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21. Uluslararası Metalurji ve Malzeme Kongresi

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KONGRE BİLDİRİLER E-KİTABI

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THE EFFECT OF THE JOHNSON COOK DAMAGE PARAMETERS ON THE CRUSHING MODES OF AN ELECTRO-BEAM MELT ADDITIVE PROCESSED Ti6Al4V BODY-CENTERED-CUBIC LATTICE STRUCTURES

H. İrem ERTEN, Burak HIZLI, M. Arslan Bin RIAZ, Samed ENSER, Mustafa GÜDEN

Izmir Institute of Technology
Türkiye

Keywords: Additive Manufacturing, Ti6Al4V, Body-Centered-Cubic Lattices, Damage Modes, Modelling

Abstract

Additively manufactured titanium alloys show an impressive energy absorption capacity and high specific mechanical strength. Variation in Johnson Cook damage parameters are quite effective for the crushing modes occurring in the compression simulation of electron-beam-melt (EBM) Ti6Al4V (Ti64) Body-Centered-Cubic lattices (BCC). In this study, the effects of these damage parameters were analyzed numerically and their convergence to the experimentally obtained crushing modes was investigated. Cells having 125 units with 10 mm size, 2 mm strut diameter and 2 mm face sheet thickness were fabricated for this particular study. After the lattice structures were subjected to the experimental compression test, they were simulated using the Johnson Cook damage model in the LS-DYNA program. The optimum value was obtained by comparing the crushing modes of the experimental samples and the numerical lattice models with different initial failure strains (D_1).

1. Introduction

Additively manufactured lattice structures produced from titanium and its alloys are being researched intensively due to their impressive properties like the strength of weight ratio and corrosion resistance. The current literature on the collapse modes of these structures are mixed in that the collapse mode varied between brittle strut fracture, a sudden collapse of successive layers, shear location, cell extension mode and so on [1]. Noting characterizing the material behavior under the effects such as strain, flow stress and strain rate has become a very important issue, especially in industrial applications, the present study focused on obtaining a suitable/applicable stress and strain model formulation for such lattices [2]. In this study, experimental and numerical studies were carried out to investigate the effects of Johnson Cook damage parameters [3] of EBM- Ti64 BCC lattices on the fracture modes of these structures. Initially, quasi-static compression tests were performed on 125-unit cell EBM-Ti64 BCC lattice structure samples to obtain the material parameters to be used for modelling in the LS-DYNA commercial program. To be able to use lattice structures in various applications, mechanical property characterization of mechanical properties is required. Due to the properties of the EBM method, manufacturing defects, microstructure, loading conditions and building direction have a great effect on the mechanical properties of lattice structures [4]. For this reason, parameters obtained from bulk material tests do not always give accurate results in the characterization of lattice structures and determination of crushing mode when used in numerical analysis. Also, the initial failure strain values as it affects the crushing mode of the lattice structure were investigated.

2. Experimental and Finite Element Procedures

BCC Ti64 lattices were designed using SolidWorks and fabricated with producer-set parameters using 30-110 µm (57 µm mean size) powder on the Arcam Q20+ EBM device. As shown in Figures 1(a-c), the lattice structure is manufactured with 125-unit cells, a unit cell size of 10 mm, a strut diameter of 2 mm, and a face sheet thickness of 2 mm. The z-axis is the build direction, and the tests were carried out on the y-axis which is perpendicular to the build direction. Archimedes' method was used to determine the densities and to calculate the porosity of the Ti64 lattice structure specimens accordingly. The relative density of the BCC lattice structure was determined by CAD calculation. The Maxwell criterion [5] was used to decide whether the BCC lattice structure exhibits stretching or bending dominant behavior under the effect of stress. Calculation of this collapse strength in BCC lattice structures deformed by bending-dominated was calculated using the Ashby-Gibson equation [6, 7]. Then, the compression tests were performed in the Shimadzu AG-X Universal Test Machine at $1x10^{-3}$ s^{-1} with at least three tests.

The material properties obtained from the test results are shown in Figures 2(a, b) and their approximate values are used for modelling.

After the experimental compression tests, uniaxial quasi-static compression behaviors of 125 unit-cell lattices were modeled with a strain rate of $1x10^{-3}$ s^{-1} in the LS-DYNA program as shown in Figure 3.

The modified Johnson-Cook flow stress (1) and damage equation (2) were used to model the lattices:

$$\sigma = (A + B\varepsilon^n) \quad (1)$$

$$\varepsilon_f = [D_1 + D_2 exp(D_3\sigma^*)] \quad (2)$$

In this equation, ε and σ are the true plastic strain and equivalent true strain, respectively. A are the initial yield stress and B and n are strain hardening constant. D_1, D_2 and D_3 are initial failure strain, exponential factor and triaxiality constant, respectively.Initially, the upper and lower compression heads of the device were modeled using 500 solid elements to simulate the compression test environment. The lattice structure to be analyzed is meshed in hexahedron form with a 0.7 mm element size.

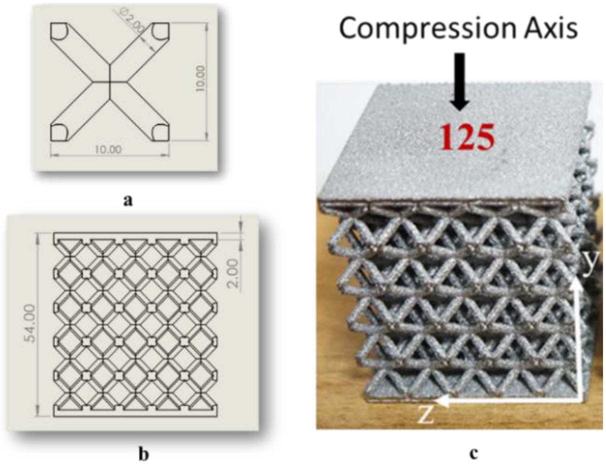

Figure 1. (a) CAD model of unit cell and (b) BCC Lattice Structure and (c) EBM-Ti64 BCC Lattice Structure

In addition, the Ti64 material was modeled with the Johnson Cook damage model using the A, B and n values in Figures 2(a, b) and the polynomial equation of state (Eos). According to the experimentally obtained data, the elastic modulus, Poisson ratio and Ti64 density in this model were entered as 107 GPa, 0.31 and 4317 kg m-3, respectively. However, the low initial failure strain value (D_1) and geometric inhomogeneity obtained as a result of the test made the lattice structure very brittle resulting in sudden failure. For this reason, new initial failure strain values that comply with the experimental results have been studied.

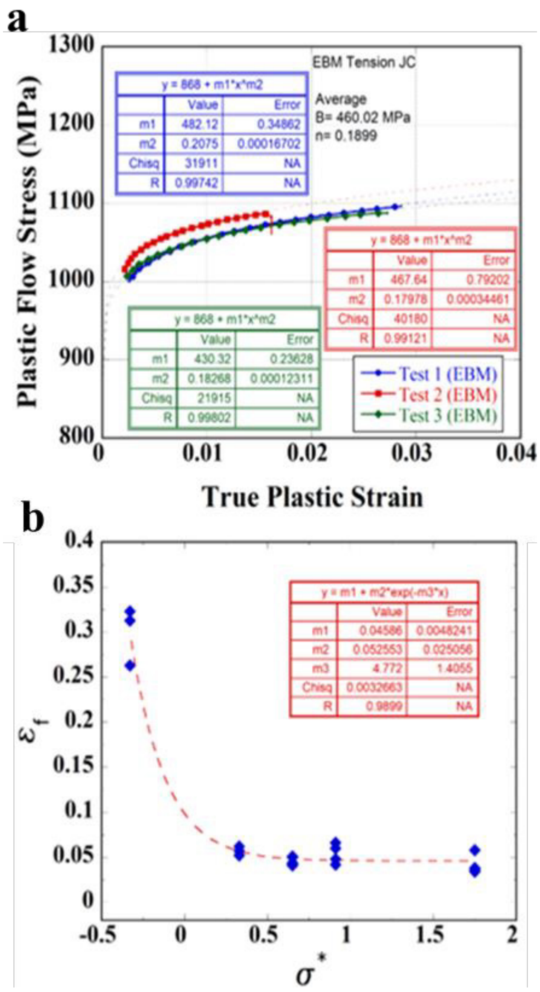

Figure 2. Determination of Johnson Cook parameters (a) A, B, n and (b) D_1, D_2 D_3 values

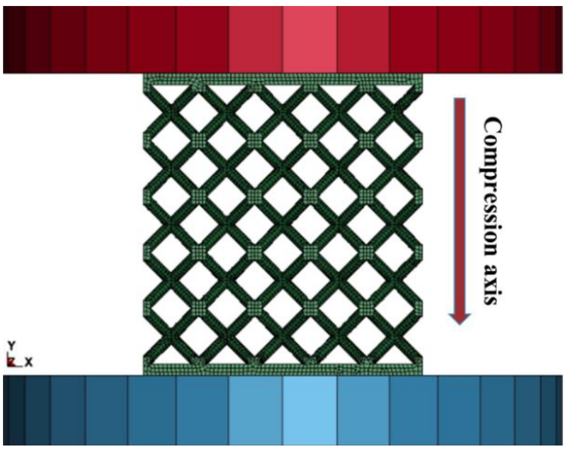

Figure 3. The compression test model of BCC lattice structure

3. Results and Discussion

The experimental and numerical stress-strain curves with different initial failure strains for BCC lattice as shown in Figure 4. As seen in the figure, the slump strength of the mesh decreases as the initial failure value decreases. Therefore, the deformation modes of lattices with different D_1 values are quite different.

It was obtained as D_1=0.04 from bulk material tests. However, the established model has not matched the test result by exhibiting a quite brittle crushing mode. Therefore, as a result of the analyzes made to obtain a reliable crushing mode in the model, the D_1 parameter was determined as 0.2. In addition, as can be seen from the figure, when D_1=0.2 in the model, the trends in experimental and simulation curves are similar.

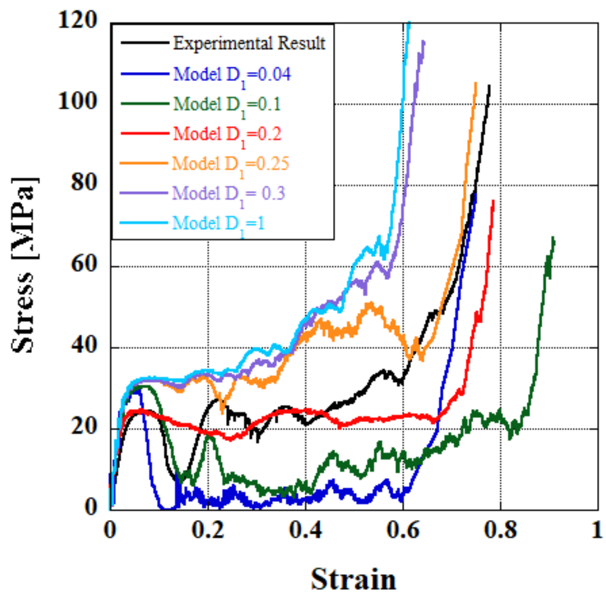

Figure 4. The stress-strain curves with different D_1 parameter

The deformation behaviour of BCC lattices with 125 cells can be seen in Figure 5. A comparison has been made between the deformation shapes for several initial failure strain (D_1) values at different strain rates. When the values of D_1 were 0.04 and 1 we can see no correlation between the experimental and numerical deformation behaviours. But for the D_1 value of 0.2, we see strong similarities in the bending behaviour of the lattices. This value of failure strain gives comparable results between experiments and simulations

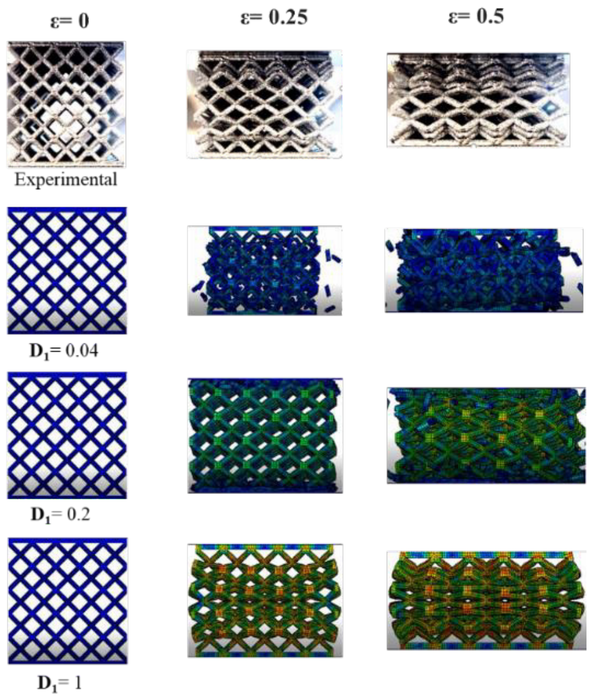

Figure 5 The experimental numerical deformation stage of Ti64 BCC lattices at different strains and initial failure strain

4. Conclusion

In conclusion, experimental and numerical studies were carried out to investigate the effect of Johnson-Cook damage parameters on the fracture modes of EBM-Ti64 BCC lattice structures. The Johnson-Cook damage model values obtained from the tests of a bulk material showed a crush mode mismatch between the model and the test. A correct material damage parameter is necessary for the reliable modelling of a lattice structure. Therefore, an optimization study was performed on the D_1 value (0.04) in order to capture the crush mode obtained from the test. As a result of the study, when the D_1 value was taken as 0.2, it was found that the test and model stress-strain curves converged with each other in a better way.

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