ORNL/TM-2017/451
CRADA/NFE-16-06278

Additive Manufacturing for Low Volume Bearings

Brad Richardson
Dr. Lonnie Love

John G. Tate
Schaeffler Group USA

September 28, 2017

CRADA FINAL REPORT
NFE-16-06278

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via US Department of Energy (DOE) SciTech Connect.

Website http://www.osti.gov/scitech/

Reports produced before January 1, 1996, may be purchased by members of the public from the following source:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone 703-605-6000 (1-800-553-6847)
TDD 703-487-4639
Fax 703-605-6900
E-mail info@ntis.gov
Website http://www.ntis.gov/help/ordermethods.aspx

Reports are available to DOE employees, DOE contractors, Energy Technology Data Exchange representatives, and International Nuclear Information System representatives from the following source:

Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831
Telephone 865-576-8401
Fax 865-576-5728
E-mail reports@osti.gov
Website http://www.osti.gov/contact.html

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/TM-2017/451
CRADA/NFE-16-06278

Energy and Transportation Science Division
Advanced Manufacturing Office

Additive Manufacturing for Low Volume Bearings

Brad Richardson
Dr. Lonnie Love
John Tate

Date Published:
September 28, 2017

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

Page

LIST OF FIGURES

ACKNOWLEDGEMENTS

This CRADA NFE-16-06278 was conducted as a Technical Collaboration project within the Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF) sponsored by the US Department of Energy Advanced Manufacturing Office (CPS Agreement Number 24761). Opportunities for MDF technical collaborations are listed in the announcement “Manufacturing Demonstration Facility Technology Collaborations for US Manufacturers in Advanced Manufacturing and Materials Technologies” posted at http://web.ornl.gov/sci/manufacturing/docs/FBO-ORNL-MDF-2013-2.pdf. The goal of technical collaborations is to engage industry partners to participate in short-term, collaborative projects within the Manufacturing Demonstration Facility (MDF) to assess applicability and of new energy efficient manufacturing technologies. Research sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

The Schaeffler Group USA’s John Tate and Bob Southam supported this effort. Their contact information is: John Tate, JohnTate@Schaeffler.com and Bob Southam, Robert.Southam@Schaeffler.com.

ABSTRACT

ORNL worked with the Schaeffler Group USA to explore additive manufacturing techniques that might be appropriate for prototyping of bearing cages. Multiple additive manufacturing techniques were investigated, including fused deposition modeling, electron beam melting, binder jet printing and laser based processes. The binder jet process worked best for the thin, detailed cages printed.

1. ADDITIVE MANUFACTURING FOR LOW VOLUME BEARINGS

This phase 1 technical collaboration project (MDF-TC-2016-094) was begun on September 1, 2016 and was completed on August 1, 2017. The collaboration partner Schaeffler Group USA is a large business. Various additive manufacturing techniques were investigated, with binder jet printing yielding the best set of parts.

1.1 BACKGROUND

Schaeffler Group USA is an integrated automotive and industrial supplier of bearings and precision components headquartered in Fort Mill, SC with six manufacturing plants and three research and development centers in North America.

Schaeffler's automotive transmission customers often have a need to simultaneously prototype a large number of different thrust needle roller bearings to satisfy pilot transmission build requirements. In an automatic transmission there may be up to 14 different axial bearing positions that would need to be prototyped in a short period of time. In situations where prototypes are needed quickly, the tooling for a stamped axial cage is the most challenging to create of all the bearing components, and can take significant time and resources for tool design, tool manufacturing, and stamping of each individual cage design. The ability to make thrust needle bearing cages using additive manufacturing (AM) for initial prototype or "proof of concept" builds would significantly reduce overall lead time to produce such components.

In addition, customers may require multiple revisions to these same parts as the design evolves from initial concept through design validation (DV) and production validation (PV). These revisions can create the need for multiple prototype versions of a given part in a greatly accelerated timeframe during the evolutionary process toward final hard tooled designs that will then use established Schaeffler technologies.

In order to obtain low volume prototypes of many different parts in a short time the process of additive manufacturing was investigated, with the intent to provide cages printed in a similar material to production parts. Ideally the AM process would yield parts with similar material properties that meet our design standards, can be conventionally assembled, and can pass DV testing requirements at both Schaeffler and the customer.

1.2 TECHNICAL RESULTS

The primary focus of this effort was to evaluate the ability to manufacture thin, detailed parts sufficient for use as prototype bearing cages. Two different sizes of bearing cages were used to compare and evaluate the state of the art for multiple processes. Past attempts by Schaeffler to make these types of parts using additive manufacturing had proven unsatisfactory.

Sample parts were fabricated using several techniques. Specifically, parts were made using fused deposition modeling (FDM), electron beam melting (EBM), direct metal laser sintering (DLMS) and binder jet technologies. Pictures of the fabricated parts, with varying degrees of success are shown below.

The FDM parts, made both from ultem on a Stratasys Fortus 900 and from acrylonitrile butadiene styrene (ABS) on a Stratasys Fortus 400, would not have been strong and durable enough to serve as a viable working prototype. These parts were printed to verify the print geometry and to gage the ease or difficulty of printing thin parts of this type. As can be seen in Fig. 1, the ABS parts, which use dissolvable support, are whole and complete. The ultem parts, which use break away support, were damaged during removal from the build sheet. The smaller bearing cage came completely apart. Some of the radial spokes of the large ultem cage were damaged removing from the build sheet and removing support. The difficulty in removing from the build sheet and or removing support proved to be problematic for multiple processes.

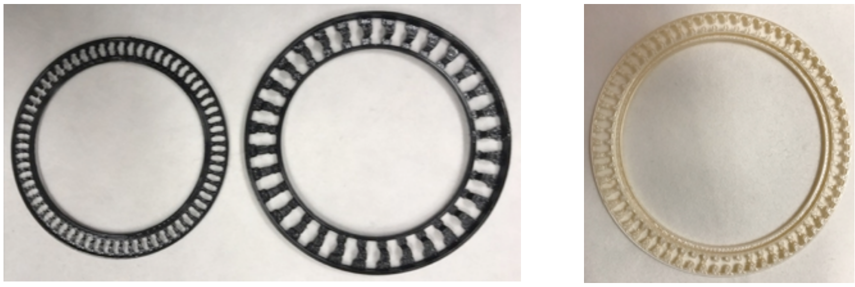

Fig. 1. FDM bearing cages.
ABS small and large bearing cages (left). Ultem large bearing cage (right).

Sample cages were then fabricated using an electron-beam melting process on an ARCAM machine. The parts were made out of titanium 6Al-4V. Figure 2 shows the top and bottom sides of the fabricated parts. The larger cage turned out much better. Removing the printed part from the build plate and removing support from the part were issues. The first small cage came apart during removal. A second small cage was printed with a modified support and fared much better. However, as can be seen in Fig. 2, the support was going to be difficult to remove and was left attached. The overall surface finish of the EBM parts was not deemed suitable for the application.

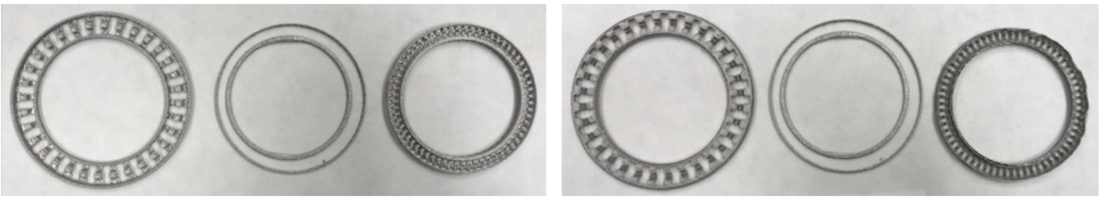

Fig. 2. Cages printed on ARCAM out of titanium.
Top surfaces (left) and bottom surfaces (right). Small cage in middle came apart during removal from build plate and was reprinted.

Both a large and a small sample cage were next printed with laser based process out of 316L stainless steel on a Renishaw system (Fig. 3). The larger cage turned out better than the smaller one. As can be seen in Fig. 3 below, the inner diameter of the smaller cage is rough and uneven. Overall surface quality is less than desired for prototype testing.

Fig. 3. Cages printed on the Renishaw out of 316L stainless steel. Large cage above (top and bottom surface). Small cage in the middle (top and bottom surfaces). Top of both large and small cages below.

Binder jet printing is another additive manufacturing process in which instead of melting powder with an electron beam or a laser, a liquid binding agent is used to join powder together. Over the course of many layers, a part is constructed. The part is then cured and sintered and infiltrated with another material which fills the voids. One of the advantages of binder jetting is the ability to make complex parts with fine detail. However, multiple attempts to print the cages at ORNL failed due to a series of hardware issues. Parts were sent to the system manufacturer, ExOne, who was able to successfully print both the large and the small sample parts. The small cages are shown in Fig. 4, the large cages in Fig. 5. They are made from 420 stainless steel infused with bronze.

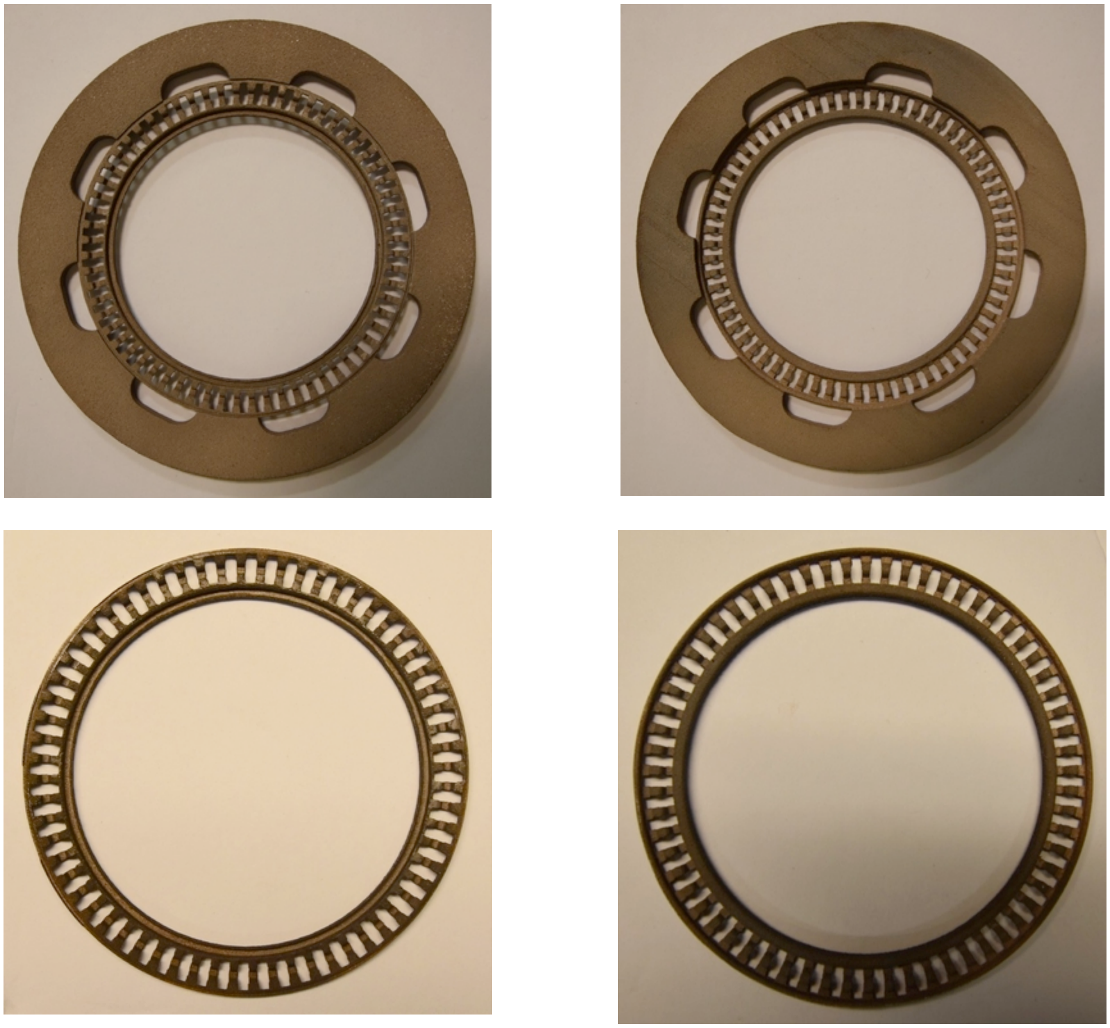

Fig. 4. Small bearing cage printed by ExOne.
Top and Bottom surfaces. Before support removal (above) and after support removal (below).

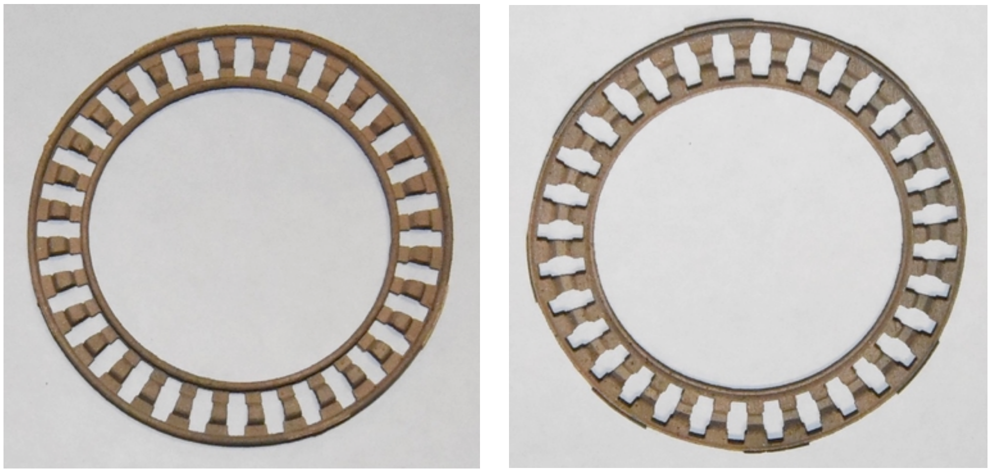

Fig. 5. Large bearing cage printed by ExOne. Top and bottom surfaces after support removal.

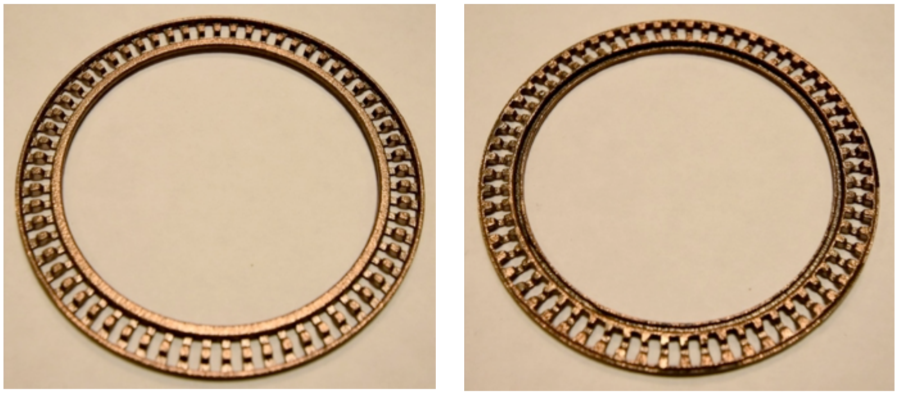

Fig. 6. Small bearing cage printed by ExOne following surface treatment. Top and bottom surfaces.

One of the two small bearing cages printed by binder jetting was sent to Custom Aerospace for surface treatment (Fig. 6). The part was processed in a Spinner Deburring Machine, which provides a tumbling like process with small rods serving as the media. The process is targeted for more delicate parts. The small bearing cage was treated for approximately 2 hours. The surface finish was improved without noticeable changes to the part geometry.

For comparison purposes, Fig. 7 shows closeups of bearing cages fabricated by three different processes. It can be clearly seen that the part fabricated by the Renishaw has a better surface finish than the one fabricated by the ARCAM. While it is less clear from the figures, the finish from the ExOne is superior to that from the Renishaw.

Fig. 7. Closeup of 3 printed cages.
From Renishaw (above), ARCAM (middle) and ExOne (below).

1.3 IMPACTS

The primary impacts from this effort relate to the proof-of-principle of an alternative process for making prototype versions of bearing cages. Verification of such a process allows for the elimination of the need to design and fabricate multiple versions of hard tooling for prototype systems. The result is a savings of time, cost and the material and energy required to make multiple versions of tooling required for stamping and drawing of the prototype components, particularly when several concept design changes may be required in a short period of time.

1.4 CONCLUSIONS

A number of additive manufacturing methods were used to print sample bearing cages. As noted above, removing the parts from support proved challenging for most processes. Surface finish was also a challenge for these small parts. As printed part tolerances proved difficult to achieve as compared to the model when using the AM methods explored. As a result, part form, fit, and function were not equivalent to series production parts.

Of the additive manufacturing processes tested, binder jetting came the closest to providing usable parts.

2. SCHAEFFLER GROUP USA BACKGROUND

Schaeffler Group USA is an integrated automotive and industrial supplier of bearings and precision components headquartered in Fort Mill, SC with six manufacturing plants (2470 employees) and three research and development centers (280 employees) in North America. Globally, Schaeffler is an employer of 84,000 people in 50 countries and is headquartered in Herzogenaurach, Germany.

Automotive divisions include Transmission, Engine, and Chassis Systems. Industrial applications include Production Machinery, Aerospace, Energy, and Mobility.

Schaeffler Group USA manufacturing specialties include raw material processing, tool management and prototyping, precision manufacturing, and surface treatments.