Investigation on maximum tensile force and Shore D hardness of 3D printed samples of Polyamide PA6-CF

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Abstract: *In this article, the maximum tensile strength and hardness of 3D printed samples of Nylon CF15 Carbon were investigated. 20 test specimens were produced with dimensions according to the ASTM D 638 standard for tensile strength and 3 specimens for Shore D hardness testing. The experimental results were processed statistically.*
Keywords*: TENSILE STRENGHT,3D PRINTING,HARDNESS*

1. Introduction

3D printing technology is the creation of a three-dimensional object from a 3D model by adding material[1].The technology has evolved from a limited technology for rapid prototyping to being increasingly used in modern industry[2]. 3D printing finds applications in a number of sectors - space industries, dental and medical industries, mechanical engineering, automotive industry, etc.[3] A number of materials can be used in 3D printing such as ceramics, metals and composites, but the technology is mostly used for thermoplastic plastics. There are different technologies for 3D printing - Stereolithography (SLA), Fused Deposition Modeling (FDM), PolyJet, etc. The use of 3D printing for responsible applications increases the requirements for parts. The object of study of plastics are the mechanical, physical and chemical properties, with particular interest in mechanical properties, because to a large extent industrial application of 3D printed parts depends on their behavior under force loads..

Mechanical properties characterize the behavior of materials under external load, as well as determine the scope of application and serve to assess the expected service life. Mechanical properties serve to classify all types of materials and the production technology[4]. They are not constant and depend on different conditions such as temperature, type of load, etc. Very often there is a large variation in results tested under the same conditions. This makes the study of mechanical properties very relevant. The main mechanical properties are hardness, plasticity, strength, stiffness, elasticity, fatigue strength, etc..

Ultimate tensile strength(UTS) is the maximum stress that the specimen can withstand before breaking[5]. For brittle materials, the value is close to the yield strength. The test is applicable to alloys, ceramics, plastics, rubbers and other materials. The determination of the UTS is key for materials used for constructions. The essence of the test is to measure the maximum tensile strength and relative elongation. The equipment for testing the maximum tensile strength is universal tensile machine, load cells, controller or indicator, suitable jaws for fixing specimens.

Hardness is defined as the resistance to penetration by a harder indenter. It is a key engineering parameter in design of devices, machines, tools, machines and systems. Various standardized methods are used to determine hardness. The characteristic is used to evaluate all types of materials - alloys, ceramics, elastomers, etc. The results of hardness tests also provide information about other strength characteristics of materials. An important advantage of hardness testing methods is that they are non-destructive,

Carbon fiber reinforced plastics are extremely light and strong materials that contain carbon fibers. They are characterized by a high strength-to-weight ratio, rigidity, high durability, corrosion resistance. They find wide application - shipbuilding, automotive, aerospace applications, civil engineering, sports goods, etc.

2. Materials and methods

Polyamide PA6-CF carbon is a high-temperature material. Carbon fibers significantly increase the strength characteristics of the material. It is characterized by low linear shrinkage, chemical resistance, high creep resistance. It is used for tooling, prototyping, industrial modeling, etc.

The Shore durometer is used to test hardness, primarily for plastics[6]. Different scales are used for softer and harder materials. The Shore hardness test is performed in dimensionless units. According to ASTM D2240, 12 scales are distinguished. For hard plastics, the Shore D method is used, the indenting foot is hardened steel rod 1.1 mm – 1.4 mm diameter, with a 30° conical point, 0.1 mm radius tip. The test range is from 0-100. The Shore D test is characterized by high accuracy. The Shore durometer used is calibrated.

The maximum tensile force test was performed on a calibrated universal mechanical testing machine. The gripping jaws are tapered to prevent slipping during the test. A graphical interface displays the stress strain graph.

For the tensile strength test, 20 specimens with a standardized shape according to ASTM D638 and a thickness of 6 mm were used (fig.1).

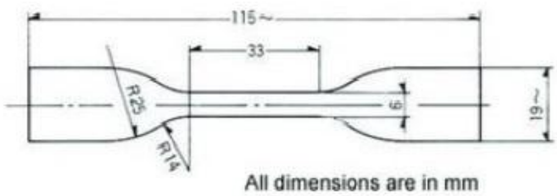

Fig. 1 *Tensile strength specimen dimensions*

Three hardness specimens with dimensions of 40x40x6 mm were produced. fig.2

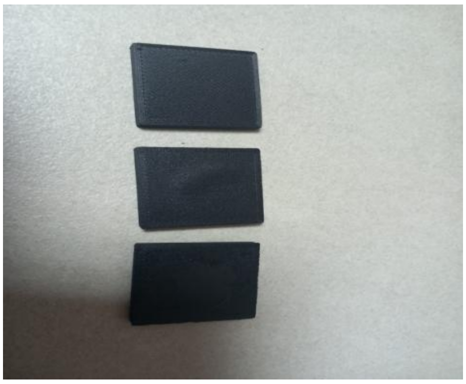

Fig 2. *Hardness Shore D test specimens*

The minimum number of attempts per sample according to the standard is 5, for greater accuracy 8 attempts per sample were made. The distance between the tests is at least 6mm.The parameters for 3D printing are as follows:

- Layer height-0.275 mm
- 3D printing speed-350 mm/s
- Bed temperature-105^0

- Nozzle-0.6 mm
- Infill-100%
- Flow-86%

.3. Results and discussion

The results of the test for maximum tensile force are presented in tab.1

***Tab.1** Maximum tensile force experimental results*

Sample	1	2	3	4	5	6	7
F_{max} kN	1.38	1.31	1.28	1.34	1.3	1.25	1.34
Sample	**8**	**9**	**10**	**11**	**12**	**13**	**14**
F_{max} kN	1.3	1.27	1.33	1.35	1.31	1.38	1.35
Sample	**15**	**16**	**17**	**18**	**19**	**20**	
F_{max} kN	1.29	1.26	1.3	1.33	1.35	1.36	

No deviations were noted during the test, as well as breakage in uncharacteristic areas, fig.3. The statistical processing of the data is presented in Table 2.

***Fig.3** Test specimens after the tests*

***Tab.2** Statistical summary ultimate tensile force*

Summary	
Mean	1.319
Standard Error	0.008488
Median	1.32
Mode	1.3
Standard Deviation	0.037961
Sample Variance	0.001441
Kurtosis	-0.83696
Skewness	-0.13239
Range	0.13
Minimum	1.25
Maximum	1.38
Sum	26.38
Count	20

From the obtained statistical processing, it is noticeable that the mean, median and mode are extremely close in values, which means that the data are symmetrical. Low values of standard deviation and sample variance are also observed. The negative value of kurthosis indicates a flat distribution. The obtained value of skinness in the range -0.5 and 0.5 also indicates that the values are symmetrical. A diagram of the obtained distribution is shown in Fig. 4.

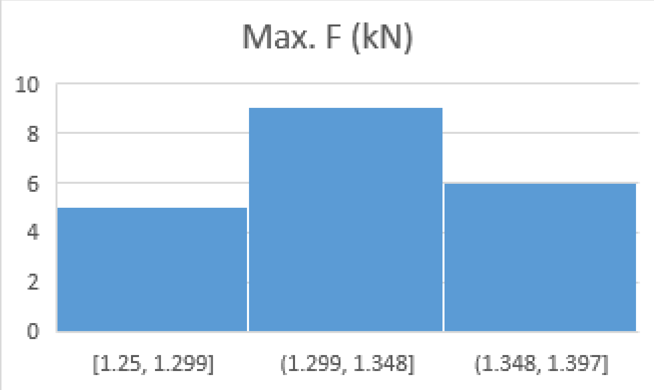

***Fig.4** Results distribution.*

Hardness results are presented in table 3 and statistical summary is presented in table 4.

***Tab.3** Hardness results*

Sample 1	Sample 2	Sample 3
82	81.6	82.2
81.5	82	82.2
82.7	81.1	83.3
80.3	83	83.2
82.6	81.7	81.8
82.2	81.9	82.2
83.6	83.1	83
82.2	81.7	82.5

***Tab. 4**. Statistical summary hardness results*

Summary	
Mean	82.23333
Standard Error	0.154834
Median	82.2
Mode	82.2
Standard Deviation	0.758526
Sample Variance	0.575362
Kurtosis	0.533763
Skewness	-0.36801
Range	3.3
Minimum	80.3
Maximum	83.6
Sum	1973.6
Count	24

The statistical summary is similar to the study of maximum tensile force with the exception of kurtosis. At a value above 0.5 the distribution is moderately skewed,fig.5

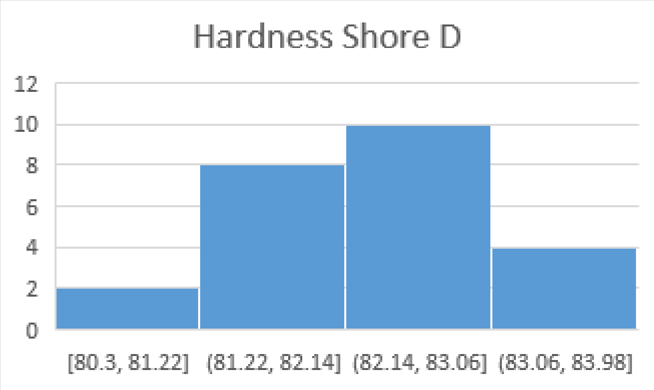

Fig.5 *Distribution Shore D hardness results*

4.Conclusions

From the studied results and the subsequent statistical processing, the following conclusions can be drawn:

1. The study of the maximum tensile strength of Polyamide PA6 CF showed a range in the interval 1.25-1.38 kN.

2. The study of the hardness of Polyamide PA6 CF according to Shore D showed a range in the interval 80.3-83.6

3. The data of both mechanical strength tests are symmetrical, which means that no deviations were obtained in the tests

4. The distribution of the results for maximum tensile force is flat, and for hardness moderately skewed.

5.References

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