Multi-material 3D printing of vacuum nozzle of rocket engine: design, manufacturing, weight, and cost savings

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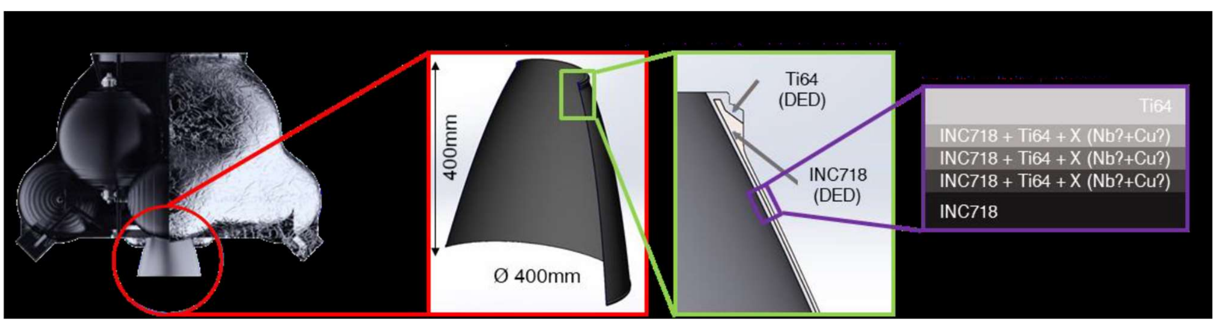
Abstract

Metallic materials additive manufacturing is extremely challenging nowadays. Several manufacturers are currently trying to adapt the newly developed technology to produce parts of complex geometry that usually involves numerous machining operations, resulting in high-performance materials loss. Skyrora is a company focused on the production of several launch vehicles and rockets with the aim to become a commercial provider for access to space. One of the Skyrora goals is to develop innovative and long-term solutions for future growth and within the Horizon European project "MADE-3D" aims to improve the rocket engine of the launch vehicle Skyrora XL. More specific, the focal point is the improvement of the engine efficiency in a vacuum and to avoid gaseous propellant flow separation, as the LEO rocket engine is equipped with a vacuum nozzle of a total length of 400 mm and a diameter of 400 mm in its outlet area, as can be seen in the below figure.



The vacuum nozzle is entirely made of nickel-based alloy Inconel 718 since temperatures can reach up to 750 °C. Currently, the vacuum nozzle is manufactured by the Direct Energy Deposition (DED) method using Skyprint 1 and Skyprint 2, in-house developed 3D-printers. Since the vacuum nozzle is joined to the other components by means of thermal welding, the surrounding parts of the vacuum nozzle are also made of Inconel 718. Nevertheless, optimization of the nozzle could be performed as not all the areas of the vacuum nozzle are exposed to temperatures above 450 °C and therefore the nickel-based superalloy can be replaced by the lower-density (approximately two times lower) titanium alloys. Joining of Ni to Ti alloys has clear lightweighting benefits, however direct joints of such dissimilar materials are prone to cracking, potentially leading to catastrophic failure, due to detrimental intermetallics formation and development of thermal stresses during fabrication and operation. Replacing direct joints with functionally graded structures, utilizing additions of supplementary materials such as Cu and Nb based alloys in the transition zone, has the prospective of enabling joining by navigating round detrimental phase fields and minimizing the risk of cracking. The aim of the current investigation within the MADE-3D project is to efficiently perform multi-material design via a computational approach and printing of the vacuum nozzle by exploiting the designed functionally graded structures between Ni and Ti alloys.

The main goal of the present work is to present the solution proposed for the multi-material design of the rocket nozzle. The exploitation of the proposed methodology and design presents specific benefits that will be quantified in the present study. The manufacturing processes of the (a) conventional mono-material and (b) multi-material demonstrator were documented and compared in terms of weight, manufacturing cost, lead processing time and CO_2 equivalent emissions. Preliminary results showed that calculated weight saving is essential, exceeding 25 % when compared to the conventional mono-material rocket nozzle. For the consideration of a serial production of one such rocket nozzle, total process time is increased by approximate 13 % for the multi-material demonstrator. The calculated manufacturing costs showed that the new design also shows significant advantages in terms of cost savings as well as of carbon footprint of the manufacturing processes of the rocket nozzle.

Acknowledgements

The authors gratefully acknowledge the financial support of the HORIZON Research and Innovation Actions, European Health and Digital Executive Agency for the implementation of the project «MULTI-MATERIAL DESIGN USING 3D PRINTING» having an acronym “MADE-3D” of the act HORIZON-CL4-2022-RESILIENCE-01 with Grant Agreement code 101091911.