PRILOG ISTRAŽIVANJU ZATEZNE ČVRSTOĆE DIJELOVA DOBIJENIH FDM PROCESOM CUBE 3D PRINTANJA

CONTRIBUTION TO THE TENSILE STRENGTH RESEARCH FOR PARTS OBTAINED BY CUBE 3D PRINT FDM PROCESS

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REZIME

U ovom radu vršena su ispitivanja zatezne čvrstoće dijelova dobivenih postupkom Cube 3D printanja od PLA plastične mase. U sprovedenom istraživanju kroz statističku obradu rezultata provjeravalo se da li je zatezna čvrstoća standardnih epruveta izrađenih ovim postupkom jednaka zateznoj čvrstoći materijala. Eksperimentalna istraživanja su se sastojala od izrade standardnih epruveta od PLA plastične mase i ispitivanja njihove zatezne čvrstoće. Cube 3D proces je proces koji omogućava jednostavno i brzo dobijanje prototipova, direktno iz 3D CAD modela. Pored niza prednosti ovog postupka, istraživanje u ovom radu je pokazalo da zatezna čvrstoća dijelova nastalih postupkom Cube 3D printanja je nešto manja od čvrstoće samog materijala. Razlog je način printanja, koji produkuje poprečne presjeke dijela u kojim ima vrlo malih šupljina.

Professional paper

SUMMARY

The tensile strength of parts obtained by Cube 3D printing is described in this paper. The material of the parts are PLA. In the research through the statistical analysis of results we checked whether the tensile strength of standard test specimens made by this method is equal to the tensile strength of the material. Experimental research has consisted of making parts of PLA plastics and testing the tensile strength of standard specimens obtained by Cube 3D printing process. Cube 3D process allows to easily and quickly obtain the prototype directly from 3D CAD models. Besides a number of advantages of this process, the research in this paper has shown that the tensile strength of parts produced by Cube 3D printing is somewhat less than the strength of the material. The reason is the way of printing that produces cross-sectional of part in which there are a very small cavities.

1. UVOD

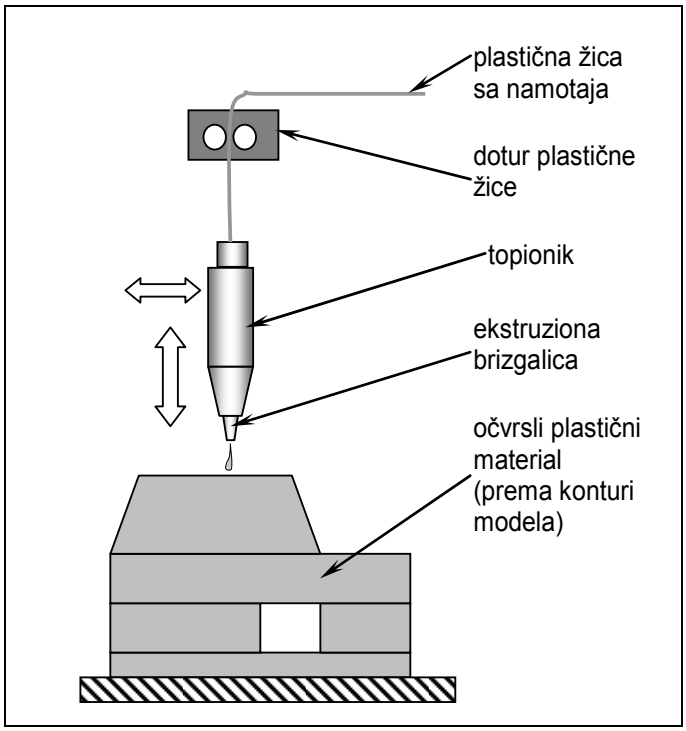
Svi FDM postupci rade na principu predstavljenom na slici 1. Materijal u vidu žice se dovodi u ekstruder, gdje se topi i deponuje sloj po sloj, pri čemu očvršćava, tako da se dobija radni komad zadatog oblika i dimenzija.

Cube 3D printer može izrađivati dijelove veličine do 140 mm u sva tri pravca. Kompanija 3D Systems uz Cube 3D printer daje i jednostavan softver, koji STL fajl pretvara u CUBE fajl. U ovom istraživanju korišten je materijal PLA – *Polylactic Acid*, koji je biorazgradiv materijal i dobija se iz biomaterijala. Ovaj materijal nema mirisa, pa se može koristiit za printanje u uredu [5, 6]. Neke negativne karakteristike Cube 3D printera su: printer je prilično glasan i dugo se „priprema za posao“, a dimenzije na isprintanom modelu nisu vrlo precizne [11].

1. INTRODUCTION

All FDM methods operate on the principle presented in Figure 1. The material in the form of wire is brought into the extruder, where it melts and is deposited layer by layer. Each layer solidifies and the workpiece receives a specified shape and dimensions.

Cube 3D printer is one of many that use FDM technology. The company 3D Systems with Cube 3D printer provides a simple software, which converts STL file into CUBE file. In this study we have used material PLA - *Polylactic Acid*, which is a biodegradable material and obtained from biomaterials. This material is odourless, so it can be used for printing in the office [5, 6]. Some negative characteristics of Cube 3D printer are: printer is quite loud and it need long time to "prepare for the job". The dimensions of printed models aren’t very accurate [11].



Slika 1. *FDM postupak [1]*
Figure 1. *FDM process [1]*

Slika 2. *Cube 3D printer [11]*
Figure 2. *Cube 3D printer [11]*

2. ISTRAŽIVANJE

U literaturi je data zatezna čvrstoća PLA materijala između 48 i 53 MPa. Eksperimentalnim ispitivanjem u ovom radu nastojalo se utvrditi da li je zatezna čvrstoća dijelova dobivenih postupkom Cube 3D printanja jednaka toj vrijednosti. Ispitivanje modela dobivenih postupkom Cube 3D printanja je izvršeno na kidalici maksimalne sile od 50 kN (Slika 3. i 4.).

Prilikom ispitivanja modela na kidalici pomoću odgovarajućeg softvera na osnovu zadatih vrijednosti za debljinu i širinu modela dobijene su vrijednosti za maksimalnu silu i izduženje.

2.1. Statistička obrada podataka

U eksperimentu je izvršeno mjerenja maksimalne sile zatezanja. Aritmetička sredina primijenjena na rezultate eksperimenta daje srednju ocjenu zatezne čvrstoće materijala PLA: $\bar{x}_{Rm} = 36{,}32$ MPa. Standardna devijacija:

$$\sigma_{Rm} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x}_{Rm})^2} = 3{,}065$$

Procjena standardne devijacije osnovnog skupa:

$$S_{Rm} = \sigma_{Rm}\sqrt{\frac{n}{n-1}} = 3{,}43$$

2. RESEARCH

Tensile strength of PLA material in the literature is between 48 and 53 MPa. We sought to determine whether the tensile strength of parts obtained by the method Cube 3D printing is equal to that value or not by experimental research. We conducted our test of models obtained by the Cube 3D printing on the testing machine with maximum force of 50 kN (Figure 3. and 4.).

When testing the model on the testing machine we get a value of maximum force and elongation with the appropriate software based on the given value for the thickness and width of the model.

2.1. Statistical analysis

We measured the maximum tension force in the experiment. We get a tensile strength on the basis of that. The arithmetic mean gives evaluation of tensile strength for material PLA: $\bar{x}_{Rm} = 36{,}32$ MPa. Standard deviation:

$$\sigma_{Rm} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x}_{Rm})^2} = 3{,}065$$

Estimate the standard deviation of the basic set:

$$S_{Rm} = \sigma_{Rm}\sqrt{\frac{n}{n-1}} = 3{,}43$$

Slika 3. *Ispitivanje na zatezanje*
Slika 3. *Testing Machine*

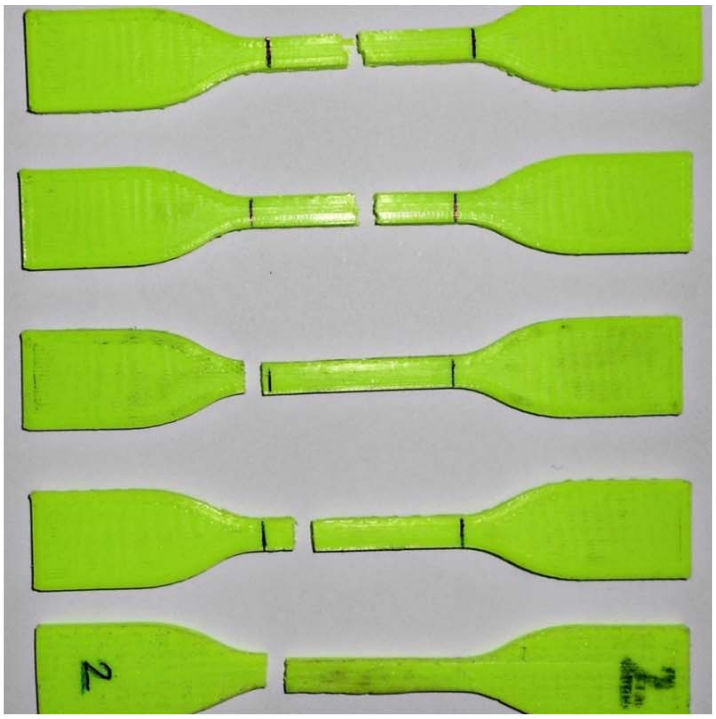


Figure 4. *Epruvete nakon ispitivanja na kidalici*
Figure 4. *The specimens after tests on the testing machine*

Provjera hipoteze o aritmetičkoj sredini osnovnog skupa na osnovu malog uzorka (Studentov t – test):

$$t_{Rm} = \frac{\bar{x}_{Rm} - \bar{X}_{Rm}}{\frac{S_{Rm}}{\sqrt{n}}} = \frac{|36{,}32 - 48|}{\frac{3{,}43}{\sqrt{5}}} = 7{,}614365591$$

Iz tabele za broj stepeni slobode $k=n$-1=5-1=4 i t_{Rm}=7,614365591 nalazi se:

$$0{,}001 < P(|t| \geq t_1) < 0{,}01$$

Na osnovu toga može se konstatovati da je: $P(|t| \geq t_1) < 0{,}05$. Tada razlika između aritmetičke sredine osnovnog skupa i aritmetičke sredine uzorka $\bar{x}_{Rm}$ i $\bar{X}_{Rm}$ nije slučajna već signifikantna, odnosno visoko signifikantna, to znači da se ne može pretpostaviti da je aritmetička sredina osnovnog skupa jednaka traženoj vrijednosti, tj. 48.

$$t_{Rm} = \frac{\bar{x}_{Rm} - \bar{X}_{Rm}}{\frac{S_{Rm}}{\sqrt{n}}} = \frac{|36{,}32 - 53|}{\frac{3{,}43}{\sqrt{5}}} = 10{,}8739399$$

Testing the hypothesis about arithmetic mean of the basic set based on a small sample (Student t - test):

$$t_{Rm} = \frac{\bar{x}_{Rm} - \bar{X}_{Rm}}{\frac{S_{Rm}}{\sqrt{n}}} = \frac{|36{,}32 - 48|}{\frac{3{,}43}{\sqrt{5}}} = 7{,}614365591$$

We can find from a table for the number of freedom degrees $k=n$-1=5-1=4 and t_{Rm}= 7,614365591:

$$0{,}001 < P(|t| \geq t_1) < 0{,}01$$

On this basis, we can conclude that: $P(|t| \geq t_1) < 0{,}05$. So, the difference between the arithmetic mean of the basic set and of the sample ($\bar{x}_{Rm}$ and $\bar{X}_{Rm}$) is not random but significant, or highly significant, this means that we cannot assume that the mean of basic set equal to the requested value, i.e. 48MPa.

$$t_{Rm} = \frac{\bar{x}_{Rm} - \bar{X}_{Rm}}{\frac{S_{Rm}}{\sqrt{n}}} = \frac{|36{,}32 - 53|}{\frac{3{,}43}{\sqrt{5}}} = 10{,}8739399$$

Iz tabele za broj stepeni slobode k = n-1 = 5-1 = 4 i t_{Rm}= 10,8739399 nalazi se: $P(|t| \geq t_1) < 0{,}001$

Na osnovu toga možemo konstatovati da je sigurno: $P(|t| \geq t_1) < 0{,}05$

Dakle, razlika između aritmetičke sredine osnovnog skupa i aritmetičke sredine uzorka je visoko signifikantna, to znači da se ne može pretpostaviti da je aritmetička sredina osnovnog skupa jednaka traženoj vrijednosti, tj. 53MPa.

Pošto je $P(|t| \geq t_1) < 0{,}05$ u oba slučaja na osnovu t – testa može se zaključiti da je zatezna čvrstoća materijala dijelova dobivenih postupkom Cube 3D printanja različita od vrijednosti zatezne čvrstoće materijala, tj. manja je.

From the table for the number of freedom degrees $k=n$-1 = 5-1 = 4 and t_{Rm}= 10,8739399: $P(|t| \geq t_1) < 0{,}001$

From this we can conclude for sure: $P(|t| \geq t_1) < 0{,}05$. So, the difference between the arithmetic mean of the basic set and of the sample is highly significant for value 53MPa, too.

Since in both cases based on the "t - test" $P(|t| \geq t_1) < 0{,}05$, we can conclude that the tensile strength of the parts obtained by the method Cube 3D printing is different from the materials' tensile strength, i.e. it is less.

Tabela 1. *Statistička obrada rezultata dobivenih ispitivanjem na zatezanje*
Table 1. *The results of statistical data processing*

	Rm (MPa)
Zatezna ćvrstoća PLA *the tensile strength of PLA*	*48 - 53*
$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$	*36,31888859*
$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$	*3,065052312*
$\bar{x} - t_p \frac{S}{\sqrt{n}}$ *(nivo pouzdanosti 95%)* *(confidence level 95%)*	*32,06459599*
$\bar{x} + t_p \frac{S}{\sqrt{n}}$ *(nivo pouzdanosti 95%)* *(confidence level 95%)*	*40,5731812*
$C = \frac{S}{\sqrt{n}}$ *(mjera nepouzdanosti)* *(measure of uncertainty)*	*4,254292609*
$c = \frac{C}{\bar{x}} \cdot 100\%$ *(relativna nepouzdanost)* *(relative unreliability)*	*11,71371915 %*

Potvrda ovog izvršiti će se i pomoću ocjene tačnosti aritmetičke sredine osnovnog skupa na osnovu uzorka. Provjeriti će se tačnost aritmetičke sredine dobivene eksperimentom.

Confirmation of this will be done also by evaluation accuracy of the arithmetic mean of the basic set based on a sample. We will check the accuracy of the arithmetic mean obtained by experiment.

$$P\left(\bar{x} - t_p \frac{S}{\sqrt{n}} < \bar{X} < \bar{x} + t_p \frac{S}{\sqrt{n}}\right) = 2S(t_p, k) = 95\%$$

Za P = 95% = 0,95 i k = n–1 = 5-1 = 4, iz tabele očita se vrijednost t = 2,776. Tada je aritmetička sredina osnovnog skupa za R_m:

$$36{,}32 - 2{,}776\frac{3{,}43}{\sqrt{5}} < \mu_{Rm} < 36{,}32 + 2{,}776\frac{3{,}43}{\sqrt{5}}$$

$$32{,}06 < \mu_{Rm} < 40{,}57$$

Na osnovu rezultata, može se zaključiti da se zatezna čvrstoća materijala ne nalazi u intervalu pouzdanosti 32,06 ÷ 40,57. Time je potvrđeno da je zatezna čvrstoća materijala dijelova dobivenih postupkom Cube 3D printanja različita od vrijednosti zatezne čvrstoće materijala, tj. manja je.

U Tabeli 1. dati su rezultati statističke obrade podataka. Iz Tabele 1. se vidi da zatezna čvrstoća materijala PLA (48 ÷ 53)MPa ne ulazi u interval pouzdanosti (32,06 ÷ 40,57)MPa.

3. ZAKLJUČAK

Na osnovu Studentovog t – testa i ocjenom tačnosti aritmetičke sredine osnovnog skupa pokazano je da razlika aritmetičkih sredina $\overline{x}_{Rm}$ i $\overline{X}_{Rm}$ nije slučajna već signifikantna, odnosno visoko signifikantna. Zatezna čvrstoća materijala dijelova dobivenih postupkom Cube 3D printanja je različita od vrijednosti zatezne čvrstoće materijala, tj. manja je.

Cube 3D printer prilikom printanja, nastoji da uštedi materijal, te cijeli prototip nije od punog materijala. Vanjske stjenke modela su od punog materijala, a unutrašnje presjeke Cube 3D printa pod uglom od 45°. Zbog toga postoje vrlo sitne šupljine u poprečnim presjecima modela i zatezna čvrstoća dijelova je malo niža od zatezne čvrstoće materijala. Na to treba računati kada se izrađuju dijelovi ovim postupkom.

For P=95% = 0,95 and $k=n-1=5-1=4$, we obtain the value t from a table: t=2,776. Then the arithmetic mean of the basic set of R_m:

$$36{,}32 - 2{,}776\frac{3{,}43}{\sqrt{5}} < \mu_{Rm} < 36{,}32 + 2{,}776\frac{3{,}43}{\sqrt{5}}$$

$$32{,}06 < \mu_{Rm} < 40{,}57$$

Based on this, we can conclude that the tensile strength of the material is not in the confidence interval 32,06 ÷ 40,57. This confirmed that the tensile strength of the parts obtained by the method Cube 3D printing is different from the materials' tensile strength, i.e. it is less.

Table 1. shows the results of statistical data processing. The tensile strength of the material PLA (48 ÷ 53)MPa does not fall within the confidence interval (32,06 ÷ 40,57)MPa as we can see from Table 1.

3. CONCLUSION

According to the Student t - test and evaluation of the accuracy of the arithmetic means has been proved that the difference between the arithmetic means ($\overline{x}_{Rm}$ and $\overline{X}_{Rm}$) is not random but significant, or highly significant. So, the tensile strength of the parts obtained by the method Cube 3D printing is different from the materials' tensile strength, i.e. it is less.

Cube 3D printer is trying to save material during printing process, and the whole prototype is not made of solid material. External model's walls are made of solid material, and the inner sections Cube 3D prints at angle of 45°. Therefore, there is a very small cavity in the cross sections of the model and the tensile strength of parts is slightly lower than the tensile strength of the material. It should be borne in mind when we make the parts by this process.

4. LITERATURA - REFERENCES

[1] Tiro D., Fajić A.: *Trodimenzionalno printanje i ostali postupci brze izrade*, Univerzitet „Džemal Bijedić“ Mašinski fakultet u Mostaru, ISBN: 996860433, Mostar 2008.

[2] Vrbanec D.: *Analiza dostupnih postupaka brze izrade prototipova*, Sveučilište u Osjeku, Strojarski fakultet Slavonski Brod, 2011.

[3] Stanić, J.: *Upravljanje kvalitetom proizvoda – Metode I*, Mašinski fakultet Beograd, 1995.

[4] Stanić, J.: *Upravljanje kvalitetom proizvoda – Metode II*, Mašinski fakultet Beograd, 1991.

[5] http://www.3d-tisk.si/S7500/Materiali

[6] http://www.utwente.nl/ctw/opm/research/design_engineering/rm/RM%20processes/

[7] http://www.cnet.com/products/3d-systems-cube-2013/

[8] Manish S., Kumar S. et al.: *Influence of Process Parameters on Product Characteristics in Direct Metal Deposition: A Review",* Conference: Recent Advancements in Manufacturing and its Management, India, February, 2014.
[9] http://www.explainingthefuture.com/3dprinting.html
[10] http://www.3dsystems.com/
[11] Tiro D., Brdarević S.: *Prilog istraživanju dimenzione tačnosti dijelova dobijenih FDM procesom Cube 3D printanja,* 9th Research/Expert Conference with International Participations "QUALITY 2015", Neum, B&H, June 10 – 13, 2015., p.

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