University Turbine System Research (UTSR)
Gas Turbine Industrial Fellowship Program
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CMC Stage 2 Nozzle Development and CMC Tip Shroud Analysis

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Due to confidential information, details and images are left out of this report.

1 Introduction

Ceramic matrix composite (CMC) is a unique material that has grown in use over the past decades in the gas turbine and aircraft engine industry. This material is roughly one-third the density of comparable metals, offers similar toughness and has a 20% higher temperature capacity. It has become a valuable tool for many companies in the past years. For example, GE Aviation has used this material to create more than 40,000 CMC turbine shrouds. Using CMC blades allows their engines to be lighter and burn hotter.
GE Power has been designing with this technology in mind for many years. One of the largest projects on-going is the High Temperature Ceramic Matrix Composite Nozzle. This project was initially funded by the Department of Energy in October 2014 and is set to finish April 2021. At its base, this project combines metal and CMC components to increase the efficiency of gas turbines. I assisted the Emerging Technologies team on this project during my fellowship.

2 CMC Overview

As a relatively new material, CMC is still improving and undergoing research. This material is made up of many individual fibers which are 5 times thinner than the human hair. Each fiber is coated in a matrix slurry and then combined with other fibers to create sheets. Like carbon fiber, these sheets are then combined to create a full part.

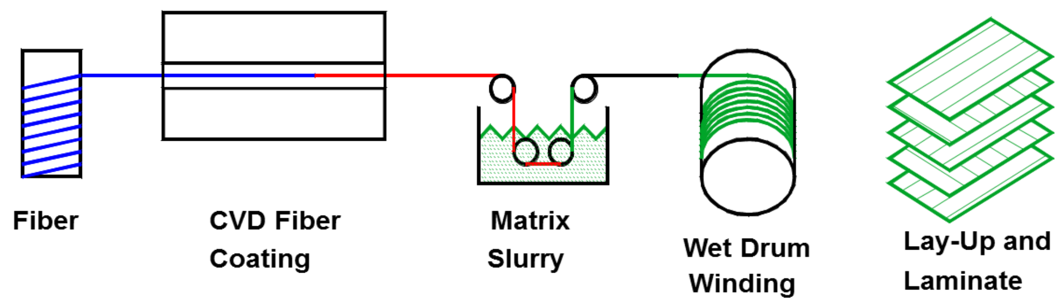

FIGURE 1. Process to create sheets of CMC material.

After the CMC sheets have been combined to create a part, it must go through a series of furnaces. These furnaces harden the part, burn off binders, and add silicon to the part. Adding silicon at a porous state increases the final strength and density.

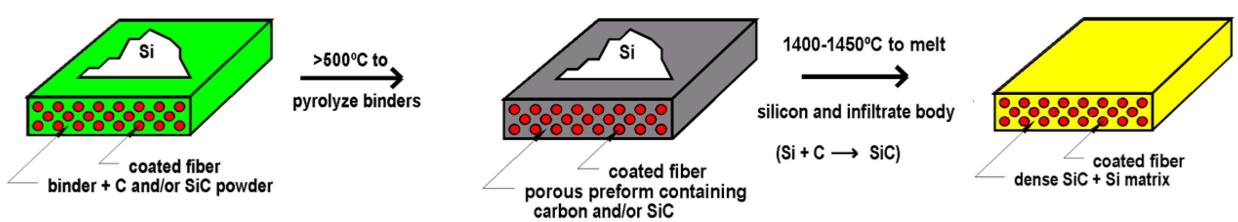

FIGURE 2. Process for strengthening and finishing the final CMC part.

3 CMC Nozzle Overview

One of GE Power's CMC projects in progress is the Stage 2 CMC Nozzle. This nozzle is groundbreaking because the combination of CMC and metal parts allows for efficiency and power output to be dramatically increased. In this setup, the metal components take the mechanical stress and the CMC parts take the thermal load. This setup contains two vanes and the combination of these doublets creates a full set, as seen in Figure 3.

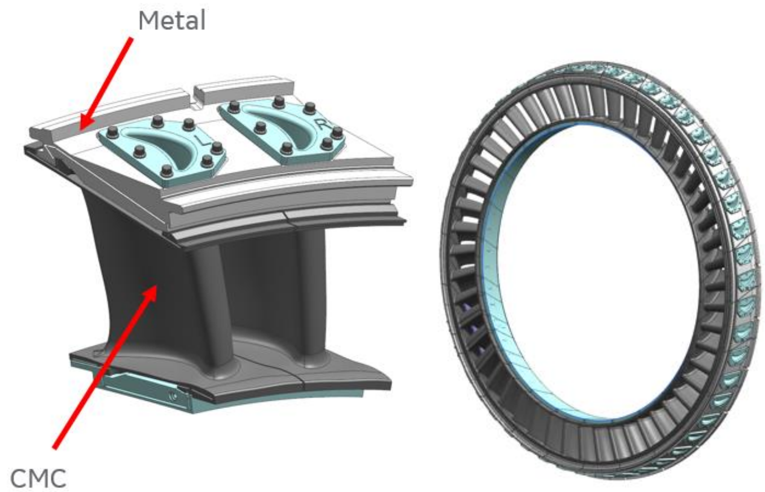

FIGURE 3. Stage 2 Nozzle model.

This is the final iteration of the design and will be manufactured and assembled for future testing in GE's full speed, full load test center.

3.1 Stage 2 Nozzle Work

To have a complete understanding of the concept before manufacturing, physical prototypes are necessary. 3D printing on an FDM printer was the easiest approach. Tolerances were created on the surfaces of the model to ensure that the printed parts would fit together well. After, three half-scale models were printed using MakerBot 3D printers.

FIGURE 4. Half-scale model of the Stage 2 CMC Nozzle.

These half-scale models were created as demonstration pieces and to learn how to properly create a full-scale model. Tolerances were changed for the full-scale model to be assembled properly. Once all the pieces of the full-scale model were printed, many surfaces were sanded to create a desirable fit and to hide blemishes.

FIGURE 5. Full-scale model of the Stage 2 CMC nozzle.

Many other parts were also printed and designed over the course of my fellowship to support this project.

4 CMC Tip Shroud Overview

Another CMC project I worked on over my rotation with GE revolved around the last stage blade. The tip shroud on the last stage blade creates a strong pull force on the blade, which causes shorter blade life. If the tip could be replaced with CMC, the pull force would be dramatically smaller.

FIGURE 6. Last stage blade example, with CMC tip.

4.1 CMC Tip Shroud Work

A short analysis was conducted to understand the idea. The volume of the tip was roughly 4 in^3, and this created a pull force of 29,280 pounds-force with a solid metal tip. When the calculations were done with a CMC tip, the pull force was 10,016 pounds-force. Seeing that there could be significant change with a CMC tip, three models were designed in Unigraphics to attach the CMC tip to the metal blade.

After some unique designs were created, they were then meshed in HyperMesh. Next, they could be brought into ANSYS Mechanical and ANSYS Workbench to apply material properties and boundary conditions.

I had many new learnings over this process. One of which was creating proper element size. If elements in a mesh were too small, the analysis would take a long time. On the contrary, if the element size was too large, the results would not represent the analysis accurately. Another key learning was understanding how model geometry effects the results. For example, when sharp angles are in a model, FEA software has a very difficult time accurately calculating the results.

5 Flow Testing Shrouds

On the Emerging Technologies team at GE Power, there are many projects that require testing to support calculated results. Over the course of my fellowship, flow testing was being prepared for a new shroud design. The shroud was made through additive manufacturing and required a unique set of flow fixtures. In support of this project, I 3D printed many sets of fixtures and prepared them for testing. In order to use ABS 3D printed parts, they must be treated to seal any gaps between layers. To do so, an acetone vapor process was used.

First, a part is placed on an aluminum foil raft to ensure it does not contact any liquid acetone. Next, the walls of the container are lined with paper towels that have been soaked in acetone. Since, acetone evaporates at room temperature the container would fill with the vapor and slowly smooth the layers of the 3D print. This process takes roughly five hours.

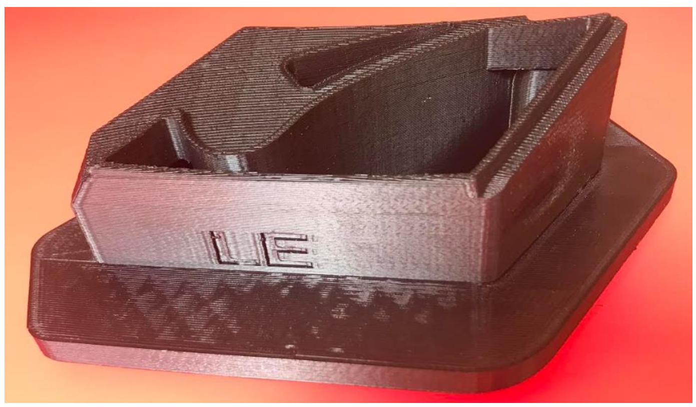

FIGURE 7. ABS part not treated in acetone.

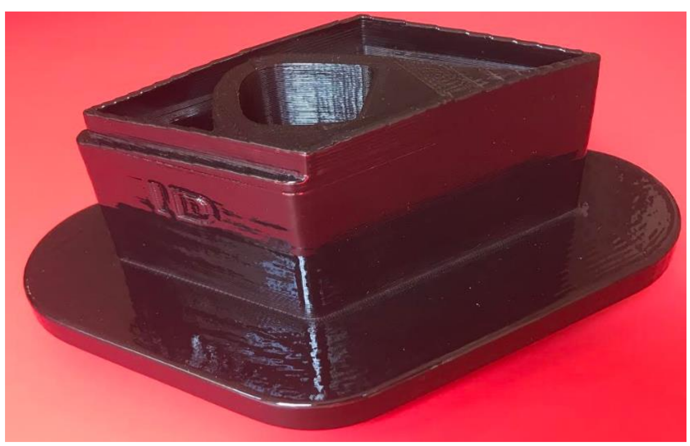

FIGURE 8. ABS part treated using acetone.

6 Build Volume Boxes for 3D printers

Since the Emerging Technologies team at GE uses metal 3D printers often, I created boxes to represent the build volumes for three of the printers. Each design consisted of eight parts that snap together. Since the part snap together, it allowed for easily assembly and transport. This simple project gives a visual understanding of the many dimensions commonly used.

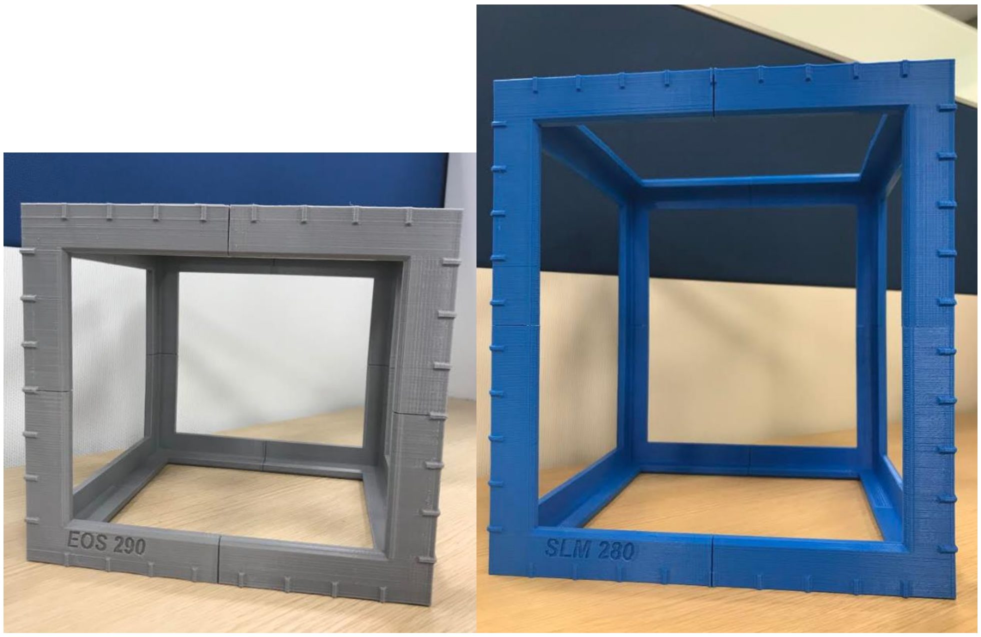

FIGURE 9. Boxes that represent the build volume of the EOS 290 and the SLM 280.

7 Conclusion

Over my fellowship I 3D printed many parts to support a variety of projects. I fine-tuned the printers and printed parts for the team whenever needed. While I already had experience in this before the fellowship, I learned many new tactics to print parts both quickly and with great strength.

I also developed new designs skills and learned to run detailed analysis. The opportunity to join GE Power allowed me to understand additive manufacturing's impact on technology as well as the growth of CMC material. As more research is conducted about CMC material, it will grow to be more prevalent in the gas turbine industry. The material's strength and thermal capabilities make it a great choice for new designs and innovative technology.

8 Acknowledgments

Thank you to everyone at GE Power for taking the time to guide and teach me specific software, gas turbines components, company culture, and more. Specifically thank you to the Emerging Technologies team and the group manager Markus Feigl. Moreover, thank you to John Delvaux, John Greene, James Zhang, and Glenn Taxacher for their time and support on many projects over my fellowship.