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ADDITIVE MANUFACTURING OF SUPERALLOYS FOR AEROSPACE APPLICATIONS (PREPRINT)

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14. ABSTRACT
The Air Force Research Laboratory has been exploring the possibility of using metal additive manufacturing processes for depositing superalloy materials in engine component applications. Through the Metals Affordability Initiative, managed by the Metals Branch in the Materials and Manufacturing Directorate, the "Additive Manufacturing of Superalloys" project has demonstrated the deposition of nickel superalloy features on substrates using two different process. The goals of the project are to determine the quality and mechanical property capabilities of these processes while developing a cost model to measure economic feasibility.

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Additive Manufacturing of Superalloys for Aerospace Applications

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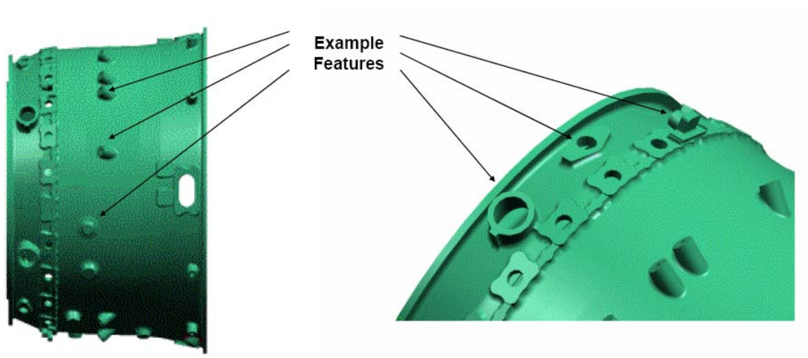
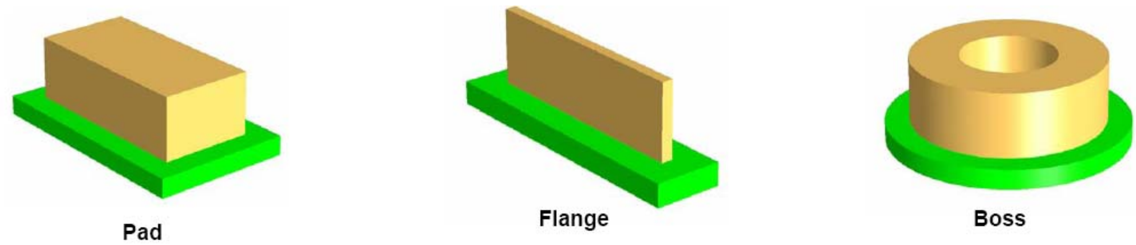
The Air Force Research Laboratory has been exploring the possibility of using metal additive manufacturing processes for depositing superalloy materials in engine component applications. Through the Metals Affordability Initiative, managed by the Metals Branch in the Materials and Manufacturing Directorate, the "Additive Manufacturing of Superalloys" project has demonstrated the deposition of nickel superalloy features on substrates using two different processes. The goals of the project are to determine the quality and mechanical property capabilities of these processes while developing a cost model to measure economic feasibility.

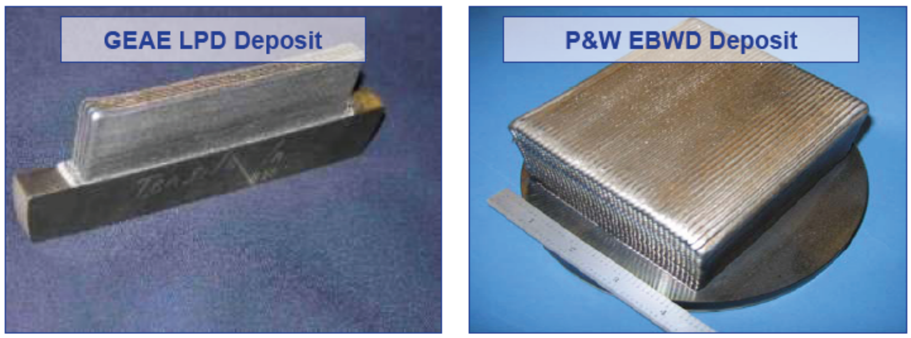


Sample engine cases with features that can be deposited using metal additive manufacturing processes.

The two processes demonstrated in this project are electron beam wire-feed deposition (EBWD), and laser powder deposition (LPD). The EBWD process is performed in a vacuum, using an electron beam for its heat source. The material is fed to the system in wire form and forms a small molten pool where it meets the electron beam. Material is built up, layer by layer, using CNC to control the deposition path. The LPD process is performed in an inert gas atmosphere, using a laser for its heat source. Material is fed to the system in powder form and also forms a molten pool where is meets the laser beam. In a similar fashion as EBWD, a layer-by-layer build is controlled with CNC. Both processes have shown to be capable of meeting minimum quality standards, for example, as defined in MIL-STD 2219, Fusion Welding for Aerospace Applications, Class A.

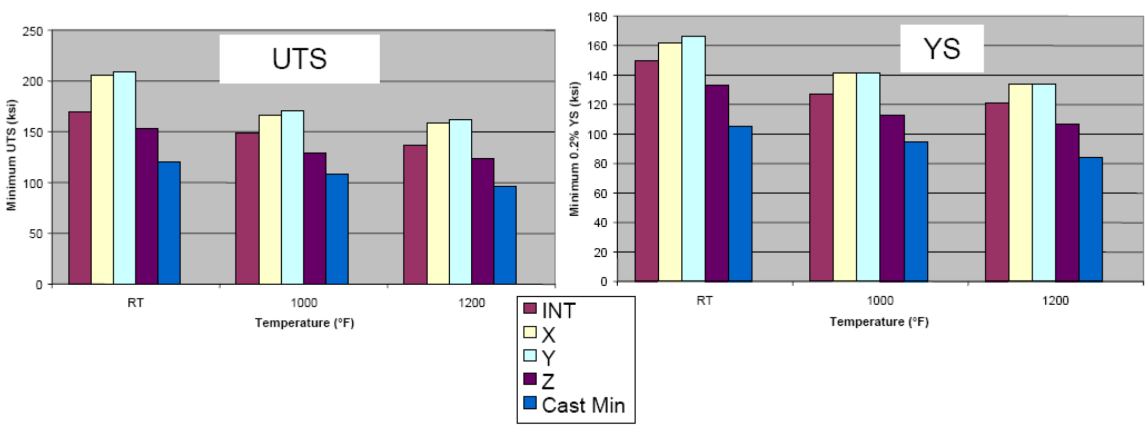
Typical features that one might find on the exterior of an engine case can generally be represented by three geometries: a rectangular pad shape, a thin-wall flange shape, and a cylindrical boss shape. These are the geometries that were demonstrated in the Additive Manufacturing of Superalloys project. The deposits were post deposit heat treated, inspected non-destructively, examined metallographically, and tested for mechanical properties.



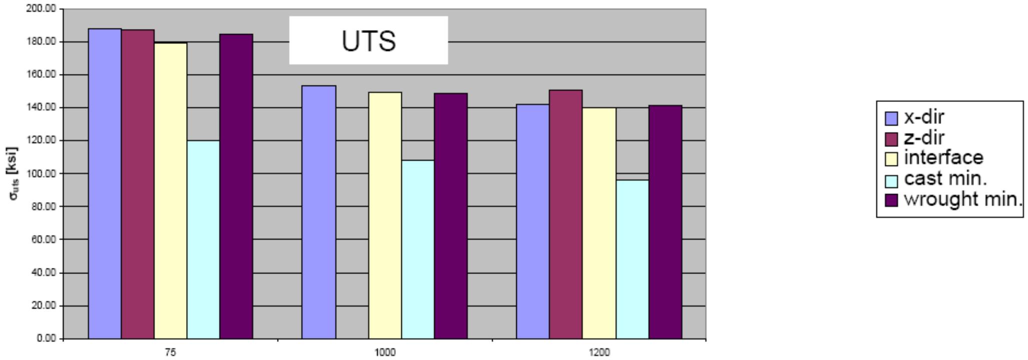


Representative feature geometries (above) and actual LPD (below left) and EBWD (below right) Nickel deposits.

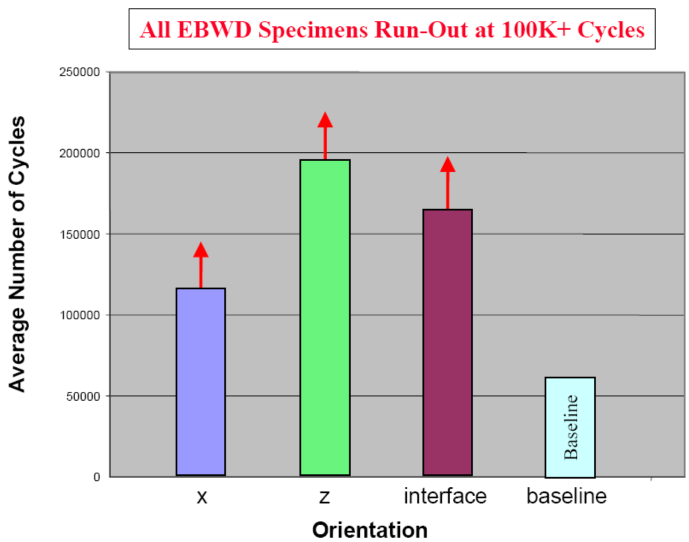
Testing of deposited components has included tensile properties at room temperature and elevated temperatures, creep stress rupture, and some low cycle fatigue. Selected typical results are shown for the two processes. Since these are layered processes, anisotropy is typical, and specimens of various orientations must be tested. Results show tensile properties that generally exceed those of cast components. The processes are ready for demonstration on non-critical production parts and may be economically ready in certain applications.



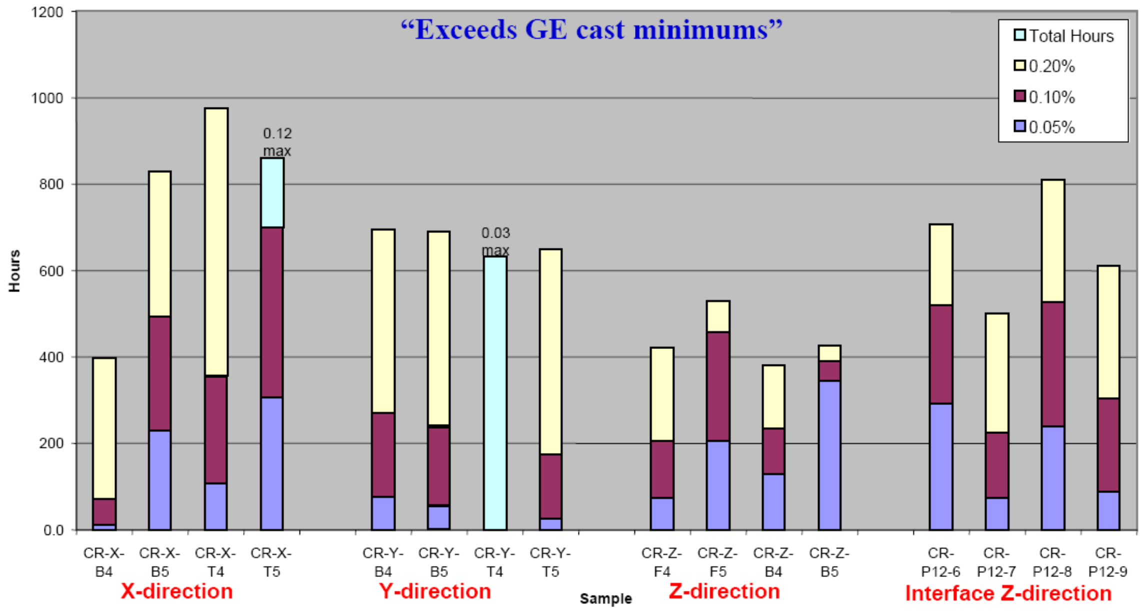
Ultimate tensile and yield strength results for IN 718 using the LPD process. Comparison is made to cast properties.



Ultimate tensile strength results for IN 718 using the EBWD process. Temperature in degrees F.

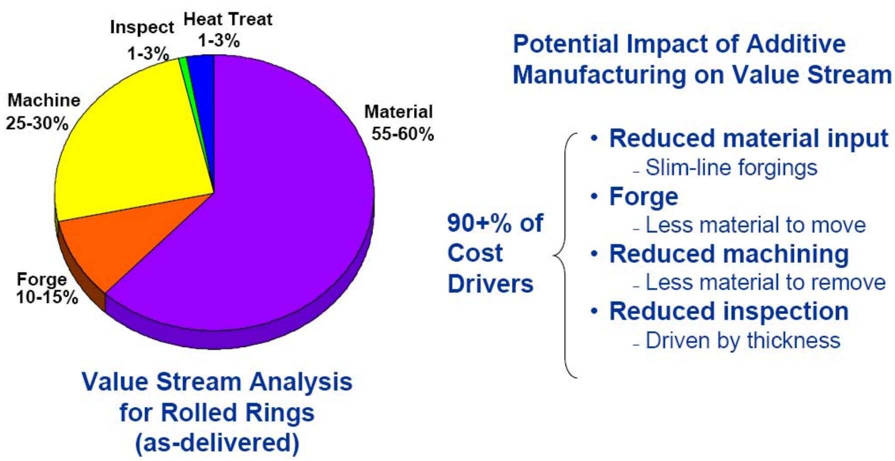


Low cycle fatigue test results for IN 718 using the EBWD process. Strain-controlled LCF at 1000^oF, A=1.0, strain=0.4%.



Creep testing results for IN 718 using the LPD process. Hours to 0.2% creep at 1200°F at 75 ksi.

The development of a cost model has been a significant portion of this project. The additive processes and the associated manufacturing steps required to build features onto engine cases were incorporated into the model so that the potential cost savings of this approach could be estimated. The cost model is a useful tool not only for cost comparison, but also for determining which additive processes might be the best suited for a certain application. Using the cost model, it was determined that more than 30% savings can be realized for a forged engine case by building a case with a smaller outline and attaching features using additive processes. It was also shown that such savings do not exist for a cast engine case, but an additive approach might instead allow significant weight savings.



Challenges still remain in the development of these processes. For example, residual stresses must be controlled to minimize warpage, and incoming powder or wire material quality must be ensured. One particular issue raised in this project is non-destructive testing: ultrasonic methods are difficult with such deposited material because the "noise" in the microstructure inhibits the inspection depth. As the process is developed and matured, these issues will be specifically addressed, and process specifications will be generated.

Additional depositions have been made on substrate rings that are more representative of engine cases. These deposits were also tested and found to have similar results to those shown. The next step is to try these processes out on actual production parts. While they are not yet ready for critical applications, there are several opportunities for demonstration on non-critical components. Once process parameters and specifications are in place, more challenging parts may be attempted.

Metal additive manufacturing processes most likely will not replace existing processes, but can offer benefits in certain superalloy applications in terms of cost savings or providing otherwise unavailable processing capabilities, e.g., dual-alloy deposition and functionally-graded materials. Such capabilities enable innovative design for future Air Force and DoD systems.

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