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A method to determine the depowdered height in lattices manufactured by electron beam melting

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ABSTRACT

After completing a part in electron beam melting (EBM), a depowdering operation is required to separate the sintered but unmelted powder from the manufactured part. Depowdering lattice structures can be difficult or even impossible due to their intrinsic shape. The aim of this paper is to propose a criterion to ensure that a lattice structure manufactured by EBM can be depowdered. The objective is to use this criterion during the design phase of lattice structures to make them manufacturable and depowderable. Experiments are conducted on depowdering octet-truss lattice structures with variable bars thickness and mesh sizes. Different criteria are introduced, among them the criterion "hydraulic diameter" of a lattice structure, inspired by the Darcy–Weisbach hydraulic law used to calculate the pressure drop in a pipe. This criterion can be determined using only geometrical characteristics of lattices available in the CAD model of the part. Results show that the levels of depowdering for lattice structures are proportional to this hydraulic diameter. As a validation, a bike stem has been manufactured following the criterion and has demonstrated its efficiency.

1. Introduction

Nowadays, with the emergence of additive manufacturing processes [1], complex shapes that respondent at precise functional criteria can be produced [2]. We therefore want to push the limits in terms of design and optimization of parts, seeking to obtain the best possible shapes [3–6]. One way to achieve this goal is to use lattice structures that make possible to manufacture products lighter in weight with acceptable mechanical properties [7].

Electron beam melting (EBM) is an additive manufacturing process used for producing metal parts and has the potential to manufacture lattice structures with fine features [8]. EBM is a "powder bed" additive manufacturing process: the part is built layer-by-layer by melting the metal powder using a powerful electron beam [9,10]. For each layer, the metal powder is spread on a plate by a rake, is sintered by the electron beam to increase thermal and electrical conductivity and is locally melted to produce the required part. Then the plate goes down of the value of a layer (50) and the cycle is repeated (Fig. 1). During this study, the manufacturing has been done with an Arcam A1 machine [10]. The diameters of the titanium powder that we use range from 45 to 110 µm and follow a distribution with a median value at 74 µm, with $d(0.1)$: 53.2 µm and $d(0.9)$: 102.9 µm [20].

At the end of the EBM process, the part is included in a "cake" of sintered powder. This powder has to be removed to obtain the final part and is then recycled. To perform this depowdering operation, a powder recovery system (PRS) [11] is used: the "cake" of sintered powder containing the manufactured part is blasted with titanium powder under 5 bar air pressure [12]. The removed powder is then sieved, so it can be reused. Depowdering lattice structures can be difficult or even impossible due to their intrinsic shape. The aim of this paper is to propose a criterion to ensure that a lattice structure manufactured by EBM can be entirely depowdered. The objective is to use this criterion during the design phase of lattice structures to design manufacturable and depowderable parts.

2. Preliminary data and methods

2.1. Presentation of the structures

The parts that are studied here are those with lattice structure. There are various geometries of lattice structures (diamond, octet-truss, dodecahedron, …) with different properties [13,14]. Our study will deal particularly with octet-truss: this type of lattice is the best compromise in terms of mechanical properties [15].

The lattice structures are made by a unit cell that is repeated in the three directions (Fig. 2). Three parameters define this cell: the mesh size

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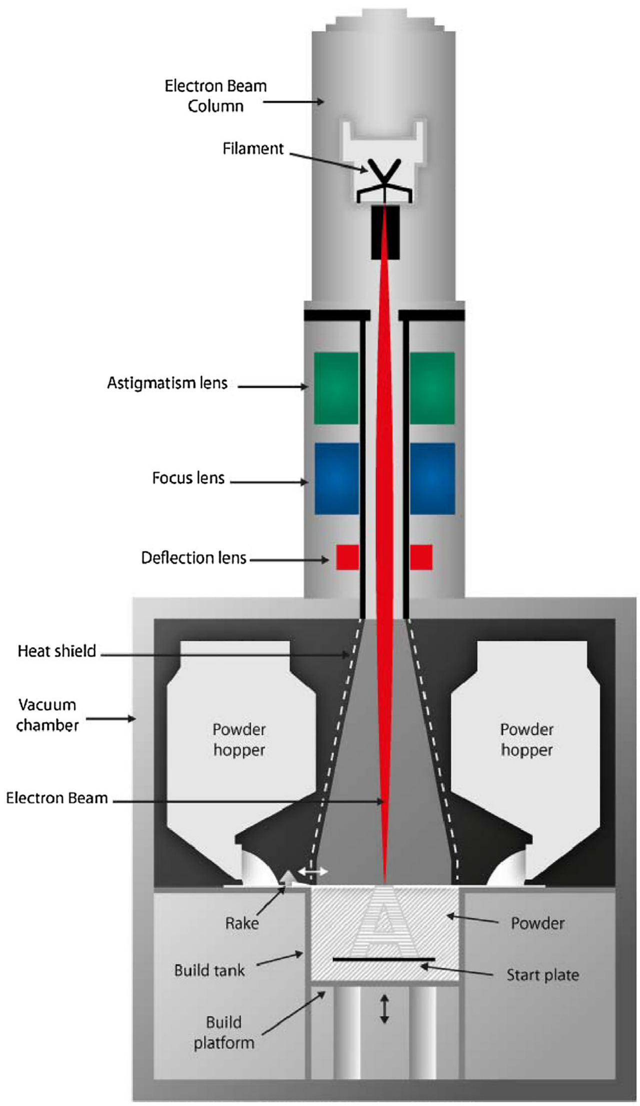

Fig. 1. Architecture of an EBM machine [10].

p, the bars thickness e, and the density of the lattice structure d in percentage. One parameter is given by the value of the two others, so only two of them must be chosen.

The CAD is realized thanks to a macro that creates a cell with fixed p and e, and then this cell is repeated in the three directions. The density d in percentage is the ratio between the structure volume given by the CAD software and the full cube volume with the same external dimensions of the lattice structure. The manufacturing is prepared with Magics software [17] that allows to place and to orientate the parts on the support plate, and to take into account correcting coefficients due to thermal constraints during manufacturing (the geometry is not affected by any electrical effects).

The hypotheses taken and the boundaries of this study are:

- The structure density must be the same than the cell density; so the number of repetitions of the cell in the three directions must be an integer.
- The standard parameters of the EBM machine are used for manufacturing the part.
- Depowdering is studied only in one direction: the removed powder has to go out of the structure through the depowdered face. In that goal, the parts will have a "skin" on five faces, and the last one will be open (Fig. 2, right). This makes the worst case, because in a real case with an open lattice, the powder will go out through all faces, and the depowdering would be easier.
- The PRS system is used to depowder the parts, with a pressure of 5 bar, which is the maximum allowable value to allow optimal depowdering. The depowdering is done during 3 min: some studies show that it permits to remove more than 90% of the consolidated powder [12].

The structures studied can be divided in three groups: the first is composed of 8 unit structures (the unit cell is only repeated in the height), and 12 lattice structures (the unit cell is repeated in the three directions) with mesh sizes between 4 mm and 15 mm. Those 20 parts have a density of 25%: this value is the best compromise between a light structure and a good rigidity, and allows a large choice of mesh size and bars thickness. The widths of the lattice structures are 24, 30 and 36 mm, and the heights of the 20 parts are from 48 mm to 63 mm, to satisfy the hypothesis of an integer number of repetitions.

The second group is composed of 8 square cylinders, with a width between 4 mm and 15 mm, and a height of 49 mm (for a comparison with available data on depowdering circular cylinders [12,16]).

In the third group, there are 22 lattice structures with a density between 3% and 66% and mesh sizes between 4 mm and 12 mm. The width and the height are 24 and 30 mm. Those parts will permit to have a larger range of results.

2.2. Calculation of the depowdered height

Each part is weighed before and after depowdering: so the initial mass m_i and the final mass m_f are known.

For the square cylinders, the depowdered height is calculated as follows, with S the hollow section and ρ_c the density of the consolidated powder:

$$h_d = \frac{m_i - m_f}{S \cdot \rho_c} \quad (1)$$

For the lattices, the structure is more complex. In particular, the 1 mm thick skin is extended around the open face, to create a step that permits not to begin the lattice on the start plate (Fig. 3).

For calculations, h_t is the lattice height, S the lattice section, $V_{p,i}$ the initial volume of consolidated powder in the whole structure

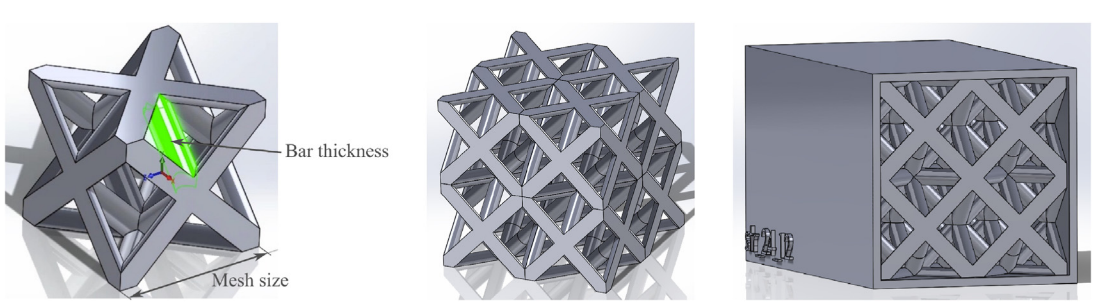

Fig. 2. Unit cell (left) and lattice structure.