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Novel high strength titanium-titanium composites produced using field-assisted sintering technology (FAST)

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ABSTRACT

To increase the strength of titanium alloys beyond that achievable with α-β microstructures, alternative reinforcing methods are necessary. Here, field-assisted sintering technology (FAST) has been used to produce a novel Ti-5Al-5Mo-5V-3Cr (Ti-5553) metal-matrix-composite (MMC) reinforced with 0-25 wt.% of a ~2 GPa yield strength TiFeMo alloy strengthened by ordered body-centred cubic intermetallic and ω phases. The interdiffusion region between Ti-5553 and TiFeMo particles was studied by modelling, electron microscopy, and nanoindentation to examine the effect of graded composition on mechanical properties and formation of α, intermetallic, and ω phases, which resulted in a >200 MPa strengthening benefit over unreinforced Ti-5553.

High strength, heavily alloyed titanium alloys such as Ti-5Al-5Mo-5V-3Cr (Ti-5553) can possess yield strengths of ~1300 MPa, which given the relatively low density of Ti, results in favourable combinations of specific strength (~280 kNm kg^{-1}) and specific toughness (~9 kNm$^{3/2}$ kg^{-1}) [1] compared to even the best steels, such as A300 M (267 kNm kg^{-1} and 9 kNm$^{3/2}$ kg^{-1}) [2,3]. This leads to their use for high integrity, weight critical structures such as the landing gear of twin-aisle commercial aircraft, which can account for as much as 10 % of airframe weight; this is a significant consideration in terms of fuel efficiency and therefore the emissions associated with air travel.

These alloys achieve these strengths and toughnesses through the precipitation of a high volume fraction of 10–25 nm fine scale *hcp* α phase within the *bcc* β matrix [4,5], but the improvement in properties achieved in Ti alloys has begun to plateau in recent years, following much progress that was achieved in the 1950s to 1970s [6]. Long-fibre ceramic reinforcement, e.g. with SiC has long been proposed, chiefly using relatively conventional alloys such as Ti-6Al-4 V as the matrix [7], and more recently the use of high strength Ti-5553 as the matrix has achieved specific strengths as high as 2050 MPa (in tension) and 3500 MPa (in compression) [8]. However,

Table 1
Chemical analysis of Ti-5Al-5Mo-5V-3Cr gas atomised powder, and TiFeMo alloy powder (wt.%).

	Al	Cr	Fe	Mo	Ni	V	Ti
Ti-5553	5.1	2.7	0.4	5.1	0.1	5.2	80.8
TiFeMo	0	0	15.8	36.6	0	0	47.6

Table 2
Particle size distribution (PSD) of spherical Ti-5553 powder, and angular TiFeMo powder (for both the Ti-5553–10 wt.% TiFeMo and Ti-5553–25 wt.% TiFeMo composites) (μm).

	Dx10	Dx50	Dx90
Ti-5553	22	63	115
10 wt.% TiFeMo	16	40	158
25 wt.% TiFeMo	14	35	63

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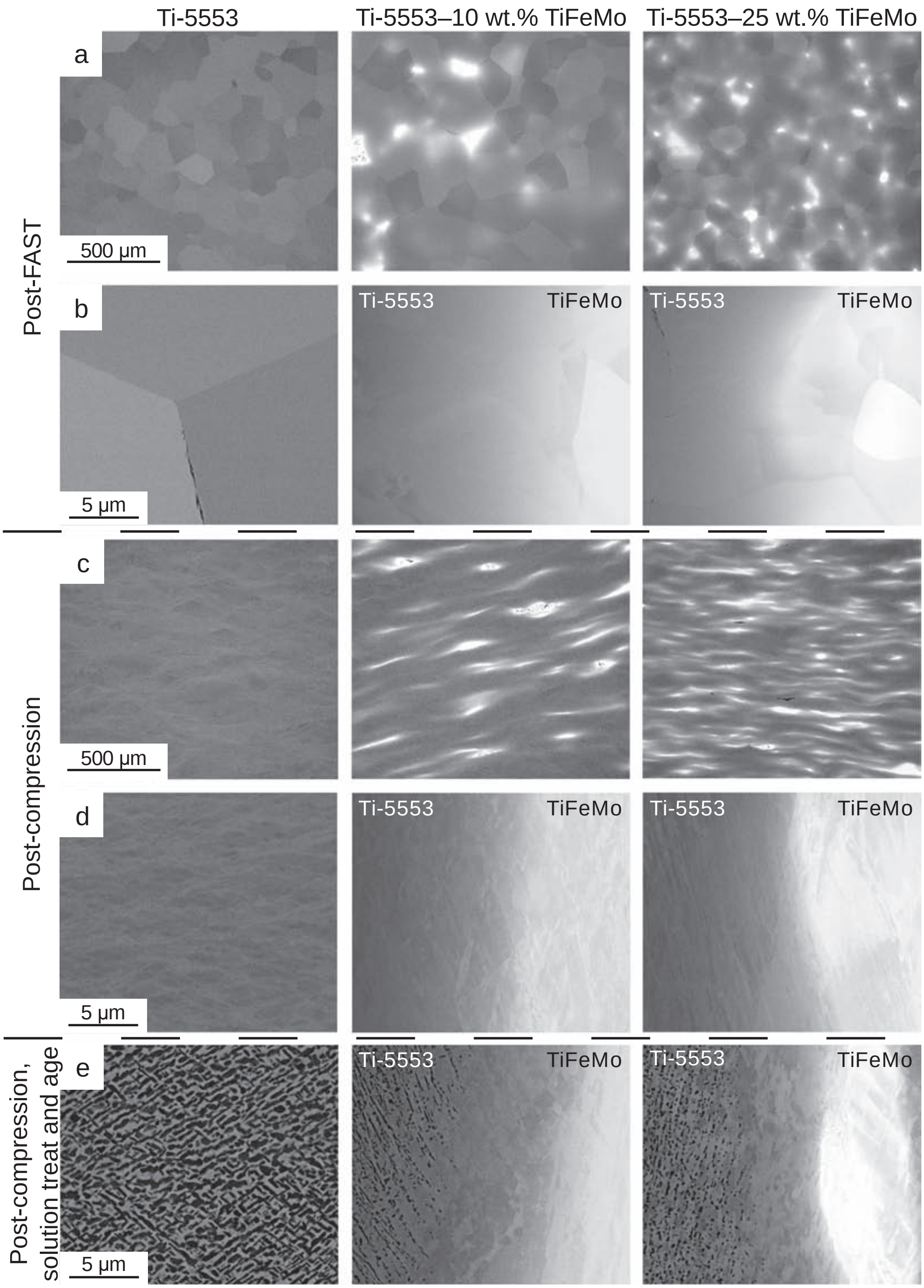

Fig. 1. Low magnification micrographs of Ti-5553 (30 min dwell) and Ti-5553–TiFeMo composites: (a) post-FAST and (c) post-compression. High magnification micrographs of Ti-5553 (30 min dwell) and Ti-5553–TiFeMo composites: (b) post-FAST; (d) post-compression; and (e) post-compression, solution treat and age.

such microstructures require the laying-up of a composite structure using ceramic fibres, which is a costly manufacturing route.

Recently, progress has been made in the development of so-called '*bcc* superalloys', which in the titanium alloy system can be realised using ~50 nm ordered β' B2 intermetallics such as TiFe in a *bcc* β A2 Ti, Mo matrix [9]. Such TiFeMo alloys can possess strengths in the order of 2 GPa, but are brittle.

Powder manufacturing of Ti components has long possessed the possibility to realise substantial cost savings through a reduction in the processing steps and machining requirements of ingot