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IMPACT ENERGY ABSORPTION CHARACTERISTICS OF 3-D PRINTED AlSi10Mg TPMS GYROID METALLIC STRUCTURES

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Abstract

This work aims to understand the behavior of 3-D printed Triple Periodic Minimal Surface (TPMS) gyroid lattice structure under quasistatic and dynamic compression tests. The samples were manufactured using selective laser sintering (SLS) 3-D printing processes using AlSi10Mg as material. Further quasistatic and dynamic tests were carried out on the 3-D printed specimens to examine the behaviour and energy-absorbing characteristics. Findings showed that the energy-absorbing capacity of gyroid lattice SLS structures are suitable for impact energy absorption applications in engineering

Keywords: gyroid lattice, selective laser sintering, energy absorption, quasistatic behaviour, dynamic behaviour.

1.0 Introduction: In the present technology, many researchers are attracted towards lightweight, high-performance manufactured lattice structures with toughness and durability. Lattice structures in the form of cellular materials in nature have stimulated the development of interest in building materials with the best possible mechanical and functional performance. Such stronger and lighter material is the impending objective of developing engineering [1] structures that are highly desirable in many areas such as aerospace, transportation, and medical engineering.

The advances in the field of Additive Manufacturing (AM) provide the freedom of designing intricate structures by building the component/structure layer-by-layer technique, which is otherwise highly impossible by conventional methods of manufacturing. Fused deposition modelling, stereolithography, binder jetting, multijet fusion, selective laser sintering, selective laser melting, electron beam melting, and other techniques are the featured techniques of additive manufacturing.

Impact energy absorbers are used to absorb the kinetic energy of a body in a controlled and predictable manner, promoting safety for individual and expensive engineering components. Investigating the use of cellular material structures in the field of impact energy absorption becomes the state of the art.

Generally, metal foams, honeycombs, etc., produced by conventional techniques are presently used for impact energy absorption. Triple Periodic Minimal Surface (TPMS) gyroid lattice structures manufactured by

AM is gaining much attention toward impact energy absorption capabilities.

Diab [1] explored the Mechanical properties of polymeric 3D-printed gyroid cellular structures and their manufacturing techniques. Shen et al. [2] evaluated the titanium alloy panels with a lattice structure created using SLM. The findings demonstrate that during manufacturing, the selective laser process parameters control the impact resistance qualities of lattice structures. The authors emphasized that research into the characteristics of materials with lattice structures is necessary for usage in [7] high-performance lightweight components. Vrana [3] investigated the impact of SLM process parameters on the impact resistance of lattice structures. Samples of BCC lattice structures (20x20x20 mm, d = 0.6 mm, length of unit cell = 4 mm) were used to test the process parameters. The outcome demonstrated that process variables had a substantial impact on the lattice's impact resistance as well as the size of the trusses inside the lattice structure. The highest transmitted force during impact testing followed a nearly identical curve to the increase in truss diameter. Numerous investigations have been made into the Impact Energy absorption capacities of TPMS-based structures made by different AM techniques and many have shown promising results [4].

This article presents the efforts in studying the behavior of energy absorption of 3D printed TPMS lattice structures using a selective laser sintering technique of AlSi10Mg material. Experiments were conducted under quasi-static and dynamic conditions. The load-deformation response values, photographic views of progressive deformation, specimens are given and discussed.

1.1 Energy absorption criteria

Many criteria were employed to express the crushing response of TPMS structures under the quasi-static compression tests [4]. The area under the load-deformation response is used to calculate impact energy absorbed by TPMS structures under quasi-static compression, mathematically,

$$\text{IEA}(x) = \int_0^d F(x)dx \qquad (1)$$

Where:

F= compression loading.

d = compression distance and
x =displacement respectively

Specific energy absorption (SEA) is the energy absorbed per unit mass which is formulated as:

$$\text{SEA}=\frac{IEA}{m} \qquad (2)$$

Where: IEA= Impact Energy Absorption and m= Mass of the TPMS structure

The peak load (F_{peak}), which is the first load value at the elastic deformation stage and is calculated using the load-displacement curves.

2.0 Materials and Methods

2.1 Specimen and material:

Initially, the part model (3-D CAD model) of the specimen (TPMS gyroid structure) was created by using CAD software and further TPMS gyroid structures manufactured using SLM 3D printing technique. The specimen is of cube-shaped gyroid structure shown in Figure (a) with a unit cell of size 25 × 25 × 25 mm having side length two-unit cells, resulting in 50 × 50 × 50 mm configuration. Thus one TPMS gyroid structure has 8 unit cells.

Figure (a) **Figure (b)**

Figure 1: 3-D views of TPMS gyroid structure (a) 3-D CAD model (b) 3-D printed model

All TPMS gyroid lattice structures of AlSi10Mg samples were manufactured using the SLM technique, in Amace STLR 400 series machine with a capacity of printing layer by layer 0.01 mm as shown in Figure 1(b). The chemical composition of AlSi10Mg and process parameters details as specified by the manufacturer are listed in Table 1 and Table 2 respectively.

Table-1 Chemical Composition of AlSi10Mg [6]

Alloying element	Wt. %
Al	Balance
Si	9-11
Fe	0.55
Cu	0.05
Mn	0.45
Mg	0.2-0.45
Ni	0.05
Zn	0.10
Ti	0.15

Table-2 Process parameters of SLM technique

Parameters	Process condition
Particle size (µm)	15 - 63
Thickness of layer (µm)	50
Scan speed (mm/sec)	1900
Laser power (W)	370
Laser spot size (µm)	100
Layer orientation	Stripe angle keeps changing with 63^0 per layer

2.2 Experiments:

2.2.1 Uniaxial Quasi-Static Tests

Uniaxial quasi-static compression tests were carried out using a 400 kN electronic universal testing machine. Figure 2 shows an experimental test setup. The 3D-printed cubic TPMS specimen was positioned between two parallel compression platens and loaded with an 8 mm/min crosshead speed. Tests were carried out until the structure undergoes a complete densification state and Five specimens were investigated in similar conditions. The deformation behaviour and load-displacement response data of the samples were recorded.

Figure 2: Universal Testing Machine

2.2.2 Dynamic test:

Dynamic tests were carried out using a drop hammer, which is indigenously developed and commissioned by the Department of mechanical engineering with a height of 5.8 m (10.77 m/s) Figure 3 shows the drop hammer test setup.

The drop height of an Impactor mass was determined from the quasi-static test results. The 3D-printed TPMs specimens were placed on the load cell platform and the known drop mass was dropped from a calculated height. Five specimens were tested for the same height and for the same impact mass.

Figure 3: Impact testing machine

3.0 Results and Discussions:

3.1 Uniaxial Quasi-Static Tests

The progressive deformation behavior of the TPMS gyroid structure test specimens were shown in Figure 4. In all of the examined specimens, a homogeneous compressive deformation was seen along the heights of the specimen. The load-displacement response of a gyroid structure under quasistatic test were presented in Figure 5 in which an initial linear loading followed by plateau region and finally becomes densification, which is consistent in all the specimens.

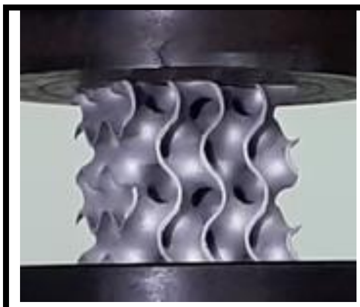	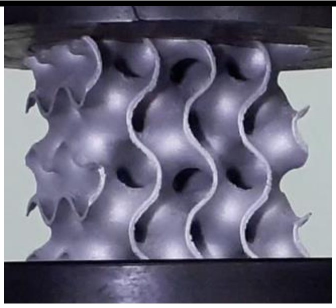	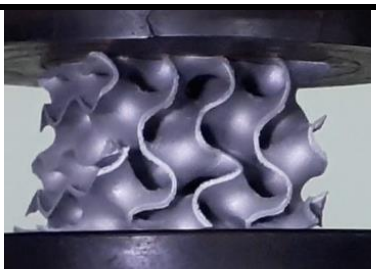
Unreformed Structure between two flat platens (δ=0)	Beginning of elastic deformation (δ=2 mm)	Bottom layer undergoes plastic deformation (δ=8 mm)
		
Plastic deformation folding continued in second layer from bottom (δ=14 mm)	Continued crushing in platue fracture occurs (δ=20 mm)	Gross densification (δ=34.08 mm)

Figure 4: Photographic views of progressive deformation stages of gyroid structure

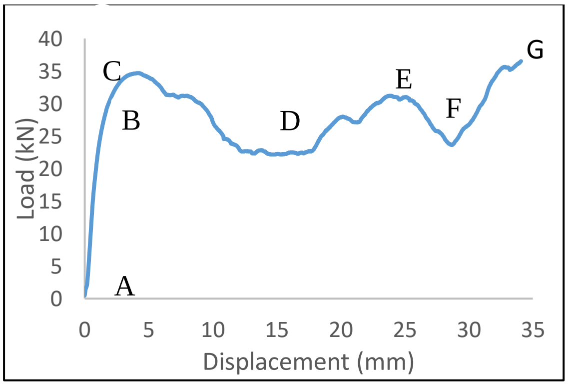

Figure 5: Load-displacement response of a typical gyroid structure under quasistatic test

At the beginning (A) the loading started. Once loading started it undergoes an elastic deformation up to B on further loading reaches a peak load (C). On continuing loading, specimen undergoes plastic deformation and bottom part starts folding and makes

contact with next layer (CD). On further loading specimen starts taking load once again, and attains a second peak load (E) and it undergoes next folding (F) and finally on further increasing the load specimen undergoes a final densification (G). Hence, it is observed that, all the tested TPMS structures, undergoes an initial elastic region, variation in loads in the middle region and a final densification where load rapidly rises with a less deformation. Figure 6 shows the combined results of Load-Displacement response of TPMs structures.

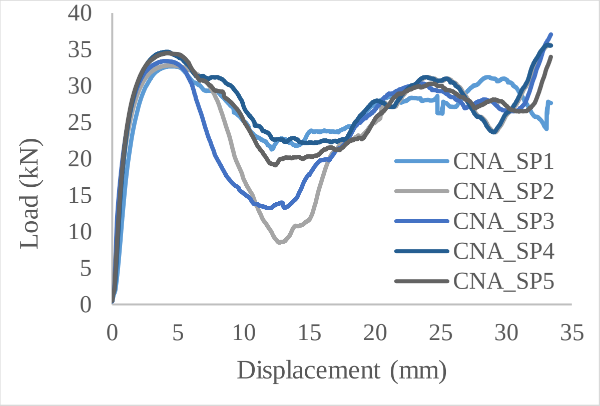

Figure 6: Combined Load-displacement responses of TPMS structures.

Based on the equations 1& 2 the results are tabulated in Table 3.

Table 3: Quasistatic test results

Sl.No.	Specimen	Mass (gm)	Peak load (kN)	Impact Energy Absorbed (J)	Specific Energy Absorbed (kJ/kg)
1	CNA_SP1_QS	45.21	32.68	840.94	18.60
2	CNA_SP2_QS	45.16	32.80	845.29	18.72
3	CNA_SP3_QS	45.13	33.40	826.00	18.30
4	CNA_SP4_QS	45.18	34.08	946.26	20.94
5	CNA _SP5_QS	45.22	33.80	902.35	19.45
Avg.			33.35	872.16	19.20

3.2 Uniaxial Impact test:

Based on the average energy absorbed in the quasistatic test and the Impactor mass, the drop height (h) is found using the equation

$E = mgh$ (3)

Where: E= Impact Energy Absorption (J)

m= Impactor Mass (kg) and

g= Acceleration due to gravity (m/s^2)

h= Impactor mass drop height (m)

Here the Impactor mass 43.95 kg, average impact energy absorption in quasistatic test is 872.16 J and acceleration due to gravity is $9.81 m/s^2$.

Using Equation 3 drop height (h) was found to be 2.02 m.

The impactor mass is dropped approximately 2.0 m as per the calculations above.

Figure 7 show a load-displacement response of TPMS gyroid structure under dynamic loading.

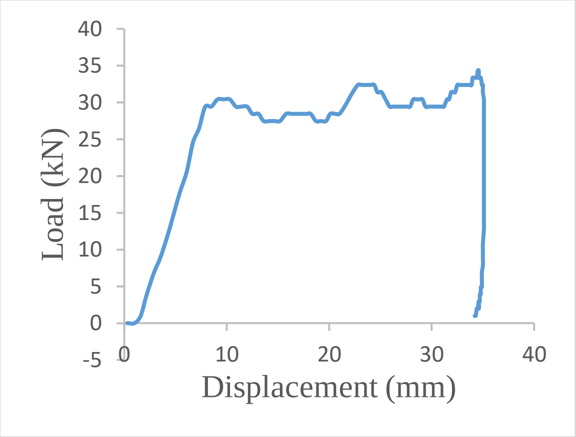

Figure 7: Load-displacement response of a TPMS gyroid structure under dynamic test

Here as mass is dropped all of a sudden from a known height, the specimens undergoes deformation behaviour and finally attains densification.

Under similar conditions, different test specimens of same type were tested and using the equations 1 & 2 the results are tabulated in Table 4. Figure 8 shows the combined results of Load-Displacement response of TPMS structures under dynamic test.

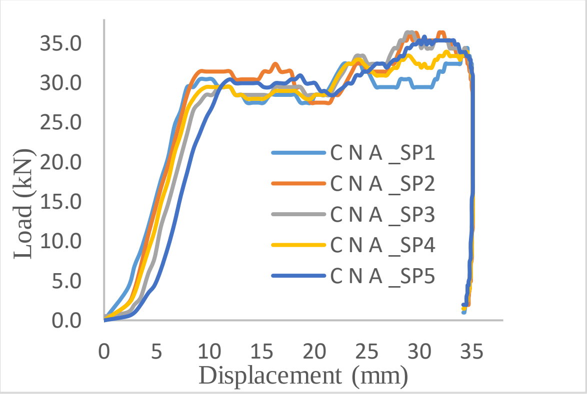

Figure 8: Combined load-displacement responses of TPMS structures under dynamic test.

Conclusions:

In this study, the TPMS gyroid structures made of AlSi10Mg were fabricated using SLS technique without any joint or discontinuities. Impact energy absorption of these structures were investigated under quasistatic and dynamic tests. The main observations of the study are as follows

TPMS gyroid structures under quasistatic test at the beginning, undergoes elastic deformation then changes to plastic deformation before proceeding to complete densification. And it was noticed that, an average specific energy absorbed is 19.20 kJ/kg.

Similarly, from the load-displacement response of dynamic test, it is observed that TPMS gyroid under goes elasto-plastic deformation before final densification. An average specific energy was found to be 20.01 kJ/kg.

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Table 4: Dynamic test results

Sl.No	Specimen	Mass (gm)	Drop Height (m)	Impact Energy (J)	Specific Energy (kJ/kg)
1	C N A _SP1_IT	45.08	2.0	903.6	20.04
2	C N A _SP2_IT	45.12	2.0	942.8	20.89
3	C N A _SP3_IT	45.18	2.0	900.7	19.93
4	C N A _SP4_IT	45.21	2.0	900.7	19.92
5	C N A _SP5_IT	45.17	2.0	870.4	19.26
Avg.				903.64	20.01

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