MANUFACTURING METROLOGY TEAM

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Low thermal expansion machine frame designs using lattice structures

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Introduction

- In a measurement system, the metrology frame is subjected to heated load from sources. These cause temperature changes which lead to thermal expansion in the measurement system
- Additive Manufacturing technologies allow us to freely design to higher degrees of geometry complexity, including the internal geometry of structures
- The work presents a study of a design concept for a lattice structure with a tailorable coefficient of thermal expansion (CTE)

Methodology

Design → **Analyse/ FEM** → **Manufacture** → **Experiment**

- Design: SolidWorks version 2018 is used for computer-aided design
- Analyse/ FEM: Abaqus version 2018 is used for finite element method (FEM)
- Manufacture: Powder bed fusion technique is used to produce specimens
- Experiment: A plane mirror interferometer is used to measure the expansion

Designs and analyse results

- The designed unit cell is an assembly of two parts: a lattice (outer part) and a cylinder (inner part) which fits inside the lattice
- The two parts are made of different homogenous materials with different positive CTEs
- Nylon 12 is chosen as base material (lattice) with CTE of 109×10^{-6} K^{-1}
- Nine different designs were investigated and their thermal and structural behaviour analysed using finite element method. The 8th and 9th designs were assigned ultra-high-molecular-weight polyethylene (UHMWPE) with CTE of 200×10^{-6} K^{-1} as the cylinder

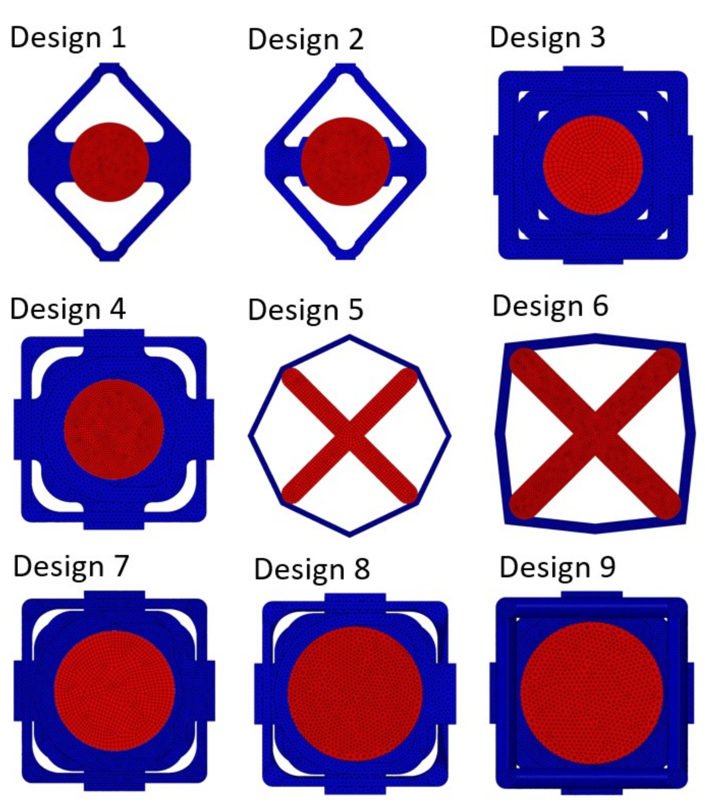
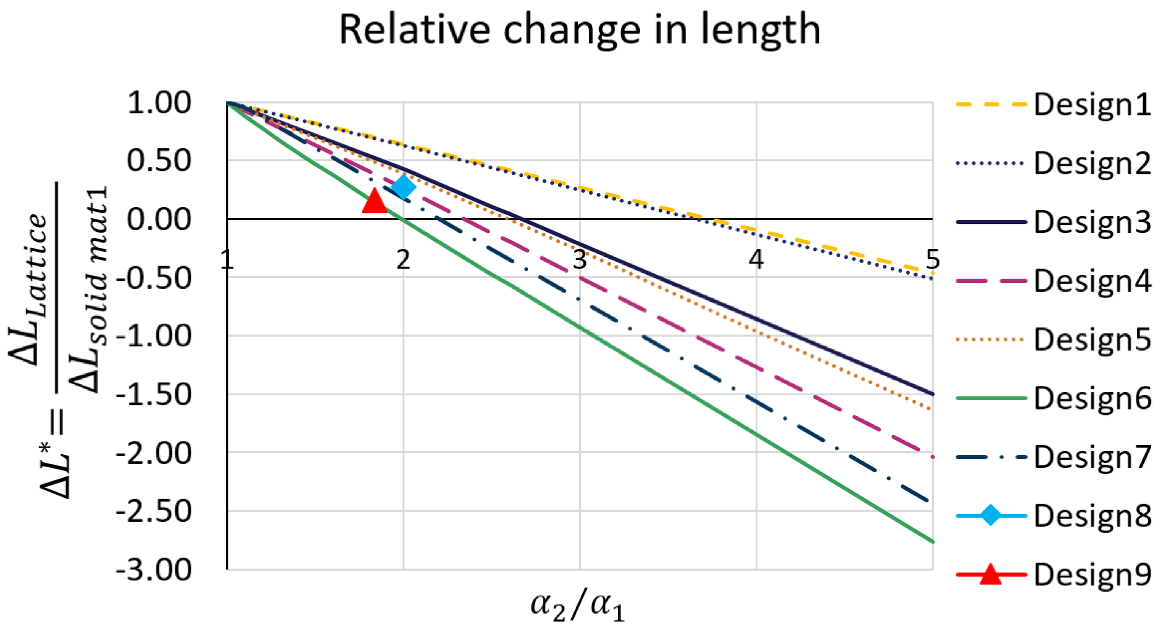


Fig.1 Top view of Design 1 to 9



Notation	Description
ΔL^*	Relative change in length of designed lattice/ solid volume of outer part material
$\Delta L_{Lattice}$	Change in length of designed lattice
$\Delta L_{Solid\ mat1}$	Change in length of solid volume outer material
α_1	The coefficient thermal expansion of outer part material
α_2	The coefficient thermal expansion of inner part material

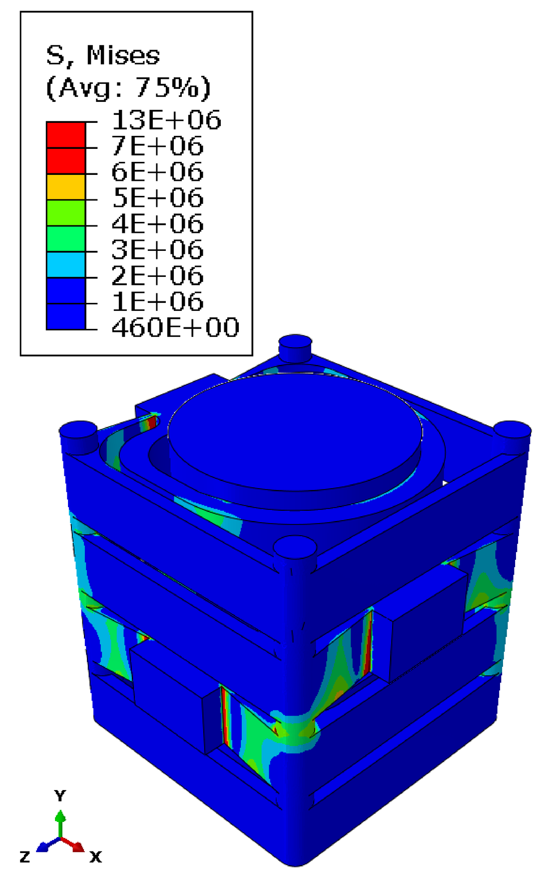


Fig.2 Design 8: Contour plot of Von Mises' stress

Manufacture

- Design 8 was selected for manufacture in various sizes from $(19\ mm)^3$ up to $(47\ mm)^3$ using EOS Formiga P100; laser powder bed fusion machine
- Nikon MCT225; X-ray computed tomography was used to measure the dimensions of the built specimens

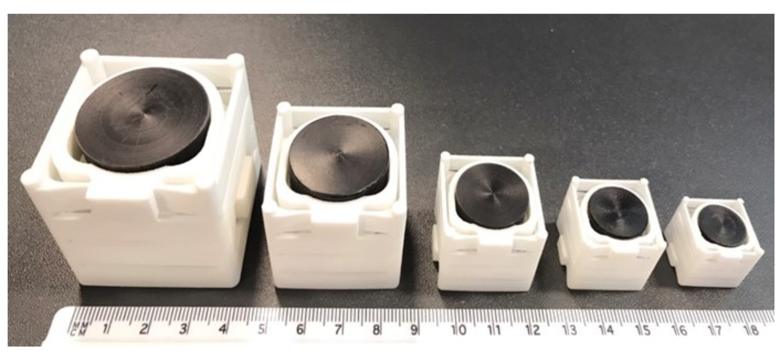


Fig.4 Assembled Manufactured Design 8 in various sizes

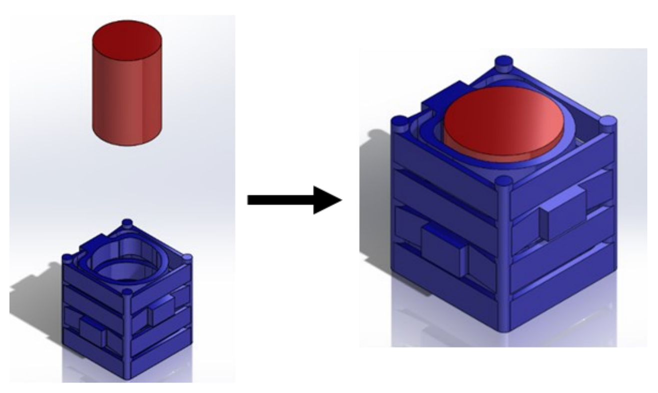


Fig.5 An example of how the inner part (red) is press-fit to the outer part (blue)

Experimental set-up

- An experimental rig was designed to measure the thermal expansion of the model for a range of temperatures

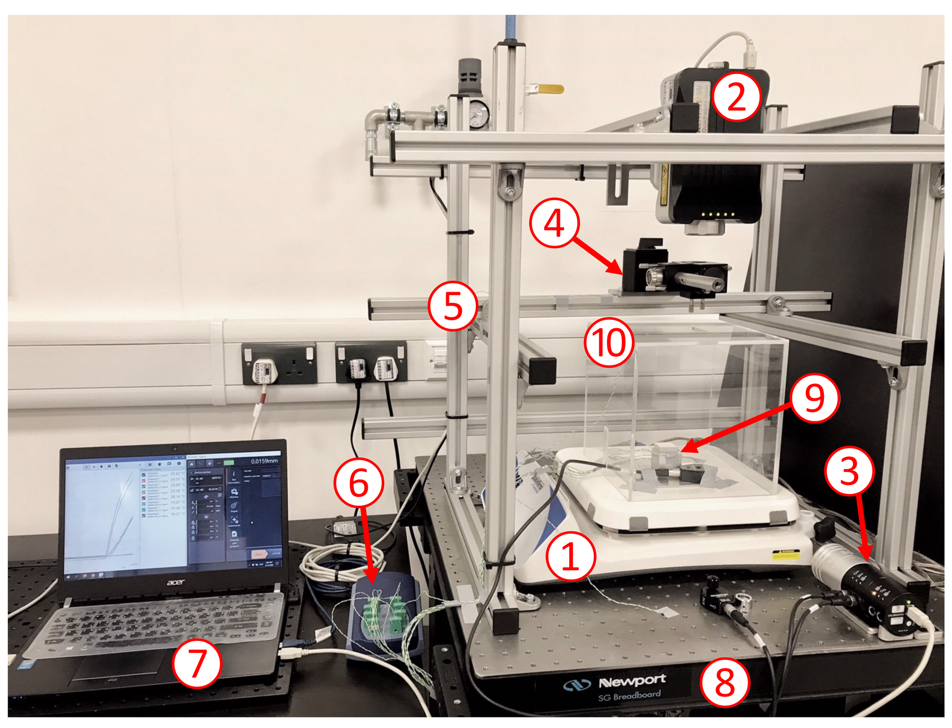


Fig.6 Experimental set-up: ① hot plate, ② Renishaw XL-80; interferometer, ③ XC-80 Environmental compensator, ④ measurement optics kit, ⑤ aluminium frame, ⑥ thermocouple equipment, ⑦ laptop, ⑧ vibration isolation table, ⑨ specimen, and ⑩ acrylic box

The relationship between the size of the cylindrical inner part and the lattice outer

- Design 8 was selected to demonstrate the relationship

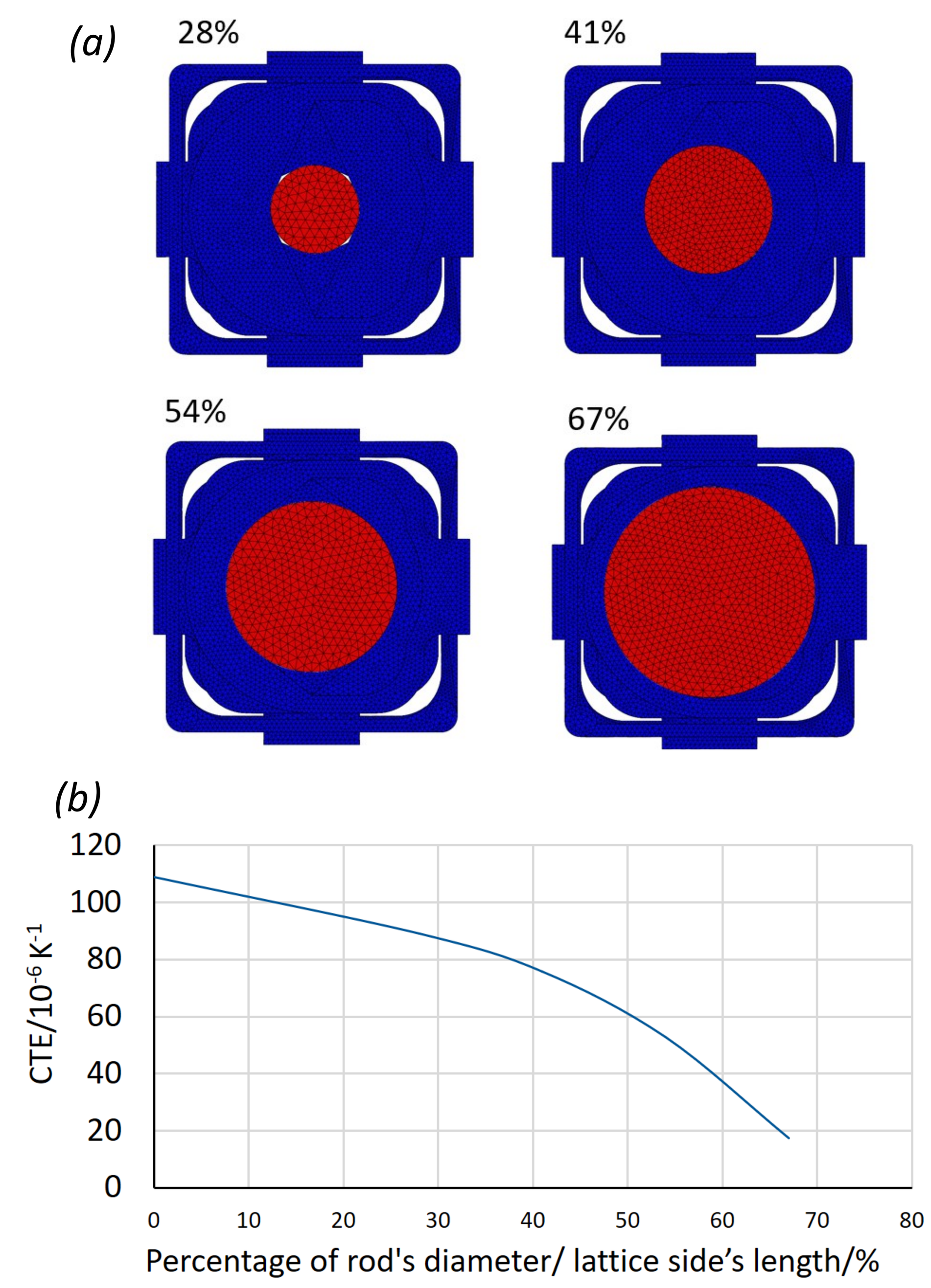


Fig.3 The relationship between the size of the cylindrical inner part and the lattice outer part was mapped out to understand their relationship and the effects on the CTE. (a) Top views of Design 8 in various sizes of inner and outer parts and (b) the plot shows relationship of sizes that effects on CTE of the design

Conclusions

- The novel structures for this project have taken advantage of the thermal deformation mechanisms of a material's internal geometry to maintain the global dimension
- The concept of designed lattice structures uses two materials with CTE for assembly together
- The simulation showed that for a lattice design, using nylon 12 and UHMWPE, the thermal expansion can be reduced from 109×10^{-6} K^{-1} to 12×10^{-6} K^{-1}
- This work proves that the combination of design optimisation and additive manufacturing can be used to achieve low CTE structures and therefore low thermal expansion machine frames at low cost

Future work

- Verify the experiment procedure by comparing the measuring data with the standard data
- Test CTE of manufactured lattices using the experiment setup
- Implement the newly developed design process to produce a thermally isolated metrology frame

Acknowledgements

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