

Simulation of energy absorption behaviour of structures manufactured by LENS technology

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Abstract

Dynamic development of additive manufacturing (AM) techniques allows obtaining products for various applications, including new aerospace, medical or engineering structures. This paper presents numerical modeling of gradient cellular structures manufactured using AM technology LENS (Laser-Engineering Net Shaping). Finite element modeling (FEM) is aimed at analyzing behavior of structures subjected to quasi-static and dynamic loads (analysis of deformation and damage process prediction). FEM is a useful tool for supporting a classic experiment, due to its relatively low cost and time consumption.

Keywords: additive manufacturing, LENS technology, finite element method, energy absorption

1. Introduction

The main aim of this study is to present development of a numerical model of regular cellular structures made of Ti-6Al-4V subjected to static and dynamic loading conditions. The structures are obtained LENS technology. Numerical analysis allows for optimization of the geometrical form of the cell structure with respect to its energy absorption properties.

2. Design of gradient cellular structures

LENS technology allows obtaining high-quality, geometrically complex, near-net shaped components in a single step procedure, which reduces the production cost and time. In addition, a unique feature of this method is a possibility to repair or modify machine parts in service.

In Figure 1, the scheme of the LENS system is shown. A high-power laser is used to melt the target surface, whereas a stream of powdered metal is provided in a specified area. The working chamber is filled with the inert gas (usually argon) in order to maintain high density and good mechanical properties of the material. The material may be applied at different angles, which favors the production of parts characterized by complex geometry. The mechanical properties of products obtained using LENS technology are comparable to the properties of cast or forged elements. [1]

During the manufacturing process, there are significant temperature gradients resulting from alternating rapid heating and cooling of the finished product layer. As a result, a high residual stress (equal even to the yield stress of a given material) is introduced to the structure. In order to reduce the residual stress, the heat treatment is often applied, thus, the ductility and strength of structure are significantly improved. [2]

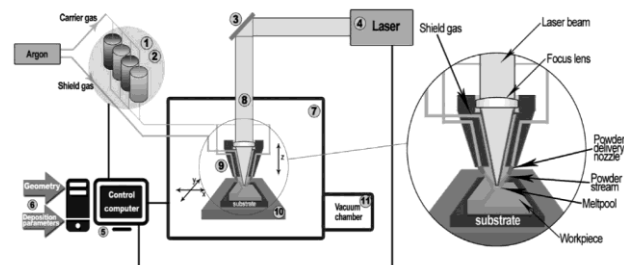


Figure 1: Scheme of the LENS system [1]

2.1. Investigation on Ti-6Al-4V

Ti-6Al-4V is the most commonly used titanium alloy, due to its good biocompatibility, good corrosion resistance, high strength and low relative density.

It should be noticed that mechanical properties of the alloy are closely associated with the obtained type of the structure and the applied heat treatment conditions. In the case of LENS technology, it is possible to obtain α' and $\alpha+\beta$ phase of Ti-6Al-4V alloy.

Figure 2 illustrates the microstructure of the considered alloy without heat treatment. There are two phases visible: lamellar martensitic α' phase (light areas) and low-temperature ductile β phase (dark areas). Furthermore, many of pores which number and shape is closely related to the process parameters such as laser power or scanning speed, can be also noticed. Pores are treated as a notch - a place of local stress concentration and potential crack initiation. [3]

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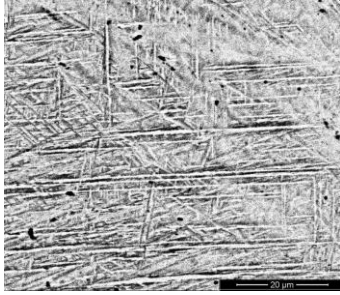


Figure 2: Optical micrograph of Ti-6Al-4V

A characteristic property of products obtained with additive manufacturing methods is the anisotropy of mechanical properties. The products show greater (around 10%) structural strength in the direction consistent (parallel) with the direction of layer deposition. [4]

2.2. Energy absorption

Energy-absorbing structures are capable of dissipate kinetic energy. The main energy absorbing mechanism is conversion of kinetic energy into—work of erosion (crushing, breaking, damaging, loss of stability, interlayer interaction) of the structure. Therefore, they should be designed with the use of thin-walled elements. Furthermore, for the destruction process, to it is essential not to extend rapidly but rather as progressive failure, which means that each volume of the sample should erode to the smallest possible pieces.

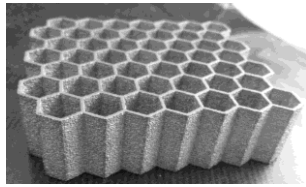


Figure 3: Honeycomb structure Ti-6Al-4V obtained with the use of LENS technology

3. Numerical model development - idea

Local geometric imperfections (in the considered pores) can cause local stress concentrations which are essential for initiation and development of cracks in this area. To implement an influence of local imperfections on the entire structure, a two-step analysis may be used (Fig. 3).

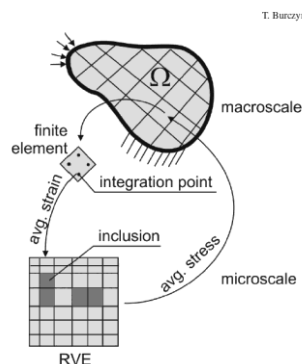


Figure 4: Multiscale modeling scheme [5]

At the first stage of the analysis, a condition of displacement of the mechanically loaded structure is determined without considering imperfections. At the second stage, the loads obtained from the first stage are applied to the local area with imperfections, which allows finding local stress concentrations.

Numerical simulations represent—the uniaxial compression tests of structures with various geometries presented in Figure 3.

3.1. Constitutive modeling

As a material model, the constitutive Johnson Cook model available in library materials of LS-DYNA software is implemented. The model expresses flow stress as a function of strain, strain rate and temperature effects [6]:

$$\sigma_y = (A + B\bar{\epsilon}^n)(1 + c \ln \dot{\epsilon}^*)(1 - T^{*m}) \quad (1)$$

where strain at fracture is given by:

$$\epsilon^f = \max([D_1 + D_2 \exp D_3 \sigma^*][1 + D_4 \ln \dot{\epsilon}^*][1 + D_5 T^*], EFMIN) \quad (2)$$

EFMIN – the amount of plastic strain before fracture

Constants D_1 - D_5 will be designated experimentally on SHPB (Split Hopkinson Pressure Bar).

4. Conclusions

Using a specific numerical modeling methodology, it is possible to examine the process of energy absorption of structures manufactured with LENS technology. A multiscale approach is preferable to analyze such structures and it will be used to perform geometry optimization. The obtained results will be validated based on experimental tests.

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