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Effects of Environmental Factors on Additive Manufactured Materials

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NPS NRP Executive Summary

Title: Effects Of Environmental Factors On Additive Manufactured Materials

Report Date: 10/14/2019 Project Number (IREF ID): NPS-19-N180-A

Naval Postgraduate School / GSEAS

NAVAL RESEARCH PROGRAM

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

EFFECTS OF ENVIRONMENTAL FACTORS ON ADDITIVE MANUFACTURED MATERIALS

Executive Summary Type: Final Report

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EXECUTIVE SUMMARY

Project Summary (Abstract)

The emergence of additive manufacturing (AM) as an approach to generate parts is changing the way our industries operate and is shifting our mindset regarding procurement, distribution, and supply networks. The use of AM technologies is expected to increase the supply chain proficiency and lower costs, however, those benefits can only be realized if the materials produced reach their anticipated lifecycle. Thus, with the expanding use of AM approaches for the fabrication of key parts and components for Department of Defense (DoD) applications, there is also a growing need to identify the factors that could put the predicted advantages of the technology at risk. Knowing which variables could affect the lifetime of an object will allow stakeholders to use realistic estimates regarding when to supply new ones.

The literature in regard to the mechanisms that three-dimensional (3D)-printed materials suffer as result of environmental attack is scarce, thus, this study attempted to address such deficiency. The research conducted aimed to determine the effects that humidity-, ultraviolet (UV) light-, and salt-containing environments have in the composition, microstructure, and properties of the most common materials used for 3D printing of parts.

Keywords: *additive manufacturing, AM, three-diminsional printing, 3D printing, environmental degradation, marine environment*

Background

The use of AM techniques to produce parts has grown exponentially in recent years; in fact, the technology has the potential to become the standard manufacturing process for many polymeric parts and for selected metals/alloy components.

Multiple research groups are already addressing the challenges identified in recent years for the wide adoption of AM fabrication: from basic understanding of the process and material evolution during the layer-by-layer deposition, to complex parts design, post-processing steps, certification/qualification and repair strategies. However, despite the widespread attention that AM has received and the advances made regarding the accuracy and reliability of the equipment and processes, we noticed that information regarding how the raw materials and the 3D-printed parts will age or degrade due to environmental factors is extremely limited.

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As mentioned in the abstract, the emergence of AM fabrication routes as a new approach to generate parts is changing the way our manufacturing industry operates. Thus, information about how environmental conditions will affect the materials useful life and performance should be available to stakeholders. The work conducted fits very well with the mission and objectives of the sponsor's portfolio. Material scientists/engineers and supply chain/logistics specialists are some of the groups that could benefit from the study, since the data generated could provide a better prognosis of materials cycle life.

Hypothesis: Subjecting 3D printed materials to accelerated weather testing will allow us to determine if, and to what extent, the environment affects the properties of materials used for 3D printing and those of the objects produced.

The research questions that the study helped answer include:

- Are the raw materials used to 3D print parts going to suffer changes in dimensions, composition, or properties due to environmental factors?
- Which environmental factors will have a major impact on materials properties?
- If there are changes in properties, are those large enough to compromise the material performance?
- Which materials will be more susceptible to environmental exposure?

Methods

An accelerated weather tester was used to perform aging treatments in 3D-printed polymers and composites. Each environmental cycle was a week long and alternated four hours of UV exposure with four hours of a dark humid environment. Different polymers, including polylactic acid (PLA), glycol modified polyethylene terephthalate (PETG), acrylonitrile butadiene styrene (ABS), and nylon and their composites were studied. For the steel studied, a salt fog chamber was employed to expose tensile specimens to environments that simulate conditions similar to marine environments. For the polymeric and composite samples, optical and electron microscopy were employed to assess the changes. The changes in mechanical properties of the as-printed (AP) and heat-treated (HT) materials after environmental exposure were analyzed using tensile and hardness testers. For the alloy under study, the chemical and microstructural features after controlled exposure to environmental factors were also identified using a scanning electron microscope coupled with energy dispersive spectroscopy.

Findings and Conclusions

Based on visual and microscopic examination of the materials and the mechanical properties of the specimens after exposure, this study identified which polymers and composites are more likely to degrade under the UV and humidity conditions and which could withstand them. We found that carbon fiber (CF) fillers increased the resistance to exposure while other fillers, such as bronze and steel, reduced it. The mechanical properties of nylon composites remained unchanged after the environmental treatments, while PLA and ABS composites suffered the largest reduction in strength.

3D-printed maraging steel tensile specimens were used as example of alloy behavior and were exposed to corrosive environments using a salt-fog chamber. Samples were used directly in the AP condition and after being heat treated. All samples suffered changes in properties, however, the HT parts showed to be much more susceptible to corrode and present reduced strength. Defects in the prints, such as lack of fusion near the surface, exacerbated the corroding effect of the salt-fog environment on the tensile specimens under examination.

We observed that 3D-printed PLA with CF became brittle after exposure, however, withstood three weeks of UV exposure as opposed to PLA with other fillers, such as bronze and steel, that were too brittle to test after one to two weeks. ABS filled with CF lost some strength upon three-week UV exposure but could be utilized to perform adequately for lower strength applications. Nylon reinforced with CF was the strongest material and showed no significant degradation in yield or tensile strength through week three of UV/humidity treatments.

After 500 hours of salt fog exposure, the mechanical properties of 3D-printed maraging steel are changed: Samples printed in 45 direction and heat-treated at 600^{o} C saw a 5.8% decrease in strength. Samples printed in Z direction with no HT showed a 0.57% decrease in strength. Corrosion-induced degradation in tensile properties was greater in maraging steel samples which were heat treated. HT samples saw a 4.3% degradation after exposure as compared to a 2.2% degradation in non-HT samples.

Acronyms

additive manufacturing	AM
three-dimensional	3D
heated treated	HT
carbon fiber	CF
polylactic acid	PLA
glycol modified polyethylene terephthalate	PETG
acrylonitrile butadiene styrene	ABS