DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Ceramic Additive Manufacturing for Gas Turbine Engine Blades

Report Number:
DSIAC-2018-0900
Completed February 2017

DSIAC is a Department of Defense Information Analysis Center

MAIN OFFICE
4695 Millennium Drive
Belcamp, MD 21017-1505
Office: 443-360-4600

REPORT PREPARED BY:
Brian Benesch

ABOUT DSIAC

The Defense Systems Information Analysis Center (DSIAC) is a U.S. Department of Defense information analysis center sponsored by the Defense Technical Information Center. DSIAC is operated by SURVICE Engineering Company under contract FA8075-14-D-0001.

DSIAC serves as the national clearinghouse for worldwide scientific and technical information for weapon systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability; advanced materials; military sensing; autonomous systems; energetics; directed energy; and non-lethal weapons. We collect, analyze, synthesize, and disseminate related technical information and data for each of these focus areas.

A chief service of DSIAC is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry. For more information about DSIAC and our TI service, please visit www.DSIAC.org.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information on current research, development, testing, and evaluation (RDT&E) efforts on ceramic additively manufactured (AM) gas engine turbine blades. DSIAC staff contacted subject matter experts in ceramic AM and generated a summary of RDT&E in this area, including specific application for gas engine turbine blades and air foils. Additionally, a literature research was conducted, and a list of relevant reference documents was compiled from the Defense Technical Information Center Research and Engineering Gateway and open sources.

Contents

1.0 TI Request

1.1 SUBJECT: Ceramic Additive Manufacturing for Gas Turbine Engine Blades

1.2 DESCRIPTION

The inquirer requested information on research, development, test, and evaluation (RDT&E) efforts in ceramic additively manufactured (AM) gas engine turbine blades. The Defense Systems Information Analysis Center (DSIAC) staff identified relevant organizations and documents that can provide additional detailed information on specific work efforts.

2.0 TI Response

DSIAC staff worked with its academic partners West Virginia University Innovation Corporation, Georgia Tech Research Institute, and Texas Research Institute, Austin, Inc. to identify relevant organizations and associated points of contact (POCs). DSIAC and its partners identified several organizations and POCs who have expertise in ceramic AM and can offer a summary of their work in that area and specific applications for gas engine turbine blades and air foils. Additionally, a literature research was conducted, and a list of relevant reference documents to provide background for the technical inquiry was compiled.

2.1 RELEVANT ORGANIZATIONS

DSIAC identified the following organizations that have RDT&E efforts related to ceramic AM gas engine turbine blades or air foils. POCs for each organization were identified but are not listed; they can be obtained by contacting DSIAC.

- **Air Force Research Laboratory.** Materials and Manufacturing Directorate, Manufacturing Technology Division.
- **Naval Air Systems Command (NAVAIR).** Additive Manufacturing/Digital Thread Integrated Product Team.
- **American Manufacturing, LLC.** Awarded a Small Business Technology Transfer grant in 2016 on "Additive Manufacturing of Ceramic Composites for Next Generation Gas Turbines" by the National Science Foundation.
- **Ohio Aerospace Institute.** Received National Aeronautics and Space Administration funding to develop an AM method for ceramic blades.
- **Free Form Fibers.** Exhibitor at United States Advanced Ceramics Association (USACA) conference advertising ceramic AM.
- **Plasma Processes.** Exhibitor at USACA conference advertising ceramic AM.

2.2 LITERATURE SEARCH RESULTS

A search of technical literature yielded the following most relevant results on the topic of RDT&E of ceramic AM gas engine turbine blades or air foils. An excerpt and a reference for more information are provided for each listed item.

- **Patent: "Gas Turbine Engine Blade with Ceramic Tip and Cooling Arrangement"** [1]

  This disclosure relates to a gas turbine engine blade and its cooling configuration….

The advancement of additive manufacturing to create metal parts enables for extremely detailed, intricate and adaptive feature designs. The ability to utilize this technology not only increases the design space of the parts but allows for a much higher degree of manufacturing robustness and adaptability. It enables the elimination of costly manufacturing tooling and only requires three dimensional definition of the part. However, the current state-of-the-art in additive manufacturing does not allow for the creation of single crystal materials due to the nature of the process to be built by sintering or melting a powder substrate to form….

In one exemplary embodiment, an airfoil for a gas turbine engine extends a span from a root to a tip. The airfoil is provided by a first portion near the root and has a metallic alloy. A third portion near the tip has a refractory material. A second portion joins the first and third portions and has a functional graded material.

For more information, see the following link: http://www.freepatentsonline.com/y2016/0312617.html [1]

- **"Rapid Fabrication of Nb-Si Based Alloy by Selective Laser Melting: Microstructure, Hardness, and Initial Oxidation Behavior"** [2]

With remarkably higher operating temperatures than advanced Ni-base superalloys, Nb-Si based ultrahigh temperature alloys show great promise for applications as the next generation turbine blade materials [1] and [2]. They are designed as in situ composites, composed of Nb solid solution (Nbss) and Nb_5Si_3 phases. Nbss offers room-temperature ductility and silicides supply high-temperature strength and creep resistance. To achieve a property balance, elements such as Ti, Cr, Hf and Al have been added and striking progress has been achieved on improving the overall properties of Nb-Si based alloys [2], [3] and [4]. But the mechanical and environmental properties of Nb-Si based alloys still need further improvement for application, which will be most probably provided by innovation in processing and production technology.

For more information, see the following link: http://www.sciencedirect.com/science/article/pii/S0264127516309418 [2]

- **Patent: "Manufacturing Method for a Dual Wall Component"** [3]

  A method for forming a blade extending from a root to a tip includes forming a pressure side outer wall extending from a leading edge to a trailing edge, forming a suction side outer wall extending from the leading edge to the trailing edge, forming a first inner wall having a shape complimentary to the pressure side outer wall, and forming a second inner wall having a shape complimentary to the suction side outer wall. The first inner wall and the pressure side outer wall are separated by a first cavity, the second inner wall and the suction side outer wall are separated by a second cavity, and the second inner wall and the first inner wall are separated by a third cavity. The pressure side outer wall, the suction side outer wall, the first inner wall and the second inner wall are formed by additive manufacturing and without using cores to form the first, second and third cavities.

  For more information, see the following link: http://www.freepatentsonline.com/y2016/0222790.html [3]

- **Patent: "Uber-Cooled Turbine Section Component Made by Additive Manufacturing"** [4]

  The ability to produce an actively cooled turbine engine airfoil that can operate thousands of hours in a thermal environment where metal temperatures operate less than 200 degrees Fahrenheit of the melting temperature of the superalloy is important. This has been achieved using a combination of cored passages and laser drilled holes and/or electrodischarge machine drilled holes that communicate with one another to provide passageways within the superalloy casting for which cooling air can enter and exit. This enables the superalloy material to retain sufficient mechanical properties to withstand operational induced loads and achieve or exceed part life requirements.

  For more information, see the following link: https://patents.google.com/patent/US20140169981A1/en [4]

- **Patent: "High Temperature Additive Manufacturing for Organic Matrix Composites"** [5]

  There is an ongoing effort to replace metal components in a gas turbine engine with lighter components made from alternative materials, even if the components experience significant loads or are subjected to environmental concerns (e.g., high or low temperatures, erosion, foreign-object damage) during use. For example, in the aerospace industry, manufacturers of gas turbine engines are considering the use of alternative materials for fan blades, compressor blades, and possibly turbine blades. Suitable non-metal alternative materials include, but are not limited to, reinforced polymers, polymer matrix composites, ceramics, and ceramic matrix composites.

  For more information, see the following link: http://www.freepatentsonline.com/y2016/0153102.html [5]

- **"GE Aviation to Build Unique Materials Factories"**[6]

  In a ceremony here today with Alabama public officials, GE Aviation broke ground on two adjacent factories to mass-produce silicon carbide (SiC) materials used to manufacture ceramic matrix composite components (CMCs) for jet engines and land-based gas turbines for electric power.

  For more information, see the following link: https://www.geaviation.com/press-release/other-news-information/ge-aviation-build-unique-materials-factories-0 [6]

- **"Materials for a Non-Steady-State World"** [7]

  Over the course of the past decade, GE Aviation has introduced a large number of new materials and processes as it refreshed its family of aero-turbine engines and responded to demands of the marketplace. The new materials and process technologies included the following… Ceramic matrix composite, SiC/SiC, for turbine shrouds. Additive Manufacturing to produce advanced turbine combustor fuel nozzles.

  For more information, see the following link: https://link.springer.com/article/10.1007%2Fs11663-016-0655-4 [7]

REFERENCES

[1] Slavens, T. N., M. C. Blake, T. J. Jennings, N. M. Loricco, S. M. Moore, and C. J. Musto. "Gas Turbine Engine Blade with Ceramic Tip and Cooling Arrangement." United States Patent Application 20160312617, 27 October 2016, http://www.freepatentsonline.com/y2016/0312617.html, accessed February 2017.

[2] Guo, Y., L. Jia, S. Sun, B. Kong, J. Liu, and H. Zhang. "Rapid Fabrication of Nb-Si Based Alloy by Selective Laser Melting: Microstructure, Hardness and Initial Oxidation Behavior." *Materials & Design*, vol. 109, 5 November 2016, pp. 37–46, https://www.sciencedirect.com/science/article/pii/S0264127516309418, accessed February 2017.

[3] Spangler, B. W. "Manufacturing Method for a Dual Wall Component." United States Patent Application 20160222790, 4 August 2016, http://www.freepatentsonline.com/y2016/0222790.html, accessed February 2017.

[4] Bales, D. A., A. Kulcha, and G. M. Dolansky. "Uber-Cooled Turbine Section Component Made by Additive Manufacturing." United States Patent Application 20140169981A1, https://patents.google.com/patent/US20140169981A1/en, accessed February 2017.

[5] Watson, C. R., and G. O. Grant. "High Temperature Additive Manufacturing for Organic Matrix Composites." United States Patent Application 20160153102, 2 June 2016, http://www.freepatentsonline.com/y2016/0153102.html, accessed February 2017.

[6] GE Aviation. "GE Aviation to Build Unique Materials Factories." https://www.geaviation.com/press-release/other-news-information/ge-aviation-build-unique-materials-factories-0, 16 June 2016.

[7] Schafrik, R. E. "Materials for a Non-Steady-State World." *Metallurgical and Materials Transactions B*, vol. 47, no. 3, pp 1505–1515, June 2016, http://link.springer.com/article/10.1007%2Fs11663-016-0655-4, accessed February 2017.