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Effects of inclusion on the in-plane mechanical performance of micro-lattice structure

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Abstract

In this paper, the effects of the existence of inclusion or missing cells on the overall in-plane mechanical behavior of micro-lattice plate is discussed by using the numerical finite element analysis. The micro-lattice plate can be manufactured using the selective metal laser melting technique, and various shapes of its micro-architecture can be easily produced even if there are non-uniform cells. In particular, effects of boundary condition of the plate's edges, cell's geometry and the shapes of non-uniform region on the initial stiffness and plastic collapse strength are investigated. Also, based on the numerical results, empirical equations for estimating these mechanical properties are proposed.

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Keywords: Micro-lattice Structure, Initial Stiffness, Yield Strength, Finite Element Method

Nomenclature

h, h_0	heights of the plate and its defect region
w, w_0	widths of the plate and its defect region
L_x, L_y, L_z	lengths of a cell in x-, y- and z-directions
d and L	diameter and length of a strand
N_x,N_y	numbers of unit cells along x- and y-directions

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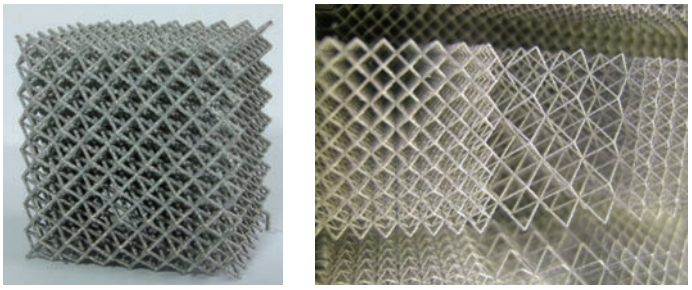
E_s, σ_s, ν_s	Young's modulus, Yield stress and Poisson's ratio for applied material
E^*_0 and σ^*_{pl0}	initial stiffness and plastic collapse strength of the micro-lattice plate without inclusion
E^* and σ^*_{pl}	initial stiffness and plastic collapse strength of the micro-lattice plate with inclusion

1. Introduction

Cellular structures, such as honeycombs, lattices and foams have been taken attention and used for many structural applications owing to their superior mechanical performance per unit mass. For decades, many researchers have been investigated the mechanical properties of cellular structures with regular and irregular cells by using numerical, theoretical and experimental approaches (Gibson and Ashby (1997)).

One of co-authors have developed the selective laser melting (SLM) technique for manufacturing micro-lattice structures at length scales of microns. The micro-lattice structure can be produced by using CAD data, so the micro-architecture of the structure can be changed easily to enhance the overall mechanical properties such as initial stiffness, plastic collapse or buckling strength and impact energy absorption capacity. Fig. 1 shows the example of micro-lattice block with two types of inner cells.



(a) with uniform cells (b) with non-uniform cells

Fig. 1. Pictures of micro-lattice structure by SLM technique.

The effects of hole and inclusions on the mechanical performance of honeycomb structures have been investigated by other researchers (Silva and Gibson (1997), Guo and Gibson (1999), Chen et al. (1999, 2001)). However, the micro-lattice structure investigated has much potential for improving the mechanical properties by changing the strand's length, angles between adjacent strands.

In this study, the in-plane mechanical properties of the micro-lattice plate with inclusion is analyzed by using numerical analysis applying Finite Element Method. The main purpose is to estimate the initial stiffness and strength of the plate directly from the inclusion data. The inclusion is centered in the plate, and subjected to in-plane tension load. In our investigation, the effects of inclusions on the initial stiffness and plastic collapse strength are discussed. The inclusions investigated here are modelled by holes, softer (coarser) cells and harder (finer) cells.

2. Method of Numerical Analysis

In our calculation, the commercial FE analysis software, Msc.Marc, is used to demonstrate the in-plane deformation behaviour of a lattice plate with irregular cells. Figure 2 (a)(b) show the schematic of boundary condition in our calculation. Assuming that non-uniform cells are centered in a plate, and a tensile or compressive load is applied on the upper and lower edge. Also, in order to discuss the effect of clamped status of the edge on the overall performance, two kinds of boundary conditions are considered. The dashed line shows the analytical region in our FE analysis by considering the symmetry. Figure 3(a)(b)(c) show the example of lattice plate with irregular cells. As the weakest inclusion can be regarded as a hole, the missing cell model is also investigated.