Enhancing 3D Printed (FDM) Structure with Embedded Strain Gauge Sensor

Mechanika 2024

Contents

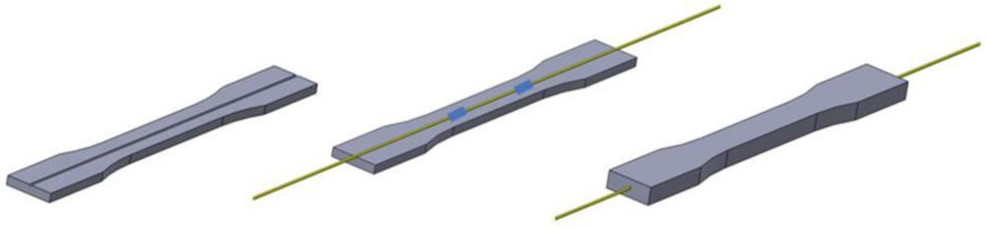
Overview of 3D/4D Printed Structures and Structures with Embedded Sensors

Benefits of embedded sensors:

- **Improved Data Collection:** Embedded sensors can collect data in real-time, providing more accurate and comprehensive information than manual data collection.
- Increased Efficiency: Automated data collection through embedded sensors can reduce the time and resources.
- **Cost Savings:** Embedded sensors can be less expensive than traditional data collection methods (low cost - can be left in field)
- **Enhanced Precision:** Embedded sensors can provide more precise measurements.
- **Remote Monitoring:** Embedded sensors can be used to monitor conditions in remote or hard-to-reach locations (nuclear power plant)

Overview of 3D/4D Printed Structures and Structures with Embedded Sensors

Fiber Braggs Grating (FBG) sensors in additively made materials when subjected to fatigue loading. Tensile fatigue testing of both regular Acrylonitrile Butadiene Styrene (ABS) specimens and ABS specimens with FBG sensors was used to accomplish this.

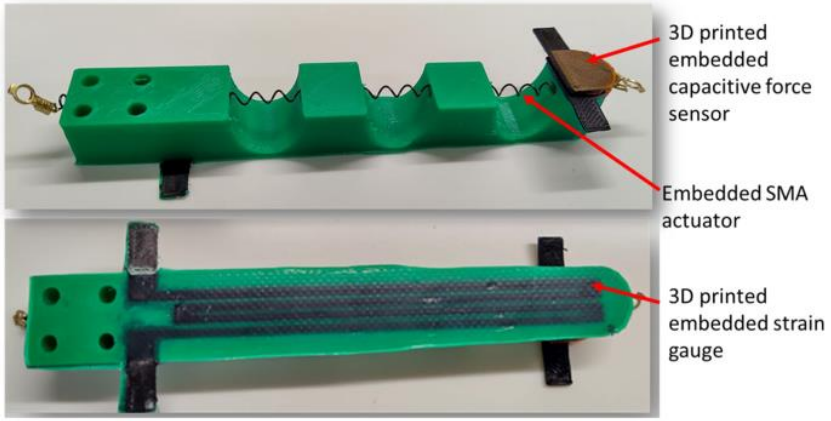


ktu

Overview of 3D/4D Printed Structures and Structures with Embedded Sensors

3D printed robot gripper finger presented.

The primary innovation in this study is the *one shot* manufacturing of a soft finger made in 3D printing that has two separate sensors inserted inside it as well as a shape memory alloy (SMA) actuator.

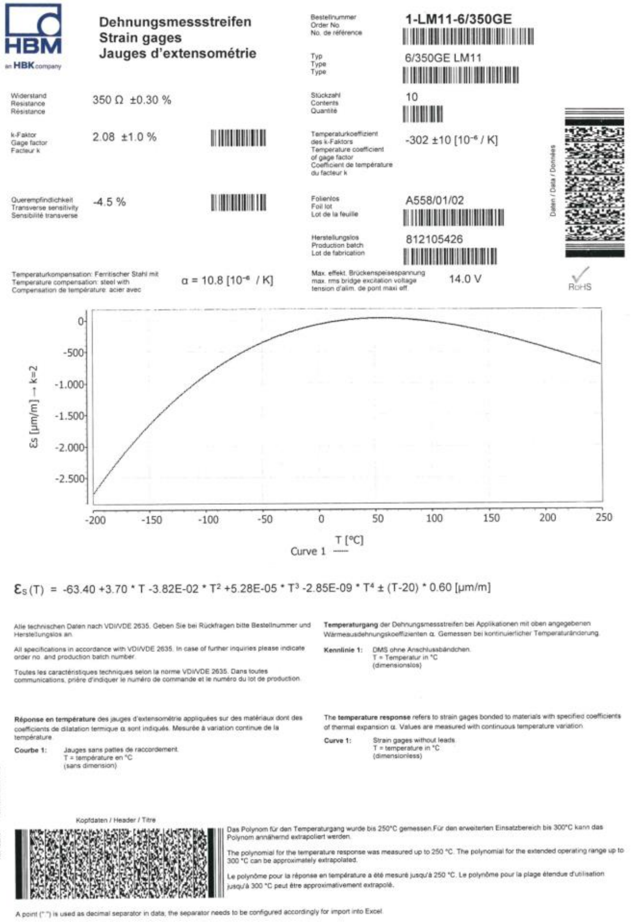


Sensor selection

Strain gauge selection and requirements:

After considering temperature resistibility as the primary selection criteria for the strain measuring sensor, there were explored several types of gauges. Technical parameters, availability, and budget were evaluated before settling on the *1-LM-6/350GE* strain gauge produced by HBM for further steps.

The strain resistor has a nominal resistance of 350Ω with a tolerance of ±0.3%. The strain gauge can be used in temperatures up to 250 °C, which is a crucial property for its application during the 3D printing process. Its gauge factor is around 2.08 ±1.0%.



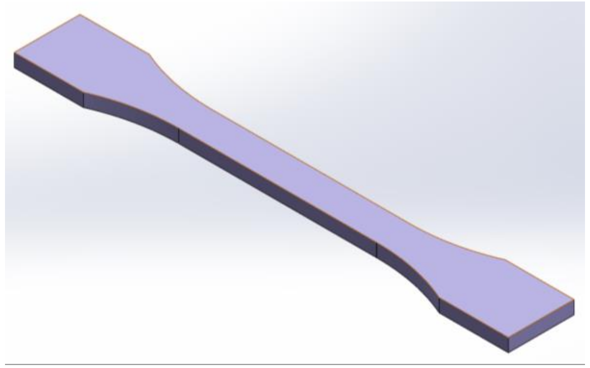
ktu

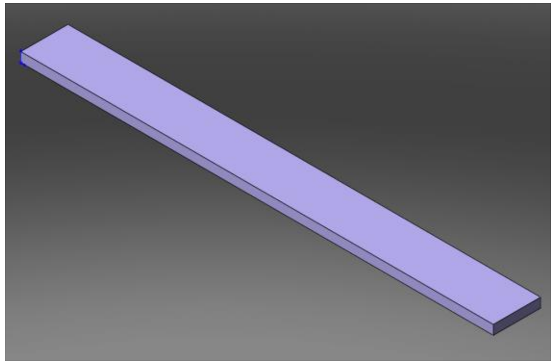
Design of the Samples

Structure shape definition:

For the purposes of the research, multiple samples were specifically designed and manufactured. The samples were intended for tension testing on a specialized equipment, and additional samples were planned for the application of strain gauges on their surface and incorporation within the structure's core layers.

	Specimen type	1B
l_3	Overall length	≥150
l_1	Length on narrow parallel side portion	60,0 ± 0,5
r	Radius	60 ± 0,5
l_2	Distance between broad parallel sided portions	108 ± 1,6
b_2	Width at ends	20,0 ± 0,2
b_1	Width at narrow portion	10,0 ± 0,2
h	Preferred thickness	4,0 ± 0,2
L_0	Gauge length	50,0 ± 0,5
L	Initial distance between grips	115 ± 1



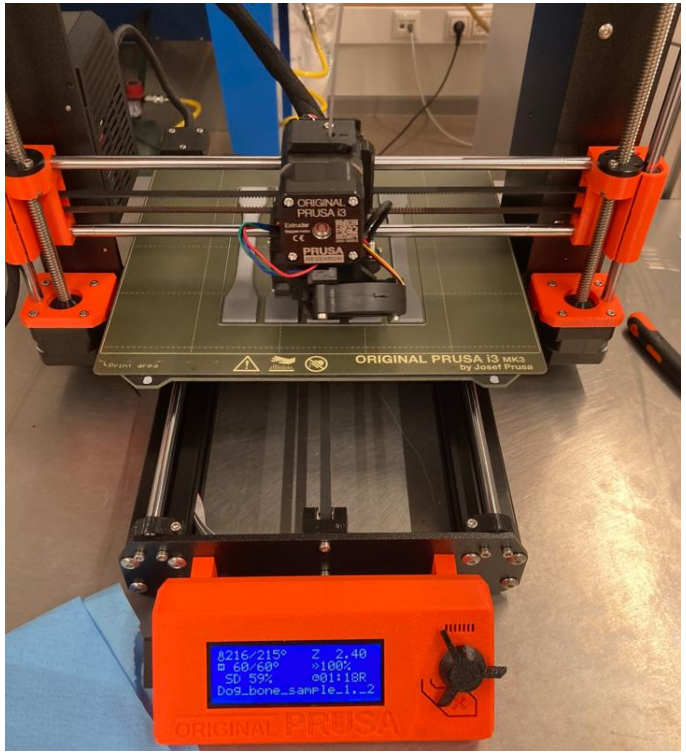


Production of the Samples

For the data preparation for the production in additive manufacturing way the Prusa Slicer application was used to generate control code for machine and set all main parameters. The production was made using the Prusa i3 MK3S+ 3D printer.

PLA material was used for the structure.

Setting	Value
Nozzle temperature, Cº	215
Print bead temperature, Cº	60
Infill, %.	100
Layer thickness, mm.	0,2
Printing time, min.	192



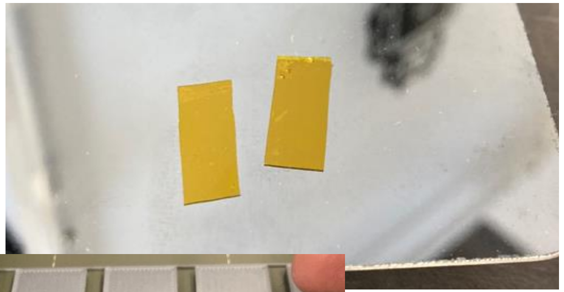
Production of the Samples (Kapton)

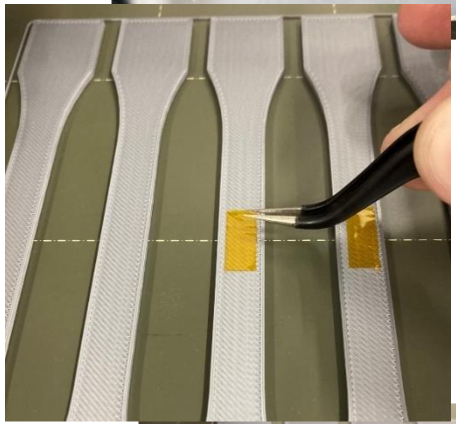
Samples for the test of the influence of the strain gauge on the overall structure.

As far as it was no need for the strain gauges to provide data, it was decision made to embed the mock-up of the strain gauge.

As the material for the strain gauge the Kapton tape produced by Pro Power was used. After the physical measurement of the strain gauge, the decision was made to use two layers of the Kapton tape in order to have same layer thickness.

The main parameter for the Kapton tape is that it withstands temperature up to 280 ° Celsius.





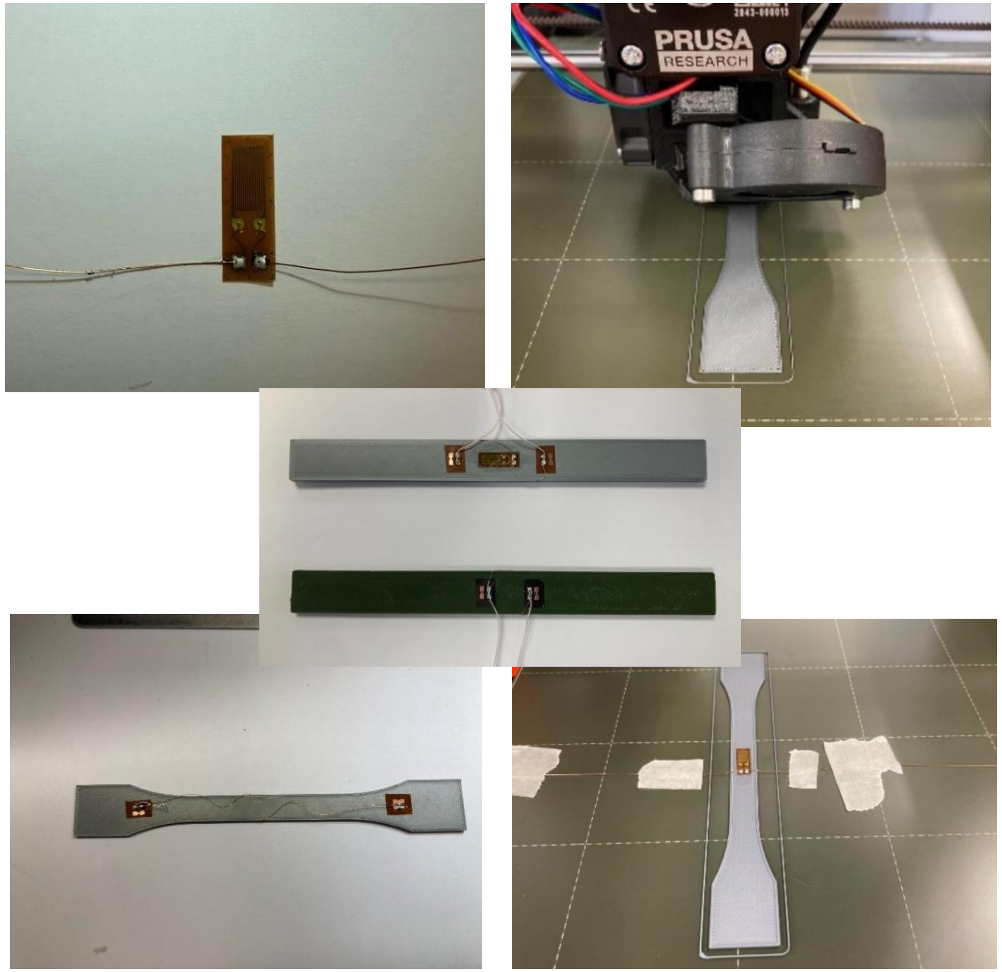
Production of the Samples (Strain Gauge)

After the production of the simplified samples batch, the samples with embedded strain gauges were produced.

The strain gauge was prepared in advance and the coper wires were soldered to the strain gauge base.

The manufacturing process was paused in the middle of the process in order to glue the strain gauge on the top layer of the specimen. After that the production process resumed.

After each step the strain gauge health status was checked and recorded.

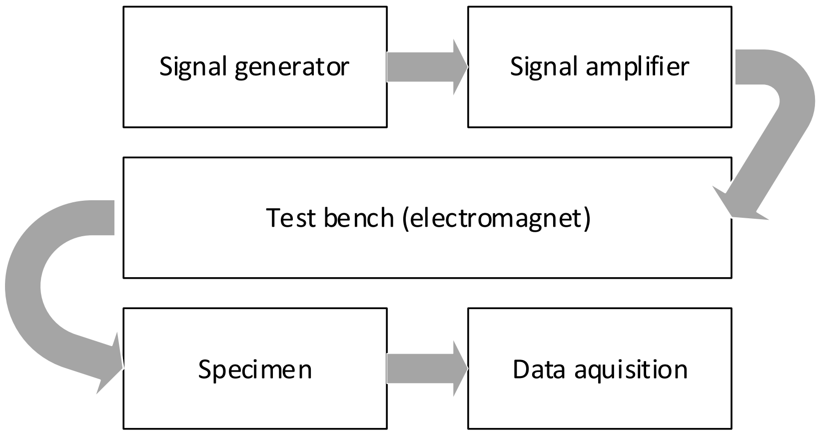


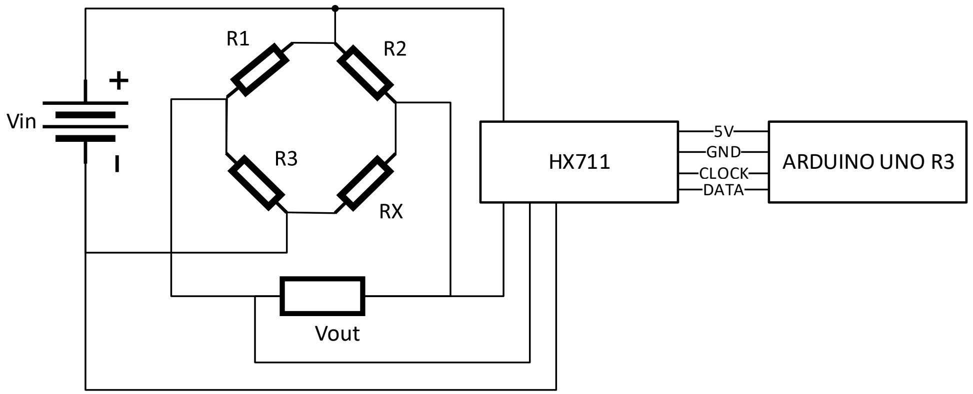
Data Acquisition System Design

In order to successfully test the samples and gain the reliable data the testing bench was built, and the Data Acquisition System designed.

For the main element of the DAQ system the Arduino microcontroller with HF711 load cell amplifier was selected and embedded software code was written.

For the data logging the MS Excel with data streamer add on was used.

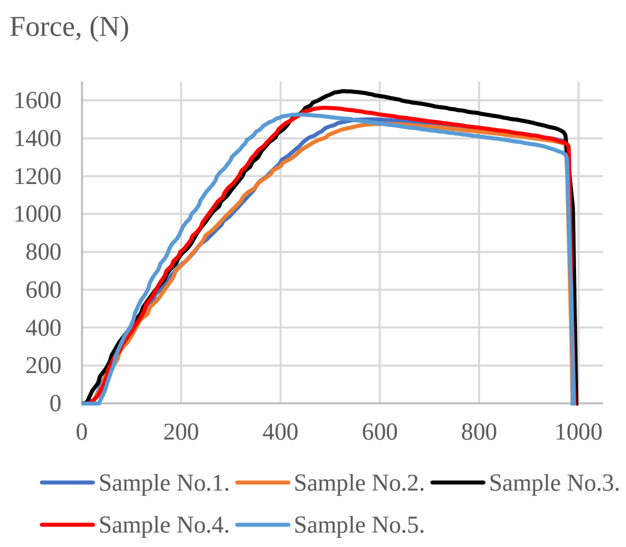


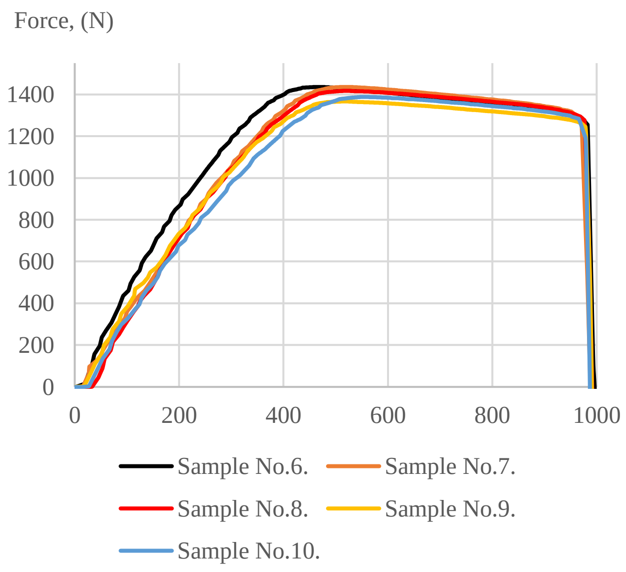


ktu

Testing of the samples till disintegration (Kapton)

The batch of 5 + 5 samples was tested in order detect the influence of the embedded strain gauge on overall structure.





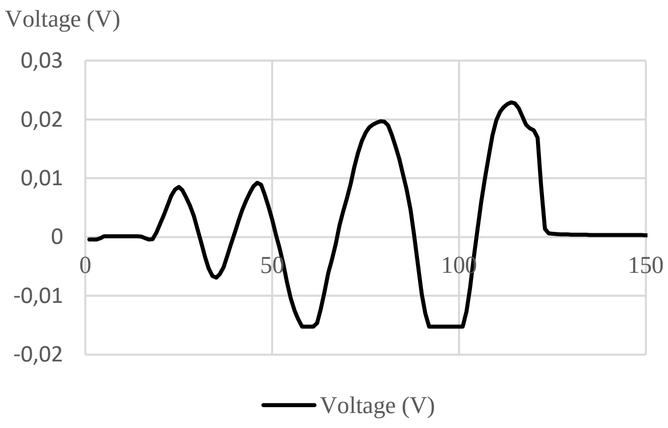
Testing of the samples (Kapton)

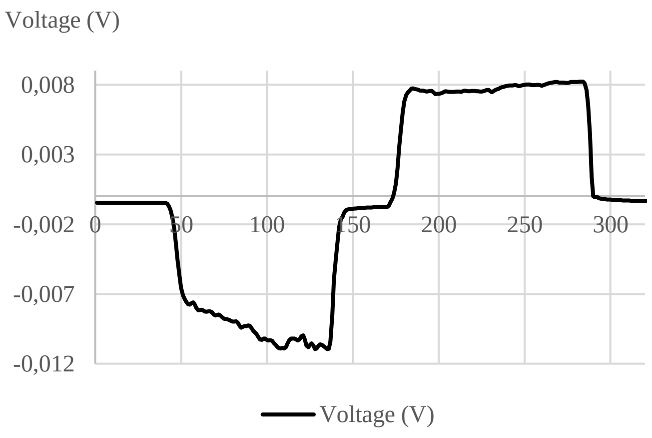
The batch of 5 + 5 samples was tested in order detect the influence of the embedded strain gauge on overall structure.

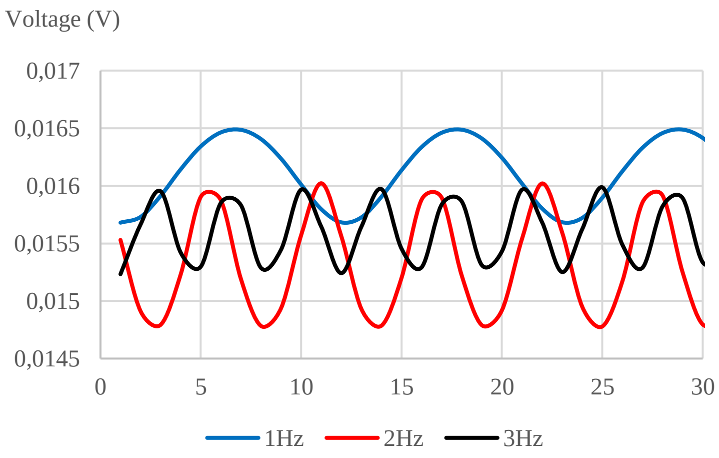
ktu

Testing of the samples produced (No.1.)

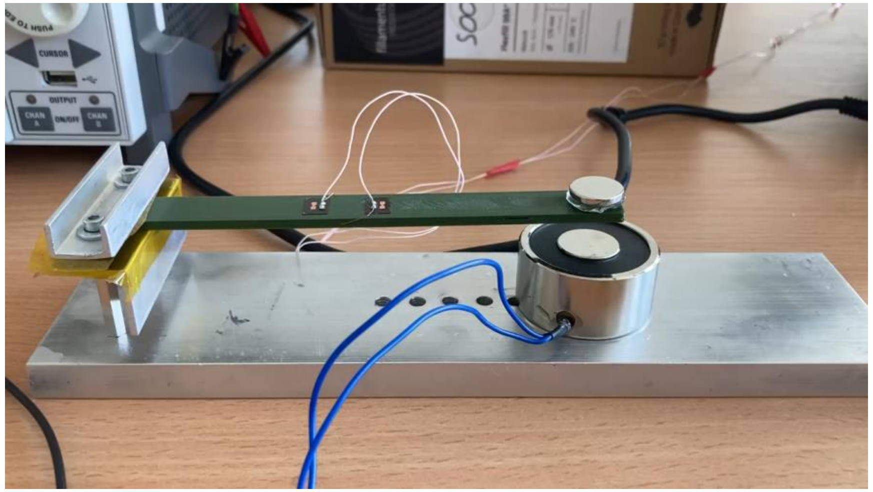
Various test cases were analyzed, and data recorded including the bump test and tests on various excitation frequencies.



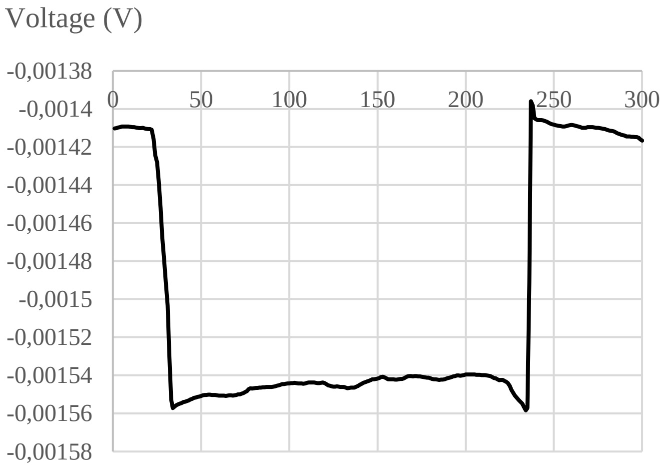


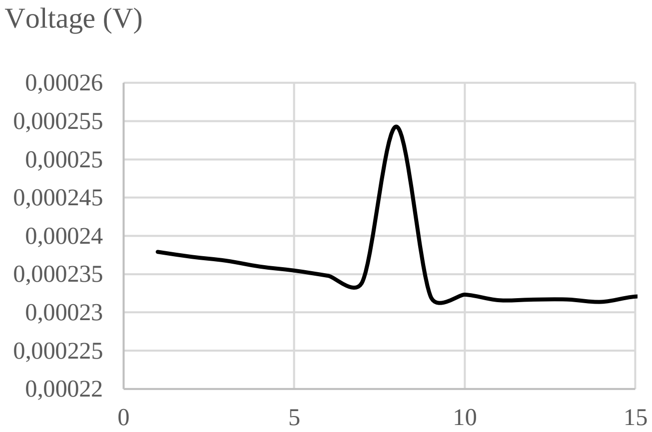


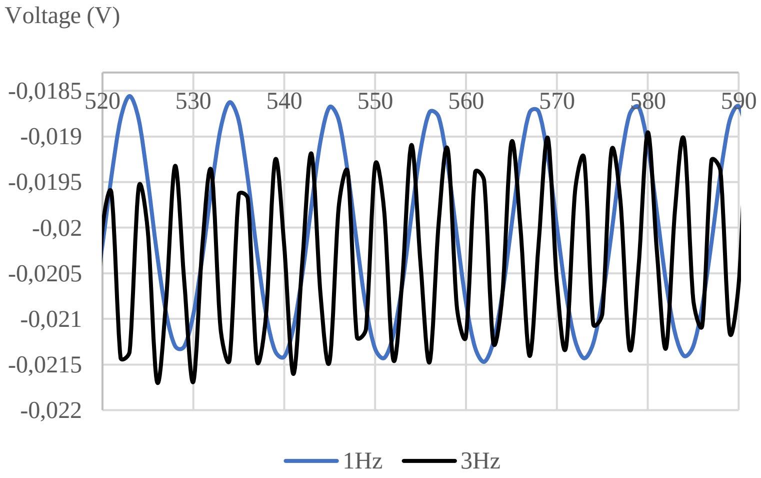
Testing of the samples produced (No.2.)



Various test cases were analyzed, and data recorded including the bump test and tests on various excitation frequencies.





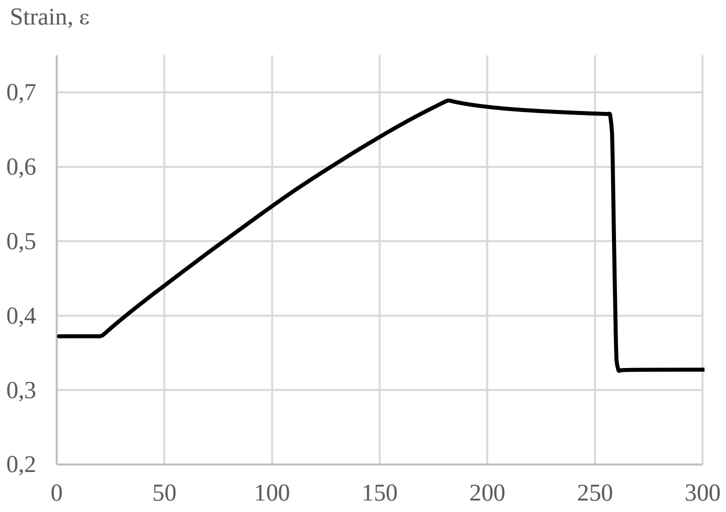


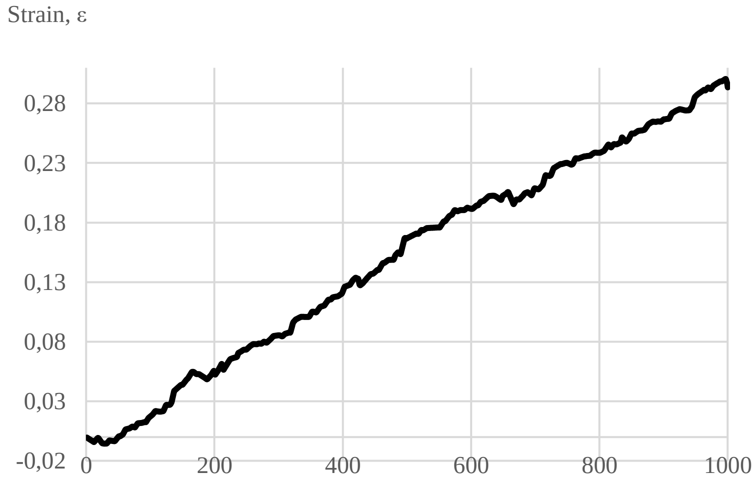
Research of Structures with Embedded Sensors

ktu

Testing of the samples produced (No.1.)

In order to gain more data and know how about the specimens with integrated strain gauges the tests in the testing machine were conducted. The testing machine Tinius Olsen H25KT with VEM 300 series tensiometer was used. The first test was conducted with tension of the specimen up to 0, 3% of length, with the speed of 2mm per minute.

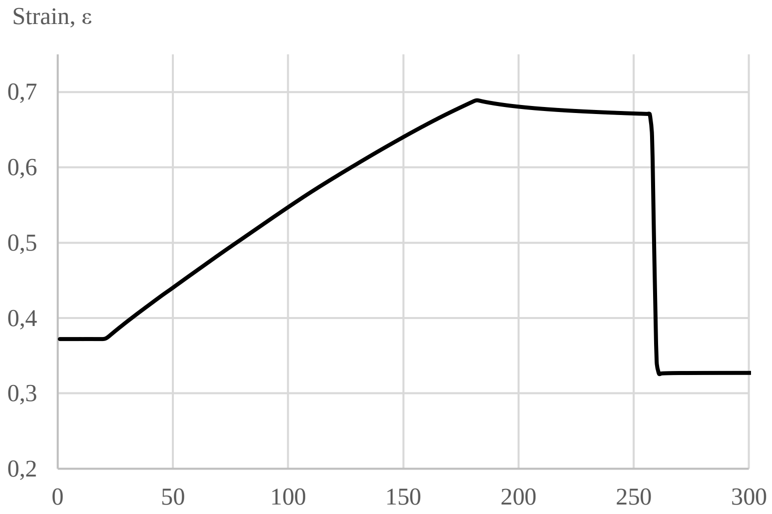


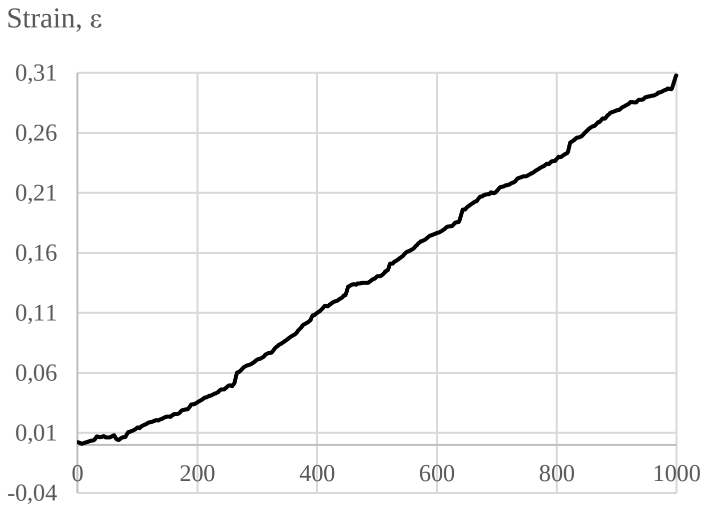


Research of Structures with Embedded Sensors

Testing of the samples produced (No.2.)

In order to gain more data and know how about the specimens with integrated strain gauges the tests in the testing machine were conducted. The testing machine Tinius Olsen H25KT with VEM 300 series tensiometer was used. The first test with conducted was tension of the specimen up to 0, 3% of length, with the speed of 2mm per minute.





Conclusions

- A methodology for manufacturing structures with embedded sensors was successfully developed and applied to test samples. Initially, samples were created using PLA and a Prusa MK3S 3D printer, optimized with 100% infill and 0.2mm layer thickness. Subsequently, samples with HBM strain gauges capable of withstanding temperatures up to 250°C were produced. Impact tests indicated minimal structural impact, demonstrating the feasibility of using compact strain gauges. Mechanical behavior under dynamic and static loads was evaluated, with tests showing a small deviation (0.016 to 0.043 strain units) between strain gauge and optical extensometer measurements for embedded sensors, confirming the system functional viability.