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Thin-Film Strain Gauge Sensor to determine the difference between infill cell designs for the sandwich beams

Rafał Trzeciakowski, Rafał Pawłowski, Karolina Laszczyk, Paweł Piórkowski*
Wroclaw University of Science and Technology, 27 Wybrzeże Stanisława Wyspiańskiego st.
50-370 Wrocław, Poland
**contact: karolina.laszczyk@pwr.edu.pl*

Summary:
This study investigates the utility of a thin-film strain gauge sensor for measuring axial stresses to determine the difference between various infill cell designs for 3D-printed sandwich beams. A dedicated measurement system was designed and implemented to do the measurements. Two designs were tested under three-point bending tests. The results confirmed that use of strain gauge measurements ato be used as one of the approaches to further optimize the 3D printed beams.

Keywords: 3D printing, sandwich beam, stress measurements, bending tests, strain gauge

Background, Motivation and Objective

The particularly promising area of research in 3D printing is the optimization of the models so as to get the more reliable and mechanically resilient structures. Previous research has emphasized the benefits of different core topologies in enhancing properties such as stiffness and energy absorption [1-2]. One of the methods to determine the printable structure mechanical stresses is to use strain gauges. The present study was conducted to confirm the use of strain gauges as a consistent and accurate tool for measuring mechanical stresses in 3D-printed beams with complex cell topologies as a possible approach to optimize their design. By applying strain gauges to the beams with various infills, it was possible to capture stresses along axes and determine differences between various infill cell designs. Establishing a systematic measurement approach can contribute to the method to optimize 3D-printed beams and other structures through the adequate infill cell design.

The materials and methods

The measurements were conducted on samples with two different cell topologies: Schwarz P and Star (Fig. 1a). The specimens, i.,e the beams, with dimensions of (63.2 × 6.3 × 6.6) mm^3, were manufactured using vat-photopolymerization in a 3D printer Asiga MAX X35 (ASIGA, AU). Each beam infill cells were arranged in a particular configuration: 21 × 2 × 2. Before mounting the thin-film strain gauge, the surface of each specimen was cleaned with isopropyl alcohol (IPA) and then coated with a primer (Ataszek, PL). The strain gauge was precisely positioned in the central area of the beam surface and glued using a cyanoacrylate adhesive. Next, left for 15 minutes to ensure proper bonding between the components. A three-point bending test was performed on five specimens of each topology using the tensile testing machine CS2-1100 Chatillon (Ametek, US; Fig. 1b). The recorded force-deflection characteristics present the stiffness of each design by analyzing the linear region of the curve, followed by the calculation of Young's modulus based on a formula presented in [3]. The entire testing process was recorded using a digital camera to synchronize the data with strain gauge measurements. The strain gauge was integrated into a Wheatstone bridge circuit, and changes in the output voltage caused by the specimen's deflection were recorded using a digital multimeter 34461A (Keysight, US). From the measured voltage, the deflection of the specimen was determined. Hooke's law was applied within the elastic range of the sample to calculate stress, following the approach described in [4]. The collected data was analyzed to identify both the advantages and limitations of the performed measurements.

Results

The graph in Figure 1c presents the relationship between the average stress and the average deflections for both infill topologies. The noticeable difference in the slope of the lines indicates distinct mechanical properties of the structures. The Schwarz P topology achieved an average stress of (1.22±0.25) MPa at the average deflection of 1.7 mm, whereas the Star infill beams reached (0.94±0.25) MPa at the average deflection of 1.6 mm. The higher stress value for Schwarz P suggested greater stiffness of the beam. At the same time, Young's modulus analysis showed that the Schwarz P topology resulted in Young's modulus value of (305.3±8.3) MPa. Meanwhile the Star topology resulted in slightly lower Young‘s modulus (236.2±30.0) MPa, indicating a higher ability to undergo the elastic deformation.

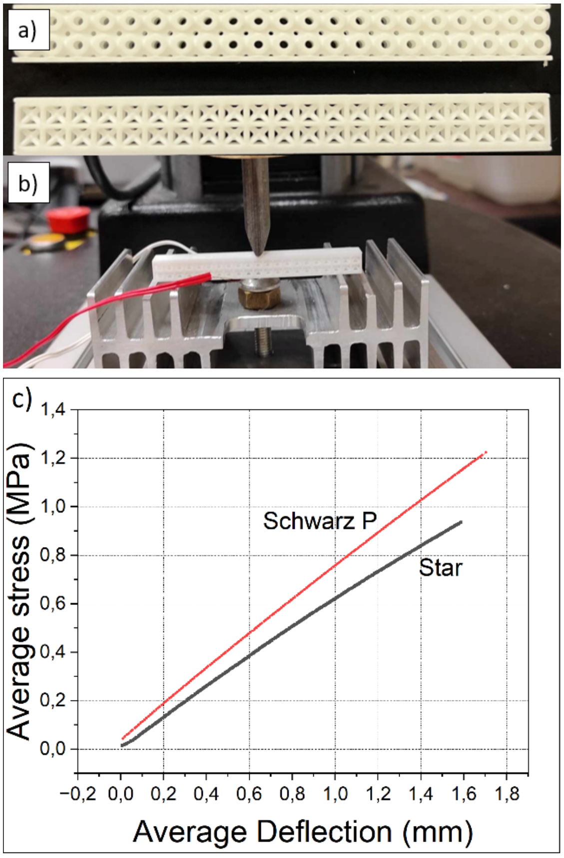

Fig. 1. The tested samples with the strain gauge: a and b photographs: of printed beams (a), with Schwarz P (top) or Star (bottom) topology and the three-point bending test (b); c) the graph: the averaged stress values as a function of the averaged deflection values for sandwich structures with the Schwarz P and Star topologies

Conclusions

The conducted measurements enabled the determination of axial stresses using the strain gauges. Based on the results, we confirmed the difference in the mechanical properties of the beams with different infill topologies. The Schwarz P topology made the beam stiffer, resulting in a higher average stress compared to the Star topology (about 23%). However, the analysis also highlighted the possible limitations of such approach excluding ist use in some engineering applications, e.g. in the health monitoring and the mechanical component testing. These applications are particularly sensitive to factors including temperature fluctuations, surface preparation quality, and the adhesive properties. Further studies should include fatigue analysis and the impact of various printing parameters on the mechanical properties. Additionally, the use of alternative measurement method, such as X-ray diffraction (XRD) should be considered to more accurately determine local stresses and deformations, allowing for design optimization. To precisely determine Young's modulus, the implementation of additional measurement techniques and analytical methods should be explored, especially if we would like to scale-down components for microsystems. The proposed future research directions include conducting tests under controlled conditions to maximize measurement repeatability and identify the influence of external factors on test results. It is also crucial to determine the exact Young’s modulus value, for example, through computer simulations, which would enable more precise modeling of the analyzed structures' behavior and their practical engineering applications.

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