M.2: Development of thin wall dome structure for aerospace application using LAM-DED process

In aerospace, dome structures with diameter more than 300 mm are used as pressure vessels for spacecraft fuel tanks, and rocket engine components that demand high strength and thermal resistance. Dome structures are commonly developed using sheet forming, spinning, deep drawing, or segment-wise forming followed by welding. These traditional approaches require dedicated tooling, multiple forming stages, and extensive post-processing in addition to long manufacturing cycles. In thin sections, they are often associated with challenges such as dimensional inaccuracy, spring-back, residual stresses, weld-induced distortion, and material wastage. In contrast, the laser directed energy deposition based additive manufacturing (LAM-DED) process enables near-net-shape fabrication directly from a digital model, eliminating the need for complex dies and reducing the number of processing steps. Further, the layer-by-layer deposition approach provides precise control over heat input, bead geometry, and wall thickness, which is particularly critical for thin-wall dome structures. Furthermore, additive manufacturing minimizes material loss, enables rapid design modification, and facilitates in-situ repair of high-value aerospace components capabilities that are limited in conventional methods.

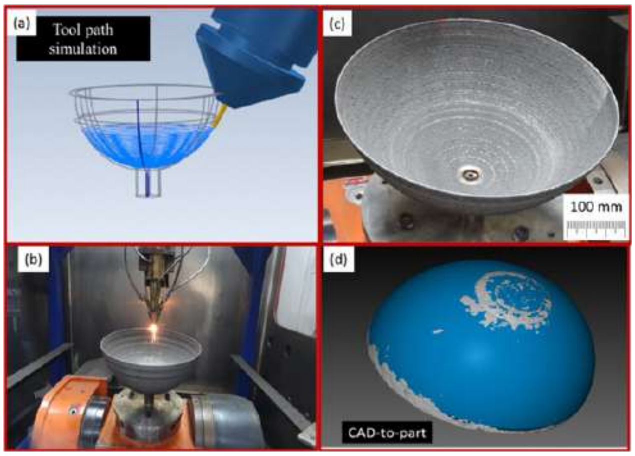

Fig. M.2.1: (a) Photograph of tool path simulation, (b-c) photograph of actual dome structure during and after deposition process, (d) CAD to part comparison

In the present study development of dome structure of SS 304 L steel with diameter ~400 mm is undertaken using LAM-DED process. A novel methodology has been developed in this study for developing a thin-walled hemispherical dome of SS 304L steel with diameter approximately ~400 mm using LAM-DED without the need for support structures. A custom-designed 5-axis kinematic system is employed to overcome challenges associated with large overhang angles, thereby enhancing slicing precision and deposition accuracy. The process incorporates meridional slicing to ensure melt-pool stability and circumferential rotation for uniform layer deposition. A unique slicing algorithm is introduced, which incrementally adjusts slice height along the meridian axis, enabling dome fabrication on a cylindrical substrate. Process parameters such as laser power, powder feed rate, and scan speed are optimized, and novel toolpath simulations (Fig. M.2.1a) confirm collision-free deposition. Using the optimized parameters laser power of 750-850 W, a constant linear scan speed of 600 mm/min, and a powder feed rate of 8.6 g/min, a hemispherical dome structure with a diameter of ~425 mm and wall thickness of 2.5 mm is successfully developed. Photographs captured during and after deposition are shown in Fig. M.2.1 (b & c). Geometrical characterization of the as-built dome includes surface roughness analysis, CAD-to-part comparisons. The CAD-to-part comparison (Fig. M.2.1d), based on 3D scanning, indicates an average wall thickness of 2.49 ± 0.08 mm, with outer and inner diameters measured at 425.08 ± 0.15 mm and 422.43 ± 0.29 mm, respectively. The dimensional deviation from the nominal diameter is only 0.41%, well within acceptable tolerance limits, indicating high dimensional accuracy and geometrical stability. Surface roughness measurements over a 2 mm scan length show average R_a values of 2.35 ± 0.17 µm for the outer surface and 9.51 ± 0.63 µm for the inner surface, as depicted in Fig. M.2.2(a & b). Optical microscopy (Fig. M.2.2(c)) reveals a defect-free microstructure comprising of cellular, columnar, and equiaxed dendritic grains. Additionally, Pulse-Echo ultrasonic testing under submerged conditions confirms the absence of porosity and cracks in the as-built dome structure. This approach offers a scalable and support-less manufacturing solution for complex hemispherical geometries, with potential applications in the aerospace and energy sectors.

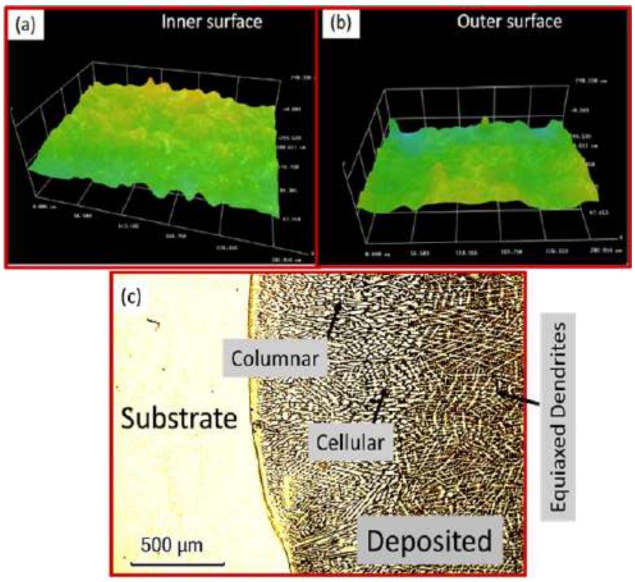

Fig. M.2.2: (a-b) 3D surface profile of outer and inner surfaces, (c) Optical micrograph of the as built dome structure.

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