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Strain concentrations in BCC micro lattices obtained by AM

L. Boniotti*, S. Beretta, S. Foletti, L. Patriarca

Politecnico di Milano, Dept. Mechanical Engineering, Via La Masa 1, 20156 Milano, Italy

Abstract

The micro-lattices produced by additive manufacturing process (AM) represent a recent important advancement for engineering structural applications, in particular for weight-saving purposes. The design of the components manufactured with these meta-materials generally refers to the idealized structures. In reality, the geometry obtained by the AM process profoundly differs from the original one, in particular local geometrical irregularities were found to produce local stress and strain localizations which are difficult to be a-priori predicted by the analyses on the idealized structures. These geometrical defects may have a significant role for the structural integrity of the component and it is important to quantify their effect on the local stress and strain fields. In this study, we present an experimental investigation of a typical AlSi10Mg micro-lattice, namely the BCC cell. 3D tomography was used to reconstruct the original geometry and, successively, full-field digital image correlation strain measurements were performed to capture the localization of strains which are considered the precursor of the micro-lattice damage. The local strain measurements were used to calculate and classify the strain concentration factors arising from the geometrical irregularities. These results were compared with the finite element results obtained for the idealized and the real micro-lattice geometries providing important considerations for the structural integrity assessment of the components produced with the AM micro-lattices.

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Keywords: Additive Manufacturing, 3D tomography, Digital Image Correlation, Strain localization

* Corresponding author. Tel.: +039 02 2399 8248.
E-mail address: laura.boniotti@polimi.it

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1. Introduction

Nowadays, the additive manufacturing (AM) process enables the fabrication of complex geometric shapes, such as the lattice and the cellular structures, which imparts a profound improvement for manufacturing mechanical structures where the weight is a crucial design parameter, for example for the aerospace industry. The main advantage of using AM to produce lattice structures is the design flexibility, which is almost unconstrained from the manufacturing process [1]. Selective Laser Melting (SLM) is an AM technology capable of producing functional prototypes with complex geometries and thin structural walls. In SLM technology, the metallic powders are molten layer-by-layer by the laser energy to produce dense metal parts. Aluminum alloys have been found to be very attractive for manufacturing parts characterized by relatively good mechanical properties and a high strength to weight ratio [2]. The construction of small metallic parts with complex shapes and high resolution is feasible only using this process route [3]. Metallic micro-lattices consist of micro struts stacked in different arrangements where the volume fraction of the metal is much lower than the one of the metamaterial so obtained. Relative density and strut stacking are the prime design variables of this ultra-light material and the mechanical properties can be engineered by controlling these parameters [4]. For this reason, micro-lattice materials can be considered as a uniform material at the macroscale [5] while, at the microscale, the structure is detailed as formed by joined struts [6-7].
One of the most relevant problem is that the design of the components manufactured with these meta-materials generally refers to the idealized structures. In reality, the geometry obtained by the AM process profoundly differs from the original one [8-9-10], in particular local geometrical irregularities were found to produce stress and strain localizations, which are difficult to be a-priori predicted by analysing the idealized structures. All these defects can lead to the failure of the structure and, therefore, it is crucial to analyze the stress and strain concentrations inside the unit cells in order to improve the design of these microstructures.

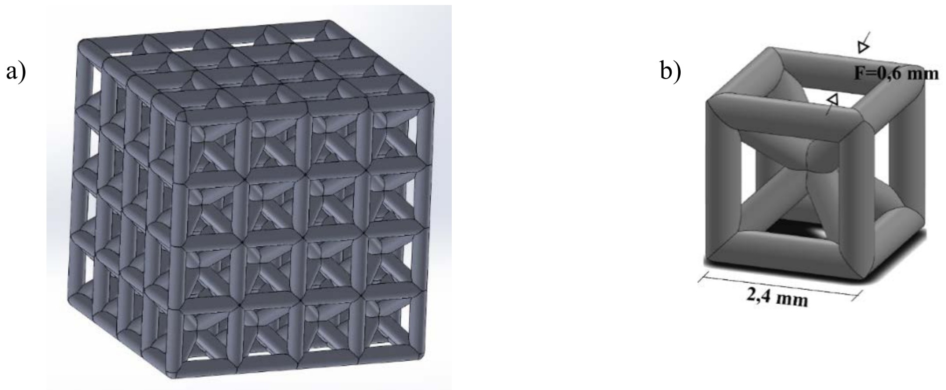

Figure 1. (a) Ideal geometry of the specimen; (b) BCC ideal unit cell. (aggiungere sistema di rif)

This work presents an experimental investigation of a typical AlSi10Mg micro-lattice, namely the BCC cell (Figure 1a, 1b). The 3D tomography [11] was used to reconstruct the original geometry for a detailed model of the lattice structure for the sake of analysis. Successively, full-field digital image correlation (DIC) strain measurements were performed during a compressive test to capture the localization of strains, which are considered the precursor of the micro-lattice damage. Then the geometrical defects were classified in three groups according to their origin and a strain concentration factor K_ε was introduced to quantify these localizations. The local strain measurements were used to calculate and classify the strain concentration factors arising from the geometrical irregularities.

The experimental results were compared with the elastic finite element (FE) results obtained for the idealized and real micro-lattice geometries providing important considerations for the structural integrity assessment of the components produced with the AM micro-lattices.