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Development Of Nanoparticle Based Alternative for Metal Additive Manufacturing

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DEVELOPMENT OF NANOPARTICLE BASED ALTERNATIVE FOR METAL ADDITIVE MANUFACTURING

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EXECUTIVE SUMMARY

Project Summary

The research conducted had the objective of developing an additive manufacturing (AM) strategy to produce metal or alloy parts through the use of layer-by-layer extrusion of small particle paste formulations along post-processing steps. That is, we aimed to hybridize additive manufacturing approaches with known powder metallurgy (PM) processes to produce alloys of naval relevance. The work that we are reporting herein generated metal parts using, instead of expensive direct sintering equipment (metal tri dimensional (3D) printer), a conventional 3D printer (as the ones used for polymeric filaments). The later was equipped with an extruder capable of deliver paste composed of metal nano or micron particles and binding media that evaporated after the printing operation was completed. The 3D parts produced using those paste formulations had similar characteristics that the ones observed in green specimens generated by PM. Using the same type of post-treatments that AM and PM routes employ, such as annealing and hot isostatic pressing (HIP), we were able to generate 3D specimens of NiTi and NiCu alloys. We demonstrated that the new process could successfully generate solid specimens, which, after HIP operations, showed mechanical robustness. This new approach could be easier to adapt than laser or e-beam sintering routes and has potential to be used for metal/alloy parts that do not require stringent load bearing specifications.

Keywords: *metal additive manufacturing, paste formulations, AM, powder metallurgy*

Background

Additive manufacturing (AM) techniques to fabricate metal parts require lasers or electron beams to produce localized melt or sintering of the raw powder, allowing the layer-by-layer fabrication of complex components. The resulting build has to be heat treated after printed to produce the final microstructural features and be able to reach the desired mechanical properties. Despite the advantages of AM of metals, the instrument and operational costs are still very high.

Powder metallurgy refers to techniques that allow the fabrication of consolidated parts from metal powders that are compressed into the desired shape. The result is a green specimen that requires annealing in controlled atmospheres to join the particulates.

AM and PM techniques share some characteristics: a) small size particulates are employed as the raw material, b) builds generated require post-processing (annealing or hot isostatic pressing) to achieve the desired microstructure, reduce porosity and gain the targeted mechanical properties, and c) since no tooling or material removal is required, costs can be drastically reduced when compared with other fabrication approaches.

Developing a hybrid technique that uses paste composed of metal powder to create parts layer-by-layer to then sinter or hot isostatically press them to imprint the desired properties and microstructure expands the type and complexity of parts that can be produced. Operational sites that could not afford a metal printer and do not have stringent load bearing requirements could greatly benefit from the proposed manufacturing approach.

Findings and Conclusions

Nano and micron size particulates of Ni, Cu and Ti were mixed to generate NiTi or NiCu alloy parts. The fluid component of the paste that presented the optimal consistency to be 3D printed along the metal particulates was a mixture of water, ethanol, and a thickening agent. Other liquid phases, such as ethylene glycol and a mixture of semi-solid, saturated hydrocarbons, mainly of paraffinic nature, were also tested. The post treatments including furnace annealing at temperatures between 800-1000 degrees C and hot isostatic pressing at 1000 degrees C at pressures between 20-30 K psi. The samples crystalline components were identified by X-ray diffraction, their microstructures and degree of porosity studied by optical and electron microscopy. Hardness tests served as initial indication of mechanical properties and tensile tests as a more complete evaluation.

The research conducted provided a proof of concept that alloy solids can be 3D printed using affordable polymeric printers; however, post processing steps are needed to reach the desired mechanical values.

Recommendations for Further Research

This research demonstrated that the new process could successfully generate solid specimens, which, after HIP operations, showed mechanical robustness. This new approach could be easier to adapt than laser or e-beam sintering routes and could be applied for metal/alloy parts that do not require stringent load bearing specifications. Next steps include the fabrication of complex shapes and treatments at higher HIP pressures/temperatures.

Acronyms

powder metallurgy (PM)
additive manufacturing (AM)
tri dimensional (3D)
hot isostatic pressing (HIP)