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Supporting Information

I. THE DIAGRAM DISPLAYS OUR EXPERIMENTAL APPROACH

Work methodology flowchart, as seen in Figure **S1**:

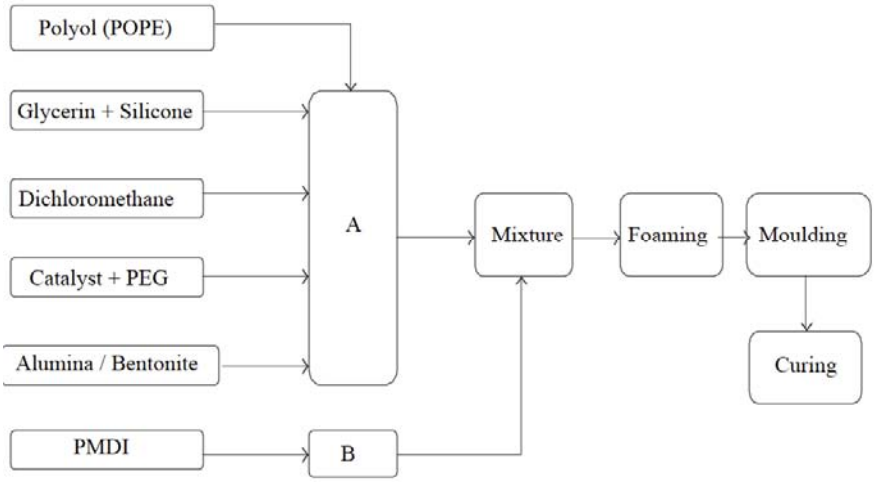

Figure S1: Work methodology flowchart.

At the end of the preparation phase of the test specimens for the impact tests, we can distinguish the samples that will subsequently undergo impacts at different energies. We deliberately shaped the test samples, as shown in Figure **S2**.

Figure S2: Formulated products (PUR) for testing.

Polyurethane foams can be manufactured with better characteristics than the basic constituent polymers. Every polyurethane foam manufacturer envies the main components, such as polyol and isocyanate, and the amount of catalyst. The explanation is that a mixture of polymeric components of the catalyst is first emulsified and distributed

on a conveyor belt in thick layers. This liquid layer begins to grow like bread dough immediately. The chemical reaction induces a powerful release of heat. This water vapor increases with its lightness and pressure. Of course, there are several recipes and, therefore, a variety of polyurethane foams, as the effect of expanding or swelling the dough becomes increasingly spongy. The processing method is the same. Only the characteristics desired (density, elasticity, strength) determine the dosage of the mixture. Polyurethane foams are more spongy, with larger cells that allow better air circulation [1].

The viscoelastic action of polyurethane foams is essential due to their connection with the foam's recoverability after being compressed or tired. ASTM tests usually describe this activity, which imitates using these kits. These experiments usually require compression tests such as static compression. Furthermore, the viscoelastic actions described in these tests were shown to calculate environmental conditions in polyurethane foams and foam formulations. Therefore, compression tests are used to understand polyurethane foams' viscoelastic actions. Also, understanding both microscopic morphologies in characterizing polyurethane foam viscoelastic behavior is essential. Figure **S3** represents the various optimized formulas for samples prepared for testing.

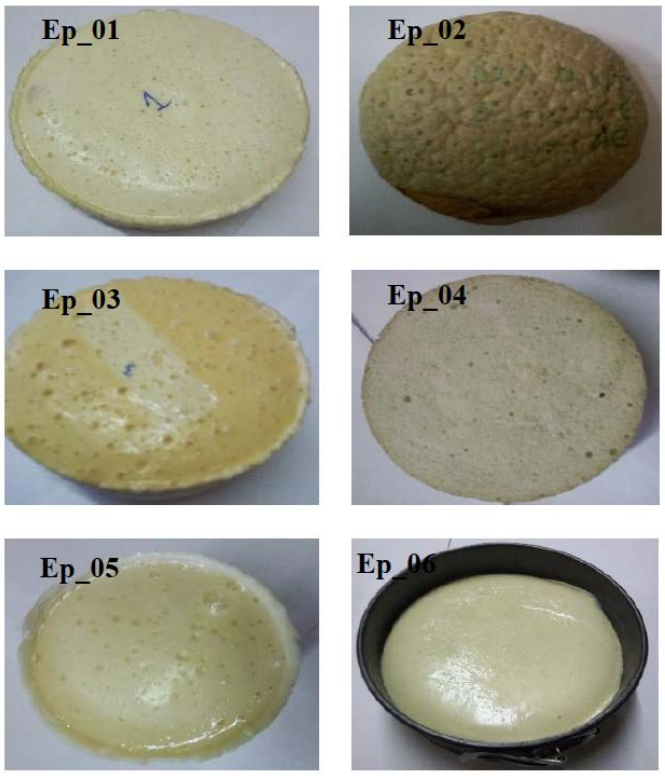

Figure S3: Chains of polyurethane foam.

The desired specimens of polyurethane foam in the cutter machine of the mechanical engineer's department CFM-EMP are cut into 20 mm for this research, as shown in Figures **S4** and **S5**.

Figure S4: Method of cutting samples PUR with the necessary precision.

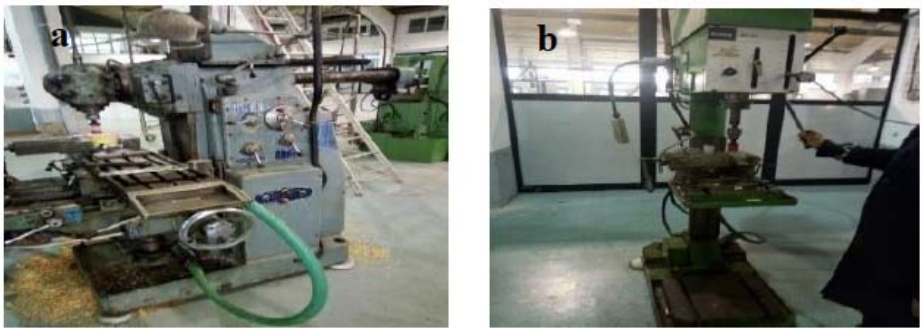

Figure S5: Mechanical milling machine.

As seen in Figure **S6**, the polyurethane foam parts are cut into small pieces for inspection.

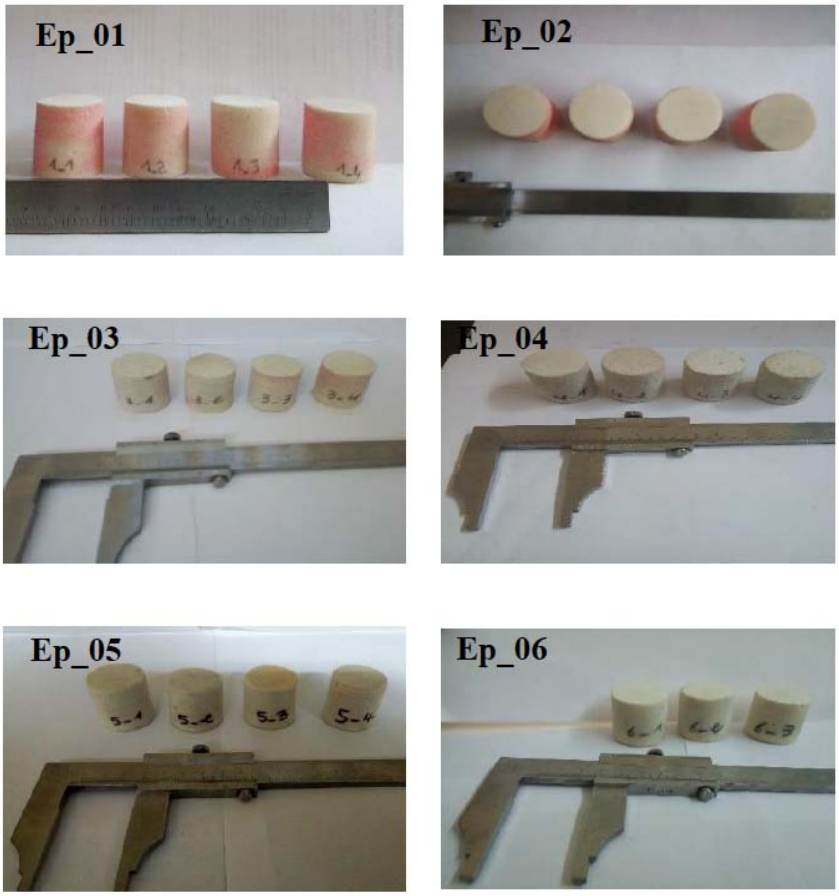

Figure S6: Range of test specimens manufactured respectively on the polyurethane foam formulation.

II. THE METHOD OF DIFFERENT MACHINES USED

II.1. Means and Procedures for Impact Testing

II.1.1. Preparation of Samples

We cut larger samples using the guillotine cutting machine shown in Figure **S7**. Since we are studying a phenomenon that requires great accuracy in the dimensions of the shape of the samples, we have adopted the method of manually cutting samples as well. We made sure that the length of the cylindrical sample was about 1 cm and its diameter was 10 cm, are given in Figure **S8**. Since the polyurethane foam is compressible, there was little difference in the required dimensions.

Figure S7: La guillotine de découpage.

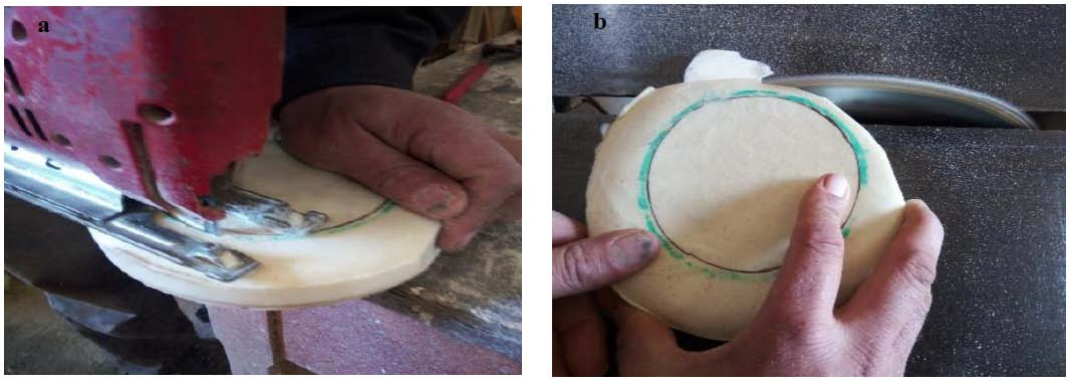

Figure S8: The method of cutting samples to preserve the dimensions required for dynamic tests.

II.1.2. Manual Polishing

The EcoMet^{TM} 30 Manual is a good quality polymer grinder-polisher machine for polymeric materials to ascertain their micro-physical structure based on specific materials types, as shown in Figure **S9**. The machine contains a motor, a metal frame, a shoe, a rotating shaft, and a wooden board. This fixture is an assembled, forming, and polishing machine. The device is tested for application rate and operating speed according to the type of polymeric sample. This machine can have a smooth surface, is intended for many substances, is easy to operate, and requires minimal maintenance.

Polishing is the last step before creating a flat, smooth, polished finished surface. A consistent surface is important for a more detailed description, testing, and study of a sample. This equipment uses coarse grinding papers of 60 grit to 240 grit. They are mostly used for extracting burrs from divisions, rounding corners that must not be retained for inspection, flattening a scratched surface to be engraved, or eliminating segment damage.

II.1.2.1. Specimen Dynamics

One or two hands carry the sample and turn counter-clockwise to the revolving polishing wheel. Moreover, the polyurethane foam sample is constantly shifted back and forth between the middle and the border of the disk, ensuring an even combination of abrasive to the polishing samples and providing consolidated wear. (Some benefits of slight wrist movement when shifting the sample from the middle to the brink of one disk surface.) After each stage, the sample is turned 45 to 90 degrees while maintaining the direction of rotation.

II.1.2.2. Polishing Pressing

The right amount of pressure needs to be applied based on experience. Sometimes, measurements are taken when firm hand stress is suited to the sample (see Figure **S9**).

Figure S9: Manual polishing method using the EcoMet ™ 30 polishing machine.

III. DROP WEIGHT TESTS

The drop tower is made by Material Testing Technologies (MTT) and utilizes a drop weight of 60 joules, as shown in Figure **S10**. It contains a square-shaped head impactor constructed of steel, 10 cm in diameter. The dropping load is 5.7 kilograms, and the overall drop height is one meter.

Figure S10: Impact tower.

The theory of this machine is that gravity forces a mass at a certain height down without any initial speed. The dropping mass is directed by two longitudinal and parallel columns, helping to keep the mass from dropping in a path inconsistent with the intended target. The impact machine helps one adjust the drop's height while offering up to three degrees of impact rates. Also, multiple impact energies from 5 J to 60 J can be obtained.

III.1. Impact Tests Formulations

In the case of free fall, the most widely used representation to reproduce impact tests, the impact energy is defined by the height of fall noted h. The potential energy Ep determines this:

$$E = mgh \quad (1)$$

With m is polyurethane foam shell block, g is the velocity of gravity.

Also, a calculation of the speed at the time of impact is made. We consider energy conservation at the time of impact. Therefore, we have an equilibrium between the potential energy Ep and the kinetic energy Ec:

$$E_P = E_C \quad (2)$$

With E_c defined by:

$$E_C = \frac{1}{2} m v^2 \quad (3)$$

So, we get the speed calculation:

$$V = \sqrt{2gh} \quad (4)$$

III.1.1. Foam Density Estimation

Estimating the density of the different polyurethane foams tested consists of the electronic balance of the samples with a precision of 0.01 g and the measurement of the test piece length. Therefore, the density can be calculated from the relationship (5):

$$\rho = \frac{m}{p} \quad (5)$$

Where m and p denote the mass in grams, respectively, and the volume in cm^3 correspondingly, Figure **S11** shows the electronic balance's accuracy is 0.01 g.

Figure S11: Balance electronic accuracy of 0.01 g.

A representative sample, in a normal shape, round or square, devoid of lines and condensation, of at least 1000 mm^3 shall be sheared from a vacuum-free fraction and as similar to the site as possible for the pressure samples taken.

III.1.2. Poisson Ratio Determination (υ)

The Poisson ratio is the proportion of the cross stress divided by the axial stress (Formula 6). The Poisson ratio can vary from-1 to 0.5 in material properties [2]. The Poisson ratio enables the contraction in the track of the product of the practical force specified. This coefficient was analytically demonstrated by Denis Poisson, a French mathematician (1781-1840), an author who decided its values from the molecular theory of the constitution of matter, mathematical physics, and mechanics.

$$\upsilon = \frac{(d_0 - d)/d_0}{(D - D_0)D_0} \quad (6)$$

The Poisson ratio is one of the elastic constants designated by the Greek letter v. It is theoretically equal to 0.25 and, in reality, very similar to this value for a perfectly isotropic substance. The Poisson ratio is always less than or equal to 0.5, and the material is completely incompressible when equal to 0.5 [3]. Both thermoplastic resins and thermosetting can now be produced as foams. Depending on the glass transfer temperature Tg, the chemical composition, the crystalline level, and the cross-linking degree [4], The mold may be flexible, rigid, semi-flexible, or semi-stiff. Conventional materials have a positive Poisson ratio and suffer from lateral contraction when stretched and, when compressed, axial expansion. An exotic substance with a negative Poisson ratio swells when compressed and shrinks. The ratio materials of Negative Poisson have several proven and postulated advantages [5] hanks for the material. For a substance isotropic elastic, the permissible Poisson ratio previously corresponded to 1.0-0.5 [6]. Materials with negative Poisson ratios are well-known for their high shear rigidity [12]. Manufacture synthetic materials and structures with negative Poisson ratios, such as composite laminates, microporous polymers, two-dimensional honeycombs, and 3D foam [7].

The Poisson ratio is the crosswise strain negatively divided by the strain rate. Following stabilization arguments, the Poisson ratio must be within 1 to +0.5 [8] when interacting with isotropic compounds. This spectrum of Poisson ratios is equal to positive compressive and bulk modulus. A constricted material block would be fragile to a minor disturbance when either modulus was negative. Until recently, the Poisson ratio was assumed to be stuck at 0 with +0.5 for the isotropic kit. Most materials provide a Poisson ratio of 1/3, while rubber products have values of about 1/2. Foam Isotropic products that display negative actions of Poisson first produced from surface water [8], auxetic [9], also dilation and extraction [14], are called anti-rubber [10]. The concept behind the negative foam ratio of Poisson is our entering structure. By persistent compression, the curved structures of a regular foam are transformed into a re-entrant with wedged ribs. The cells are exposed to stress, resulting in a negative Poisson ratio. This results in the peculiar mechanical properties of these foams. Consider, for example, the interaction between the modulus of elasticity E, the rigidity module G, and E = (2G)×(1+v). The modulus of elasticity is at least twofold G in typical isotropic materials. If the Poisson ratio is below zero, the two modules begin to draw closer until they are identical at -0,5. In addition to-0,5, the rigidity module approaches the elastic module [11]. The Poisson ratio negative allows these components to act as exceptional press-fitted fasteners, adjust to pregnancy surfaces by bending, and improve the transducer's piezoelectric efficiency. Foams and a negative Poisson ratio have improved characteristics, including tear protection and the potential to coat the objects when they are impacted less.

The method of calculating the Poisson ratio of a polyurethane foam sample while subjected to uniaxial stress was by obtaining images of the sample with different pressure ratios. The cross-sectional range is determined using MATLAB image processing techniques (see Figure **S12**).

Figure S12: Vertical images of uniaxial compression foam under 0%, 25%, 50%, 75% and 80%.

VI. RECOMMENDATIONS FOR SAMPLING

The axial pressure experiment could use the produced product achieved with mechanical testing, in which the optimal formulas pick representative samples. When collecting samples proportionate to our probationary, such as in cases where the whole sample is not needed or adaptable to testing, the cutting method and the exact location must be determined from which the samples will be taken. Density and processing conditions can differ in different sections of the final product, particularly if the piece has a complex shape or varying size, and these characteristics affect the sample's physical properties. Also, the number of surfaces cut on the sample influences density. If the test samples are cut from the die, then the thickness must be entirely restored over the entire width of the samples. If the final cast product cannot be checked or sampled due to complex form, small scale, insertion or texture, adhesion, or other factors, molded test plates, as accepted, shall be appropriate as per test standards. If the test results vary due to difficulty in earning appropriate samples of the final components, samples can be taken from the same prepared foam mold. Some samples of polyurethane foams of interesting formulas, as shown in Figure **S13**.

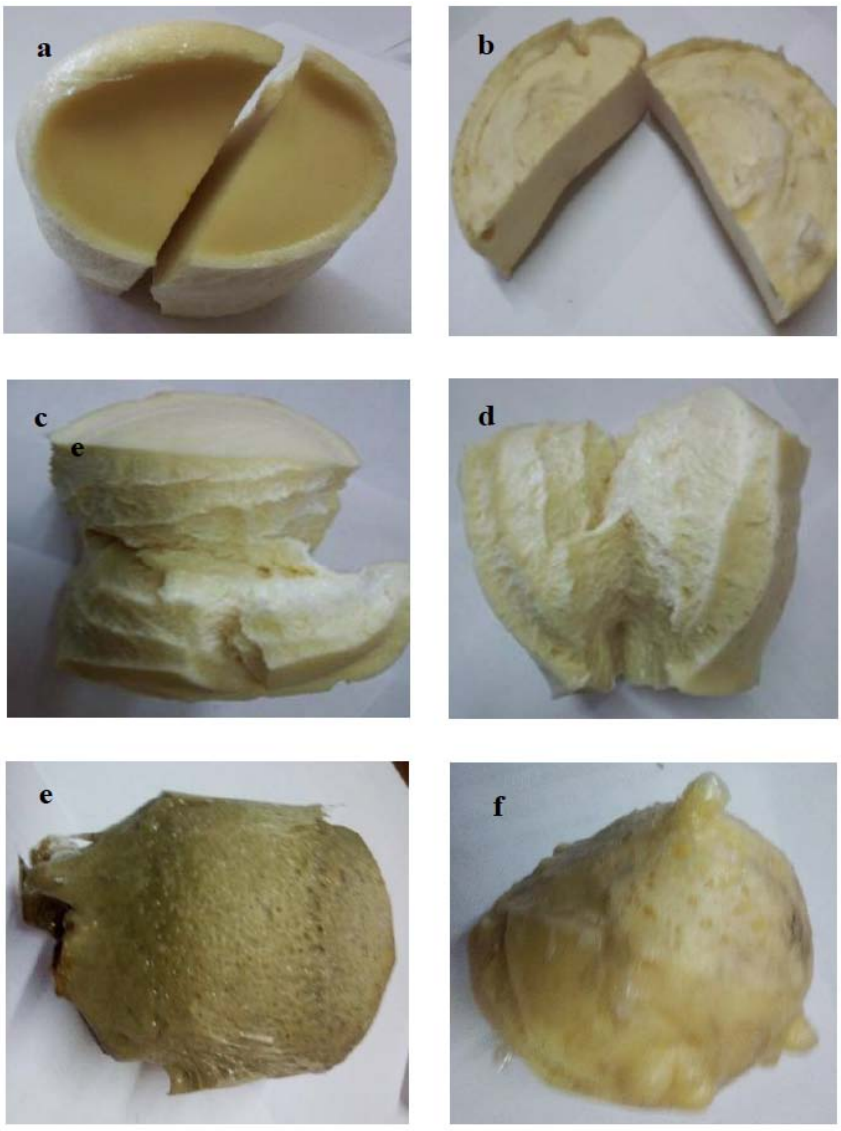

Figure S13: Some samples of polyurethane foams of interesting formulas.

Generating a good quality foam requires a careful mixing of the components of the foam system. Improperly mixed foams can appear fine but not stable for a long time or have no desired strength or shockproof properties. The opposite shape represents the various samples that did not have the properties we were seeking. Despite their failure, they were the beginning of the success of the various formulas of other samples that evolved to become the ideal model for the non-lethal projectile [12,13].

VII. ABBREVIATION LIST

Table S1: Abbreviations list

Abbreviation	Meaning
Polyurethane foam PUR	A flexible product created by the interaction of polyols and isocyanates.
Additives	Any substance applied to another substance to modify or enhance consistency or prevent undesirable characteristics.
Core	The molded part's inner section is skin-free.
Flexible foams	Normally cylindrical, but not essentially, shaped or cut into a material normally orthogonal to the direction of foam elevation and extending a segment or through the parts

Cellular structure	An organic cellular polymer material that does not break when a sample of 200 by 26 mm or 25 mm bends to 25 mm in diameter at a uniform ratio of 1 lapper 5 s at temperatures between 19 and 29 °C.
Catalysts	An agent acts as a catalyst in a reaction without being modified.
Urethane	A chemical compound containing the chemical formula CH_2O_2R.
Polymer	A molecule comprises repeating morphological and structural units with covalency chemical bonds of its chemical formula. Though polymer in common usage implies plastic, the term applies to several common chemical samples.
Hydroxyl groups	The univalent group is in inorganic compositions, including Sodium Hydroxide, Sodium Hydrate, or inorganic compounds such as Ethyl Alcohol, ethyl hydrate Often named the OH radical.
Diisocyanate	A compound of two isocyanate molecules is called diisocyanate. The diisocyanate is formed by chemical reactions that take place in the manufacture of polyurethane foam.

VII.1. Glossary

Symbols:
T Temperature, K
P Pressure, Nm^{-2}
Greek letters:
ρ the apparent density (g/cm^3)
BNT Bentonite
PEG Polyethylene glycol
PMDI Polymeric diisocyanate diphenylmethane

REFERENCES

[1] Bezazi A, Scarpa F. Tensile fatigue of conventional and negative Poisson's ratio open cell PU foams. Int J Fatigue 2009; 31: 488-94. https://doi.org/10.1016/j.ijfatigue.2008.05.005

[2] Bezazi A, Scarpa F. Mechanical behaviour of conventional and negative Poisson's ratio thermoplastic polyurethane foams under compressive cyclic loading. Int J Fatigue 2007; 29: 922-30. https://doi.org/10.1016/j.ijfatigue.2006.07.015

[3] Chiang F-P, Ding Y. Size effect on stress-strain relation of neat polyurethane foam. Compos B Eng 2008; 39: 42-9. https://doi.org/10.1016/j.compositesb.2007.02.011

[4] Landrock AH. Handbook of plastic foams: types, properties, manufacture and applications. Elsevier; 1995. https://doi.org/10.1016/B978-081551357-5.50006-1

[5] Goussery-Vafiadès V. Caractérisations microstructurale et mécanique de mousses de nickel à cellules ouvertes pour batteries de véhicules hybrides 2004.

[6] Yang DU, Lee S, Huang FY. Geometric effects on micropolar elastic honeycomb structure with negative Poisson's ratio using the finite element method. Finite Elements in Analysis and Design 2003; 39: 187-205. https://doi.org/10.1016/S0168-874X(02)00066-5

[7] Wei G, Edwards SF. Auxeticity windows for composites. Physica A: Statistical Mechanics and Its Applications 1998; 258: 5-10. https://doi.org/10.1016/S0378-4371(98)00220-9

[8] Lakes R. Foam structures with a negative Poisson's ratio. Science (1979) 1987; 235: 1038-41. https://doi.org/10.1126/science.235.4792.1038

[9] Alderson KL, Evans KE. The fabrication of microporous polyethylene having a negative Poisson's ratio. Polymer (Guildf) 1992; 33: 4435-8. https://doi.org/10.1016/0032-3861(92)90294-7

[10] Glieck J. Anti-rubber. New York Times 1987; 14.

[11] Choi JB, Lakes RS. Non-linear properties of polymer cellular materials with a negative Poisson's ratio. J Mater Sci 1992; 27: 4678-84. https://doi.org/10.1007/BF01166005

[12] Boumdouha N, Duchet-Rumeau J, Gerard J-F, Eddine Tria D, Oukara A. Research on the Dynamic Response Properties of Nonlethal Projectiles for Injury Risk Assessment. ACS Omega 2022. https://doi.org/10.1021/acsomega.2c06265

[13] Boumdouha N, Safidine Z, Boudiaf A. Preparation of Nonlethal Projectiles by Polyurethane Foam with the Dynamic and Microscopic Characterization for Risk Assessment and Management. ACS Omega 2022. https://doi.org/10.1021/acsomega.2c01736