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Analysis of Mechanical Properties of Printed Polyamid PA11

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Abstract. The contribution deals with the analysis of mechanical properties of printed polyamide PA11. More specifically, the mechanical properties are evaluated for three different orientations of specimens when printed and for different positions of specimens in printing chamber. Values of yield strength, ultimate stress and ductility are stated. Significant differences of results were found out. In order to explain these differences, the microscopic analysis of fracture surfaces was performed. Uneven structure of fracture surface can be observed.

Introduction

For needs of the contemporary design which reaches limits of material properties the correct values of material properties are required. The point of interest of this contribution are mechanical properties of PA11 material printed by HP Multi Jet Fusion Technology on the printer HP Jet Fusion 4200 Series. Since the further strength analysis of printed products by finite element method will be required, the tension test was chosen as the most common analysis providing necessary parameters such as Young´s modulus, tangent modulus, yield strength, ultimate strength, etc.

HP Multi Jet Fusion is a new technology placed on the market in 2014. HP Multi Jet Fusion technology uses the powder material without the use of lasers and can be used even for series production. [1] The process of the 3D print starts with laying down the thin layer of material in the printing area. Further, the carriage containing an HP Thermal Inkjet array passes from left to right side, printing chemical agents across the full printing area. The layering and energy processes are combined in a continuous pass of the second carriage from top to bottom side. The process continues, layer by layer until a complete part is formed. At each layer, the carriages change its direction. [2]

The material PA11 is the polyamide of natural origin obtained from renewable resources – ricin oil. It is the versatile material used for applications requiring properties such as chemical, thermal or mechanical endurance.[3] One of typical products made of material PA11 are orthopedic aids, such as prostheses and braces. Since medical product are subjected to the strict safety requirements, designers require as much as possible accurate mechanical parameters of materials used.

Experiments

Tension tests on flat specimens, see Fig. 1, printed from the material PA11 on the printer HP Jet Fusion 4200 Series were performed using the testing machine TESTOMETRIC M500-50CT equipped by the extensometer which measures the elongation of the specimen in its active part. The loading speed was set to 10 millimeters per minute. The output of tension tests performed is the tension diagram – graph of engineering stress versus engineering strain values of particular specimens whereas the directional orientation and position of specimens inside the printing chamber were taken in the account.

In order to evaluate the influence of the printing direction on mechanical properties of the structure, three kinds of specimens printed in different orientation were used. Layers of specimen A were laying down in the direction of its thickness, layers of specimen B in the direction of its width and layers of specimen C in the direction of its height. The orientation of specimens when printed is obvious from Fig. 2.

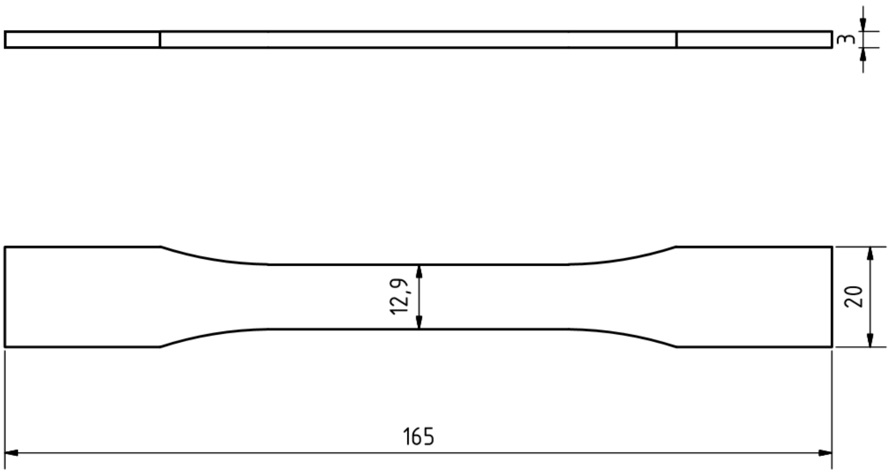

Fig. 1: Specimen used for tension tests

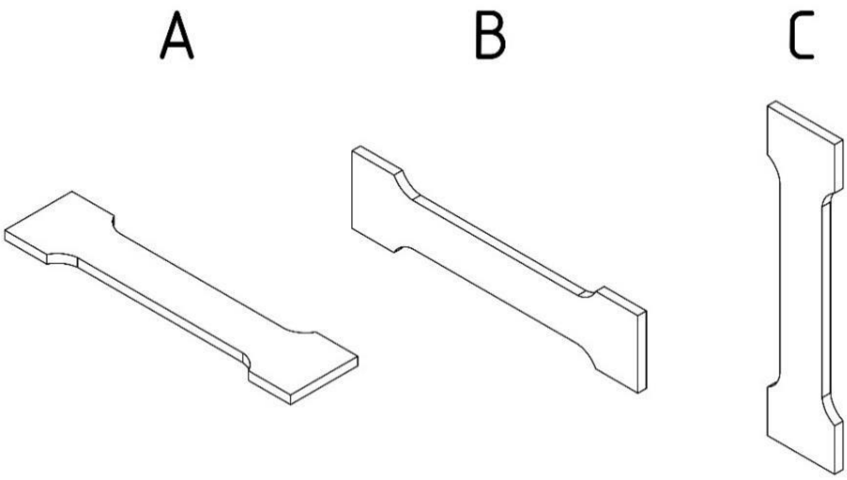

Fig. 2: Orientation of specimens when printed

In order to discover the influence of the position of the printed structure in the chamber on its mechanical properties, the location of each specimen in the printing chamber was recorded. Specimens A10-A50, B10-B50 and C10-C53 were distributed in each corner and in the middle part of the printing chamber.

The printing chamber was filled by two series of eighteen specimens whereas results of tension tests of the first series is presented in this contribution, the other series will be used later in order to evaluate the influence of material aging on its mechanical properties. Except two series of specimens mentioned above, the printing chamber did not contain any other objects to be printed.

Results

Results of individual tension tests are presented in Fig. 3 in the form of tension diagrams – graph of engineering stress versus engineering strain values of each specimen.

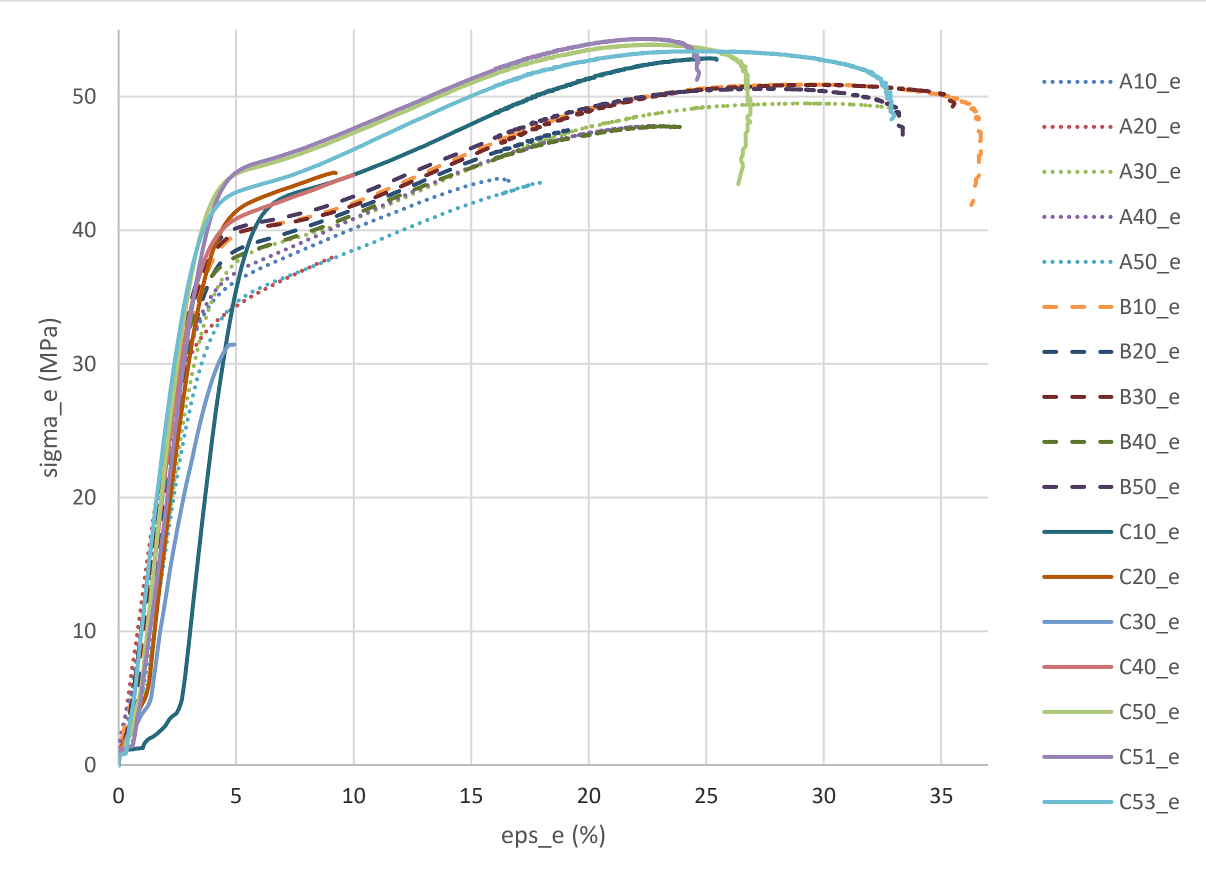

Fig. 3: Tension diagrams of tests performed

Stress-strain curves of specimens printed according to the orientation A (see Fig. 2) are plotted in Fig. 3 by solid lines, orientation B by dashed line and orientation C by dotted line.

Significant differences in stress-strain curves can observed not only for different orientations (A, B, C) of specimens but also for their positions in the printing chamber.

Concerning the yield strength and ultimate stress, the highest values were reached largely for specimens with the printing orientation C – (25-40) MPa and (32-56) MPa respectively, lowest values then for specimens with orientation A – (28-30) MPa, (38-43) MPa, respectively.

Observing the ductility of specimens, its highest values were reached largely for printing orientation B – (18-36)%, lowest values then for the orientation A – (8-16)%.

In order to explain differences among specimens printed in one direction, the microscopic analysis of selected specimens was performed. Fracture surfaces of specimens A20, A30, B20, B30, C30 and C51 are depicted in Fig. 4 to Fig. 9. Fracture surfaces were chosen so that specimens with better and worse material properties is presented whereas specimens with better mechanical properties (A30, B30, C51) are depicted in right columns of table, specimen with worse properties in left columns (A20, B20, C30).

From presented figures it is obvious that even individual fracture surfaces contain differences in the surface structures. Areas with smooth surface, flat furrows and deep cavities leading in the direction which is perpendicular to the fracture surface can be observed. It is also obvious from Fig. 3 and Fig. 4-9 that deeper structure located in the fracture surface improves material properties significantly.

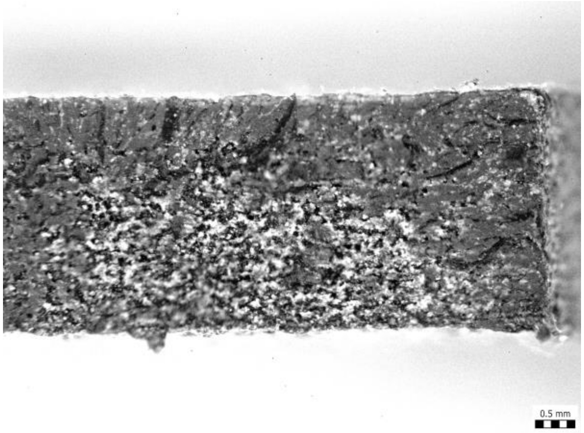

Fig. 4: Fracture surface – specimen A20

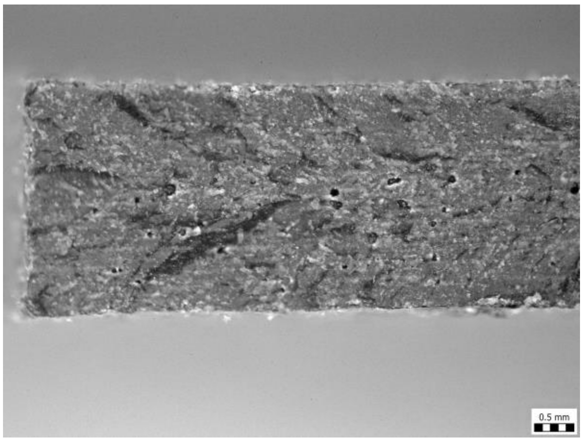

Fig. 5: Fracture surface – specimen A30

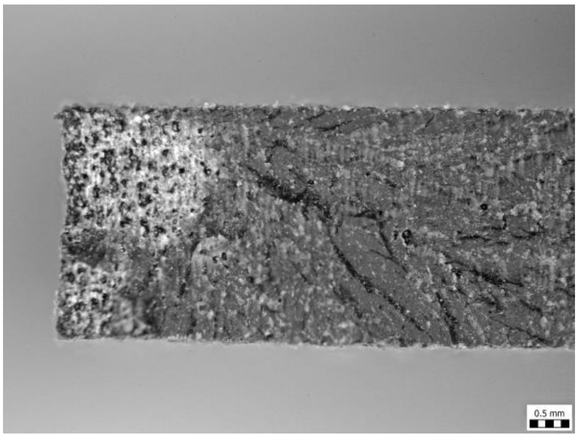

Fig. 6: Fracture surface – specimen B20

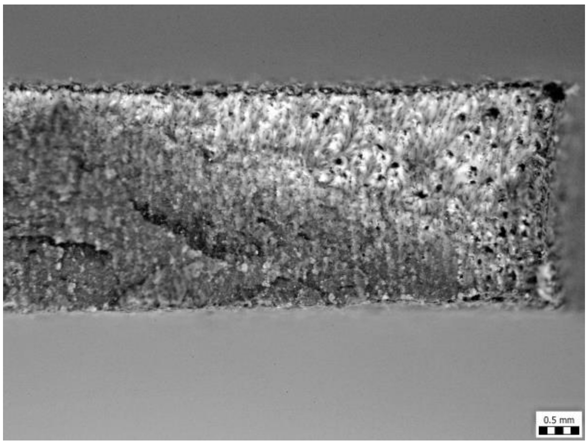

Fig. 7: Fracture surface – specimen B30

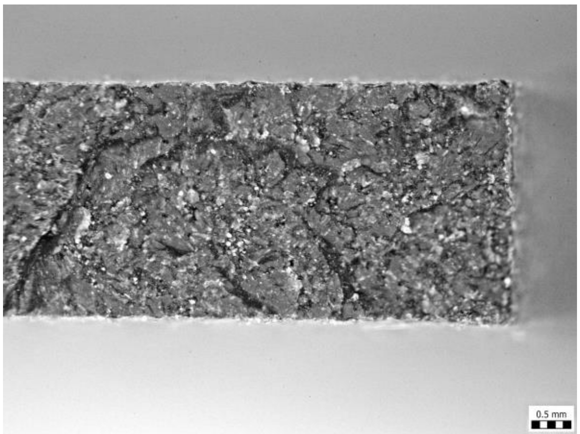

Fig. 8: Fracture surface – specimen C30

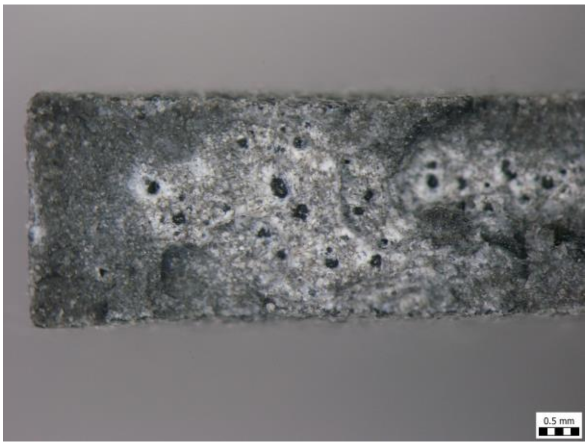

Fig. 9: Fracture surface – specimen C51

Conclusion

The mechanical analyses of the set of specimens printed from polyamide PA11 was performed. Three kinds of specimens with different printing directions were evaluated. In order to incorporate the influence of specimen´s position in the printing chamber, the location of each specimen was recorded. Except specimens printed, the printing chamber did not contain any other objects to be printed. In order to explain differences in results, the microscopic analysis of fracture surfaces was done.

Based on results obtained, the significant differences of mechanical properties for three printing directions and also for different position in printing chamber were found out. Concerning the yield strength and ultimate stress, best properties showed largely specimens with printing orientation C, worse parameters were found out for specimens with printing orientation A. Observing the ductility, the highest values show mostly specimens with orientation B, lowest values then specimens oriented according to A.

Significant differences in mechanical behavior of specimens printed in the same direction were found out as well. However, no strong connection between mechanical properties and position of the specimen in the printing chamber was found out in the set of experiments performed.

The microscopy analysis of fracture surfaces of chosen specimen showed different kind of material structure. Smooth surfaces, flat furrows and deep cavities leading in the direction which is perpendicular to the fracture surface can be observed. Authors of this contribution explain these structure inconsistences by the uneven heat distribution during the printing process and/or by the use of the combination of new and used PA11 powder. The use of this powder mixture is the common process in the printing practice.

Finally, it can be stated that printed specimens do not show isotropic material properties. Better prediction of mechanical behavior of printed parts can be done under the assumption of orthotropic properties. However, different mechanical properties can be also observed for specimens with the same printing direction but in different location in the printing chamber. According to figures presented in this contribution, it can be observed that the presence of deep cavities leading perpendicular to the fracture surface improve significantly mechanical properties of the structure printed. On the other hand, the prevailing smooth fracture surface determines poorer mechanical properties.

Acknowledgement

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