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EXPERIMENTAL STUDIES ON DEFORMATION BEHAVIOUR OF ALUMINIUM LATTICE STRUCTURE UNDER AXIAL COMPRESSION

Ashokkumar C N, Vijayasimha Reddy B.G, MujeebPasha
Department of Mechanical Engineering,Vemana I.T,Bengaluru

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Abstract-- Lattice structure offers the potential to produce desirable macro-scale material properties for a wide variety of engineering applications including blast and impact protection system, thermal insulation, structural aircraft and vehicle components body implants. The work presented here to study the characteristics of quasistatic and dynamic behaviour of lattice structure of different materials. Initially cuboidal lattice structures were investigated to study the stress-strain response, failure behaviour and energy absorbing capacity. Drop hammer test were carried out to understand the behaviour of lattice structures under dynamic behaviour. The results obtained shows quasistatic tests are agreeable with dynamic tests.

Keywords: Lattice, energy absorption,dynamic analysis,drop hammer.

I.INTRODUCTION

Concepts for protecting structures from impulsive loads are of current interest. The choice of material for a given structural problem requires a careful balance of strength, stiffness, cost, durability and relative static and dynamic properties. Lattice structures are multi-functional materials that can offer arrange of these desirable properties. They are commonly constructed by duplicating three-dimensional meso-scale unit cells, typically at the scale of a few mm. The stiffness and strength of these materials depend on relative density, strut aspect ratio (radius/length), unit cell geometric configuration, unit-cell size, properties of parent material, and rate of loading. By changing the spatial configuration of struts and/or strut diameters, different geometries with different material properties can be produced, which will be explored herein the context of protection against blast and impact loading. Although lattice structures are different from cellular materials, certain concepts carry over from the well-studied cellular materials to the less well-know lattice structures, especially under transient dynamic loading conditions.

Ozdemir et.al(1)., have investigated, lattice structures commonly constructed by duplicating three dimensional meso scale unit cells. The stiffness and strength of these materials depends on relative density, unit cell geometric configuration, unit cell size, properties of parent material and rate of loading. By changing the spatial configuration of strut, different geometries with different material properties can be produced. Although lattice structures are different from cellular materials certain concepts carry over from the well-studied cellular materials. Energy absorption performance of multi cell thin walled structure perform much better compared to single thin walled structure shown by Modh Sofi et.al (2). As a typical class of energy absorbers, thin walled structures have been widely used in crash test applications such as automotive industries to protect passengers from severe injuries. Thin walled structures are widely used as kinetic energy absorbers for their high energy absorption performance and weight efficient. They can dissipate a large amount of kinetic energy through plastic deformation and fracture in case of collision.

The energy absorbing component should be light weight itself, so that it will increase the energy absorption capacity which is vital for vehicle carrying energy absorbers and personal safety devices. Lattice structure made from repeated body centered cubic (BCC) unit cell composed of four thin trusses. Four series of BCC-structure samples with different diameters of truss designed, were tested under impact loading by Vrana et.al(3).The measured data were used for calculation of the absorbed energy using numerical integration. The results show that the BCC structure with the diameter of the truss d=0.8mm have the best combination of stiffness and energy absorption for the parameters of the impact test.

At present porous materials such as metal foams or honeycombs are used for energy absorption applications. These porous materials are produced by conventional process. By using additive manufacturing technology, it is possible to produce a lattice structure with exactly same properties. The advantage of the lattice structure materials produced by additive manufacturing is that its stiffness can be controlled by geometrical properties. Lattice structures are structurally efficient but complex designs that enables high strength and reduces weight shown by Kanta reddy et.al(4). Lattice structures are traditionally difficult to manufacture by conventional method so additive manufacturing process is used.

Lattice structures are open cellular structures with a continuous network of truss like members. They can be arranged in different configurations. The open cellular structures have large surface area, thereby helps in improving heat transfer from the structure. Lattice structures can be designed in hollow circular or square or any other shapes too. The design of lattice structure using CAD assistive tools and libraries has been studied by Azman et.al (5). for metallic additive structures. In this work quasistatic tests were carried using Universal Testing Machine having a capacityof 400kN.Dynamic tests were carried using drop hammer tests.

II.MATERIAL

Aluminium (6060) tube (outer diameter 9.6 mm, inner diameter 6 mm) and solid rod (diameter 10 mm) have been taken for investigation. Mechanical properties were tested using universal testing machine and are Young's Modulus(E)= 69.25 GPa and Yield stress(σ_y)= 151 MPa. A typical stress Vs strain graph is shown in figure 1.

Figure-1: Stress Vs Strain graph of Al6060

A unit lattice structure configurations were considered for this study to examine the energy absorption capability. The dimensions of a single unit cell is shown in figure2.

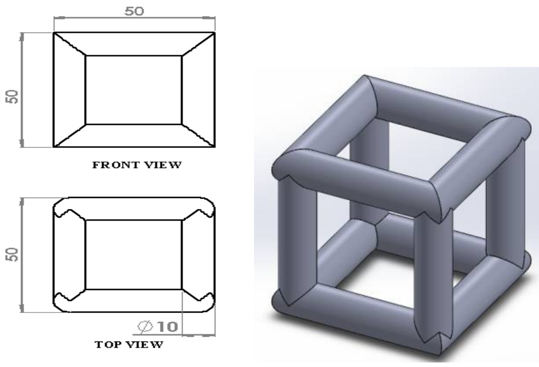

Figure-2: Unit cell lattice structure.

III. EXPERIMENTS

A unit lattice structures consisting of 50x50x50mmwerefabricatedusing conventional brazing method. The weight of aluminium solid lattice structure is 120 gms and aluminium tube lattice structure is 73 gms. Quasi-Static compression tests were carried out on Universal Testing Machine having a capacity of 400kN.The lattice structures were centrally located between two plates. Load is applied at constant elongation rate of 8 mm/s. To avoid the build orientation effect, the compression tests were conducted in the build direction (z direction).

3.1 Quasistatic tests:

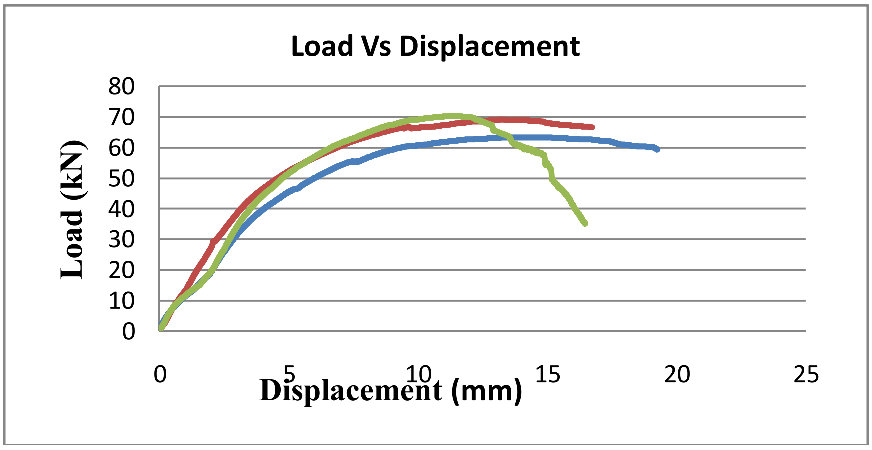

Figure3: Load Vs Displacement of aluminum solid rod lattice structure.

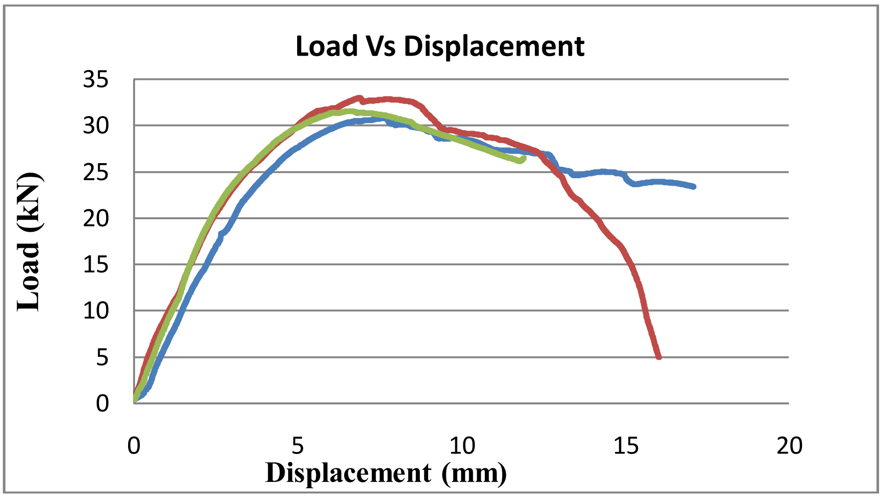

Figure-4: Load Vs Displacement of aluminum tube lattice structure.

A series of unit lattice structures having different cross section were tested under quasistatic test. Load-displacements curves of corresponding lattice structures are shown in Figure (3) Aluminium solid rod lattice structure, Figure (4) Aluminium tube lattice structure. The maximum load carrying capacity for aluminium solid lattice structure is 70 kN and aliminium tube lattice structure is 33 kN. The energy absorption of the solid and tube aluminium lattice structure found to be 975.21J and 407.59J respectively

Figure-5:Aluminium solid rod lattice structures after test.

Figure-6: Aluminium tube lattice structures after test.

From figure 5 & 6, it is observed that joints debond and structures break mostly at the corners and the vertical columns buckle in outward direction. Loading stopped when debonding starts. Both of the lattice structures shows almost similar behavior. Energy absorption and maximum force absorbed by each type of lattice structure are given in Table1

Table- 1 Quasistatic test results

Lattice structure type	Energy Absorbed (J)	Specific Energy Absorbed (kJ/kg)	Maximum Force (kN)
Aluminium solid rod	975.21	8.12	63.28
	914.12	7.61	69.08
	842.00	7.01	70.01
Aluminium tube	407.59	5.58	30.78
	386.17	5.29	32.98
	380.77	5.21	31.64

3.2 Dynamic tests:

In these experiments, lattice structures were tested using drop hammer setup. A drop mass of 63.5 kg was dropped from a height of 1.57 m and 0.62 m for solid and tube aluminium unit lattice structure respectively, based on energy absorbed during quasistatic tests.

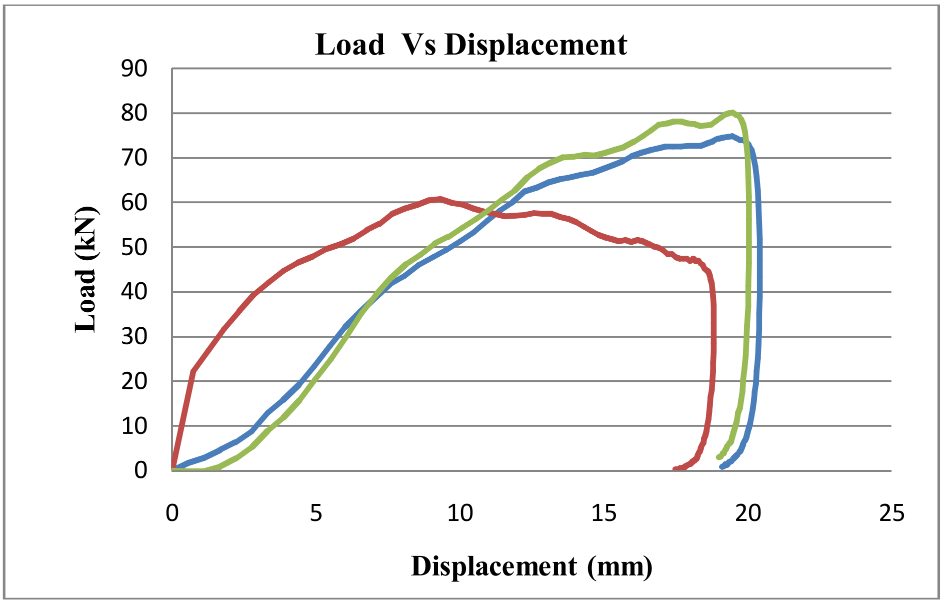

Figure-7: Load Vs Displacement of aluminium solid rod lattice structure

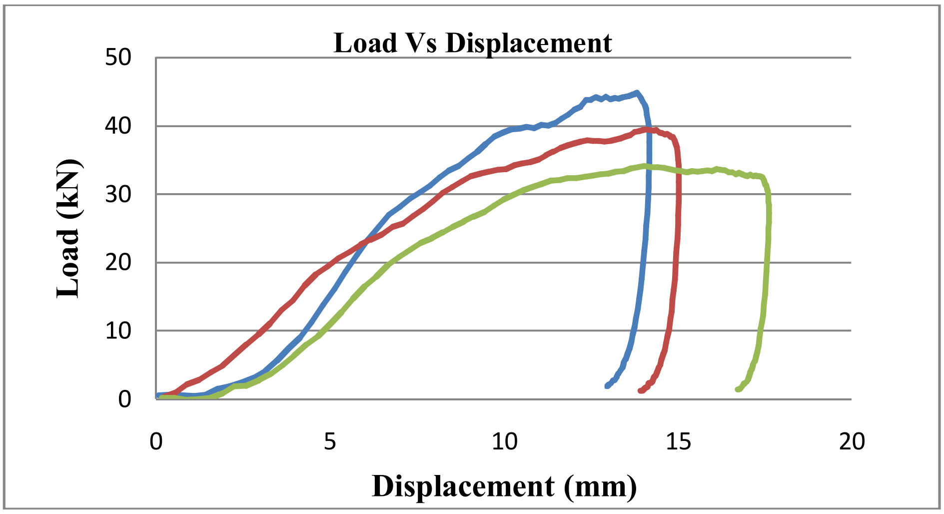

Figure-8: Load Vs Displacement of aluminium tube lattice structure.

A series of unit lattice structures having different cross section were tested under dynamic loading. Load-displacement curves of corresponding lattice structures are shown in Figure (7) Aluminium solid rod lattice structure,Figure (8) Aluminium tube lattice structure.The maximum load carrying capacity for aluminium solid lattice structure was80.18 kN and aliminium tube lattice structure 44.45 kN. The energy absorption of the solid and tube aluminium lattice structures found to be 943.43J and 366.34J respectively.

Figure–9: Aluminium solid rod lattice structures after dynamic test

Figure–10: Aluminium tube lattice structures after dynamic test

Figure 9 & 10 depicts the results of the impact tests under amass of 63.5 kg and a velocity of 5.5m/s and 3.48 m/s for solid and tube aluminium lattice structure respectively. Both of the lattice structures shows almost similar behavior.

Table-2 Dynamic test results.

Lattice structure type Dynamic	Energy Absorbed (J)	Specific Energy Absorbed (KJ/kg)	Maximum Force (kN)
Aluminium solid rod	932.73	7.77	74.7
	943.43	7.86	61.4
	926.49	7.72	80.18
Aluminium tube	358.46	4.91	37.98
	347.27	4.75	44.45
	366.34	5.01	33.9

Energy absorption and maximum force absorbed of both the lattice structures are given in table 2. It is observed that both lattice structures bear more load in case of dynamic loading. In case of quasistatic tests lattice structures undergo a debonding at the joints. Specific energy absorbed in both the lattice structures under quasistatic and dynamic loading conditions are approximately remain same, as formation of folding were not observed.

IV. CONCLUSIONS.

With many potential applications across a wide range, it is difficult to explore novel energy absorbing materials. Energy absorption characteristics of lattice structures were studied by means of experimental work. The material properties were tested by conducting tensile test. The specimens were investigated under quasi static test using FIE make UTM and dynamic tests were conducted using drop hammer apparatus in-house built. Load-Displacement curves were plotted for each case. Area under Load-Displacement curves were used, to find the energy absorption. It is observed that aluminium solid unit lattice structure has more specific energy absorbing capacity than aluminium tube unit lattice structures in both quasi static and dynamic loading conditions, also the struts buckle outwards .

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