Consolidation of Ti-5553 using the FAST-*forge* process.

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Highlights

- Ti-5553 has been consolidated by FAST at 850 and 1000°C, with a 30 minute dwell time.
- Compression testing was performed at 785, 810 and 835°C, and 0.01, 0.1, 1, and 5 s^{-1}.
- The flow behaviour of both FAST conditions was similar to conventionally produced Ti-5553.

1. Introduction

The high strength titanium alloy Ti-5553 has been fully consolidated and thermomechanically processed from powder using the FAST-forge process, in only three steps. Titanium alloy components are conventionally produced using a time-consuming process, which involves carbo-chlorination extraction of TiO_2, triple vacuum arc re-melting, and multiple thermomechanical and heat treatment steps, before machining. The proposed FAST-forge processing route for titanium alloy components cuts out or significantly reduces these stages, and uses field-assisted sintering technology (FAST) to consolidate powder. The effectiveness of the process for a conventionally used high-strength beta titanium alloy, Ti-5553, has been investigated.

2. Methods

Ti-5553 powder was produced by gas atomizing small pieces of a landing gear forging, provided by Safran Landing Systems. Gas atomization was performed by TLS Technik Spezialpulver.

FAST was performed using an FCT Systeme GmbH Spark Plasma Sintering furnace type H-HP D 250 at Kennametal Manufacturing UK Ltd. 100 mm specimens were produced at dwell temperatures 850 and 1000°C, below and above the beta transus respectively, and a dwell time of 30 minutes. A pressure of 50 MPa was used and sintering was performed in a vacuum.

FAST specimens were machined to produce compression cylinders (10 mm diameter and 15 mm height) for axisymmetric compression testing (to simulate forging). Isothermal tests were performed at 785, 810, and 835°C, and at strain rates 0.01, 0.1, 1, and 5 s^{-1} using a Servotest ThermoMechanical Compression (TMC) machine at The University of Sheffield. Compression specimens were heated at 4°C per second to the compression temperature, and held at temperature for 20 s before being transferred into the furnace for compression testing. The specimens were quenched to preserve the as-compressed microstructure, which was subsequently analyzed by scanning electron microscopy (SEM).

3. Results and discussion

As-FAST microstructure at 850°C is a mixture of blocky platelet alpha, formed because of FAST processing high in the alpha + beta phase field, and retained beta phase [1]. However, above the beta transus temperature, at 1000°C, the primary alpha has fully transformed to the beta phase, due to FAST processing above the beta transus temperature. At this temperature the lack of primary alpha grains enabled significant beta grain growth to approximately five times the initial powder grain size. As the cooling rate was relatively slow (~14°C/min), secondary alpha has formed along the grain boundaries and very fine secondary alpha laths have precipitated within the grain upon cooling [2]. The grain boundary alpha is approximately 0.1 µm thick, and the much finer secondary alpha has grown from the grain boundary towards the center of the beta grain.

Flow stress data was generated from the compression testing for both FAST conditions. Both FAST conditions produce typical flow stress curve trends: lower forging temperatures and higher strain rates lead to an increase in flow stress [3].

In general, the amount of flow softening increases as the strain rate increases and the temperature decreases, which is as observed by Weiss and Semiatin [4] for other beta titanium alloys and as found previously for Ti-5553 by Jones and Jackson [5]. The flow stress has been corrected for adiabatic heating, so any flow softening is purely as a result of microstructural changes during deformation [6].

The flow stress is generally higher for material FAST-produced at 1000 than 850°C, and there is generally more flow softening at 1000 than 850°C. Following flow softening, the flow stress reaches a constant stress value which remains constant regardless of increased strain, and is known as the steady state stress.

There is substantial flow softening at 785 and 810°C for both FAST conditions before the steady state stress is reached, whereas there is very little flow softening or work hardening at 835°C, with the steady state stress reached at low strain. However, at ~0.6 strain the steady state flow stress values are very similar for all forging temperatures. The strain rate, therefore, has more of an effect on the steady state stress than the forging temperature.

Overall, the flow stress values for both FAST conditions were comparable with that of conventionally processed Ti-5553, and the flow curves exhibited similar characteristics to those for conventionally processed Ti-5553 [7].

This is highly significant, as it indicates that material processed in two steps by FAST-*forge* behaves in a similar manner to Ti-5553 which has been through the Kroll extraction method, VAR, and multiple preceding thermomechanical processes.

4. Conclusions

There is more flow softening in the flow stress curves of material FAST-produced at 1000 than 850°C due to break up of acicular alpha present at 1000°C. Aside from this, there is little difference in flow behavior between different starting microstructures.
Overall, FAST-*forge* is capable of producing forged Ti-5553 microstructures, and flow behavior similar to that of conventional processing, while significantly reducing the number of processing steps.

References

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Keywords
Field-assisted sintering technology; Spark plasma sintering; Ti-5553; forging.