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# Impacts Of Hot Isostatic Pressing 3D Printed Parts

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**NPS NRP Executive Summary**
Title: Impact of Hot Isostatic Pressing 3D Printed Metal Parts
Report Date: 10/14/2019 Project Number (IREF ID): NPS-19-M283-A
Naval Postgraduate School / GSEAS

MONTEREY, CALIFORNIA

# IMPACT OF HOT ISOSTATIC PRESSING 3D PRINTED METAL PARTS

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# EXECUTIVE SUMMARY

## Project Summary

The use of additive manufacturing (AM) techniques, also referred as three dimensional (3D) printing, to generate objects layer by layer presents multiple advantages over technologies that rely on machining or removing sections of a larger piece. AM methods can produce complex parts without waste of raw materials and promise to greatly reduce costs and increase efficiency in our supply chain. Polymeric materials can be directly 3D printed and immediately used. In contrast, metals and alloy components require post-processing operations, such as thermal treatments and hot isostatic pressing in order to obtain the desired properties. Without the proper treatments, the 3D-printed metal parts will be unreliable and will pose a risk to the systems that will integrate them.

The goal of this study was to conduct materials characterization of 3D-printed maraging steel specimens after each processing step to identify which post-printing conditions should be employed to produce parts with the mechanical properties that could meet the sponsor's objectives and/or operational needs. For this effort, NPS faculty and students worked with Albany's Marine Corps Logistics base personnel.

Overall, the study identified which printing direction, heat, and surface treatments render parts with the highest hardness, yield, and ultimate strength and provided recommendations regarding the optimal parameters to employ during printing to maximize the above.

**Keywords:** *additive manufacturing, AM, metal/alloy AM, three-dimensional, 3D, 3D metal printing, maraging steel, post-processing*

## Background

Metal and alloy 3D printing techniques physically join the materials layer upon layer to render tridimensional objects. Some of the common technologies available for metal AM include directed energy deposition (DED) and powder bed fusion (PBF) methods, although others are under development. In DED, melted material is directly deposited onto the part undergoing printing using a raised nozzle. In PBF, a roller or spreader distributes powder in a platform and a heat source is directed to the sections to be joined. Independent of the method, after AM fabrication, a few post-processing steps are required to render an object with the microstructure, properties, and surface finish desired for engineering applications:

- *Residual stresses and stress relief*
  The heating and cooling cycles that the metal suffers as it is built layer by layer produce internal stresses that need to be relieved to prevent warping and cracking in the final part. Heat treatments after the part is built are conducted in inert atmospheres to prevent oxidation.
- *Heat treatments*

The as-produced parts might require aging, solution annealing, and controlled cooling procedures to develop the microstructures that will fulfill the properties expected.

- *Surface treatments*
  The surfaces of AM parts might also require surface finishing steps to reduce roughness and remove partially melted particles that otherwise will act as stress concentrators.

In sum, post-processing treatments are indispensable to produce 3D-printed metal parts that will fulfill their load bearing and lifecycle requirements.

The hypothesis of this study was: Tensile test data and microstructural analysis of 3D-printed samples heat-treated under different conditions will allow us to determine which post-printing steps are required to produce specimens that meet the sponsor operational needs.

The research questions that the study helped answer included:

- What is the impact of heat-treating 3D-printed parts on the properties of the material?
- What microstructures are present at diverse conditions?
- Will the heat-treatment operations produce changes in the local composition of the materials?
- How do the mechanical properties of the heat treated (HT) specimens compare to those of parts before treatment?
- How do the properties of 3D-printed parts compare to samples produced by subtracting methods such as computer numerical control (CNC)?
- What is the distribution of phases and properties in the samples' cross section?

## Methods and Findings

The methods employed to characterize the mechanical properties, the microstructures and the composition of the specimens under study, were a perfect fit to fulfill the goal of the analysis. Instruments such as the scanning electron microscope and energy dispersive spectrometer, along with hardness and tensile tests, allowed us to determine the effects that post-printing steps, such as diverse heat-treatments, had on the features and properties of parts printed in diverse directions.

Some of the key findings included:

- Samples heat-treated at 490 $^{0}$C had the highest ultimate tensile strength and yield strength while parts manufactured by traditional techniques, such as CNC, and samples heat-treated at 900 $^{0}$C had the lowest values.
- Specimens printed in the z and xy directions had the highest strength and closely matched the 3D printer manufacturer's benchmark values. The lowest strength was found in samples printed using a 45 degree angle. The later observation is supported by fracture mechanics calculations.

- The AP samples presented unusual fracture surfaces. This observation seemed to be related to surface imperfections and a lack of fusion. However, those features did not have a measurable impact on the yield strength, ultimate tensile strength or hardness. Susceptibility to corrosion, however, might increase due to lack of fusion found near surface.
- Sand-blasted samples had a typical fracture surface with crack initiation forming towards the middle and propagating outward. Sand-blasting samples decreased surface roughness and had an observed impact in the failure mode of AP sample. In order to reduce the number of surface imperfections that will act as stress raisers, it is recommended that samples are sand blasted after support structures are removed.

## Conclusions

Margaging steel tensile specimens were printed at the Marine Corps Logistics Base Albany and sent to NPS for heat treatments, testing, and analysis. Mechanical properties such as yield strength, tensile strength, and hardness were determined and compared with articles produced by traditional manufacturing techniques and with the benchmark set by the 3D printer manufacturer. The properties of as-printed (AP) and HT parts indicated that 490°C is the temperature that renders the strongest specimens when compared to those heated to 600 and 900 °C. Electron microscopy observations identified the presence of precipitates responsible for the increase in strength in HT-490. The data gathered helped identify that the printing direction (xy, z or 45 degree angle) greatly influenced the samples' properties, with 45 degrees showing the weaker parts. Fractographic analyses were conducted to determine crack initiation points and failure mechanisms for each printing condition. The microstructural analysis identified small areas with evident of lack of fusion near the surface of most specimens. However, those features did not have a measurable impact on the yield strength, ultimate tensile strength, or hardness. Nonetheless, susceptibility to corrosion increased due to lack of fusion. As result, it is recommended that heat treated maraging steel parts are stored in conditions that will prevent the exposure of corrosive environments or coated immediately after thermal processing.

## Acronyms

| | |
|---|---|
| additive manufacturing | AM |
| as-printed | AP |
| three-dimensional | 3D |
| heat-treated | HT |
| directed energy deposition | DED |
| powder bed fusion | PBF |
| computer numerical control | CNC |