the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Computational Materials Design of Castable SX Ni-based Superalloys for IGT Blade Components—QuesTek Innovations

Background

Higher inlet gas temperatures in industrial gas turbines (IGTs) enable improved thermal efficiencies, but creep—the tendency of materials to deform gradually under stress—becomes more pronounced with increasing temperature. In order to raise inlet temperatures of IGTs, turbine blade materials are required to have superior creep rupture resistance. Nickel (Ni)-based single crystal (SX) blades have higher creep strength in comparison with directionally solidified blades and are widely used in aerospace engines. However, their use in IGTs, which require larger-size castings (two to three times the size needed in aerospace applications), is limited due to casting-related defects including freckling, high-angle boundary formation between grains, grain nucleation, and shrinkage/porosity, as well as post-cast defects such as incipient melting and recrystallization during high-temperature solution heat treatment. Current techniques for developing new SX alloys are empirical in nature and are inadequate for identifying unique alloy compositions that can satisfy both the processing and property objectives for gas turbine blades.

QuesTek Innovations LLC (QuesTek), with involvement from Siemens Power Generation and PCC Airfoils, proposes to implement a systematic, science-based approach that calculates optimum composition and processing routes to achieve desired material properties to design new castable SX Ni-based superalloys that can be cast effectively as large IGT blade components.

This turbine project was competitively selected under the Small Business Innovative Research (SBIR) Program. It is managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from high-hydrogen-content fuels derived from coal that is clean, efficient, and cost effective, minimizes carbon dioxide (CO_2) emissions, and will help to maintain the nation's leadership in the export of gas turbine equipment.

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PARTNERS

Siemens Power Generation
PCC Airfoils

PROJECT DURATION

Start Date	End Date
02/19/2013	11/18/2013

COST

Total Project Value
$149,618

DOE/Non-DOE Share
$149,618 / $0

AWARD NUMBER

SC0009592

U.S. DEPARTMENT OF ENERGY

Project Description

QuesTek is a leader in computational materials engineering and will employ a systems engineering design framework based on existing CALPHAD (CALculation of PHAse Diagrams) multicomponent tools. QuesTek will invoke reliable physics-based models to predict intrinsic freckling potency, alloy hot-tearing tendency during casting, and other casting related defects. The computational materials design will consider trade-offs between the blade property requirements such as creep strength, resistance to topologically close-packed phase formation, tensile strength, corrosion resistance, grain-boundary strength, and SX processing requirements such as freckling resistance, hot-tearing resistance, and a solution heat-treat window that avoids incipient melting. The Phase I focus will be on computationally designing candidate alloys that can provide enhanced castability while achieving increased metal temperature capability of 1050–1100 degrees Celsius. The Phase II program will focus on developing the entire systems-based materials design and validation through casting complex blade components with internal cooling passages using actual OEM (original equipment manufacturer) blade tooling.

QuesTek plans to collaborate with key stakeholders to define specific property goals and processing constraints that will enhance QuesTek's process-structure models for castability and structure-property models for superalloy design, sketch out microstructural concepts capable of achieving the program goals, and use the enhanced tools to design SX superalloy compositions incorporating these microstructural concepts. Also, QuesTek plans to fabricate baseline commercial alloy compositions (or variants of these compositions) as demonstration IGT tooling castings to characterize their casting behavior and compare it against QuesTek's model predictions. These model castings and the comparison against predictions will serve as a Phase I concept feasibility demonstration.

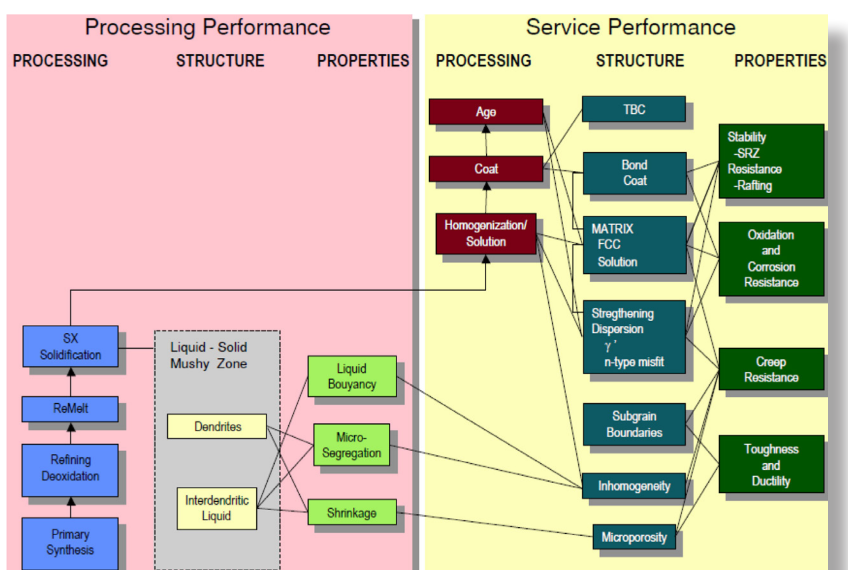
Goals and Objectives

The overall goal of the SBIR program is to design and develop more castable SX Ni-based superalloys that can be cast effectively as large IGT blade components, provide hot corrosion resistance, and provide superior creep performance comparable to state-of-the-art SX aeroturbine blades. The specific objectives of the Phase I program are to utilize QuesTek's models to design such alloys computationally and to demonstrate Phase I concept feasibility by comparing QuesTek's predictions against the casting behavior of certain commercial alloy systems.

Benefits

This SBIR project supports DOE's Hydrogen Turbine Program, which is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. The SBIR program is positioned to leverage the agility and innovative competencies of small businesses like QuesTek. IGTs operating at higher temperatures, enabled by new high yield SX castings, can operate at higher efficiency and thus reduce electricity-generation costs and CO_2 emissions. The high yield of the new SX alloys will accelerate their adoption by the IGT community, and their enhanced temperature capability will allow hydrogen-fueled turbines and ultra-high temperature steam turbines to be developed, thus bringing the vision of zero-emission fossil-fuel power plants a step closer to realization.

A single-crystal model blade (length:170mm).



System design chart developed by QuesTek for SX castings that illustrates the links among the performance properties, structure, and processing of the systems engineering approach. The properties are a function of the microstructure which can be achieved by the appropriate processing steps.