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Selective Laser Melting of a Biomedical Ti-24Nb-4Zr-8Sn Alloy

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Introduction

Table 1. Comparison of the mechanical properties of bones and titanium implant materials.

	Stiffness (GPa)	Tensile Strength (MPa)	% Elongation at break
Cortical Bone	**17-24**	90-130	1-3
CP-Titanium and α+β type Titanium Alloys			
CP-Ti (Grade 4) or ASTM F67 30 % Cold Worked	**110**	760	15%
Ti-6Al-4V or ASTM F136 annealed	**114**	900	14%
Low-modulus β Ti alloys			
Ti-29Nb-13Ta-4.6Zr (TNTZ)	**80**	910	13
Ti-36Nb-2Ta-3Zr-0.3O (Gum Metal)	**55-75**	1000-1200	10-15
Ti-24Nb-4Zr-8Sn (Ti2448)	**42-55**	800-1200	13-15

◀ Current titanium implants, i.e. CP-Ti (α type) and α+β type Ti alloys, have a stiffness ~10 times that of bone, which causes stress shielding in the bone and leads to bone resorption.

◀ The new generation β type Ti alloys have much lower stiffness.

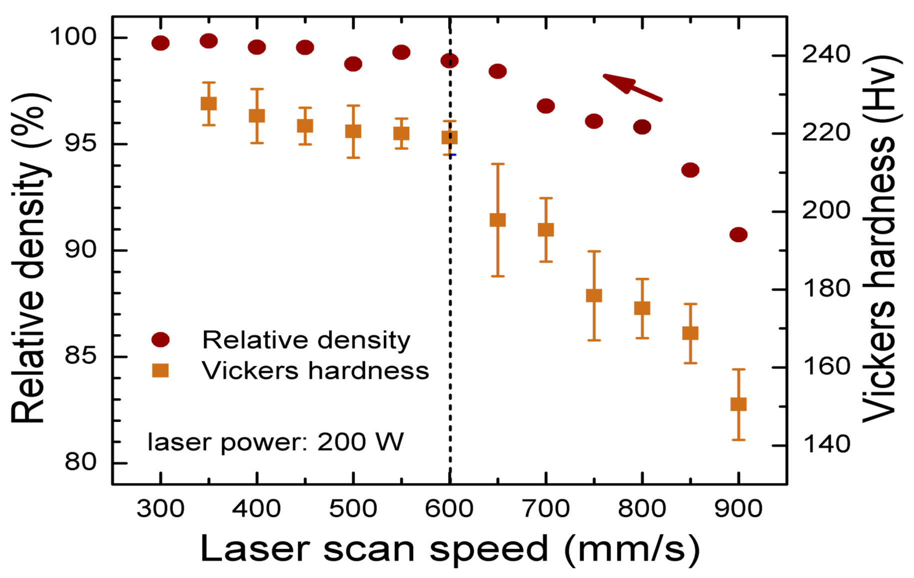
◀ Introducing porosity can further reduce stiffness, but optimisation of the porous structure is needed.

◀ Complex porous structure designs can only be realised by Selective Laser Melting (SLM).

Aims

- Design of optimised scaffold structures for titanium implants.
- Manufacture of biomedical β type Ti2448 alloys by selective laser melting.
- Study of the mechanical behaviour of SLM-produced β type Ti2448 alloys.

Results



◀ **Figure 1. Density and Vickers hardness of the SLM samples.**

- An overall trend is evident of the increasing density with decreasing scan speed for speeds up to ~600 mm/s, after which the density tends to plateau at >99%.
- There is a strong correlation between Vickers hardness and density.

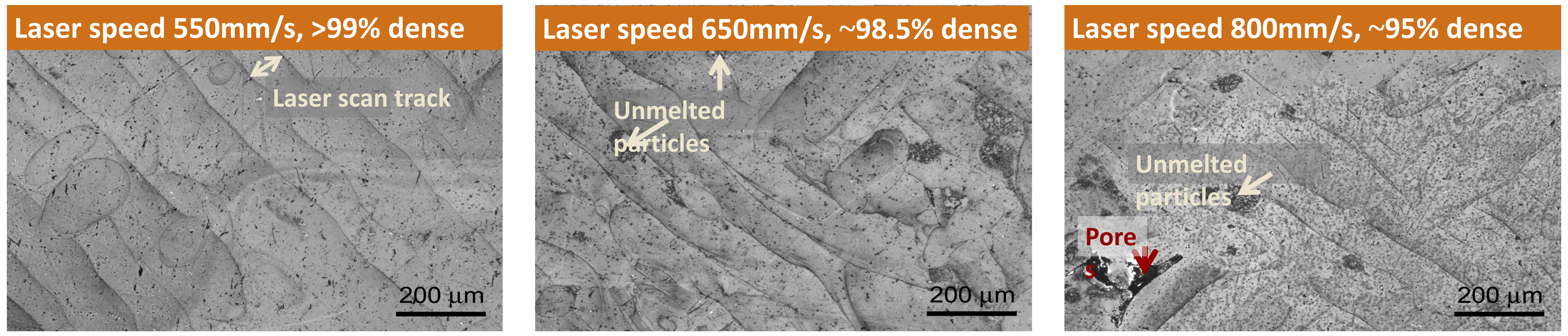


Figure 2. Optical microstructures of the parts manufactured at different laser scan speeds.

▲ In the near fully dense sample, the powders are completely melted.

▲ At 650 mm/s, unmelted particles are evident due to insufficient laser energy.

▲ In the lowest dense sample, the number of unmelted particles has increased and porosity is apparent.

Table 2. Comparison of the tensile properties for the Ti2448 alloys manufactured by Selective Laser Melting and by conventional processing methods. Laser power: 200 W; laser scan speed: 550 mm/s, Stiffness E, yield strength $\sigma_{0.2}$, ultimate tensile strength σ_{UTS}, and elongation δ.

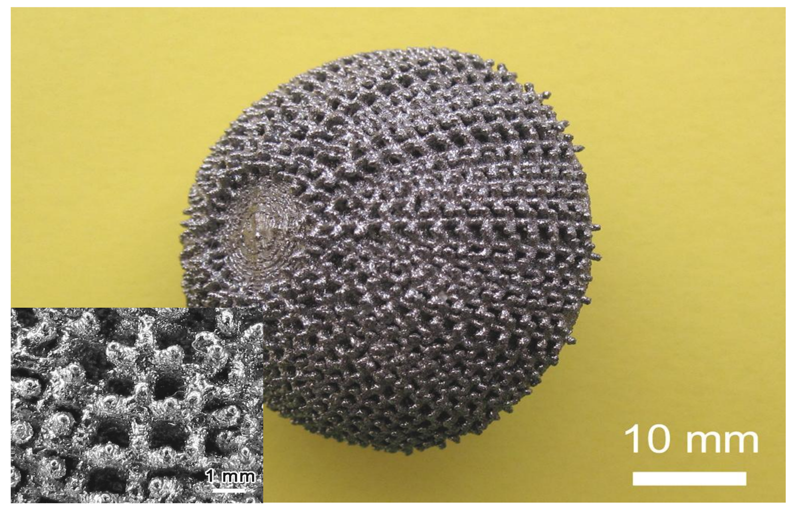
Processing methods	E (GPa)	$\sigma_{0.2}$ (MPa)	σ_{UTS} (MPa)	δ (%)
Selective Laser Melting	**53 ± 1**	563 ± 38	665 ± 18	13.8 ± 4.1
Hot rolling^	**46**	700	830	15.0
Hot forging*	**55**	570	755	13.0

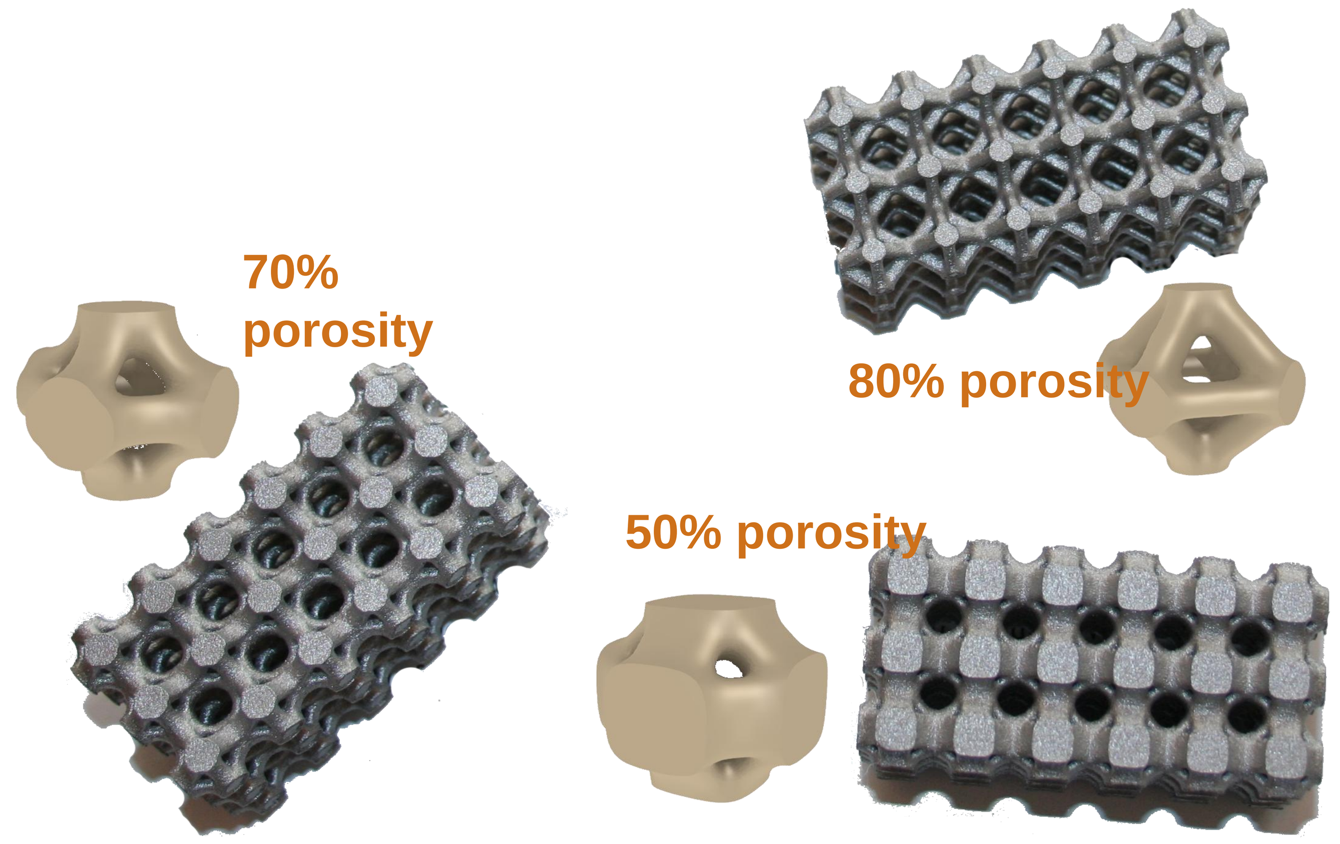
^ data from S.Q. Zhang, S.J. Li, M.T. Jia, Y.L. Hao, R. Yang, Scripta Mater. 60 (2009) 733.
* data from S.J. Li, T.C. Cui, Y.L. Hao, R. Yang, Acta Biomater. 4 (2008) 305.

The strength and stiffness are independent of the scan speed, however, the ductility is closely linked to the density and therefore to the scan speed.

◀ Compared with the hot-rolled or hot-forged material, the SLM Ti2448 has a similar stiffness and ductility, but lower strength.

▼ An acetabular (hip) cup complete with complex outer scaffold has been manufactured. The complex, fine-scaled scaffold structure on its outer surface is aimed at improving osseointegration and is an example of the geometric complexity that is possible with SLM.
The acetabular cup design courtesy of Rob Day, Royal Perth Hospital.





▶ Design and manufacture of the scaffolds with different porosity levels. The scaffolds were designed by topological optimisation.

▶ The stiffness of the Ti2448 scaffolds can be tailored to match that of bone by altering the level of porosity.

Table 3. Comparison of the stiffness for the SLM-produced Ti2448 alloys and bone as well as Ti-6Al-4V implant.

Materials		Stiffness (GPa)
Cortical Bone		17-24
Ti-6Al-4V or ASTM F136 annealed		114
Ti-24Nb-4Zr-8Sn alloy manufactured by Selective Laser Melting	100% solid	53
	30% porosity	30
	50% porosity	15
	70% porosity	7
	80% porosity	4

Summary

- We have shown, for the first time, that components from a novel biomedical beta Ti-24Nb-4Zr-8Sn alloy can be manufactured using Selective Laser Melting.
- The density and microhardness generally increase with decreasing laser scan speed, which corresponds to a higher laser energy density. Near full density parts (>99%) have been obtained at a laser power of 200 W and a scan speed range of 300 – 600 mm/s.
- Compared with material prepared by conventional processing routes, SLM processing produces samples with similar mechanical properties.
- A demonstration acetabular cup complete with complex outer scaffold has been manufactured.
- Scaffold structures have been designed using topology optimisation and produced using SLM; their stiffness can be tailored to match that of bone by altering the level of porosity.

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More information can be obtained from : L.C. Zhang *et al.*, Scripta Mater. 65 (2011) 21-24, V.J. Challis *et al* and Adv. Eng. Mater. 12 (2010) 1106-1110.