Design of Parts for Technology Additive Manufacturing of Hybrid Machine

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Abstract

This paper discusses treatise on the proposal for production of parts method additive manufacturing (AM) for hybrid machines, which can print 3D part layer by layer and machining them on the end. Machining parts may not always be easy, mainly it is a thin-walled workpieces or shells. Therefore, in this work will be discussion of the design of these products.

Key words: Hybrid Manufacturing, Additive Manufacturing, Micro Lattice Structure.

1. Introduction

Additive manufacturing is among the relatively young production process, which is experiencing great prosperity. Parts produced by additive manufacturing can be practically used in any sector, whether from the automobile through the aerospace industry, to the food industry. Such large use of this technology, due to its wide range of materials that can be printed (whether it's plastic, steel, titanium alloys, ceramics, concrete and food). This work focuses on a metal printing. Parts are typically printed layer by layer the form of 3D printing.

Because in the printed piece could be seen each printed layer (it depends on the technology and layer thickness), or surface of the part after printed is rough, therefore it is necessary to machine in some phases of the production (for example: for the observance of the geometrical tolerances, or roughness). Fig. 1 till Fig. 4 show sequential production of the compressor, which includes a complete 3D printing with continuous machining to final shape.

Fig. 1. *The start of printing [1]*

Fig. 2. *Machining between printing [1]*

Fig. 3. *The final printing [1]*

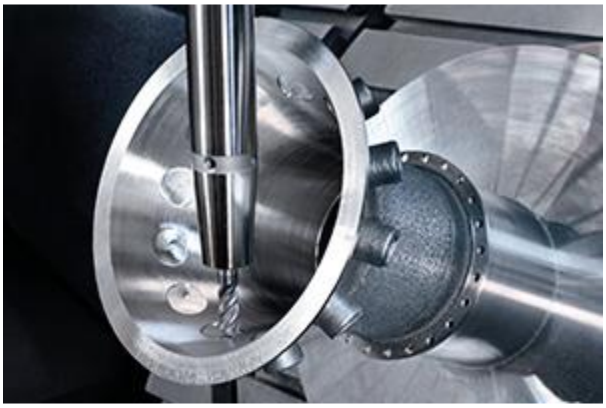

Fig. 4. *Final finish milling [1]*

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Therefore, the companies manufacture cutting machines combining advantages of 3D printers and CNC machines in the last ten years. This new machine is called a hybrid machine. Most of hybrid machine use technology 3D printing called Laser Deposit Welding (LDW), which is situated in to five-axis machine tool.

By additive manufacturing technology could be printed thin shells, which are very difficult to machinable. Therefore, it will also depend on the design of construction, filling the structure, or supporting structures.

2. Lattice structures

Many of the research report and the papers are written about 3D print and producing lattice structures, especially some papers focus on the specific basic cell of (micro)-lattice structures, which are loaded pressure only. Some types of basic cells of micro-lattice structures are shown on the Fig. 5.

Fig. 5. *The kind of cells [2]*

When designing parts must be taken into account the properties of filling and support structures for the 3D printer.

Suard et al. [3] investigated the influence of surface quality on diameter and mechanical properties of the beam. They compared the differences between CAD data and experimentally produced patterns of micro-lattice structures. These constructions were analysed on CT after printing. On the basis of this analysis is defined the so-called. "Effective volume of material" (Fig. 6), which is compared with production parameters and stiffness of patterns. The authors mention that it is necessary to consider the effective volume of the material when determining stiffness of lattices structures.

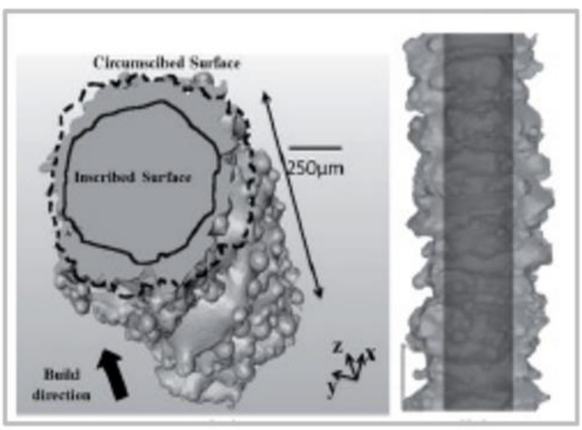

Fig. 6. *Effective volume of materiál [3]*

Suard et al. described the significant influence of the orientation beams in structures in their further paper [4]. They have two approaches to evaluate this diameter were followed:

(i) A geometrical equivalent diameter was estimated geometrically from the inscribed surface of the strut.
(ii) A numerical equivalent diameter was estimated from a numerical calculation performed on 3D images of struts.

In another research team Ushijima et al. [5] was performed a theoretical analysis of the failure mechanism beams periodic structure during compressive loading. Objective was to predict the initial stiffness, modulus of elasticity and tensile strength Body-Centered cubic (BCC) lattice structures. This analysis is based on the deformation mechanisms, which can be applied to other shapes of basic cells micro-lattice structures. Analytical assumptions are compared with FEM calculations using 1D beam elements and 3D solid.

Ushijima et al. are considering the load beams basic BCC cells only bending moment. These beams are fixed on one side for simplification (see Fig. 7). On the basis of this assumption, are derived equations mechanical properties. The obtained relations were verified using FEM analysis.

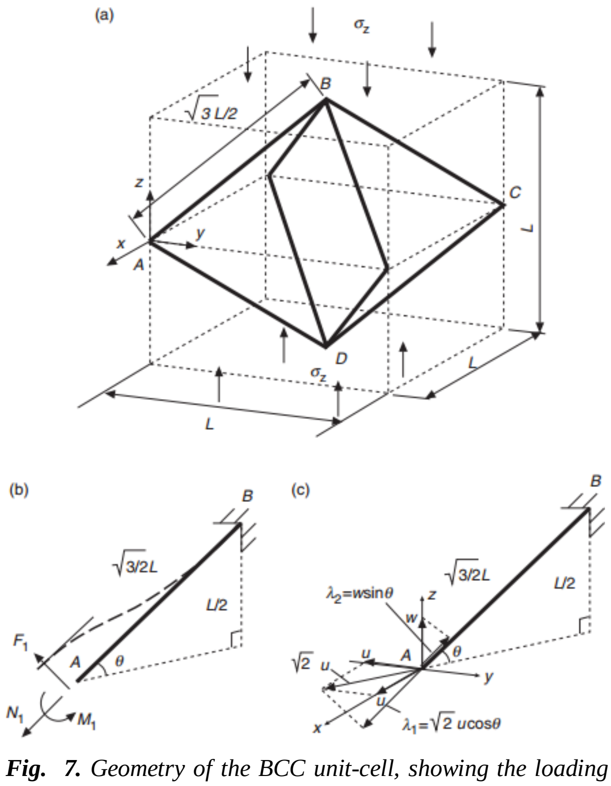

Fig. 7. *Geometry of the BCC unit-cell, showing the loading conditions and movement of each strand: (a) geometry of the BCC unit cell, (b) loading conditions, (c) movement of 'A' relative to 'B'. [5]*

Ushijima determine deflection between points A and B as:

$$\lambda = \lambda_1 - \lambda_2 = \sqrt{2}ucos\Theta - wsin\Theta = \frac{\sqrt{3}}{3}(2u - w) \quad (1)$$

Axial force N1 can be written as a function of u and w as:

$$N_1 = \frac{2EA}{3L}(2u - w) \quad (2)$$

Where A is the cross-sectional area of each strand ($=\pi d^2/4$).

$$F_1 = \frac{32\sqrt{2}EI}{3L^3}(u+w) \tag{3}$$

$$M_1 = \frac{8\sqrt{6}EI}{3L^2}(u+w) \tag{4}$$

Where I is the moment inertia of the beam (=πd4/64). They expressed deformation energy of one beam as: the elastic strain energy stored in a strand AB can be obtained by summing the energy stored in axial stretching and bending as follows:

$$U_{AB} = \frac{\sqrt{3}EA}{9L}(2u-w)^2 + \frac{32\sqrt{3}EI}{9L^3}(u+w)^2 \tag{5}$$

Therefore, the stored strain energy for one unit cell, U_{BCC}, is:

$$U_{BBC} = 8U_{AB} = \frac{8\sqrt{3}EA}{9L}(2u-w)^2 + \frac{256\sqrt{3}EI}{9L^3}(u+w)^2 \tag{6}$$

The initial stiffness of the BCC structure, E_{BCC}, is given as:

$$E_{BBC} = \frac{\sigma_z}{\varepsilon_z} = \frac{\rho^*}{\rho_s}\cdot\frac{E}{1+2(L/D)^2} \tag{7}$$

Where the relative density is $\rho^*/\rho_s=\sqrt{3}\pi(d/L)^2$.

Ushijima et al. explore of yield strength of micro-lattice structures BCC using uniaxial and biaxial stress in next paper [6]. They defined the conditions for the creation of elastic buckling.

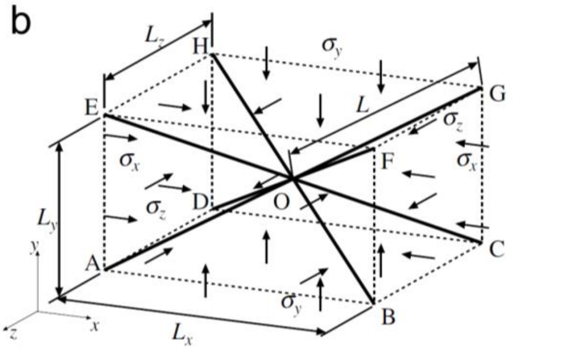

Fig. 8. *Geometries and loading condition for a representative unit-cell [6]*

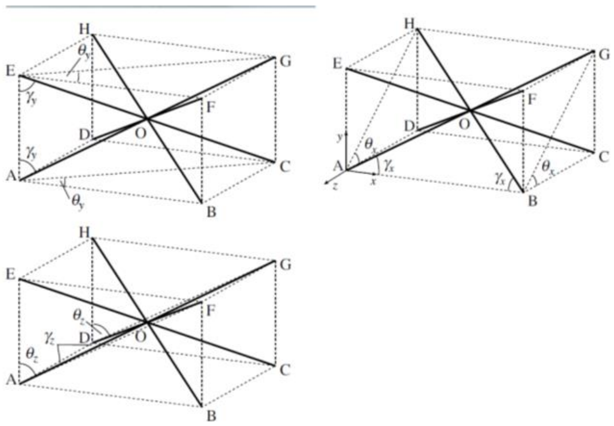

Fig. 9. *Definition of angles $\gamma_x,\gamma_y,\gamma_z$ for aunit-cell. [6]*

They defined initial stiffness BCC structure in axis x, y and z.

$$E_X^* = \frac{\sigma_x}{(2u/L_x)} = \frac{3\pi E_S}{16}\cdot\left(\frac{L}{D}\right)^4\cdot\frac{\cos\gamma_x}{\sin^2\gamma_x\cos\gamma_y\cos\gamma_z} \tag{8}$$

$$E_Y^* = \frac{\sigma_y}{(2v/L_y)} = \frac{3\pi E_S}{16}\cdot\left(\frac{L}{D}\right)^4\cdot\frac{\cos\gamma_y}{\sin^2\gamma_y\cos\gamma_x\cos\gamma_z} \tag{9}$$

$$E_Z^* = \frac{\sigma_z}{(2w/L_z)} = \frac{3\pi E_S}{16}\cdot\left(\frac{L}{D}\right)^4\cdot\frac{\cos\gamma_z}{\sin^2\gamma_z\cos\gamma_x\cos\gamma_y} \tag{10}$$

From the above relations and papers show that properties of the workpiece can be influenced by the type of cell, density of cell corresponding to a ratio L/D. These parameters have a great influence on the stiffness of the workpiece, which contains the lattice structures. These lattice structures are used to reduce the weight of components and a useful reinforcement elements for its subsequent use.

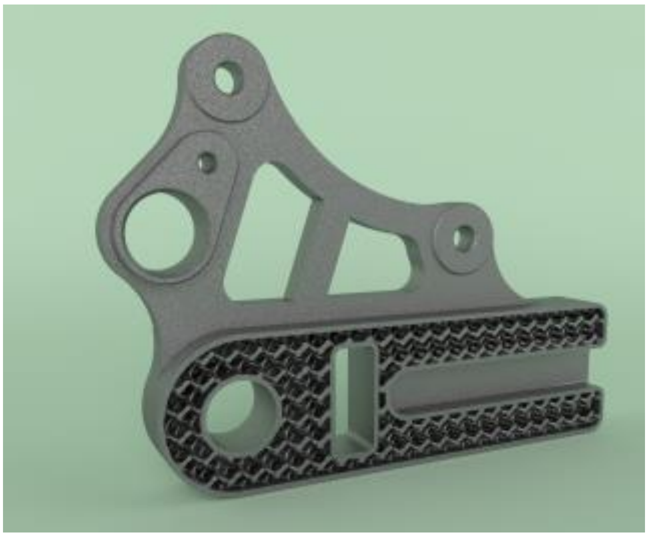

Fig. 10. *Symmetric lattice structure [7]*

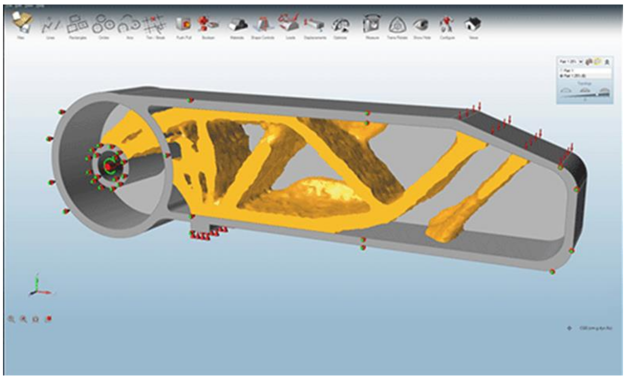

Fig. 11. *The optimized distribution of filling materials according to the static load acting on the part [8]*

Filling the structure may now be chosen in two ways.

A) Symmetric lattice structure (Fig. 10)

B) The optimized distribution of filling materials according to the static load acting on the part. (Fig. 11)

According to point A: Structure is meant to fill the entire part volume by complete system consisting of one type of the basic cell. Thus propounded of part ignores the optimal time for printing and machining. The structure is symmetric and is mechanically oversized too.

According to point B: Structure is meant to create such a filling structure, which helps fill the shell with effectively distribution of material so as to reduce weight and guarantee stiffness of part. The structure is not symmetric and do not constitute a comprehensive system.

The idea is to combine both variants. The lattice structure is composed of the same cells connected to each other, but different sized. This leads to different density across the part volume and allows reduction in the density but maintain the stiffness of the part.

3. Conclusions

The idea is to optimize the lattice structure of large parts, thereby reducing the density of inside volume and it leads to shortening of the time of the printing and all this leads to a reduction in the price of printing. The cutting parameters can be chosen appropriately due to optimized part without machining speed had to be reduced. The ratio L/D has great importance in optimizing the lattice structure, which has an effect on initial stiffness and density of the cell.

The list of symbols

λ, λ_1, λ_2	deflection (mm)
γ_x,γ_y,γ_z	angle (°)
σ_x,σ_y,σ_z	normal stresses (MPa)
π	constant (1)
ρ_s	the density of the base material (kg/m^3)
ρ^*	the density of the cell (kg/m^3)
θ	angle (°)
A	cross-sectional area of each strand (mm^2)
d	diameter of the beam (mm)
E	the initial stiffness (MPa)
E_{BBC}	the initial stiffness of the BCC structure (MPa)
E_S	young's modulus (MPa)
E_X^*, E_Y^*, E_Z^*	the initial stiffness in axis X, Y and Z (MPa)
F_1	shear load (N)
I	moment inertia of the beam (mm^4)
L	length (mm)
L_x,L_y,L_z	length in axis X, Y and Z (mm)
M_1	bending moment (Nmm)
N_1	axial force of the beam (N)
u	displacement (mm)
U_{AB}	the elastic strain energy stored in a strand AB (J)
U_{BBC}	the stored strain energy for one unit cell (J)
v	displacement (mm)
w	displacement (mm)

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