An Origami Inspired Impact Energy Dissipator

Ahmed S. Dalaq*, Shadi Khazaaleh* and Mohammed F. Daqaq *

Engineering Division, New York University Abu Dhabi (NYUAD), Saadiyat Island, UAE

Abstract. A bio-inspired Origami pattern known as the Kresling pattern can make a versatile spring that is capable of exhibiting linear, nonlinear, and bistable behavior. One of the most notable yet often overlooked attributes of this Kresling Origami spring (KOS) is its kinematics that intrinsically couples the translation and rotational degrees of freedom. We employ this attribute in the design of an energy dissipating column that transmits incident energy (loads and impacts) into rotational motion at the base of the column, that is then dissipated by dry friction. The amount of energy dissipation can be tuned by adjusting the geometric design parameters of the KOS, the friction coefficient at the base, and/or the stroke distance.

Introduction

Countless architectures emerge in nature as a result of evolutionary processes occurring at several length scales. In the entima of Hawk moths (*Acherontia atropos* [1]), lies an intricate corrugation-like architecture that is related to an Origami pattern known as the Kresling pattern. Among the many different applications inspired by this unique pattern, engineers have proposed its utilization as a nonlinear tunable spring for niche applications including locomotion, switching, vibration isolation, and impact absorption [2,3]. One key yet often overlooked attribute of a Kresling spring is its unique kinematics which intrinsically couples translational and rotational motions by a process of folding at the interfaces between the panels forming the spring [2]. Combining this attribute with recent advances in computational modeling [1] and fabrication [3] permits designing compact devices for energy capture and transfer that were, otherwise, made of bulky cams, gears, springs and traditional mechanical elements. Herein, we exploit this translation-rotational coupling to design origami-inspired impact absorbing columns made of a stack of Kresling springs, particularly intended to convert incident pulse loads or displacements into in-plane rotation. The rotational energy is then dissipated through dry-friction pads mounted at the base of the column (Fig. 1a). We develop analytical and computational models to capture the response of the proposed impact absorber and tune its behaviour to maximize energy dissipation as function of i) the number of stacked Kresling units in the column, ii) the individual geometric properties of the unit, and iii) the geometry and size of the base. An optimum design is then fabricated and tested for assessment of its intended function and performance.

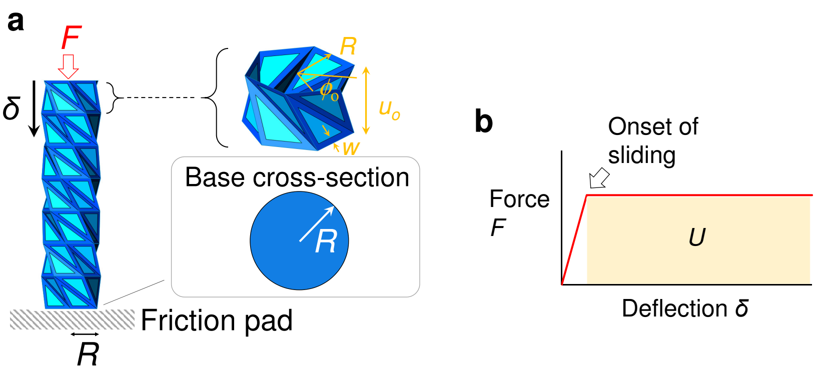

Figure 1: (a) Origami based column; (b) typical force-deflection curve as a response to incident loads.

A short note on the mechanical response

The response of ta Kresling based column made of N units depends on the geometric parameters of the Kresling unit, namely, radius R, relative angle ϕ_o, height u_o, flexible frame width w, and panel thickness t. Those parameters $(u_o/R, \phi_o, w/t)$ define the mechanical response prior to the onset of sliding. After the onset of sliding, the friction coefficient between the friction pad and the base solely dictates the ensuing force-deflection response, provided that the developed shear forces at the base maintain sliding friction during which energy U is dissipated (shaded region in Fig. 1b). The dissipated energy scales with the number of unit cells; i.e. $(U \propto N)$.

References

[1] Kresling B. (2020) The Fifth Fold: Complex Symmetries in Kresling-origami Patterns. *J. Symmetry: Culture and Science* **31**:403-416.

[2] Dalaq A. S., Daqaq M. F. (2022) Experimentally-validated computational modeling and characterization of the quasi-static behavior of functional 3D-printed origami-inspired springs. *J. Materials Design* **16**:110541.

[3] Khazaaleh S., Masana R., Daqaq M. F. (2022) Combining advanced 3D printing technologies with origami principles: A new paradigm for the design of functional, durable, and scalable springs. *J. Composites Part B: Engineering* **236**:109811.