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Tessellations in Topologically Interlocked Stereotomic Material Systems

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Topologically interlocked stereotomic material (TISM) systems are load-carrying assemblies of unit elements interacting by contact and friction [1,2]. Past research on these material systems has demonstrated attractive mechanical response characteristics, including damage tolerance, impact resistance, adaptive property control, tuneable acoustical characteristics, as well as disassembly and reuse.

In this work, we aim to expand the range of topologically interlocked material systems for which such response is found. The theory of tessellations is the underpinning to create new material systems. We present a comparative study on the deflection response to transverse loading for two underlying tessellations and boundary conditions. We demonstrate the relationship between stiffness, strength, and toughness (and their dependency on boundary conditions) and the tessellations structure. In particular, we compare the TISMs based on a regular tessellation (the square tiling $\{4,4\}$, Fig. 1(a)) and a semiregular tessellation (the truncated square tiling $t\{4,4\}$, Fig. 1(b)) [3]. The assemblies considered in this work have the same in-plane dimensions, thickness, and inter-element face angle. The $t\{4,4\}$ TISM has a volume fraction of 0.94 and the $\{4,4\}$ TISM has a volume fraction of 0.98.

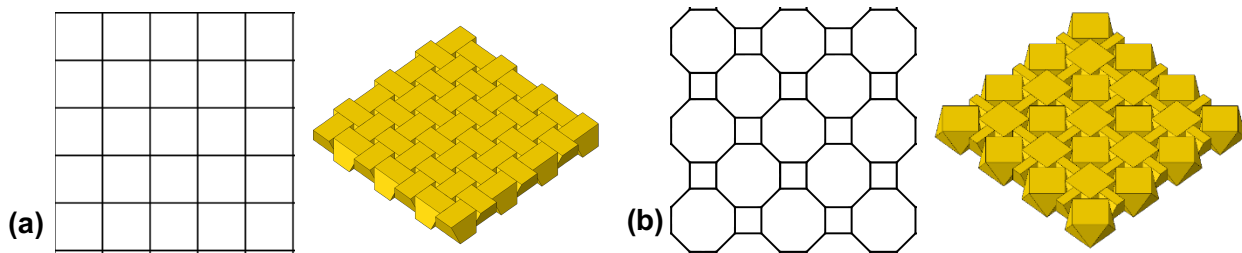


Figure 1: (a) Square tiling $\{4,4\}$ and resulting TISM. (b) Truncated square tiling $t\{4,4\}$ and resulting TISM.

The tessellation structure defined the type of displacement and rotation boundary conditions possible. The $\{4,4\}$ structure can possess two types of boundary conditions, one rotation free (simply supported) and one rotation constrained (clamped). The $t\{4,4\}$ structure, however, allows for only one type of boundary condition in which rotation of the unit blocks relative to the boundary is constrained. We show that these boundary conditions have a significant influence on the response of the structure, Fig. 2(a). In addition to the boundary condition, the load direction also influences the response. The geometry of the $\{4,4\}$ TISM is symmetric with regards to the tessellation plane so its force-deflection response is the same when loaded from either side, but the $t\{4,4\}$ TISM is geometrically non-symmetric with regard to the

tessellation plane. However, the stiffness, strength, and toughness are approximately similar for both transverse load directions of the $t\{4,4\}$, despite its asymmetry, Fig. 2(b).

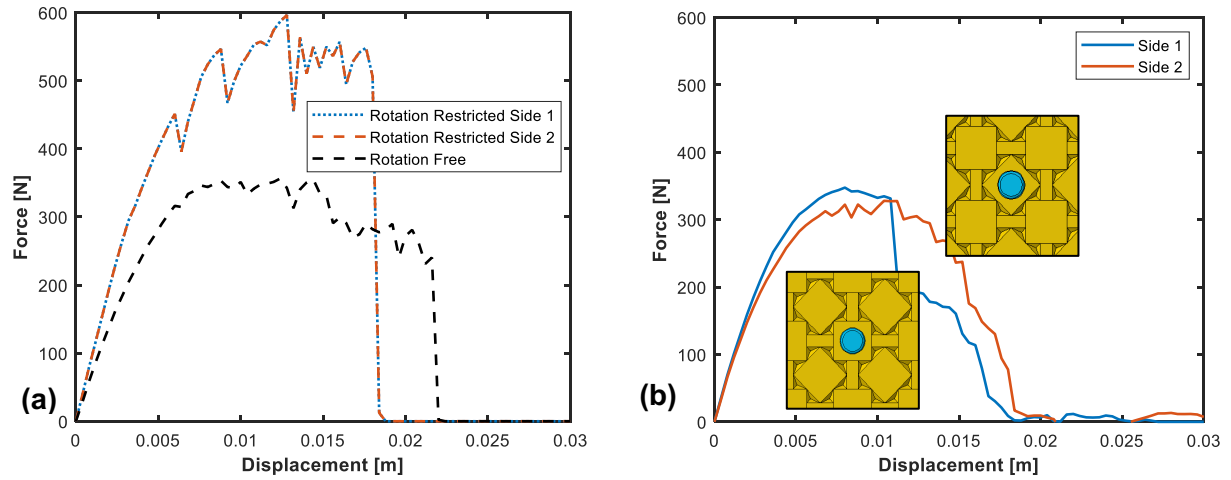


Figure 2: (a) Force-deflection response for the $\{4,4\}$ structure – dependence on boundary conditions. (b) Force-deflection response for the $t\{4,4\}$ structure – dependence on loading direction.

Prior work on a $\{4,4\}$ system composed of regular tetrahedra unit elements has shown that strongly confined load paths develop [4]. These load paths were found to be orthogonal to each other and occur normal to their respective borders. We show that internal load paths are influenced by the geometry and boundary conditions, and that they increase in complexity as the tessellation becomes more complex. Figure 3 depicts the spatial distribution of the maximum compressive principal stress in the $\{4,4\}$ and the $t\{4,4\}$ TISM, both for the rotation constrained boundary condition (the borders are not shown here). The $\{4,4\}$ TISM has load paths that are primarily orthogonal, and the load transfer into the border is greatest closest to the middle of each side. The $t\{4,4\}$ TISM has diagonal load paths at 45° in addition to orthogonal paths. It transfers load into the border primarily through the octahedral elements on each side, excluding the corner elements.

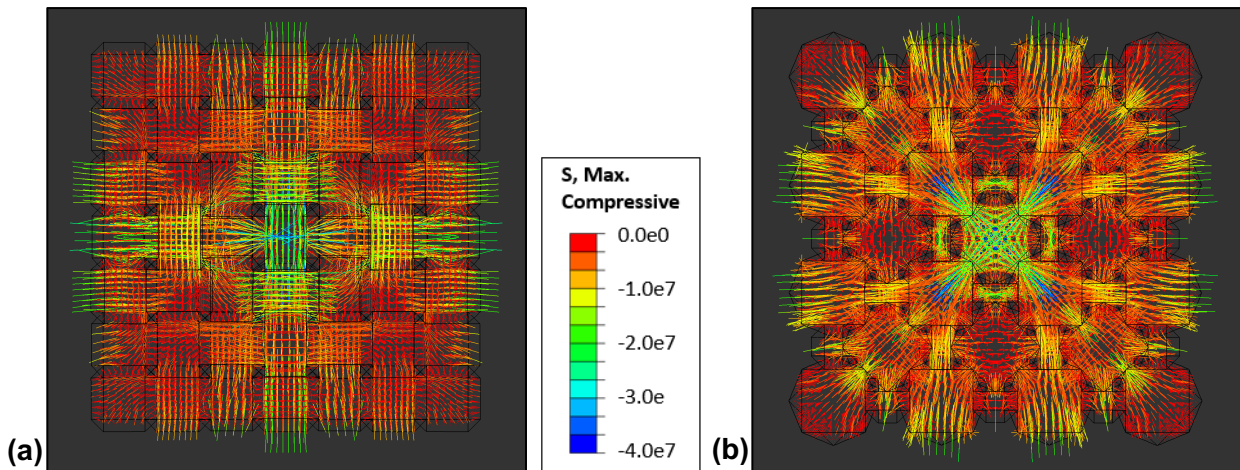


Figure 3: Computed distribution of maximum compressive principal stress for the (a) $\{4,4\}$ and the (b) $t\{4,4\}$ structures.

In summary, we show that the $t\{4,4\}$ TISM has a more complex load pattern, but the $\{4,4\}$ TISM with a similar rotation constrained border is significantly stronger and tougher than the

$\{4,4\}$ TISM despite having the same overall dimensions and inter-element face angle. Consequently, this study indicates that the tiling from which a TISM is developed has a significant impact on the mechanical properties of the TISM.

Acknowledgments

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