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Joining Technologies for Gamma Titanium Aluminide Castings Final Report CRADA No. TC-1088-95

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Joining Technologies for Gamma Titanium Aluminide Castings

Final Report
CRADA No. TC-1088-95
Date Technical Work Ended: May 1, 2000

Date: February 2, 2001 Revision:

A. Parties

The Parties to this CRADA are The Regents of the University of California as operators of the Lawrence Livermore National Laboratory (LLNL) and United Technologies Corporation, acting through Pratt & Whitney Division.

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B. Project Scope

The purpose of this project was to assist the Paton Electrical Welding Institute in developing the technology and brazing consumables required to join and repair gamma-TiAl castings. This technology was critical to the introduction of gamma-TiAl components into the next generation of lightweight, fuel-efficient aircraft engines.

Pratt & Whitney and other engine manufacturers were highly interested in this technology and targeted this material in the low-pressure turbine sections of their engines. Improvements in weldability were required prior to implementing this material.

The CRADA developed the capability to join gamma-TiAl couples and repair gamma-TiAl castings using methods that allow full utilization of the parent material properties.

C. Technical Accomplishments

The joining development efforts focused on two areas:

1) Appropriate consumables and brazing schedules for joining gamma-TiAl
2) Welding process equipment and control methods for fusion welding and repair welding of gamma-TiAl

In the brazing development, all team members jointly selected a series of candidate braze consumables for evaluation. Paton fabricated brazing foils, evaluated brazing characteristics, developed brazing schedules, and produced demonstration components. In parallel, LLNL fabricated, evaluated, and demonstrated diffusion brazing methods for joining gamma-TiAl. Pratt & Whitney inspected and evaluated the brazed joints. In the welding/welding repair development, Paton developed the welding process.

There were two phases to this project:

1) Technology Evaluation
2) Technology Demonstration

Phase I – Technology Evaluation

Phase I had six tasks:

1) Candidate Braze Alloy Compositions Were Defined
2) Braze Consumables Were Fabricated
3) Brazing Characteristics Were Evaluated
4) Diffusion
5) Service Temperature Limits for Candidate Braze Systems Defined
6) Fusion Weldability of Gamma-TiAl Evaluated

Task 1: Candidate Braze Alloy Compositions Were Defined

Candidate brazing alloys were selected from analysis of existing phase diagram data and from the published literature on brazing of titanium and titanium-aluminide alloys. Braze alloys with potential for improved high temperature performance were selected using two approaches:

1) Modifications to conventional Ti braze alloys
2) Additions of melting point depressant to Ti-Al based alloys

Paton provided written documentation of candidate braze alloy characteristics including; anticipated brazing temperatures, maximum service temperatures, and potential brazing foil fabrication methods. Pratt & Whitney and LLNL evaluated the data and, with Paton, selected a series of brazing alloy compositions for experimental evaluations.

Task 2: Braze consumables Were Fabricated

Paton fabricated brazing foils sufficient for testing and evaluation of each candidate brazing alloy. Paton demonstrated the capability to produce foils with acceptable uniformity.

Task 3: Brazing Characteristics Were Evaluated

Paton obtained gamma-TiAl substrate material from local or international suppliers. Paton developed brazing process schedules and produced data on brazing characteristics including wettability, spreading rates, and filling of joint gaps.

Paton performed preliminary microstructural analyses as necessary to develop brazing schedules. Paton supplied brazed couples from each candidate brazing alloy to Pratt & Whitney and produced a report summarizing the brazing characteristics and microstructures of each candidate braze alloy. Pratt & Whitney performed microstructural characterization of selected candidate brazes. Paton, Pratt & Whitney, and LLNL ranked and selected braze alloys for demonstration testing in Phase II.

Task 4: Diffusion

LLNL performed a series of diffusion brazing evaluations on coated substrates and produced data on weldability of the substrates. LLNL produced a series of interdiffusion heat treatments to quantify the extent of joint homogenization. LLNL characterized the microstructures of the diffusion-brazed joints. Pratt & Whitney and LLNL ranked and selected braze alloys for demonstration testing in Phase II.

Task 5: Service Temperature Limits for Candidate Braze Systems Defined

Paton performed screening tests of the successful braze alloy candidates to determine the peak temperature limitations of the brazements at a predefined stress level. Paton provided a written report of the high temperature mechanical test results

Task 6.: Fusion Weldability Of Gamma-TiAl Evaluated

Paton utilized their electron beam processing capabilities and manual Gas Tungsten Arc Welding (GTAW) to develop fusion welding procedures for gamma-TiAl.

Paton demonstrated the relationships between preheat temperature and cracking resistance in high-restraint conditions using circular-patch welds, a high-restraint joint configuration, in welding atmospheres with controlled oxygen and moisture contents. Paton developed processing capabilities for welding with unusually high preheat temperatures. Paton inspected the welds using suitable fluorescent penetrant inspection and radiographic methods, documented the extent of hot and cold cracking and other discontinuities, and characterized the weld fusion zone and heat affected zone microstructures. Paton provided a written report of the test results and shipped sample welds to LLNL/Pratt & Whitney for concurrent microstructural characterization.

Phase II - Technology Demonstration

Phase II had six tasks:

1) Braze Consumables for Demonstration Assemblies Fabricated
2) Optimized Brazing Schedules and Braze Demonstration Assemblies
3) Diffusion Braze Demonstration Assemblies
4) Optimize Fusion Welding Processes
5) Demonstration of Casting Repair
6) Final Report

Task 1: Braze Consumables for Demonstration Assemblies Fabricated

Paton produced brazing foils of selected alloys for brazing demonstrations. Paton examined commercially feasible production methods for fabrication of braze foils with thicknesses approaching 150 μm.

Task 2: Optimized Brazing Schedules and Braze Demonstration Assemblies

Pratt & Whitney specified component shapes to be brazed. Paton optimized brazing process schedules for up to three candidate braze alloys. Paton produced five sets of brazed assemblies from each of the candidate braze alloys using the optimized brazing schedules. Paton performed non-destructive evaluation of braze discontinuities using radiography or other suitable techniques. Paton sectioned and evaluated the microstructures of two assemblies and shipped the remaining assemblies to Pratt & Whitney.

Task 3: Diffusion Braze Demonstration Assemblies

Diffusion braze demonstration assemblies were not fabricated or evaluated.

Task 4: Optimize Fusion Welding Processes

Paton developed weld process controls and parameters suitable for repair of casting defects in a manufacturing environment. Paton performed test welds in a high restraint condition and evaluated the microstructures and mechanical properties of the weldments.

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Task 5: Demonstration of Casting Repair

Paton performed repair welds on defective castings using crack-resistant process methods. Paton performed fluorescent penetrant and radiographic inspections.

Task 6: Final Report

This document is the final report.

D. Expected Economic Impact

D.1 Specific Benefits:

The impact of TiAl joining technology on jet engine manufacturing will be limited.

Restructuring of needs in the industry have made the inclusion of TiAl parts in turbine compressors economically unfavorable.

Future applications of TiAl in the Aerospace industry include use of this alloy as a skin material in proposed high-speed transports. The technology developed in this project may be transferable to these or similar thin sheet applications.

E. Partner Contribution

E.O. Paton demonstrated the viability of several welding and brazing methods for joining of TiAl. The company has developed braze alloys suitable for joining TiAl with acceptable microstructures. E.O. Paton also developed and demonstrated high preheat welding methods for joining TiAl using GTAW technology.

No subject inventions were created during this project. There are no plans to utilize the technology in manufacturing or to perform additional developmental work. There are presently informal discussions to assess the feasibility of using this or similar technology for the joining of TiAl for use in other areas.

F. Documents/Reference List

a) Reports

The following reports were generated during the course of this project.

V.F. Khorunov, S.V. Maximova, and S.M. Samokhin, Task 1. Technical Report on Identification of Five Braze Alloys, E.O. Paton Electric Welding Institute.

V.F. Khorunov, S.V. Maximova, and S.M. Samokhin, Task 2. Technical Report on the Methods for Fabrication of Suitable Brazing Consumable, E.O. Paton Electric Welding Institute.

V.F. Khorunov, S.V. Maksimova, and S.M. Samokhin, Task 3. Evaluate Brazing Characteristics and Brazing Joint Microstructures, E.O. Paton Electric Welding Institute.

M. Strum and L. Wagner, Summary Report on Diffusion Brazing Studies at LLNL, Lawrence Livermore National Laboratory, March 1997.

V.F. Khorunov, S.V. Maximova, and S.M. Samokhin, Task 4. Technical Define and Demonstration Methods for Joining Gamma titanium Aluminides, E.O. Paton Electric Welding Institute.

V.F. Khorunov, Development of Procedures for Preheating the TiAl Samples Prior to Fusion Welding, E.O. Paton Electric Welding Institute.

V.F. Khorunov, Investigation of Relationship Between Cracking Resistance of Samples Under Conditions Their Rigid Restraint, Preheating and Postweld Heat Treatment, E.O. Paton Electric Welding Institute.

V.F. Khorunov, Evaluation of Microstructure and Tensile Properties of Welds Made by Fusion Welding, E.O. Paton Electric Welding Institute.

V.F. Khorunov and S.V. Maksymova, Task 7. Technical Report on the Methods of Producing Amorphous or Fine-Crystalline Materials by Quenching from the Liquid State and Equipment and Technology for Melting Brazing Alloys of the Selected Compositions, E.O. Paton Electric Welding Institute.

V.F. Khorunov, Task 9c. Development of Welding Equipment and Parameters of Welding and Postweld Heat Treatment of Welding of Plates of different Thickness Under Factory Conditions, E.O. Paton Electric Welding Institute.

V.F. Khorunov, Task 9d. Making of Welds with a High Degree of Restraint on Demonstration Samples, Evaluation of Microstructures and Mechanical Properties of the Welds, E.O. Paton Electric Welding Institute.

V.F. Khorunov, Task 9e. Welding of Demonstration Samples, E.O. Paton Electric Welding Institute.

b) Patent/Copyright Activity

There is no known patent or copyright activity.

c) Subject Inventions

No subject inventions have been disclosed by LLNL or industrial partners.

d) Background Intellectual Property (BIP)

There is no known activity regarding licensing of Background Intellectual Property (BIP).

G. Acknowledgement

Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The participants certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed or are included on a list attached to this report.
4) The Participant certifies that if real property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Leonard T. Summers — Date: 4/1/01
Lawrence Livermore National Laboratory

J. Carter Barone — Date: 3/15/01
United Technologies Corporation/Pratt & Whitney

Attachment I – Final Abstract

Joining Technologies for Gamma Titanium Aluminide Castings

Final Abstract (Attachment I)
CRADA No. TC-1088-95
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C. Benefit to Industry

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