Dynamic Crushing of Regular and Functionally Graded Cellular Structures

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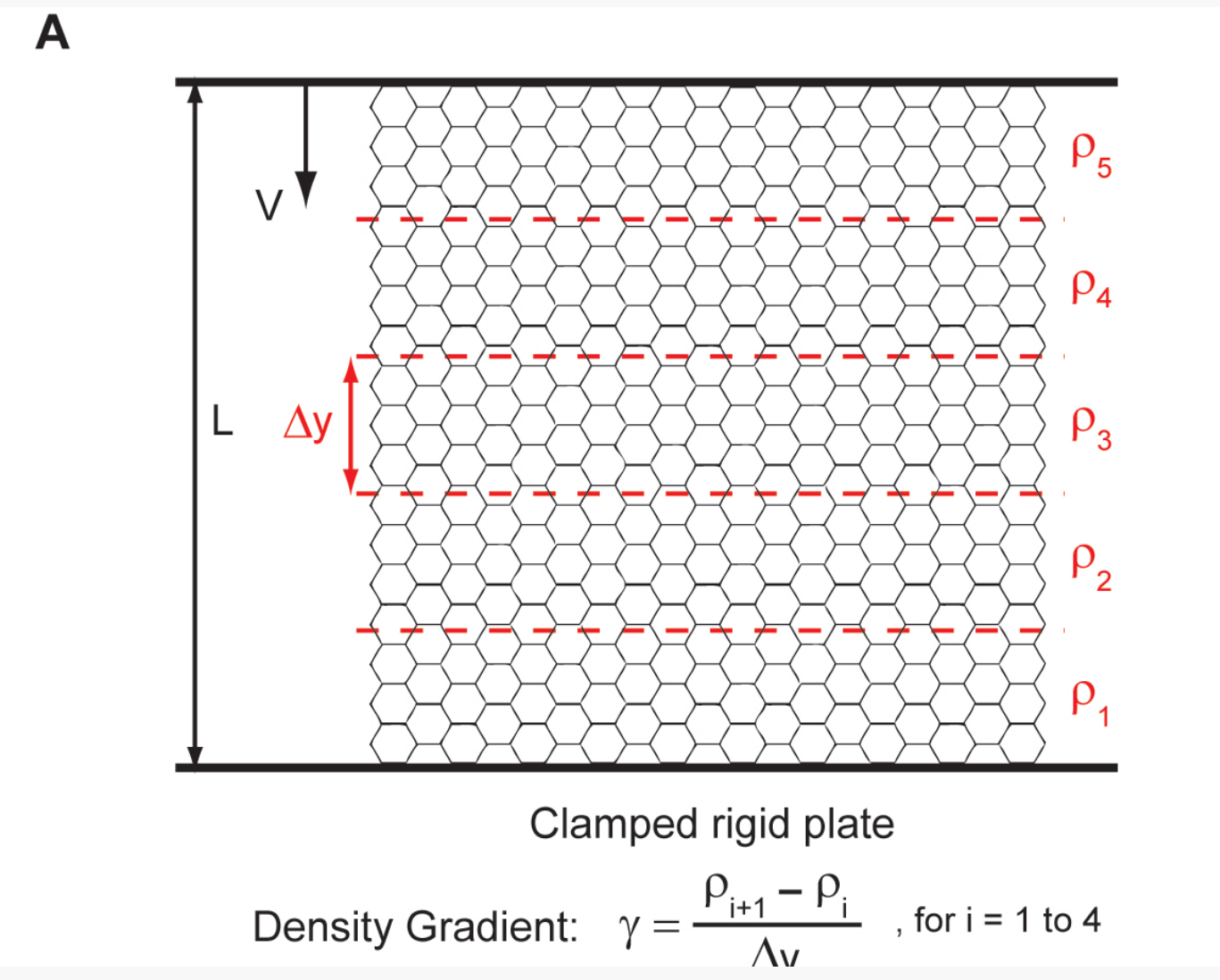
Introduction

- Metallic foams are widely used in many engineering applications due to their unique mechanical properties and energy absorption characteristics.
- Dynamic response of these structures, which involves both material and geometric nonlinearity, is governed by complex localized phenomena, including buckling and micro-inertial resistance.
- In this work, we investigated the in-plane dynamic crushing of two-dimensional cellular structures using finite element method.
- Both regular hexagonal cellular honeycomb and functionally graded materials, where the honeycomb cell size distribution in one direction results in a material density gradient, are considered and their response is modeled up to large crushing strains.

Methodology

- Models of two dimensional regular hexagonal and non-periodic Voronoi structure are developed using Matlab.
- Effect of Defects by introducing missing clusters
- Relative density gradient:



- Dynamic behavior of structures with different relative densities are investigated using ABAQUS.
- Material properties of Aluminum with elastic-perfectly plastic behavior is assumed for each cell wall.
- Mesh sensitivity analysis is performed to ensure the results are reliable.
- Normalized plastic dissipation and deformation mode shapes are compared .

Results

- A systematic study was performed to highlight the role of relative density and impact velocity, as well as the density gradient of functionally graded honeycomb structures, on the deformation shapes and the plastic energy dissipation under crushing.
- Our numerical simulations show three distinct crushing shapes of regular hexagonal cellular materials: quasi-static, moderate-rate dynamic mode and high-rate dynamic mode.
- An important dimensionless parameter governing inertial effects is $V_0/(c_0\varepsilon_Y)$, where V_0 is the relative velocity of the sandwich faces, $c_0 = (E/\rho)^{0.5}$is the elastic wave speed of the cell wall material, and E, ρ and ε_Y are the Young's modulus, density and initial yield strain of the metal. [Xue and Hutchinson 2006].
- Total plastic energy dissipation and deformation modes are compared for different relative densities and crushing strain rates; a comprehensive map is provided as a conclusion.

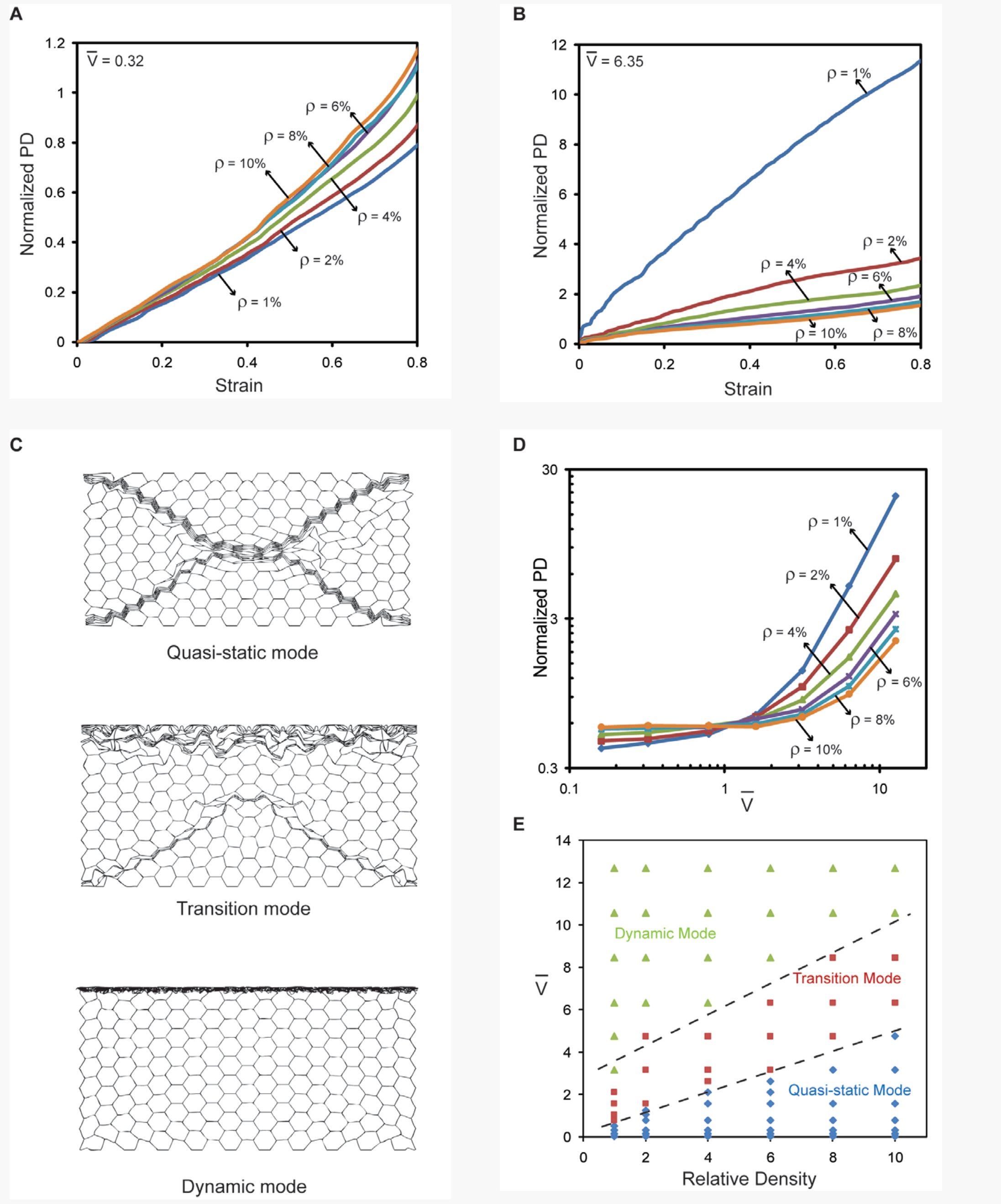


Figure 1 – Plastic dissipation for regular honeycomb structure with different densities (A) shows the comparison for low velocity crushing (B) shows the results for high velocity crushing (C) illustrates the deformation mode at 50% crushing and definition of different deformation shapes (D) is the map of PD for different velocity and different relative densities

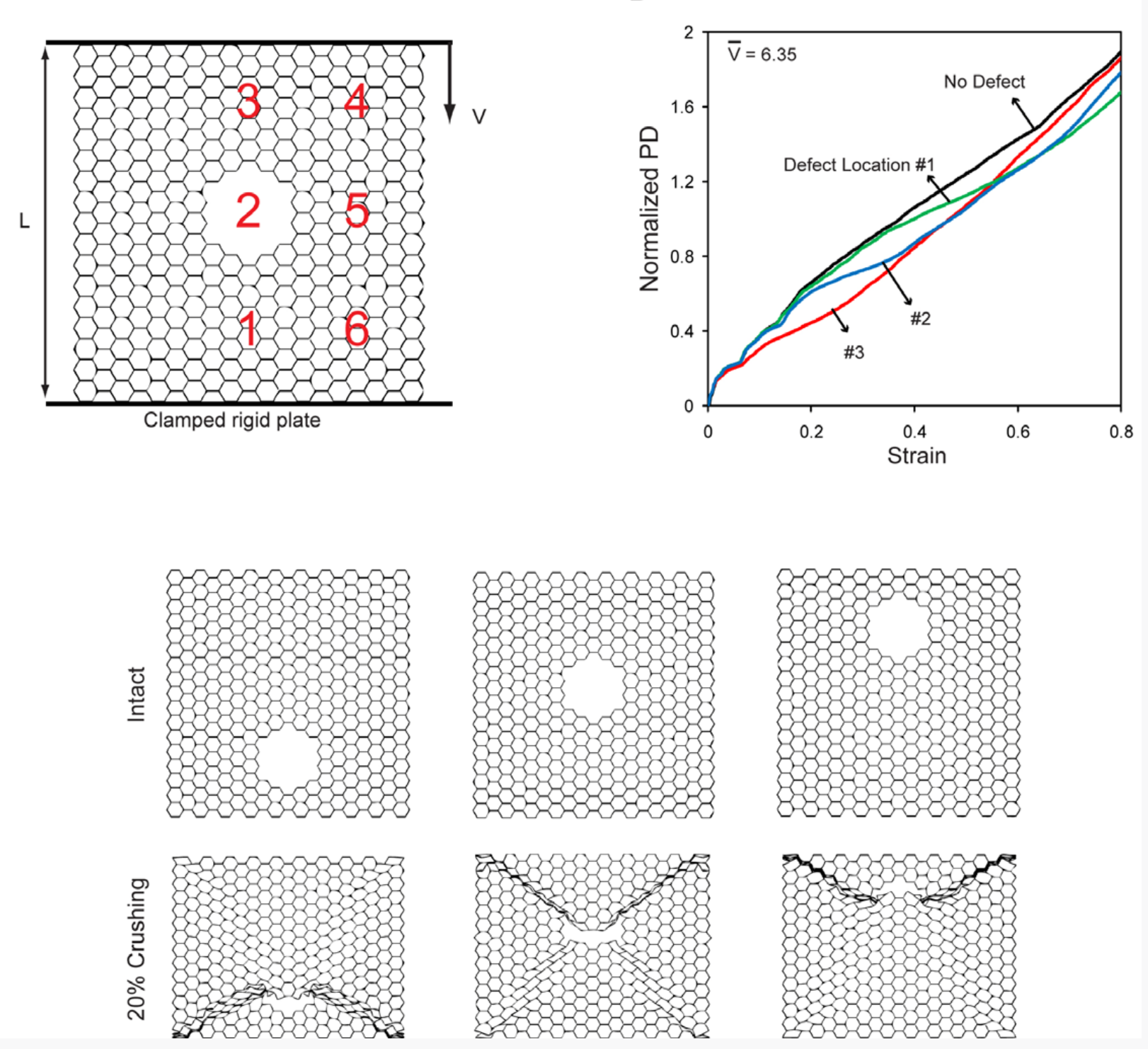


Figure 2 – Effect of defect location on PD for regular honeycombs (A) illustrates structures with different location of cluster defects (B) compares the results for Low and high velocity crushing , it also shows the results for intact structure (C) illustrates the deformation mode for three different location of cluster defects (location 1, 2 and 3 in section A)

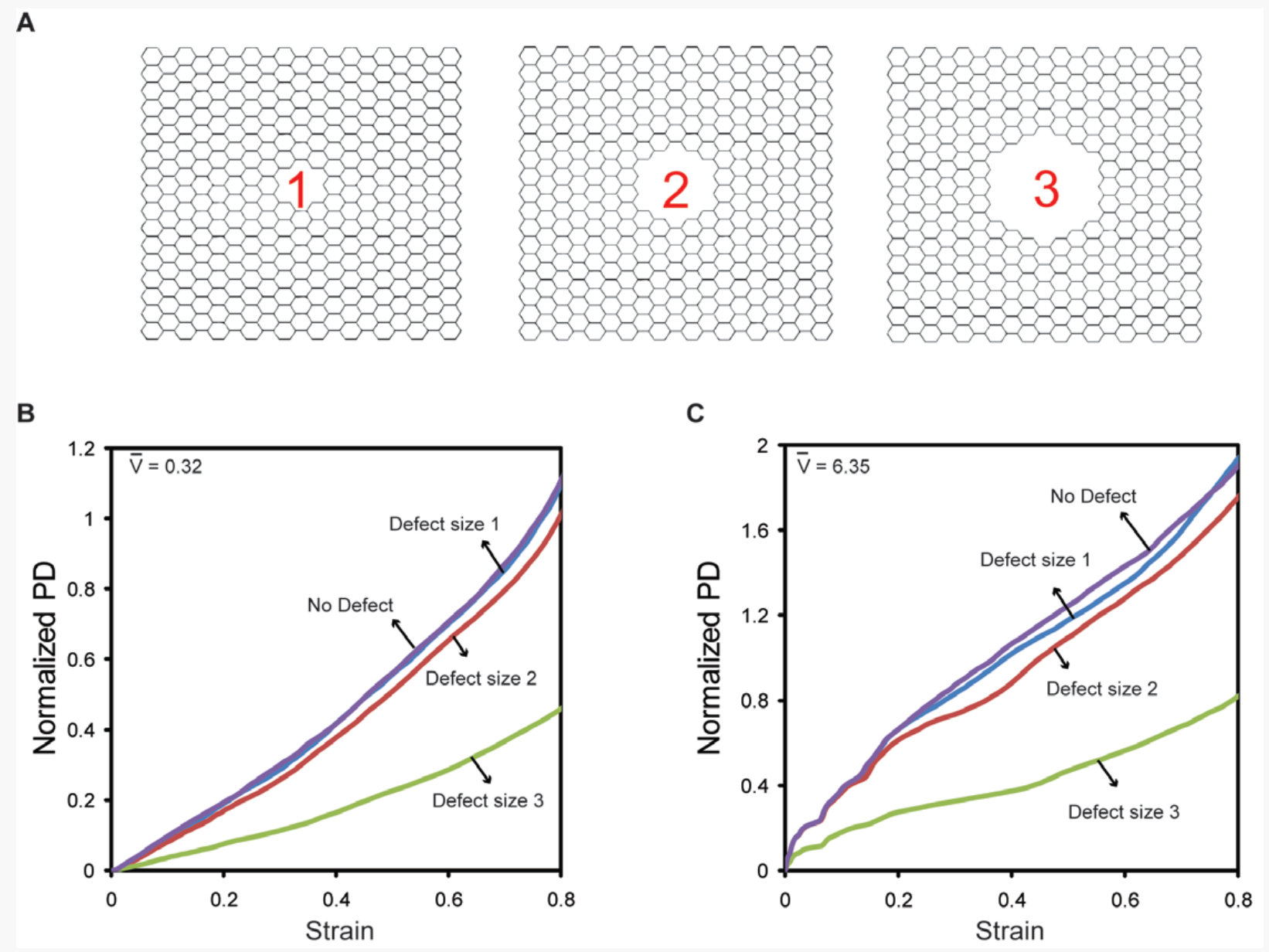


Figure 3 – Normalized dissipation for different defect size (A) illustrates the different defect size (B) compares the results for low velocity dynamic impact and (C) shows the results for high velocity impact

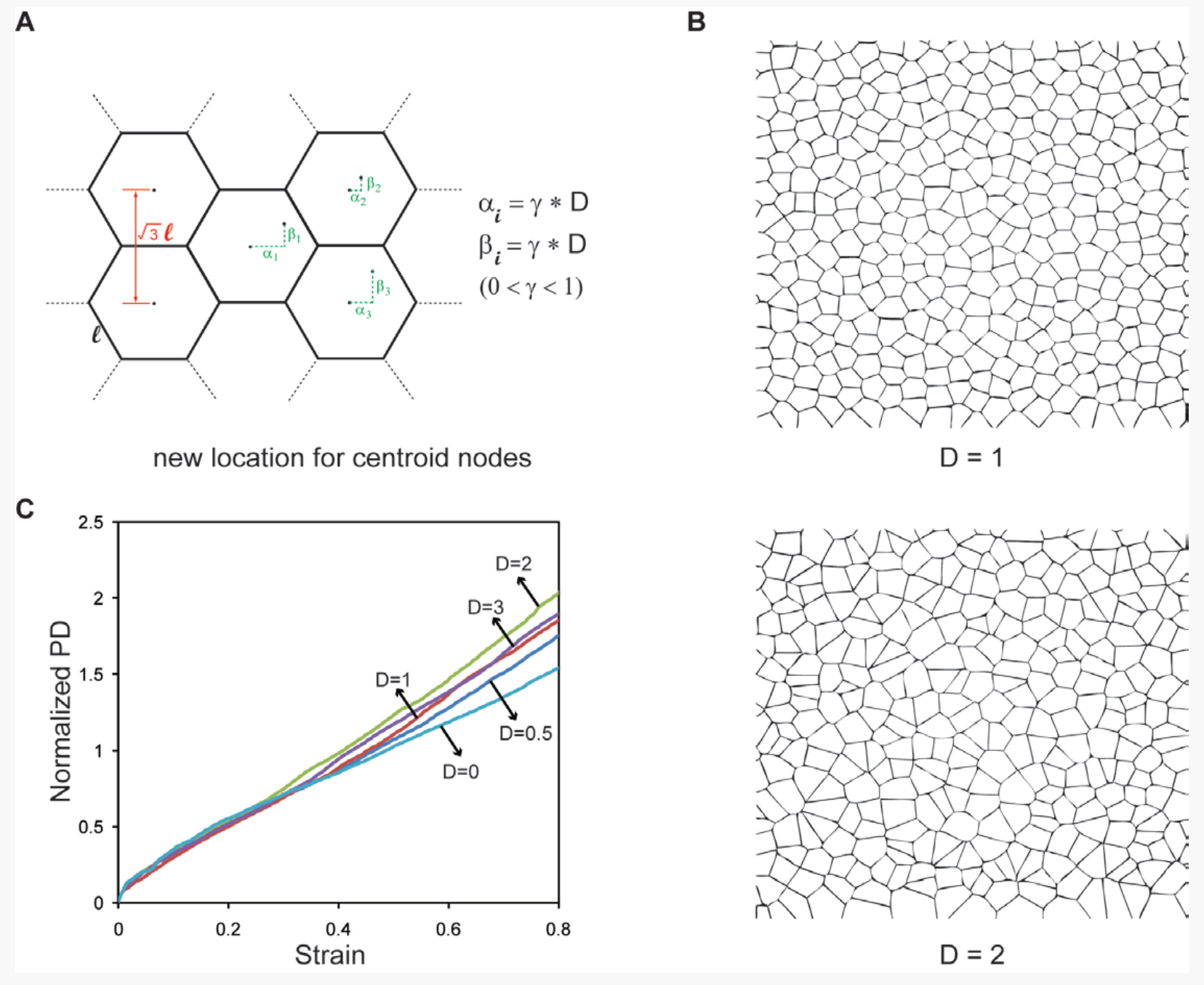


Figure 4 –Impact behavior of Irregular structures. (A) Schematic of a regular hexagonal structures and location of centroids for irregular structures where D is the maximum dislocation of the centroids and is a random number between zero and one(B) shows Voronoi structures for different value of D (D=1 and 2) (C) compares the normalized plastic dissipation of irregular structures with different values of D

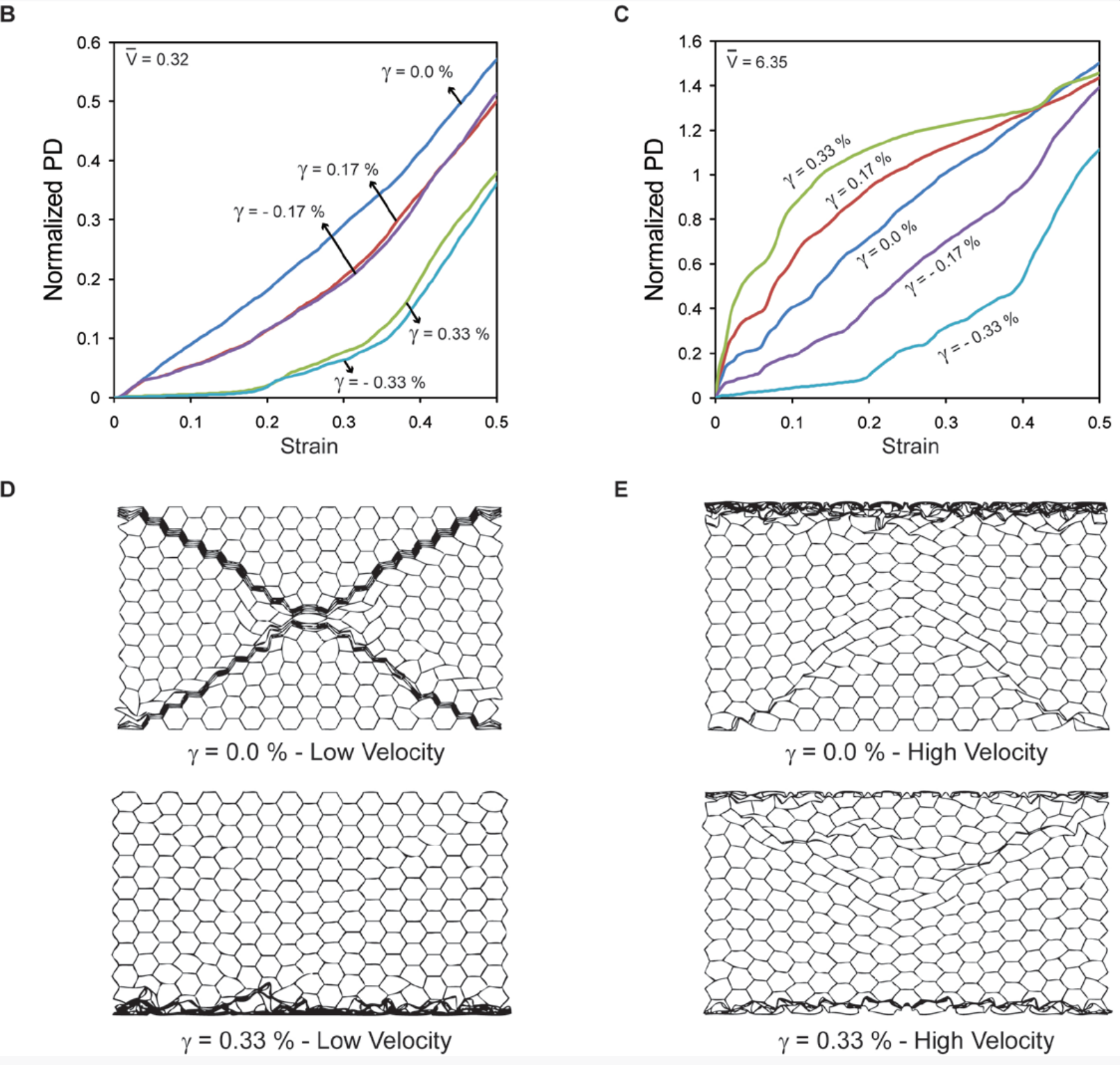


Figure 5 – Dynamic crushing of Functionally Graded structures (A) illustrate the schematic hexagonal structures where the density gradient is defined by γ (B) shows the normalized PD for regular hexagonal structures with different density gradient at low velocity (C) normalized PD for high velocity dynamic crushing (D) illustrates the deformation shape for low velocity crushing (E) illustrate the deformation shaped for high velocity impact

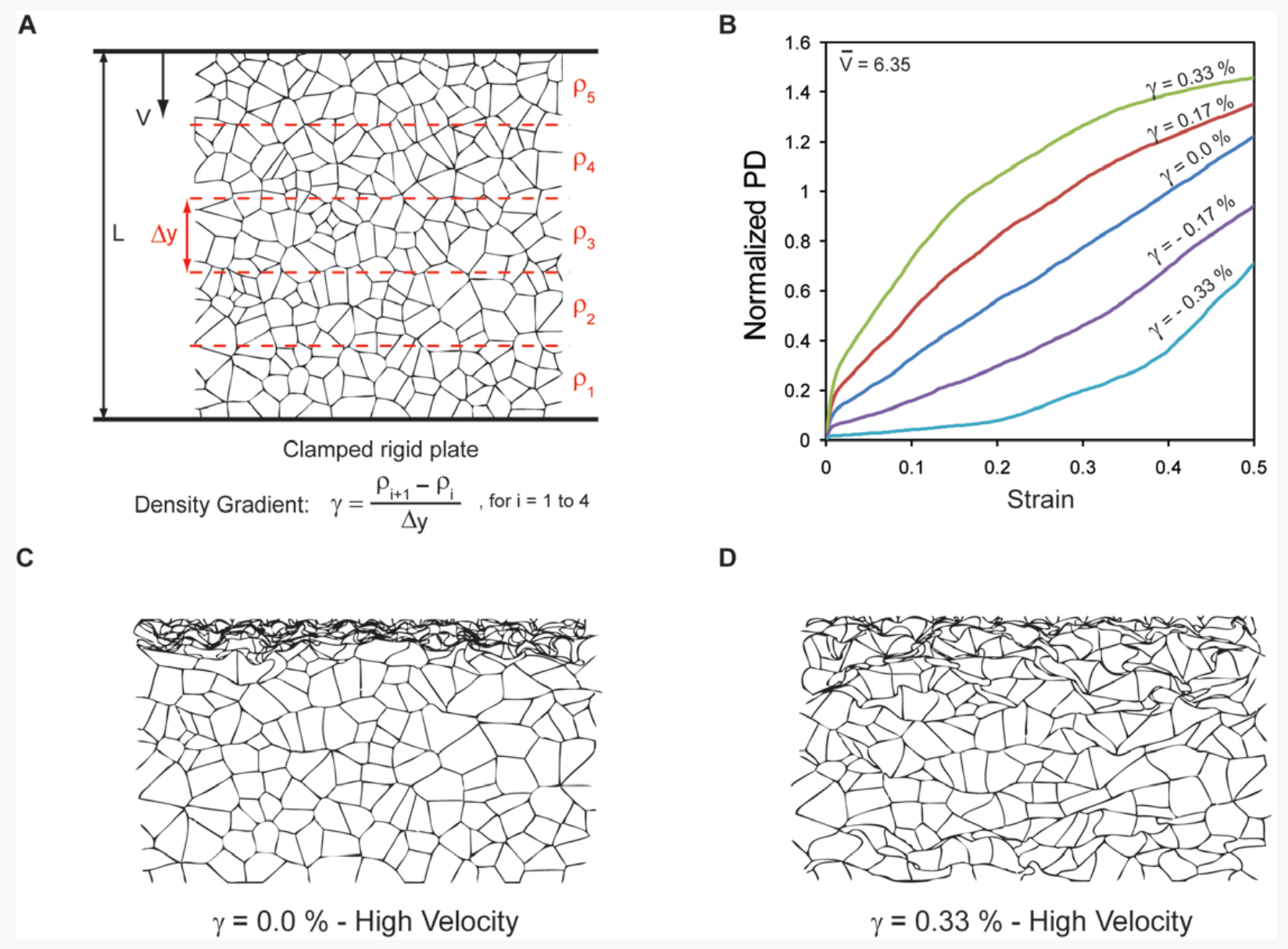


Figure 6 – Dynamic crushing of Functionally Graded Voronoi structures (A) illustrate the schematic Voronoi structures where the density gradient is defined by γ (B) shows the normalized PD for regular hexagonal structures with different density gradient at high velocity impact (C) illustrates the deformation shape for high velocity crushing for no gradient structure (E) illustrate the deformation shaped for high velocity impact for a Voronoi structure with 0.33% density gradient as defined in (A)

Conclusion

The results provide new insight into the behavior of cellular materials under crushing, and thus, may provide new avenues for development of a new class of cellular materials with enhanced energy absorption characteristics.

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