DEFORMATION ANALYSIS OF 3D PRINTED MICRO LATTICE STRUCTURES USING FINITE ELEMENT ANALYSIS (FEA)

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INTRODUCTION

Mechanical Metamaterials

1. Metamaterials are any materials engineered to have a property not found in naturally occurring materials.
2. Properties ranging from electromagnetic, acoustic, optical and solid state physics could be tailored to give smart properties capable of achieving benefits that go beyond what is possible with conventional materials.
3. Mechanical Metamaterials are artificial structures with mechanical properties defined by their structure rather than their composition.
4. Their mechanical properties can be designed to have values which cannot be found in nature such as ultrahigh specific strength, resilience, negative Poisson's ratio, high bulk modulus-to-shear modulus ratio etc.

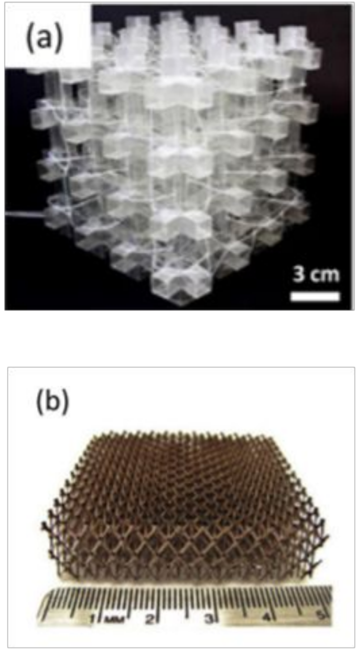

Fig. 1

1. There are frequently definite couplings between certain materials' fundamental features, such as the intimate coupling between strength and density, where high strength materials have a high density and vice versa.
2. The Eiffel Tower is roughly twice as tall as the Great Pyramid of Giza, yet due to its hierarchical and three-dimensional architecture, it has equivalent structural integrity and is over three orders of magnitude lighter.
3. Bones are stronger than most synthetic cellular materials developed by humans.
4. 3D printing, have enabled the fabrication of cellular materials with complex architectures across multiple length scales

Fig. (2.1) Eiffel tower

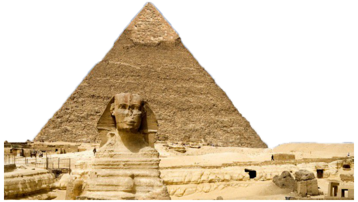

Fig. (2.2)Great Pyramid of Giza

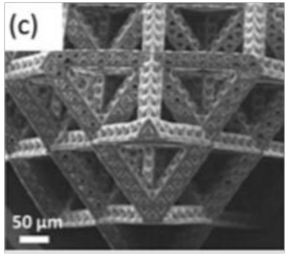

Fig. (2.3) 3D printed lattice structure

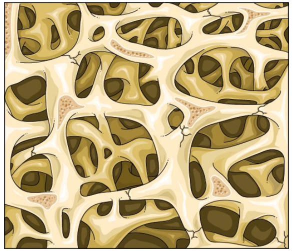

Fig. (2.4) Bone architecture

Origami Mechanical Metamaterials

1. In recent years, a significant interest towards origami assembly methods has been seen both in science as well as engineering.
2. A recent development in the field, like the Shrimp pattern, a novel origami pattern which has a segmented structure similar to arthropods such as shrimps, has been realised with our understanding of the natural world around us.
3. In our pursuit to engineer some of these materials, the influence random imperfections may have on the materials have also been studied and presented.

Fig. 1 Various stable states of a multi-stable Shrimp pattern tessellation, which has a segmented structure similar to arthropods such as shrimps. This curved design is a generalization from the standard Shrimp pattern, whose geometry is elaborated upon in Appendix A.

Fig. 3

1. Origami has been employed to build deployable mechanical metamaterials through folding and unfolding along the crease lines. This had led to the development of an origami inspired mechanical metamaterial, with on-demand deployability and selective collapsibility through energy analysis.
2. Finding applications in aerospace, architecture, bioengineering etc
3. On the robotics and fabrication front, there have also been significant advances in programmable foldable sheets, printable self-foldable robots, and self-folding microstructures and nanostructures.
4. Concepts of structural mechanics, which are commonly used in civil and mechanical engineering are incorporated into these metamaterials to produce structures with on-demand structural performance.

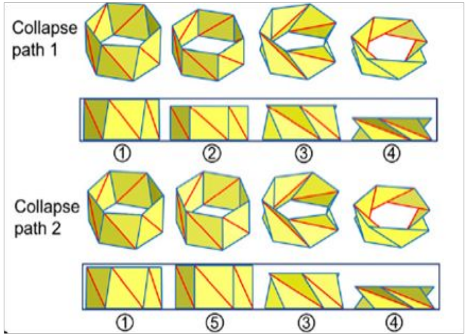

Fig. 4

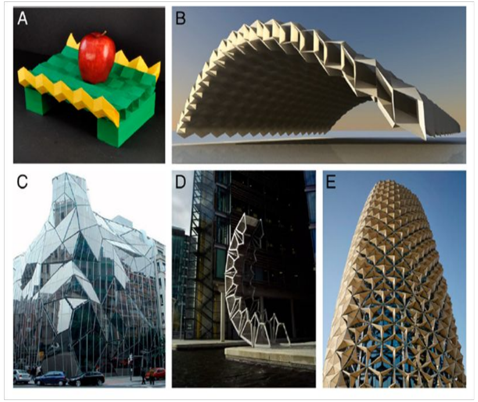

Fig 5

Research Purpose

The primary objective of the research work that I was a part of was to find out whether machine learning can be used to find the best Topology Optimization of 3D printed lattice structures and the simulations done using finite element analysis (FEA) were for the purpose of creating training datasets to be used for the algorithm. However, our research is limited to only the deformation analysis of 3D printed lattice structures and plotting their engineering stress-strain curves using the displacement and reaction force datasets obtained.

Research Methodology

1. The centre of our study is a 6X6X6 cm^3 FCC-BCCZ lattice structure as shown in fig. (6.) which is symmetric along the three perpendicular axes.
2. There are 216(=6X6X6) unit cells in total and we have chosen to employ a total of 24 BCCZ structures in between the lattice. So initially a total of ${}^{216}C_{24}$ combinations are possible for the structure. However, since we made it symmetric about the perpendicular axes, the total combinations were reduced to ${}^{27}C_3 = 2925$ combinations.
3. Now using Finite Element Analysis (FEA) we obtain the stress-strain curve for each of the 2925 combinations of the lattice under deformation.
4. We explore the results of any 4-lattice combination for the sake of simplicity.

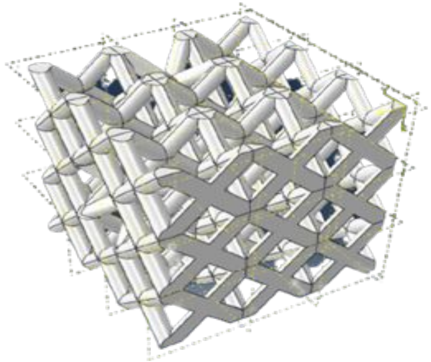

Fig. (6.1)

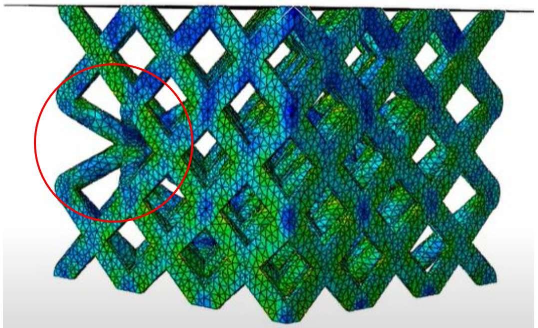

Fig. (6.2)

Steps optimised in Abaqus CAE

- The material properties given to the structure are as follows:
  - Density: 9.19×10^{-10} tonne/mm^3
  - Young's Modulus: 1340 MPa
  - Poisson's Ratio: 0.33
- Under the material section, we have assigned PA12 material as we are dealing with a high strain rate of 1000s^{-1}.
- Tie constraint was assigned to the upper and lower interface between plates and micro-lattice.
- The reference point on the bottom plate was given the ENCASTRE condition, while the velocity input is given to the reference point on the top plate.
- For a strain rate of 1000s^{-1}, and 80% strain, time period and velocity comes out to be 0.008 secs a 3000 cms^{-1}.
- Micro-lattice was meshed using an explicit linear element with C3D4 (a 4-node linear tetrahedron) scheme in ABAQUS CAE.
- Global Mesh Size of 0.5

RESULTS

FEA Simulation

RESULTS

Stress-Strain Curve

1. When PA12 material is taken and tested using FEA with an assumed strain rate of 1000 s^{-1}, the following engineering stress-strain response is obtained as shown in fig. (6)
2. This Stress-Strain graph is a training dataset to the machine learning model to be used for topology optimization.
3. The area under the curve up to the densification point gives the toughness value or stiffness of the material.

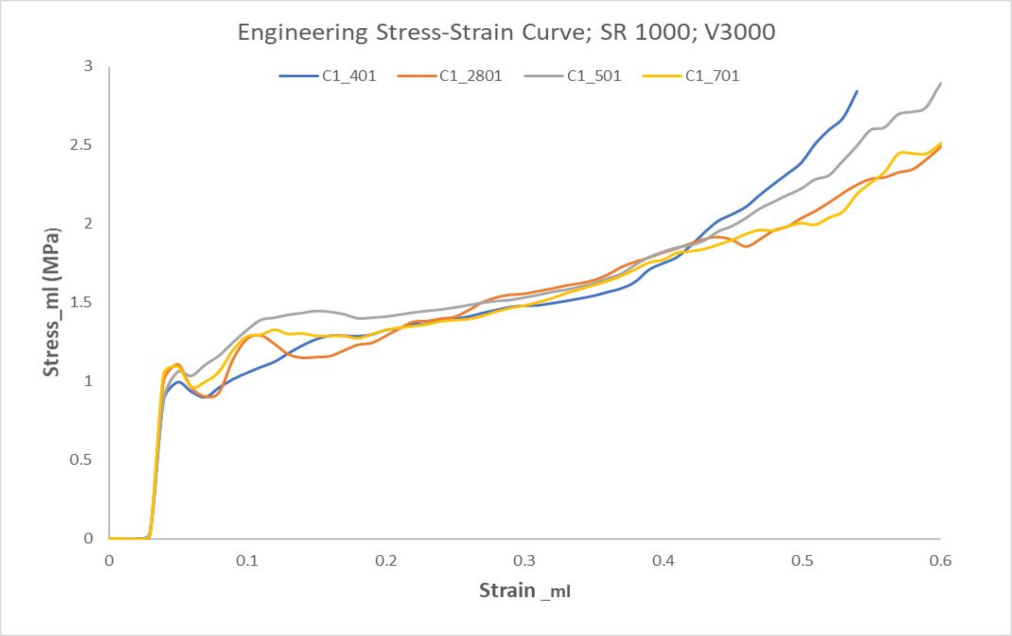

Fig. (7) Stress- Strain behaviour of the four lattices under deformation using FEA

BCC metallic microlattice

1. In a similar pursuit to finding out the toughness value of a BCC metallic microlattice structure as shown in Fig. (7) for a higher strain rate of 2300 s^{-1} for the material SS316L using the same approach, we have obtained the following stress-strain curve as shown in fig. (8)
2. The Impact toughness value of the micro lattice comes out to be around 30.753 ($J/m^3 \times 10^6$).
3. Based on the impact toughness value, Metallic microlattice could be a good candidate material for impact absorption.

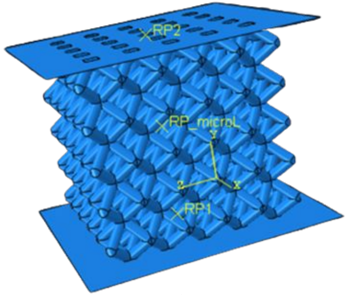

Fig. 8

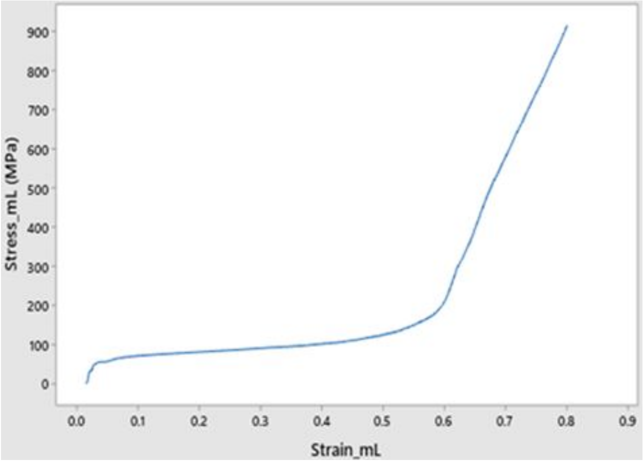

Fig. 9

CONCLUSION

1. Due to the emergence of mechanical metamaterials, we have been able to infiltrate previously inaccessible areas of the conventional material property space.
2. Origami mechanical metamaterials are artificial materials, given shape and structure similar to origami paper folding. Recent developments, in these fields have been inspired by the biological world around us, in the form of sustainable energy efficient patterns and also there have been efforts to print the produced origami structures obtained.
3. There has been work to use ideas from origami patterns to build deployable structures.
4. Using Finite Element Analysis (FEA) on 3D printed micro lattice structures it has been observed that metallic microlattices can be a viable candidate for impact absorption.

THANK YOU