On the preliminary evaluation of formability of Ti6Al4V selective laser melted sheets

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Abstract. Additive manufacturing (AM) processes has been gaining interest for the last few years within a number of sectors including the industrial, the medical or the aerospace. To this regard, the characterization of mechanical properties of AM parts have been recently addressed for determining their elastic behaviour, strength, fatigue properties, among others. In this context, this paper addresses a preliminary investigation on formability of Ti6Al4V selective laser melted sheets under conventional forming. To this regard, conventional forming tests were carried out including tensile tests, double notched tensile tests and Erichsen cupping tests, in order to obtain a variety of strain states resulting in uniaxial tension, plane strain and biaxial strain, respectively. The results obtain provided the process window for deforming plastically this kind of materials, allow assessing the corresponding modes of failure and associated mechanisms and pointed out the importance of post-processing heat treatments for increasing the material ductility.

Keywords: Additive Manufacturing; Selective laser melting; Formability; Sheet metal forming.

1 Introduction

Selective Laser Melting (SLM) has gained particular attention for processing titanium alloys, especially Ti-6Al-4V, due to its high mechanical strength, corrosion resistance, and biocompatibility, making it suitable for aerospace, biomedical, and automotive applications [1].

SLM-printed Ti-6Al-4V sheet exhibits high strength but limited ductility, presenting challenges for forming processes [2]. Understanding the formability of SLM-printed Ti-6Al-4V sheets is therefore critical for expanding their industrial applications.

Forming Limit Diagrams (FLDs) are widely used to evaluate the formability of metallic sheets under different strain conditions. However, the formability of SLM-printed Ti-6Al-4V has been scarcely investigated. Recent studies have shown that AM materials tend to exhibit lower strain-to-fracture values compared to their conventionally processed counterparts, primarily due to higher residual stresses and a lack of strain hardening capacity. However, very few attempts have been done so far for the characterization of the plastic behaviour of AM parts beyond some initial investigations on polymeric sheets obtained using fused deposition modelling [3].

In this study, the formability of Ti-6Al-4V sheets produced by SLM is evaluated within the FLD through uniaxial, double-notched tensile tests and Erichsen tests. The results provide valuable insights of the deformation and failure mechanisms of the material, contributing to the optimization of AM-printed Ti-alloy components.

2 Methodology and experimentation

The material used is Ti-6Al-4V alloy sheet with a thickness of 1.2 mm, manufactured via SLM. The sheets were produced using a Renishaw AM500 S Flex printer, equipped with an Ytterbium Fiber Laser. The main printing parameters are summarized in Table 1.

Table 1. Printing parameters of the Ti-6Al-4V sheet.

Manufacturing parameters	
Material	Ti-6Al-4V
Layer thickness [μm]	60
Power Output [W]	320
Scan Rate [mm/s]	1500
Energy Dens (3D) [J/mm^3]	74,9

The uniaxial mechanical properties of the sheet were determined through three tensile tests performed on an Instron 1196 universal testing machine at a strain rate of 1 mm/min. The specimens, as shown in Fig. 1, were extracted from the SLM-printed sheets and subsequently machined in the critical region to ensure smooth edges and prevent premature fracture. Additionally, the edges were polished using sandpaper up to #1200.

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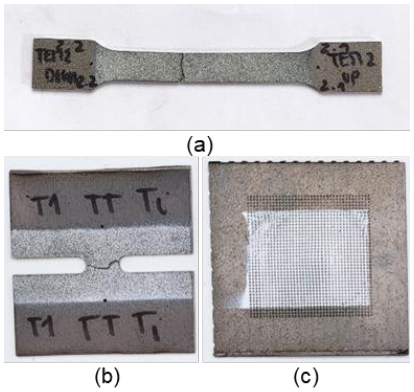

Fig. 1. The specimens after testing: (a) uniaxial, (b) double notch specimen and (c) Erichsen specimens.

The strain evolution during the tests was measured using the Digital Image Correlation (DIC) system Aramis, while forces were recorded through a load cell with a capacity of up to 50 kN. The resulting true stress-strain curve is presented in Fig. 2.

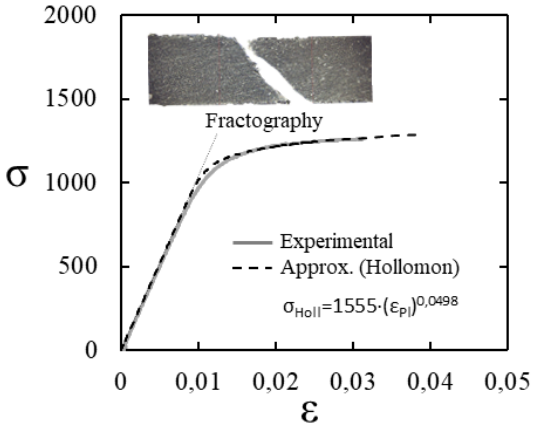

Fig. 2. True stress-strain curve of SLM-printed Ti6Al4V sheet and fractography of the failure zone.

The sheet behaviour under plane strain conditions was assessed via tensile tests using double-notched specimens, as depicted in Fig. 1(b). This specimen geometry allows using the minimum quantity of material, which is particularly advantageous given its high cost. In the uniaxial test, the notch was polished to ensure accurate testing conditions.

To evaluate fracture under biaxial loading Erichsen Cupping Tests were carried out, performed on square specimens of 60x60 mm, as shown in Fig. 1(c). Due to the test setup, the strain evolution could not be recorded. Instead, fracture strains were determined using Circle Grid Analysis (CGA), complemented by thickness measurements in the fractured region.

3 Results

The primary aim of this work was to obtain the FLD of the material, which exhibited very low ductility, as depicted in Fig. 2, where fracture strain is approximately 0.03, significantly lower than that of the same material obtained via rolling. Furthermore, as far as no necking was observed in any of the conducted tests, the FLD was represented using the Fracture Forming Limit (FFL) based on fracture points obtained from the various tests. The fracture strains were determined through thickness measurements at fracture, assuming the strain state for each test. As shown in Fig. 3, the FFL curve consists of two distinct regions: one with a slope close to "-1" in the second quadrant of the diagram, and another with a gentler slope in the first quadrant, differing from the typical behaviour observed in more ductile metals.

Although the results indicate significantly reduced ductility, a preliminary analysis has shown that a vacuum heat treatment at a constant temperature of 920°C for 2 hours increases the major strain in uniaxial test from 0.03 up to 0.15.

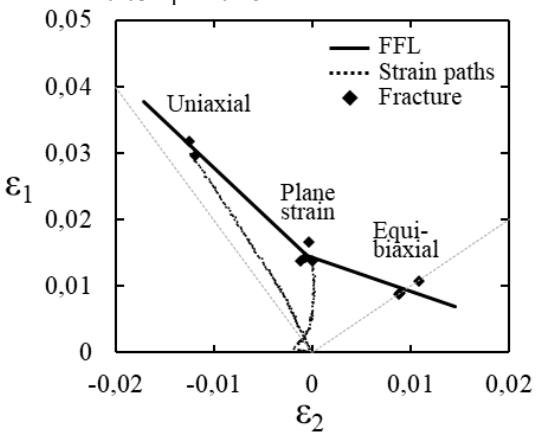

Fig. 3. FLD of Ti6Al4V sheet printed by SLM.

4 Conclusions

Formability of SLM-printed Ti-6Al-4V sheets has been investigated for the first time. The material exhibits an FFL with a -1 slope in the second quadrant, consistent with conventional metallic behaviour, whereas in the first quadrant, the curve follows a descending trend. The results reveal low ductility, with fracture strains significantly lower than those expected for the same alloy in rolled form. Furthermore, a preliminary analysis has shown that the strain level can be significantly increased by applying a heat treatment, which opens the possibility of forming the material using non-conventional processes such as incremental forming.

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References

1. T. DebRoy, H.L. Wei, J.S. Zuback, T. Mukherjee, J.W. Elmer, J.O. Milewski, A.M. Beese, A. Wilso n-Heid, A. De, W. Zhang, Progr. In Mat. Sci. **92** (2018).
2. B. Vrancken, L. Thijs, L., J. P. Kruth, J. Van Humbeeck, Act. Mat. **68,** 15 (2014).
3. A. Rosa-Sainz, I. Ferrer, M.L. García-Romeu, G. Centeno, Pol. Testing **134** (2024).