<u>Welding and Weld Repair of Single Crystal Gas Turbine Alloys</u>
(Oak Ridge National Laboratory)

FACT SHEET

I. PROJECT PARTICIPANTS

A. Prime Participant: Oak Ridge National Laboratory (ORNL)
B. Project Partners (no project funds to these partners):

General Electric Corporation
Electric Power Research Institute (EPRI)
Honeywell Aerospace Services
South Carolina Institute for Energy Studies
Siemens-Westinghouse Corporation
PCC Airfoils
Pratt and Whitney Corporation

II. PROJECT DESCRIPTION

A. Objective

It is the purpose of this project to investigate the potential for weld refurbishment and repair of single crystal gas turbine engine components and to determine processes, process conditions, and alloy compositions that will make such weld processing possible.

B. Background/Relevancy

Background. To achieve high-performance goals of future land-based gas turbine engines, it is expected that critical components will need to be made from single crystal nickel-base superalloys, as has been done for aerospace turbine engines. Welding is a desirable technology for the refurbishment and repair of worn or failed single-crystal components. However, during welding these alloys are prone to stray grain formation and cracking. Stray grain formation is the nucleation and growth of new grains which thereby destroys the single crystal nature of the alloy and concurrently reduces the mechanical properties of the material. Grain boundaries that form as a result of stray grain formation are also vulnerable sites for crack initiation and propagation.

Earlier work at ORNL on model single crystal alloys has provided much insight into the evolution of microstructure in single crystal welds. A geometrical model has been developed that can be used to predict the solidification microstructure. This work has also led to an understanding of the possible mechanism for stray grain formation. This knowledge base will be applied to the study of stray grain formation in nickel base superalloys with the objective of identifying potential alloy modifications that will reduce the stray grain formation tendencies.

The development of thermo-mechanical stresses during welding plays a critical role in the cracking behavior of these alloys. ORNL has modeling capabilities to predict the level of stress development as a function of weld process and process parameters and these will be applied to identify the optimum welding conditions for yielding crack-free welds.

Relevancy. Due to the increase in size of land-based turbine engines compared to comparable aircraft turbine engines, component cost will be increased dramatically and component quality will be a major manufacturing concern. Consequently, current casting yields are unacceptable and will need to be improved to make the costs manageable. The problem of improving casting yields will be exacerbated by the fact that the larger component size increases the likelihood of having defects. One solution is to develop a reliable repair process that can be used to refurbish defective castings and thereby improve the net yield. Similarly, a technology for repairing parts is essential since replacement costs will be prohibitive. Such a repair technology will be needed for worn parts as well as failed components.

This program addresses the issue of welding and weld repair of single crystal gas turbine engine components by identifying the weld process and procedures that yield suitable and reliable welded components. Potential alloy modifications for weld filler metals that minimize the stray grain formation and cracking tendencies, and produce microstructures in-line with mechanical property requirements, will also be identified. The development of effective welding procedures will allow for higher engine efficiencies and cost savings.

C. Period of Performance: October, 2001 through September, 2004, but it is planned to continue the program beyond FY2004 depending upon the availability of funds.

D. Project Summary: A two-pronged approach is undertaken. First, the problem of stray grain formation in single crystal welds is being examined in detail using model alloys. Their formation must be avoided in order to achieve viable single crystal welds. Thermodynamic, thermal, and solidification modeling as well as examination of model alloys and filler metal composition modifications are being used to identify the necessary conditions for the elimination of stray crystals in weldments. Second, a variety of fusion welding techniques, including electron and laser beam welding, and transient liquid phase bonding, are utilized on commercial alloys in order to identify process conditions that are amenable to producing crack-free welds. Complementary thermo-mechanical modeling and simulation testing is being carried out to identify weld cracking behavior. The welds will be evaluated by advanced characterization techniques in order to understand the microstructural development and cracking behavior, and to tailor the weld procedures to yield sound welds that meet microstructure and anticipated property requirements prior to and after long-term service. The program is being coordinated with an industry-university consortium that provides in-kind support and direction to the program.

III. PROJECT COSTS

A. DOE Costs: $1,095,000 for first 3 years
B. Prime Contractor Cost Sharing: NA
C. Partner Cost Sharing, If Applicable: In-kind support for materials, single crystal castings and weld repair test are being provided voluntarily by the project partners.

IV. MAJOR ACCOMPLISHMENTS SINCE THE BEGINNING OF THE PROJECT

- The industrial advisory board for the project was established. This board is comprised of alloy manufacturers, gas turbine engine manufacturers, and repair organizations. Their input will provide valuable guidance for making the project relevant to industrial practice. In addition, they have already provided commercial alloys for use in the project. Finally, repair facilities have contributed by making test welds using state-of-the-art laser powder deposition processes for evaluation and characterization.
- Model alloys were identified by ORNL and prepared by PCC Airfoils. The alloy compositions were based on computational thermodynamic calculations to provide alloys that would have varying degrees of sensitivity to stray grain formation. Multiple single crystal rods were cast and are presently being evaluated as a function of welding conditions.

V. <u>MAJOR ACCOMPLISHMENTS PLANNED DURING THE NEXT 6 MONTHS</u>

- Computational thermodynamics calculations will be made to determine the effect of alloy composition on the solidification temperature range, which is associated with the stray grain formation behavior. A neural network model to predict solidification temperature range as a function of alloy composition will be developed. This will provide the basis for identifying future alloy modifications for commercial alloys for use as filler metals.

VI. <u>MAJOR ACCOMPLISHMENTS PLANNED IN OUTYEARS (6 - 18 MONTHS)</u>

- The weldability of commercial single crystal alloys will be evaluated as a function of weld process and process conditions. Thermo-mechanical modeling will be performed to evaluate the favorable conditions for minimizing stresses and crack formation tendencies. Simulation tests will be completed to evaluate the hot ductility of several commercial alloys. Results from all of these studies will provide valuable insight for identifying the optimum welding conditions needed to avoid hot cracking.
- Based on results of stray grain formation in model alloys as a function of welding conditions, the basic mechanism for stray grain development during welding will be identified. This will enable us to identify the processing conditions and alloy requirements to minimize stray grain formation in commercial alloy welds.

VII. <u>MAJOR MILESTONES FOR THE ENTIRE PROJECT</u>

- Establish a consortium of industry organizations to act as an advisory group for this project.
- Procure commercial and model alloys for the project from advisory group members.
- Make welds at Honeywell Aerospace Services using their laser powder deposition process and evaluate the cracking sensitivity as a function of filler metal composition.

- Make welds on thin sheet commercial alloys to assess the variation of cracking behavior as a function of welding conditions and crystal orientation.
- Prepare welds on model single crystal alloys and determine the effect of welding conditions on the stray grain formation behavior in model alloys.
- Using computational thermodynamic models, calculate the effect of composition on solidification temperature range for commercial alloys.
- Conduct simulation tests to evaluate the hot cracking behavior as a function of composition of commercial alloys.
- Carry out thermo-mechanical modeling calculations to determine the effect of welding conditions on stress development within the welds.
- Characterize the weld microstructures and analyze the effect of welding conditions on microstructural development.
- Make additional welds at Honeywell Aerospace Services to determine the cracking behavior as a function of groove geometry and weld pre-heat.
- Prepare welds using a cladding technique to determine the potential of cladding to achieve single crystal microstructures for blade tip repair.
- Investigate alternative joining and repair techniques including transient liquid phase bonding for joining single crystal alloys.
- Identify potential filler metal compositions for improved resistance to stray grain formation while maintaining superior mechanical properties.
- Procure modified filler metal alloys.
- Produce and evaluate test welds using modified filler metal compositions and optimum welding conditions.

VIII. ISSUES: No major issues have been identified.

IX. ATTACHMENTS: None