An introduction to metal mirror fabrication using additive manufacture

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An introduction to metal mirror fabrication using additive manufacture

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Abstract: Metal mirror fabrication using additive manufacture is an emerging field which has clear design benefits, but also challenges inherent within the print process. This paper explores these attributes and provides an introduction to the field.

1. Introduction

Additive manufacture (AM; 3D printing) creates a structure layer-by-layer from a digital file. A key benefit of AM is the increase in design freedom, as geometrically complex structures can be recreated with ease. Lightweight metal mirrors are a clear candidate to benefit from the increase in design freedom, as the lightweight structure is no longer restricted by the tool access imposed by conventional subtractive machining (mill, drill and lathe).

AM lightweight metal mirrors is an emerging field within mirror fabrication, with the first prototypes documented in 2015 [1]. Since then, a number of lightweight structures have been investigated for mirrors, such as cubic lattices [2], conformal lattices [3], Voronoi structures [4] and topology optimisation [5]. In parallel, a range of metal alloys have been trialled, such as AlSi10Mg [2], AlSi40 [4] and Ti64 [1, 2]. Examples of AM mirrors are split into two categories, those that polish or single point diamond turn (SPDT) the AM substrate directly and those that coat the AM substrate in nickel phosphor (NiP) and then polish or SPDT. Excellent optical qualities have been demonstrated by coating in NiP [2,4]; however, this paper considers the post-processing of the AM substrate directly, where the challenge is to ensure the AM substrate is defect free to ensure the best optical performance.

2. Design benefits

2.1. Lightweight mirror design

The majority of conventional manufactured lightweight mirrors have two styles: open back, where material is removed from a solid substrate; and sandwich mirrors, where a composite structure is created using two face plates and an internal honeycomb. Typically, open back mirrors are easier to manufacture than sandwich mirrors, but are less rigid, and this compromise is an attribute that AM can remove. Building layer-by-layer, enables a sandwich design to be made in a one material without interfaces, where the internal honeycomb can be optimised for thickness to minimise deflection under operating loads. Furthermore, part consolidation, combining of multiple parts to create a single component, can be used to combine mirror and mount to reduce mounting related defects.

2.2. Design example & getting started

Fig. 1 presents a lightweight AM mirror design with a body centred cubic (BCC) lattice in the internal cavity [6]. To ensure metal powder could be removed from the cavity, holes were included on the base. When commencing this prototype, the optical, mechanical and machining engineers considered the part requirements and AM limitations to converge on the design, e.g. ensuring the cavity was free of AM support material. Drawing a simple BCC in computer aided design (CAD) is laborious, but possible; however, there are many AM specific design packages that can generate a variety of lattices, requiring inputs of only unit cell size and strut/wall thickness.

3. Challenges and considerations

AM is not a standardised process, the parameters that define the print (e.g. hatch direction and laser power & speed) are all variables that can be altered. External AM design bureaux often operate a single set of parameters which are successful in the majority of cases; however, these parameters might not provide the required optimum substrate; whereas, in research institutes, the parameters can be optimised for the function of the AM component.

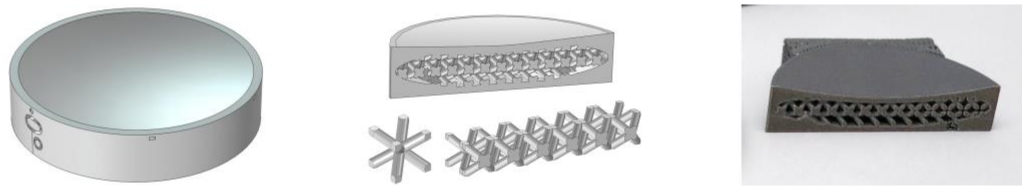

Fig. 1. An example of design freedom offered by AM: *left* the external CAD geometry; *middle* - the internal BCC lattice; and *right* - an AlSi10Mg printed cross-section.

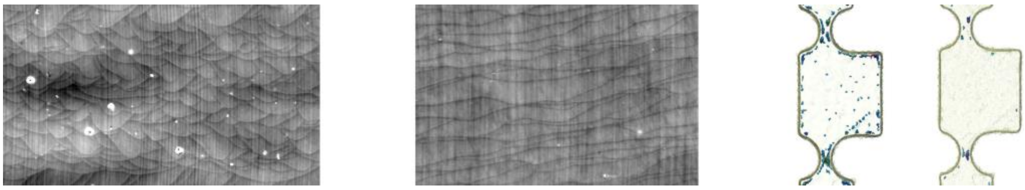

Fig. 2. *Left & middle* - a SPDT surface intersecting the meltpools normal and parallel to the laser travel respectively; and *right* porosity within an AlSi10Mg print before and after HIP.

3.1. Print set up & porosity

To ensure optimum build parameters, a 'design of experiment' method is beneficial to trial a number of parameter settings, which can be studied in relation to the primary function of the part [7] and in this case, reflectivity. Fig. 2 *left & middle* highlight microscope interferometer images of SPDT parts where the optical surface is generated normal and parallel to the laser path respectively; the meltpools generated by the laser are visible; however, they do not appear to significantly affect the roughness in comparison to the porosity.

Porosity within AM components is a common defect and is typically caused by the machine parameters, which result in a part that is either too hot or too cold during build. In the left-hand image of Fig. 2 *right*, porosity has been highlighted within the volume of this AlSi10Mg print, it is common to find porosity located near a contour-hatch interface. Porosity can be reduced at source by using optimum parameter settings for the part; however, porosity can also be reduced after build using a hot isostatic press (HIP), shown right-hand image of Fig. 2 *right*.

4. Conclusion

AM is a method of manufacture that is now on a par with conventional manufacture, both subtractive and formative (casting and forging). AM will not replace conventional mirror manufacture and AM is not suited for mass production, rather it enhances the field of mirror manufacture by adding a new method that allows the optimisation of certain attributes where a bespoke mirror and a low part count is required.

Acknowledgements

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