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Recycled paper – the influence of digital prints

Reciklirani papiri – utjecaj digitalnih otisaka

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ABSTRACT The process of paper recycling changes the properties of cellulose fibres. The fibres become harder, more brittle, less flexible and more fragile. Their swelling ability is also reduced. These changes reduce the contact surface and weaken the hydrogen bonds between the fibres in recycled paper. Paper recycling takes place in several phases, the most important of which is the process of de-inking. This is particularly important in the production of recycled printing paper. De-inking is a process by which the particles of printing ink are removed from the pulp, i.e. from de-fibrated prints. Due to the fact that in every printing technique the ink adheres in a specific way to the substrate, the de-inking process for various types of prints can have a different outcome. Chemical de-inking flotation, along with particles of ink, extracts a certain amount of fibres and fillers from the pulp. With respect to the optical properties of recycled paper, the efficiency of de-inking directly affects quality.

The aim of the study is to determine to what extent the extraction of certain quantities of fillers from the pulp influences the mechanical properties of recycled paper. To test evaluate access this effect, we expect that tests of tensile strength, tearing and bursting resistance of handsheets made of recycled fibers from offset and digital prints, will provide some answers. The addition of digital prints during recycling will decrease the mechanical properties of handsheets despite the presence of primary cellulose fibers. This is due to the influence of the fillers, as well as the residual ElectroInk particles in the recycled paper.

Key words: Recycled fibres, mechanical properties, tensile strength, tearing resistance, bursting resistance, digital offset printing, conventional offset printing

SAŽETAK Tokom postupka recikliranja papira celuloznim vlaknima se mijenjaju svojstva. Vlakna postaju kruća, krtija, manje fleksibilna i lomljiva, a smanjuje im se i sposobnost

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bubrenja. Sve to utječe na smanjenje površine međusobnih kontakata vlakana kao i na slabljenje vodikovih veza među vlaknima u recikliranom listu papira.

Pojam "recikliranje starog papira" obuhvaća nekoliko faza procesa od kojih najvažnijom možemo smatrati postupak deinkinga, barem u proizvodnji recikliranih tiskovnih papira. Deinking je postupak uklanjanja čestica tiskarske boje iz pulpe, razvlaknjenog otiska. Budući da se kod svake tehnike tiska boja na specifičan način vezuje na papir, i rezultati postupka deinkinga različitih otisaka se mogu međusobno razlikovati. Kemijskom deinking flotacijom se uz čestice boje iz pulpe izdvaja i određena količina vlakana, kao i punila. Sa aspekta optičkih svojstava efikasnost de-inkinga direktno utječe na kvalitetu recikliranog papira. No, zanima nas da li izdvajanje određene količine punila iz pulpe ima utjecaja na mehanička svojstva recikliranog papira. Ispitivanja čvrstoće papira na vlak, te otpornosti prema cijepanju i prskanju recikliranih laboratorijskih otisaka ofsetnih i digitalnih tehnika tiska mogu dati smjernice za odgovore na ta pitanja. Dodatak digitalnih otisaka prilikom recikliranja utjecat će na smanjenje ispitivanih mehaničkih svojstava laboratorijskih listova usprkos kvalitetnijih vlakana koja su ušla u sustav. Uzrok tome mogao bi biti zaostajanje većih čestica ElektroInka nakon flotacije, kao i prisutnost punila koji svojom prisutnošću utječu na slabljenje veza među vlakancima, a time i na mehanička svojstva recikliranog lista.

Ključne riječi: reciklirana vlakna, mehanička svojstva, čvrstoća na vlak, otpornost prema cijepanju, otpornost prema prskanju, digitalni ofsetni tisak, konvencionalni ofsetni tisak

1. INTRODUCTION

1. UVOD

From the ecological point of view, the recycling of paper contributes to the preservation of nature's resources, such as water and wood. The economical aspect makes paper recycling acceptable too. The production of one tonne of primary cellulose fibres requires about 100 t of water and ca 1.2 t of wood (Springer, 1999).

Recycled paper differs from virgin paper in its mechanical and optical properties, which is particularly relevant in the application in graphic technology.

The optical characteristics of recycled paper are influenced by the presence of dirt specks, which are defined as optical inhomogeneities impairing the quality of pulp and papers. The size, shape and surface characteristics of the residual ink particles will primarily depend on the conditions of the recycling process and the characteristics of the processed print with regard to the applied printing technique (McCool, Silveri, 1987; Bolanca et al, 2002). These particles can be visible, greater than 40 μm , or much smaller, less than 40 μm (Zabala, McCool, 1988). The latter are invisible to the human eye and are responsible for the decrease in whiteness and brightness of recycled paper (Merriman, 1993).

Mechanical properties of recycled paper are influenced by the changes which

every fibre undergoes in the recycling process, as well as by the decrease of the bonding potential in handsheet (Ellis, Sedlachek, 1992). The drying process is considered to have the greatest impact on the change of the properties of the fibres. During the first drying process in the production of primary paper the cell walls of the fibre lose water and the lamellas shrink. In some places they adhere one to another so strongly that the water molecules are unable to penetrate among the lamellas when the fibres are dipped again into water. The macroscopic consequence of this shrinkage is that fibre can never reacquire its primary swelling diameter (Smith et al, 1992). The impossibility of total swelling decreases the flexibility of the fibre and the adhesion to the neighbouring fibres is weaker, i.e. the fibre bonding potential is reduced. Reduced bonding has been described as irreversible hornification, which implies a stiffening or hardening of the fibre (Ellis, Sedlachek, 1993). Reduction of fibre length also influences sheet properties (Smith et al, 1992). During the recycling process, fibres become more brittle and subsequent refining shortens them.

Apart from changes in the fibres themselves, another factor influencing the mechanical properties of recycled paper is the presence of fillers (Howard, Bichard, 1992). Mechanical properties of paper are dependent on the type, proportion, preparation and

amount of fibres present in the sheet, as well as on their formation, internal sizing and, to some degree, the additives.

Only recycled fibres are used as raw material for the industrial production of newsprint paper. For the most part, those fibres originate from ONP (old newspaper), which means that the fibres have been used at least twice before. ONP fibres are improved by adding OMG (old magazines) printed on paper that is going to be recycled for the first time.

There are several reasons for introducing prints of primary paper to ONP: ONP fibres that have already been recycled several times are unable to produce new recycled paper that would have satisfactory strength properties. In this segment, the role of primary paper, with its longer and more flexible fibres, is to help weaker old-newspaper fibres to knit the stronger newsprint paper.

The strength of newsprint paper is of great importance because of the web printing which exposes the paper to tensile and tear stresses.

Furthermore, the production of recycled print paper involves the de-inking stage, following which a certain quantity of ink particles remains among the fibres. Even though those particles are very small, individually invisible, their presence in the recycled paper diminishes the optical properties of the paper. Introducing primary fibres can help to increase the brightness of the recycled paper, partly through fibres that are clearer and partly through fillers that are brought in by coated paper.

It can be assumed that in the production of newsprint paper, OMG prints may be substituted by the digital prints. Digital printing is developing rapidly in all types of technological configurations, and it is spreading through global printing production. Therefore, the study of the influence of digital prints on the properties of recycled handsheets may be of future industrial interest.

Newspaper recycling

Many authors have studied newspaper recycling from different aspects.

Mahagaonkar and Banham (1995) and Mahagaonkar et al. (1997) studied the presence of OMG in ONP and its influence on the mechanical properties of recycled paper. Eriksson et al. (1997) investigated the alteration of handsheets caused by subsequent recycling, printing and aging of the paper. Fabry et al. (2001) explained the mechanisms of friction between the fibres and ink particles in the pulp as a factor of better dis-

integration of ONP. Gomez et al. (2001) suggested the introduction of silicone oil into the pulp before the flotation stage. Oil spreads all over the air bubbles and improves the de-inking efficiency of ONP and OMG. Ben and Dorris (2000) offered a solution for solving the problem that was earlier described by Sjöström and Calmell (1997). Ben and Dorris suggested altering the mixing intensity during the disintegration of the aged ONP. As Sjöström and Calmell noticed, the printing ink of aged ONP disintegrates into very tiny particles, even smaller than one micrometer. Those tiny particles are dragged into the fibre lumen, and therefore are inaccessible to air bubbles during the flotation stage. Residual ink particles in the recycled paper decrease the brightness of the paper. Scheldorf and Strand produced the computer models SPECSEP, CONINK and BRIGHT, based on the Kubelka – Munk theory for the brightness of the pulp (Scheldorf, Strand, 1996), (Parson, 1981). They may be used for predicting the de-inking efficiency of the newspaper. The confirmation of those models was done by comparison with the results obtained by Borchardt and Matalamaki (1994). The level of the concordance of the compared results gave very high credibility to the computer models.

When digital prints are used as raw material for recycling, they are usually classified as OWP, office waste; ORP, office recovered paper; MOW, mixed office waste or CPO, computer printout (Borchardt, Rask, 1994), (Ling, 1994).

Chemical de-inking by flotation, a conventional recycling method, is sometimes not efficient enough for recycling different types of digital prints (Bolanca, 1999), (Bajpai, Bajpai, 1998).

2. EXPERIMENTAL

2. MATERIJAL I METODE

Handsheets of recycled paper were produced under laboratory conditions by the standard TAPPI method (T 205 sp-95). The conditions for the recycling process are presented in table 1. Input material consisted of prints produced by conventional offset printing technique on the "Koenig & Bauer Albert" printing machine on newsprint paper and of digital offset prints printed on the "Indigo E-Print 1000+" printing machine on fine art coated paper. The four colour printing was done using cyan, magenta, yellow and black (CMYK) ink. The input proportion for laboratory recycling of those two types of prints varied in steps of 20%.

The recycling process includes the de-

fibring processes for detaching the printing ink from the fibres of the input prints in the disintegrator, and the chemical de-inking flotation process for removing ink particles from the pulp.

The air bubbles are blown into the de-fibred pulp. Ink particles adhere to the air bubbles and are transported to the surface forming the foam.

Every input compound of fibres was used to produce handsheets after the pulping stage (before the flotation) and after the flotation stage. On each of the handsheets measurements of tensile, tear and burst strength were performed, as well as of the ash content, dirt count and brightness.

Tensile strength is the maximum tensile force per unit width over 150 mm span that paper will withstand before breaking. The tensile index is tensile strength divided

by weight of the examined paper (ISO-1924-2/1994; T 494om-96; T 404cm-92).

Tearing resistance is the mean force required to continue the tearing started by the initial cut. The tear index is the tearing resistance of the paper divided by its weight (ISO1974/1990; T 414om-98).

The bursting strength of the test piece is the maximum value of the applied hydraulic pressure on the test piece of paper. Burst index is the bursting strength of the paper divided by the weight of the examined paper (ISO 2758/2001; T 807om99).

The ash content is determined by complete burning, i.e. glowing of dry paper in a Mufoln oven at a temperature of about 900°C. The residual ash indicates the filler quantity of the burnt paper (T 413om-93).

The number and the size of the remaining ink particles (dirt count) of handsheets is

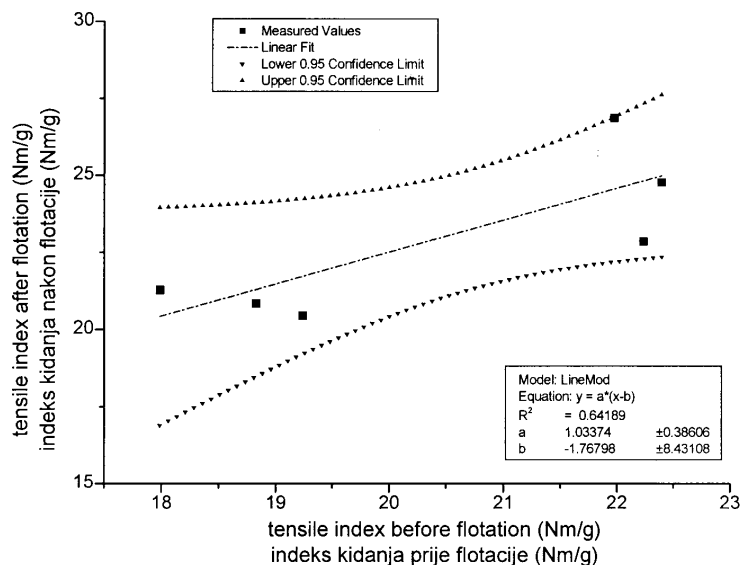
Table 1.

Conditions of pulping and flotation Uvjeti razvlaknjivanja i flotacije

Parameter Uvjeti	Pulping Razvlaknjivanje	Flotation Flotacija
NaOH Natrijeva lužina	1.0 (%)	
H ₂ O ₂ Vodikov peroksid	1.0(%)	
Water glass Vodeno staklo	2.0(%)	
DTPA complex agent Agent za kompleksiranje	0.2(%)	
Surfactant Površinsko aktivna tvar	0.4(%)	
Consistency Konzistencija	10.0(%)	0.6(%)
Time Vrijeme	45 (min)	8(min)
Temperature Temperatura	40°C	30°C

Figure 1.

The tensile indices of the handsheets before and after the flotation stage Indeksi kidanja laboratorijskih listova prije i poslije flotacije



determined on the 80 x 80 mm samples using image analysis method (T 563 pm – 97).

The brightness of handsheets is measured spectrophotometrically (T 452 om – 98).

3 RESULTS AND DISCUSSION 3. REZULTATI I DISKUSIJA

In figures 1, 2 and 3 the tensile, tear and burst indices of handsheets after the pulping and after the flotation stages are presented, standardized based on the percentage of ash content for each corresponding input compound.

The applied equation for calculating the linear regression was $y = a(x - b)$ according to the linear model. The obtained determination coefficient R implies the average connection between the examined mechanical properties of the handsheets before and

after the flotation stage, standardized on the percentage of ash content.

In figures 4, 5 and 6 the tensile, tear and burst indices of the handsheets after the flotation stage are presented for various degrees of percentage of digital print input.

After the pulping stage each of the observed strength properties decreased with increased percentage input of digital offset printing on coated paper.

The obtained mechanical properties of handsheets after pulping are the result of the combined influence of an increased quantity of fillers, an increase in the proportion of coated paper, and an increase in the proportion of digital prints on coated paper made from primary cellulose fibres. As a general principle, the addition of fillers decreases the strength. The strength of handsheets is due mainly to fibre – fibre bonds (Mahagaonkar et al, 1995). Filler particles occupy the spaces

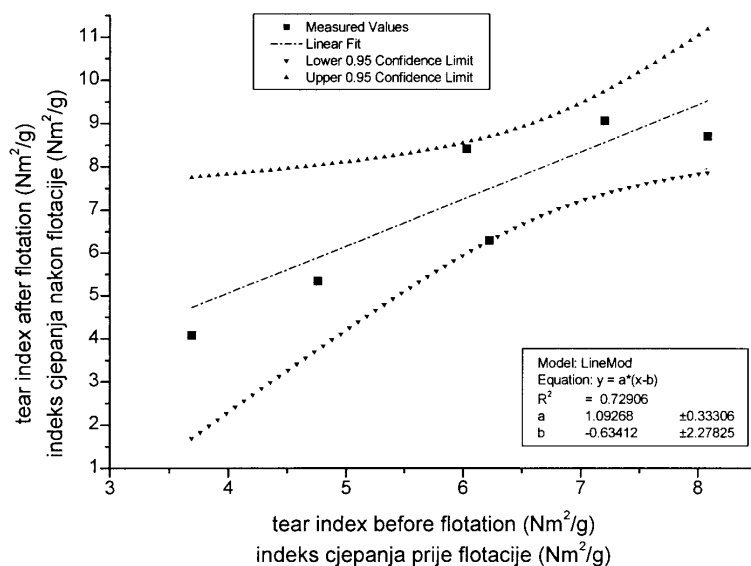


Figure 2. The tear indices of the handsheets before and after the flotation stage *Indeksi cijepanja laboratorijskih listova prije i poslije flotacije*

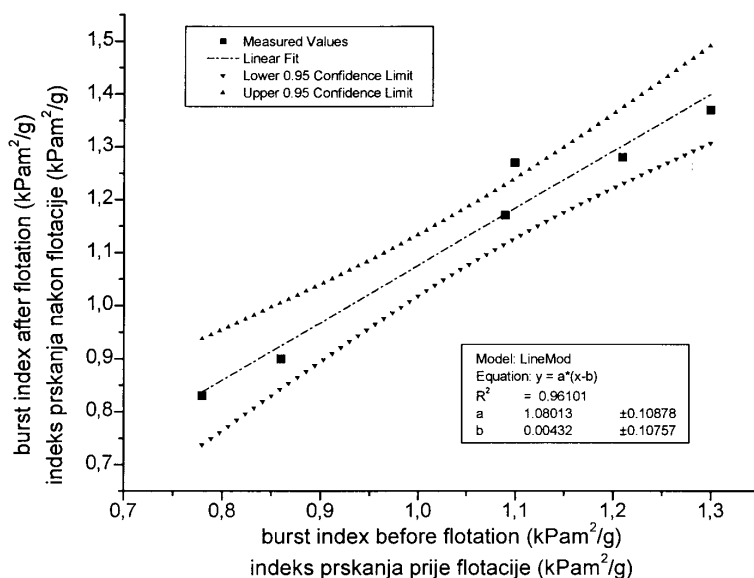


Figure 3. The burst indices before and after the flotation stage *Indeksi prskanja laboratorijskih listova prije iposlije flotacije*

between the fibres and interfere with fibre bonding, which causes the decrease in strength. The results suggest that the observed presence of fillers offsets the positive influence of increasing the quantity of primary fibres.

The great differences between digital and conventional offset prints in the size, number and surface characteristics of the residual ink particles on the handsheets after the pulping stage are presented in Figure 7. Those particles may have a direct or indirect influence on the monitored mechanical properties of the handsheets.

Under experimental conditions, the residual ink particles of conventional offset prints are tiny, mostly ranging from 0.01 to 0.04 mm² each. On the other hand, on the Indigo digital offset prints plate-like ElectroInk particles of about a micron in thickness and far greater than a microne in

diameter prevail. Due to their size, such particles are unsuitable for efficient removal by the conventional process of chemical flotation de-inking, since only particles between 50-150 µm in size are removed efficiently (Gottsching, Pakarinen, 2000).

The presented discussion explains the results of the examined mechanical properties of the handsheets after the de-inking flotation. As the input proportion of digital prints increases, the tensile, tear and burst indices diminish. Also, other characteristics of the handsheets, such as ash content or brightness, indicate the inadequacy of de-inking flotation of Indigo digital prints.

The ash content, starting from 27.61% for Indigo digital print at input, decreased to 14.26% in the handsheet after the pulping stage and to 12.51% after the flotation stage.

The increase in brightness of the handsheets before and after flotation is presented

Figure 4.

The tensile index of handsheets after flotation, by proportion of input prints Indeks kidanja laboratorijskog lista nakon flotacije u ovisnosti o sastavu ulaznog papira

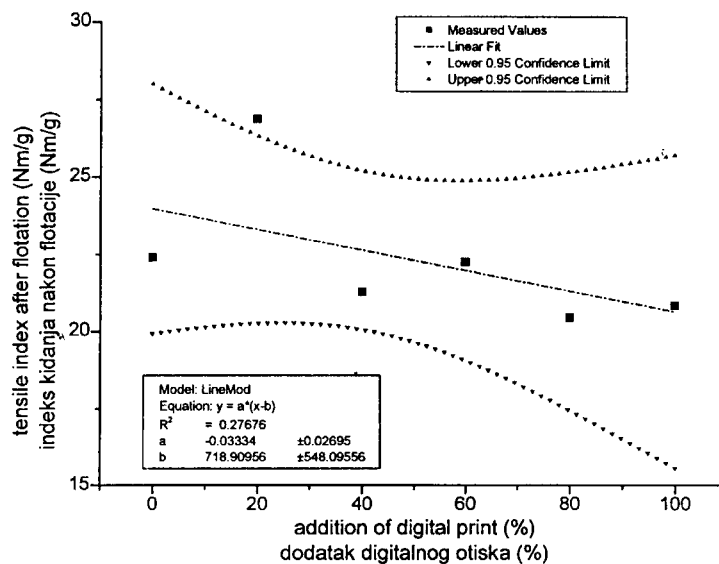
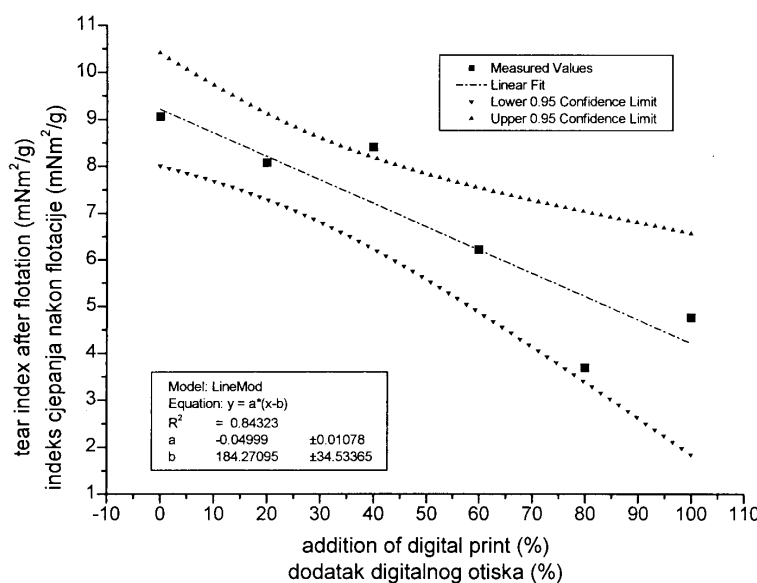


Figure 5.

The tear index of handsheets after flotation, by proportion of input prints Indeks cijapanja laboratorijskog lista nakon flotacije u ovisnosti o sastavu ulaznog papira



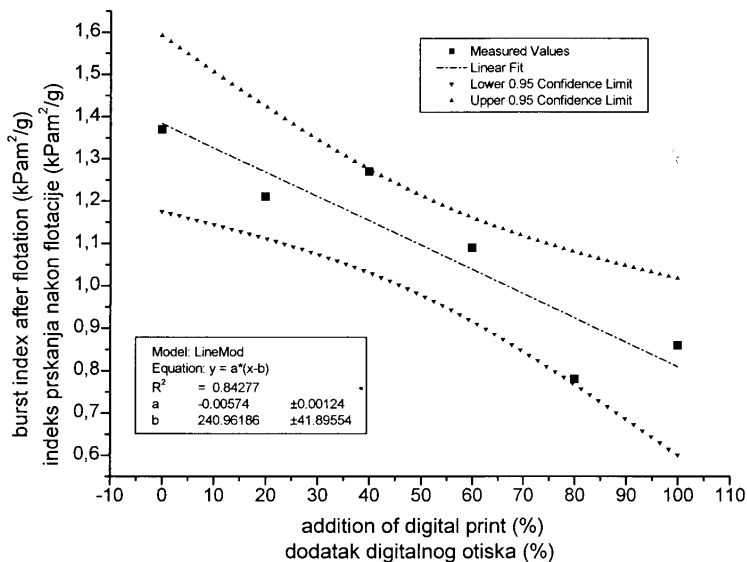
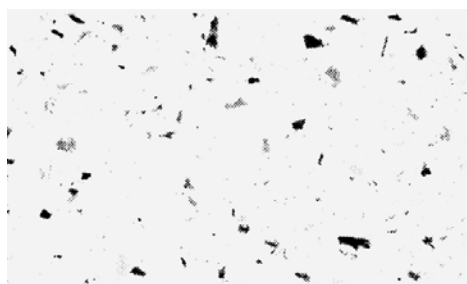
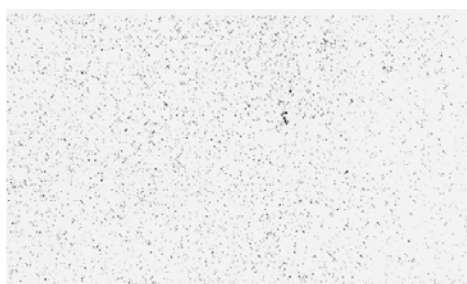


Figure 6.
The burst index of handsheets after flotation, by proportion of input prints Indeks prskanja laboratorijskog lista nakon flotacije u ovisnosti o sastavu ulaznog papira



Digital offset



Conventional offset

Figure 7.
Residual ink particles on the handsheets before flotation Zaostale čestice boje na laboraotrijskim listovima prije flotacije

Particle size class (mm ²) Klase veličine čestica (mm ²)	Number of particles Broj čestica	Area of particles (mm ²) Površina pokrivena česticama(mm ²)
0 – 2	1095	146,8
> 2	145	1223,3

Digital offset

Particle size class (mm ²) Klase veličine čestica (mm ²)	Number of particles Broj čestica	Area of particles (mm ²) Površina pokrivena česticama(mm ²)
0 – 2	13584	1152
> 2	125	401

Conventional offset

Table 2.
The area of handsheet covered by ink particles Površina laboratorijskog lista pokrivena česticama boje

in table 3.

These results demonstrate that handsheets containing residual ink particles of larger size generally have greater brightness than those with a greater number of small particles which contribute to the sheet greyness.

4. CONCLUSION 4. ZAKLJUČAK

The mechanical properties of recycled paper depend on a complex set of factors. These include not only the characteristics of the substrate of the processed prints and the mechanism and conditions of the recycling process, but also the basic principle of the printing technique.

Tensile, tear and burst indices of handsheets after the pulping stage decrease as the proportion of digital prints in the input is increased. After the flotation stage, tensile, tear and burst indices continue the descending tendency. This is due to the influence of the fillers, as well as the residual ink particles in the recycled paper. Both influences interfere with fibre bonding and outweigh the presence of primary fibres in the input compound.

The results of the presented research contribute to knowledge of how recycling techniques relate to the strength of recycled fibres from the theoretical point of view. They are also important in the context of graphic production because they point to the

Table 3

The increase of brightness of handsheets in the process of de-inking flotation
Prirast svjetline laboratorijskog lista flotacijom

Proportion of digital print in the sample (%) Udjel digitalnog otiska u uzorku (%)	Increase in brightness (%) Prirast svjetline (%)
0	4.28
20	4.57
40	4.89
60	5.22
80	5.69
100	6.05

necessity of searching for other satisfactory ways to dispose of used digital offset prints.

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**CITED STANDARDS AND METHODS
NAVEDENE NORME I STANDARDNE
METODE**

T 205 sp – 95 Forming handsheets for physical tests of pulp
 ISO 1924 – 2 Paper and board – Determination of tensile properties Part 2: Constant rate of elongation method
 T 494 om – 96 Tensile properties of paper and paperboard
 T 404 cm – 92 Tensile breaking strength and elongation of paper and paperboard
 ISO 1974 - 90 Paper – Determination of tesring resistance (Elmendorf method)
 T 414 om – 98 Internal tearing resistance of paper (Elmendorf type method)
 ISO 2758 - 01 Paper – Determination of bursting strenght
 T 807 om – 99 Bursting strength of paperboard and linerboard
 T 413 om – 93 Ash in wood, pulp, pa-

per and paperboard: Combustion at 900°C
T 563 pm – 97 Equivalent Black Area
(EBA) and count of visible dirt in pulp, paper
and paperboard by image analysis

T 452 om – 98 Brightness of pulp, pa-
per and paperboard (directional reflectance
457 nm)