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EVALUATION OF ELECTROCHEMICAL MACHINING TECHNOLOGY FOR SURFACE IMPROVEMENTS IN ADDITIVE MANUFACTURED COMPONENTS

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ABSTRACT

ORNL Manufacturing Demonstration Facility worked with ECM Technologies LLC to investigate the use of precision electro-chemical machining technology to polish the surface of parts created by Arcam electron beam melting. The goals for phase one of this project have been met. The project goal was to determine whether electro-chemical machining is a viable method to improve the surface finish of Inconel 718 parts fabricated using the Arcam EBM method. The project partner (ECM) demonstrated viability for parts of both simple and complex geometry. During the course of the project, detailed process knowledge was generated. This project has resulted in the expansion of United States operations for ECM Technologies.

1. EVALUATION OF ELECTROCHEMICAL MACHINING TECHNOLOGY FOR SURFACE IMPROVEMENTS IN ADDITIVE MANUFACTURED COMPONENTS

1.1 BACKGROUND

ECM Technologies LLC is a company that provides manufacturing and services related to Precision Electrochemical Machining (PECM). The company employs a team of engineer specialists focused on volume manufacturing and PECM research and development. They proposed a project to address machining challenges related to complex part geometries created by additive manufacturing. The project was to utilize electro-chemical machining to transform the rough surface of additively manufactured parts to one that rivals that of traditionally machined parts. The first objective was to determine whether Arcam Electron Beam Melting (EBM) produced Inconel 718 parts could be machined using the PECM process. Once machining was successfully demonstrated, polishing of complex and internal geometries was explored.

The Oak Ridge National Laboratory's (ORNL) Manufacturing Demonstration facility (MDF)'s responsibility was to provide parts built using the Arcam electron beam melting process. Inconel 718 test coupons of simple geometric shape were produced using a variety of build parameters and orientations for process testing and development. Altered build parameters were then used to study whether parameter variations affected the post-machining process. Once the process was developed, complex shaped parts were fabricated. ECM would use these parts to demonstrate the effectiveness of PECM on real geometry. The parts supplied would include turbine blades and a matching electrode base. The electrode base would become part of their test apparatus for machining the provided blades.

A second task of the project partnership included the development, production, and polishing of parts with complex geometries that cannot be produced using traditional machining methods. MDF supplied the additive manufactured parts along with cross-sectioning and analyzing surface microstructure. The ultimate goal of task two was to polish internal and otherwise inaccessible surfaces. Achieving the phase one goals would clear a major hurdle in the acceptance of additive metals manufacturing. Achieving the phase two goal would greatly advance additive metals manufacturing in the internal geometry arena, an arena where it already excels over traditional technologies.

1.2 TECHNICAL RESULTS

ECM performed early testing using a setup to simulate one of their electro-chemical machining centers. The process involved fixing the piece to be machined onto an electrode, cross-flowing an electrolyte mixture over the surface, and placing a second (polishing) electrode near the surface to be machined. The electrolytic reaction produced between the electrodes, target surface, and electrolyte mixture constituted a machining process with many variable parameters. The promising results of early testing at ECM were the basis for subsequent MDF involvement.

1.2.1 TECHNICAL RESULTS (INITIAL TESTING)

Prior to machining, the surface roughness of the Arcam Electron Beam Melting Inconel 718 test samples was out of range for the measuring equipment. To investigate the dissolution behavior under conditions used in electrochemical machining tests were performed using a flow channel cell (FCC, Fig.1), in which the conditions of interest can be measured and varied. In this research the influences of pulse waveform, electrolyte temperature and electrolyte type were investigated. Following machining, roughness was measurable, thus demonstrating the effectiveness of the machining technique. The surface roughness Ra after ECM decreases with increasing supplied charge; the lowest surface roughness was measured on the coupons which were exposed to a charge of 250C (Fig. 2). ECM noted a gradient in surface finish that depended upon the electrolyte flow direction, which prompted a question as to whether the part orientation during the additive build phase was important to the post machining process. A gradient in surface finish dependent upon the distance of electrolyte flow with respect to the target surface edge revealed the need for more uniform flow.

Fig 1. Flow Channel Cell (FCC) and related equipment.

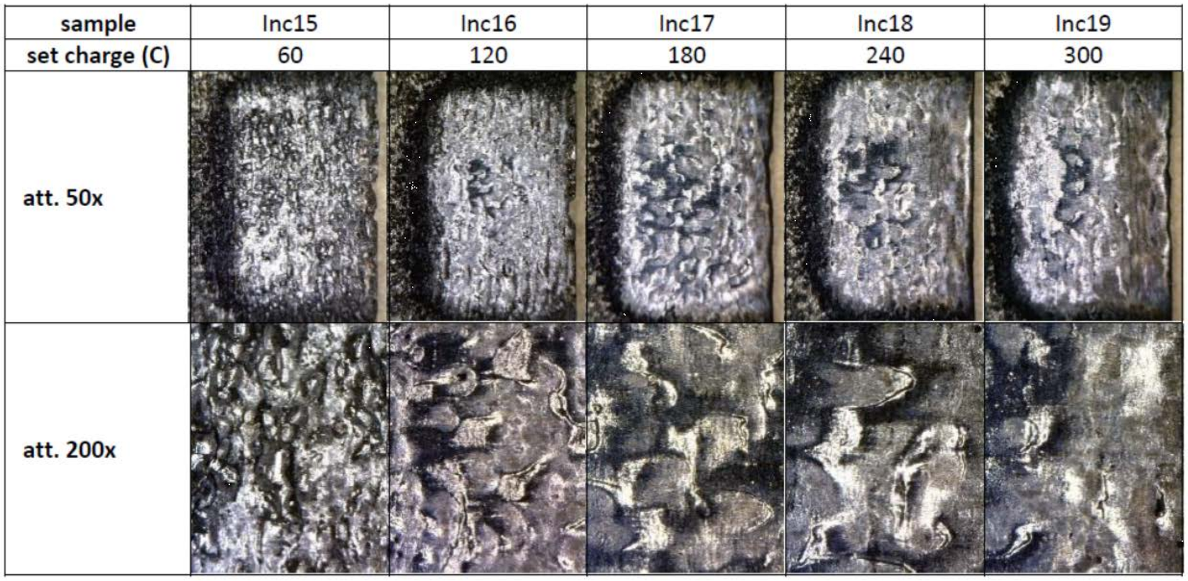


Fig. 2. Surface appearance of electron beam melted Inc718 after ECM treatment with different supplied charges.

1.2.2 TECHNICAL RESULTS (SECONDARY TESTING)

To address the orientation question, additional target samples with build orientations at 45°, and 90° were prepared at the MDF. (Note: The initial samples tested had a 0° build orientation.) The variation in initial roughness of the coupons is quite large, independent on the build orientation of the coupons. The variation in initial roughness of the coupons has a large influence on the surface roughness of the machined coupons. ECM tested these samples with the same apparatus and procedure used in the initial testing. The surface roughness of the coupons treated with ECM seems mainly to depend on the initial surface roughness of the coupon and the amount of material removed (supplied charge).The results of this testing were inconclusive. This leaves open the question of whether PECM processing needs to account for variations in build orientation during additive manufacturing.

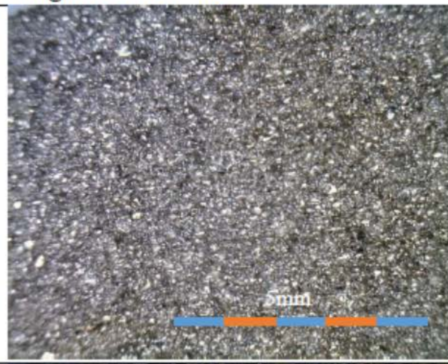
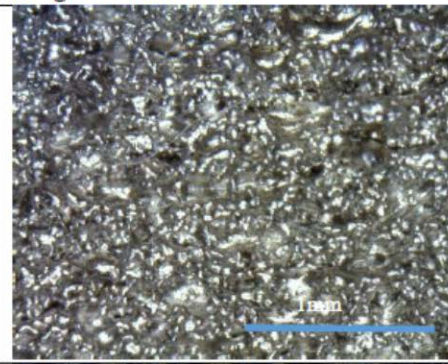
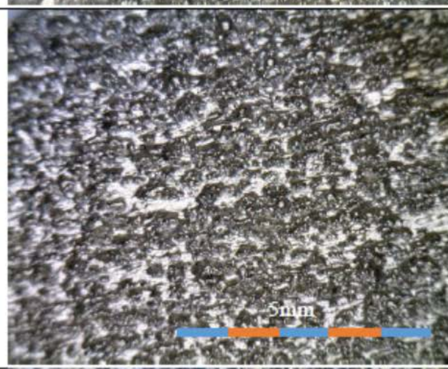
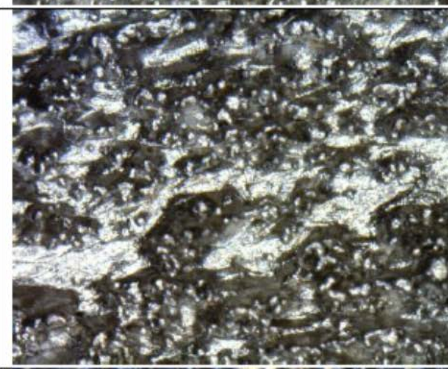
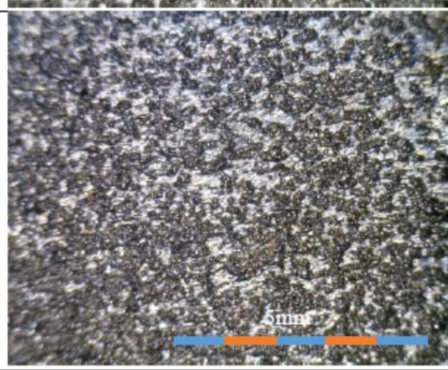
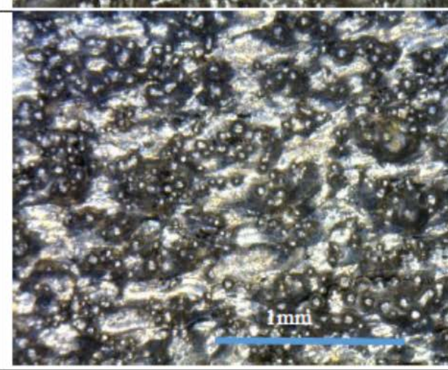
orientation	magnification 50x	magnification 200x
90°		
45°		
0°		

Fig. 3. Examples of the surfaces before ECM of the electron beam melted coupons with different build orientation, at two magnifications.

1.2.3 TECHNICAL RESULTS (COMPLEX GEOMETRY TESTING)

To demonstrate the efficacy of the PECM process, ECM proposed using an unpolished electrode made by additive methods as the base electrode in their test setup. They suggested then creating display pieces by machining one side of a part leaving the other side untouched. This would offer a direct visual comparison between the surface polished by electro-chemical machining and the original additive surface finish. The ORNL team produced a number of multi-contoured turbine blades for testing.

Two electrodes (base and polishing) are required for this process. The part to be machined is placed upon the base electrode. The polishing electrode is suspended at a minimal gap above the part surface. Fluid electrolyte is then passed between the part and the polishing electrode in a cross-flow manner. The electrolyte chemically machines the part, and the flow refreshes the electrolyte at the part surface. Both electrodes must be form fitted to mate with the contours of the part surface. A

Renishaw laser based additive metals system was used to build the electrodes for the complex geometry test.

The original electrode was used as a baseline. The first design iteration perforated the polishing face, added a hollow equalizing chamber, and created electrolyte flow channels. Testing revealed non-uniform electrolyte flow from the perforated face. The electrode design was then modified to accommodate a larger volume of fluid, keeping the same perforated face. The more uniform flow pattern from this design was useful for ECM testing. This design could be improved to deliver better the flow required by the electrochemical machining process. Improving electrode design for complex geometry could be a portion of phase two of the project. Design elements might include minimizing the size of the perforations in the polishing face and generating a uniform flow pattern across the polishing face.

Initial testing revealed a polishing gradient related to the distance of the electrolyte flow. The polished surface was smoothest near the part edge where the electrolyte first contacted the part. It grew rougher as the distance increased from the leading edge. The gradient effect was exaggerated by the length and multi-contoured shape of the target turbine blade surface and could result in part failure. To combat this, the polishing electrode was perforated on the multi-contoured polishing surface and embedded with internal flow passages. This allowed the electrolyte to be passed through the electrode and deposited more uniformly across the target part surface.

Fig. 4. Redesigned electrode fin.

Complex geometry testing revealed positive results. Dispensing the electrolyte through the electrode across the entire target ensured machining of the full surface. This shows that electro-chemical machining can be used to improve the surface finish of parts of complex geometry created by additive manufacturing methods. Analysis of the surfaces of polished parts revealed slight imperfections mimicking the geometry of the polishing electrode perforations. Better results are likely possible by minimizing the size of the perforations in the polishing electrode face. This establishes the groundwork to advance the project to the next phase.

1.3 IMPACTS

This project stands to have a great impact upon the advancement of the additive manufacturing industry. Surface roughness is a common issue for additively manufactured metal components when compared to the smooth finish possible with traditional, subtractive machining. Additive manufacturing has many advantages in industries including tool-making, mold-making, low volume production parts, prototypes, and medical components. Combined with PECM, additive manufacturing may compete with traditional machining on a small-scale. Additive manufacturing is also able to produce parts with shapes and internal geometry that are not possible or very expensive to manufacture otherwise. Successful completion of project phase two (machining internal/unreachable surfaces) is a demonstration with far-reaching effects on many processes of manufacturing on a global-scale.

ECM performed the complex geometry portion of this project at their Netherlands facility due to an absence of an electro-chemical machining center in the United States. As a result of the findings of this project, ECM has expanded their U.S. operations facility, purchasing machinery and setting up an electro-chemical machining center at their Raleigh, North Carolina location. The expansion includes the hiring of multiple employees to staff the expanding operations and facilitates future collaborations with the ORNL Manufacturing Development Facility.

1.4 CONCLUSIONS

The goals for phase one of this project have been met. The project goal was to determine whether electro-chemical machining is a viable method to improve the surface finish of Inconel 718 parts fabricated using the Arcam EBM method. The project partner (ECM) demonstrated viability for parts of both simple and complex geometry. During the course of the project, detailed process knowledge was generated. Project findings led ECM to purchase new equipment and expand their operations in the United States.

Improving and perfecting the technology demonstrated during this project has not only helped ECM advance, but also has contributed to the development of additive metals technology as a whole. The demonstrated technology helps additive manufacturing compete with traditional manufacturing in low volume and/or small-scale production and suggests a pathway to overcome issues of surface finish for complex geometries.

2. PARTNER BACKGROUND

ECM Technologies LLC is an advanced manufacturing company specializing in Precision Electrochemical Machining (PECM). Working with its customers in aerospace, industrial turbine, and energy sectors, ECM-T utilizes a four-phase approach including fundamental research, application research, prototype production, and implementation. ECM Technologies LLC focuses on providing volume manufacturing in North America utilizing the latest innovations in PECM to create breakthroughs in component design, part performance, efficiency, and cost.