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EVALUATION OF FINISHED PRODUCT QUALITY DEPEDING ON PAPER PROPERTIES AND BINDING TECHNIQUE

VREDNOVANJE KVALITETE GOTOVOG PROIZVODA OVISNO O SVOJSTVIMA PAPIRA I TEHNICI LJEPLJENJA

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Abstract

Perfect bound book is certainly the most used type of book product on the market. The quality of this kind of product can be identified with the binding strength of the book block. There is only one standardized method for book block strength determination and it refers to the static testing of interrupted tensile force required to separate precisely defined leaves within a test sample. In this paper, six groups of book block were investigated, different with regard to paper composition, i.e. the share of primary and recycled fibres and thus the content of ash and calcium carbonate. Furthermore, two binding techniques were used, but all other parameters – volume, format, pressure and drying time, temperature and humidity, were always same and strictly controlled. Based on obtained results, evaluation of finished product quality was performed, depending on paper properties, as well as evaluation of the used binding techniques. By calculating coefficients of variation, a binding technique that allows a more uniform application and guarantees reliability and repeatability of the quality results was chosen, regardless the paper composition.

Keywords: *binding technique, perfect bound book, bookbinding strength, primary fibre, recycled fibre*

Sažetak

Najzastupljenija forma uveza na tržištu svakako je bešavna forma uveza knjige. Kvalitetu tog knjigoveškog proizvoda moguće je poistovjetiti s čvrstoćom uveza knjižnog bloka. Jedina standardizirana metoda određivanja čvrstoće odnosi se na statičko ispitivanje prekidne jačine sile kidanja potrebne za odvajanje točno definiranih listova unutar ispitivanog uzorka. U ovom radu ispitivalo se šest skupina uzoraka knjižnih blokova koji su se razlikovali s obzirom na sastav papira tj. udio primarnih i recikliranih vlakana, a time i prema udjelu pepela i kalcijeva karbonata. Nadalje, korištene su dvije tehnike lijepljenja, a svi ostali parametri - opseg, format, vrijeme prešanja i sušenja, temperatura i vlaga bili su uvijek jednaki i strogo kontrolirani. Na temelju dobivenih rezultata izvršila se evaluacija kvalitete gotovih proizvoda ovisno o svojstvima papira te evaluacija korištenih tehnika lijepljenja. Izračunom koeficijenata varijacije odabrana je tehnika lijepljenja koja omogućava ujednačeniji nanos te jamči pouzdanost i ponovljivost rezultata, neovisno o vrsti papira.

Ključne riječi: *tehnika lijepljenja, bešavna forma uveza, čvrstoća knjižnog bloka, primarno vlakno, reciklirano vlakno*

1. Introduction

1. *Uvod*

World economic crisis, social networks phenomenon and online marketing development influenced the negative trend within the graphics industry, which led to a decrease of volume in book production [1]. With the emergence of unused existing capacities and the increasing popularity of e-books, researches show that, globally by 2020, more than half of the printing products will be in short runs, between 1 and 2000 copies [2, 3]. With the fact that 95% of active Croatian graphic companies have been qualified as small, designing durable and quality on-demand or self-published single or short run products has never been more important [4].

The most common and the most popular type of book binding form today is perfect binding (glue binding). Although we use that form more often in production of soft cover books, because of its cost, simplicity, production speed and very good quality, it is increasingly used during production of permanent hard cover book products. The compatibility of used materials and technological process during perfect bounded books production have most affect on the finished product quality. In this case, the quality of finished product can be identified with strength of book blocks, i.e. the quality of paper leaves bonding process after gathering into the book block. Bonding quality is directly related to the adhesion and cohesion forces, but researches about quality of adhesive joint related to the book binding processes are still unexplored theme and this researches are mainly based on study of used materials and their relation within observed adhesive joint [5, 6, 7]. The issue of introducing new innovative materials and techniques in all segments of graphic production requires examination of well-known production processes and analysis of obtained results, in order to meet high market technological criteria and ensure optimum ratio between invested resources, achieved quality and final product price.

The main aim and purpose of this paper is examination of quality - strength of book blocks depending on different paper properties, but also binding technique and compatibility of used binding technique with different types of paper.

2. Materials and methods
2. *Materijali i metode*

2.1. Used materials
2.1. *Korišteni materijali*

Three types of paper, with same grammage (80 g/m2), were used for this research. All papers samples belong to an office paper group and they are different in their composition and paper properties. Used paper samples are listed in Table 1, with their tested properties.

Polyvinyl acetate adhesive (PVAc) was used as adhesive. It is water dispersion of vinyl acetate homopolymers with polyvinyl alcohol with the addition of plasticizers, containing 45% (±2%) of solid content. It has many desirable features, such as: film elasticity, aging resistance, use at room temperature, easy handling, adequate viscosity and no toxicity. The main disadvantage is long drying time that extends the production process [8 – 11].

For the purpose of this research, 60 handmade unprinted book blocks were bounded (20 book blocks for one type of paper). All book blocks have same volume (140 pages), format (140 x 200 mm) and paper leaf as binding unit. They are produced according strictly defined parameters, conditions and binding techniques (adhesive thickness, glue application technique, pressing and drying time, room temperature and humidity).

2.2. Determination of paper properties
2.2. *Određivanje svojstava papira*

The manufacturers defined the paper composition, R0 – Portucel Soporcel Finepaper SA (Portugal), R30 – Mondi (Austria) and R100 – Papyrus (Sweden). Paper roughness was measured on 10 paper samples of each type of paper using the Qualitest Surface Roughness Tester TR200 (ISO 4287-1).

The ash content was determined according the TAPPI T 413 om-93 standard. Crucibles with weight test specimen were placed into the muffle furnace at 900 ± 25°C. After reaching the set temperature, crucibles were left at a given temperature for about an hour. When the specimen was completely combusted, crucibles were removed from furnace, cooled and placed in a desiccator to reach room temperature. Percent of ash content was calculated based on the moisture-free weight of the paper test samples as follows (Equation 1):

$$Ash = \frac{m_{(ash)}}{m_{(speciment)}} \times 100\ [\%] \qquad (1)$$

For determination calcium carbonate ($CaCO_3$) content, prepared paper samples were placed in an Erlenmeyer flask with 25 mL of distilled water and subjected to digestion in a known quantity of standardized hydrochloric acid ($_{CHCl}$=0,1 mol/L, V_{HCl}=20 mL).

Table 1: *Properties of analysed paper samples*

Tablica 1: *Svojstva analiziranih uzoraka papira*

SAMPLE	PAPER COMPOSITION	ROUGHNESS [µm]	ASH [%]	$CaCO_3$ [%]
R0	100% primary cellulose fibers	2,56 ± 0,001	13,67	20,55
R30	30% recycled + 70% primary	2,83 ± 0,119	11,51	20,27
R100	100% recycled fibres	3,09 ± 0,074	17,91	29,96

After heating up to the boiling point and cooling to a room temperature, back titration with standardized sodium hydroxide ($_{CNaOH}$= 1 mol/L) was used to determine the amount of consumed hydrochloric acid, with phenolphthalein as indicator. The percentage of calcium carbonate was calculated based on the moisture-free weight of the paper test specimen, assumed that all of the alkaline material neutralized was calcium carbonate (Equation 2):

$$\omega(CaCO_3) = \frac{(c_{HCl} \times V_{HCl} - c_{NaOH} \times V_{NaOH}) \times 0.05}{m_{(speciment)}} \times 100\ [\%] \quad (2)$$

2.3. Used binding techniques

2.3. *Korištene tehnike lijepljenja*

In addition to the different types of paper, two bonding techniques were used. Therefore, 10 book blocks of every type of paper were made with double-fan binding technique and other 10 were perfect bounded with mechanical pre-treatment spine roughening. Until now, the comparison of investigated binding techniques has not been of great importance because researches were mostly related to mass production. Due to constant print products volume reduction and the fact that only a few pieces of book products are made more often, double-fan binding technique is becoming more popular than perfect binding technique with mechanical spine pre-treatment [12, 13].

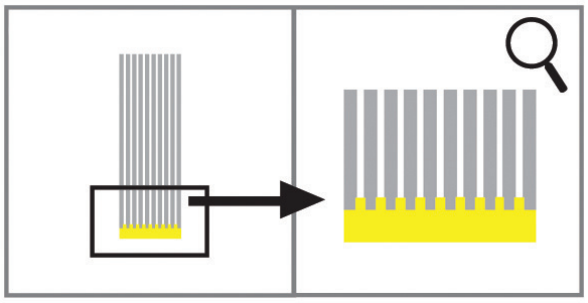


Figure 1: *Double-fan binding technique*

Slika 1: *Tehnika lepezastog lijepljenja*

After binding processes book block samples were pressed and dried for 48 h. After drying, it is also necessary, to trim book blocks on three sides to get end format dimension.

2.3.1. Double-fan binding technique

2.3.1. *Tehnika lepezastog lijepljenja*

In double-fan binding technique, after gathering, book blocks are placed between clips to eliminate moving during the binding processes. Then, book blocks are bended by pressing the book block to one and then to the other side. In both cases, the spine of the book, during spine bending is coated with an adhesive layer. Book block bending allows penetration of adhesive between binding units too (Figure 1).

2.3.2. Perfect binding technique with mechanical pre-treatment

2.3.2. *Tehnika lijepljenja hrapavljenjem hrpta*

Perfect binding technique with mechanical pre-treatment of book spine is mainly used. After gathering and placing book blocks between clips, mechanical treatment of book spine is performed – roughening.

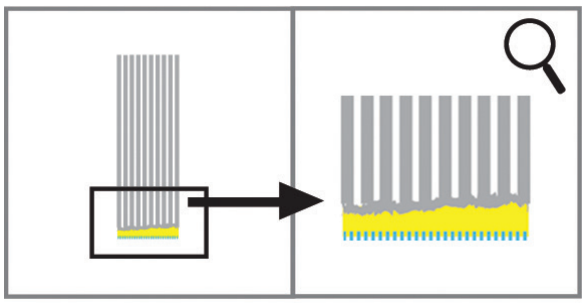


Figure 2: *Perfect binding technique with mechanical pre-treatmen*

Slika 2: *Tehnika lijepljenja uz prethodno hrapavljenje hrpta*

The main goal of such pre-treatment is to increase the spine roughness and the surface area itself, in order to achieve better adhesive adhesion. After roughening and adhesive application, gauze strip, which contributes a lot on final book block strength, is added too (Figure 2).

2.4. Determination of book block binding strength

2.4. *Određivanje čvrstoće uveza knjižnog bloka*

Devices for book block binding strength determination are measuring the tensile force (N) needed for pull out individual leaves from adhesive joint in tested book block sample. To obtain values comparable to the existing standard (ISO 19594) (Table 2), the value of tensile force should be divided by the high of the book block (N/cm). Device features can also affect on obtained results and unfortunately it is not possible to influence on them. Mainly, they are related with direction of tensile force and its angle, but also the speed of tensile tearing force. Used device, IDM Page Pull Tester (model P0011) is measuring upwards tensile force considering the position of tested book block sample. Final value of tensile force is defined at the moment of tensile force interruption, which is usually caused by poor adhesion between adhesive and paper and is manifested by separation of tested leaf from the rest of the book block. Beside poor adhesion, the reason for tearing can be a poor cohesion between the adhesive particles itself, poor adhesion between surface paper coatings and paper structure or poor cohesion inside the paper.

According to the used ISO standard, determination of book block binding strength always requires multiple consecutive measurements. Based on individual measurements, the mean value of tensile force required to pull out tested leaf from the adhesive film on book spine is calculated. The minimum recommended number of blocks samples for testing is 8, but during this research 10 samples were tested for each type of paper and binding technique. In addition to number of samples, the position of the tested leaves within the book block may also affect on the results, so each sample should be divided into the front, middle or rear part of the book block. Therefore, 1st, 10th and 18th, than 26th, 34th, 37th and 45th, and 53rd , 61st and 70th leaf is marked in every book block sample before beginning of measurement. It is important that obtained mean values, related to the defined position of leaves, are observed separately from the total average for each book block sample.

3. Results

3. *Rezultati*

Following tables (Tables 3 – 6) show results of binding strength according to above listed standardized method, depending on the type of paper and binding technique. Each table shows one type of paper and one type of binding technique with individual values of binding strength relative to defined position of tested leaf within a book block and sample number. Also, tables show mean values and standard deviation for each sample number and each leaf position. Finally, the total mean value for tested type of paper and binding technique is also shown.

Table 2: *Evaluation of book block binding strength according to ISO 19594*

Tablica 2: *Vrednovanje čvrstoće knjižnog bloka po standardu ISO 19594*

TENSILE FORCE VALUE (N/cm)	STRENGTH EVALUATION
< 5,5	poor strength
5,5 – 6,5	sufficient strength
6,5 – 7,5	good strength
> 7,5	very good strength

Table 3: *Test results of bookbinding strength R0 – double-fan binding*

Tablica 3: *Rezultati ispitivanja čvrstoće knjižnih blokova R0 - lepezasto lijepljenje*

SAMPLE NUMBER (N/cm) – R0 (double-fan)												
POSITION	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	$\bar{x}$	σ
1.	8,585	10,634	8,780	7,561	8,366	8,902	7,829	7,000	9,683	11,537	**8,888**	1,324
10.	10,756	10,976	10,317	11,463	10,488	10,488	11,463	5,268	6,293	8,049	**9,556**	2,106
18.	11,024	11,854	8,463	9,805	6,366	11,293	6,976	10,073	7,951	11,024	**9,483**	1,830
26.	11,244	10,756	6,927	11,537	7,073	11,415	10,927	8,561	7,878	11,707	**9,803**	1,856
34.	9,585	8,854	7,341	9,732	7,707	9,415	11,780	11,732	6,024	11,537	**9,371**	1,860
37.	11,561	8,561	11,561	5,561	10,756	10,463	11,537	11,659	7,268	9,073	**9,800**	2,012
45.	11,366	11,707	11,098	10,415	11,024	11,098	5,805	5,390	9,366	6,707	**9,398**	2,343
53.	11,561	11,585	11,390	11,463	11,537	9,737	5,293	6,024	9,195	5,171	**9,296**	2,616
61.	8,341	11,049	9,756	10,829	9,463	11,683	9,878	11,220	9,683	11,366	**10,327**	1,006
70.	8,439	6,220	11,537	9,463	11,610	11,780	7,293	6,244	6,488	7,707	**8,678**	2,161
$\bar{x}$	**10,246**	**10,220**	**9,717**	**9,783**	**9,439**	**10,627**	**8,878**	**8,317**	**7,983**	**9,388**	**9,460**	
σ	1,291	1,705	1,663	1,819	1,835	0,949	2,385	2,521	1,364	2,256	**1,779**	

Table 4: *Test results of bookbinding strength R0 - perfect binding with spine roughening*

Tablica 4: *Rezultati ispitivanja čvrstoće knjižnih blokova R0 - lijepljenje nakon hrapavljenja*

SAMPLE NUMBER (N/cm) – R0 (roughening)												
POSITION	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	$\bar{x}$	σ
1.	11,854	11,610	11,024	10,122	11,634	11,171	10,780	11,463	11,317	10,951	**11,193**	0,479
10.	3,976	9,732	3,561	5,902	7,805	2,439	10,024	2,073	9,390	3,829	**5,873**	2,959
18.	3,146	5,317	10,707	5,098	8,805	8,244	8,049	5,854	9,244	7,341	**7,181**	2,170
26.	3,220	10,244	5,780	11,220	5,951	3,805	8,927	7,314	11,439	3,732	**7,163**	2,989
34.	11,463	8,439	11,634	5,878	8,732	5,439	5,488	8,122	7,220	11,341	**8,376**	2,317
37.	9,000	3,439	10,756	7,073	5,220	4,293	5,683	3,463	11,390	3,829	**6,415**	2,854
45.	6,268	8,854	6,244	3,561	10,049	11,683	10,537	4,268	7,341	9,585	**7,939**	2,695
53.	4,610	8,317	10,122	2,390	2,780	2,244	11,341	2,317	9,780	6,951	**6,085**	3,450
61.	10,195	6,512	6,683	9,390	8,073	10,854	8,683	11,293	10,146	8,854	**9,068**	1,552
70.	9,537	9,537	6,439	8,951	7,049	10,317	11,659	11,317	11,146	11,024	**9,698**	1,702
$\bar{x}$	**7,327**	**8,200**	**8,295**	**6,959**	**7,710**	**7,049**	**9,117**	**6,748**	**9,841**	**7,744**	**7,899**	
σ	3,280	2,330	2,698	2,761	2,509	3,607	2,082	3,538	1,504	2,935	**2,724**	

Table 5: *Test results of bookbinding strength R30 – double-fan binding*

Tablica 5: *Rezultati ispitivanja čvrstoće knjižnih blokova R30 - lepezasto lijepljenje*

SAMPLE NUMBER (N/cm) – R30 (double-fan)												
POSITION	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	$\bar{x}$	σ
1.	7,658	6,897	8,346	8,024	6,478	6,974	7,125	6,356	7,024	6,034	**7,092**	0,697
10.	5,973	9,234	8,975	8,946	7,489	7,891	9,124	9,489	8,947	9,467	**8,554**	1,059
18.	6,872	9,367	8,346	7,489	7,894	7,423	9,248	9,425	9,142	8,469	**8,368**	0,873
26.	7,824	8,745	6,879	7,245	8,469	7,250	9,436	9,236	10,254	8,654	**8,399**	1,034
34.	8,932	7,349	7,980	6,498	9,156	5,642	8,457	8,635	11,260	7,269	**8,118**	1,486
37.	9,526	6,324	7,645	7,246	6,249	6,128	9,236	7,349	9,167	7,168	**7,604**	1,218
45.	9,342	6,378	6,713	8,410	7,942	7,469	7,364	8,369	8,470	6,498	**7,695**	0,929
53.	7,342	6,483	7,892	7,923	9,142	7,659	7,859	5,915	8,750	7,468	**7,643**	0,901
61.	9,875	10,234	8,974	9,142	11,163	9,125	8,165	7,364	9,167	9,468	**9,268**	0,995
70.	10,250	8,349	7,346	9,036	7,408	8,034	6,569	9,598	6,264	7,248	**8,010**	1,234
$\bar{x}$	**8,359**	**7,936**	**7,910**	**7,996**	**8,139**	**7,360**	**8,258**	**8,174**	**8,844**	**7,774**	**8,075**	
σ	1,351	1,356	0,744	0,843	1,367	0,927	0,960	1,282	1,351	1,124	**1,131**	

Table 6: *Test results of bookbinding strength R30 - perfect binding with spine roughening*

Tablica 6: *Rezultati ispitivanja čvrstoće knjižnih blokova R30 - lijepljenje nakon hrapavljenja*

SAMPLE NUMBER (N/cm) – R30 (roughening)												
POSITION	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	$\bar{x}$	σ
1.	8,978	9,258	11,700	11,860	9,258	9,298	8,346	9,346	8,724	9,472	**9,624**	1,124
10.	9,120	8,260	7,480	8,820	6,725	6,975	11,340	9,422	6,742	6,972	**8,186**	1,429
18.	3,740	6,380	7,180	9,760	4,962	5,378	3,247	9,435	6,758	5,424	**6,226**	2,050
26.	5,780	6,180	3,880	8,740	2,367	5,243	3,349	6,423	2,724	5,782	**5,047**	1,864
34.	8,900	7,680	7,280	7,160	9,263	6,712	7,982	7,893	4,562	7,012	**7,444**	1,229
37.	7,160	4,340	8,640	9,500	6,398	2,789	6,752	5,364	5,346	8,243	**6,453**	1,954
45.	9,320	2,600	4,140	2,460	6,789	1,478	5,713	4,128	2,314	6,728	**4,567**	2,384
53.	7,520	7,700	6,500	4,280	5,813	4,612	1,937	5,326	3,424	3,425	**5,054**	1,779
61.	9,780	10,020	4,220	7,940	7,236	9,369	7,462	9,427	4,000	7,724	**7,718**	2,040
70.	11,785	10,120	9,160	9,760	10,273	9,234	7,865	10,523	9,423	10,523	**9,867**	0,994
$\bar{x}$	**8,208**	**7,254**	**7,018**	**8,028**	**6,908**	**6,109**	**6,399**	**7,729**	**5,402**	**7,131**	**7,019**	
σ	2,141	2,310	2,360	2,642	2,200	2,601	2,715	2,125	2,327	1,930	**2,335**	

Table 7: *Test results of bookbinding strength R100 – double-fan binding*

Tablica 7: *Rezultati ispitivanja čvrstoće knjižnih blokova R100 - lepezasto lijepljenje*

SAMPLE NUMBER (N/cm) – R100 (double-fan)												
POSITION	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	$\bar{x}$	σ
1.	3,480	5,173	6,123	2,498	6,133	4,398	5,489	5,321	6,379	4,852	**4,985**	1,174
10.	6,349	6,197	6,189	6,478	5,697	6,128	7,985	6,325	6,159	5,697	**6,320**	0,606
18.	3,348	7,148	7,498	5,465	6,985	9,167	5,349	4,319	6,200	8,659	**6,414**	1,747
26.	5,348	9,433	6,498	6,298	7,548	10,249	6,325	4,269	7,983	8,457	**7,241**	1,751
34.	6,348	9,143	6,482	6,348	7,596	10,039	6,258	3,293	7,198	9,625	**7,233**	1,897
37.	5,236	7,426	9,169	6,255	7,924	8,346	3,197	1,789	4,198	9,168	**6,271**	2,451
45.	4,319	6,452	6,138	7,984	6,397	7,201	4,398	8,349	4,789	6,982	**6,301**	1,349
53.	3,489	6,180	4,395	10,361	4,268	6,998	4,925	2,393	7,169	6,578	**5,676**	2,162
61.	9,460	10,246	10,249	10,349	5,697	4,593	6,318	7,492	5,870	4,190	**7,446**	2,318
70.	6,000	3,148	5,478	6,349	3,250	4,397	5,912	4,319	4,970	5,178	**4,900**	1,055
$\bar{x}$	**5,338**	**7,055**	**6,822**	**6,839**	**6,150**	**7,152**	**5,616**	**4,787**	**6,092**	**6,939**	**6,279**	
σ	1,771	2,025	1,643	2,191	1,425	2,150	1,225	2,008	1,125	1,848	**1,741**	

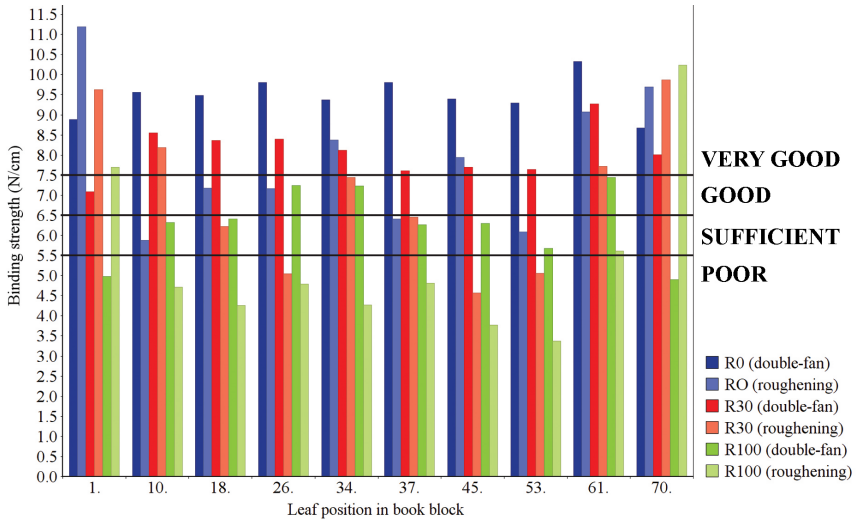
Table 8: *Test results of bookbinding strength R100 - perfect binding with spine roughening*

Tablica 8: *Rezultati ispitivanja čvrstoće knjižnih blokova R100 - lijepljenje nakon hrapavljenja*

SAMPLE NUMBER (N/cm) – R100 (roughening)												
POSITION	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	$\bar{x}$	σ
1.	9,694	7,897	9,369	6,978	6,978	6,470	6,120	9,124	9,235	5,136	**7,700**	1,510
10.	1,560	7,720	6,480	6,760	4,369	3,152	3,453	0,425	6,942	6,278	**4,714**	2,372
18.	2,340	6,940	6,260	8,040	1,569	2,425	4,128	2,498	6,218	2,26	**4,254**	2,264
26.	7,760	8,760	5,380	5,940	3,678	1,413	4,574	4,599	2,372	3,423	**4,790**	2,161
34.	11,540	3,440	6,300	2,180	3,987	1,972	4,692	5,950	0,397	2,269	**4,273**	2,990
37.	7,880	5,360	2,140	9,340	5,614	5,369	5,298	5,269	1,369	0,467	**4,811**	2,636
45.	5,900	1,780	3,800	1,000	5,348	5,347	5,127	5,098	3,258	1,029	**3,769**	1,804
53.	2,340	4,320	1,800	2,240	3,470	5,024	1,489	5,431	4,369	3,290	**3,377**	1,313
61.	5,420	8,880	2,240	10,800	5,645	3,375	2,476	8,243	5,693	3,396	**5,617**	2,751
70.	12,260	11,475	11,264	7,412	9,712	9,345	8,978	10,413	10,120	11,378	**10,236**	1,366
$\bar{x}$	**6,669**	**6,657**	**5,503**	**6,069**	**5,037**	**4,389**	**4,634**	**5,705**	**4,997**	**3,879**	**5,354**	
σ	3,640	2,768	2,981	3,091	2,105	2,287	1,949	2,835	3,076	2,996	**2,773**	

By comparing the obtained result for double-fan binding and perfect binding with mechanical pre-treatment, for all types of papers, double-fan binding provide to be much better. By comparing the total mean values listed in Tables 3 – 8 and by comparing these values with standardized values from Table 2, the book blocks with RO paper, regardless the binding technique, belong to the category of very good strength (9,460 N/cm; 7,899 N/cm).

The R30 book blocks, in the case with double-fan binding technique, belong to the category of very good strength also (8,075 N/cm), while R30 blocks with mechanical pre-treatment belong to the category of good strength (7,019 N/cm). Unlike these previous four listed types of book blocks, the book blocks R100 showed a much lower strength and they achieved a sufficient strength (6,279 N/cm) for double-fan binding and poor strength (5,354 N/cm) for perfect binding with mechanical pre-treatment.



Graph 1: *Strength of tested book blocks considering the leaf position and comparison with defined strength categories (all paper samples and binding techniques)*

Grafikon 1: *Čvrstoća ispitivanih knjižnih blokova s obzirom na položaj listova te usporedba s definiranim kategorijama čvrstoće (sve vrste papira i tehnike lijepljenja)*

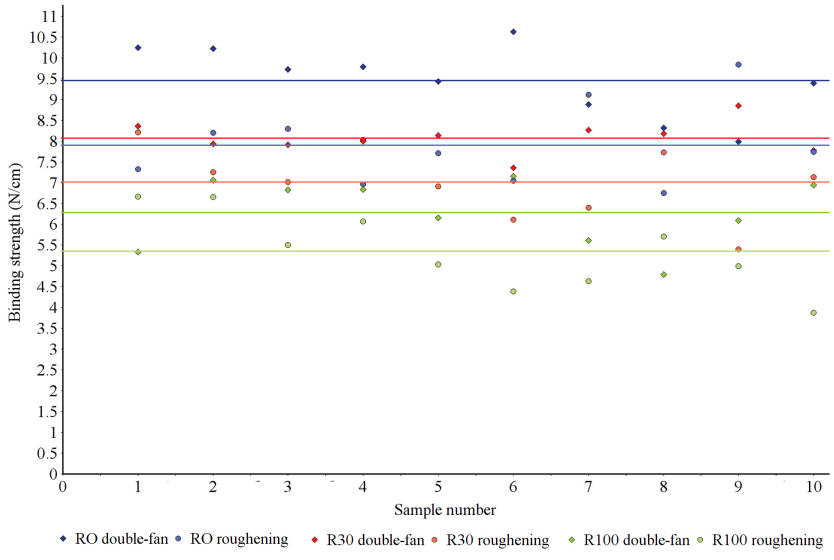
For further discussion, it is also important to observe and analyse mean values related to defined leaves positions and compare them with the standard values in Table 2. These results, with their standard deviation ranges, pointing to uniformity of adhesive application on all parts of book block spine, the reliability and quality of each binding technique, as well as the compatibility of tested type of paper and selected binding adhesive. All double-fan book blocks showed a smaller range of standard deviations and lower dispersion of results within different strength categories. Most even results are obtained for double-fan R0 book blocks, where all results belong to the very good binding strength category (Graph 1). According to the Graph 1, the largest dispersion of results showed R30 book blocks with mechanical pre-treatment, where results belong to all four categories of binding strength.

4. Discussion
4. *Diskusija*

According to a previous chapter, tables and graphs, it can be concluded that by testing binding strength of 60 book blocks, at IDM Page Pull Tester, double-fan binding was significantly better than perfect binding technique with mechanical pre-treatment of spine roughening and addition of gauze strip. Further analysis of the results (Graph 2), where mean values of binding strength for every book block sample are compared, show dispersion of results for each group of tested book blocks.

While all R0 double-fan book blocks belong to the group of very good strength, four of ten RO book blocks with pre-roughening belong to the group of good strength, not in a group of very good – which is assumed by their mean value. R30 paper show most even results, and only one book block for double-fan binding technique, minimally deviates from its predetermined group of very good strength. For perfect binding with mechanical pre-treatment, three R30 book blocks belong to the group of sufficient strength, while rest are in the group of good strength. R100 results have the largest deviation range from their assumed values. Although for double-fan binding only two R100 book blocks belong to the poor group, instead to the satisfactory group, and only two mechanically pre-treated R100 book blocks belong to the satisfactory group, instead to the poor group, on Graph 2 is clearly visible dispersion of results and larger distance from the assumed mean values – indicated with full straight lines for six tested groups of book blocks.

In order to discuss the relevance and repeatability of this research, during results analyse, standard deviations i.e. coefficients of variation must be considered too (Table 9). The expected coefficient of variation for all adhesion tests is even 20-30%. It is because there are numerous parameters that affect the quality of adhesive joint, and sometimes these parameters can not be controlled. This primarily refers to the temperature and humidity of the environment and the thickness of the adhesive application, which is difficult to control when books are handmade and always depend on human factor, i.e. worker skills and experience.



Graph 2: *Strength of book blocks by number of samples*

Grafikon 2: *Čvrstoća knjižnih blokova prema broju uzorka*

Therefore, a large number of test samples are required, but also a maximum control of essential parameters. The obtained values of bookbinding strength are not generally numerically comparable among laboratories [14, 15]. The values in Table 9 show the total coefficient of variation, but also a range of coefficients of variation for individual book block samples and a range of coefficients of variation depending on defined leaves position, for three tested types of paper and two binding techniques. These results are excellent supplement to the discussion above and once again confirm the superiority of double-fan binding technique, its constant quality and reliability of this technique. Coefficients of variation for double-fan binding show expected values for R0 and R30 book blocks, but for book blocks R100 are much higher and exceed the expected 30%. To explain these results, it is necessary to analyse the properties and composition of the used paper and compatibility of the adhesive and paper used for this group of book block samples. Furthermore, analysing coefficient of variations, for a perfect binding book block with mechanical pre-treatment, it can be concluded that these binding technique does not give satisfactory results, despite the obtained mean values, which, for example, for R0 book blocks belong to the category of very good strength. Coefficient of variation for R100 book blocks, for one sample even reaches 77%. Due to the inconsistency of the paper composition during paper production process, constant quality and repeatability of the process can not be expected for recycled book block samples.

5. Conclusion
5. *Zaključak*

On demand book production eliminates the need for storage and reduces the publisher`s profitable risk, but also causes a reduction of delivery time and requires a certain degree of final product quality. With advancement in technology, using new innovative materials and shapes, perfect bound books are becoming more important and popular even for making hard cover books. Therefore, this paper work proved that it is necessary to test the compatibility of used materials and binding technique, to enable on time delivery for short run book products, with required and constant quality. Various types of adhesion tests shall be carried out, which may relate to the examination of basic material properties or the end use tests. This paper examines the end use of the finished book product, i.e. the strength of the book block which is directly related to the quality of the book. Due to the specific properties of particular type of paper or adhesive, quantitative analysis of adhesion joints sometimes are not enough. Sometimes, it is also necessary to visually analyse the cracking place in the observed adhesive joint. In this research, obtained numerical values were in accordance with final strength results, visual evaluation and to the made order of observed book block groups. Specifically, RO book blocks have been shown as numerically the strongest during Page Pull Tests and theirs visually cracking point was always between adhesive and paper (poor adhesion) or in adhesive itself (poor cohesion).

Table 9: *Coefficients of variation comparison for tested groups of samples*
Tablica 9: *Usporedba koeficijenata varijacije ispitivanih skupina uzoraka*

	DOUBLE-FAN	ROUGHENING	PAPER
Total coefficient of variation (V):	**18,81%**	**34,49%**	**RO**
Rang V - individual book block samples:	8,93 - 30,31%	15,28 – 52,43%	
Rang V - defined leaves position:	9,74 – 28,14%	4,28 – 56,70 %	
Total coefficient of variation (V):	**14,01%**	**33,27%**	**R30**
Rang V - individual book block samples:	9,41 – 17,09%	26,08 – 43,07%	
Rang V - defined leaves position:	9,83 – 18,30%	10,08 – 52,19%	
Total coefficient of variation (V):	**27,73%**	**51,79%**	**R100**
Rang V - individual book block samples:	18,46 – 41,94%	41,57 – 77,24%	
Rang V - defined leaves position:	9,58 – 39,08%	13,35 – 69,98%	

For R30 and R100 book blocks cracking points were in the structure of paper (poor cohesion), which would mean that the obtained binding strength values are not completely relevant. However, considering numerical and visual matching of the strength results, the importance of qualitative analysis in this paper can be minimized.

By analysing the results, whether it was an analysis of the total mean values of binding strength, the mean values for each book block sample or the mean values for binding strength of precisely defined leaves positions, it is sure that double-fan binding allows penetration of adhesive between binding units, unlike perfect binding with mechanical pre-treatment. Pervious statement is confirmed by the analysis of standard deviations and coefficient of variation, which showed that double-fan book blocks have more even adhesive application on a book spine. Therefore, the bonding technique can be highlighted as one of the main parameters that directly influence the quality of finished product. Further, by comparing the quality of a book blocks depending on the type of used paper, values for R0 and R30 book blocks have been quite similar. Tensile strength values were higher for R0, while standard deviations and coefficient of variation were slightly smaller for R30. R100 showed the smallest strength values and highest dispersion of results and coefficient of variation. The obtained results should be also related to the basic paper properties given in Table 1. Although roughness is one of the most influential factors in adhesion process, considering values in Table 1 and obtained similarities between used papers, in this research can be neglected. The ash content, i.e. the proportion of inorganic constituents and the share of calcium carbonate, proved to be key parameters. Recycled papers have a higher share of inorganic constituents due to fillers from old papers and additives added to improve their properties. The properties of recycled papers depend on many factors during processing (collecting, sorting, pulping, coarse screening, deinking, cleaning, sieving, washing, conserving). Due to the presence of different remains and filth, their desired properties can be changed and bonding between fibers can be reduced, which can cause cracks in paper structure [16].

The number of cracks is reduced by increasing the amount of fillers, which is also confirmed in this research – ash content for R100 was 18%, versus R0 and R30 with 11% and 13%. Considering the basic purpose of office papers used in this research, and that they are suitable for digital printing techniques, their surface smoothness is very important. So, office papers must pass the calendaring process and different types of fillers and coatings must be added [17]. Because of increased number of cracks and the reduction of primary cellulose fibres amount, the strength of material can be reduced, but also its optical properties. With the addition of calcium carbonate, which is almost 30% in R100 (R0 i R30 is about 20%), the optical properties of paper can be improved (e.g. opacity and whiteness). Based on facts and results mentioned above, it can be concluded that higher amount of calcium carbonate and inorganic fillers negatively affect the quality of the adhesive joint, i.e. the finished product quality.

Although the obtained results showed that R100 - recycled paper is not suitable for perfect bound books, R30 - papers with 30% of recycled fibres and 70% of primary fibres achieved very good binding strength values for double-fan binding. Based on determinate R30 paper properties, it can be concluded that collecting and sorting processes for this paper production were strictly controlled. Also, the amount of remains and filth from printing inks, toners, adhesives, adhesive particles from labels, coatings, varnishes and waxes was not high or was successfully removed. In this case, because the optimal ratio of primary and secondary fibres, very good paper quality was achieved, and finally the finished product quality.

Despite the simplicity of final products tests performed in this research, a great experience is needed to determinate the procedure correctness and to evaluate results and test reliability in order to apply interpreted results and use them in practice. Therefore, during test procedures, it is necessary to keep basic and main influencing factors, mentioned in chapters above, at the same level. Introduction of new materials into existing adhesion manufacturing processes requires, at least, “internal” non-standardized test methods, if there is short deliver time or there is no resources for standardized methods.

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6. *REFRENCES*

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