ORNL/TM-2022/2583

Oak Ridge National Laboratory Large Scale Metal Additive Manufacturing for Stamping Dies

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June 2022

CRADA FINAL REPORT
NFE-17-06879

Approved for Public Release
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OAK RIDGE National Laboratory

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Manufacturing Systems Research Division

LARGE SCALE METAL ADDITIVE MANUFACTURING FOR STAMPING DIES

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

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ACKNOWLEDGEMENTS

This CRADA NFE-17-06879 is 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.

ABSTRACT

Oak Ridge National Laboratory (ORNL) worked with Dienamic Tooling Systems (DTS) in a follow-on Phase 2 effort to develop and demonstrate additively manufactured conformal cooling for hot stamping dies, providing a new industry capability that did not previously exist. Current approaches to die cooling are nonoptimal and based on what can be machined with traditional technologies. The printed approach to hot stamping cooling channels allows an analytical needs-based size and placement approach to cooling. Cooling is optimized and parts count is reduced producing a simpler more reliable faster to manufacture stamping tool. An additively manufactured hot stamping die with conformal cooling channels was manufactured and successfully tested in a real-world environment.

1. LARGE SCALE METAL ADDITIVE MANUFACTURING FOR STAMPING DIES

This Phase 2 technical collaboration project (MDF/TM-2022/2583) began on August 1st, 2017 and concluded on January 1st, 2022. The collaboration partner Dienamic Tooling Systems is a small-medium business. A prototype full scale hot stamping die was designed jointly by DTS and ORNL, printed by ORNL, machined by DTS, and successfully tested on a real-world stamping production line.

1.1 BACKGROUND

DTS designs and builds metal stamping dies for all original equipment manufacturing companies.
The MDF, working in a collaborative effort with Lincoln Electric, developed the additive manufacturing process that reduces cost and timing of metal stamping dies and created the ability to additively manufacture conformal cooling channels necessary to improve manufacturability and reliability of hot stamping dies, which enables the U.S. tool and die industry to become more competitive against foreign companies.

DTS is a small-medium enterprise (SME), and this project was pursued to develop and refine new metal additive manufacturing technology while increasing the SME's competitiveness. The primary outcome of this Phase 2 project was to validate the feasibility of producing a hot stamping die tool with integrated cooling channels using metal additive manufacturing. A prototype stamping die was produced and successfully tested in a real-world production situation.

ORNL and DTS have been collaborating on stamping dies since 2017. The Phase 1 portion of this work created a small stamping die that was used to validate the premise that additively manufactured stamping dies have strong potential to impact the competitiveness of US manufacturing (Figure 1). The successful completion of Phase 1 was documented in ORNL/TM-2022/2583 as part of CRADA/NFE-17-06879.

This Phase 2 effort specifically focused on hot stamping dies with integrated cooling because traditional manufacturing is difficult, and the end-product is nonoptimal. Fabrication is based on what can be made as opposed to what will produce optimum performance. An additively manufactured hot stamping die was successfully produced to demonstrate feasibility of the manufacturing process.

Figure 1. Phase 1 small prototype stamping die and stamped part.

1.2 TECHNICAL RESULTS

ORNL and DTS chose to develop the capability to additively make hot stamping dies because AM has the capability to drastically reduce parts count (a single monolithic part rather than hundreds of parts) improving reliability and maintenance, to reduce fabrication cost, and to improve the cooling capability of hot stamping die. Properly cooled hot stamping dies have value because they provide greater production throughput of higher strength structural sheet metal components. High strength structural sheet metal components are used for functions such as a B-pillar (the body-to-roof support behind the front door of automobiles).

This Phase 2 effort was broken down into three subtasks:

- Material selection and tool design
- Tool printing and machining
- Tool testing

1.2.1 Task 2.1

Task 2.1 consisted of material selection and generation of the tool design.

Material selection for the hot stamping die was chosen based on known and previously proven materials for the wire arc system [1, 2, 3, 4]. The part was designed to have a mild steel core and a 410 series stainless steel (410SS) outer shell. The mild steel provided a cost savings; the 410SS is heat treatable to a higher hardness level suitable for lower production run stamping tools. The tool designed as part of this effort was intended to be a test prototype and not for high volume use.

The original model from DTS was sent as a STEP file of the original B-pillar tool meant to be used in a metal hot stamping application (Figure 2). The tool had nontrivial tooling surface features including overhangs, rounded edges, and two large protrusions of metal in the top half of the tool. Used in a manufacturing setting, the tool must remain at a sufficiently low temperature as hot sheet metal parts are stamped, therefore making it critical that the tool is cooled quickly and efficiently. With these key points of background information, the following general requirements were created at the beginning of the project:

1. The 3D printed tool will maintain the desired tooling surface geometry.
2. The tooling surface of the printed tool will show similar material properties when used in a hot stamping application.
3. The tool must be produced with commodity materials.
4. The 3D printed tool will have printed conformal cooling channels.
5. The conformal cooling channels will provide more uniform cooling performance compared to traditional manufacturing methods (line boring post-machining the part out of a block).
6. The conformal cooling channels will not require post-processing, aside from drilling access points and running a slurry through the channels.
7. The tool will be used in a production environment after machining the tooling surface and reference surfaces.

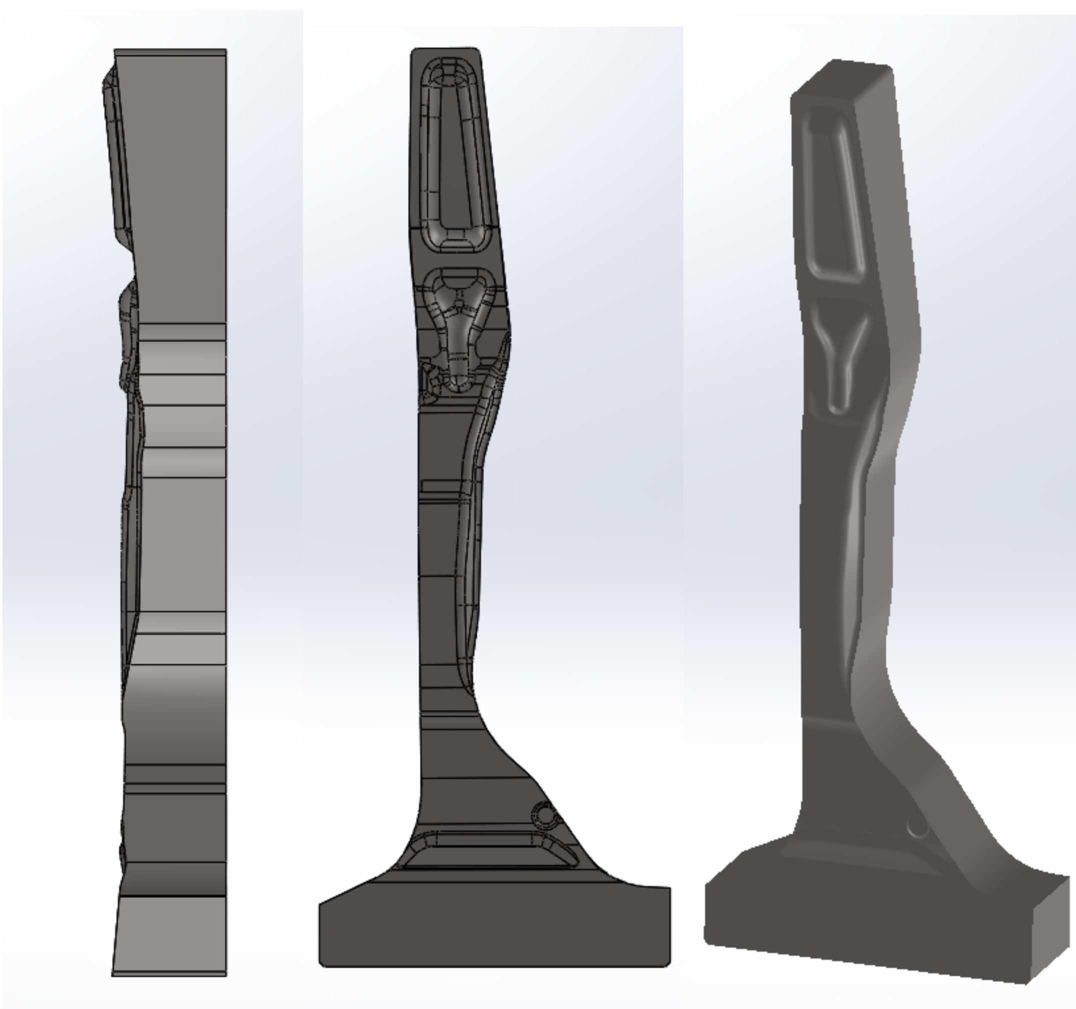

Figure 2. Original DTS tool model.

These requirements outline the critical goal of the end user: significantly decreasing costs, lead times, and skilled labor required to produce the tool while simultaneously producing a similar or higher quality tool. With this goal in mind, a deeper dive into the model could be taken to redesign it for slicing and printing. Importantly, it was made clear that traditionally manufactured cooling channels lack the ability to reach the two protruding features in the top half of the tool, and so there was an opportunity to develop a printing strategy which would (1) create a uniform, machinable surface, and (2) build conformal cooling channels with as much as possible of a constant channel distance from the tooling surface.

The approach to printing the tool began by selecting the build orientation, or how the part is printed with respect to the robot and build table. As a rule of thumb, placing the longest axis in the z-direction (vertical direction) has shown to produce the most successful builds. This success can be attributed to smaller part cross-sections when oriented in this matter, which take less time to print and can maintain higher temperatures. The chosen print orientation is shown in Figure 3.

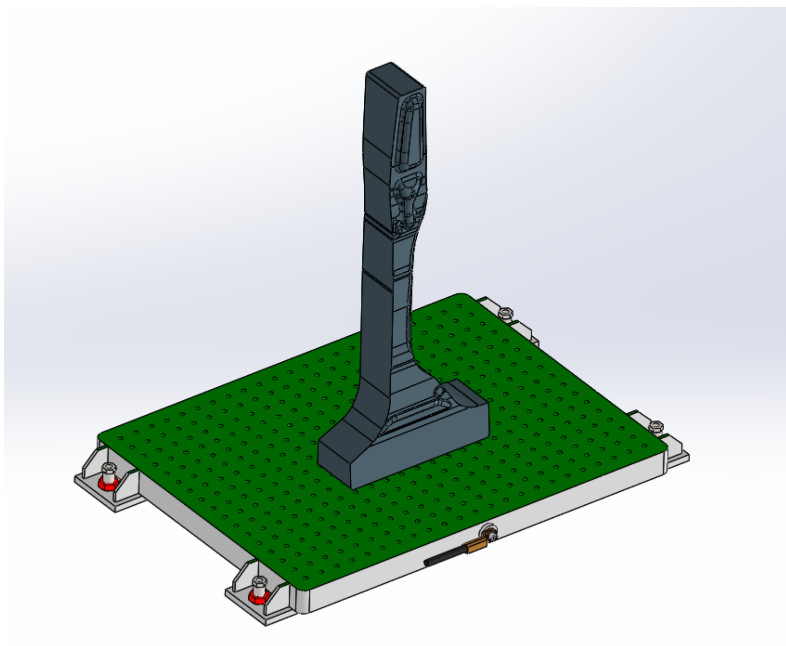

Figure 3. Build orientation.

The core design issues to be addressed included design of the cooling channels including accommodation for external connections to cooling supply lines and all necessary jigs, fixtures, and tools, and the ability to "slice" the chosen design into layers and beads so that it could be printed. The final design, shown in Figure 4, shows the internal cooling channels after multiple iterations balancing mechanical requirements, cooling requirements, and slice-ability.

Figure 5 shows one layer of the slicing for the build; the overall build layout consisted of 613 layers. The gray beads represent mild steel (Lincoln L-59) infill. The red and green beads are different slicer path modes consisting of 410SS.

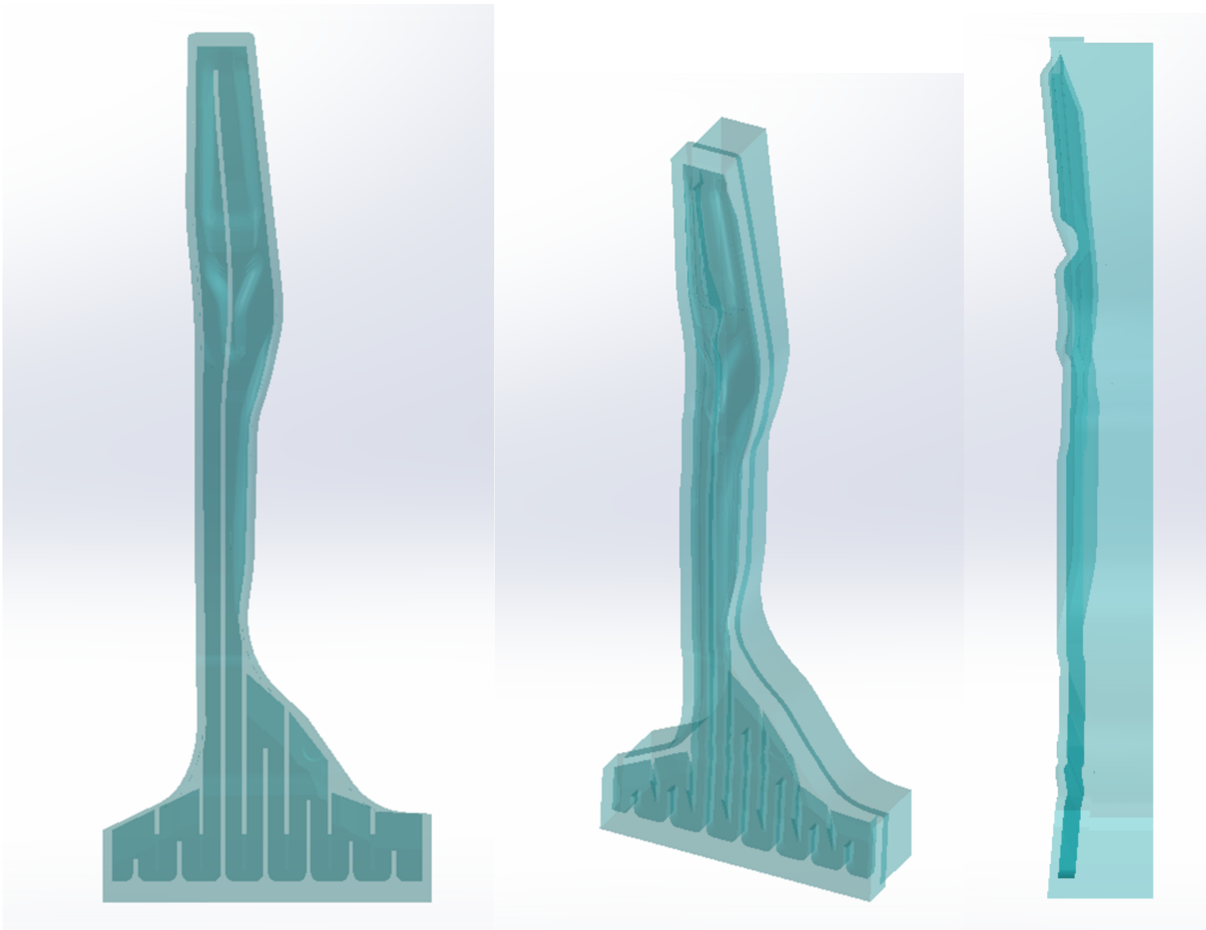

Figure 4. Final part design showing cooling channels.

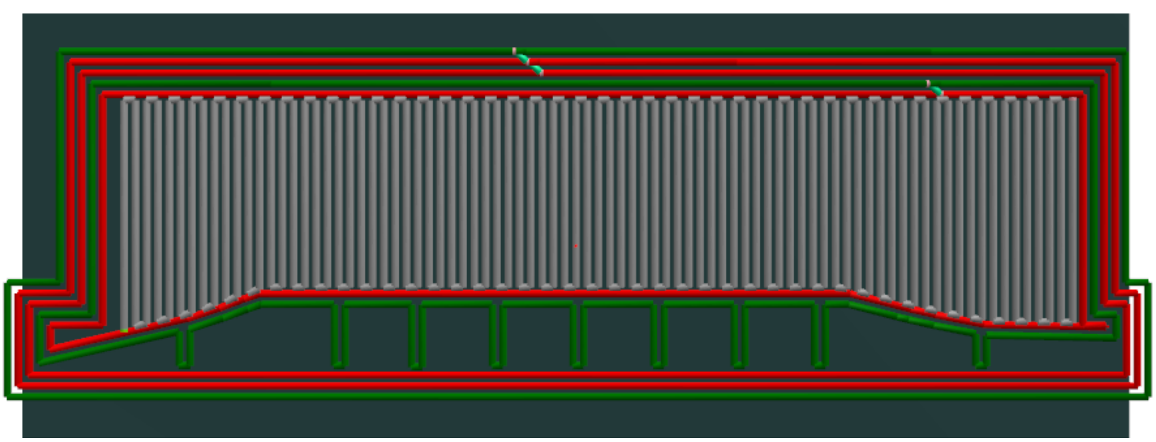

Figure 5. Example of slicing for a single layer of the die.

1.2.2 Task 2.2

Task 2.2 consisted of the manufacture (printing and machining) of the prototype hot stamping die. The final as-printed part was about 400lb and 4ft tall. ORNL used the ARC1 dual torch dual material Lincoln wire arc system for the build so that both 410SS and L-59 mild steel could be printed in the same part. This particular build tested new high deposition modes—RapidX and RapidArc—that ran at 12lb/h. The as-printed part is shown in Figure 6.

The part was machined by DTS in their Lenoir City, Tennessee facility. The stamping die is shown in Figure 7 prior to completion.

Figure 6. As-printed die.

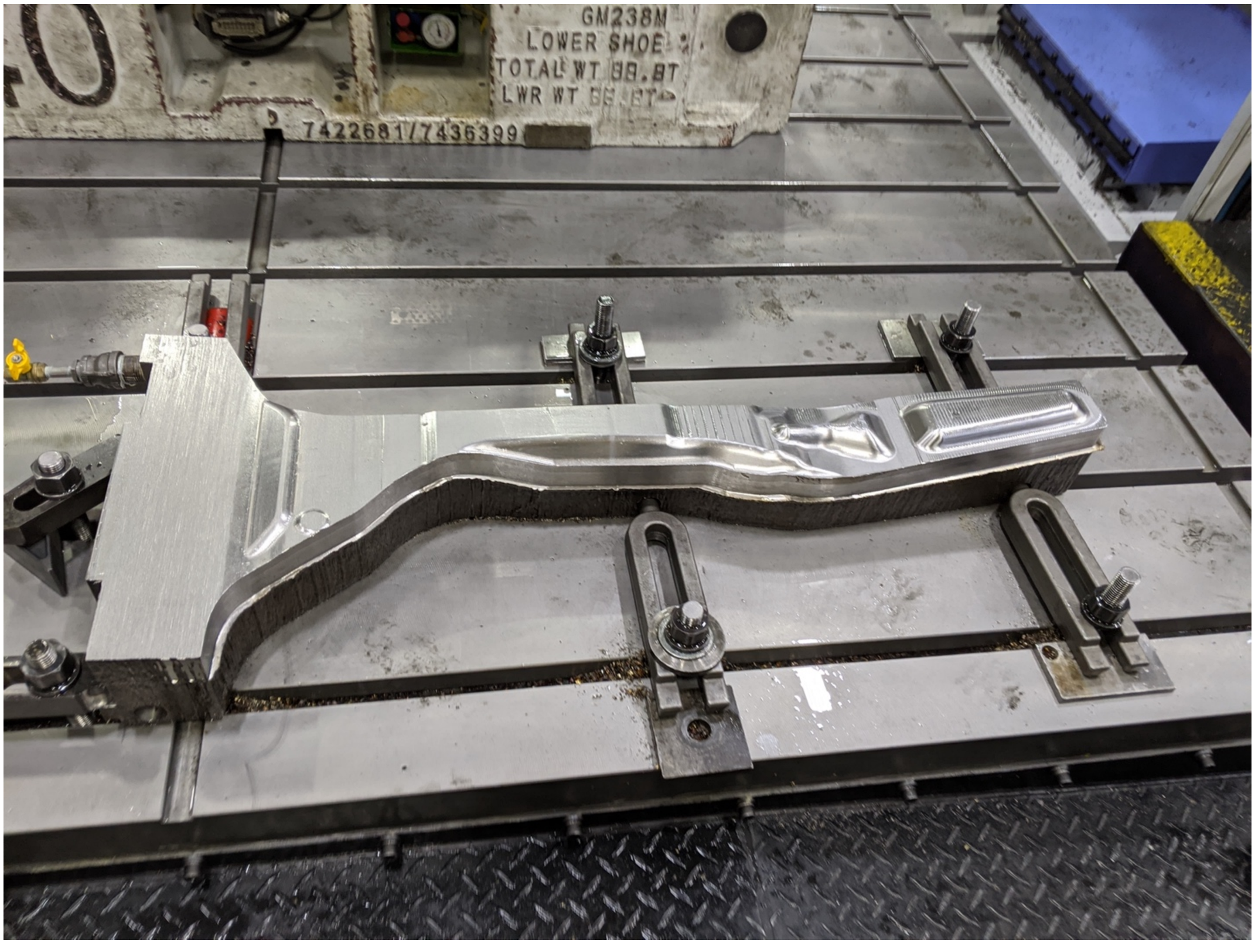

Figure 7. As-machined die.

1.2.3 Task 2.3

Task 2.3 consisted of testing and validating the tool.

The additively manufactured tool was used for a trial manufacturing run alongside a conventional tool. Data was gathered using IR imaging during the trial run, which Figure 8 illustrates. The manufacturer provided additional qualitative results that the tool was cooled much more uniformly, and that the overall coolant flow was increased in the additive tool.

An example stamped part is shown in Figure 8. The stamping die was successfully run on a DTS customer production line for testing purposes.

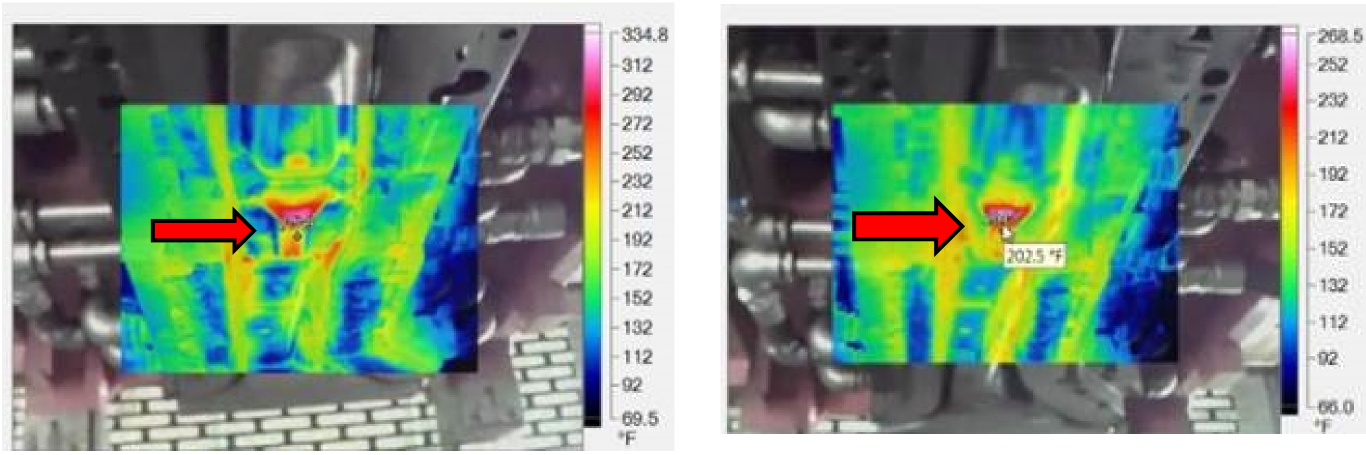

Figure 8. IR image during trial run after 25 seconds. (Left) Additive tool at 266°F, (Right) Conventional tool at 332°F

An example part is shown in Figure 9.

Figure 8. Stamped B-pillar using AM die.

1.3 IMPACTS

The hot stamping die was successfully fabricated and tested on a real-world assembly line. It worked and worked well. Due to the ability to put cooling channels where they needed to be at appropriate sizes, the stamping die provided more uniform cooling faster by 20% resulting in a higher stamping throughput for higher productivity. Since the die was printed to near net shape, there was much lower wasted material in the machining process. A reduction in parts count reduced the manual labor involved facilitating faster fabrication and less maintenance in operation. The overall AM approach to hot stamping die fabrication was estimated to reduce manufacturing time from approximately 20 days down to approximately 8 days.

Faster simpler fabrication means less energy required during manufacture. Higher throughput on the production line means less energy consumed per part manufactured. Both of these outcomes meet the EERE/AMO focus to reduce energy consumed in manufacturing. DTS is satisfied with the end result and is exploring how they can move forward with this technology in their tool and die business model.

1.4 SUBJECT INVENTIONS

There are no subject inventions associated with this project at this time.

1.5 CONCLUSIONS

The purpose of this technical collaboration between ORNL and DTS was to design, fabrication, and test a prototype hot stamping die for a demanding task—an automotive B-pillar. The stamping die was built and tested in a real-world hot stamping line producing quality results at high throughput. The goals of this technical collaboration were completely and successfully met. DTS now has access to the technology needed to fabricate high quality hot stamping dies in a manner that will improve their competitiveness in the US market.

2. DIENAMIC TOOLING SYSTEMS GROUP BACKGROUND

DTS is a Tooling Systems Group company. The Tooling Systems Group (TSG) is a collaboration of independently owned and operated companies that specialize in tooling, equipment, and service for manufacturers around the world. DTS designs, builds, re-engineers, and services medium to large sized sheet metal stamping dies and tooling. With several hundred dies under its belt, DTS has experience with:

- progressive, transfer and line dies
- deep draws, complex extrusions, and over bends
- standard, sound deadening, heat shield, and heavy thickness materials
- integration into automated assembly lines

DTS has essential equipment, processes, and staff on-site at its 50,000 sq. ft. facility to manufacture many dies and tools efficiently. DTS has the following equipment: (4) Tryout presses that range in size up to 2,500-tons (108" x 200" bed capable of running 108" x 220" dies), (7) Overhead cranes that are capable of lifting up to 40-tons, (4) High-speed CNC mills with work areas up to X168" x Y72" x Z72", and 70 employees which include: project managers, estimators, designers, die builders, machinist, and administrators.

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