Effect of Mixing Different Contents of OCC Pulp on NSSC Pulp Strength

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This research was conducted to study changes in mechanical properties due to mixing of old corrugated container (OCC) pulp with virgin neutral sulfite semi-chemical (NSSC) pulp. The OCC pulp was collected after removal of printing, glued parts, and unwanted additives. To prevent cutting of fibers, dedicated containers were broken down by hand before pulping. Handsheets with a base weight of 127 g/m^2 were made by mixing the NSSC and OCC pulps at proportions of 60, 70, and 80 wt% of NSSC. Mechanical properties, including tensile strength, burst strength, tearing strength, corrugated medium test, and ring crush test, were evaluated using TAPPI standards. Addition of up to 30% OCC improved the tensile strength, tear strength, and burst strength of the handsheets significantly in comparison with the control sample (21, 25, and 59%, respectively). However, the corrugated medium test and ring crush test decreased by about 13 and 9%, respectively. The results of this study revealed that mixing 30 wt% OCC with NSSC yielded a higher quality paper.

Keywords: Neutral sulfite semi-chemical (NSSC) Pulp; OCC; Handsheet; Strength properties

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INTRODUCTION

Recycling of paper is important for economic and environmental reasons and is considered a growing industry in Iran (Sarkhosh and Talaeipour 2011). The raw materials of many local plants are waste papers these days. Most paper manufacturers that use lignocellulosic materials for producing virgin pulp have begun collecting and recycling paper, and they may even import the waste papers from other countries to produce and supply different kinds of papers to the market (Khalili Ghasht Roodkhani *et al*. 2011; Ghaffari *et al*. 2012).

Old corrugated container (OCC) pulp is an important byproduct of the packaging industry and accounts for nearly half of the fibrous materials in the paper and carton recycling industries. This grade of pulp is typically used to produce various packaging products, such as test liner, corrugating medium, and packaging papers (Cathie and Guest 2001). Production and consumption of this kind of carton, thanks to its good flexibility and durability, is rapidly increasing for everyday applications such as the making of containers for the food products.

The major manufacturers are located in the U.S., China, Germany, and France (Food and Agriculture Organization 2010). Mixing the recycled OCC pulp with hardwood neutral sulfite semi-chemical (NSSC) pulp revealed that recycled OCC pulp dominates the NSSC pulp in terms of strength properties (Asadpour *et al*. 2008). Further research work has been performed to improve properties of the OCC pulp through refinement and use of cationic starch or imported long fiber pulp. Treatments including refining of the pulp and use of the cationic starch can lead to improved OCC pulp strength (Rasa *et al*. 2012). Ghaffari *et al*. (2012) studied optimization of the cationic starch consumption for improvement of the mechanical properties of the pulp formed from combination of the OCC and NSSC pulps. Their results demonstrated that increased cationic starch addition can enhance the mechanical strength of the paper, with the best addition rate determined as being 3%. Taking into account the existing limitations for using the raw materials, the present work aims to address the best mixing ratio of these two pulps for reaching the proper strength properties.

MATERIALS AND METHODS

Preparation of Carton Wastes and Making NSSC Pulp

Old corrugated container pulp was collected from Mazandaran Wood and Paper Industries located in Mazandaran, Iran, after removing print, glued parts, and unwanted additives. To prevent unwanted cutting of the fibers, the containers were broken down by hand before pulping. A laboratory fiber detachment apparatus running at 5000 rpm was used to detach the carton fibers and ensure uniform raw materials. Neutral sulfite semi-chemical pulp from a storage tank at Mazandaran Wood and Paper Mill was transferred to the laboratory. Refining was conducted to reach a freeness degree of 400 mL CSF using a laboratory hammer (PFI Mill, LABTEC Model) from Canada, which followed the TAPPI method T 248 sp-00. The various ratios of NSSC to OCC pulp are displayed in Table 1.

Table 1. Mixing ratios of NSSC and OCC pulp

Treatments	Mixing Ratio of Pulps (%)		Treatment Code
	NSSC	OCC	
Control Sample	100	0	A
1	80	20	B
2	70	30	C
3	60	40	D

Making Handsheets

The standard (TAPPI T205 sp-02 2002) was used in the preparation of the 127 g/m^2 handsheets.

Determination of Properties

Mechanical tests, including tensile, burst, and tear strengths, CMT, and RCT, were conducted according to the TAPPI standards T494 om-01 (2001), T403 om-02 (2002), T414 om-04 (2004), T 809 om-99 (1999), and T818 om-97 (1997), respectively.

Data Analysis

One-way variance of analysis was conducted using SPSS statistical software (IBM Software, Armonk, New York; version 11.5). The Duncan test, at the 95% confidence level, was used for comparing and grouping of the mean values.

RESULTS AND DISCUSSION

The analysis results for the strength properties are presented in Table 2.

Table 2. Statistical Analysis of Handsheet Samples

Properties	F-Value
Tensile Strength Index	120.660*
Tear Length	9.449*
Burst Strength Index	15.445*
Tear Strength Index	19.789*
Corrugated Medium Test	3390.914*
Ring Crush Test	432.851*

* denotes significance at the 95% confidence level

Tensile Strength Index

Based on the obtained results, treatment D had the maximum tensile strength, 17.54 mN/g, and treatment A had the minimum value, 14.24 mN/g (Fig. 1). The most important factor affecting tensile strength of paper is the number and quality of the fiber connections to each other (Scott 1995). For the tensile strength, the strengths of both the connection between the fibers and the fibers themselves are exposed to tension. Therefore, longer fibers and stronger connections between the fibers contribute to this strength. The tensile strength increased by increasing the OCC pulp content from 0 to 40%. This improvement of the tensile strength is a result of longer length, better flexibility, and greater tendency to bond, as well as a stronger connection of the OCC pulp added to the new NSSC pulp (Asadpour *et al*. 2008).

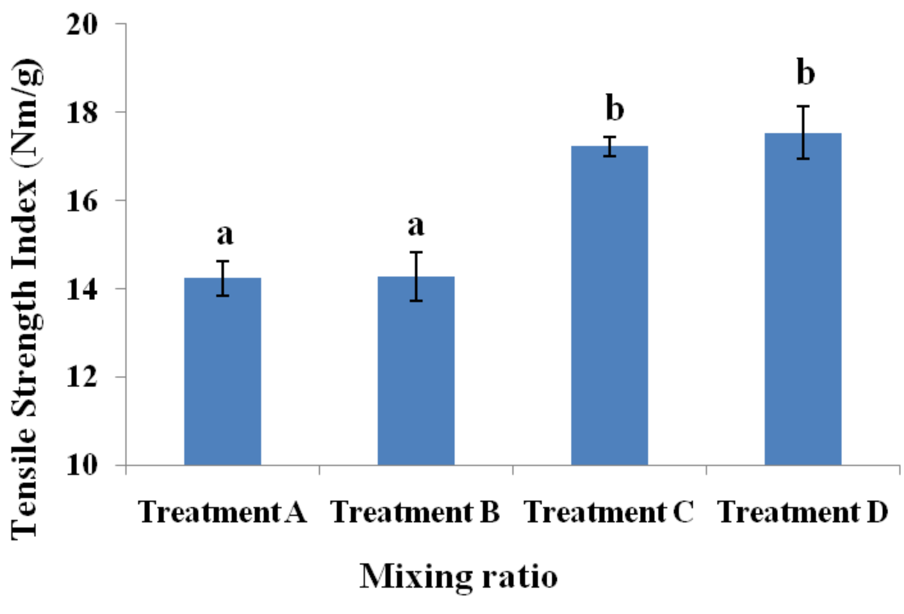

Fig. 1. Tensile strength index for various sample ratios. Treatment A, control sample; treatment B, 80/20; treatment C, 70/30; and treatment D, 60/40; a and b are significantly different (p<0.05)

Burst Strength Index

As shown in Fig. 2, treatment D achieved the greatest burst strength index, 1.62 KPa.m^2/g, and treatment A had the lowest burst strength index, 0.96 KPa.m^2/g. The burst strength index depends on the fiber length and fiber-fiber bonding, with fiber-fiber bonding having the greater influence (Asadpour *et al*. 2008). The pure NSSC pulp gave the lowest burst strength, which is affected by the shorter length of the fibers, the smaller flexibility of the fibers, and the weaker bond between them. One of the strongest bonds that occurs between the fibers is the hydrogen bond. Thread and string structure of fibers will further reinforced the bond between them. This means that thin fibers generally have better contact and there is better bonding within the sheet in the case of thin fibers. This property increase the burst strength. The obtained results indicate that increasing the amount of OCC pulp from 0 to 40% will increase the burst strength. This can be attributed to a greater tendency for more connections, longer fibers, and greater flexibility of the OCC pulp (Asadpour *et al*. 2008).

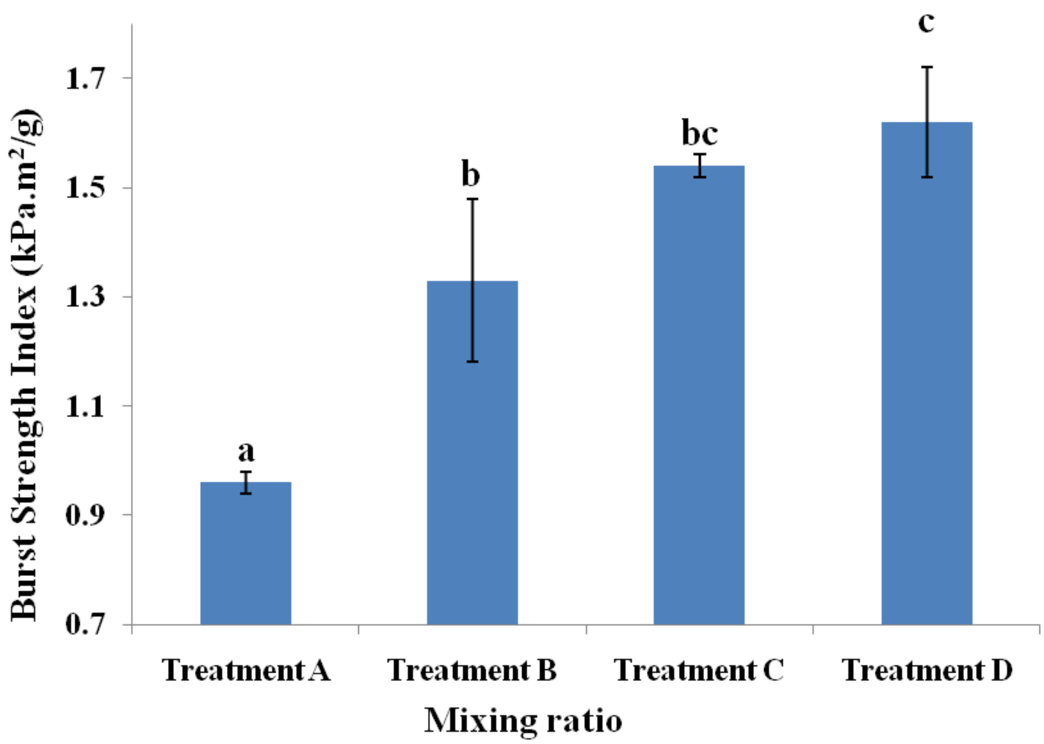

Fig. 2. Burst strength index for various sample ratios. Treatment A, control sample; treatment B, 80/20; treatment C, 70/30; and treatment D, 60/40; a, b, and c are significantly different ($p<0.05$)

Tear Strength Index

One of the effective parameters for the tear strength is length of the fibers. Sample A has the highest content of NSSC pulp. Thus, all of the fibers are short in sample A, and this property will decrease tear strength index. In sample D the OCC content is 40%, and the longer fiber present in the OCC can be expected to lead to a greater tear strength index. Accordingly, Duncan's test uncovered that the maximum and minimum tear strength indices were related to treatments D and A, with magnitudes of 6.687 and 5.212 $mN.m^2/g$, respectively (Fig. 3).

Increasing the ratio of long fibers to short fibers led to strength index improvement. Therefore, with respect to the above-mentioned properties, the high content of lignin, and the short fibers in NSSC pulp, the tear strength index isn't reasonable. The length of the fiber and the bond between the fibers are the most important effective factors in tear strength index. The fibers in the NSSC pulp are shorter than the OCC fibers. As a result, a greater number of the fibers in the NSSC pulp will cause a much smaller tear strength. The OCC pulp includes a greater number of the long fibers in comparison with the NSSC pulp, so addition of the OCC pulp could improve this property (Asadpour *et al*. 2008). Therefore, increasing the OCC pulp from 0 to 40% will enhance the tear strength.

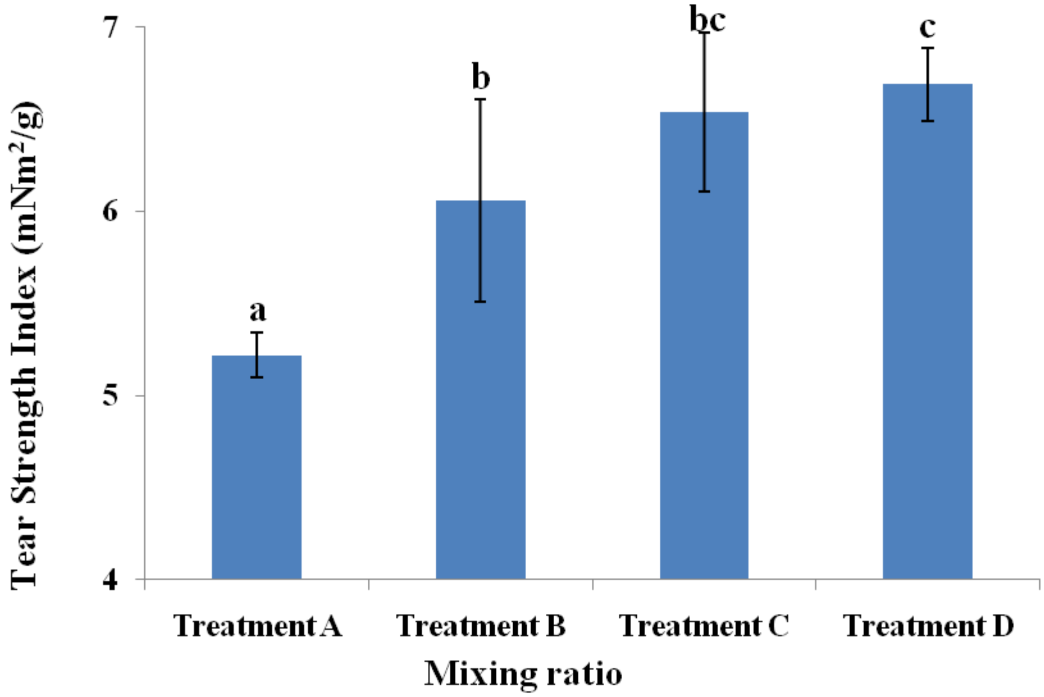

Fig. 3. Tear strength index for various sample ratios. Treatment A, control sample; treatment B, 80/20; treatment C, 70/30; and treatment D, 60/40; a, b, and c are significantly different ($p<0.05$)

Corrugated Medium Test

Treatments A and D provided the maximum and minimum CMT, with values of 346.2 and 193.58 N, respectively (Fig. 4). The NSSC pulps are considered optimal for preparing the corrugated cartons due to their great stiffness (Casey 1980; Cathie and Guest 2001). Because of their high lignin content and also the more amount of hemi-cellulose, they will show a great stiffness. In fact, the diameter and thickness of the cell wall are significantly large in the hardwood NSSC pulp because direction of the applied force is perpendicular to their length, so they have a greater corrugated medium test. Thus, the maximum CMT is achieved using 100% NSSC and 0% OCC. Increasing the consumption of the OCC pulp will degrade this property of the products (Asadpour *et al*. 2008). This test examines a thin layer of the corrugated carton, and the direction of the applied force is perpendicular to the fiber length. As a result, long fibers with a thin cellular wall may be crushed, leading to a weaker strength. Therefore, this property decreases with increasing the OCC pulp content.

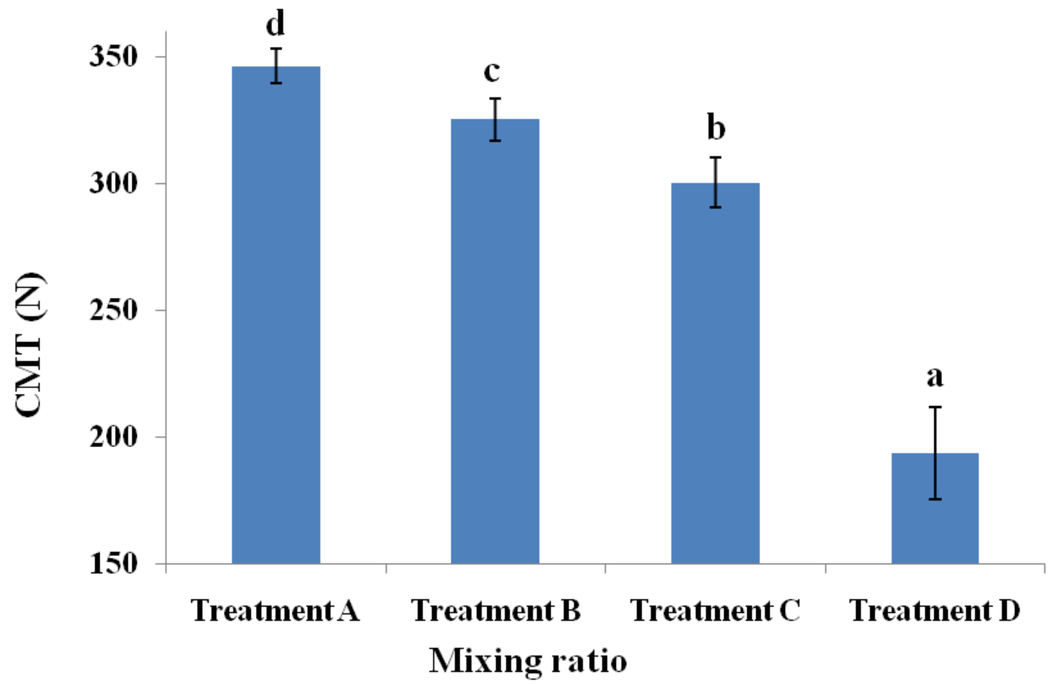

Fig. 4. CMT for various sample ratios. Treatment A, control sample; treatment B, 80/20; treatment C, 70/30; and treatment D, 60/40; a, b, and c are significantly different (p<0.05)

Ring Crush Test

The maximum and minimum RCT are met in treatments A and D, with values of 143.45 and 105 N, respectively (Fig. 5). The ring crush test is dependent on the force and pressure that are applied to edge of the carton. The result is generally proportional to the CMT (Casey 1980). The applied force is along cylinder axis. The NSSC pulp has the maximum ring crush test. The wall diameter and thickness are large for hardwood NSSC pulp (due to the greater lignin content), while the content of hemi-cellulose is also significant; therefore, this pulp will show an excellent stiffness. In general, NSSC pulps have a good stiffness and are favorable for the ring crush test. The cell-wall thickness tends to be greater, as there is greater lignin content in the hardwood pulp like the NSSC pulp. The thickness of the cell-wall in the NSSC pulp are more than that of the OCC pulp. In statistical analysis, the ring crush test was increased by increasing the NSSC pulp content. In other words, this strength will decrease significantly (Asadpour *et al*. 2008). The ring crush test also decreases by increasing the consumption of the OCC pulp from 0 to 40%. This effect can be attributed to the presence of the long pulp fibers with thin wall thicknesses, which are crushed due to the applied pressure. Therefore, the ring crushing test decreases as the OCC pulp content increases.

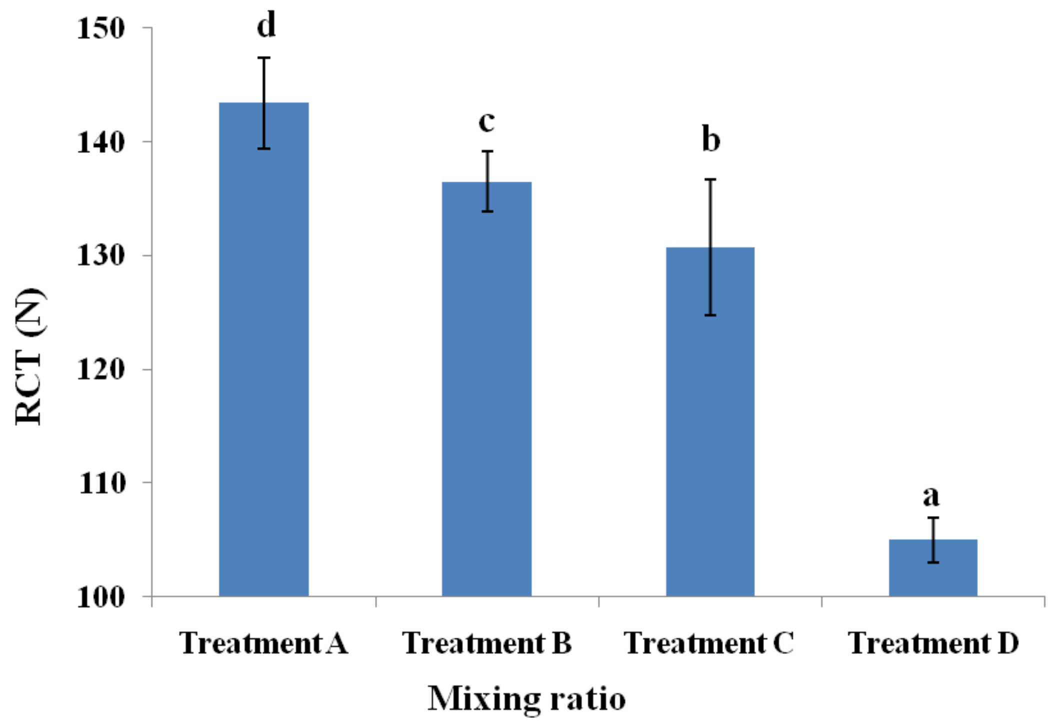

Fig. 5. RCT for various sample ratios. Treatment A, control sample; treatment B, 80/20; treatment C, 70/30; and treatment D, 60/40; a, b, and c are significantly different ($p<0.05$)

Paper strength is a key property because a paper is often used in different conditions. Numerous strength experiments have been proposed for the paper products; the most important of which are burst strength, tensile strength, tear strength, ring crush test, and corrugated medium test. None of these properties are fundamental for a paper, but a combination of them, including flexibility, strength of bonds between the fibers, and intrinsic strength of fibers, could act as a fundamental indicator of its quality. All types of the paper strengths are dependent on type, length, thickness, flexibility, and network of the fibers, as well as the number of connections, base weight of paper, and density (Scott 1995). The strength properties of the OCC pulp depend on type of the raw materials and also their production process. In case a pure corrugated carton, coming from an integrated kraft and NSSC mill, is used to produce the OCC pulp, the obtained pulp would actually be a combination of the unbleached kraft pulp of softwoods which is itself obtained from a liner paper (top layer) of the carton and the NSSC pulp which is extracted from the floating paper and carton.

CONCLUSIONS

1. By increasing the OCC pulp content in containerboard, the tensile, burst, and tear strength index will be increased. Addition of up to 30% OCC improves the tensile strength, tear strength, and burst strength of the handsheets significantly in comparison with the control sample (21, 25, and 59%, respectively).
2. By increasing the OCC pulp CMT, the RCT was decreased. In fact, the corrugated medium test and ring crush test were degraded by about 13 and 9%, respectively.

3. The results of this study revealed that mixing 30% of OCC with NSSC yielded a paper of significantly higher quality.

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