EXPERIMENTAL INVESTIGATION OF FATIGUE BEHAVIOUR OF ADDITIVELY MANUFACTURED AIRCRAFT STRUCTURAL MATERIALS

Wyman ZHUANG[1]

[1] Aerospace Division, Defence Science and Technology, Melbourne, VIC, Australia

E-mail: wyman.zhuang@dst.defence.gov.au

Introduction

Additive manufacturing (AM) has demonstrated to have great potential for aerospace applications since it is able to optimise design freedom for fabricating more complex geometry and lightweight structures and components, and to achieve higher fuel efficiency and reduced lead-time and cost of ownership. Although AM has been successfully applied for many secondary structures or other non-critical applications, most aircraft fracture-critical components are currently still machined out of forged metal alloys [1]. This is mainly because of the confidence in aerospace industry in understanding the mechanical properties (specifically fatigue strength and fracture toughness) of forgings adequately and accurately [2]. Given this conventional manufacturing often resulted in typical buy-to-fly ratios more than 10:1 with lengthy lead times and high cost, there is a demand for further R&D to unlock the potential of AM especially for aircraft fracture-critical structures and parts.

Deep Surface Rolling of AMed Specimens

This paper firstly outlined the various technical challenges to be considered in the qualification of additively manufactured alloys for aerospace applications, focusing on critical load bearing components. Although, in recent years, extensive R&D efforts have been devoted to achieving lower cost fabrication of Ti-6Al-4V parts using AM, it has founded that the fatigue strength of additively manufactured Ti-6Al-4V published so far is equivalent to that of casting counterparts. Secondly, some promising post processing technologies to enhancing fatigue performance of additively manufactured Ti-6Al-4V alloys (Fig. 1) were experimentally investigated. The post processing technologies investigated include post heat-treatment, hot isostatic pressing, and surface enhancement technologies such as deep surface rolling as shown in Fig. 2.

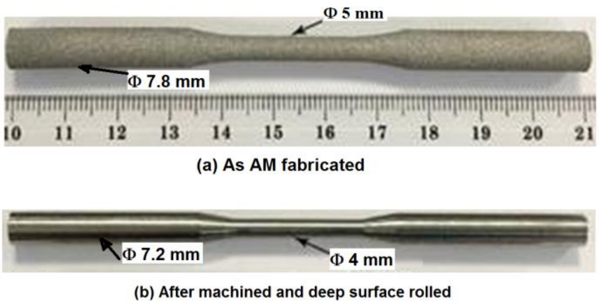

Fig. 1. (a) Additively manufactured Ti-6Al-4V and (b) The specimen after post machining.

Fig. 2. Deep surface rolling processing on the surface of additively manufactured specimen.

Experimental Results

Fatigue testing was performed at four stress levels for each group of the specimens, using a MTS testing machine (100 kN), at the stress ratio (R = min/max stress amplitudes) of 0.1 at the frequency of 10 Hz at room temperature, as listed in Table 1. Fig. 3 presents fatigue behaviours of additively manufactured Ti-6Al-4V with different post processing technologies. Finally, the mechanics and mechanisms of how these post processes to enhance fatigue performance of additively manufactured alloys were discussed from a perspective of certification specifications and requirements in accordance with airworthiness standards.

Table 1. Fatigue testing matrix

Specimen ID	Stress Ratio R	Max Stress (MPA)
DSR-AM05	0.1	900
DSR-AM10	0.1	900
DSR-AM15	0.1	900
DSR-AM20	0.1	900
DSR-AM01	0.1	800
DSR-AM02	0.1	800
DSR-AM03	0.1	800
DSR-AM04	0.1	800
DSR-AM06	0.1	700
DSR-AM07	0.1	700
DSR-AM08	0.1	700
DSR-AM09	0.1	700
DSR-AM11	0.1	600
DSR-AM12	0.1	600
DSR-AM13	0.1	600
DSR-AM14	0.1	600
DSR-AM16	0.1	500
DSR-AM17	0.1	500
DSR-AM18	0.1	500
DSR-AM19	0.1	500

Conclusions

The recent experimental results clearly demonstrated that the deep surface rolling technology is able to considerably improve the fatigue strength of AMed Ti-6Al-4V specimens, compared with other common post processing technology such as HIP.

Additive manufacturing has not been found to be ready for aircraft flight-critical parts from the current literature in the public domain;

To unlock the potential of deep surface rolling on additive manufacturing for aircraft fracture-critical structures, it is recommended that further research on DSR induced beneficial residual stresses using synchrotron X-ray diffraction and associated surface nanocrystallization using scanning TEM should be conducted.

References

[1] Zhuang, W., Miller, J., Fatemi, A., Liu, Q. and Sharp, K., Fatigue Performance of Additive Manufactured Alloys: Challenges and Opportunities for Aerospace Applications, Keynote to *CAMS 2018 – Advancing Materials and Manufacturing*, Wollongong, NSW, Nov 27-29, 2018.

[2] Li, P., Warner, D.H., Fatemi, A., Phan, N., Critical assessment of the fatigue performance of additively manufactured Ti–6Al–4V and perspective for future research, *International Journal of Fatigue*, Vol. 85, pp. 130–143, 2016.

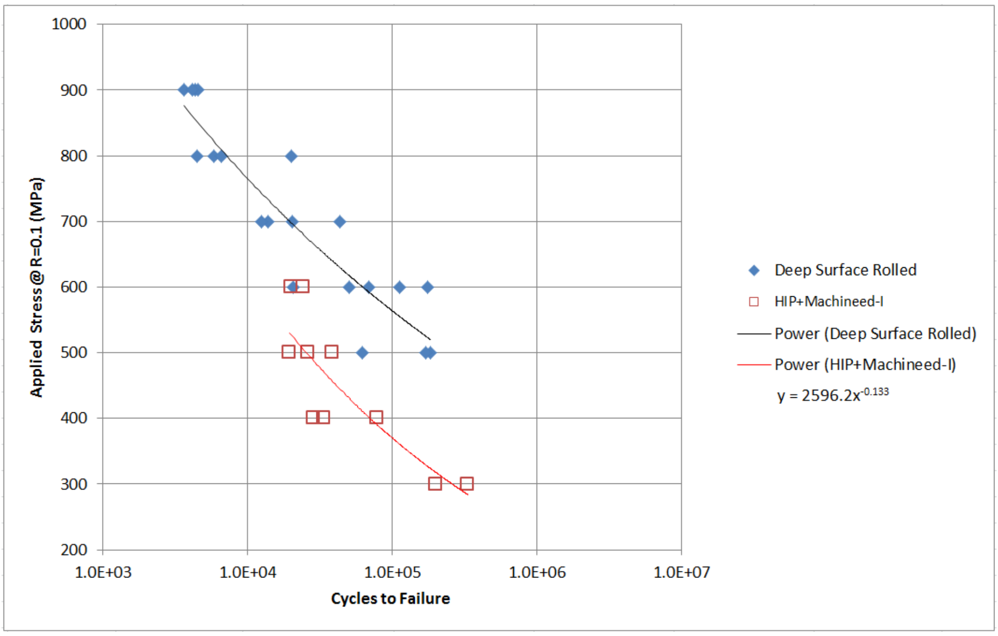

Fig. 3. Fatigue behaviours of additively manufactured Ti-6Al-4V with different post processing technologies