# ИЗСЛЕДВАНЕ НА АРАМИД-ПОЛИАМИДНИ КОМПОЗИТИ, ПРОИЗВЕДЕНИ ОТ ДОБАВЪЧНО ПРОИЗВОДСТВО

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# INVESTIGATION OF ARAMID-POLYAMIDE COMPOSITES PRODUCED BY ADDITIVE MANUFACTURING

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## INTRODUCTION

*The additive manufacturing was intensively developed in the last years and at the current time there are already commercially available 3D printers, which can place carbon, glass or aramid filaments additionally to the thermoplastic material. Such one is the printer Mark One of the company Markforged [1]. The samples were printed with a resolution of 0.1 mm. This allows production of parallel layers where the reinforced material is directed and placed in the most efficient way for the current construction. This method is also called FLM (Fused Layer Modelling). With the Fused Layer Modelling a wire is pressed about a heated nozzle and the diameter of the nozzle determines the layer thickness. In the heated nozzle, the material is melted accordingly over the melting temperature of the material used and printed layer by layer. In the case of most printers, the print head and not the print bed are moved in the xy direction, only the z axis is usually realized by the print bed. Furthermore, the 3D printing allows production of such parts individually, which is cost efficient compared with other technologies.*

*This work presents experimental investigation of the mechanical properties of Aramid-Polyamide composite samples, produced by additive manufacturing.*

***Keywords:*** *Aramid, Polyamide, fiber reinforced composites, additive manufacturing, 3D printing*

## MATERIALS AND METHODS

In order to determine the material properties of the composites, several forms with different orientation were produced. The form of the samples is determined by the DIN EN ISO 20753 (***Figure1***). Because the placement of the filament is limited by the software of the printer, the form had to be scaled (1:2) so that the testing area consists of Aramid filament layers with enough length with different orientation. The test area applies in length of 30 mm and is identical for all samples.

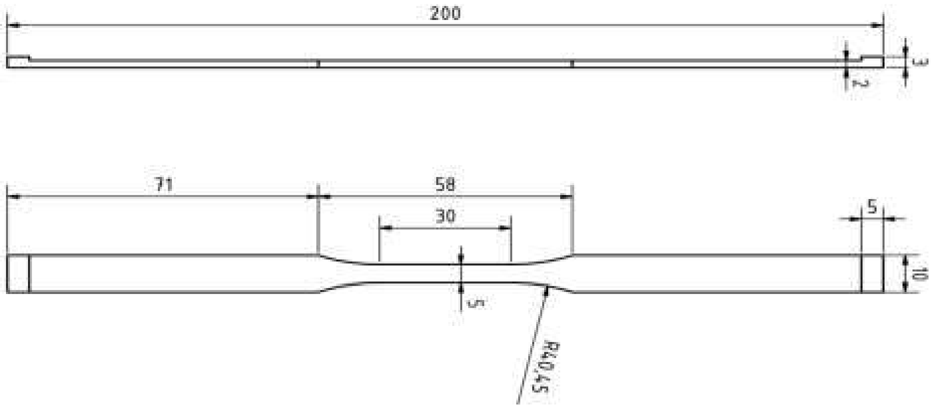


***Figure 1*** Tensile bar complying with DIN 20753.
The edges are modified in the form of additional thickness, so that during the test are locked in the testing jaws to avoid slippage and to allow testing without too high pressure of the jaws to the materials.

## EXPERIMENTAL SETUP AND RESULTS

In the first series, test samples with different fill levels were printed and compared with one another. Filling volumes of 20%, 40%, 60%, 80% and 100% were tested with three different filling patterns (triangular, rectangular and hexagonal).

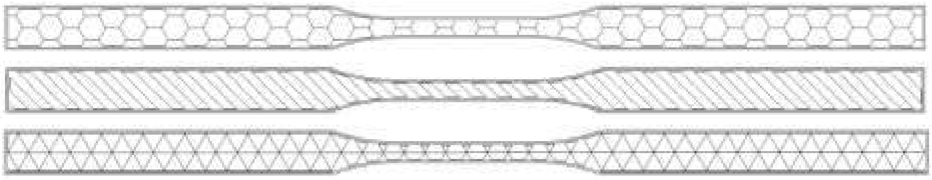

***Figure 2*** top-down: 20% hexagonal, 20% rectangular and 20% triangular

The rectangular pattern was the only pattern that could fill the experimental sample completely with matrix material. For the further samples with the aramid reinforcing fiber, the fill pattern rectangular 100% was chosen to ensure a complete filling of the test samples.

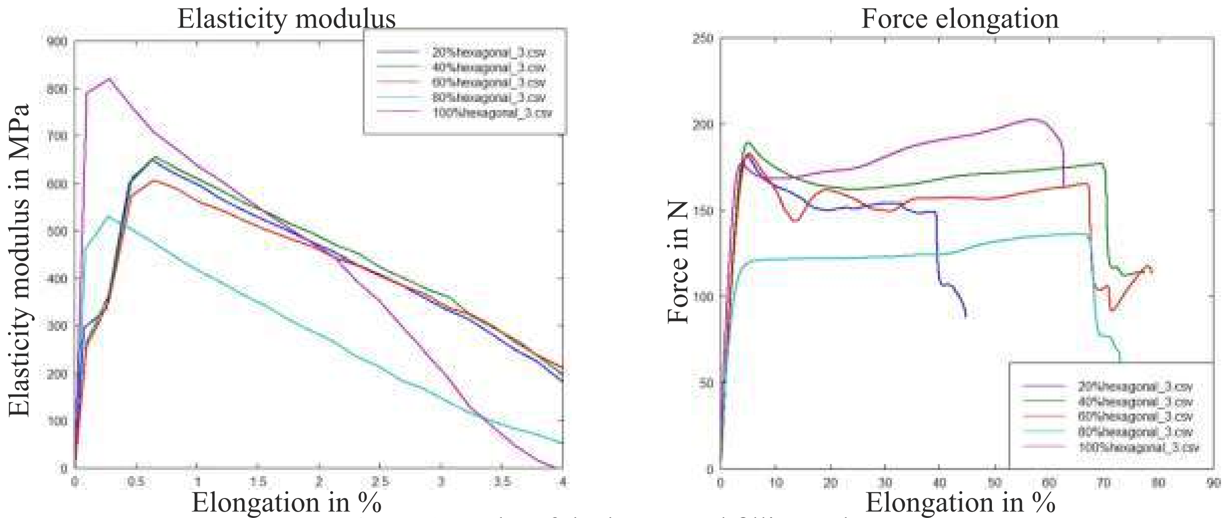


***Figure 3*** results of the hexagonal filling volumes

The second series of samples consists of fibres inserted in the middle (layer 10 of 20) with different angles (0°, 15°, 30°, 45°, 60°, 75°, 90°.). All samples in this series have a thickness of 2 mm.


***Figure 4*** Fiber layer at 15° aramid for first series

The last 10 of 30 layers are only for the printing of the additional material at both ends for fixing the samples in the clamp (jaws).

The following points are included in the results monitoring:

- After the maximum force has been reached, a decrease in the force can be observed in the F/ε diagram.
- With an insertion angle of 0° parallel to the tensile direction, the highest tensile force could be obtained as well as a decrease in the tensile force in the x direction, the higher the angle of the inserted reinforcing fiber.
- The fracture of the aramid fiber at maximum force can be clearly read by the elastic modulus diagram.
- When the insertion angle is increased, the elongation increase.

The elastic modulus decreases approximately linearly to approx. 2% after the maximum value.

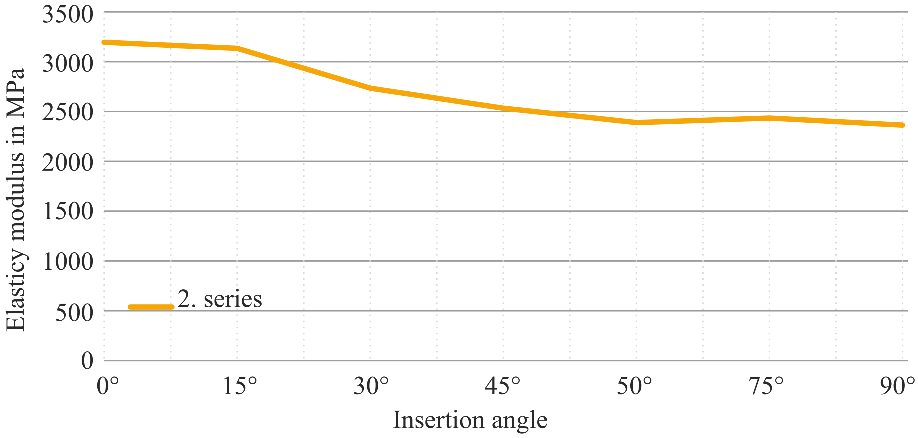


***Figure 5*** Comparison elasticity modulus and insertion angle. As might be expected, the elasticity module decreases with increasing angle

***Table 1***
comparison 100% filling with 90° insertion angle

| 100 % hexagonal without aramid fiber | 100 % triangular without aramid fiber | 100 % rectangular | |
|---|---|---|---|
| | | without aramid fiber | Insertion angle 90° with aramid fiber |
| 975 MPa | 1015 MPa | 2069 MPa | 2379 MPa |

For the insertion angle of 90° with aramid fiber expected the same elasticity modulus as for the measurement of the first series at 100% rectangular fill volumes. This is explained by the fact that the fibers are not placed exactly into the test samples at 90°, but are in the form of a loop (see ***Figure 5***). This obviously has a stiffening effect on the trial.

***Figure 6*** Microscopic image from a 90° sample

The third series consists of fibres in layer 3 and 18 with same or different angles. The example on ***Figure 7*** consists of layer 3 with 0° Aramid and layer 18 at 15°.

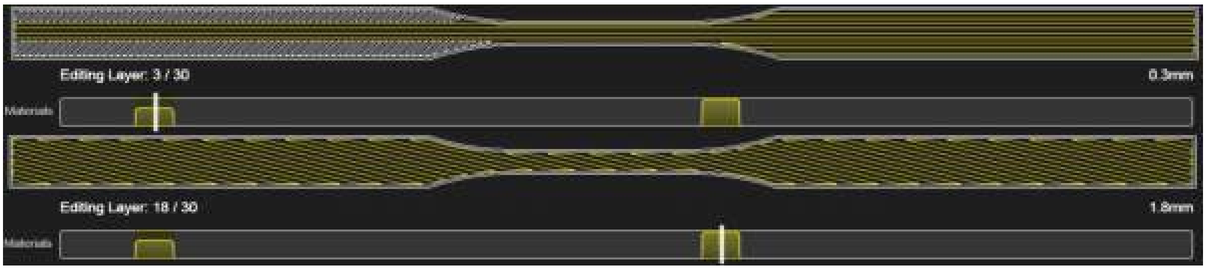


***Figure 7*** Fiber layer 0° and 15° Kevlar

***Figure 8*** presents an image of the printed material as a complete part and an enlarged section of the testing area.

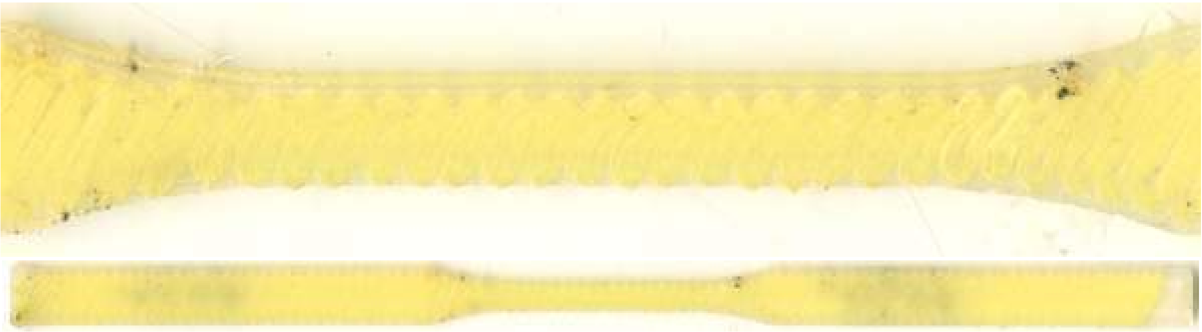

***Figure 8*** Tension rod fiber layer 60°

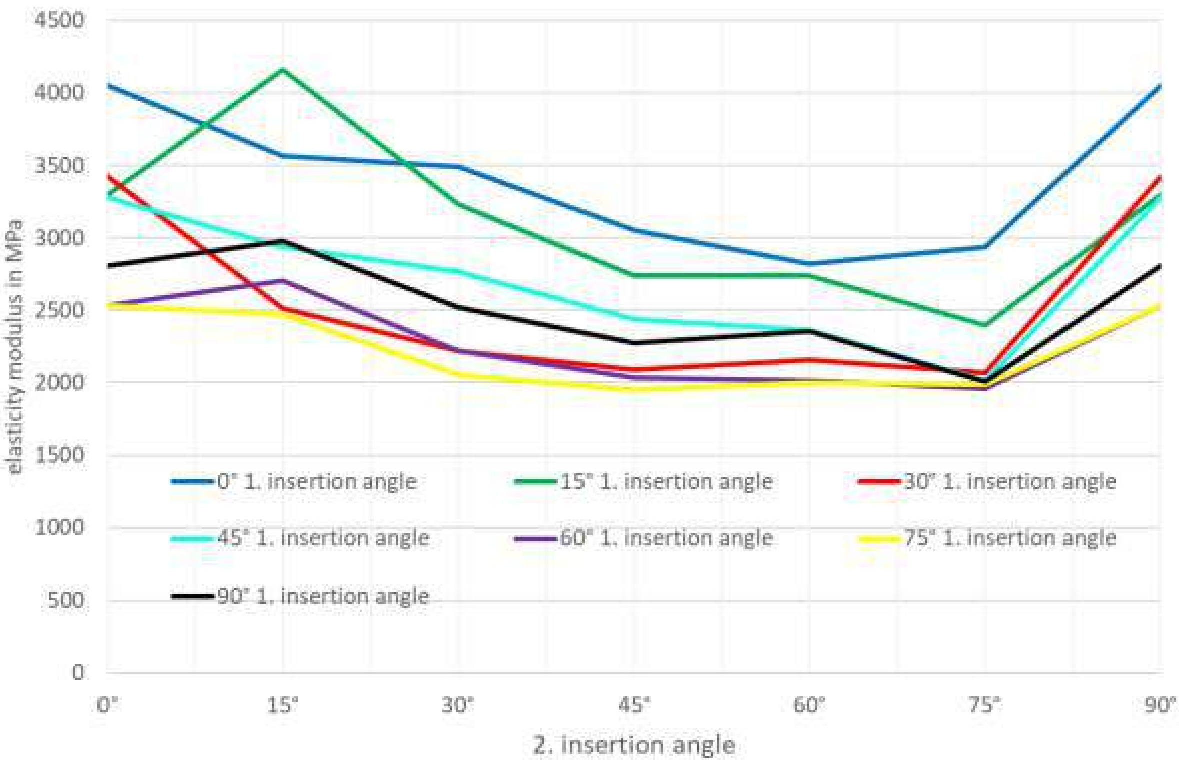


***Figure 9*** Comparison the different elasticity modulus with the insertion angles

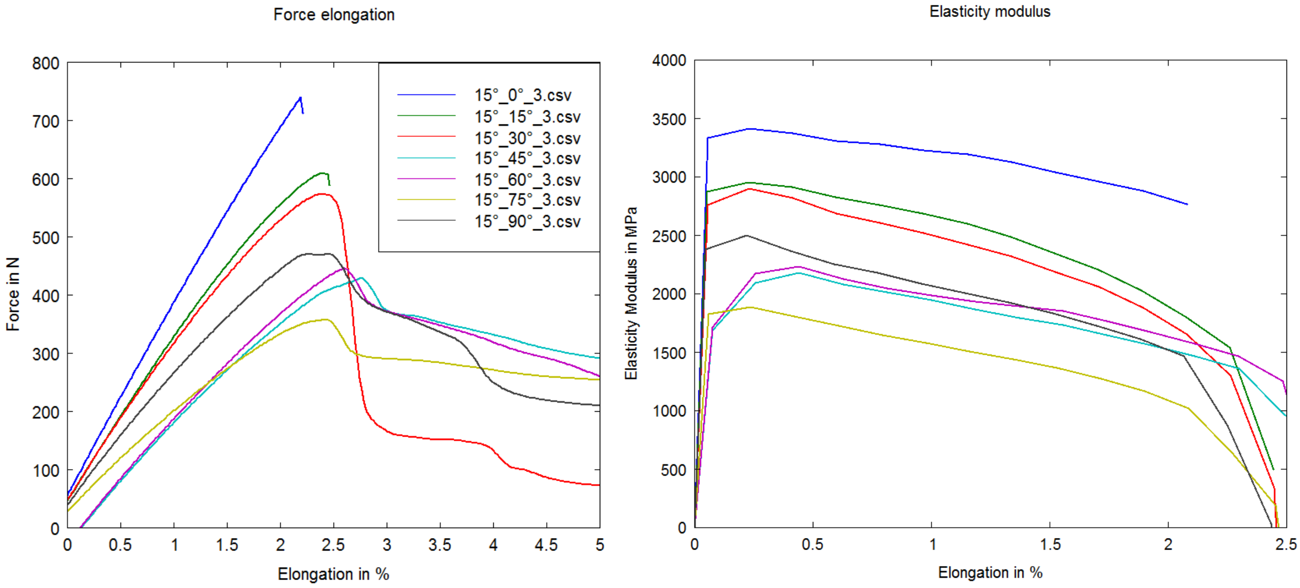


***Figure 10*** Results from the third series.
In the right picture the converted results up to 2,5% elongation

The following points are included in the results monitoring:

- With the same first insertion angle, the maximum tensile forces decrease with increasing angles. The test samples are excluded with a second insertion angle of 90°. In these samples, the maximum tensile force decreases less than in the test specimens before.
- The mean values of the maximum tensile force have high fluctuations.
- The smaller the angle sum of series 3, the greater the maximum tensile force.
- The greater the angle sum of series 3, the greater the maximum elongation.

## CONCLUSIONS

The E-modulus was ascertained using tensile testing machine of the company Zwick.

The tensile tests show for several structures initial high elasticity modulus, caused by the reinforced fibers and after that long elongation – up to 70%, based on similar to kinematical rearrangement of the polyamide filling walls. The resisting force for some of the structure types after the first peak remains high enough, so such structures can give additionally safety factor in constructions without increasing of their weight.

The results of the different angles and of pure Aramid plates will be compared. The experimental results will be used as well as validation data for prediction of the properties of the plates based on the classical lamination theory [2] and application of the method of inclusion implemented in Wisetex [3] and TexComp [4] for UD laminates. In this way it will be proven if the classical methods for computation of the properties of composites can be applied as well for 3D printed (additive manufacturing) parts.

## REFERENCES

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