FAST-*forge*: From rutile sand to novel titanium alloy aerospace component in 3 steps

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Highlights

- Alloy derived directly from synthetic rutile gives properties comparable to Ti-6Al-4V.
- A demonstrator landing gear component has been produced from powder in just three steps.
- Potentially disruptive technology allowing step-change in the economics of titanium.

1. Introduction

The excellent combination of properties exhibited by titanium alloys make them well suited to a variety of applications, especially where specific strength and/or corrosion resistance are important. The high cost of titanium alloy components continues to preclude their use in industries where the improved performance cannot justify the price penalty (e.g. automotive applications). Therefore, lowering the cost of titanium alloy components has received significant attention over the preceding decades, both in terms of alternative ore extraction techniques and more cost-effective downstream processing [1,2].

Previous work has shown that field assisted sintering technology (FAST) can produce fully dense and microstructurally homogeneous titanium alloy specimens from a variety of powder feedstock sizes, chemistries, and morphologies even when scaled up to 5.6 kg level [3]. However, the range of shapes and microstructures producible directly via FAST is currently more limited than conventional processing techniques. Performing an additional hot forging operation on a shaped FAST preform billet allows the production of near net-shape components with wrought properties. This two-step process has been demonstrated on the laboratory-scale and termed FAST-*forge* [4]. This paper presents results from a collaborative research project that is further developing the FAST-*forge* processing route to produce a cost-effective near net-shape aerospace component from rutile ore in just three steps, see Figure 1. In the first step a novel titanium alloy powder is created using electrochemical reduction of titanium oxide in the Metalysis FFC process. Steps two and three (FAST-*forge*) consolidates the titanium alloy powder into fully dense shaped preform billets, which are finished to near net-shape components via hot forging.

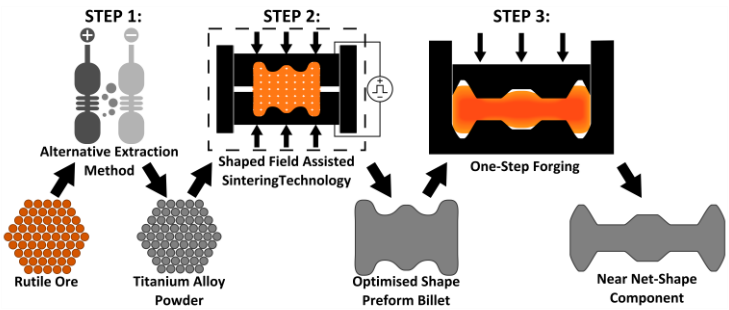

Figure 1. Schematic diagram outlining the three steps utilised to convert rutile ore into a novel titanium alloy aerospace component; including the Metalysis FFC process and the two-step hybrid FAST-*forge* process.

2. Methods

The powder feedstocks used were synthetic rutile derived alloy produced via the Metalysis FFC process and commercially available Ti-6Al-4V hydride dehydride (HDH); the size fractions were 212-500 µm and 45-150 µm respectively. Initial investigations to collect data on mechanical properties of material produced via FAST-*forge* used an FCT Systeme GmbH Type H HP D 250 FAST facility based at Kennametal Manufacturing (UK) Ltd was used to produce discs of 100 mm diameter and 20 mm thickness from each powder. A standard graphite mould assembly was utilized. A dwell temperature of 1200°C, dwell pressure of

40 MPa, and dwell time of 30 mins were used, with 100°C/min heating rate and pulsed (15/5 ms on/off) DC current applied. One disc of each material was used to produce 10 mm diameter by 15 mm tall cylinders for compression testing at a range of temperatures and strain rates to assess forgeability in the as-FAST condition.

3. Results and discussion

The flow curves showing true stress versus true strain for both synthetic rutile derived alloy and Ti-6Al-4V HDH powder consolidated via FAST are shown in Figure 2a. The two alloys have different β transus temperatures, so the curves are plotted normalized with regard to their respective β transus. Synthetic rutile displays similar flow properties to Ti-6Al-4V, with classic flow softening observed after an initial period of intense work hardening. At lower strain rates the synthetic rutile shows a reduced flow strength compared to Ti-6Al-4V, but the values converge at higher strain rates. The synthetic rutile derived alloy also exhibits a similar microstructural evolution to Ti-6Al-4V, see Figure 2b. At lower strain there is little modification of the α laths in the transformed β structure that is seen post FAST. At higher strains, the α laths have rotated perpendicular to the compression direction and begun the globularisation process, which is classical behavior of α/β titanium alloys under thermomechanical processing [5].

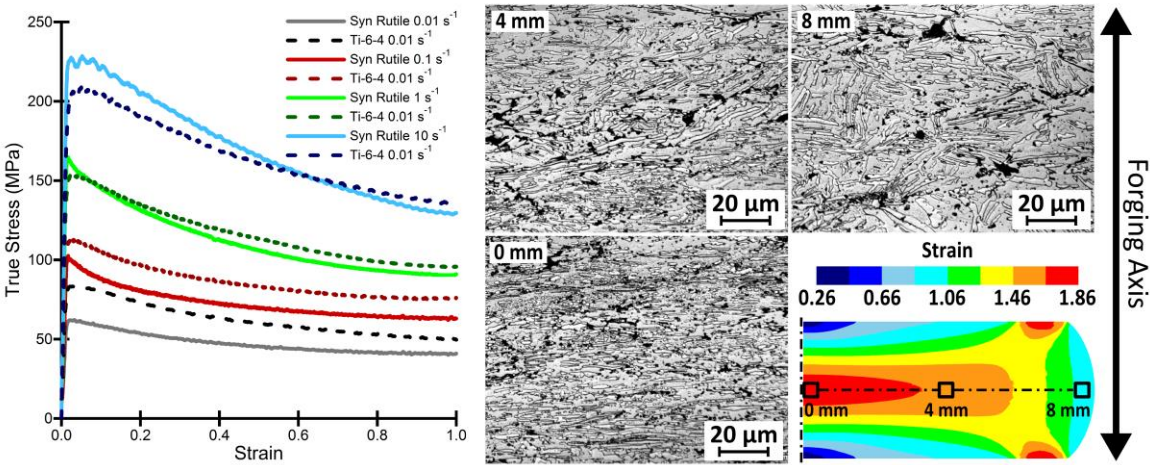

Figure 2. (a) Graph showing the flow curves (normalised to 75°C below β transus temperature) of synthetic rutile derived alloy powder and Ti-6Al-4V HDH powder consolidated via FAST tested at the indicated stain rates. (b) Micrographs showing the evolution of synthetic rutile derived alloy from low to high strain after hot compression.

4. Conclusions

Initial results indicate the forgeability and microstructural evolution of an alloy powder derived directly from synthetic rutile and fully consolidated via FAST compares favourably with Ti-6Al-4V. Optimisation of FAST and forging conditions will allow further property improvements. Further work needs to be undertaken to (1) assess the mechanical properties post forging (2) asses the ability of FAST to produce increasingly complex preforms whilst maintaining control of density and microstructure, and (3) assess the size limitations of FAST. However, combining lower-cost alternative feedstocks with the FAST-*forge* process offers potential to produce a step-change in the economics of titanium; offering cost-effective titanium alloy components for a range of industries and applications.

References

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Keywords
Spark plasma sintering (SPS), Metalysis FFC, hot forging, low-cost titanium