher than F-Class turbines, leading to a potential 4% increase in the combined cycle efficiency of new power plants using these turbines. For each gigawatt of power generation capacity, a 4% improvement in combined-cycle efficiency saves approximately 4.8 trillion Btu. Application in 50% of the 300+ gas-fired and ICGCC plants expected to be built from 2006-2025 will result in energy savings totaling 770 trillion Btu/yr. Carbon dioxide emissions are also proportionately reduced. Large, advanced superalloy castings are also expected to be required for ultrasupercritical (USC) steam turbines.

Freckle and center segregation are two of the most frequent solidification defects that occur in superalloy castings. The formation of these defects is caused by the segregation of alloying elements added to the base metal. Because the solid composition differs from that of the liquid, alloying elements tend to segregate during the solidification process, producing density differences between the liquid metal very near the solidification boundary and the bulk liquid. The most important factor affecting the macrosegregation in superalloy ingots is the partition of alloying elements between liquid and solid during solidification. Existing partition coefficient data are insufficient to support accurate prediction of alloy behavior, particularly at the temperatures and compositions of interest. This discrepancy is especially significant for IN-718.

We are developing improved methodologies for preventing macrosegregation in superalloy remelting processes. Weaknesses in existing models, particularly the inability to accurately predict partition coefficients of key elements, will be addressed. The targets of this project include: (a) obtaining accurate partition coefficients for IN-718 and 706 through thermodynamic calculation and experimental measurements; (b) quantitatively identifying the effect of minor elements and kinetic effects on partition coefficients and other solidification characteristics; (c) establishing and experimentally verifying the solidification model to predict macrosegregation based on predicted interdendritic liquid composition, liquid temperature, and phase formation during the solidification; and (d) providing guidelines of composition and processing control to prevent solidification defects in industrial VAR/ESR practice, verified by comparing model predictions with solidification defect experience in actual commercially-produced ingots. The ultimate goal is to develop a predictive technology that can be applied commercially to prevent solidification defects for large superalloy castings used in advanced electric power systems.