Numerical modelling of dynamic compression tests on multi-layer Origami plates

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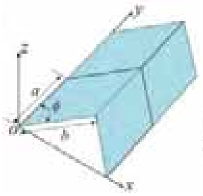
Abstract: *In this work, the dynamic response of multi-layered Origami plates subjected to uniaxial compression tests has been numerically analyzed. The plates are based in the Miura-Ori single cell, which is defined through four independent geometrical parameters: two side lengths a and b, sector angle ϕ and folding angle θ. Four-layer specimens have been considered, and two different configurations: homogeneous or graded stiffness structures. Experimental results, involving quasi-static compression tests published in the scientific literature, have been used in order to validate the developed numerical model. The results show the influence of compression velocity: the slope of the densification area is higher as the compression velocity increases and the apparition of waves due to dynamic effects is more pronounced for higher velocities.*

1. Description of the Problem

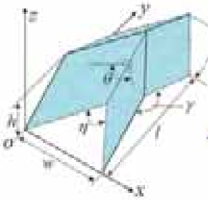
The problem analyzed consists on the uniaxial compression test of multi-layer Origami plates, in dynamic regime. The base geometry is the Miura-Ori unit cell, which can be defined using four independent geometrical parameters, which lead to six new geometrical entities defined by the following equations:

$$\cos\gamma = \frac{\sin^2\phi\cos^2(\theta/2) - \cos^2\phi}{\sin^2\phi\cos^2(\theta/2) + \cos^2\phi} \qquad \cos\eta = \sin^2\phi\cos\theta + \cos^2\phi \qquad w = 2b\cdot\sin(\eta/2) \qquad l = 2a\cdot\sin(\gamma/2) \qquad h = a\cdot\cos(\gamma/2) \qquad v = b\cdot\cos(\eta/2)$$

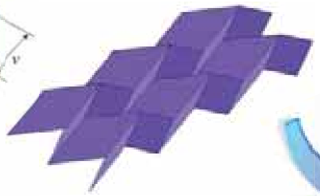
Geometrical parameters of the Miura-Ori unit cell



Unfolded Miura-Ori Unit Cell [1]



Folded Miura-Ori Unit Cell [1]



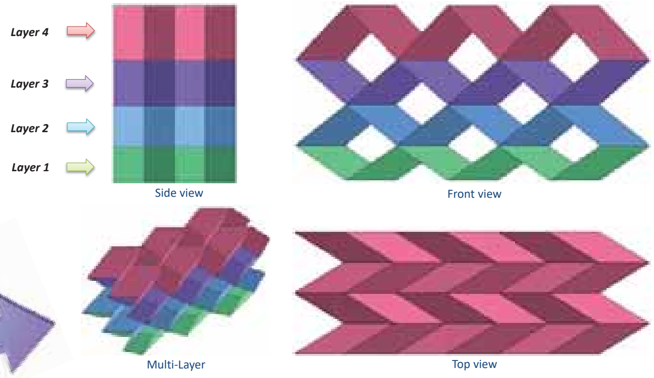
Single Layer

1.1. Configurations analyzed:

- Homogeneous structure: $\phi_1 = 48^\circ$ $\phi_2 = 48^\circ$ $\phi_3 = 48^\circ$ $\phi_4 = 48^\circ$
- Graded structure: $\phi_1 = 42^\circ$ $\phi_2 = 46^\circ$ $\phi_3 = 50^\circ$ $\phi_4 = 54^\circ$

1.2. Geometry of the graded structure:

To create a 3D structure with geometric gradient, layers with different sector angles are stacked in the out-of-plane z direction. In this case, the geometrical parameters must fulfil some additional constraints



$$a_j = \frac{a_1\cos\phi_1}{\cos\phi_j} \qquad b_j = b_1 \qquad \theta_j = \cos^{-1}\left(1 - \frac{2\sin^2(\theta_1/2)\sin^2\phi_1}{\sin^2\phi_j}\right)$$

Geometrical constraints for the multi-layer structure

2. Material and Numerical Model

2.1. Material properties for Brass (CuZn40)

The material of the main structure has been considered has elastic-plastic with linear hardening equation.

Density	ρ = 8.33 g·cm^{-3}
Elastic Modulus	E = 111.1 GPa
Poisson coeficient	ν = 0.346
Yield stress	σ_b = 142 MPa
Tensile strength	σ_u = 424.9 MPa
Elongation	ε_u = 0.242

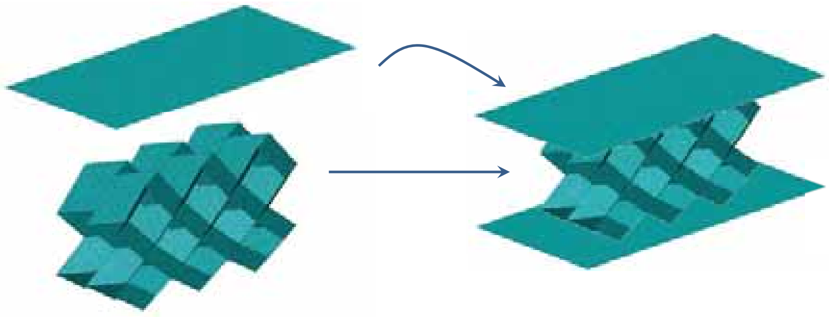
2.2. Material properties for steel:

Material considered for the compressive plates.

Density	ρ = 7.85 g·cm^{-3}
Elastic Modulus	E = 210.0 GPa

2.3. Numerical model

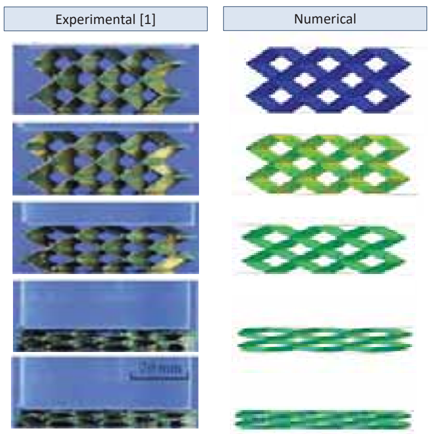
All the components, the two plates and the multi-layer origami structure, are defined as shell geometries

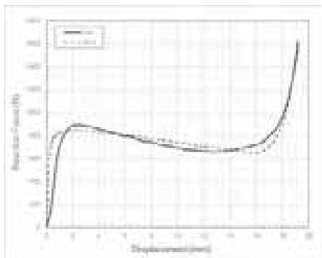


Model Information	
Number of elements	45600
Element type	S4R

3. Validation

The numerical model has been validated with experimental results presented in the literature [1]

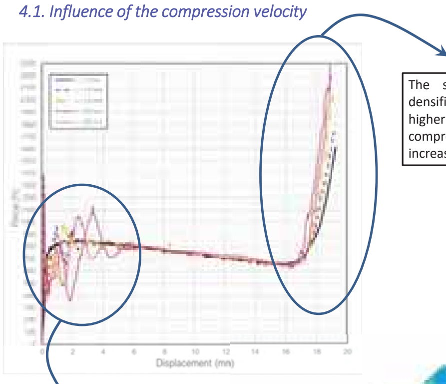




The relative error in terms of absorbed energy is **3.28 %** → MODEL VALIDATED

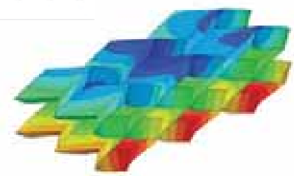
4. Results

4.1. Influence of the compression velocity



The slope of the densification area is higher as the compression velocity increases.

The apparition of waves due to dynamic effects is more pronounced for higher velocities



5. Concluding Remarks

- Using the Finite Element Method, a full 3-D numerical model of the compression tests in multi-layer metamaterial plate, has been implemented.
- The numerical model has been validated with results published in the literature, leading to a relative error of about 3 %.
- The morphological evolution of the structure during the compression process reproduce accurately the experimental observations.
- The apparition of waves in the initial stages of the compression test, due to dynamic effects, is more pronounced for higher velocities.
- The value of the displacement at which the force stabilization occurs, increases with the compression velocity.
- The slope of the densification area in the Force-Displacement curve is higher as the compression velocity increases.
- The model will be used in future investigations, analyzing different geometrical configurations.

References

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