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Correspondence to:
Sergiu-Valentin Galatanu
sergiu.galatanu@upt.ro

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Impact properties of laser sintered polyamide, according to building orientation

Dan Ioan Stoia, Sergiu-Valentin Galatanu and Liviu Marsavina

Politehnica University Timisoara, Mihai Viteazu no.1, Timisoara, Romania

Abstract The paper presents the dynamic impact properties of laser-sintered polyamide PA2200 in accordance with the building orientation. The idea of determining the impact properties in relation to building orientation lays on orientation-property dependence founded in our previous studies of tensile, bending and fracture mechanics testing. The specimens were manufactured under the same energy density and temperature conditions, at four orientations, as described in the paper content. The experimental investigation was carried out on a pendulum impact testing machine to determine the impact energy and strength according to the building orientation. Brittle fracture was observed for all specimens, independent of building orientation, and a similar behavior was also observed in the elastic zone of deflection. However, impact strength and impact energy are influenced by orientation.

1. Introduction

Determining the mechanical behaviour of additively manufactured (AM) components manifests high interest to researchers today. The attractivity of the domain is based on the inconsistency obtained in mechanical and geometrical properties, when the manufacturing parameters change. Additionally, the type of additive technology used for manufacturing will have a great impact on the result [1-3].

Numerous authors focus on determining the elastic and strength properties of additively manufactured materials, but fewer studies can be found on the static and dynamic fracture behaviour of parts [4-6].

The evaluation of Charpy impact strength and energy can be found in the literature conducted on composites, cellular materials and even on additively manufactured materials [7-10].

The purpose of this study was to determine the impact energy and strength of polyamide PA2200 specimens, according to the manufacturing orientation of the specimens. The results will give a broader picture of mechanical properties in close relation to the manufacturing aspects.

2. Materials and methods

2.1 Manufacturing of the specimen

The polyamide PA2200 specimens were built by selective laser sintering on an EOS Formiga P100 machine. The variable in the manufacturing process was the arrangement of the specimen within the building envelope. The size and shape of the specimen were designed according to the ISO 179 standard [11]. The notched beams were then arranged in the building environment in following way: horizontal 1: having the width of the beam along the growing direction; horizontal 2: having the thickness of the beam along the growing direction; Vertical: having the length of the beam along the growing direction and Oblique at 45° to the XY plane (Fig. 1).

The parameters used for laser sintering process are: energy density of 0.067 J/mm² (power of 25 W, laser velocity to 1500 mm/s and scan spacing 0.25 mm), building chamber 170.5 °C

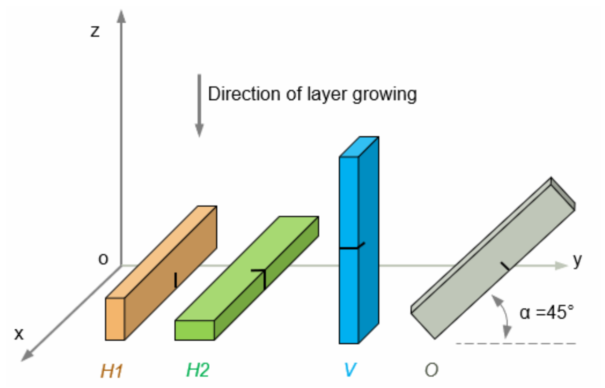

Fig. 1. Orientation of the specimen in the building environment: Horizontal 1 (H1); horizontal 2 (H2); vertical (V); oblique at 45° with respect to the XY plane (O).

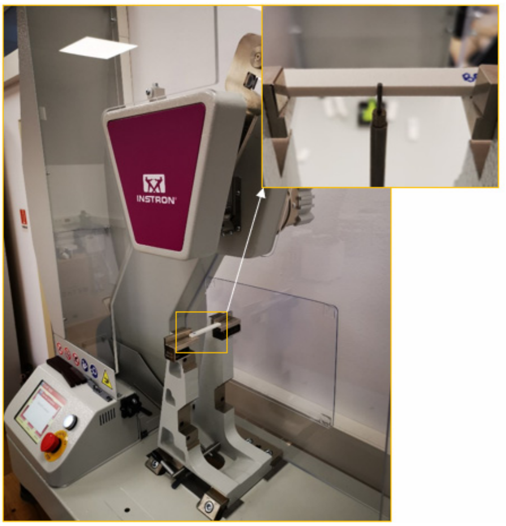

Fig. 2. Specimen on Instron CEAST 9050 instrumented impact testing equipment.

and removal chamber temperature 159 °C î. The scaling factor of 2.0 % was applied in each direction in order to compensate for the shrinkage at cooling. All selected parameters were extracted from our own previous work [2, 4, 12, 13].

2.2 Testing methods

The Charpy test is the most widely used method to evaluate the impact strength of materials. It can be used on various types of materials, such as polymers, ceramics, and composites.

In this study, the Instron CEAST 9050 Charpy test machine (Fig. 2) was used to determine the impact strength and energy of the AM specimens, according to the ISO 179 standard.

The equipment consists of a 229.7 [mm] long impact pendulum combined with a 1.186 [kg] hammer at the end of the striker, possessed of a potential energy of 5 [J] and an impact speed of 2.9 [m/s]. The recorded force signal measurements were forwarded to the equipment computer software through a data acquisition system connected to the hammer. The pendulum is raised to a defined height and released to fall. The difference between the initial and final height of the pendulum is directly proportional to the amount of energy lost as a result of the fracturing of the specimen.

The pendulum was automatically calibrated and the symmetrical support of the specimens measured a 60 mm span. To conduct the tests, the specimens were placed horizontally, in the edgewise manner - on the supports of the test rig and pushed against the anvils.

Samples were taken from each specimen to determine their volumetric density for each orientation. Each sample was first measured and then weighed using a 500 g Kerrn balance, with a 0.001 g resolution.

3. Results

Twenty specimens, five for each orientation, were tested under the same conditions. Impact force was recorded in both in the time and in the deflection domain. All specimens experienced brittle fracture behavior regardless of the orientation of the building. Also, the energy data are very well grouped in the elastic impact domain (0 to 0.6 mm) while they begin spreading in the crack propagation phase.

In particular, the first damage event in instrumented puncture tests often appears as a slight sudden decrease in force (crack initiation), followed by a gradual increase in force. Force increases after crack initiation are never observed in instrumented three-point bending impact tests [11].

The deflection - impact force and deflection - impact energy curves were plotted as a function of deflection for all specimens and presented in Fig. 3. The results of the specimens manufactured in the H1 direction are depicted in magenta color line, the H2 direction are yellow lines, the vertical V direction is with a red line while the oblique O direction is green.

Figs. 4 and 5 show the averages of the impact force and impact energy of the specimens, computed for each building orientation. Standard deviation values are high for H2 orientation both in terms of force and energy. This instability in property can be put on intralayer effect of fracture, the manufacturing layers being perpendicular to the notch.

The impact energy W, in joules, was determined by integration according to the Eq. (1).

The Charpy impact strength of notched test specimens a_{cN}, in kilojoules per square metre, was calculated using the Eq. (2).

$$W_j = \int_0^{Sj} F(s) \cdot ds \quad (1)$$

$$a_{cN} = \frac{W_B}{h \cdot b_N} \cdot 10^3 \quad (2)$$

Where: W_j is the impact energy in [J], s_j is the deflection in [m], F is the force in [N], W_B is the energy at break in [J], h is the thickness of the specimen in [mm] and b_N is the width of the

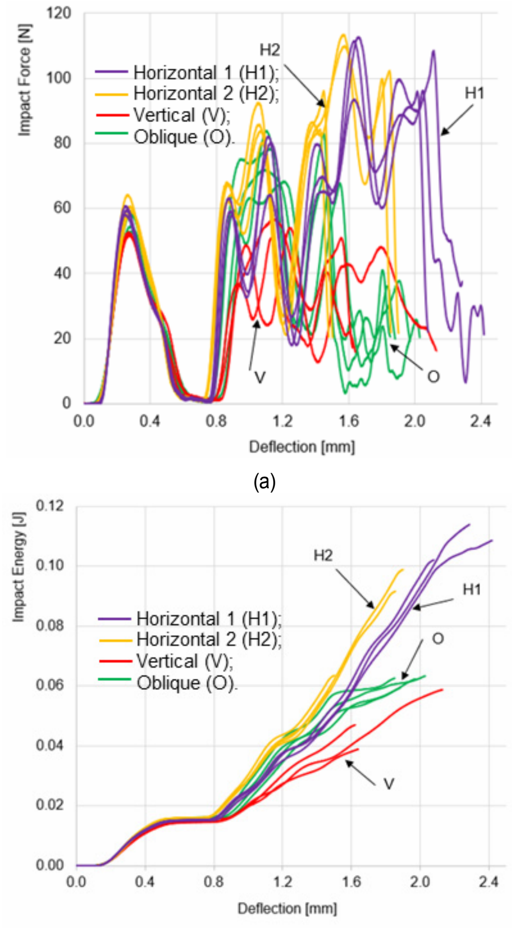

Fig. 3. (a) Impact force vs. deflection of all specimens; (b) impact energy vs. deflection of all specimens.

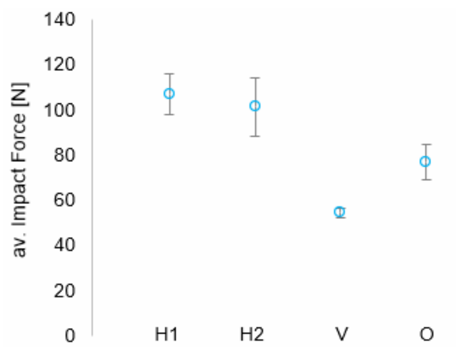

Fig. 4. Average impact force and standard deviation according to the building orientation of the specimens.

specimen in [mm].

The data are fairly well grouped according to the orientation of the specimens. Fig. 6 shows the Charpy impact strength in KJ/m^2. As expected, the best results were recorded for the horizontal specimens and the worst for the vertical specimens. If the average of the Charpy impact strength results for the specimens built horizontally was 3.18 KJ/m^2, for the specimens

Table 1. Impact properties according to the building orientation.

	H1	H2	V	O
Impact force (N)	106.80±9.09	101.33±12.74	54.53±2.02	76.77±7.83
Impact energy (J)	0.108±0.01	0.078±0.02	0.048±0.01	0.062±0.02
Impact strength (KJ/m^2)	3.18±0.17	2.35±0.59	1.46±0.31	1.86±0.05

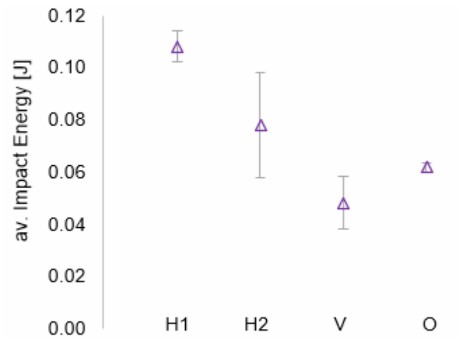

Fig. 5. Average impact energy and standard deviation according to the building orientation of the specimens.

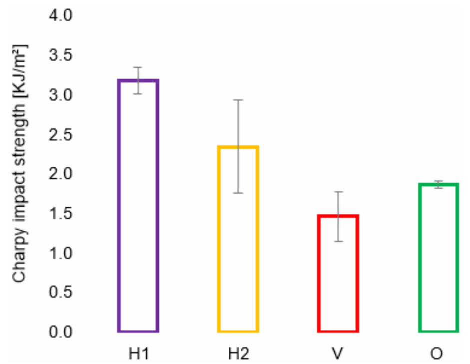

Fig. 6. Charpy impact strength and standard deviation according to the building orientation of the specimens.

built vertically, the average was 1.46 KJ/m^2.

All in all, the properties seem to follow the same trend, where the poorest values are record for the case of vertical growth of the part. This is the most susceptible case of interlayer fracture or delamination, the manufacturing layers being parallel to the impact direction.

The best properties are recorded for horizontal H1 positioning, in the case in which the loading direction is perpendicular to the manufacturing plane.

Regarding the behaviour in the elastic impact zone, the slopes up to the inertial peak are very similar in all specimens. This may lead to the conclusion that the dynamic coefficient of elasticity is similar for all orientations. However, crack propagation is very dependent on the relation between the orientation of the manufacturing layer and the direction of loading.

The average impact properties according to the building orientation and the standard deviation associated with are presented in the Table 1.

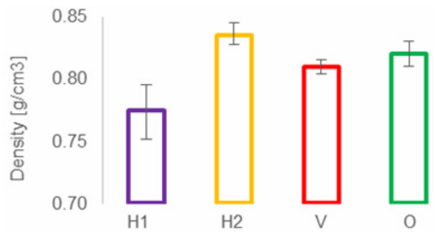

Fig. 7. Density and standard deviation according to the building orientation of the specimens.

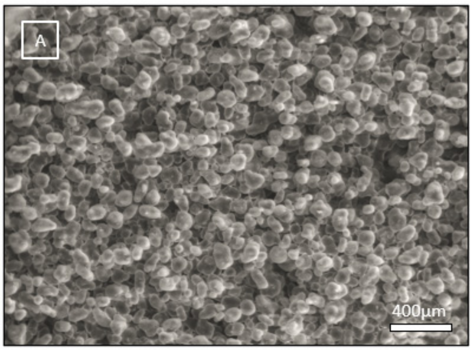

Fig. 8. SEM image of the PA2200 structure, 200X.

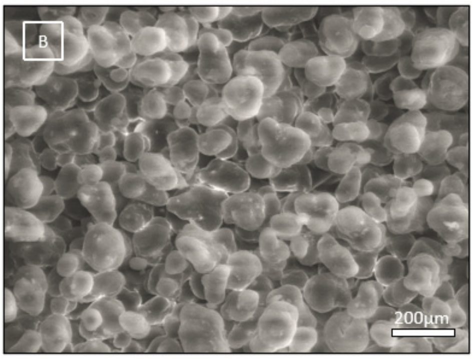

Fig. 9. SEM image of the PA2200 structure, 500X.

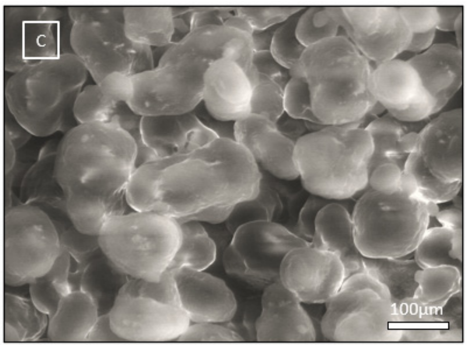

Fig. 10. SEM image of the PA2200 structure, 1000X.

Fig. 7 shows the average density values for the specimens, computed for each building orientation. The SEM images of the PA2200 structure were taken at magnifications of 200, 500 and 1000X (Figs. 8-10). The SEM images present the particle sizes of around 80 microns and also the particle bond. The bonding size and number is a direct indication of the volumetric density of the parts. Dark areas in the image are presenting micro-pores in different planes.

4. Conclusions

The paper presents the Charpy impact results carried out on PA2200 test specimens, obtained by selective laser sintering. The specimens were manufactured under the same conditions but at different orientations in the building environment. The following conclusions could be drawn:

1) Highly consistent data are recorded especially for the elastic domain of impact, where no difference in energy or force can be associated with the orientation of the specimen.

2) All manufacturing orientations lead to brittle fracture of the specimen.

3) H1 shows a higher ductility of the sample due to the elasticity of the layer plane, a larger deflection and implicitly a higher impact energy. In the case of H2, the layer thickness is stiffer compared to H1.

4) The fracture energy depends on crack propagation and therefore on the orientations of the layers in relation to the loading direction.

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Nomenclature

W_j : Impact energy, J
s_j : Deflection, m
F : Force, N
a_{cN} : Charpy impact strength, KJ/m^2
W_B : Energy at break, J
h : Thickness on the specimen, mm
b_N : Width of the specimen, mm

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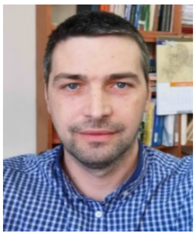

Dan Ioan Stoia is Associate Professor in the Department of Mechanics and Strength of Materials, Faculty of Mechanical Engineering, Politehnica University of Timișoara. He received his Ph.D. in Mechanical Engineering from Politehnica University Timișoara. His research interests include additive manufacturing, mechanical testing, FEA and biomechanics.

Sergiu-Valentin Galațanu is a lecturer in the Department of Mechanics and Strength of Materials, Faculty of Mechanical Engineering, Politehnica University of Timișoara. He received his Ph.D. in Mechanical Engineering from Politehnica University Timișoara. His research interests include mechanical testing, welding, numerical modelling, finite element analysis and additive manufacturing.

Liviu Marșavina is Professor in the Department of Mechanics and Strength of Materials at University Politehnica University Timișoara and Correspondent Member of Romanian Academy. He received his Ph.D. in Mechanical Engineering from University Politehnica Timișoara and worked as Postdoc and Experienced Researcher at Loughnorough University (UK), University of Sheffield (UK), Ghent University (Belgium) and Lublin University of Technology (Poland). His research interests include fracture mechanics and fatigue of materials, mechanical testing, composites, additive manufacturing, finite element analysis.