Damage and deformation analysis of Ti-6Al-4V Diamond lattice structures

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Abstract. Additive layer manufacturing has been extensively used in recent years to develop structures with a better strength to weight ratios. Deformation and damage mechanisms of diamond lattices made from a Ti-alloy has been investigated. Axial compression tests have been used combined with Digital Image Correlation (DIC) to measure local strain maps and identify local deformation and damage mechanisms. Damage starts by crack initiation and propagation from nodal positions with a deformation localized in shear mode at various locations within the structures. Local strain maps revealed that despite the global compressive stress, some of the struts are under tensile deformation resulting brittle failure at nodal positions.

Introduction

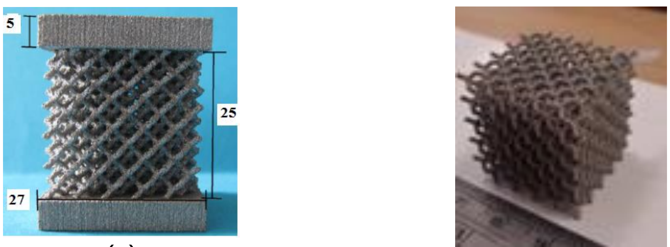
Metal lattices combine a novel set of material properties; high strength-to-weight ratios, high heat resistance, good sound and energy absorption, etc. As such they provide a novel set of properties which are of great interest to many different industrial sectors. Titanium lattices are of particular interest, due to their corrosion resistance and ability to form dual phase alloys, allowing the tailoring of microstructures. However for the lattices to be utilised their properties need to be fully understood, and there remain many unanswered questions about their mechanical behaviour which need to be addressed. Additive layer manufacturing opens up a whole new range of manufacturing possibilities with significant material savings during manufacturing, due to subsequent machining steps being removed, resulting in net savings. Additionally the variation in design incurs no additional manufacturing costs, so opening up many different possible applications for which it can be used. Due to the unique nature of additive layer manufacturing optimisation of lattices is a viable possibility, as designs can be created for each unique application.

Cellular materials show characteristic mechanical properties in tension and compression. The compressive strength is most likely affected by the presence of manufacturing-induced defects within the structure and as more struts are engaged with the applied loads, the structures are more ductile when subject to compressive forces [1]. The Diamond cell structures undergo a bending moment, axial and shear stresses when they are subjected to an axial load. This will lead to a complex deformation mechanism as well as stress/strain distribution for a structure developed based on the diamond unit cells. To restrict lateral deformation of free struts, sandwich structures could be used where barrelling effect can be observed leading to a larger displacement to failure [2].

In the present research, deformation and damage mechanisms of diamond lattices subjected to uniform compression have been investigated. Digital Image Correlation (DIC) has been used to determine full field strain distribution across the whole samples and within individual struts.

Experiments

Diamond lattice samples with 6x6x6 unit cells were designed by Netfabb Professional software to produce a sample size of 25x25x25 mm^3. Two types of samples were then manufactured by Electron Beam Melting (EBM) technique using the Arcam EBM machine. In the first type two solid sections were also designed to constrain top and bottom of the lattice structures to ensure uniform distribution of compressive force (Fig. 1a) while the second type was made without the solid plates (Fig. 1b). A 50kN universal test frame was used to apply compression with a quasi-static displacement rate of 0.5mm/min. Spray paints were used to apply random speckle pattern prior to the testing and strain distributions were quantified by Davis strain master from LaVision.



(a) (b)

Fig. 1: Designed compression samples with the diamond lattice structure and solid plates (dimensions are in mm)

Results

Several stages of strain localisation in sample type 1 are shown in Fig. 2 where the structure is subject to a uniform deformation until the bottom struts gradually fail (Fig. 2a) as a result of local crack initiation and development at nodal locations (Fig. 3). The deformation is localized within band of about 45° with respect to the loading direction (Fig. 2b) until the unit cells located inside the localised band cannot tolerate further deformation and the sample fails completely (Fig. 2b). The presence of manufacturing defects may play a key role at the initial stages of localisation. The compressive forces are distributed more uniformly across the struts by adding the solid plates and deformation localisation is shifted towards the centre of structure combined with a barrelling effect as the top and bottom sections are fully restrained (Fig. 2c and d). Fig. 3b shows that failure mechanism in sample type 2 is similar to the one without the solid plates except the fact that nodal failure occurs away from the loading plates.

The presence of the solid plates proved to improve the total deformability of the structure and larger total deformation could be applied to this type of lattice structure before the onset of local damage initiation.

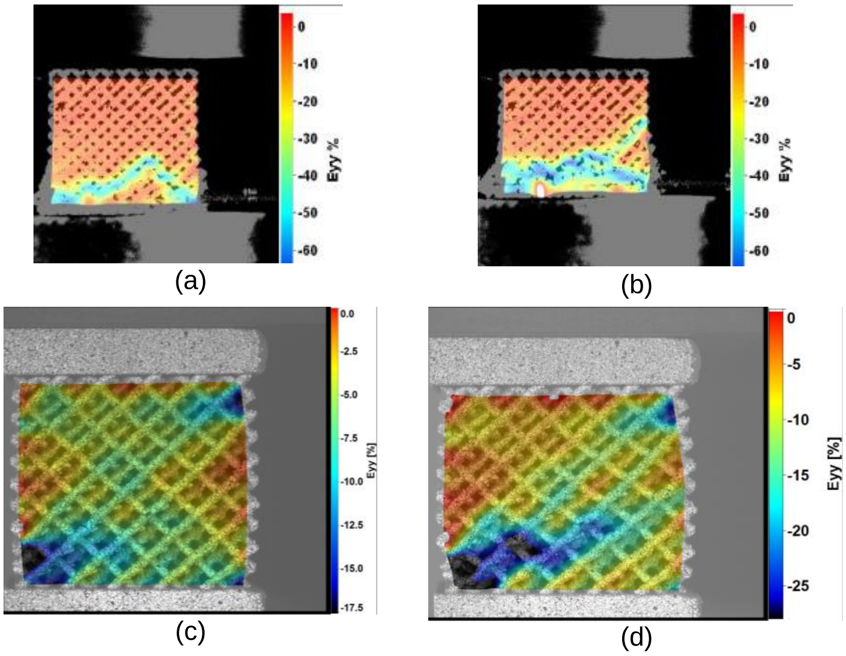


Fig. 2: (a, b)Development of strain localisation within the sample type 1 and (c,d) sample type 2 subjected to compression showing deformation localisation in bands at about 45° with respect to the loading direction (vertical in the figures)

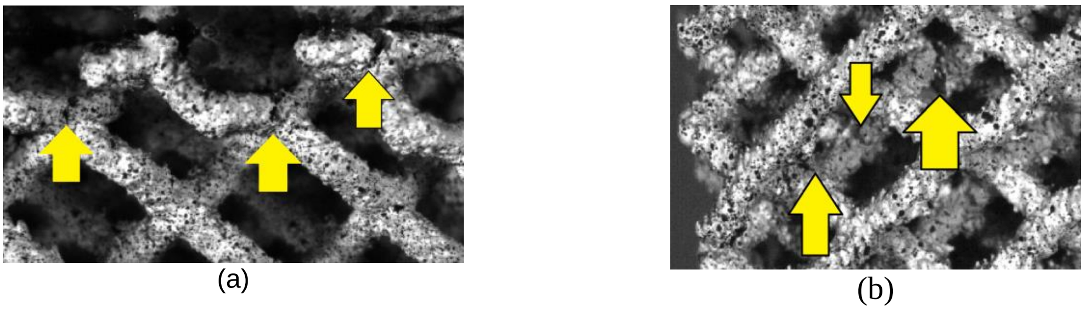


Fig.3: Damage initiation at nodal locations in samples (a) without and (b) with solid plates attached to lattices

Conclusion

The observed failure mechanisms indicate that tensile stress in nodes and struts plays a critical role in damage initiation therefore lattices should be designed in such a way to minimise this type of stress in the struts and consequently increase the failure strain.

References

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