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MODELING AND SIMULATION OF AUXETIC MATERIALS FOR BALISTIC PROTECTION

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ABSTRACT

A type of structural metamaterials known as auxetics has a negative Poisson's ratio. Auxetic structurals have been found to possess a number of better qualities when compared to traditional ones, including: greater energy absorption, stronger indentation resistance, and enhanced mechanical properties. As a result, auxetic structures are becoming more known as a high-performance, lightweight defensive construction that can survive collisions and blasts.

KEYWORDS: modeling, simulation, auxetic materials, balistic protection

1. Introduction

Auxetic materials are of interest due to their counterintuitive behavior under deformation and enhanced properties due to negative values of Poisson's ratio. Auxetic materials' qualities must in some way correspond to the fundamental requirements of the application to be useful. Numerous elements and considerations must be taken into account when deciding which auxetic cell structure to use in a certain application [1-10].

An application's fundamental criteria must be identified first. For instance, auxetic structures are employed in some applications because of their capacity to enlarge under strain, with the size of the negative Poisson ratio (NPR) being the attribute to be focused on [11-15]. However, a minimal degree of stiffness might be necessary. Each unit cell's characteristics and constraints will reveal how well-suited it is. By altering the geometry of the unit cell, structural qualities can be changed, which will ultimately affect how the cell can be optimized for an application. If it is subjected to a stretch greater than a small one, some unit cells quickly lose their auxetic characteristics. Additionally, during the same stretch, some unit cells will suffer a localized maximum stress intensity in comparison to others. Some unit cells display auxetic activity for only one type of strain or are more restricted in that strain due to the geometry of their structure. It is crucial to take an application's required extents into account. The 2D or 3D nature of an auxetic unit cell is a crucial consideration [16-21].

2D geometry can be used to describe 2D unit cells. On the other hand, 3D unit cells require 3D geometry to be defined. While three-dimensional unit cells can display auxetic behavior in all three dimensions, two-dimensional unit cells can only do so in two of the four dimensions. As a result, 3D unit cells must be used in applications that call for an auxetic reaction in all three dimensions [22-24]. One such application is impact resistance, where the impact may be generated from an unknowable direction. The deformation mechanism of auxetic structures can be used to improve other qualities, whether through theory or practice.

In contrast to the characteristics and actions that may be seen at the cellular level, structural material attributes are the characteristics that an auxetic network displays at the macro level. There are several characteristics that are inherently auxetic, meaning they can be connected to a structure that exhibits an NPR and are not frequently observed in conventional structures. The performance is mostly determined by the geometry, not the material, because they directly depend on the special deformation mechanism of auxetic structures.

In this study, the ballistic impact behavior of auxetic sandwich composite armour was investigated.

2. Experimental procedure

In this research, a hybrid structure composed of an auxetic core was made sandwiched between front and back plates. We aim to simulate the effects of a projectile traveling at various speeds on composite auxetic sandwich armour. The Inventor Nastram program was used. The 3D model proposed is presented in Figure 1. The results were compared with monolithic armour under the same boundary conditions and speeds. The auxetic core was constructed from discrete re-entrant cellular units using 3D Inventor modeling software. The parametric geometry of the unit cell is presented in Figure 2. The Momentum and Kinetic Energy impulse of the model was converged with a fine mesh of solid tetrahedral and hexahedral elements for the auxetic armour models, with 463,835 elements and 418,512 nodes. The width of ballistic protection is 40 mm.

3. Results and discussions

Following the numerical experiments performed on the 3 D model proposed, the analysis demonstrates that the auxetic structure, as opposed to the monolithic panel, experiences a larger energy translation of a projectile's kinetic energy into elastic energy as a result of the elastic deformation of the unit cells. The auxetic structure outperforms the monolithic panel due to its better absorption capacity. Although the auxetic model experiences more deformation than the monolithic panel, the rear plate is unaffected by this deformation, elastic's dissipation. In the auxetic structure, elastic energy dissipation is stronger. The threat level is greatly decreased by the auxetic structure, which may be used at higher speeds and is secure up to 450 m/s.

The Figure 4 shows the projectile penetration and response behavior of the auxetic core. In the, the penetration is minimal and the energy absorption is mostly elastic, shown by deformation patterns in auxetic cells. It was noticed that the front face was slightly damaged after projectile impact. Auxetic cells could be observed vibrating frequently as the projectile was ricocheting.

It has been shown that due to the sufficient densification and indentation resistance provided by the auxetic core, the projectile cannot penetrate the rear face plate, up to a projectile velocity of 450 m/s.

The auxetic structure is safe up to 450 m/s and can be used at higher speed, significantly reducing the threat level. At 650 m/s, the rear face is damaged.

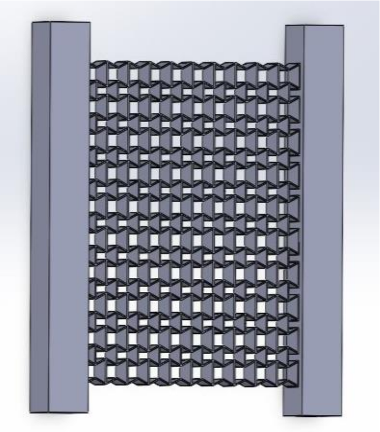

***Fig. 1.** 3D model proposed*

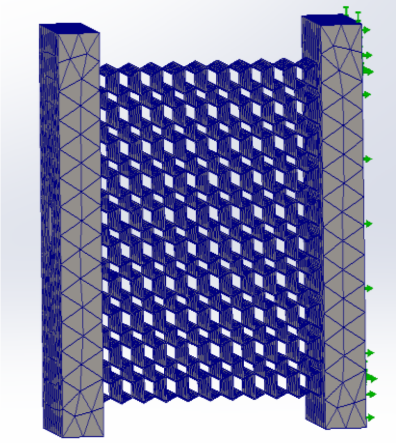

***Fig. 2.** Mesh model for analyzed area*

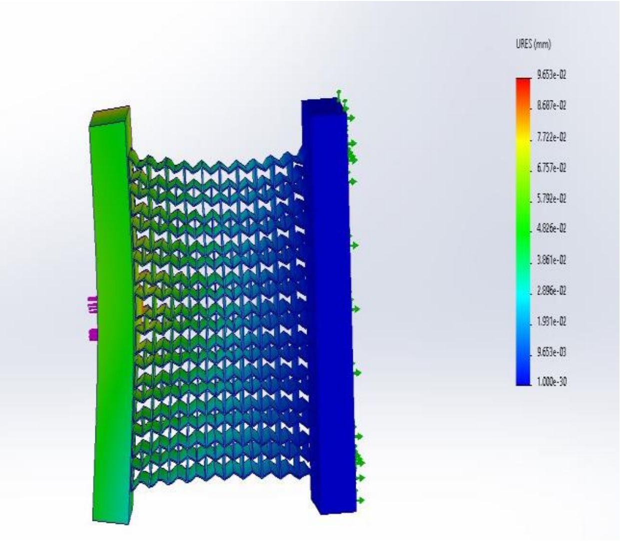

Fig. 3. *The deformed 3D model*

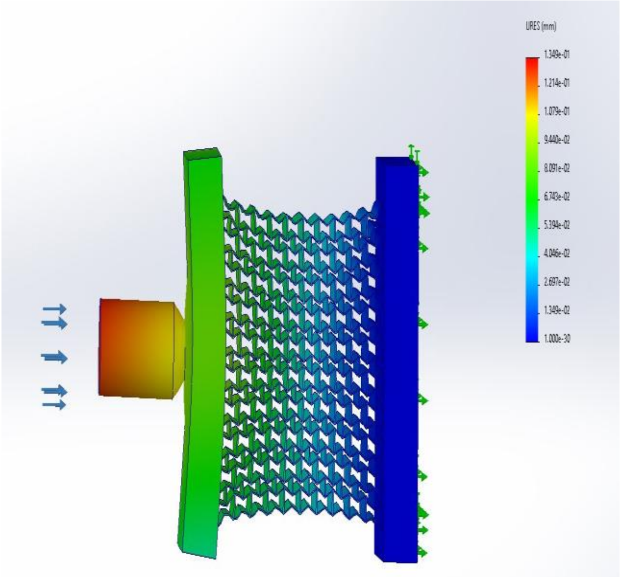

Fig. 4. *The projectile penetration and the response behavior of the auxetic core*

4. Conclusions

The ballistic impact behavior of composite armour was examined in this work using an auxetic sandwich. The Inventor Nastran program was used to simulate the effect of a projectile traveling at various speeds on composite auxetic sandwich armour. The results were compared with monolithic armour under the same boundary conditions and speeds. From the research, the following conclusions were drawn:

1. The auxetic structure outperforms the monolithic panel due to its better absorption capacity.

2. The threat level is greatly decreased by the auxetic structure, which may be used at higher speeds and is secure up to 450 m/s.

3. The auxetic method can be considered appropriate for the application if the advantages of auxetic structures satisfy the fundamental requirements of the application and the constraints are not of concern.

References

[1]. Anand P., Chandrakant R. K., Satish S. B., *Development of materials and structures for shielding applications against Blast and Ballistic impact: A Detailed Review*, Thin-Walled Structures, vol. 179, 2022.

[2]. Yongqiang L., Hualin F., Xin-Lin G., *Ballistic helmets: Recent advances in materials, protection mechanisms, performance, and head injury mitigation*, Composites Part B: Engineering, vol. 238, 2022.

[3]. Qian M., Pee D. L., *Development of spiral auxetic structures*, Composite Structures, vol. 192, p. 310-316, 2018.

[4]. Wu S., Sikdar P., Bhat G. S., *Recent progress in developing ballistic and anti-impact materials: Nanotechnology and main approaches*, Defence Technology, vol. 21, p. 33-61, 2023.

[5]. Rajendra P. B., Steven L., Tuan N., Abdallah G., Tuan N., *Anti-blast and -impact performances of auxetic structures: A review of structures, materials, methods, and fabrications*, Engineering Structures, 2023.

[6]. Zhenhua Z., Zhan Z., Xiufeng H., *Experimental study on the impact response of the polyurea-coated 3D auxetic lattice sandwich panels subjected to air explosion*, Composite Structures, vol. 323, 2023.

[7]. Xing C. T., Wei G. Z., Jiang X., Dong H., Xi H. N., Hang H., Jian H., Tong G., Yu F. W., Yi M. X., Xin R., *A stretchable sandwich panel metamaterial with auxetic rotating-square surface*, International Journal of Mechanical Sciences, vol. 251, 2023.

[8]. Feng J., Shu Y., Chang Q., Hai T. L., Alex R., Lian Z., *Blast response and multi-objective optimization of graded re-entrant circular auxetic cored sandwich panels*, Composite Structures, vol. 305, 2023.

[9]. Stefan B., Franziska H., Dirk B., Anne J., *Optimized design for modified auxetic structures based on a neural network approach*, Materials Today Communications, vol. 32, 2022.

[10]. Jianjun Z., Guoxing L., Zhong Y., *Large deformation and energy absorption of additively manufactured auxetic materials and structures: A review*, Composites Part B: Engineering, vol. 201, 2020.

[11]. Nejc N., Lovre K. O., Zoran R., Matej V., *Mechanical properties of hybrid metamaterial with auxetic chiral cellular structure and silicon filler*, Composite Structures, vol. 234, 2020.

[12]. Ying L., Zihao C., Dengbao X., Wenwang W., Daining F., *The Dynamic response of shallow sandwich arch with auxetic metallic honeycomb core under localized impulsive loading*, International Journal of Impact Engineering, vol. 137, 2020.

[13]. Qiang G., Xuan Z., Chenzhi W., Liangmo W., Zhengdong M., *Multi-objective crashworthiness optimization for an auxetic cylindrical structure under axial impact loading*, Materials & Design, vol 143, 2018.

[14]. Grujicic M., Galgalikar R., Snipes J. S., Yavari R., Ramaswami S., *Multi-physics modeling of the fabrication and dynamic performance of all-metal auxetic-hexagonal sandwich-structures*, Materials & Design, vol. 51, 2013.

[15]. Imbalzano G., Tran P., Ngo T. D., Lee V. S., *A numerical study of auxetic composite panels under blast loadings*, Composite Structures, vol. 135, 2016.

[16]. Chang Q., Feng J., Shu Y., Remennikov A., Shang C., Chen D., *Dynamic crushing response of novel re-entrant circular auxetic honeycombs: Numerical simulation and theoretical analysis*, Aerospace Science and Technology, vol. 124, 2022.

[17]. Nejc N., Biasetto L., Rebesan P., Zanini F., Carmignato S., Krstulovi-Opara L., Vesenjak M., Ren Z., *Experimental and computational evaluation of tensile properties of additively manufactured hexa- and tetrachiral auxetic cellular structures*, Additive Manufacturing, vol.45, 2021.

[18]. Ying L., Zihao C., Dengbao X., Wenwang W., Daining F., *The Dynamic response of shallow sandwich arch with auxetic metallic honeycomb core under localized impulsive loading*, International Journal of Impact Engineering, vol. 137, 2020.

[19]. Yuanlong W., Yi Y., Chunyan W., Guan Z., Aminreza K., Wanzhong Z., *On the out-of-plane ballistic performances of hexagonal, reentrant, square, triangular and circular honeycomb panels*, International Journal of Mechanical Sciences, vol. 173, 2020.

[20]. Chang Q., Remennikov A., Pei L., Yang S., Yu Z., Ngo D., *Impact and close-in blast response of auxetic honeycomb-cored sandwich panels: Experimental tests and numerical simulations*, Composite Structures, vol. 180, p. 161-178, 2017.

[21]. Jie M., Jiayi L., Mangong Z., Wei H., *Experimental and numerical study on the ballistic impact resistance of the CFRP sandwich panel with the X-frame cores*, International Journal of Mechanical Sciences, vol. 232,

[22]. Nejc N., Luka S., Matej V., Zoran R., *Blast response study of the sandwich composite panels with 3D chiral auxetic core*, Composite Structures, vol. 210, 2019.

[23]. Mehvesh I., Muhammad U., Ghulam H., Malik A. U., Wasim K., Asad H., *Development of mortar filled honeycomb sandwich panels for resistance against repeated ballistic impacts*, Journal of Materials Research and Technology, vol. 24, 2023.

[24]. Thawani V., Hazael R., Critchley R., *Numerical modelling study of a modified sandbag system for ballistic protection*, Journal of Computational Science, vol. 53, 2021.