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Numerical and Experimental Investigation on Compressive Properties of Egg Box Cores in Biodegradable Sandwich Panels

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ABSTRACT: In this study, the compression behavior of cardboard egg box cores with various stacking sequences used in sandwich structures is investigated both experimentally and numerically. A critical requirement of the design is that the structure is compatible with the environment (biodegradable), and its properties have been investigated through compression and tension testing. Egg boxes were chosen as the core material for sandwich structures due to their mechanical properties, excellent insulation properties, and strength. Also, the core shape in various stacking sequences were modeled in ABAQUS Finite Element code to simulate the behavior of the egg box core in compression. The results showed that the surrounding edges of the core were crushed and the truncated top region compressed. The increase in thickness of the egg boxes directly affected the compression properties. By doubling the thickness of the layers, the amount of energy absorbed by the core increased by more than 100%. By comparison of various stacking sequences of the cores, the one with double layers of the egg boxes overlapped showed an increase of 49% in stiffness, 108% in energy absorption, and 128% in strength. According to the results, the tangled arrangement of the second type of the core exhibits the highest load bearing, the greatest energy absorption, and less damage as compared to other core stacking sequences.

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1- Introduction

The sandwich panel is made up of a low-density core and a thin skin layer that is attached to both sides. Sandwich panels are often utilized in applications that require structural stiffness while being lightweight. Sandwich panels have a construction similar to the conventional I-beam; two sides resist in-plane bending loads, while the center resists shear stresses. To accomplish this, the core is composed of a light/soft yet thick layer, while the face sheet is composed of a strong, but thin layer. This causes the panel's thickness to rise, which enhances structural properties such as bending stiffness while maintaining or even lowering its weight [1-4]. Cai et al. [5] examined the plastic forming of sandwich panels with egg-box-like cores using experimental investigations, finite element simulations, and theoretical models. Among the many failure modes, the most prevalent failure modes of sandwich panels are sheet deflection and core cell failure in the plastic region. Galik et al. [6] investigated the mechanical properties of ten-egg boxes made of cardboard, expanded polystyrene, and solid polystyrene. According to the findings, cardboard boxes might provide the best mechanical protection for eggs. The compressive behavior of egg box cores with three distinct types of stacking in a biodegradable sandwich structure was investigated in this study. The sandwich structure's outside layers are formed of polylactic acid / Kanaf-cotton [7], while the central layer is an egg box. The compatibility of all of its components with the environment is a key aspect of this structure. The properties of a biodegradable sandwich structure made of egg box core and green composite face sheets were investigated using quasi-static compressive experimental tests and numerical simulation with ABAQUS finite element software to investigate the effect of the arrangement type parameter and core thickness, as well as experimental validation of this analysis.

2- Methodology

2- 1- Experimental compression test of the egg box

Cardboard egg boxes in sizes of 100×100 mm with 4 egg housings were used as the core of sandwich panels. The core thicknesses of the single, two boxes inside each other, and two boxes over each other vary between 50, 55, and 100 mm, with all specimens being loaded under quasi-static compressive pressure using a HOUNSFIELD H25KS test machine according to ASTM C364 standard.

2- 2- Numerical simulation

Due to the unique geometry of the egg box, a geometric model of the egg box was produced using the surface modeling component of CATIA software, and tensile and compressive

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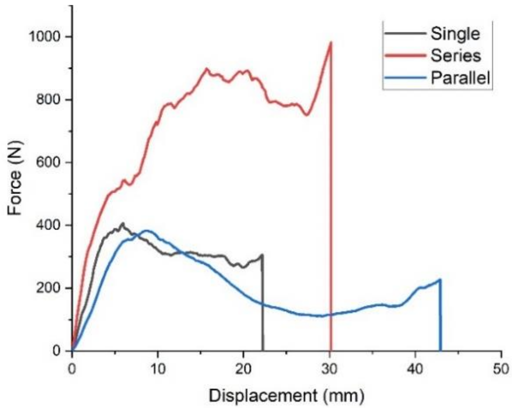

Fig. 1. Force-displacement diagram for egg box cores under compression

(A)

(B)

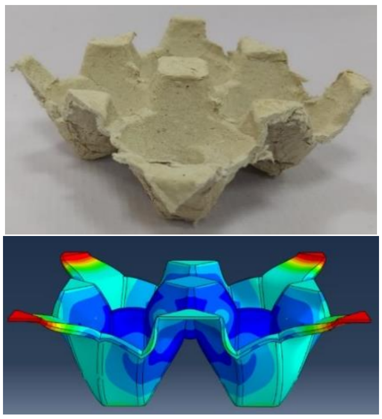

Fig. 2. The single egg box specimen after unloading; (A) tested single type sample, (B) FE simulation

forces on the cardboard were numerically studied using ABAQUS Finite Element (FE) software. An analysis of the global connection and cohesive tie contact between the cardboard cores and stiff boundary conditions was conducted, and a universal contact method with friction coefficients of 0.15 was developed [8]. There is a maximum discrepancy of around 13% between numerical and experimental results in tensile and compression testing of the cores. The mismatch between the FE code simulations and the experimental results is related to the absence of failure behavior, the approximate shape of the egg box, fragmentation, and the rough surface of the core.

3- Results and Discussion

In the single-core specimen, both the corners of the core and the lower section of the core were crushed as the load increased, and as shown in Fig. 1, when forces reached 406.6 N, the force dropped owing to core compression and failure in the egg box corners. According to the observed sample at the end of the test, the core has restored to some extent to its previous condition, and the most damage and compression

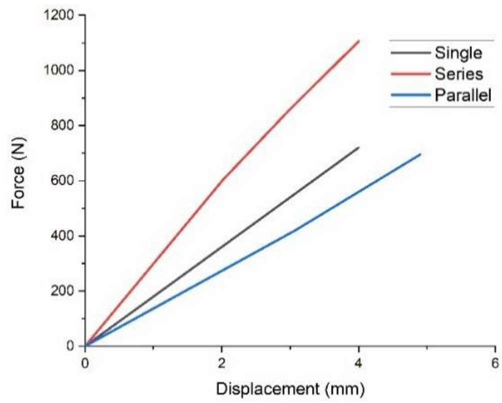

Fig. 3. Force-displacement diagram for egg box cores with doubled thicknesses under compression

Table 1. Mechanical properties of egg box cores under compression

Specimen	Single	Inside each other	Over each other
Stiffness (N/mm)	97797.45	135898.40	85850.87
Strength (N)	406.4	898.5	382.2
Specific strength (Nm^3/kg)	960.07	2122.61	902.91
Absorbed energy(J)	6.63	20.92	8.67
Specific absorbed energy (Jm^3/kg)	15.67	49.43	48.20

have been applied to the areas of contact between the bottom plate and the core (Fig. 2). The failure behavior of two boxes inside each other and two boxes over each other cores is the same as that of a single core specimen. The second type of core suffered from higher deformation at its lower area as compared to the single-core specimen due to the presence of space between the lower parts of the cores. The two boxes over each other specimen had the highest deformation of all of the specimens and the top core had significant damage and was crushed following deformation at the corners.

According to Table 1, the amount of energy absorbed by single, inside, and over each other specimen, are 6.63, 20.92, and 8.67 Joules, respectively. Based on these results, the two boxes inside each other specimen have about 215% and 2.5% more specific absorbed energy than the first and third specimens, respectively. Additionally, the two boxes inside each other specimen showed an average specific strength which is 128% higher than the other two specimens. The effect of the thickness parameter of the core layers was investigated by numerical simulation in all three cases. Numerical simulation results show that increasing the thickness of each layer increases the energy absorbed by the core of the structure by about 100% to 120%. As demonstrated in Fig. 3, the series core resisted approximately 65% higher force than the weakest core (single type core) in earlier experiments.

4- Conclusions

The compressive behavior of cardboard egg boxes with three different arrangements as the middle layer (core) in biodegradable sandwich structures was studied experimentally and numerically. An important feature of this structure is its compatibility with the environment; the mechanical properties of this structure were studied by quasi-static compression tests. The cardboard egg box core is exceptionally resistant to compression and has absorbed a significant amount of energy. The crushing of the outer edges and compression of the egg housing are the mechanisms of failure in the core. The two boxes inside each other core had the highest strength as compared to other cores. This core tolerates 121% more working load than the single-core and 135% more than the two boxes over each other core. The inside each other core is 49% stiffer and absorbed 108% higher energy, and 128% higher strength as compared to other specimens. The thickness of egg boxes directly affects the compression properties of the structures, and doubling the thickness of the core has increased the amount of energy absorbed by the structure's core by about 100%.

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