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EXPERIMENTAL TESTING OF QUALITY OF POLYMER PARTS PRODUCED BY LAMINATED OBJECT MANUFACTURING – LOM

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Preliminary notes

Rapid prototyping procedures make it possible to produce relatively complicated geometries based on the computer 3D model of products in relatively short time. This requires that the respective product features have good quality, good mechanical properties, dimensional accuracy and precision. However, the number of available materials that can be used for prototyping is limited and their properties can differ significantly from the properties of the finished product. However, RP parts are not inexpensive and sometimes it is difficult to decide which procedure to use to manufacture them in order to obtain their maximal usability. The Laminated Object Manufacturing (LOM) procedure can be used to produce low cost polymeric products (from poly(vinyl chloride)) that have to meet certain mechanical properties, especially if they are used to perform functional tests. Past studies in LOM procedure have been carried out mainly with paper, and a few on metal. The paper deals with testing the influence of the position of products in the machine working area on the mechanical properties (tensile and flexural properties) of the product.

Key words: *dimensional accuracy, flexural properties, LOM, roughness, tensile properties*

Eksperimentalno ispitivanje kvalitete polimernih tvorevina proizvedenih LOM postupkom

Prethodno priopćenje

Postupcima brze proizvodnje prototipova moguće je izraditi relativno komplicirane geometrije na temelju računalnog 3D modela tvorevine u relativno kratkom vremenu. Pritom se zahtjeva da odgovarajuća tvorevina bude dobre kvalitete, dobrih mehaničkih svojstava, dimenzijske točnosti i preciznosti. No broj raspoloživih materijala koje je moguće upotrijebiti za proizvodnju prototipova je ograničen i njihova svojstva se mogu dosta razlikovati od svojstava konačnog proizvoda. Međutim, RP dijelovi nisu jeftini i odlučiti kojim postupkom ih izraditi da se dobije maksimalna korist od njih, ponekad je teško. Postupkom proizvodnje laminiranih objekata (LOM) moguće je napraviti jeftinije polimerne tvorevine (od poli(vinil-klorida)), koje moraju zadovoljiti određena mehanička svojstva pogotovo ako se pomoću njih provode funkcijska ispitivanja. Dosadašnja istraživanja kod LOM postupka odnosila su se na ispitivanje papira i nešto malo na metalu. U radu će se ispitati utjecaj položaja proizvoda u izradbenom prostoru stroja na mehanička svojstva tvorevine (rastezna i savojna svojstva).

Ključne riječi: *dimenzijska točnost, hrapavost, LOM, rastezna svojstva, savojna svojstva*

1
Introduction
Uvod

Physical objects produced by rapid prototyping are mainly used as prototypes or models for other manufacturing processes. However, there is a tendency to improve these procedures, so that the prototypes can be used also as functional and finished products, and this requires the knowledge about the properties of the materials, e.g. mechanical, thermal, and electrical properties. Apart from paper and metal that had been used until now, with LOM procedure it is possible to use also polymeric films, thus achieving improved mechanical properties. Apart from the procedure, the mechanical properties of the materials are affected also by some manufacturing parameters; e.g. the position of the product in the working area (it may influence the mechanical properties and aesthetic appearance of the prototype).

2
Laminated Object Manufacturing - LOM
Proizvodnja laminiranih objekata

LOM procedure is used to manufacture a prototype by lamination and laser finishing (cutting) of materials such as paper, polymeric films and foils, and of metal laminates. With polymeric foils better mechanical properties are achieved than with paper. The sheets are laminated into solid blocks by adhesion joining, clamping and ultrasonic welding. [1, 2, 3]

Using heat and pressure each sheet, foil or paper is adhered to the block and a new layer is formed. The material is supplied by means of a roller on one side of the machine and taken to another side (Fig. 1). The heated roller provides pressure and heat necessary for the new layer to be glued to the already produced prototype part. The working platform is lowered for the foil thickness, which is usually a thickness of 0,07 mm to 0,2 mm. [1, 2, 3]

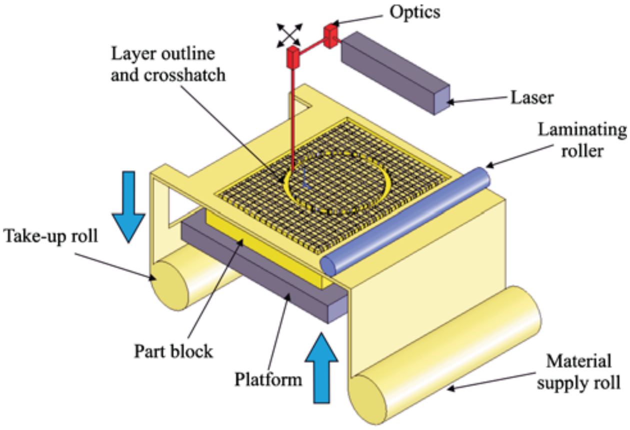


Figure 1 *Laminated object manufacturing* [3]
Slika 1. *Proizvodnja laminiranih objekata* [3]

After the layer (foil) has been deposited, the laser beam or knife cuts a part of the material into the form of the finished product. Usually CO_2 laser of 25 W or 50 W power is used. The *Solido* Company from Israel, in their laminated object manufacturing procedure use film on which a layer of glue is applied, which is then cut by a knife into adequate form. Then, an "anti-glue" layer is applied on certain places

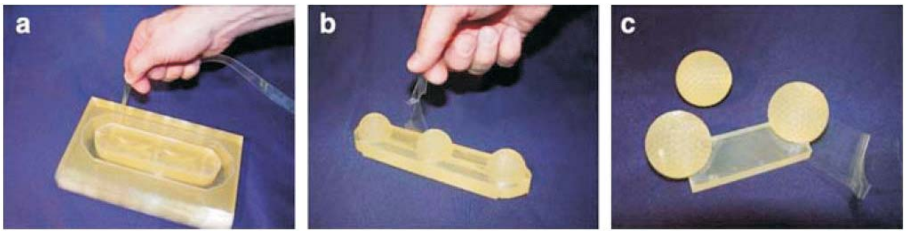


Figure 2 *Separation of surplus materials* [3]
Slika 2. *Postupak odvajanja viška materijala* [3]

where there is no prototype, i.e. the glue is neutralized. The next film layer is applied and it is glued to the previous one and the prototype is manufactured all the way to the final layer. As in other procedures, the process starts with the lower transverse section. When the uppermost prototype layer is finished, the excess material is removed from the prototype manually (Fig. 2). [1, 2, 3, 4]

The presence of the auxiliary material around the prototype has its advantages and drawbacks. First, the external support structure is not necessary. In prototype manufacturing inside a supporting material, the entire geometry during manufacturing is protected against deformation due to its proper mass. LOM avoids the need to design special supporting structures that hold the isolated contours. Removal of unnecessary material after the prototype has been manufactured is far from an easy task. Careful manual cleaning procedure is necessary not to damage the sensitive parts and to insure that only the excessive material is removed. Furthermore, the hollow structure with closed surface cannot be processed as a separate part due to the excessive material which gets stuck between the mould edges. The difficulty of removing the unwanted material refers to all the parts with narrow passages, internal hollows with limited access, indentations, etc. Also, the majority of materials used in case of LOM procedure do not contribute to the prototype itself. It remains with continuous strip (foil) or finishes as supporting material which is discarded after construction. The price of such waste is important if used materials are more expensive than paper. Furthermore, with its advantages and drawbacks LOM procedure has the following characteristics: [2]

- It forms layers that reduce the material (e.g. material is cut in order to form a layer that has the necessary cross-section). All other RP procedures form layers by adding material.
- The prototype is formed from alternating layers of material and glue. Thus, their physical properties are non-homogeneous and anisotropic.
- The possible precision of the LOM procedure is high. Since any arbitrary thin sheets may be used in LOM, good direction resolution in prototyping is maintained. In fact, the production of thin mono-dispersion foil material is not difficult and shrinking during lamination is not a problem since the contours are cut after the shrinkage occurs.
- Although the procedure can be applied to many materials, including polymers, composites and metals, the paper sheets and PVC films are currently the most popular ones. [2, 5]

The advantages of LOM procedure are: small shrinkage, low residual stress and warpage, fast manufacture of big parts, the machines do not use toxic materials so that no special area is needed, low prices of equipment and materials in comparison with other RP procedures. [1, 3, 6]

Drawbacks of LOM procedure: the paper requires the use of protective coatings due to absorption of humidity and wear, due to swelling and unequal thickness of material foil the control of dimension precision in *z*-axis is difficult, the mechanical and thermal properties are non-homogeneous due to the use of glue between the layers, during removal of unused material small parts can be damaged, it is not possible to manufacture hollow parts. [3, 7, 8]

2.1
Previous experiments in area of laminated object manufacturing
Dosadašnja istraživanja na području proizvodnje laminiranih objekata – LOM

Before prototyping by means of the LOM procedure it is necessary to determine its orientation in the working area, especially if the part consists of curved surfaces. It is better to position such a prototype in the $x - y$ direction due to greater precision of dimensions than in the $x - z$ or $y - z$ directions. However, if the prototype consists of several curved surfaces, one of the manufacturing possibilities is at a certain angle. It is also necessary to take into consideration the manufacturing time. The manufacturing time will be longer in case of greater height in *z*-axis, since in manufacturing this layer, a certain time is necessary to draw a new foil. [6, 9, 10]

Past studies in LOM procedure have been carried out mainly with paper, and a few on metal. This work deals with tests on polymeric materials (poly(vinyl chloride) - PVC), and will see the influence of the position of the test specimens in the machine working area on the mechanical properties, roughness and dimensional precision.

3
Experimental set-up
Postavke pokusa

The test specimens made by LOM procedure are made of PVC film (Fig. 3).

The test bodies in LOM procedures are made on the machine *SD 300 Pro*, produced by *Solido*. *SD 300 Pro* (Fig. 4) is a machine which can produce transparent prototypes of PVC film, has small dimensions, and is practical for use in offices.

The characteristics of the *SD 300 Pro* machine are: [5]

- precision: 0,1 mm (in *x*,*y* axis)
- layer thickness: 0,168 mm
- working area: 160 × 210 × 135 mm
- machine size: 465 × 770 × 420 mm
- machine mass: 45 kg.

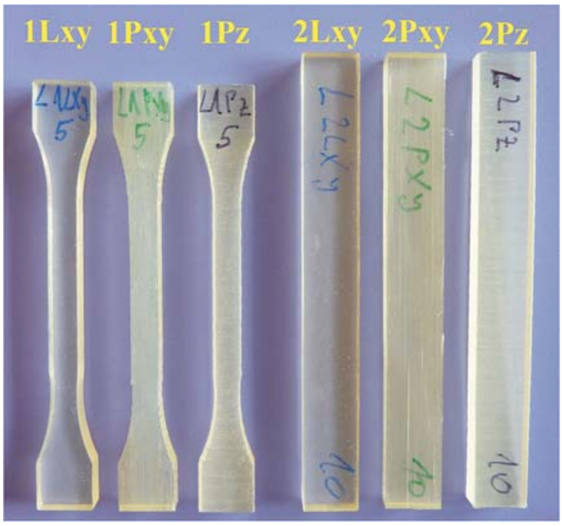


Figure 3 *Test specimen obtained by LOM*
Slika 3. *Ispitna tijela dobivena LOM postupkom*

Figure 4 *Machine SD 300 Pro*
Slika 4. *Stroj SD 300 Pro*

The dimensions of test specimens were determined by digital caliper *Mitutoyo*, of measuring range 0 – 150/0,01 mm.

For testing surface roughness *Mahr Perthometer S8P*, serial number 0265 is used. Measurements have been carried out with the external guided probe FRW – 750, with probe needle radius of 10 m and probe needle angle 90°. The important machine data are:

- marginal value of the GS electrical filter (marginal wavelength for roughness profile) $\lambda_c = 0{,}8$ mm
- reference length $L_t = 5{,}6$ mm.

Tests have been carried out on specimens made using various orientations in the working area (Fig. 5):

- Lxy – test specimen laid in *xy* plane with height in *z* direction 4 mm;
- Pxy – test specimen raised in *xy* plane with height in *z* direction 10 mm;
- Pz – test specimen raised in *z*-axis with height 75 mm and 80 mm depending on whether the specimen is for tension or bending tests.

The tensile properties are tested according to ISO 527:1993 standard and the bending properties according to ISO 178:2001 standard. For tensile properties the 75 mm long specimens 1BA were made, since the working chamber is of maximum height of 135 mm so that it is not possible to make several test specimens in *z* direction.

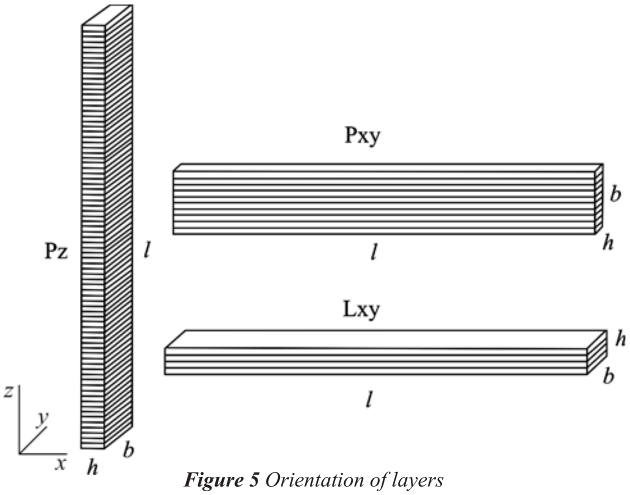


Figure 5 *Orientation of layers*
Slika 5. *Orijentacija slojeva*

4
Results of experiment
Rezultati ispitivanja

4.1
Results of dimension testing of test specimen
Rezultati ispitivanja dimenzija ispitnih tijela

Tab. 1 and Tab. 2 show the values of dimensions of tensile and flexural test specimens and their deviation from nominal values. According to standard it was tested thickness *h*, width of narrow portion b_1, width at ends b_2 and overall length *l* for tensile specimen, and thickness *h*, width *b* and length *l* for flexural test specimen.

Fig. 6 shows the deviation of all dimensions for all three orientations, but they are not so high and they are within the range of limits defined by the standard (of 0,2 mm). The smallest deviations have the orientation Lxy. It is, however, interesting that in Pz orientation the highest deviations are in *x*-axis, i.e. thickness *h*, and in Pxy orientation in *z*-axis, i.e. width *b,* whereas Lxy orientation has by far the least deviations. Such deviations in *z*-axis are consequences of the very thickness of PVC film of 0,168 mm and glue between the layers.

4.2
Roughness of test specimen
Hrapavost ispitnih tijela

LOM procedure provides low surface roughness parameters in all three orientations. However, the lowest are in Lxy orientation (arithmetic mean $\overline{x}$ of the mean arithmetic deviation of profile $Ra = 0{,}03$ μm) which is only logical since the final layer is pure PVC film, independent of the construction method (lamination method) (Tab. 3).

In test specimens Pxy and Pz, *Ra* is 95 times greater ($Ra \cong 3$ μm) than in Lxy orientation (Tab. 4 and Tab. 5).

Fig. 7 shows the appearance of the surface of all orientations of LOM specimens in vertical increase of 25 μm ≅ 10 mm.

4.3
Tensile properties of prototypes
Rastezna svojstva prototipova

Tab. 6 gives the calculated values of the tensile

Table 1 *Dimension of tensile test specimen*
Tablica 1. *Dimenzije rasteznih ispitnih tijela*

	Measured values / mm				Deviation from nominal values / %			
1Lxy	*h*	b_1	b_2	*l*	*h*	b_1	b_2	*l*
1	3,97	5,04	9,98	74,98	-0,75	0,8	-0,2	-0,03
2	4	5,05	9,96	74,92	0	1	-0,4	-0,11
3	3,98	5,06	9,99	74,93	-0,5	1,2	-0,1	-0,09
4	4,03	5,08	10	74,93	0,75	1,6	0	-0,09
5	4,03	5,1	9,96	74,95	0,75	2	-0,4	-0,07
$\bar{x}$	**4,00**	**5,07**	**9,98**	**74,94**	**0,05**	**1,32**	**-0,22**	**-0,08**
S	**0,028**	**0,024**	**0,018**	**0,024**	**0,694**	**0,482**	**0,179**	**0,032**
1Pxy	*h*	b_1	b_2	*l*	*h*	b_1	b_2	*l*
1	4,06	4,83	9,9	75,04	1,5	-3,4	-1	0,05
2	4,01	4,83	10,2	74,97	0,25	-3,4	2	-0,04
3	3,99	4,83	9,89	75	-0,25	-3,4	-1,1	0
4	4,05	4,83	10,06	74,89	1,25	-3,4	0,6	-0,15
5	4	4,85	9,98	75,07	0	-3	-0,2	0,09
$\bar{x}$	**4,02**	**4,83**	**10,01**	**74,99**	**0,55**	**-3,32**	**0,06**	**-0,01**
S	**0,031**	**0,009**	**0,128**	**0,069**	**0,779**	**0,179**	**1,284**	**0,093**
1Pz	*h*	b_1	b_2	*l*	*h*	b_1	b_2	*l*
1	4,06	4,99	9,95	74,68	1,5	-0,2	-0,5	-0,43
2	4,03	5	9,95	74,86	0,75	0	-0,5	-0,19
3	4,06	4,99	9,95	74,58	1,5	-0,2	-0,5	-0,56
4	4,02	5	9,96	74,69	0,5	0	-0,4	-0,41
5	4,04	4,99	9,92	74,56	1	-0,2	-0,8	-0,59
$\bar{x}$	**4,04**	**4,99**	**9,95**	**74,67**	**1,05**	**-0,12**	**-0,54**	**-0,43**
S	**0,018**	**0,005**	**0,015**	**0,119**	**0,447**	**0,110**	**0,152**	**0,159**

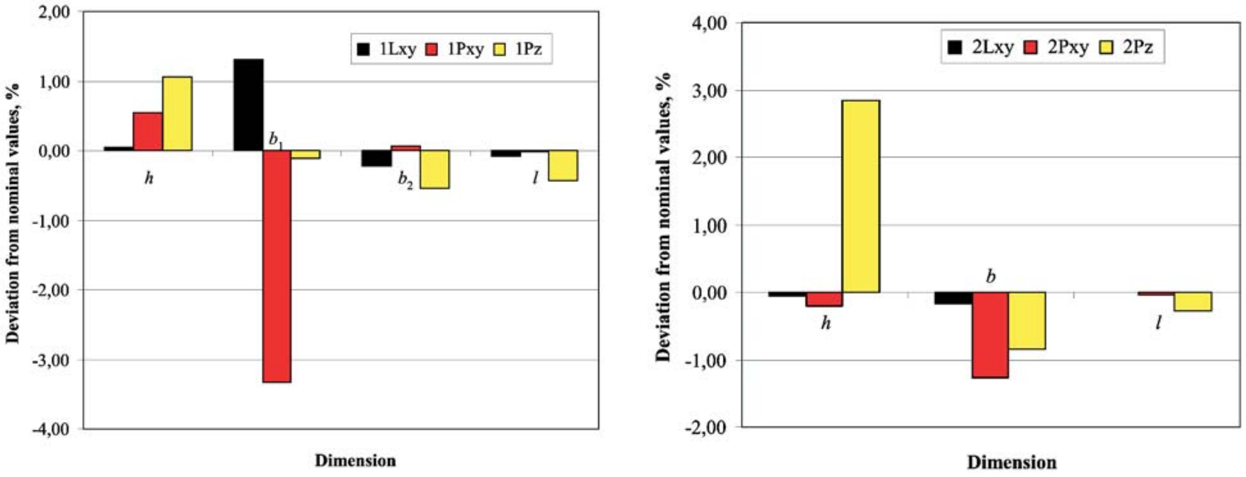
Table 2 *Dimension of flexural test specimen*
Tablica 2. *Dimenzije savojnih ispitnih tijela*

	Measured values / mm			Deviation from nominal values / %		
2Lxy	*h*	*b*	*l*	*h*	*b*	*l*
1	3,98	10	80	-0,5	0	0,00
2	4,02	9,96	80,05	0,5	-0,4	0,06
3	4,03	9,96	79,93	0,75	-0,4	-0,09
4	4,02	9,99	80,01	0,5	-0,1	0,01
5	3,94	10,01	80,02	-1,5	0,1	0,02
$\bar{x}$	**4,00**	**9,98**	**80,00**	**-0,05**	**-0,16**	**0,00**
S	**0,038**	**0,023**	**0,044**	**0,942**	**0,230**	**0,055**
2Pxy	*h*	*b*	*l*	*h*	*b*	*l*
1	3,99	9,87	80,02	-0,25	-1,3	0,02
2	3,99	9,88	79,95	-0,25	-1,2	-0,06
3	3,96	9,97	79,97	-1	-0,3	-0,04
4	4,02	9,83	79,9	0,5	-1,7	-0,12
5	4	9,82	79,98	0	-1,8	-0,02
$\bar{x}$	**3,99**	**9,87**	**79,96**	**-0,20**	**-1,26**	**-0,04**
S	**0,022**	**0,059**	**0,044**	**0,542**	**0,594**	**0,055**
2Pz	*h*	*b*	*l*	*h*	*b*	*l*
1	4,11	9,98	79,82	2,75	-0,2	-0,23
2	4,1	9,92	79,83	2,5	-0,8	-0,21
3	4,11	9,86	79,66	2,75	-1,4	-0,43
4	4,12	9,84	79,75	3	-1,6	-0,31
5	4,13	9,98	79,83	3,25	-0,2	-0,21
$\bar{x}$	**4,11**	**9,92**	**79,78**	**2,85**	**-0,84**	**-0,28**
S	**0,011**	**0,065**	**0,074**	**0,285**	**0,654**	**0,092**

properties of specimens at room temperature for all three orientations, and Fig. 8 shows the diagram of tensile stress – elongation. The test was carried out at a speed of 5 mm/min at a temperature of 23 °C.

The specimens of Lxy orientation have the highest strain, even up to an average of $\varepsilon_p = 207$ %, whereas the test specimens of Pz orientation have only $\varepsilon_p = 24$ %, which is 8,5 times lower value. However, it is interesting to note that the highest strength is not the feature of the test specimens of Lxy orientation, but the test specimens of Pxy orientation.

Orientation affects also the fracture surface (Fig. 9), and in test specimens Pxy the surface is toothed, i.e. delamination of layers has occurred, whereas in Lxy and Pz the surface is flat. Such fracture in Pxy orientation occurs because the stresses are applied along each layer, and in Pz orientation the fracture occurs perpendicularly to the



a) b)

Figure 6 *Deviation from nominal values: a) tensile test specimen, b) flexural test specimen*
Slika 6. *Odstupanje od nazivnih dimenzija: a) rastezna ispitna tijela, b) savojna ispitna tijela*

Table 3 *Roughness parameters of Lxy test specimen*
Tablica 3. *Parametri hrapavosti Lxy ispitnih tijela*

Lxy					*N* = 3
Roughness parameters / μm	$\bar{x}$	*S*	*R*	*Max*	*Min*
R_{max}	0,37	0,17	0,31	0,56	0,24
Rz	0,25	0,04	0,08	0,28	0,21
Ra	0,03	0	0,01	0,03	0,02
Rp	0,24	0,17	0,31	0,44	0,13
Rpm	0,13	0,03	0,06	0,17	0,11
Wt	0,55	0,26	0,52	0,81	0,29
Rt	0,38	0,18	0,34	0,58	0,24
Pt	0,78	0,3	0,52	0,95	0,43

Table 4 *Roughness parameters of Pxy test specimen*
Tablica 4. *Parametri hrapavosti Pxy ispitnih tijela*

Pxy					*N* = 3
Roughness parameters / μm	$\bar{x}$	*S*	*R*	*Max*	*Min*
R_{max}	20,23	6,16	12,12	25,66	13,53
Rz	16,69	4,66	9,3	21,15	11,85
Ra	2,86	0,83	1,53	3,44	1,91
Rp	10,65	3,39	6,6	14,40	7,80
Rpm	8,43	2,70	5,34	11,33	5,99
Wt	26,77	3,73	7,41	30,20	22,79
Rt	21,48	5,17	10,09	25,86	15,77
Pt	42,85	6,50	12,70	48,4	35,71

Table 5 *Roughness parameters of Pz test specimen*
Tablica 5. *Parametri hrapavosti Pz ispitnih tijela*

Pz					*N* = 3
Roughness parameters / μm	$\bar{x}$	*S*	*R*	*Max*	*Min*
R_{max}	26,01	3,68	7,35	29,81	22,45
Rz	19,42	2,41	4,26	20,9	16,64
Ra	3,36	0,26	0,45	3,52	3,07
Rp	14,02	3,22	6,0	16,35	10,35
Rpm	10,6	1,89	3,77	12,41	8,64
Wt	38,1	2,48	4,62	39,89	35,27
Rt	26,36	3,7	7,35	29,81	22,45
Pt	53,01	6,39	12,59	58,67	46,08

applied test force, and this is at the same time the layer lamination. Colour changes observed in specimens are result of macromolecular orientation of amorphous polymer in the direction of tensile stretching (Fig. 9).

4.4
Flexural properties of prototypes
Savojna svojstva prototipova

Test specimens of Pz orientation break in bending

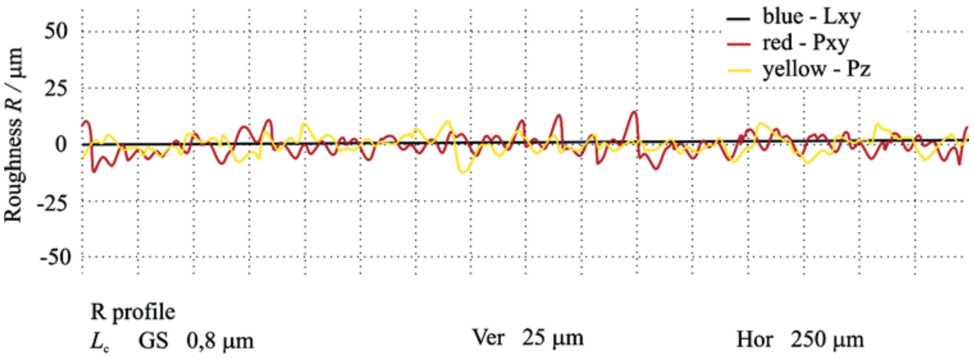


***Figure** 7 Surface roughness of test specimen*
***Slika** 7. Hrapavost površine ispitnih tijela kod LOM postupka*

***Table** 6 Tensile properties of LOM test specimens at room temperature*
***Tablica** 6. Rastezna svojstva LOM ispitnih tijela pri sobnoj temperaturi*

1Lxy	h / mm	b_1 / mm	A_0 / mm^2	F_m / N	R_m / MPa	R_r / MPa	ε_p / %	R_p / MPa	E / GPa
1	4	5,07	20,28	464,4	22,90	17,72	229,80	22,68	0,912
2	3,98	5,03	20,02	428,4	21,40	18,31	154,80	21,29	0,519
3	4,04	5,05	20,40	447,6	21,94	15,66	237,20	19,50	1,036
$\bar{x}$	**4,01**	**5,05**	**20,23**	**446,8**	**22,08**	**17,23**	**207,27**	**21,16**	**0,822**
S	**0,031**	**0,020**	**0,195**	**18,012**	**0,760**	**1,391**	**45,588**	**1,594**	**0,270**
1Pxy									
1	4	4,84	19,36	473,4	24,45	18,01	108,00	24,98	0,799
2	4	4,98	19,92	458,8	23,03	16,82	85,92	23,10	1,11
3	4,06	4,85	19,69	443,0	22,50	17,19	80,56	22,50	0,826
$\bar{x}$	**4,02**	**4,89**	**19,66**	**458,4**	**23,33**	**17,34**	**91,49**	**23,53**	**0,912**
S	**0,035**	**0,078**	**0,282**	**15,156**	**1,008**	**0,609**	**14,544**	**1,294**	**0,172**
1Pz									
1	4	5,01	20,04	105,7	5,27	4,71	21,88	3,53	0,691
2	4,04	5	20,20	145,1	7,18	5,01	27,22	3,56	0,736
3	4,06	5	20,30	73,1	3,60	-	24,07	3,54	-
$\bar{x}$	**4,03**	**5,00**	**20,18**	**107,9**	**5,35**	**4,86**	**24,39**	**3,55**	**0,713**
S	**0,031**	**0,006**	**0,131**	**36,031**	**1,791**	**0,213**	**2,684**	**0,014**	**0,032**

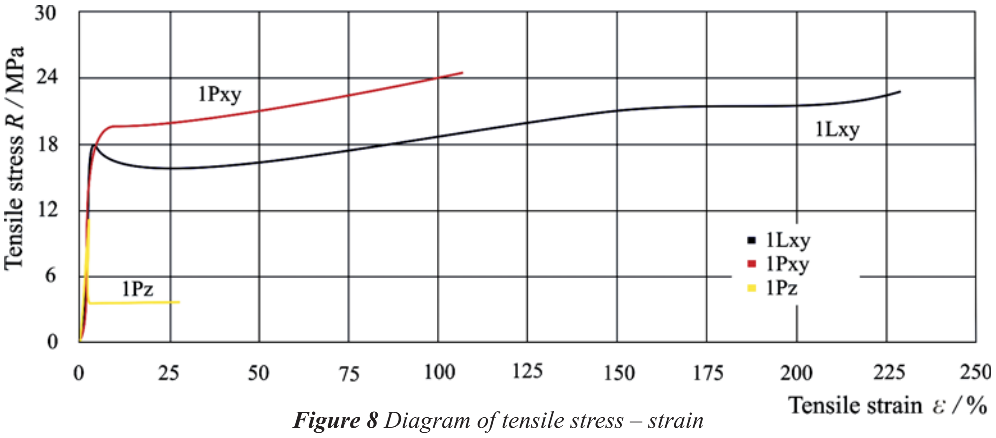


***Figure** 8 Diagram of tensile stress – strain*
***Slika** 8. Dijagram rasteznog naprezanja – istezanja*

before the agreed deflection $S = 1,5 \cdot h = 6$ mm defined by the standard, whereas other orientations fall within the testing device supports, so that yield flexural stress σ_{fp} and yield flexural elongation ε_{fp} are not calculated for them (Tab. 7). The test was carried out at a speed of 5 mm/min at a temperature of 23 °C.

The diagram in Fig. 10 shows that the least favourable position, i.e. the one with the lowest bending properties is the Pz orientation, while Pxy has somewhat lower properties than Lxy orientation, except for the flexural modulus.

5
Conclusion
Zaključak

Laminating technologies can be used to manufacture complicated products that cannot be produced by some classical processing procedures. However, the laminating procedures are limited by the type of material and the properties that depend on numerous parameters, primarily on the position of the product in the working area. The previous material used in LOM procedure, paper, can be replaced by polymeric film, achieving thus improved

***Table** 7 Flexural properties of LOM test specimens at room temperature*
***Tablica** 7. Savojna svojstva LOM ispitnih tijela pri sobnoj temperaturi*

2Lxy	h / mm	b / mm	A_0 / mm^2	F_{max} / N	σ_{fM} / MPa	ε_{fM} / %	S_{max} / mm	ε_{fp} / %	σ_{fp} / MPa	E_f / GPa
1	4,01	9,98	40,02	55,15	32,99	4,68	7,97	-	-	0,917
2	4	9,98	39,92	52,90	31,80	5,05	8,61	-	-	1,093
3	3,95	9,97	39,38	55,15	34,04	4,52	7,82	-	-	1,144
$\bar{x}$	**3,99**	**9,98**	**39,77**	**54,40**	**32,94**	**4,75**	**8,13**	**-**	**-**	**1,051**
S	**0,032**	**0,006**	**0,343**	**1,299**	**1,121**	**0,268**	**0,421**	**-**	**-**	**0,119**
2Pxy										
1	4,03	9,84	39,66	50,65	30,43	4,45	7,53	-	-	1,162
2	3,98	9,84	39,16	50,65	31,20	4,25	7,29	-	-	1,173
3	4	9,85	39,40	52,90	32,22	5,08	8,67	-	-	1,142
$\bar{x}$	**4,00**	**9,84**	**39,41**	**51,40**	**31,28**	**4,59**	**7,83**	**-**	**-**	**1,159**
S	**0,025**	**0,006**	**0,246**	**1,299**	**0,898**	**0,433**	**0,737**	**-**	**-**	**0,016**
2Pz										
1	4,16	9,96	41,43	24,80	13,81	2,09	3,43	2,78	1,28	0,584
2	4,1	9,93	40,71	25,90	14,90	2,44	4,07	3,03	1,32	0,454
3	4,08	9,93	40,51	23,65	13,74	2,80	4,69	3,14	0,67	0,475
$\bar{x}$	**4,11**	**9,94**	**40,89**	**24,78**	**14,15**	**2,45**	**4,06**	**2,98**	**1,09**	**0,504**
S	**0,042**	**0,017**	**0,484**	**1,125**	**0,650**	**0,355**	**0,626**	**0,186**	**0,367**	**0,070**

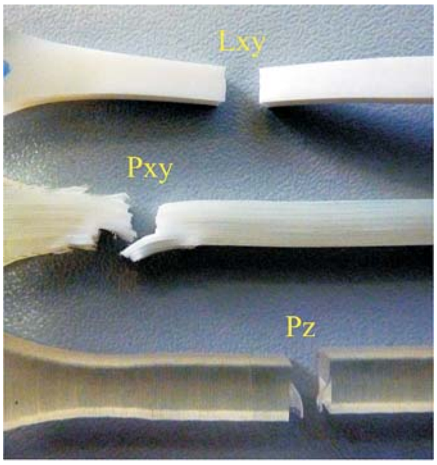


***Figure 9** Fracture during tensile test*
***Slika 9.** Područje loma prilikom rastezanja*

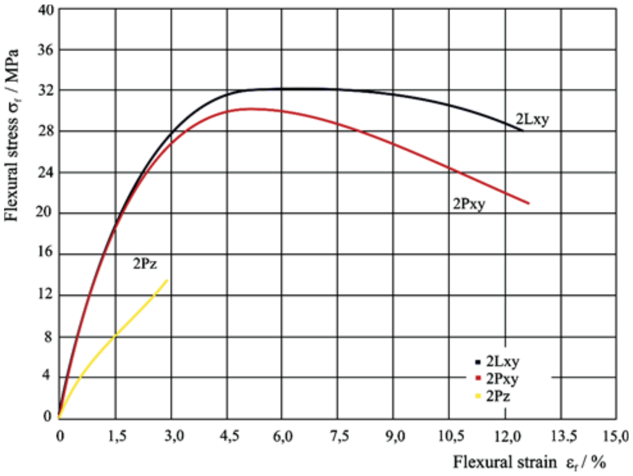


***Figure 10** Diagram of flexural stress – strain*
***Slika 10.** Dijagram savojnog naprezanja – istezanja*

properties of the finished product.

The tests carried out at LOM test specimen lead to the conclusion that Pxy orientation features optimal properties. Possibly, in case of minimal roughness requirement and higher yield stress, Lxy orientation should be selected. The price and the manufacturing speed also depend on the orientation and chamber filling, so that the orientations in *z*-axis direction should be avoided as much as possible.

For further improvement of the procedure and expanded use of the products in various branches of industry, the use of films of some other types of polymeric materials should also be provided.

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References
Literatura

[1] Liou, F. W. Rapid Prototyping and Engineering applications: A Toolbox for Prototype Development, CRC Press – Taylor & Francis Group, SAD, 2008.
[2] Kunwoo, L. Principles of CAD/CAM/CAE Systems, Addison – Wesley Longman Inc., Reading, Massachusetts, 1999, ISBN 0-201-38036-6.
[3] Gibson, I.; Rosen, D. W.; Stucker, B. Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing, Springer, SAD, 2010.
[4] Godec, D. Utjecaj hibridnog kalupa na svojstva injekcijski prešanog plastomernog otpreska, doktorski rad, Fakultet strojarstva i brodogradnje, Zagreb, 2005.
[5] http://www.solido3d.com/, 22.07.2010.
[6] Cooper, K. G. Rapid Prototyping Technology: Selection and Application, Marcel Dekker Inc., SAD, 2001.
[7] Pahole, I.; Drstvenšek, I.; Ficko, M.; Balič, J. Rapid prototyping processes give new possibilities to numerical copying techniques. // Journal of Materials Processing Technology, 164-165 (2005), str. 1416 – 1422.

[8] Lim, T.; Corney, J. R.; Ritchie, J. M.; Davies, J. B. C. RPBlox – a novel approach towards rapid prototyping, str. 1–8, Third National Conference on Rapid Prototyping, Tooling and Manufacturing, edited by: Rennie, A. E. W.; Jacobson, D. M.; Bocking, C. E.; 20-21. June 2002, Buckinghamshire Chilterns University College, Professional Engineering Publishing Limited, London, Velika Britanija, ISBN: 1-86058-374-1.
[9] Kechagias, J. An experimental investigation of the surface roughness of parts produced by LOM process. // Rapid Prototyping Journal, 13, 1(2007), str. 17-22.
[10] Kechagias, J. Investigation of LOM process quality using design of experiments approach. // Rapid Prototyping Journal, 13, 5(2007), str. 316-323.

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