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Effects of decreasing grammage on the handsheet properties of unbeaten and beaten kraft pulps

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Abstract: The aim of this study was to investigate the effects of decreasing grammage on handsheet properties of unbeaten (15 °SR) and beaten (35 °SR) kraft pulps of European aspen (*Populus tremula* L.) and maritime pine (*Pinus pinaster* Ait.). Six different basis weights from 100 g/m^2 to 50 g/m^2 (with 10 g/m^2 intervals) were employed. Tensile index, TEA (tensile energy absorption), burst index, tear index, opacity, and apparent density of the handsheets gradually decreased with decreasing handsheet grammage. The decrease in strength properties that occurred with decreasing grammage was more evident in unbeaten pulps of both species than in beaten pulps. However, the effect of decreasing grammage on apparent density and opacity was more pronounced in beaten pulp handsheets of both species than in unbeaten pulp handsheets.
Keywords: Decreasing grammage, European aspen, Maritime pine, Kraft, Paper properties

Dövülmüş ve dövülmemiş kraft hamurlarının kağıt özellikleri üzerine azalan gramajın etkileri

Özet: Bu çalışmada, dövülmemiş (15 °SR) ve dövülmüş (35 °SR) titrek kavak (*Populus tremula* L.) ve sahil çamı (*Pinus pinaster* Ait.) kraft hamurlarından elde edilen deneme kağıtlarının özellikleri üzerine azalan kağıt gramajının etkileri belirlenmiştir. 100 g/m^2'den 50 g/m^2'ye kadar (10 g/m^2 aralıklarla) 6 farklı gramajda kağıtların üretilmiştir. Kağıtların kopma indisi, TEA, patlama indisi, yırtılma indisi, opaklık ve yoğunluk değerleri azalan kağıt gramajı ile tedrici olarak azalmıştır. Hem titrek kavak hem de sahil çamı örneklerinde, azalan gramajla meydana gelen sağlamlık kayıplarının dövülmemiş hamurlarda dövülmüş hamurlara göre daha belirgin olduğu tespit edilmiştir. Fakat, kağıdın opaklığı ve yoğunluğu üzerine azalan gramajın etkisinin dövülmüş hamurlarda dövülmemiş hamurlara nazaran daha belirgin olduğu görülmüştür.
Anahtar kelimeler: Azalan gramaj, Titrek kavak, Sahil çamı, Kraft, Kağıt özellikleri

1. Introduction

The grammage of paper is defined as the weight per unit area. Since last decades, paper grammage has been decreased to reduce the raw material consumption, energy costs, postal costs, and waste (Mansfield et al., 2004; Sood et al., 2005). As a matter of fact, almost all paper properties are significantly influenced by the grammage of paper (Seth et al., 1989).

The mechanical treatment applied to furnish is called beating or refining (Annergren and Hagen, 2009; Lumiainen, 2000). Beating causes an increase in the specific surface area and bonding ability of the fiber due to internal and external fibrillation of the cell wall (Lumiainen, 2000; Zakrajšek, 2008). Beating also increases fiber flexibility (Nazhad et al., 1995), swelling capacity (Lumiainen, 2000), and water retention (Chen et al., 2012; Hui et al., 2009; Mutjé et al., 2005). In addition, the process brings about shortening of the fiber length and the formation of fines (Casey, 1961; Karademir and Imamoğlu, 2007; Page, 1989; Zakrajšek, 2008). Due to the above-mentioned effects on the fibers, beating affects all paper properties (Casey, 1961; Lumiainen, 2000).

The effects of grammage on handsheet properties have been reported by several authors (Brandon, 1966; I'Anson et al., 2008; Mohlin, 1992; Nordstrom, 2003; Nordstrom and Norman, 1995; Retulainen and Nieminen, 1996; Seth et al., 1989; Skowronski, 1991). In this study, the effects of decreasing grammage from 100 g/m^2 to 50 g/m^2 (with 10 g/m^2 intervals) on the handsheet properties of unbeaten and beaten European aspen (*Populus tremula* L.) and maritime pine (*Pinus pinaster* Ait.) kraft pulps were investigated.

2. Material and methods

2.1. Preparation of raw materials

Maritime pine and European aspen are important species for the pulp and paper industry. The wood samples of trees used in this study were taken from the Bartin province of Turkey. The samples were chipped manually, using a chisel, to dimensions of 25 × 15 × 5 mm for pulping. The wood chips were then air-dried and stored in dry conditions. Holocellulose, α-cellulose, and lignin content of European black pine and European aspen wood used in this study

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were 70.21%-82.68%, 47.11%-49.03%, and 28.23%-16.69%, respectively (Gülsoy and Tüfek, 2013).

2.2. Kraft pulping

Kraft cooking for each tree species was carried out using a laboratory type cylindrical rotary digester. The cooking conditions used in this study are reported in Table 1. After cooking, the pulp samples were washed to remove the black liquor and were then disintegrated in a laboratory-type pulp mixer. The disintegrated pulp samples were screened using a Somerville-type pulp screen (PTI type P40170) with a 0.15-mm slotted plate (TAPPI T 275). In this method, the separation is based on size difference between fibers and fiber bundles or uncooked chips.

2.3. Handsheet making and testing

The pulps at a consistency of 1.57% were beaten to 35 °SR in a Valley Laboratory Beater (PTI type P40130) according to TAPPI T 200. Handsheets in various basis weights (50, 60, 70, 80, 90, and 100 g/m^2) were obtained from the unbeaten and beaten pulps using a Rapid-Kothen Sheet Former (ISO 5269-2). Handsheets were kept overnight in a conditioning room in accordance with TAPPI T 402 before testing. The tensile index and TEA, burst index, and tear index of handsheets were measured according to TAPPI T 494, TAPPI T 403, and TAPPI T 414, respectively. The apparent density and opacity of handsheets were also measured in accordance with TAPPI T 220 and TAPPI T 519, respectively.

The handsheet property data for each handsheet grammage were statistically analyzed using ANOVA and Tukey's test at a 95% confidence level (SPSS version 16.0). In all the figures, different letters on the same line denote a statistically significant ($P > 0.05$) difference in the mean values of the properties among the compared groups.

3. Results and discussion

The tensile index of unbeaten and beaten pulps of both species gradually decreased with decreasing handsheet grammage and degree of beating (Figure 1). The effect of decreasing grammage on the tensile index was more pronounced on unbeaten pulps than on beaten pulps. Decreasing the grammage from 100 g/m^2 to 50 g/m^2 in the unbeaten and beaten pulps of maritime pine led to decrements in the tensile index of 18.83% and 10.82%, respectively. The same grammage decrease in unbeaten and beaten pulps of European aspen resulted in tensile index decrements of 11.26% and 10.08%, respectively. A positive correlation between handsheet grammage and tensile index has been reported in previous studies (Burgess, 1970; I'Anson and Sampson, 2007; I'Anson et al., 2007, 2008; Mohlin, 1992; Seth et al., 1989; Winters et al., 2002). This positive correlation can be attributed to the increase in the number of bonding sites in the sheet because of the increasing grammage and increasing number of fibers in the sheet. The tensile strength of paper is significantly affected by the specific bonding strength and by the bonded area (Brännvall and Annergren, 2009). On the other hand, the tensile index reduction occurring with grammage decreasing from 100 g/m^2 to 90 g/m^2 in the beaten pulp handsheets of both species was found statistically insignificant. Also, tensile index differences between 60 g/m^2 and 90 g/m^2 handsheets of European aspen unbeaten pulp were found statistically insignificant. This result was also observed in 70 g/m^2 and 80 g/m^2 handsheets of maritime pine unbeaten pulp.

The tensile energy absorption (TEA) of handsheets decreased significantly with decreasing grammage (Figure 2). This finding can be explained by decreasing inter-fiber bonding due to the positive correlation between sheet density and grammage. The effect of decreasing grammage on the TEA was more pronounced on unbeaten pulps than on beaten pulps. For example, the TEA of unbeaten maritime pine and European aspen pulps decreased by 66.90% and 62.51% when grammage was decreased from 100 g/m^2 to 50 g/m^2, respectively. However, the same grammage decreasing in beaten maritime pine and European aspen pulps led to TEA decrements of 58.61% and 60.22%, respectively. The positive correlation between TEA and grammage was reported by Seth et al. (1989).

Table 1. Kraft cooking conditions of European aspen and maritime pine chips.

Cooking conditions	Value
Active alkali (%)	18
Sulfidity (%)	25
Liquor/wood ratio	4/1
Cooking temperature (°C)	170
Time to cooking temperature (min)	90
Time at cooking temperature (min)	60

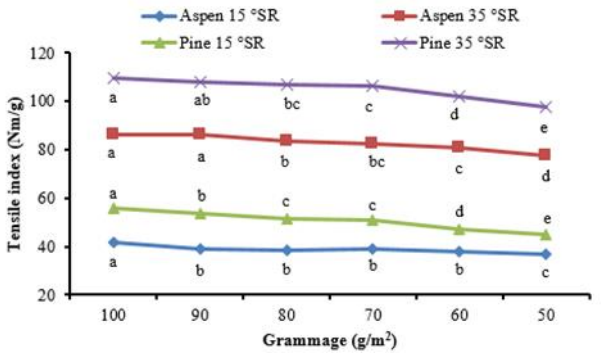

Figure 1. The relationship between grammage and tensile index of handsheets in different pulps (different letters on the same line denote a statistically significant ($P > 0.05$) difference)

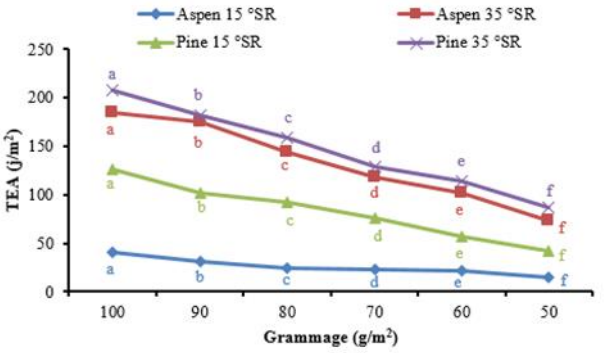

Figure 2. The effect of grammage decreasing on TEA of handsheets in different pulps

Figure 3 shows the linear correlation between the burst index of unbeaten and beaten pulps of both species and handsheet grammage. The effect of decreasing grammage on the burst index was more pronounced in unbeaten pulps than in the beaten pulps. Decreasing the grammage from 100 g/m^2 to 50 g/m^2 in unbeaten and beaten maritime pine pulps led to decrements in the burst index of 21.34% and 10.04%, respectively. The same grammage decreases on unbeaten and beaten European aspen pulps resulted in burst index decrements of 13.09% and 10.61%, respectively. Burst index differences between 70 g/m^2 and 90 g/m^2 handsheets of maritime pine beaten pulp was statistically insignificant. This finding also observed in 10 g/m^2 grammage decrements of European aspen unbeaten pulp handsheets.

The tear index of the handsheets gradually decreased with decreasing grammage (Figure 4). For European aspen, decreases in tear index were more evident in unbeaten pulp than in beaten pulp. However, with maritime pine, the effect of decreasing grammage on tear index was more pronounced in beaten pulp than in unbeaten pulp. For example, decreasing the grammage from 100 g/m^2 to 50 g/m^2 in unbeaten and beaten maritime pine pulps led to decrements in tear index of 9.05% and 26.95%, respectively. The same grammage decreases in unbeaten and beaten European aspen pulps resulted in tear index decrements of 25.39% and 21.24%, respectively. Winters et al. (2002) also noted that tear index decreased with decreasing grammage. Tear index depends on individual fiber strength, while tensile and burst indices of handsheets depend on bonding ability of fibers On the other hand, tear index increase usually reaches a peak value before falling off gradually despite tensile and burst indices increments. This result may be attributed to fiber strength losses during beating. Thus, possible fiber failure increases during tearing test (Song and Law, 2010).

The sheet density (kg/m^3) is one of the most important structural properties of paper, and it has an important effect on other properties. Higher density indicates better inter-fiber bonding in the sheet. Therefore, sheet density can be used as a measure of the degree of inter-fiber bonding (Brännvall and Annergren, 2009). A linear correlation between handsheet grammage and apparent density of the handsheets of both species was observed in this study (Figure 5). This finding is in agreement with previous studies (Girlanda and Fellers, 2007; Honkasalo, 2004; Seth et al., 1989). The decreases in apparent density that occurred with decreasing grammage were more evident in beaten pulp handsheets of both species than in unbeaten pulp handsheets. For example, the apparent density of unbeaten maritime pine and European aspen pulps decreased 8.93% and 6.90% when grammage was decreased from 100 g/m^2 to 50 g/m^2, respectively. However, the same grammage decreasing in beaten maritime pine and European aspen pulps led to decrements in apparent density of 10.39% and 14.10%, respectively. This outcome could be attributed to strong positive correlation between apparent density of the handsheets and relative bonded area (RBA), as described by Rennel (1969). On the other hand, there is a linear correlation between sheet density and beating time (Xia and Gong, 2011). The greater flexibility of beaten fibers gives them a higher probability of contact with other fibers. An increase in beating time results in an increased bonded area and more densely-packed fibers in the sheet (Brännvall and Annergren, 2009). In addition, the number of fiber fragments in pulp suspension increases with increased beating time and, by filling the spaces between fibers during formation, causes an increase in sheet density (Xia and Gong, 2011). Apparent density differences between 80 g/m^2 and 100 g/m^2 handsheets of maritime pine beaten and unbeaten pulps were found statistically insignificant. This finding also observed in between 50 g/m^2 and 70 g/m^2 of European aspen unbeaten pulp handsheets.

The opacity of handsheets gradually decreased with decreasing grammage (Figure 6). This can be attributed to a linear correlation between sheet thickness and grammage (I'Anson and Sampson, 2007; Mohlin, 1992). A positive correlation between opacity and grammage was also reported by Seth et al. (1989). The effect of decreasing grammage on opacity was more pronounced in beaten pulp handsheets of both species than in unbeaten pulp handsheets. For example, the opacity of unbeaten maritime pine and European aspen pulp handsheets decreased 3.40% and 4.52% when grammage was decreased from 100 g/m^2 to 50 g/m^2, respectively. The same grammage decreasing in beaten pulp handsheets of maritime pine and European aspen led to decrements in the opacity of 10.23% and 8.92%, respectively.

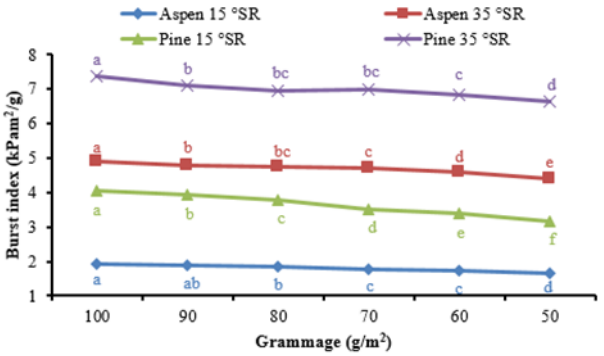

Figure 3. The relationship between grammage and burst index of handsheets in different pulps

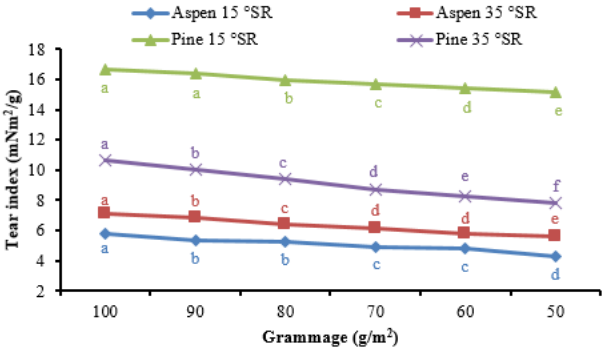

Figure 4. The effect of grammage decreasing on tear index of handsheets in different pulps

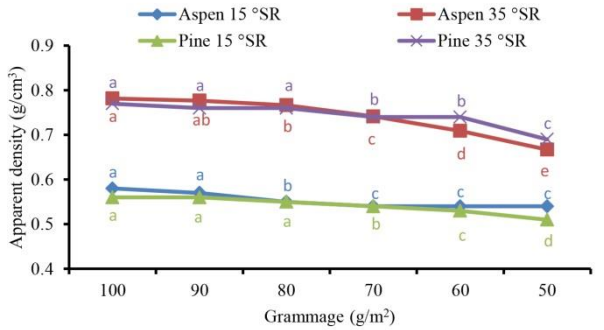

Figure 5. The relationship between grammage and apparent density of handsheets in different pulps

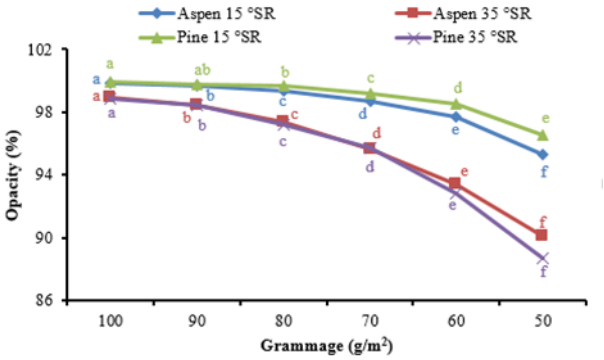

Figure 6. The effect of grammage decreasing on opacity of handsheets in different pulps

4. Conclusions

One of the most important trends in papermaking industry is reduction in paper grammage. The results of this study showed that properties of paper made from European aspen and maritime pine were highly dependent on the grammage. The decreasing in grammage caused statistically significant decreases in tensile index, TEA, burst index, tear index, apparent density, and opacity. The loss in strength properties that occurred with a decrease in grammage was decreased with beating. However, the loss in apparent density and opacity of handsheets due to decreasing grammage was increased with beating. Decrease of 10-20 g/m^2 in handsheet grammage were resulted with statistically insignificant losses in handsheet strength properties. This result enables both more efficient usage of fiber resources and reduction in furnish costs. Also, a low grammage causes the reduction in the volume of disposed waste and landfills.

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