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Comparative Mechanical Characterization of Commercial Tissue Papers by Tensile Strength, Tensile Index, Elongation, and Work-to-Rupture Analysis

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Abstract

The mechanical performance of commercial tissue paper products is a critical quality parameter affecting consumer perception, handling characteristics, and service performance. In the present study, six commercially available tissue paper products were evaluated according to ISO 12625-4 using tensile testing in both machine direction (MD) and cross direction (CD). The tensile strength, tensile index, elongation at break, work-to-rupture, and tensile energy absorption capacity were evaluated in both the machine direction (MD) and cross direction (CD), from multiple replicate measurements. Significant differences were observed among the investigated tissue products, reflecting variations in fiber orientation, paper structure, basis weight, and manufacturing conditions. Overall mean tensile strength was 127.21N/m in MD compared with 51.58N/m in CD, corresponding to an approximately 2.47-fold directional difference, confirming the anisotropic nature of tissue papers. Tensile indices ranged approximately between 1 and 4Nm g-1 depending on product type and testing direction. The work-to-rupture values followed similar trends, indicating that stronger tissue papers generally exhibited improved energy absorption characteristics. One-way ANOVA demonstrated differences among products for tensile strength, tensile index, work capacity, work-to-rupture, and strain at break ($p \leq 0.002$). A two-way factorial ANOVA further demonstrated significant effects of product, testing direction, and their interaction on tensile strength, with partial eta-squared values of 0.685, 0.842 and 0.401, respectively. The two-way analysis of variance indicated significant effects of product (product: $F(5,228)=99.221$, $p<0.001$), direction (direction: $F(1,228)=1218.711$, $p<0.001$) and their interaction (product x direction: $F(5,228)=30.517$, $p<0.001$). The model explained 89.1% of the observed variance ($R^2=0.891$; adjusted $R^2=0.886$). The interaction indicated that the magnitude of directional dependence differed among commercial products. The findings demonstrated that tensile strength and related deformation and energy-absorption parameters provided complementary measures for distinguishing tissue paper products and that machine-direction fiber orientation was a major determinant of their mechanical performance..

Keywords: Tissue paper; Tensile strength; Machine direction; Cross direction; Tensile index; Mechanical properties; Fiber orientation; Work-to-rupture; ISO 12625; Paper characterization; Anisotropy

Introduction

Tissue paper products constitute an important category of sanitary and household materials used in everyday applications including personal hygiene, household cleaning, food service operations, where a combination of softness, absorbency, strength, extensibility, and resistance to rupture is required. Although tissue products are generally lightweight materials, their mechanical behavior is determined by the structure of the fibrous network and by the manufacturing conditions under which the sheet is formed and dried. The performance of tissue products depends strongly on their mechanical properties, which are influenced by fiber type, refining conditions, sheet structure, basis weight and manufacturing processes [1,2].

Among the various quality parameters, tensile strength is one of the most important because it reflects the ability of the paper network to resist applied stresses during use. Tensile strength characterizes the ability of the fibrous network to withstand an applied tensile load before failure. In addition to absolute tensile strength, the tensile index provides a normalized measure that facilitates comparison between materials having different basis weights. Other tensile parameters, including strain at break and work-to-rupture, provide complementary information concerning deformation and energy absorption during mechanical loading [1,3,4].

A characteristic feature of paper-based materials is mechanical anisotropy. During paper manufacture, fibers tend to become preferentially oriented in the machine direction as a consequence of the hydrodynamic conditions during sheet formation and the mechanical processes associated with forming, pressing, drying, and converting. Tissue papers exhibit anisotropic behavior resulting from preferential fiber orientation developed during paper machine production. Consequently, tensile properties measured in the machine direction are generally greater than those measured in the cross direction [1,2,4].

The magnitude of this anisotropy is not necessarily identical among commercial products. Differences in fiber orientation, sheet formation, fiber bonding, basis weight, refining, creping and other manufacturing parameters can modify both the tensile performance and the ratio between machine- and cross-direction properties [1,2,5,6].

The tensile index provides a normalized measure of strength independent of basis weight and enables comparison among different tissue products. Additional parameters such as elongation at break and work-to-rupture provide information regarding deformation behavior and energy absorption capacity prior to failure [3,4].

The objective of the present study was therefore to compare the mechanical properties of six commercially available tissue paper products using standardized tensile testing. Particular emphasis was placed on tensile strength in the machine and cross directions, differences among commercial products and the degree of mechanical anisotropy expressed by the MD/CD tensile-strength ratio. A two-factor analysis was also performed to determine independently the effects of product type and testing direction and to establish whether the effect of testing direction differed among products.

This study evaluates and compares the mechanical performance of several commercial tissue paper products using standardized tensile testing according to ISO 12625-4. Particular attention was given to directional strength differences, tensile indices, elongation behavior, and energy absorption characteristics.

Experimental

Materials and specimen preparation

Six commercially available tissue paper products were investigated. For each commercial product, two sub-samples, designated A and B, were examined. Representative test specimens of (50.0±0.5) mm x (95±1) mm were collected from each product and conditioned prior to testing according to the requirements of the ISO 12625-4 standard [7]. The sample specimens were conditioned before testing under the standard atmosphere of (23±1) °C and (50±2)% relative humidity according to ISO 187 [8]. The sample specimens were selected in accordance with ISO 186 [9]. Each product/sub-sample combination was evaluated separately in the machine direction (MD) and cross direction (CD). Importantly, the MD and CD measurements were obtained from separate physical specimens, rather than measuring both directions on the same specimen. Thus, direction was treated as a between-specimen factor in the statistical analysis. The experimental design comprised six products x two sub-samples x ten specimens x two testing directions, giving a total of 240 tensile observations.

Tensile testing

Tensile measurements were performed according to ISO 12625-4:2022, "Determination of tensile strength, stretch at break, and tensile energy absorption" procedure described in the experimental work. The testing conditions included, a pre-load of $5Nm^{-1}$, a test speed of 50mm min^{-1}, and a gauge length of approximately 80mm±1mm. Ten specimens were tested for each product/ sub-sample/ testing direction. Measurements were carried out in both machine direction (MD) and cross direction (CD). The following mechanical parameters were determined, the tensile strength (Nm^{-1}), the tensile index (Nmg^{-1}), the elongation at break (%), the work-to-rupture ($J\ m^{-2}$), and the specific work-to-rupture ($J\ g^{-1}$). Grammage [10] and absorbency [11] were also recorded as physical characteristics of the tissue products.

Tensile-strength anisotropy

The directional anisotropy of tensile strength was assessed using the MD/CD ratio:

$$\text{MD/CD ratio} = \text{MD tensile strength} / \text{CD tensile strength}$$

A ratio greater than unity indicated higher tensile resistance in the machine direction. Higher values indicated a greater difference between MD and CD tensile performance.

Statistical analysis

Descriptive statistics were calculated for the investigated properties. One-way ANOVA was used to examine differences among the six products for individual mechanical parameters. A two-way factorial ANOVA was subsequently performed for tensile strength, with Product and Testing Direction as fixed factors and their interaction included in the model. Because the MD and CD specimens were physically different specimens, testing direction was treated as an independent between-specimen factor. For the tensile-strength analysis, product-level pairwise comparisons were performed using Tukey procedures, while estimated marginal means were compared using Bonferroni adjustment. Effect sizes were expressed as partial eta squared (η^2). Before interpretation of the factorial ANOVA, the assumptions of the analysis were examined, including variance homogeneity and distributional characteristics. The Levene test indicated significant heterogeneity of variance; therefore, the

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magnitude and consistency of the observed effects were considered together with the balanced experimental design and the very large observed effect sizes.

Results

General physical and mechanical characteristics

The six tissue products showed relatively similar basis weights but considerable differences in tensile behavior. The six tissue paper products were each represented by two subsamples (A and B), with ten independent specimens evaluated in each testing direction. Thus, the complete experimental design consisted of 240 tensile observations. MD and CD measurements were obtained from separate physical specimens; consequently, testing direction was treated as a between-specimen factor in the factorial analysis rather than as a repeated measurement on the same specimen. The mean grammage across the twelve product/subsample combinations was approximately 17.04g/m^2, with values ranging from 15.8 to 18.0g/m^2. Mean absorbency was approximately 6.42s. The tensile properties, however, showed much greater variation than grammage. The overall mean tensile strength was 127.21N/m in the machine direction and 51.58N/m in the cross direction. That difference demonstrated that relatively small differences in basis weight were associated with substantially different mechanical performance among the commercial products (Table 1). The individual tensile curves and associated instrument statistics presented in Figures 1-12 provided the experimental basis for these differences. The instrument-derived values in these figures were consistent with the summarized values reported in Table 1.

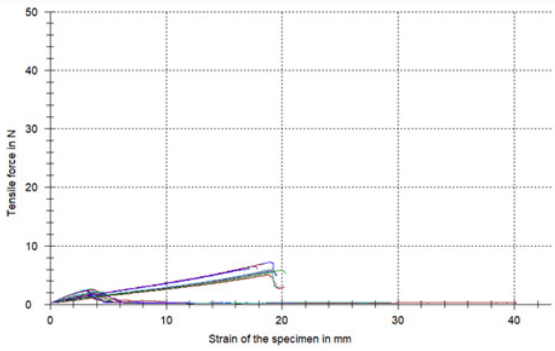
Table 1: Physical and tensile properties of six commercial tissue paper products and their corresponding sub-samples (A and B), measured according to ISO 12625-4. Results were presented as mean ± standard deviation (n=10). Parameters included grammage according to ISO 12625-6: 2005, absorbency according to TAPPI T432, machine-direction (MD) and cross-direction (CD) tensile strength, tensile index, work capacity, strain at break, and work-to-rupture. The data demonstrated the directional dependence of tissue paper mechanical performance resulting from fiber orientation during manufacture.

Property	Sample 1A	Sample 1B	Sample 2A	Sample 2B	Sample 3A	Sample 3B
Grammage (g/m^2)	17.6±1.8	17.6±1.8	18.0±1.8	17.9±1.8	15.8±1.8	15.9±1.8
Absorbency (s)	5±1.4	5±1.4	8±2.3	8±2.4	7±2.0	7±2.2
MD Tensile Strength (N/m)	122.497±12.810	137.296±28.904	204.405±11.364	194.794±33.794	83.939±19.600	95.041±11.888
CD Tensile Strength (N/m)	43.547±7.235	49.743±7.883	70.150±7.988	68.776±4.914	37.597±12.390	35.097±10.836
MD Tensile Index (Nm/g)	3.062±0.320	3.432±0.723	5.110±0.284	4.870±0.845	2.098±0.490	2.376±0.297
CD Tensile Index (Nm/g)	1.089±0.181	1.244±0.197	1.754±0.200	1.719±0.123	0.940±0.310	0.877±0.271
MD Work Capacity (J/g)	0.151±0.015	0.174±0.046	0.130±0.018	0.123±0.032	0.043±0.018	0.048±0.011
CD Work Capacity(J/g)	0.013±0,003	0.015±0.002	0.016±0.004	0.015±0.003	0.011±0.005	0.010±0.006
Strain at break (%)	9.1±2.7	8.3±3.8	3.8±1.4	3.7±1.5	4.1±0.7	3.9±0.3
MD Work to rupture (J/m^2)	6.1±0.6	7.0±1.8	5.2±0.7	4.9±1.3	1.7±0.7	1.9±0.5
CD Work to rupture (J/m^2)	0.5±0.1	0.6±0.1	0.7±0.2	0.6±0.1	0.4±0.2	0.4±0.2

Table 1 (continued):

Property	Sample 4A	Sample 4B	Sample 5A	Sample 5B	Sample 6A	Sample 6B
Grammage (g/m^2)	17.5±1.8	17.6±1.8	15.9±1.8	16.2±1.8	17.3±1.8	17.2±1.8
Absorbency (s)	7±2.0	7±2.0	7±2.2	6±1.9	5±1.4	5±1.4
MD Tensile Strength (N/m)	121.383±18.407	148.656±20.380	91.445±19.596	92.967±29.959	113.596±16.802	120.457±11.201
CD Tensile Strength (N/m)	57.772±9.904	62.651±17.917	33.591±9.261	34.896±9.550	61.022±8.535	64.134±4.848
MD Tensile Index (Nm/g)	3.035±0.460	3.716±0.509	2.286±0.490	2.324±0.749	2.840±0.420	3.011±0.280
CD Tensile Index (Nm/g)	1.444±0.248	1.566±0.448	0.840±0.232	0.872±0.239	1.526±0.213	1.603±0.121
MD Work Capacity (J/g)	0.071±0.021	0.099±0.029	0.045±0.016	0.046±0.022	0.066±0.015	0.076±0.014
CD Work Capacity(J/g)	0.011±0,003	0.012±0.004	0.008±0.004	0.009±0.003	0.017±0.003	0.018±0.002
Strain at break (%)	3.6±1.5	3.9±1.8	4.0±0.6	4.0±0.7	4.3±0.8	4.3±1.0
MD Work to rupture (J/m^2)	2.8±0.8	4.0±1.1	1.8±0.6	1.9±0.9	2.6±0.6	3.0±0.5
CD Work to rupture (J/m^2)	0.5±0.1	0.5±0.2	0.3±0.1	0.4±0.1	0.7±0.1	0.7±0.1

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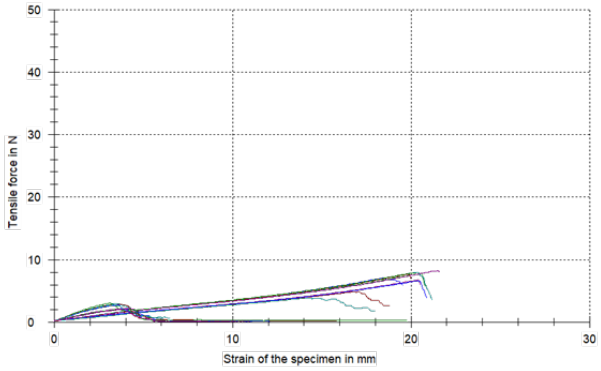
Statistics:

Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	I
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185.00	83.022	122.497	43.547	100.000	83.02	122.50	43.55	2.076
s	0.00	41.747	12.810	7.235	0.000	41.75	12.81	7.24	1.044
n	0.00	50.28	10.46	16.62	0.00	50.28	10.46	16.62	50.28

Series	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m²	J/m²	J/m²
x	3,062	1,089	9,1	-	3,8	3,3	6,1	0,5
s	0,320	0,181	2,7	-	2,3	2,9	0,6	0,1
n	10,46	16,62	29,04	-	59,70	87,11	10,09	23,17

Series	lz	lz, lengthwise	lz, crosswise
n = 20	J/g	J/g	J/g
x	0.082	0.151	0.013
s	0.072	0.015	0.003
n	87,11	10,09	23,17

Figure 1: Graph with statistics for tensile properties for tissue product 1A.



Statistics:

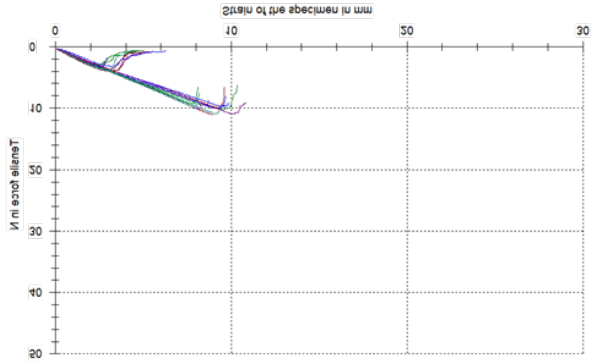
Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	I
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	93,519	137,296	49,743	100,000	93,52	137,30	49,74	2,338
s	0,00	49,421	28,904	7,883	0,000	49,42	28,90	7,88	1,236
n	0,00	52,85	21,05	15,85	0,00	52,85	21,05	15,85	52,85

Series	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m²	J/m²	J/m²
x	3,432	1,244	8,3	-	3,1	3,8	7,0	0,6
s	0,723	0,197	3,8	-	0,3	3,5	1,8	0,1
n	21,05	15,85	46,29	-	10,89	92,41	26,28	11,13

Series	lz	lz, lengthwise	lz, crosswise
n = 20	J/g	J/g	J/g
x	0,095	0,174	0,015
s	0,088	0,046	0,002
n	92,41	26,28	11,13

Figure 2: Graph with statistics for tensile properties for tissue product 1B.

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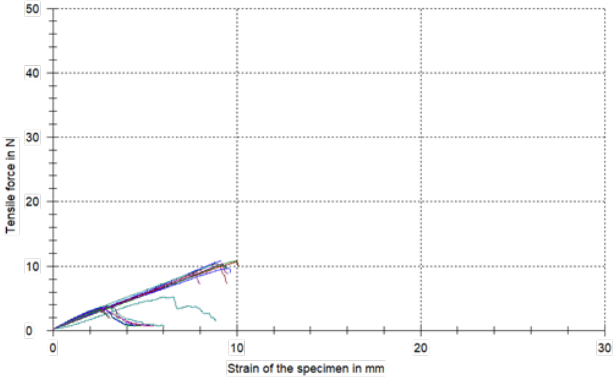
Statistics:

Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%
x	185,00	137,278	204,405	70,150	100,000	137,28	204,41	70,15
s	0,00	69,532	11,364	7,988	0,000	69,53	11,36	7,99
n	0,00	50,65	5,56	11,39	0,00	50,65	5,56	11,39

Series	l	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise
n = 20	Nm/g	Nm/g	Nm/g	%	%	%	J/m²	J/m²
x	3,432	5,110	1,754	3,8	-	2,5	2,9	5,2
s	1,738	0,284	0,200	1,4	-	0,6	2,4	0,7
n	50,65	5,56	11,39	38,47	-	25,19	81,43	13,70

Series	Z, crosswise	lz	lz, lengthwise	lz, crosswise
n = 20	J/m²	J/g	J/g	J/g
x	0,7	0,073	0,130	0,016
s	0,2	0,060	0,018	0,004
n	23,66	81,43	13,70	23,66

Figure 3: Graph with statistics for tensile properties for tissue product 2A.



Statistics:

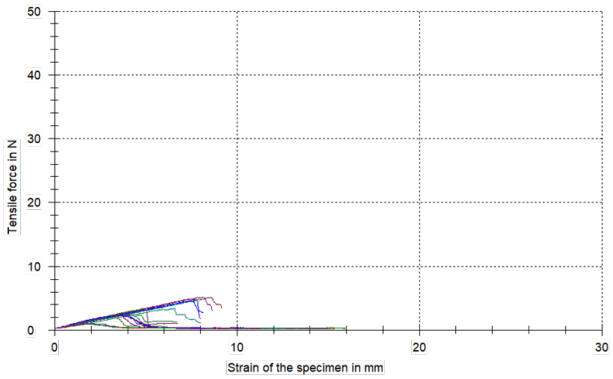
Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%
x	185,00	131,785	194,794	68,776	100,000	131,78	194,79	68,78
s	0,00	68,786	33,794	4,914	0,000	68,79	33,79	4,91
n	0,00	52,20	17,35	7,15	0,00	52,20	17,35	7,15

Series	l	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise
n = 20	Nm/g	Nm/g	Nm/g	%	%	%	J/m²	J/m²
x	3,295	4,870	1,719	3,7	-	2,3	2,8	4,9
s	1,720	0,845	0,123	1,5	-	0,7	2,4	1,3
n	52,20	17,35	7,15	40,55	-	28,88	86,68	26,25

Series	Z, crosswise	lz	lz, lengthwise	lz, crosswise
n = 20	J/m²	J/g	J/g	J/g
x	0,6	0,069	0,123	0,015
s	0,1	0,060	0,032	0,003
n	17,46	86,68	26,25	17,46

Figure 4: Graph with statistics for tensile properties for tissue product 2B..

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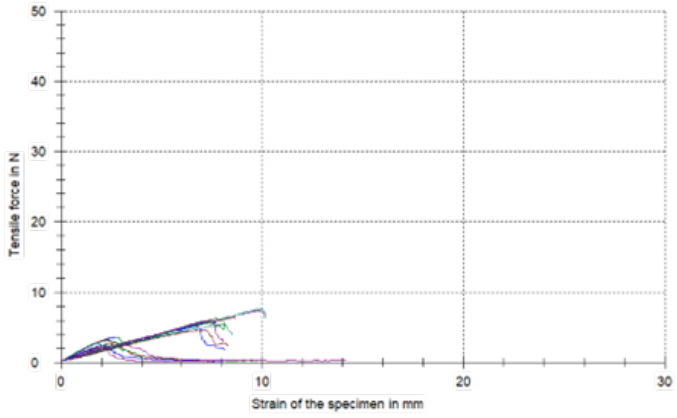
Statistics:

Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	l
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	60,768	83,939	37,597	100,000	60,77	83,94	37,60	1,519
s	0,00	28,633	19,600	12,390	0,000	28,63	19,60	12,39	0,716
n	0,00	47,12	23,35	32,95	0,00	47,12	23,35	32,95	47,12

Series	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m^2	J/m^2	J/m^2
x	2,098	0,940	4,1	-	-	1,1	1,7	0,4
s	0,490	0,310	0,7	-	-	0,8	0,7	0,2
n	23,35	32,95	15,88	-	-	76,42	40,58	46,15

Series	lz	lz, lengthwise	lz, crosswise
n = 20	J/g	J/g	J/g
x	0,027	0,043	0,011
s	0,021	0,018	0,005
n	76,42	40,58	46,15

Figure 5: Graph with statistics for tensile properties for tissue product 3A.



Statistics:

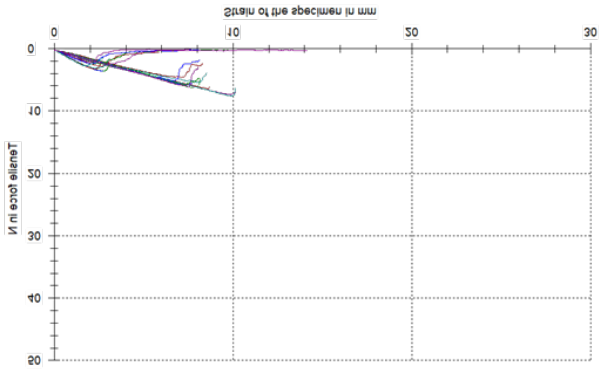
Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	l
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	89,577	121,383	57,772	100,000	89,58	121,38	57,77	2,239
s	0,00	35,662	18,407	9,904	0,000	35,66	18,41	9,90	0,892
n	0,00	39,81	15,16	17,14	0,00	39,81	15,16	17,14	39,81

Series	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m^2	J/m^2	J/m^2
x	3,035	1,444	3,6	-	1,8	1,6	2,8	0,5
s	0,460	0,248	1,5	-	0,7	1,4	0,8	0,1
n	15,16	17,14	42,13	-	37,48	82,50	29,74	26,88

Series	lz	lz, lengthwise	lz, crosswise
n = 20	J/g	J/g	J/g
x	0,041	0,071	0,011
s	0,034	0,021	0,003
n	82,50	29,74	26,88

Figure 6: Graph with statistics for tensile properties for tissue product 3B.

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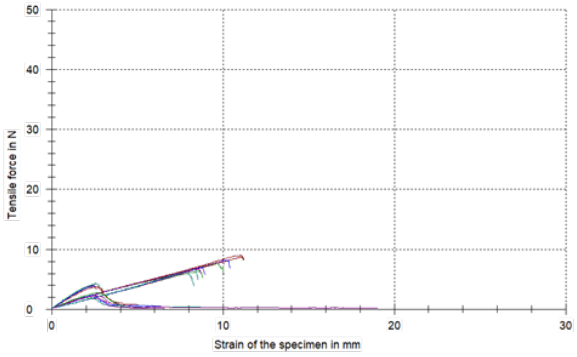
Statistics:

Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	l
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	89,577	121,383	57,772	100,000	89,58	121,38	57,77	2,239
s	0,00	35,662	18,407	9,904	0,000	35,66	18,41	9,90	0,892
n	0,00	39,81	15,16	17,14	0,00	39,81	15,16	17,14	39,81

Series	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m^2	J/m^2	J/m^2
x	3,035	1,444	3,6	-	1,8	1,6	2,8	0,5
s	0,460	0,248	1,5	-	0,7	1,4	0,8	0,1
n	15,16	17,14	42,13	-	37,48	82,50	29,74	26,88

Series	lz	lz, lengthwise	lz, crosswise
n = 20	J/g	J/g	J/g
x	0,041	0,071	0,011
s	0,034	0,021	0,003
n	82,50	29,74	26,88

Figure 7: Graph with statistics for tensile properties for tissue product 4A.



Statistics:

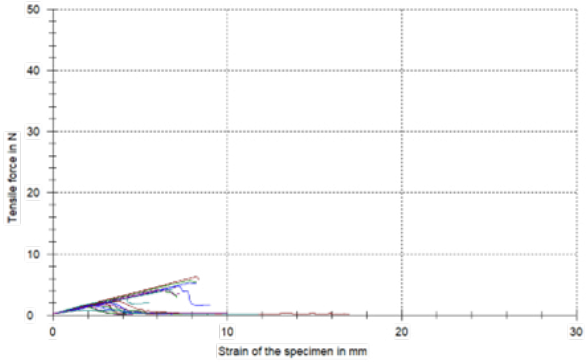
Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%
x	185,00	105,654	148,656	62,651	100,000	105,65	148,66	62,65
s	0,00	47,910	20,380	17,917	0,000	47,91	20,38	17,92
n	0,00	45,35	13,71	28,60	0,00	45,35	13,71	28,60

Series	l	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise
n = 20	Nm/g	Nm/g	Nm/g	%	%	%	J/m^2	J/m^2
x	2,641	3,716	1,566	3,9	-	1,8	2,2	4,0
s	1,198	0,509	0,448	1,8	-	0,6	2,0	1,1
n	45,35	13,71	28,60	45,37	-	32,40	88,29	28,88

Series	Z, crosswise	lz	lz, lengthwise	lz, crosswise
n = 20	J/m^2	J/g	J/g	J/g
x	0,5	0,056	0,099	0,012
s	0,2	0,049	0,029	0,004
n	32,95	88,29	28,88	32,95

Figure 8: Graph with statistics for tensile properties for tissue product 4B.

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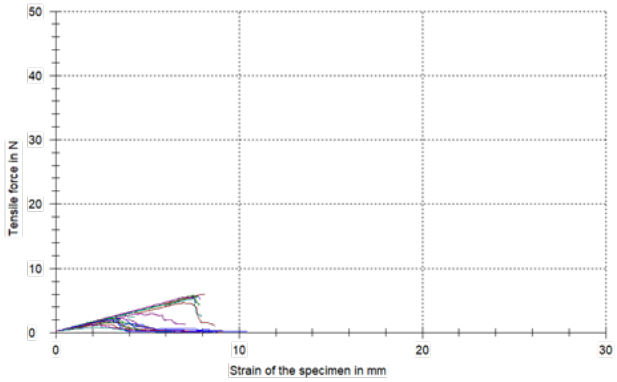
Statistics:

Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	I
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	62,518	91,445	33,591	100,000	62,52	91,44	33,59	1,563
s	0,00	33,217	19,596	9,261	0,000	33,22	19,60	9,26	0,830
n	0,00	53,13	21,43	27,57	0,00	53,13	21,43	27,57	53,13

Series	I, lengthwise	I, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m²	J/m²	J/m²
x	2,286	0,840	4,0	-	-	1,1	1,8	0,3
s	0,490	0,232	0,6	-	-	0,9	0,6	0,1
n	21,43	27,57	14,91	-	-	83,02	34,68	46,29

Series	Iz	Iz, lengthwise	Iz, crosswise
n = 20	J/g	J/g	J/g
x	0,027	0,045	0,008
s	0,022	0,016	0,004
n	83,02	34,68	46,29

Figure 9: Graph with statistics for tensile properties for tissue product 5A.



Statistics:

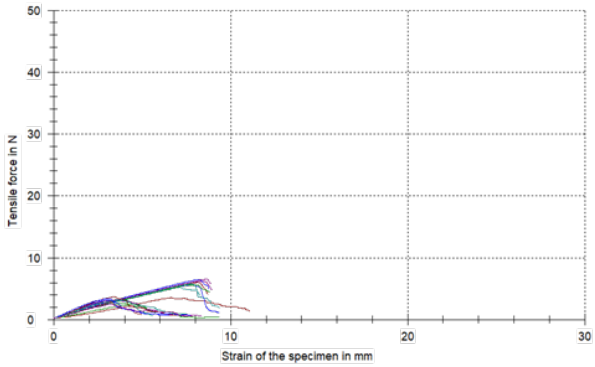
Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	I
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	63,931	92,967	34,896	100,000	63,93	92,97	34,90	1,598
s	0,00	36,821	29,959	9,550	0,000	36,82	29,96	9,55	0,921
n	0,00	57,59	32,23	27,37	0,00	57,59	32,23	27,37	57,59

Series	I, lengthwise	I, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m²	J/m²	J/m²
x	2,324	0,872	4,0	-	-	1,1	1,9	0,4
s	0,749	0,239	0,7	-	-	1,0	0,9	0,1
n	32,23	27,37	16,99	-	-	87,80	46,50	35,76

Series	Iz	Iz, lengthwise	Iz, crosswise
n = 20	J/g	J/g	J/g
x	0,028	0,046	0,009
s	0,024	0,022	0,003
n	87,80	46,50	35,76

Figure 10: Graph with statistics for tensile properties for tissue product 5B.

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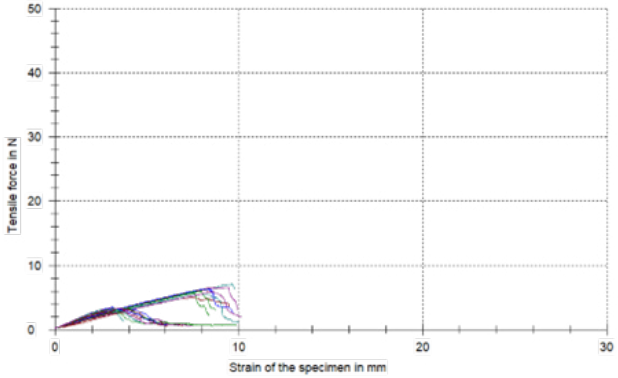
Statistics:

Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	l
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	87,309	113,596	61,022	100,000	87,31	113,60	61,02	2,183
s	0,00	29,927	16,802	8,535	0,000	29,93	16,80	8,54	0,748
n	0,00	34,28	14,79	13,99	0,00	34,28	14,79	13,99	34,28

Series	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m²	J/m²	J/m²
x	2,840	1,526	4,3	-	3,7	1,7	2,6	0,7
s	0,420	0,213	0,8	-	0,7	1,1	0,6	0,1
n	14,79	13,99	18,85	-	18,59	66,47	22,47	16,89

Series	lz	lz, lengthwise	lz, crosswise
n = 20	J/g	J/g	J/g
x	0,041	0,066	0,017
s	0,027	0,015	0,003
n	66,47	22,47	16,89

Figure 11: Graph with statistics for tensile properties for tissue product 6A.



Statistics:

Series	L0	S	S, lengthwise	S, crosswise	X_1	S_2	S_2, lengthwise	S_2, crosswise	l
n = 20	mm	N/m	N/m	N/m	N/m	%	%	%	Nm/g
x	185,00	92,295	120,457	64,134	100,000	92,30	120,46	64,13	2,307
s	0,00	30,089	11,201	4,848	0,000	30,09	11,20	4,85	0,752
n	0,00	32,60	9,30	7,56	0,00	32,60	9,30	7,56	32,60

Series	l, lengthwise	l, crosswise	e	e, lengthwise	e, crosswise	Z	Z, lengthwise	Z, crosswise
n = 20	Nm/g	Nm/g	%	%	%	J/m²	J/m²	J/m²
x	3,011	1,603	4,3	-	3,6	1,9	3,0	0,7
s	0,280	0,121	1,0	-	1,0	1,2	0,5	0,1
n	9,30	7,56	23,96	-	26,91	66,84	17,92	9,68

Series	lz	lz, lengthwise	lz, crosswise
n = 20	J/g	J/g	J/g
x	0,047	0,076	0,018
s	0,031	0,014	0,002
n	66,84	17,92	9,68

Figure 12: Graph with statistics for tensile properties for tissue product 6B

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Tensile strength in the machine and cross directions

All six products exhibited substantially greater tensile strength in MD than in CD (Table 2). The product-specific mean values were presented in Table 2.

Table 2: Mean values for tensile strength for the six products.

Product	MD Tensile Strength (N/m)	CD Tensile Strength (N/m)	Overall Mean (N/m)
1	129.90±23.05	46.65±8.02	88.27
2	199.60±25.03	69.46±6.49	134.53
3	89.49±16.77	36.35±11.40	62.92
4	135.02±23.52	60.21±14.31	97.62
5	92.21±24.65	34.24±9.18	63.22
6	117.03±14.34	62.58±6.94	89.80
Overall	127.21±42.46	51.58±14.69	89.39

The highest tensile strength was observed for Product 2, particularly in MD, where the mean value reached 199.60N/m. Product 3 had the lowest MD mean (89.49N/m), while Product 5 had a similar value of 92.21N/m. In CD, Product 2 again had the highest mean value (69.46N/m), whereas Product 5 had the lowest (34.24N/m) (Table 2).

The consistently higher MD values indicated pronounced directional dependence of the fibrous network. Such directional dependence was consistent with the orientation-dependent mechanical behavior reported for machine-made paper and tissue materials [1,5]. Fiber orientation, sheet formation, inter-fiber bonding, drying conditions and subsequent tissue-manufacturing operations could all have contributed to differences between MD and CD tensile properties [1,2,6].

The MD/CD ratio (Machine Direction Tensile Strength ÷ Cross Direction Tensile Strength) was calculated directly from the tensile strength values in Table 1. This ratio was one of the most important indicators of fiber orientation anisotropy in tissue papers (Table 3).

Table 3: MD/CD Tensile Strength Ratio.

Sample	MD (N/m)	CD (N/m)	MD/CD Ratio
1A	122.497	43.547	2.81
1B	137.296	49.743	2.76
2A	204.405	70.150	2.91
2B	194.794	68.776	2.83
3A	83.939	37.597	2.23
3B	95.041	35.097	2.71
4A	121.383	57.772	2.10
4B	148.656	62.651	2.37
5A	91.445	33.591	2.72
5B	92.967	34.896	2.66
6A	113.596	61.022	1.86
6B	120.457	64.134	1.88

All six investigated tissue products had ratios substantially greater than 1.0 (Table 4). They exhibited anisotropic mechanical behavior, with tensile strength values measured in the machine direction, exceeding those obtained in the cross direction. The calculated MD/CD tensile strength ratios ranged from 1.87 for product 6 to 2.87 for product 2, confirming the preferential alignment of cellulose fibers during paper manufacture.

Table 4: Average MD/CD Ratio per Tissue Product.

Tissue Product	Average MD/CD Ratio
Product 1	2.78
Product 2	2.87
Product 3	2.46
Product 4	2.24
Product 5	2.69
Product 6	1.87

From Table 4 we deduced that product 2 exhibited the strongest anisotropy (MD/CD=2.87), indicating pronounced fiber alignment in the machine direction. Product 6 showed the lowest anisotropy (MD/CD = 1.87), suggesting a more isotropic fiber network. All six products displayed MD/CD ratios greater than 1.8, confirming the typical anisotropic structure of tissue papers produced on paper machines. These results indicated substantial differences in fiber orientation and sheet formation among the six commercial products.

The highest machine-direction tensile strengths were observed for product 2 (194-204Nm^{-1}), whereas product 3 exhibited the lowest values (84-95Nm^{-1}). Similar trends were observed for tensile index and work-to-rupture measurements, suggesting that stronger fiber networks also possessed greater energy absorption capacity before failure. Nevertheless, tensile strength, extensibility and energy absorption should not be regarded as interchangeable properties because they described different aspects of the tensile response of the fibrous network [1,3,6]. The observed anisotropy was characteristic of tissue papers produced on continuous paper machines, where hydrodynamic and mechanical forces, oriented fibers preferentially along the machine direction. Consequently, load transfer became more efficient in the MD than in the CD, resulting in significantly higher tensile resistance.

The MD/CD ratio proved to be a useful indicator of sheet structure and fiber orientation, allowing discrimination among the investigated products. Lower MD/CD values indicated a more isotro-

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pic network structure, whereas higher values reflected stronger fiber alignment and greater directional dependence of mechanical performance.

The tensile -index results in Table 1 followed the directional pattern as tensile strength. Product 2 exhibited the highest MD tensile index, reaching 5.110Nm/g for subsample 2A and 4.870Nm/g for subsample 2B. The corresponding CD values were 1.754 and 1.719Nm/g. Products 3 and 5 exhibited considerably lower MD tensile indices, whereas Product 6 maintained a comparatively balanced relationship between its MD and CD indices. The work-capacity and work-to-rupture data in Table 1 provided additional information about the ability of the tissue network to absorb mechanical energy before failure. Products displaying high tensile strength generally also displayed higher MD work capacity and MD work-to-rupture. Product 2, exhibited MD work-to-rupture values of 5.2 and 4.9J/m^2 for subsamples 2A and 2B, respectively, whereas Products 3 and 5 showed substantially lower values. This parallel behavior indicated that stronger tissue networks could generally sustain greater mechanical work before rupture. The same relationship was not identical in CD. Although CD work-to-rupture values were substantially lower than MD values for all products, the relative ordering among products was less pronounced. That distinction was important because tensile strength, strain at break and energy absorption described different aspects of the mechanical response and should not be treated as interchangeable parameters. Strain at break provided a complementary measure of extensibility. Products 1A and 1B exhibited comparatively high strain-at-break values of 9.1% and 8.3%, respectively, whereas Products 2A and 2B showed values of approximately 3.8% and 3.7%. Products 4-6 displayed intermediate values of approximately 3.6-4.3% (Table 1). Thus, the product with the highest tensile strength was not necessarily the product with the highest extensibility. That illustrated that tissue performance represented a multi-dimentional balance between strength, deformation and energy absorption rather than a single mechanical property.

Figures 1 and 2, corresponding to Products 1A and 1B, respectively, show substantially greater tensile resistance in the lengthwise/MD direction than in the crosswise/CD direction.

The same directional pattern was evident in Figures 3 and 4 for Product 2.

The same directional pattern was evident in Figures 5 and 6, for Product 3.

The same directional pattern was evident for Figures 7 and 8, for Product 4.

Also, the same pattern in Figures 9 and 10, for Product 5.

Finally, the same directional pattern in Figures 11 and 12 for Product 6. Across all twelve products, subsample combinations, the machine-direction response was consistently stronger than the cross-direction response. The instrument-derived values in those figures were consistent with the summarized values reported in Table 1.

Statistical analysis

Mean values and standard deviations were calculated for all measured properties. Comparative evaluation of the tissue products was performed using descriptive statistical analysis. Studies also employed one-way and two-way ANOVA in order to investigate the significance of product type and testing direction on tensile performance.

Results and Discussion

Tensile strength

The tensile strength measurements revealed pronounced anisotropic behavior in all investigated tissue papers. The descriptive statistical analysis was presented in Figure 13. Across the twelve product/subsample combinations, grammage showed relatively limited variability, whereas MD tensile strength exhibited substantially greater dispersion. We then performed the Normality test for all variables.

Descriptive Statistics							
		Statistic	Std. Error	Boot strapa			
				Bias	Std. Error	95% Confidence Interval	
						Lower	Upper
Grammage	N	12		0	0	12	12
	Minimum	15,80					
	Maximum	18,00					
	Mean	17,0417		-,0030	,2359	16,5335	17,4833
	Std. Deviation	,83933		-,04555	,11688	,52064	,95924
	Variance	,704		-,061	,168	,271	,920
	Skewness	-,615	,637	-,065	,722	-2,318	,767
	Kurtosis	-1,492	1,232	,880	2,125	-2,248	6,718

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Absorbency	N	12		0	0	12	12
	Minimum	5,00					
	Maximum	8,00					
	Mean	6,4167		-,0178	,3277	5,7500	7,0833
	Std. Deviation	1,16450		-,05870	,15058	,79296	1,37034
	Variance	1,356		-,111	,315	,629	1,878
	Skewness	-,174	,637	-,025b	,601b	-1,449b	,988b
	Kurtosis	-1,523	1,232	,516b	1,244b	-2,254b	2,725b
MD Tensile strength	N	12		0	0	12	12
	Minimum	83,939					
	Maximum	204,405					
	Mean	127,20633		-,29473	10,43022	107,95432	149,11237
	Std. Deviation	39,003934		-2,631337	7,967125	18,044256	49,163881
	Variance	1521,307		-134,929	544,555	325,595	2417,088
	Skewness	1,060	,637	-,099	,594	-,329	2,178
	Kurtosis	,340	1,232	,279	1,967	-1,801	5,613
CD Tensile strength	N	12		0	0	12	12
	Minimum	33,591					
	Maximum	70,150					
	Mean	51,58133		-,08843	3,87164	43,54541	58,74804
	Std. Deviation	14,094766		-,720619	1,581199	9,885322	16,109882
	Variance	198,662		-17,297	41,072	97,720	259,528
	Skewness	-,090	,637	,000	,606	-1,354	1,219
	Kurtosis	-1,821	1,232	,531	1,027	-2,184	1,827
MD tensile index	N	12		0	0	12	12
	Minimum	2,098					
	Maximum	5,110					
	Mean	3,18000		-,00737	,26077	2,69867	3,72765
	Std. Deviation	,975147		-,065792	,199209	,451191	1,229164
	Variance	,951		-,084	,340	,204	1,511
	Skewness	1,060	,637	-,100	,594	-,329	2,178
	Kurtosis	,340	1,232	,279	1,967	-1,802	5,617
CD tensile index	N	12		0	0	12	12
	Minimum	,840					
	Maximum	1,754					
	Mean	1,28950		-,00220	,09679	1,08845	1,46872
	Std. Deviation	,352356		-,018017	,039549	,247078	,402929
	Variance	,124		-,011	,026	,061	,162
	Skewness	-,091	,637	,000	,606	-1,354	1,217
	Kurtosis	-1,820	1,232	,531	1,027	-2,184	1,832
MD work capacity	N	12		0	0	12	12
	Minimum	,043					
	Maximum	,174					
	Mean	,08933		,00019	,01284	,06675	,11533
	Std. Deviation	,045336		-,002329	,007155	,027454	,055795
	Variance	,002		,000	,001	,001	,003
	Skewness	,688	,637	-,041	,574	-,384	1,908
	Kurtosis	-,854	1,232	,276	1,440	-1,944	3,554

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CD work capacity	N	12		0	0	12	12
	Minimum	,008					
	Maximum	,018					
	Mean	,01292		,00002	,00092	,01109	,01475
	Std. Deviation	,003260		-,000174	,000460	,002110	,003908
	Variance	,000		,000	,000	,000	,000
	Skewness	,089	,637	-,013	,521	-,950	1,126
	Kurtosis	-1,253	1,232	,301	,883	-1,903	1,363
Strain at break	N	12		0	0	12	12
	Minimum	3,6					
	Maximum	9,1					
	Mean	4,750		,026	,536	3,908	5,958
	Std. Deviation	1,8647		-,1843	,6401	,1816	2,5115
	Variance	3,477		-,244	1,752	,033	6,308
	Skewness	2,035	,637	-,235	1,092	-,255	3,399
	Kurtosis	2,777	1,232	,518	4,931	-2,153	11,675
MD work to rupture	N	12		0	0	12	12
	Minimum	1,7					
	Maximum	7,0					
	Mean	3,575		,008	,519	2,667	4,625
	Std. Deviation	1,8301		-,0939	,2909	1,1046	2,2500
	Variance	3,349		-,251	,978	1,220	5,062
	Skewness	,708	,637	-,041	,580	-,380	1,949
	Kurtosis	-,834	1,232	,279	1,475	-1,938	3,699
CD work to rupture	N	12		0	0	12	12
	Minimum	,3					
	Maximum	,7					
	Mean	,525		,000	,038	,450	,600
	Std. Deviation	,1357		-,0069	,0193	,0888	,1621
	Variance	,018		-,001	,005	,008	,026
	Skewness	-,016	,637	,034	,506	-1,008	1,050
	Kurtosis	-1,163	1,232	,289	,883	-1,940	1,490
MDCD ratio	N	12		0	0	12	12
	Minimum	1,86					
	Maximum	2,91					
	Mean	2,4867		-,0008	,1034	2,2650	2,6825
	Std. Deviation	,38144		-,01875	,05625	,22822	,45487
	Variance	,145		-,011	,039	,052	,207
	Skewness	-,680	,637	-,012	,631	-2,109	,476
	Kurtosis	-1,164	1,232	,531	1,729	-2,098	4,383
Valid N (listwise)	N	12		0	0	12	12
a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples							
b. Based on 999 samples							

Figure 13: Descriptive Statistics.

The normality assessment was presented in Figure 14. The Shapiro-Wilk test did not indicate significant departure from normality for MD tensile strength (p=0.074), CD tensile strength (p=0.096), MD tensile index (p=0.074), CD tensile index (p=0.096), MD work capacity (p=0.115), CD work capacity (p=0.740), MD work-to-rupture (p=0.109), or CD work-to-rupture (p=0.237). However, grammage (p=0.020), absorbency (p=0.021), strain at break (p<0.001), and the MD/CD ratio (p=0.054 for Shapiro-Wilk) required more cautious interpretation. In particular, strain at break showed clear evidence of non-normality, indicating that its distribution was more heterogeneous among the investigated products.

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Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Grammage	,241	12	,052	,828	12	,020
Absorbency	,275	12	,013	,830	12	,021
MD Tensile strength	,215	12	,132	,874	12	,074
CD Tensile strength	,173	12	,200*	,883	12	,096
MD tensile index	,215	12	,132	,874	12	,074
CD tensile index	,173	12	,200*	,883	12	,096
MD work capacity	,199	12	,200*	,889	12	,115
CD work capacity	,155	12	,200*	,957	12	,740
Strain at break	,429	12	,000	,587	12	,000
MD work to rupture	,207	12	,167	,887	12	,109
CD work to rupture	,156	12	,200*	,914	12	,237
MDCD ratio	,259	12	,026	,863	12	,054
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Figure 14: Tests of normality for the physical and mechanical properties of the investigated tissue paper products. The table presented the Kolmogorov-Smirnov and Shapiro-Wilk tests for assessing whether the distributions of the measured variables departed significantly from normality.

Those distributional characteristics reinforced the importance of considering both central tendency and variability rather than relying exclusively on product means. The results demonstrated that commercial tissue papers with broadly similar basis weights could exhibit markedly different tensile properties. Then, one-way ANOVA was used to determine whether different tissue products differed significantly. The one-way ANOVA results demonstrated significant differences among the six products for the major tensile parameters. For tensile strength, significant product effects were observed in both MD and CD (Figure 15):

$$\text{MD tensile strength: } F(5,6)=31.510,\ p<0.001$$

$$\text{CD tensile strength: } F(5,6)=62.978,\ p<0.001$$

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
MD Tensile strength	Between Groups	16120,455	5	3224,091	31,510	,000
	Within Groups	613,921	6	102,320		
	Total	16734,376	11			
CD Tensile strength	Between Groups	2144,426	5	428,885	62,978	,000
	Within Groups	40,860	6	6,810		
	Total	2185,287	11			
MD tensile index	Between Groups	10,077	5	2,015	31,563	,000
	Within Groups	,383	6	,064		
	Total	10,460	11			
CD tensile index	Between Groups	1,340	5	,268	62,998	,000
	Within Groups	,026	6	,004		
	Total	1,366	11			
MD work capacity	Between Groups	,022	5	,004	35,266	,000
	Within Groups	,001	6	,000		
	Total	,023	11			
CD work capacity	Between Groups	,000	5	,000	29,978	,000
	Within Groups	,000	6	,000		
	Total	,000	11			

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MD work to rupture	Between Groups	35,568	5	7,114	33,475	,000
	Within Groups	1,275	6	,213		
	Total	36,843	11			
CD work to rupture	Between Groups	,187	5	,037	15,000	,002
	Within Groups	,015	6	,003		
	Total	,202	11			
Strain at break	Between Groups	37,860	5	7,572	116,492	,000
	Within Groups	,390	6	,065		
	Total	38,250	11			

Figure 15: One-Way ANOVA comparing the mechanical properties of the six tissue paper products.

The one-way ANOVA results were summarized in Figure 15. Significant product differences were observed for MD and CD tensile index, work capacity, work-to-rupture, and strain at break. For tensile strength, the product effect was significant in both MD, $F(5,6)=31.510$, $p<0.001$ and CD, $F(5,6)=62.978$, $p<0.001$. Significant product effects were also observed for MD tensile index, CD tensile index, MD work capacity, CD work capacity, MD work-to-rupture, CD work to rupture, and strain at break. The F statistic for strain at break was particularly large, $F(5,6)=116.492$, $p<0.001$. The particularly large F values demonstrated that product type was strongly associated with the mechanical properties measured in the study.

The effect-size analysis presented in Figure 16 indicated that these product effects were not merely statistically detectable but accounted for a large proportion of the observed variation. Eta-squared values were 0.963 for MD tensile strength and 0.981 for CD tensile strength. Correspondingly high values were obtained for tensile index, work capacity, work-to-rupture and strain at break. For strain at break, eta-squared reached 0.990. These findings demonstrated that commercial product identity was strongly associated with the mechanical characteristics measured in this study. The magnitude of these effects should be interpreted in conjunction with the experimental structure and the relatively small number of product-level means used in the one-way comparisons. The subsequent factorial analysis based on all 240 observations provided a more comprehensive evaluation of tensile strength by simultaneously accounting for product and testing direction.

ANOVA Effect Sizes[a,b]				
		Point Estimate	95% Confidence Interval	
			Lower	Upper
MD Tensile strength	Eta-squared	,963	,677	,970
	Epsilon-squared	,933	,407	,945
	Omega-squared Fixed-effect	,927	,386	,940
	Omega-squared Random-effect	,718	,112	,757
CD Tensile strength	Eta-squared	,981	,827	,985
	Epsilon-squared	,966	,683	,972
	Omega-squared Fixed-effect	,963	,664	,969
	Omega-squared Random-effect	,838	,283	,863
MD tensile index	Eta-squared	,963	,677	,970
	Epsilon-squared	,933	,408	,945
	Omega-squared Fixed-effect	,927	,387	,940
	Omega-squared Random-effect	,718	,112	,758
CD tensile index	Eta-squared	,981	,827	,985
	Epsilon-squared	,966	,683	,972
	Omega-squared Fixed-effect	,963	,664	,969
	Omega-squared Random-effect	,838	,283	,863
MD work capacity	Eta-squared	,967	,707	,973
	Epsilon-squared	,940	,463	,950
	Omega-squared Fixed-effect	,935	,441	,946
	Omega-squared Random-effect	,741	,136	,778

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CD work capacity	Eta-squared	,962	,662	,968
	Epsilon-squared	,929	,381	,942
	Omega-squared Fixed-effect	,924	,361	,937
	Omega-squared Random-effect	,707	,101	,748
MD work to rupture	Eta-squared	,965	,693	,971
	Epsilon-squared	,937	,437	,948
	Omega-squared Fixed-effect	,931	,416	,943
	Omega-squared Random-effect	,730	,125	,769
CD work to rupture	Eta-squared	,926	,413	,939
	Epsilon-squared	,864	-,076	,889
	Omega-squared Fixed-effect	,854	-,070	,880
	Omega-squared Random-effect	,538	-,013	,594
Strain at break	Eta-squared	,990	,904	,992
	Epsilon-squared	,981	,823	,985
	Omega-squared Fixed-effect	,980	,810	,983
	Omega-squared Random-effect	,906	,461	,921
a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.				
b. Negative but less biased estimates are retained, not rounded to zero.				

Figure 16: Effect-Size estimates for differences in mechanical properties among the six tissue paper products. The effect-size estimates included eta-squared, epsilon-squared, and omega-squared, in order to quantify the magnitude of the differences among products.

The product-level post-hoc comparisons were presented in Figures 17-19, including the multiple-comparison, bootstrap and Tukey HSD outputs. These analyses showed that Product 2 differed significantly from every other product in overall tensile strength. In contrast, Products 3 and 5 did not differ significantly from each other. Products 1,4 and 6 also showed no statistically significant differences among themselves in overall tensile strength. The Tukey homogeneous-subset analysis shown in the corresponding output in Figure 19, therefore separated the products into broad groups, products 3 and 5 occupied the lower mean-strength group, products 1,6, and 4 formed an intermediate group, and product 2 occupied a distinct higher-strength group.

Multiple Comparisons							
Tukey HSD							
Dependent Variable	(I) PRODUCTS	(J) PRODUCTS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
MD Tensile strength	1	2	-69,703000*	10,115345	,004	-109,96052	-29,44548
		3	40,406500*	10,115345	,049	,14898	80,66402
		4	-5,123000	10,115345	,994	-45,38052	35,13452
		5	37,690500	10,115345	,066	-2,56702	77,94802
		6	12,870000	10,115345	,790	-27,38752	53,12752
	2	1	69,703000*	10,115345	,004	29,44548	109,96052
		3	110,109500*	10,115345	,000	69,85198	150,36702
		4	64,580000*	10,115345	,005	24,32248	104,83752
		5	107,393500*	10,115345	,000	67,13598	147,65102
		6	82,573000*	10,115345	,001	42,31548	122,83052
	3	1	-40,406500*	10,115345	,049	-80,66402	-,14898
		2	-110,109500*	10,115345	,000	-150,36702	-69,85198
		4	-45,529500*	10,115345	,029	-85,78702	-5,27198
		5	-2,716000	10,115345	1,000	-42,97352	37,54152
		6	-27,536500	10,115345	,200	-67,79402	12,72102
	4	1	5,123000	10,115345	,994	-35,13452	45,38052
		2	-64,580000*	10,115345	,005	-104,83752	-24,32248

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		3	45,529500*	10,115345	,029	5,27198	85,78702
		5	42,813500*	10,115345	,038	2,55598	83,07102
		6	17,993000	10,115345	,536	-22,26452	58,25052
	5	1	-37,690500	10,115345	,066	-77,94802	2,56702
		2	-107,393500*	10,115345	,000	-147,65102	-67,13598
		3	2,716000	10,115345	1,000	-37,54152	42,97352
		4	-42,813500*	10,115345	,038	-83,07102	-2,55598
		6	-24,820500	10,115345	,269	-65,07802	15,43702
	6	1	-12,870000	10,115345	,790	-53,12752	27,38752
		2	-82,573000*	10,115345	,001	-122,83052	-42,31548
		3	27,536500	10,115345	,200	-12,72102	67,79402
		4	-17,993000	10,115345	,536	-58,25052	22,26452
		5	24,820500	10,115345	,269	-15,43702	65,07802
CD Tensile strength	1	2	-22,818000*	2,609606	,001	-33,20383	-12,43217
		3	10,298000	2,609606	,052	-,08783	20,68383
		4	-13,566500*	2,609606	,015	-23,95233	-3,18067
		5	12,401500*	2,609606	,023	2,01567	22,78733
		6	-15,933000*	2,609606	,007	-26,31883	-5,54717
	2	1	22,818000*	2,609606	,001	12,43217	33,20383
		3	33,116000*	2,609606	,000	22,73017	43,50183
		4	9,251500	2,609606	,080	-1,13433	19,63733
		5	35,219500*	2,609606	,000	24,83367	45,60533
		6	6,885000	2,609606	,220	-3,50083	17,27083
	3	1	-10,298000	2,609606	,052	-20,68383	,08783
		2	-33,116000*	2,609606	,000	-43,50183	-22,73017
		4	-23,864500*	2,609606	,001	-34,25033	-13,47867
		5	2,103500	2,609606	,956	-8,28233	12,48933
		6	-26,231000*	2,609606	,000	-36,61683	-15,84517
	4	1	13,566500*	2,609606	,015	3,18067	23,95233
		2	-9,251500	2,609606	,080	-19,63733	1,13433
		3	23,864500*	2,609606	,001	13,47867	34,25033
		5	25,968000*	2,609606	,000	15,58217	36,35383
		6	-2,366500	2,609606	,931	-12,75233	8,01933
	5	1	-12,401500*	2,609606	,023	-22,78733	-2,01567
		2	-35,219500*	2,609606	,000	-45,60533	-24,83367
		3	-2,103500	2,609606	,956	-12,48933	8,28233
		4	-25,968000*	2,609606	,000	-36,35383	-15,58217
		6	-28,334500*	2,609606	,000	-38,72033	-17,94867
	6	1	15,933000*	2,609606	,007	5,54717	26,31883
		2	-6,885000	2,609606	,220	-17,27083	3,50083
		3	26,231000*	2,609606	,000	15,84517	36,61683
		4	2,366500	2,609606	,931	-8,01933	12,75233
		5	28,334500*	2,609606	,000	17,94867	38,72033
MD tensile index	1	2	-1,743000*	,252691	,004	-2,74867	-,73733
		3	1,010000*	,252691	,049	,00433	2,01567
		4	-,128500	,252691	,994	-1,13417	,87717
		5	,942000	,252691	,065	-,06367	1,94767
		6	,321500	,252691	,790	-,68417	1,32717
	2	1	1,743000*	,252691	,004	,73733	2,74867

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		3	2,753000*	,252691	,000	1,74733	3,75867
		4	1,614500*	,252691	,005	,60883	2,62017
		5	2,685000*	,252691	,000	1,67933	3,69067
		6	2,064500*	,252691	,001	1,05883	3,07017
	3	1	-1,010000*	,252691	,049	-2,01567	-,00433
		2	-2,753000*	,252691	,000	-3,75867	-1,74733
		4	-1,138500*	,252691	,029	-2,14417	-,13283
		5	-,068000	,252691	1,000	-1,07367	,93767
		6	-,688500	,252691	,200	-1,69417	,31717
	4	1	,128500	,252691	,994	-,87717	1,13417
		2	-1,614500*	,252691	,005	-2,62017	-,60883
		3	1,138500*	,252691	,029	,13283	2,14417
		5	1,070500*	,252691	,038	,06483	2,07617
		6	,450000	,252691	,535	-,55567	1,45567
	5	1	-,942000	,252691	,065	-1,94767	,06367
		2	-2,685000*	,252691	,000	-3,69067	-1,67933
		3	,068000	,252691	1,000	-,93767	1,07367
		4	-1,070500*	,252691	,038	-2,07617	-,06483
		6	-,620500	,252691	,269	-1,62617	,38517
	6	1	-,321500	,252691	,790	-1,32717	,68417
		2	-2,064500*	,252691	,001	-3,07017	-1,05883
		3	,688500	,252691	,200	-,31717	1,69417
		4	-,450000	,252691	,535	-1,45567	,55567
		5	,620500	,252691	,269	-,38517	1,62617
CD tensile index	1	2	-,570000*	,065228	,001	-,82960	-,31040
		3	,258000	,065228	,051	-,00160	,51760
		4	-,338500*	,065228	,015	-,59810	-,07890
		5	,310500*	,065228	,023	,05090	,57010
		6	-,398000*	,065228	,007	-,65760	-,13840
	2	1	,570000*	,065228	,001	,31040	,82960
		3	,828000*	,065228	,000	,56840	1,08760
		4	,231500	,065228	,080	-,02810	,49110
		5	,880500*	,065228	,000	,62090	1,14010
		6	,172000	,065228	,220	-,08760	,43160
	3	1	-,258000	,065228	,051	-,51760	,00160
		2	-,828000*	,065228	,000	-1,08760	-,56840
		4	-,596500*	,065228	,001	-,85610	-,33690
		5	,052500	,065228	,956	-,20710	,31210
		6	-,656000*	,065228	,000	-,91560	-,39640
	4	1	,338500*	,065228	,015	,07890	,59810
		2	-,231500	,065228	,080	-,49110	,02810
		3	,596500*	,065228	,001	,33690	,85610
		5	,649000*	,065228	,000	,38940	,90860
		6	-,059500	,065228	,930	-,31910	,20010
	5	1	-,310500*	,065228	,023	-,57010	-,05090
		2	-,880500*	,065228	,000	-1,14010	-,62090
		3	-,052500	,065228	,956	-,31210	,20710
		4	-,649000*	,065228	,000	-,90860	-,38940

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		6	-,708500*	,065228	,000	-,96810	-,44890
	6	1	,398000*	,065228	,007	,13840	,65760
		2	-,172000	,065228	,220	-,43160	,08760
		3	,656000*	,065228	,000	,39640	,91560
		4	,059500	,065228	,930	-,20010	,31910
		5	,708500*	,065228	,000	,44890	,96810
MD work capacity	1	2	,036000	,011136	,113	-,00832	,08032
		3	,117000*	,011136	,000	,07268	,16132
		4	,077500*	,011136	,003	,03318	,12182
		5	,117000*	,011136	,000	,07268	,16132
		6	,091500*	,011136	,001	,04718	,13582
	2	1	-,036000	,011136	,113	-,08032	,00832
		3	,081000*	,011136	,003	,03668	,12532
		4	,041500	,011136	,066	-,00282	,08582
		5	,081000*	,011136	,003	,03668	,12532
		6	,055500*	,011136	,018	,01118	,09982
	3	1	-,117000*	,011136	,000	-,16132	-,07268
		2	-,081000*	,011136	,003	-,12532	-,03668
		4	-,039500	,011136	,080	-,08382	,00482
		5	,000000	,011136	1,000	-,04432	,04432
		6	-,025500	,011136	,322	-,06982	,01882
	4	1	-,077500*	,011136	,003	-,12182	-,03318
		2	-,041500	,011136	,066	-,08582	,00282
		3	,039500	,011136	,080	-,00482	,08382
		5	,039500	,011136	,080	-,00482	,08382
		6	,014000	,011136	,797	-,03032	,05832
	5	1	-,117000*	,011136	,000	-,16132	-,07268
		2	-,081000*	,011136	,003	-,12532	-,03668
		3	,000000	,011136	1,000	-,04432	,04432
		4	-,039500	,011136	,080	-,08382	,00482
		6	-,025500	,011136	,322	-,06982	,01882
	6	1	-,091500*	,011136	,001	-,13582	-,04718
		2	-,055500*	,011136	,018	-,09982	-,01118
		3	,025500	,011136	,322	-,01882	,06982
		4	-,014000	,011136	,797	-,05832	,03032
		5	,025500	,011136	,322	-,01882	,06982
CD work capacity	1	2	-,001500	,000866	,559	-,00495	,00195
		3	,003500*	,000866	,047	,00005	,00695
		4	,002500	,000866	,166	-,00095	,00595
		5	,005500*	,000866	,005	,00205	,00895
		6	-,003500*	,000866	,047	-,00695	-,00005
	2	1	,001500	,000866	,559	-,00195	,00495
		3	,005000*	,000866	,009	,00155	,00845
		4	,004000*	,000866	,026	,00055	,00745
		5	,007000*	,000866	,002	,00355	,01045
		6	-,002000	,000866	,315	-,00545	,00145
	3	1	-,003500*	,000866	,047	-,00695	-,00005
		2	-,005000*	,000866	,009	-,00845	-,00155

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		4	-,001000	,000866	,843	-,00445	,00245
		5	,002000	,000866	,315	-,00145	,00545
		6	-,007000*	,000866	,002	-,01045	-,00355
	4	1	-,002500	,000866	,166	-,00595	,00095
		2	-,004000*	,000866	,026	-,00745	-,00055
		3	,001000	,000866	,843	-,00245	,00445
		5	,003000	,000866	,087	-,00045	,00645
		6	-,006000*	,000866	,003	-,00945	-,00255
	5	1	-,005500*	,000866	,005	-,00895	-,00205
		2	-,007000*	,000866	,002	-,01045	-,00355
		3	-,002000	,000866	,315	-,00545	,00145
		4	-,003000	,000866	,087	-,00645	,00045
		6	-,009000*	,000866	,000	-,01245	-,00555
	6	1	,003500*	,000866	,047	,00005	,00695
		2	,002000	,000866	,315	-,00145	,00545
		3	,007000*	,000866	,002	,00355	,01045
		4	,006000*	,000866	,003	,00255	,00945
		5	,009000*	,000866	,000	,00555	,01245
MD work to rupture	1	2	1,5000	,4610	,110	-,335	3,335
		3	4,7500*	,4610	,000	2,915	6,585
		4	3,1500*	,4610	,004	1,315	4,985
		5	4,7000*	,4610	,000	2,865	6,535
		6	3,7500*	,4610	,001	1,915	5,585
	2	1	-1,5000	,4610	,110	-3,335	,335
		3	3,2500*	,4610	,003	1,415	5,085
		4	1,6500	,4610	,077	-,185	3,485
		5	3,2000*	,4610	,003	1,365	5,035
		6	2,2500*	,4610	,020	,415	4,085
	3	1	-4,7500*	,4610	,000	-6,585	-2,915
		2	-3,2500*	,4610	,003	-5,085	-1,415
		4	-1,6000	,4610	,087	-3,435	,235
		5	-,0500	,4610	1,000	-1,885	1,785
		6	-1,0000	,4610	,365	-2,835	,835
	4	1	-3,1500*	,4610	,004	-4,985	-1,315
		2	-1,6500	,4610	,077	-3,485	,185
		3	1,6000	,4610	,087	-,235	3,435
		5	1,5500	,4610	,098	-,285	3,385
		6	,6000	,4610	,776	-1,235	2,435
	5	1	-4,7000*	,4610	,000	-6,535	-2,865
		2	-3,2000*	,4610	,003	-5,035	-1,365
		3	,0500	,4610	1,000	-1,785	1,885
		4	-1,5500	,4610	,098	-3,385	,285
		6	-,9500	,4610	,409	-2,785	,885
	6	1	-3,7500*	,4610	,001	-5,585	-1,915
		2	-2,2500*	,4610	,020	-4,085	-,415
		3	1,0000	,4610	,365	-,835	2,835
		4	-,6000	,4610	,776	-2,435	1,235
		5	,9500	,4610	,409	-,885	2,785

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CD work to rupture	1	2	-,1000	,0500	,434	-,299	,099
		3	,1500	,0500	,147	-,049	,349
		4	,0500	,0500	,902	-,149	,249
		5	,2000*	,0500	,049	,001	,399
		6	-,1500	,0500	,147	-,349	,049
	2	1	,1000	,0500	,434	-,099	,299
		3	,2500*	,0500	,018	,051	,449
		4	,1500	,0500	,147	-,049	,349
		5	,3000*	,0500	,007	,101	,499
		6	-,0500	,0500	,902	-,249	,149
	3	1	-,1500	,0500	,147	-,349	,049
		2	-,2500*	,0500	,018	-,449	-,051
		4	-,1000	,0500	,434	-,299	,099
		5	,0500	,0500	,902	-,149	,249
		6	-,3000*	,0500	,007	-,499	-,101
	4	1	-,0500	,0500	,902	-,249	,149
		2	-,1500	,0500	,147	-,349	,049
		3	,1000	,0500	,434	-,099	,299
		5	,1500	,0500	,147	-,049	,349
		6	-,2000*	,0500	,049	-,399	-,001
	5	1	-,2000*	,0500	,049	-,399	-,001
		2	-,3000*	,0500	,007	-,499	-,101
		3	-,0500	,0500	,902	-,249	,149
		4	-,1500	,0500	,147	-,349	,049
		6	-,3500*	,0500	,003	-,549	-,151
	6	1	,1500	,0500	,147	-,049	,349
		2	,0500	,0500	,902	-,149	,249
		3	,3000*	,0500	,007	,101	,499
		4	,2000*	,0500	,049	,001	,399
		5	,3500*	,0500	,003	,151	,549
Strain at break	1	2	4,9500*	,2550	,000	3,935	5,965
		3	4,7000*	,2550	,000	3,685	5,715
		4	4,9500*	,2550	,000	3,935	5,965
		5	4,7000*	,2550	,000	3,685	5,715
		6	4,4000*	,2550	,000	3,385	5,415
	2	1	-4,9500*	,2550	,000	-5,965	-3,935
		3	-,2500	,2550	,909	-1,265	,765
		4	,0000	,2550	1,000	-1,015	1,015
		5	-,2500	,2550	,909	-1,265	,765
		6	-,5500	,2550	,370	-1,565	,465
	3	1	-4,7000*	,2550	,000	-5,715	-3,685
		2	,2500	,2550	,909	-,765	1,265
		4	,2500	,2550	,909	-,765	1,265
		5	,0000	,2550	1,000	-1,015	1,015
		6	-,3000	,2550	,834	-1,315	,715
	4	1	-4,9500*	,2550	,000	-5,965	-3,935
		2	,0000	,2550	1,000	-1,015	1,015
		3	-,2500	,2550	,909	-1,265	,765

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		5	-,2500	,2550	,909	-1,265	,765
		6	-,5500	,2550	,370	-1,565	,465
	5	1	-4,7000*	,2550	,000	-5,715	-3,685
		2	,2500	,2550	,909	-,765	1,265
		3	,0000	,2550	1,000	-1,015	1,015
		4	,2500	,2550	,909	-,765	1,265
		6	-,3000	,2550	,834	-1,315	,715
	6	1	-4,4000*	,2550	,000	-5,415	-3,385
		2	,5500	,2550	,370	-,465	1,565
		3	,3000	,2550	,834	-,715	1,315
		4	,5500	,2550	,370	-,465	1,565
		5	,3000	,2550	,834	-,715	1,315
*. The mean difference is significant at the 0.05 level.							

Figure 17: Tukey HSD Multiple Comparisons analysis

Bootstrap for Multiple Comparisons							
Tukey HSD							
Dependent Variable	(I) PRODUCTS	(J) PRODUCTS	Mean Difference (I-J)	Boot strapa			
				Bias	Std. Error	95% Confidence Interval	
						Lower	Upper
MD Tensile strength	1	2	-69,703,000	,000724[b]	5,358326[b]	-81,626007[b]	-60,701667[b]
		3	40,406,500	-,893821[d]	5,620589[d]	27,456000[d]	49,208335[d]
		4	-5,123,000	,925514[g]	9,644427[g]	-26,159000[g]	15,913000[g]
		5	37,690,500	-,120594[i]	4,494384i	29,530000[i]	45,851000[i]
		6	12,870,000	-,107390[k]	5,226721[k]	2,040000[k]	23,497685[k]
	2	1	69,703,000	-,000724[b]	5,358326[b]	60,701667[b]	81,626007[b]
		3	110,109,500	,380397[l]	4,769078[l]	99,753000[l]	120,466000[l]
		4	64,580,000	1,39459 5[n]	9,159436[n]	49,218598[n]	83,022000[n]
		5	107,393,500	,167618[k]	3,021396[k]	102,349293[k]	112,960000k
		6	82,573,000	,014558[q]	3,520577[q]	76,624000[q]	90,163767[q]

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	3	1	-40,406,500	,893821[d]	5,620589[d]	-49,208335[d]	-27,456000[d]
		2	-110,109,500	-,380397[l]	4,769078[l]	-120,466000[l]	-99,753000[l]
		4	-45,529,500	2,76301 7[r]	8,812334[r]	-60,646839[r]	-26,342000[r]
		5	-2,716,000	,244243[i]	3,381238[i]	-9,028000[i]	3,596000[i]
		6	-27,536,500	,057700[b]	4,200076[b]	-36,518000[b]	-18,555000[b]
	4	1	5,123,000	-,925514[g]	9,644427[g]	-15,913000[g]	26,159000g
		2	-64,580,000	-1,39459 5[n]	9,159436[n]	-83,022000[n]	-49,218598[n]
		3	45,529,500	-2,76301 7[r]	8,812334[r]	26,342000[r]	60,646839[r]
		5	42,813,500	-2,59438 3[g]	8,592605[g]	28,416000[g]	56,844193[g]
		6	17,993,000	-2,00721 6[i]	9,290188[i]	,926000[i]	33,478011[i]
	5	1	-37,690,500	,120594[i]	4,494384[i]	-45,851000[i]	-29,530000[i]
		2	-107,393,500	-,167618[k]	3,021396[k]	-112,960000[k]	-102,349293[k]
		3	2,716,000	-,244243[i]	3,381238[i]	-3,596000i	9,028000[i]
		4	-42,813,5 00	2,59438 3[g]	8,592605[g]	-56,84419 3[g]	-28,416 000[g]
		6	-24,820,5 00	-,276580[b]	2,031065[b]	-29,01200 0[b]	-20,695 985[b]
	6	1	-12,870,0 00	,107390[k]	5,226721[k]	-23,49768 5[k]	-2,0400 00[k]
		2	-82,573,0 00	-,014558[q]	3,520577[q]	-90,16376 7[q]	-76,624 000[q]
		3	27,536,500	-,057700[b]	4,200076[b]	18,555000[b]	36,518000[b]
		4	-17,993,0 00	2,007216[i]	9,290188[i]	-33,478011[i]	-,92600 0[i]
		5	24,820,500	,276580[b]	2,031065[b]	20,695985[b]	29,012000[b]
	1	2	-22,818,0 00	,039082[b]	1,937774[b]	-26,56268 6[b]	-19,491 000[b]
		3	10,298,000	,013389[d]	2,073146[d]	5,950000[d]	14,646000[d]
		4	-13,566,5 00	,116566[g]	2,417191[g]	-19,10400 0[g]	-8,0290 00[g]
		5	12,401,500	-,038470[i]	1,924801[i]	8,651000[i]	16,152000[i]
		6	-15,933,0 00	-,056787[k]	2,221607[k]	-20,58700 0[k]	-11,370 353[k]
	2	1	22,818,000	-,039082[b]	1,937774[b]	19,491000[b]	26,562686[b]
		3	33,116,000	,112154[i]	,840578[l]	31,522500[l]	35,053000[l]
		4	9,251,500	,234161[n]	1,597046[n]	6,565406[n]	12,378000[n]
		5	35,219,500	,034927[k]	,581052[k]	34,315000[k]	36,559000[k]
		6	6,885,000	-,098694[q]	1,014447[q]	5,100000[q]	9,035757[q]
	3	1	-10,298,0 00	-,013389[d]	2,073146[d]	-14,64600 0[d]	-5,9500 00[d]
		2	-33,116,0 00	-,112154[i]	,840578[l]	-35,053000[l]	-31,522 500[l]
		4	-23,864,5 00	,285378[r]	1,6655 44[r]	-26,60572 4[r]	-20,822 862[r]
		5	2,103,500	-,009596[i]	,848370[i]	,201000[i]	4,006000[i]
		6	-26,231,0 00	-,140776[b]	1,227316[b]	-29,0370 00[b]	-23,966 494[b]
	4	1	13,566,500	-,116566[g]	2,417191[g]	8,029000[g]	19,104000[g]
		2	-9,251,50 0	-,234161[n]	1,597046[n]	-12,37800 0[n]	-6,5654 06[n]
		3	23,864,500	-,285378[r]	1,665544[r]	20,822862[r]	26,605724[r]
		5	25,968,000	-,440025[g]	1,619328[g]	22,876000[g]	28,745490[g]
		6	-2,366,5 00	-,475926[i]	1,936519[i]	-6,362000[i]	,911444[i]
	5	1	-12,401,5 00	,038470[i]	1,924801[i]	-16,152000[i]	-8,6510 00[i]
		2	-35,219,5 00	-,034927$_{k}$	,581052[k]	-36,55900 0[k]	-34,315 000[k]
		3	-2,103,5 00	,009596[i]	,848370[l]	-4,006000[i]	-,20100 0[i]
		4	-25,968,0 00	,440025[g]	1,619328[g]	-28,74549 0[g]	-22,876 000[g]
		6	-28,334,5 00	-,125076[b]	,976282[b]	-30,5430 00[b]	-26,183 434[b]
	6	1	15,933,000	,056787[k]	2,221607[k]	11,370353[k]	20,587000[k]
		2	-6,885,0 00	,098694[q]	1,014447[q]	-9,035757[q]	-5,1000 00[q]
		3	26,231,000	,140776[b]	1,227316[b]	23,966494[b]	29,037000[b]
		4	2,366,500	,475926[i]	1,936519[i]	-,911444[i]	6,362000[i]

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		5	28,334,500	,125076[b]	,976282[b]	26,183434[b]	30,543000[b]
MDtensileindex	1	2	-1,743,00 0	,000022[b]	,133921[b]	-2,040958[b]	-1,5180 00[b]
		3	1,010,000	-,022370[d]	,140600[d]	,686000[d]	1,230276[d]
		4	-,128500	,023103[g]	,240889[g]	-,654000[g]	,397000[g]
		5	,942000	-,003016[i]	,112365[i]	,738000[i]	1,146000[i]
		6	,321500	-,002658[k]	,130605[k]	,051000[k]	,586958[k]
	2	1	1,743,000	-,000022[b]	,133921[b]	1,518000[b]	2,040958[b]
		3	2,753,000	,009488[l]	,119294[l]	2,494000[l]	3,012000[l]
		4	1,614,500	,034823[n]	,228711[n]	1,230927[n]	2,075000[n]
		5	2,685,000	,004186[k]	,075448[k]	2,559040[k]	2,824000[k]
		6	2,064,500	,000379[q]	,087857[q]	1,916000[q]	2,253888[q]
	3	1	-1,010,0 00	,022370[d]	,140600[d]	-1,230276[d]	-,68600 0[d]
		2	-2,753,0 00	-,009488[l]	,119294[l]	-3,012000[l]	-2,4940 00[l]
		4	-1,138,500	,069028[r]	,220130[r]	-1,516081[r]	-,659000[r]
		5	-,068000	,006113[i]	,084659[i]	-,226000[i]	,090000[i]
	4	6	-,688500	,001467[b]	,105031[b]	-,913000[b]	-,46400 0[b]
		1	,128500	-,023103[g]	,240889[g]	-,397000[g]	,654000[g]
		2	-1,614,50 0	-,034823[n]	,228711[n]	-2,075000[n]	-1,2309 27[n]
		3	1,138,500	-,069028[r]	,220130[r]	,659000[r]	1,516081[r]
	5	5	1,070,500	-,064781[g]	,214555[g]	,711000[g]	1,420842[g]
		6	,450000	-,050100[i]	,231942[i]	,024000[i]	,836571[i]
		1	-,942000	,003016[i]	,112365[i]	-1,146000[i]	-,738000[i]
		2	-2,685,000	-,004186[k]	,075448[k]	-2,824000[k]	-2,5590 40[k]
		3	,068000	-,006113[i]	,084659[i]	-,090000[i]	,226000[i]
		4	-1,070,500	,064781[g]	,214555[g]	-1,420842[g]	-,711000[g]
		6	-,620500	-,006893[b]	,050625[b]	-,725000[b]	-,517672[b]
	6	1	-,321500	,002658[k]	,130605[k]	-,586958[k]	-,051000[k]
		2	-2,064,500	-,000379[q]	,087857[q]	-2,253888[q]	-1,9160 00[q]
		3	,688500	-,001467[b]	,105031[q]	,464000[b]	,913000[b]
		4	-,450000	,050100[i]	,231942[i]	-,836571[i]	-,02400 0[i]
		5	,620500	,006893[b]	,050625[b]	,517672[b]	,725000b
CD tensile index	1	2	-,570000	,000968[b]	,048516[b]	-,663973[b]	-,486667[b]
		3	,258000	,000360[d]	,051915[d]	,149000[d]	,367000[d]
		4	-,338500	,002914[g]	,060458[g]	-,477000[g]	-,200000[g]
		5	,310500	-,000974[i]	,048098[i]	,217000[i]	,404000[i]
		6	-,398000	-,001379[k]	,055455[k]	-,514000[k]	-,284271[k]
	2	1	,570000	-,000968[b]	,048516[b]	,486667[b]	,663973[b]
		3	,828000	,002847[i]	,021218[i]	,787750l	,877000[i]
		4	,231500	,005884[n]	,040007[n]	,164218[n]	,310000[n]
		5	,880500	,000877[k]	,014547[k]	,857667[k]	,914000[k]
		6	,172000	-,002407[q]	,025220[q]	,127667[q]	,225650[q]
	3	1	-,258000	-,000360[d]	,051915[d]	-,367000[d]	-,149000[d]
		2	-,828000	-,002847[i]	,021218[i]	-,877000[i]	-,787750[i]
		4	-,596500	,007113[r]	,041718[r]	-,665288[r]	-,520326[r]
		5	,052500	-,000266[i]	,021227[i]	,005000[i]	,100000[i]
		6	-,656000	-,003509[b]	,030584[b]	-,726000[b]	-,599398[b]
	4	1	,338500	-,002914[g]	,060458[g]	,200000[g]	,477000[g]
		2	-,231500	-,005884[n]	,040007[n]	-,310000n	-,164218[n]
		3	,596500	-,007113[r]	,041718[r]	,520326[r]	,665288[r]

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		5	,649000	-,011018[g]	,040419[g]	,572000[g]	,718288[g]
		6	-,059500	-,011850[i]	,048272[i]	-,159000[i]	,022246[i]
	5	1	-,310500	,000974[i]	,048098[i]	-,404000[i]	-,217000[i]
		2	-,880500	-,000877[k]	,014547[k]	-,914000[k]	-,857667[k]
		3	-,052500	,000266[i]	,021227[i]	-,100000[i]	-,005000[i]
		4	-,649000	,011018[g]	,040419[g]	-,718288[g]	-,572000[g]
		6	-,708500	-,003095[b]	,024121[b]	-,763000[b]	-,655408[b]
	6	1	,398000	,001379[k]	,055455[k]	,284271[k]	,514000[k]
		2	-,172000	,002407[q]	,025220[q]	-,225650[q]	-,127667[q]
		3	,656000	,003509[b]	,030584[b]	,599398[b]	,726000[b]
		4	,059500	,011850[i]	,048272[i]	-,022246[i]	,159000[i]
		5	,708500	,003095[b]	,024121[b]	,655408[b]	,763000[b]
MD work capacity	1	2	,036000	,000117[b]	,007335[b]	,021205[b]	,048667[b]
		3	,117000	-,000725[d]	,007244[d]	,103000[d]	,128897[d]
		4	,077500	,000842[g]	,011230[g]	,052000[g]	,103000[g]
		5	,117000	-,000212[i]	,006937[i]	,105000[i]	,129000[i]
		6	,091500	-,000134[k]	,008036[k]	,075000[k]	,107705[k]
	2	1	-,036000	-,000117[b]	,007335[b]	-,048667[b]	-,021205[b]
		3	,081000	,000321[i]	,002715[i]	,075000[i]	,087000[i]
		4	,041500	,001305[n]	,009069[n]	,026244[n]	,059000[n]
		5	,081000	,000121[k]	,002196[k]	,077343[k]	,085000[k]
		6	,055500	-,000226[q]	,003636[q]	,049333[q]	,063530[q]
	3	1	-,117000	,000725[d]	,007244[d]	-,128897[d]	-,103000[d]
		2	-,081000	-,000321[i]	,002715[i]	-,087000[i]	-,075000[i]
		4	-,039500	,002539[r]	,008523[r]	-,054167[r]	-,023000[r]
		5	,000000	,000119[i]	,001552[i]	-,003000[i]	,003000[i]
		6	-,025500	-,000164[b]	,003599[b]	-,033000[b]	-,018000[b]
	4	1	-,077500	-,000842[g]	,011230[g]	-,103000[g]	-,052000[g]
		2	-,041500	-,001305[n]	,009069[n]	-,059000[n]	-,026244[n]
		3	,039500	-,002539[r]	,008523[r]	,023000[r]	,054167[r]
		5	,039500	-,002677[g]	,008800[g]	,025000[g]	,053759[g]
		6	,014000	-,002244[i]	,009873[i]	-,005000[i]	,030694[i]
	5	1	-,117000	,000212[i]	,006937[i]	-,129000[i]	-,105000[i]
		2	-,081000	-,000121[k]	,002196[k]	-,085000[k]	-,077343[k]
		3	,000000	-,000119[i]	,001552[i]	-,003000[i]	,003000[i]
		4	-,039500	,002677[g]	,008800[g]	-,053759[g]	-,025000[g]
		6	-,025500	-,000404[b]	,002923[b]	-,031000[b]	-,020044[b]
	6	1	-,091500	,000134[k]	,008036[k]	-,107705[k]	-,075000[k]
		2	-,055500	,000226[q]	,003636[q]	-,063530[q]	-,049333[q]
		3	,025500	,000164[r]	,003599[b]	,018000[b]	,033000[b]
		4	-,014000	,002244[i]	,009873[i]	-,030694[i]	,005000[i]
		5	,025500	,000404[b]	,002923[b]	,020044[b]	,031000[b]
CD work capacity	1	2	-,001500	,000004[b]	,000681[b]	-,002971[b]	-,000333[b]
		3	,003500	,000015[d]	,000694[d]	,002000[d]	,005000[d]
		4	,002500	,000014[g]	,000674[g]	,001000[g]	,004000[g]
		5	,005500	-,000002[i]	,000695[i]	,004000[i]	,007000[i]
		6	-,003500	-,000018[k]	,000716[k]	-,005000[k]	-,002029[k]
	2	1	,001500	-,000004[b]	,000681[b]	,000333[b]	,002971[b]
		3	,005000	,000070[l]	,000397[i]	,004250[i]	,006000[i]

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		4	,004000	,000080[n]	,000451[n]	,003240[n]	,005000[n]
		5	,007000	,000026[k]	,000433[k]	,006333[k]	,008000[k]
		6	-,002000	-,000012[q]	,000421[q]	-,002667[q]	-,001067[q]
	3	1	-,003500	-,000015[d]	,000694[d]	-,005000[d]	-,002000[d]
		2	-,005000	-,000070[l]	,000397[l]	-,006000[l]	-,004250[l]
		4	-,001000	,000036[r]	,000433[r]	-,001806[r]	-,000259[r]
		5	,002000	,000009[i]	,000448[i]	,001000[i]	,003000[i]
		6	-,007000	-,000050[b]	,000434[b]	-,008000[b]	-,006174[b]
	4	1	-,002500	-,000014[g]	,000674[g]	-,004000[g]	-,001000[g]
		2	-,004000	-,000080[n]	,000451[n]	-,005000[n]	-,003240[n]
		3	,001000	-,000036[r]	,000433[r]	,000259[r]	,001806[r]
		5	,003000	-,000073[g]	,000478[g]	,002000[g]	,003759[g]
		6	-,006000	-,000120[i]	,000474[i]	-,007000[i]	-,005231[i]
	5	1	-,005500	,000002[i]	,000695[i]	-,007000[i]	-,004000[i]
		2	-,007000	-,000026[k]	,000433[k]	-,008000[k]	-,006333[k]
		3	-,002000	-,000009[i]	,000448[i]	-,003000[i]	-,001000[i]
		4	-,003000	,000073[g]	,000478[g]	-,003759[g]	-,002000[g]
		6	-,009000	-,000040[b]	,000426[b]	-,010000[b]	-,008022[b]
	6	1	,003500	,000018[k]	,000716[k]	,002029[k]	,005000[k]
		2	,002000	,000012[q]	,000421[q]	,001067[q]	,002667[q]
		3	,007000	,000050[b]	,000434[b]	,006174[b]	,008000[b]
		4	,006000	,000120[i]	,000474[i]	,005231[i]	,007000[i]
		5	,009000	,000040[b]	,000426[b]	,008022[b]	,010000[b]
MD work to rupture	1	2	1,5000	,0042[b]	,2893[b]	,9088[b]	2,0000[b]
		3	4,7500	-,0286[d]	,2837[d]	4,2000[d]	5,2159[d]
		4	3,1500	,0373[g]	,4655[g]	2,1000[g]	4,2000[g]
		5	4,7000	-,0072[i]	,2737[i]	4,2000[i]	5,2000[i]
		6	3,7500	-,0057[k]	,3156[k]	3,1000[k]	4,3882[k]
	2	1	-1,5000	-,0042[b]	,2893[b]	-2,0000[b]	-,9088[b]
		3	3,2500	,0139[l]	,1132[l]	3,0000[l]	3,5000[l]
		4	1,6500	,0559[n]	,3887[n]	,9962[n]	2,4000[n]
		5	3,2000	,0058[k]	,0979[k]	3,0343[k]	3,4000[k]
		6	2,2500	-,0083[q]	,1489[q]	2,0000[q]	2,5799[q]
	3	1	-4,7500	,0286[d]	,2837[d]	-5,2159[d]	-4,2000[d]
		2	-3,2500	-,0139[i]	,1132[i]	-3,5000[i]	-3,0000[i]
		4	-1,6000	,1081[r]	,3646[r]	-2,2267[r]	-,9000[r]
		5	-,0500	,0064[i]	,0714[i]	-,2000[i]	,1000[i]
		6	-1,0000	-,0065[b]	,1440[b]	-1,3000[b]	-,7000[b]
	4	1	-3,1500	-,0373[g]	,4655[g]	-4,2000[g]	-2,1000[g]
		2	-1,6500	-,0559[n]	,3887[n]	-2,4000[n]	-,9962[n]
		3	1,6000	-,1081[r]	,3646[r]	,9000[r]	2,2267[r]
		5	1,5500	-,1134[g]	,3796[g]	,9000[g]	2,1759[g]
		6	,6000	-,0944[i]	,4196[i]	-,2000[i]	1,3078[i]
	5	1	-4,7000	,0072[i]	,2737[i]	-5,2000[i]	-4,2000[i]
		2	-3,2000	-,0058[k]	,0979[k]	-3,4000[k]	-3,0343[k]
		3	,0500	-,0064[i]	,0714[i]	-,1000[i]	,2000[i]
		4	-1,5500	,1134[g]	,3796[g]	-2,1759[g]	-,9000[g]
		6	-,9500	-,0161[b]	,1191[b]	-1,2000[b]	-,7044[b]
	6	1	-3,7500	,0057[k]	,3156[k]	-4,3882[k]	-3,1000[k]

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		2	-2,2500	,0083[q]	,1489[q]	-2,5799[q]	-2,0000[q]
		3	1,0000	,0065[b]	,1440[b]	,7000[b]	1,3000[b]
		4	-,6000	,0944[i]	,4196[i]	-1,3078[i]	,2000[i]
		5	,9500	,0161[b]	,1191[b]	,7044[b]	1,2000[b]
CD work to rupture	1	2	-,1000	-,0005[c]	,0433[c]	-,1993[c]	-,0252[c]
		3	,1500	-,0014[e]	,0290[e]	,1000[e]	,2000[e]
		4	,0500	-,0015[h]	,0259[h]	,0000[h]	,1000[h]
		5	,2000	,0037[g]	,0436[g]	,1205[g]	,3000[g]
		6	-,1500	,0017[i]	,0298[i]	-,2000[i]	-,1000[i]
	2	1	,1000	,0005[c]	,0433[c]	,0252[c]	,1993[c]
		3	,2500	,0032[i]	,0270[i]	,2000[i]	,3000[i]
		4	,1500	,0013[o]	,0273[o]	,1000[o]	,2000[o]
		5	,3000	,0014[l]	,0425[l]	,2333[l]	,4000[l]
		6	-,0500	,0007[k]	,0286[k]	-,1000[k]	,0000[k]
	3	1	-,1500	,0014[e]	,0290[e]	-,2000[e]	-,1000[e]
		2	-,2500	-,0032[i]	,0270[i]	-,3000[i]	-,2000[i]
		4	-,1000	,0000[s]	,0000[s]	-,1000[s]	-,1000[s]
		5	,0500	,0023[r]	,0338[r]	,0000[r]	,1000[r]
		6	-,3000	,0000[o]	,0000[o]	-,3000[o]	-,3000[o]
	4	1	-,0500	,0015[h]	,0259[h]	-,1000[h]	,0000[h]
		2	-,1500	-,0013[o]	,0273[o]	-,2000[o]	-,1000[o]
		3	,1000	,0000[s]	,0000[s]	,1000[s]	,1000[s]
		5	,1500	,0026[u]	,0316[u]	,1000[u]	,2000[u]
		6	-,2000	,0000[h]	,0000[h]	-,2000[h]	-,2000[h]
	5	1	-,2000	-,0037[g]	,0436[g]	-,3000[g]	-,1205[g]
		2	-,3000	-,0014[l]	,0425[l]	-,4000[l]	-,2333[l]
		3	-,0500	-,0023[r]	,0338[r]	-,1000[r]	,0000[r]
		4	-,1500	-,0026[u]	,0316[u]	-,2000[u]	-,1000[u]
		6	-,3500	,0001[p]	,0316[p]	-,4000[p]	-,3000[p]
	6	1	,1500	-,0017[i]	,0298[i]	,1000[i]	,2000[i]
		2	,0500	-,0007[k]	,0286[k]	,0000[k]	,1000[k]
		3	,3000	,0000[o]	,0000[o]	,3000[o]	,3000[o]
		4	,2000	,0000[h]	,0000[h]	,2000[h]	,2000[h]
		5	,3500	-,0001[p]	,0316[p]	,3000[p]	,4000[p]
Strain at break	1	2	4,9500	-,0093[c]	,2430[c]	4,5000[c]	5,3990[c]
		3	4,7000	,0274[f]	,2520[f]	4,2799[f]	5,2000[f]
		4	4,9500	,0235[g]	,2400[g]	4,4820[g]	5,5000[g]
		5	4,7000	,0082[j]	,2348[j]	4,3000[j]	5,1000[f]
		6	4,4000	-,0128[l]	,2494[l]	4,0000[l]	4,8000[l]
	2	1	-4,9500	,0093[c]	,2430[c]	-5,3990[c]	-4,5000[c]
		3	-,2500	,0068[m]	,0651[m]	-,3764[m]	-,1000[m]
		4	,0000	,0143[p]	,0960[p]	-,1667[p]	,2000[p]
		5	-,2500	,0023[m]	,0294[m]	-,3000[m]	-,2000[s]
		6	-,5500	,0044[k]	,0282[k]	-,6000[k]	-,5000[k]
	3	1	-4,7000	-,0274[f]	,2520[f]	-5,2000[f]	-4,2799[f]
		2	,2500	-,0068[m]	,0651[m]	,1000[m]	,3764[m]
		4	,2500	,0149[t]	,1106[t]	,0567[t]	,4496[t]
		5	,0000	-,0024[o]	,0572[o]	-,1000[o]	,1000[o]
		6	-,3000	-,0033[l]	,0611[l]	-,4000[l]	-,2000[l]

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	4	1	-4,9500	-,0235[g]	,2400[g]	-5,5000[g]	-4,4820[g]
		2	,0000	-,0143[p]	,0960[p]	-,2000[p]	,1667[p]
		3	-,2500	-,0149[t]	,1106[t]	-,4496[t]	-,0567[t]
		5	-,2500	-,0280[t]	,0911[t]	-,4000[t]	-,1000[t]
		6	-,5500	-,0160[o]	,0949[o]	-,7000[o]	-,4000[o]
	5	1	-4,7000	-,0082[j]	,2348[j]	-5,1000[j]	-4,3000[o]
		2	,2500	-,0023[m]	,0294[m]	,2000[m]	,3000[m]
		3	,0000	,0024[o]	,0572[o]	-,1000[o]	,1000[o]
		4	,2500	,0280[t]	,0911[t]	,1000[t]	,4000[t]
		6	-,3000	,0000[n]	,0000[n]	-,3000[n]	-,3000[n]
	6	1	-4,4000	,0128[l]	,2494[l]	-4,8000[l]	-4,0000[l]
		2	,5500	-,0044[k]	,0282[k]	,5000[k]	,6000[k]
		3	,3000	,0033[l]	,0611[l]	,2000[l]	,4000[l]
		4	,5500	,0160[o]	,0949[o]	,4000[o]	,7000[o]
		5	,3000	,0000[n]	,0000[n]	,3000[n]	,3000[n]

Figure 18: Bootstrap-based multiple comparisons of the paper mechanical properties of the six tissue products, with confidence intervals for pairwise differences.

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples; b. Based on 82 samples; c. Based on 80 samples; d. Based on 71 samples; e. Based on 66 samples; f. Based on 69 samples; g. Based on 70 samples; h. Based on 64 samples; i. Based on 75 samples; j. Based on 73 samples; k. Based on 81 samples; l. Based on 79 samples; m. Based on 76 samples; n. Based on 77 samples; o. Based on 72 samples p. Based on 74 samples; q. Based on 86 samples; r. Based on 68 samples; s. Based on 58 samples; t. Based on 67 samples; u. Based on 62 samples

MDTensilestrength

Tukey HSD[a]

		Subset for alpha = 0.05			
PRODUCTS	N	1	2	3	4
3	2	89,49000			
5	2	92,20600	92,20600		
6	2	117,02650	117,02650	117,02650	
1	2		129,89650	129,89650	
4	2			135,01950	
2	2				199,59950
Sig.		,200	,066	,536	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 19: Tukey HSD post hoc to identify which products differ.

Figures 20-27 provided the additional post-hoc/comparative statistical outputs retained in this study. Taken collectively with Figures 17-19, these analyses reinforced the conclusion that the differences among commercial products were systematic rather than attributable simply to random specimen-to-specimen variation. The similarity between products 3 and 5 and between products 1,4 and 6 was particularly relevant because it demonstrated that commercially distinct products could exhibit statistically comparable tensile performance even though their individual structural characteristics may have differed. Now we should have performed TWO-WAY ANOVA.

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CDTensilestrength

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05		
		1	2	3
5	2	34,24350		
3	2	36,34700	36,34700	
1	2		46,64500	
4	2			60,21150
6	2			62,57800
2	2			69,46300
Sig.		,956	,052	,080

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 20: Tukey HSD post hoc to identify which products differ.

MDtensileindex

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05			
		1	2	3	4
3	2	2,23700			
5	2	2,30500	2,30500		
6	2	2,92550	2,92550	2,92550	
1	2		3,24700	3,24700	
4	2			3,37550	
2	2				4,99000
Sig.		,200	,065	,535	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 21: Tukey HSD post hoc to identify which products differ.

CDtensileindex

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05		
		1	2	3
5	2	,85600		
3	2	,90850	,90850	
1	2		1,16650	
4	2			1,50500
6	2			1,56450
2	2			1,73650
Sig.		,956	,051	,080

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 22: Tukey HSD post hoc to identify which products differ.

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MDworkcapacity

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05		
		1	2	3
3	2	,04550		
5	2	,04550		
6	2	,07100		
4	2	,08500	,08500	
2	2		,12650	,12650
1	2			,16250
Sig.		,080	,066	,113

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 23: Tukey HSD post hoc to identify which products differ.

CDworkcapacity

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05			
		1	2	3	4
5	2	,00850			
3	2	,01050			
4	2	,01150	,01150		
1	2		,01400	,01400	
2	2			,01550	,01550
6	2				,01750
Sig.		,087	,166	,559	,315

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 24: Tukey HSD post hoc to identify which products differ.

MDworktorupture

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05		
		1	2	3
3	2	1,800		
5	2	1,850		
6	2	2,800		
4	2	3,400	3,400	
2	2		5,050	5,050
1	2			6,550
Sig.		,087	,077	,110

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 25: Tukey HSD post hoc to identify which products differ.

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CDworktorupture

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05			
		1	2	3	4
5	2	,350			
3	2	,400	,400		
4	2	,500	,500	,500	
1	2		,550	,550	,550
2	2			,650	,650
6	2				,700
Sig.		,147	,147	,147	,147

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 26: Tukey HSD post hoc to identify which products differ.

Strainatbreak

Tukey HSD[a]

PRODUCTS	N	Subset for alpha = 0.05	
		1	2
2	2	3,750	
4	2	3,750	
3	2	4,000	
5	2	4,000	
6	2	4,300	
1	2		8,700
Sig.		,370	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,000.

Figure 27: Tukey HSD post hoc to identify which products differ.

Descriptive Statistics

Dependent Variable: TensileStrength

Product	TestingDirection	Mean	Std. Deviation	N
1	MD	129,89650	10,464473	2
	CD	46,64500	4,381234	2
	Total	88,27075	48,509493	4
2	MD	199,59950	6,796003	2
	CD	69,46300	,971565	2
	Total	134,53125	75,238816	4
3	MD	89,49000	7,850299	2
	CD	36,34700	1,767767	2
	Total	62,91850	31,031869	4
4	MD	135,01950	19,284923	2
	CD	60,21150	3,449974	2
	Total	97,61550	44,646939	4
5	MD	92,20600	1,076217	2
	CD	34,24350	,922774	2
	Total	63,22475	33,474673	4
6	MD	117,02650	4,851460	2
	CD	62,57800	2,200516	2
	Total	89,80225	31,585957	4
Total	MD	127,20633	39,003934	12
	CD	51,58133	14,094766	12
	Total	89,39383	48,109705	24

Figure 28: Descriptive Statistics.

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The table in Figure 28 provided an initial comparison of tensile strength among the six tissue-paper products, taking into account both the machine direction (MD) and the cross direction (CD). The estimated marginal means were 88.27, 134.53, 62.92, 97.62, 63.22 and 89.80N/m for Products 1-6, respectively (Figure 28).

The homogeneity of error variances was assessed using Levene's test before interpreting the two-way analysis of variance (ANOVA). For tensile strength. As shown in Figure 29, Levene's test was statistically significant based on the mean, F(11,12), p<0.001. The same conclusion was obtained using the median, the median with adjusted degrees of freedom, and the trimmed mean.

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
TensileStrength	Based on Mean	7.125E+29	11	12	,000
	Based on Median	7.125E+29	11	12	,000
	Based on Median and with adjusted df	7.125E+29	11	5,388	,000
	Based on trimmed mean	9.467E+28	11	12	,000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: TensileStrength

b. Design: Intercept + Product + Direction + Product * Direction

Figure 29: Levene's Test of equality of error variances for Tensile Strength.

The table in Figure 30 presented tests of Between-Subjects Effects for tensile strength, examining the effects of tissue paper product, testing direction, (machine direction, MD and cross direction, CD) and their interaction. The overall model was statistically significant and accounted for 98.8% of the observed variability in tensile strength within the analyzed dataset.

Tests of Between-Subjects Effects

Dependent Variable: TensileStrength

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	52579,725[a]	11	4779,975	87,601	<,001	,988	963,614	1,000
Intercept	191790,179	1	191790,179	3514,886	<,001	,997	3514,886	1,000
Product	13968,698	5	2793,740	51,200	<,001	,955	256,000	1,000
Direction	34314,844	1	34314,844	628,879	<,001	,981	628,879	1,000
Product * Direction	4296,183	5	859,237	15,747	<,001	,868	78,735	1,000
Error	654,781	12	54,565					
Total	245024,685	24						
Corrected Total	53234,506	23						

a. R Squared = ,988 (Adjusted R Squared = ,976)

b. Computed using alpha = ,05

Figure 30: Tests of Between-Subjects Effects.

Multiple Comparisons

Dependent Variable: TensileStrength

Tukey HSD

(I) Product	(J) Product	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-46,26050*	5,223271	<,001	-63,80505	-28,71595
	3	25,35225*	5,223271	,004	7,80770	42,89680
	4	-9,34475	5,223271	,506	-26,88930	8,19980
	5	25,04600*	5,223271	,005	7,50145	42,59055
	6	-1,53150	5,223271	1,000	-19,07605	16,01305
2	1	46,26050*	5,223271	<,001	28,71595	63,80505
	3	71,61275*	5,223271	<,001	54,06820	89,15730
	4	36,91575*	5,223271	<,001	19,37120	54,46030
	5	71,30650*	5,223271	<,001	53,76195	88,85105
	6	44,72900*	5,223271	<,001	27,18445	62,27355
3	1	-25,35225*	5,223271	,004	-42,89680	-7,80770
	2	-71,61275*	5,223271	<,001	-89,15730	-54,06820
	4	-34,69700*	5,223271	<,001	-52,24155	-17,15245
	5	-,30625	5,223271	1,000	-17,85080	17,23830
	6	-26,88375*	5,223271	,003	-44,42830	-9,33920
4	1	9,34475	5,223271	,506	-8,19980	26,88930
	2	-36,91575*	5,223271	<,001	-54,46030	-19,37120
	3	34,69700*	5,223271	<,001	17,15245	52,24155
	5	34,39075*	5,223271	<,001	16,84620	51,93530
	6	7,81325	5,223271	,673	-9,73130	25,35780
5	1	-25,04600*	5,223271	,005	-42,59055	-7,50145
	2	-71,30650*	5,223271	<,001	-88,85105	-53,76195
	3	,30625	5,223271	1,000	-17,23830	17,85080
	4	-34,39075*	5,223271	<,001	-51,93530	-16,84620
	6	-26,57750*	5,223271	,003	-44,12205	-9,03295
6	1	1,53150	5,223271	1,000	-16,01305	19,07605
	2	-44,72900*	5,223271	<,001	-62,27355	-27,18445
	3	26,88375*	5,223271	,003	9,33920	44,42830
	4	-7,81325	5,223271	,673	-25,35780	9,73130
	5	26,57750*	5,223271	,003	9,03295	44,12205

Based on observed means.

The error term is Mean Square(Error) = 54,565.

*. The mean difference is significant at the ,05 level.

Figure 31: Tukey HSD Post Hoc Multiple Comparisons of Tensile Strength.

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The Tukey HSD post-hoc test in Figure 31 identified which of the six commercial tissue paper products differed significantly in their mean tensile strength. The analysis used a significance level of α=0.05, with statistically significant differences indicated by an asterisk and supported by the corresponding p-values and 95% confidence intervals. The results demonstrated substantial differences in tensile strength among the six products.

The table in Figure 32 grouped the tissue paper samples based on whether their mean tensile strength values differed significantly from one another. The samples that shared the same column (subset) had means that were not statistically different from each other. The samples in different columns possessed statistically significant differences in tensile strength (Figures 33-35).

TensileStrength

Tukey HSD[a,b]

Product	N	Subset 1	2	3
3	4	62,91850		
5	4	63,22475		
1	4		88,27075	
6	4		89,80225	
4	4		97,61550	
2	4			134,53125
Sig.		1,000	,506	1,000

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 54,565.

a. Uses Harmonic Mean Sample Size = 4,000.

b. Alpha = ,05.

Figure 32: Homogeneous Subsets of tissue paper products identified by Tukey HSD post-hoc analysis of tensile strength.

Correlations

		Grammage	MDTensilestrength	CDTensilestrength	Absorbency	MDtensileindex	CDtensileindex	MDworkcapacity	CDworkcapacity	Strainatbreak	MDworktorupture	CDworktorupture	MDCDratio
Grammage	Pearson Correlation	1	,833**	,855**	-,038	,833**	,855**	,789**	,599*	,272	,783**	,772**	,052
	Sig. (2-tailed)		<,001	<,001	,907	<,001	<,001	,002	,011	,393	,003	,003	,871
	N	12	12	12	12	12	12	12	12	12	12	12	12
MDTensilestrength	Pearson Correlation	,833**	1	,819**	,418	1,000**	,819**	,674*	,563	-,029	,668*	,640*	,361
	Sig. (2-tailed)	<,001		,001	,176	<,001	,001	,016	,057	,928	,018	,025	,248
	N	12	12	12	12	12	12	12	12	12	12	12	12
CDTensilestrength	Pearson Correlation	,855**	,819**	1	,156	,819**	1,000**	,447	,787**	-,188	,435	,854**	-,232
	Sig. (2-tailed)	<,001	,001		,628	,001	<,001	,146	,002	,557	,157	<,001	,468
	N	12	12	12	12	12	12	12	12	12	12	12	12
Absorbency	Pearson Correlation	-,038	,418	,156	1	,418	,156	-,175	-,325	-,638*	-,178	-,245	,382
	Sig. (2-tailed)	,907	,176	,628		,176	,629	,586	,302	,025	,580	,444	,220
	N	12	12	12	12	12	12	12	12	12	12	12	12
MDtensileindex	Pearson Correlation	,833**	1,000**	,819**	,418	1	,819**	,674*	,563	-,029	,668*	,640*	,361
	Sig. (2-tailed)	<,001	<,001	,001	,176		,001	,016	,057	,928	,018	,025	,249
	N	12	12	12	12	12	12	12	12	12	12	12	12
CDtensileindex	Pearson Correlation	,855**	,819**	1,000**	,156	,819**	1	,447	,787**	-,188	,436	,854**	-,232
	Sig. (2-tailed)	<,001	,001	<,001	,629	,001		,145	,002	,559	,157	<,001	,468
	N	12	12	12	12	12	12	12	12	12	12	12	12
MDworkcapacity	Pearson Correlation	,789**	,674*	,447	-,175	,674*	,447	1	,515	,705*	1,000**	,511	,449
	Sig. (2-tailed)	,002	,016	,146	,586	,016	,145		,087	,011	<,001	,089	,144
	N	12	12	12	12	12	12	12	12	12	12	12	12
CDworkcapacity	Pearson Correlation	,599*	,563	,787**	-,325	,563	,787**	,515	1	,177	,504	,971**	-,304
	Sig. (2-tailed)	,011	,057	,002	,302	,057	,002	,087		,582	,095	<,001	,336
	N	12	12	12	12	12	12	12	12	12	12	12	12
Strainatbreak	Pearson Correlation	,272	-,029	-,188	-,638*	-,029	-,188	,705*	,177	1	,710**	,092	,305
	Sig. (2-tailed)	,393	,928	,557	,025	,928	,559	,011	,582		,010	,777	,335
	N	12	12	12	12	12	12	12	12	12	12	12	12
MDworktorupture	Pearson Correlation	,783**	,668*	,435	-,178	,668*	,436	1,000**	,504	,710**	1	,501	,457
	Sig. (2-tailed)	,003	,018	,157	,580	,018	,157	<,001	,095	,010		,097	,135
	N	12	12	12	12	12	12	12	12	12	12	12	12
CDworktorupture	Pearson Correlation	,772**	,640*	,854**	-,245	,640*	,854**	,511	,971**	,092	,501	1	-,283
	Sig. (2-tailed)	,003	,025	<,001	,444	,025	<,001	,089	<,001	,777	,097		,373
	N	12	12	12	12	12	12	12	12	12	12	12	12
MDCDratio	Pearson Correlation	,052	,361	-,232	,382	,361	-,232	,449	-,304	,305	,457	-,283	1
	Sig. (2-tailed)	,871	,248	,468	,220	,249	,468	,144	,336	,335	,135	,373	
	N	12	12	12	12	12	12	12	12	12	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 33: Correlation Analysis.

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Correlation Matrix

		Grammage	Absorbency	MDTensilestrength	CDTensilestrength	MDtensileindex	CDtensileindex	MDworkcapacity	CDworkcapacity	Strainatbreak	MDworktorupture	CDworktorupture
Correlation	Grammage	1,000	-,038	,833	,855	,833	,855	,789	,699	,272	,783	,772
	Absorbency	-,038	1,000	,418	,156	,418	,156	-,175	-,325	-,638	-,178	-,245
	MDTensilestrength	,833	,418	1,000	,819	1,000	,819	,674	,563	-,029	,668	,640
	CDTensilestrength	,855	,156	,819	1,000	,819	1,000	,447	,787	-,188	,435	,854
	MDtensileindex	,833	,418	1,000	,819	1,000	,819	,674	,563	-,029	,668	,640
	CDtensileindex	,855	,156	,819	1,000	,819	1,000	,447	,787	-,188	,436	,854
	MDworkcapacity	,789	-,175	,674	,447	,674	,447	1,000	,515	,705	1,000	,511
	CDworkcapacity	,699	-,325	,563	,787	,563	,787	,515	1,000	,177	,504	,971
	Strainatbreak	,272	-,638	-,029	-,188	-,029	-,188	,705	,177	1,000	,710	,092
	MDworktorupture	,783	-,178	,668	,435	,668	,436	1,000	,504	,710	1,000	,501
	CDworktorupture	,772	-,245	,640	,854	,640	,854	,511	,971	,092	,501	1,000

Figure 34: Factor Analysis- Principal Component Analysis.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,382
Bartlett's Test of Sphericity	Approx. Chi-Square	415,117
	df	55
	Sig.	<,001

Figure 35: Kaiser -Meyer-Olkin (KMO) Measure of sampling adequacy and Bartllett's test of sphericity.

Anti-image Matrices

		Grammage	Absorbency	MDTensilestrength	CDTensilestrength	MDtensileindex	CDtensileindex	MDworkcapacity	CDworkcapacity	Strainatbreak	MDworktorupture	CDworktorupture
Anti-image Covariance	Grammage	,000	,000	2,723E-7	-3,969E-6	-2,722E-7	4,041E-6	1,977E-5	,000	,000	-1,990E-5	,000
	Absorbency	,000	,019	-1,331E-6	1,409E-5	1,330E-6	-1,451E-5	,000	-8,498E-5	,000	,000	,001
	MDTensilestrength	2,723E-7	-1,331E-6	6,177E-10	-8,231E-9	-6,175E-10	8,374E-9	4,748E-8	4,287E-7	-3,715E-7	-4,813E-8	-6,886E-7
	CDTensilestrength	-3,969E-6	1,409E-5	-8,231E-9	1,747E-7	8,229E-9	-1,806E-7	-5,977E-7	-6,798E-6	5,586E-6	6,000E-7	1,111E-5
	MDtensileindex	-2,722E-7	1,330E-6	-6,175E-10	8,229E-9	6,173E-10	-8,372E-9	-4,746E-8	-4,286E-7	3,714E-7	4,811E-8	6,884E-7
	CDtensileindex	4,041E-6	-1,451E-5	8,374E-9	-1,806E-7	-8,372E-9	1,869E-7	6,079E-7	6,927E-6	-5,693E-6	-6,102E-7	-1,133E-5
	MDworkcapacity	1,977E-5	,000	4,748E-8	-5,977E-7	-4,746E-8	6,079E-7	3,972E-6	2,906E-5	-2,691E-5	-4,049E-6	-4,834E-5
	CDworkcapacity	,000	-8,498E-5	4,287E-7	-6,798E-6	-4,286E-7	6,927E-6	2,906E-5	,000	,000	-2,897E-5	-,001
	Strainatbreak	,000	,000	-3,715E-7	5,586E-6	3,714E-7	-5,693E-6	-2,691E-5	,000	,000	2,701E-5	,000
	MDworktorupture	-1,990E-5	,000	-4,813E-8	6,000E-7	4,811E-8	-6,102E-7	-4,049E-6	-2,897E-5	2,701E-5	4,130E-6	4,834E-5
	CDworktorupture	,000	,001	-6,886E-7	1,111E-5	6,884E-7	-1,133E-5	-4,834E-5	-,001	,000	4,834E-5	,001
Anti-image Correlation	Grammage	,408[a]	-,203	,961	-,833	-,961	,820	,870	,967	-,994	-,859	-,961
	Absorbency	-,203	,458[a]	-,386	,243	,386	-,242	-,587	-,831	,210	,600	,144
	MDTensilestrength	,961	-,386	,391[a]	-,792	-1,000	,779	,959	,866	-,947	-,953	-,872
	CDTensilestrength	-,833	,243	-,792	,444[a]	,792	-1,000	-,719	-,816	,847	,706	,837
	MDtensileindex	-,961	,386	-1,000	,792	,391[a]	-,779	-,959	-,866	,947	,953	,872
	CDtensileindex	,820	-,242	,779	-1,000	-,779	,458[a]	,706	,804	-,834	-,695	-,825
	MDworkcapacity	,870	-,587	,959	-,719	-,959	,706	,369[a]	,732	-,855	-1,000	-,764
	CDworkcapacity	,967	-,831	,866	-,816	-,866	,804	,732	,371[a]	-,971	-,715	-,987
	Strainatbreak	-,994	,210	-,947	,847	,947	-,834	-,855	-,971	,174[a]	,842	,967
	MDworktorupture	-,859	,600	-,953	,706	,953	-,695	-1,000	-,715	,842	,370[a]	,749
	CDworktorupture	-,961	,144	-,872	,837	,872	-,825	-,764	-,987	,967	,749	,389[a]

a. Measures of Sampling Adequacy(MSA)

Figure 36: Anti-image Matrices for the factor analysis of tissue-paper properties.

The anti-image correlation matrix in Figure 36 was examined to assess the suitability of the individual variables for inclusion in the factor analysis.

The table in Figure 37 presented the initial and extraction communalities for each variable included in the analysis.

Communalities

	Initial	Extraction
Grammage	1,000	,920
Absorbency	1,000	,969
MDTensilestrength	1,000	,984
CDTensilestrength	1,000	,976
MDtensileindex	1,000	,984
CDtensileindex	1,000	,976
MDworkcapacity	1,000	,995
CDworkcapacity	1,000	,938
Strainatbreak	1,000	,988
MDworktorupture	1,000	,995
CDworktorupture	1,000	,968

Extraction Method: Principal Component Analysis.

Figure 37: Communalities of the variables included in the factor analysis of tissue-paper properties.

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The table in Figure 38 presented the eigenvalues, percentage of variance and cumulative percentage of variance explained by each factor or component.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6,811	61,921	61,921	6,811	61,921	61,921	5,215	47,405	47,405
2	2,476	22,506	84,427	2,476	22,506	84,427	3,332	30,295	77,700
3	1,409	12,807	97,234	1,409	12,807	97,234	2,149	19,533	97,234
4	,210	1,910	99,143						
5	,051	,463	99,607						
6	,026	,232	99,839						
7	,017	,152	99,991						
8	,001	,009	100,000						
9	2,447E-5	,000	100,000						
10	2,367E-7	2,152E-6	100,000						
11	3,081E-10	2,801E-9	100,000						

Extraction Method: Principal Component Analysis.

Figure 38: Total variance explained by the extracted factors in the Factor Analysis of Tissue-Paper Properties.

The plot in Figure 39, illustrated the contribution of each component to the total variance and facilitated the identification of the number of components to retain by examining the point at which the curve began to level off (the scree or elbow criterion). Components preceding this point accounted for a comparatively greater proportion of the total variance, whereas subsequent components contributed progressively less.

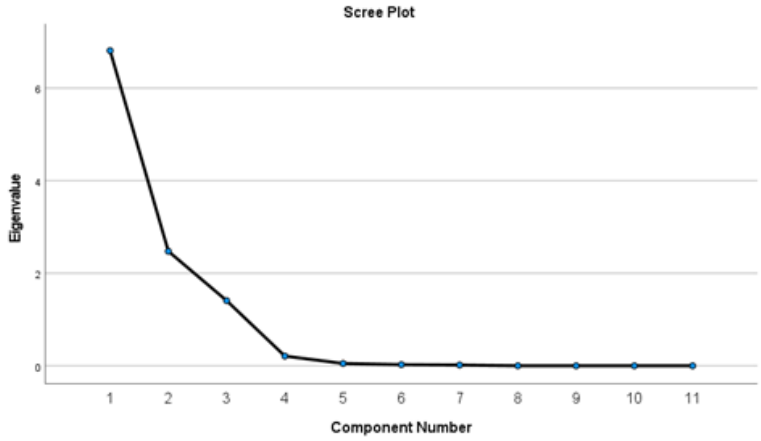


Figure 39: Scree plot of the principal component analysis (PCA), showing the eigenvalues of the extracted components in descending order.

Component Matrix[a]

	Component		
	1	2	3
Grammage	,955		
MDTensilestrength	,899		
MDtensileindex	,899		
CDtensileindex	,898		
CDTensilestrength	,898		
CDworktorupture	,864		-,471
CDworkcapacity	,818		-,510
MDworkcapacity	,782	,509	
MDworktorupture	,774	,516	
Strainatbreak		,958	
Absorbency		-,789	,588

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Figure 40: The Component Matrix obtained from principal component analysis (PCA), showing the loadings of the measured variables on the extracted components.

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The table in Figure 40 displayed the component loadings, which were the Pearson correlation coefficients between each original observed variable and each extracted principal component. The rows represented the properties measured in the dataset and the columns represented the extracted principal components.

The table in Figure 41 showed the factor loadings of the measured physical and mechanical properties of the tissue paper samples after component rotation.

Rotated Component Matrix[a]

	Component		
	1	2	3
CDworktorupture	,953		
CDtensileindex	,942		
CDTensilestrength	,942		
CDworkcapacity	,911		
Grammage	,754	,567	
MDtensileindex	,659	,451	,589
MDTensilestrength	,659	,451	,589
MDworktorupture		,938	
MDworkcapacity		,933	
Strainatbreak		,838	-,513
Absorbency			,960

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Figure 41: Rotated component matrix obtained from principal Component analysis (PCA).

The table in Figure 42 showed the coefficients describing the rotation applied to the initial component solution.

Component Transformation Matrix

Component	1	2	3
1	,832	,517	,200
2	-,248	,669	-,701
3	-,496	,534	,685

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Figure 42: Component transformation matrix obtained from principal component analysis.

Principal Component Analysis (Figure 43) revealed which properties-controlled tissue performance. Figures 33-43 presented correlation and principal component analysis (PCA) outputs.

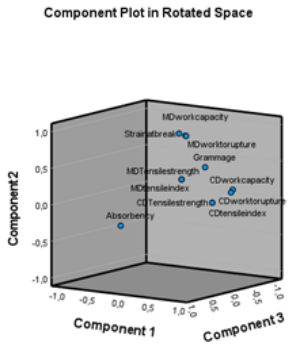


Figure 43: Component plot illustrating the relationships between the physical and mechanical properties of the investigated tissue paper products in the principal component space.

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Two-way analysis of variance

A two-way factorial ANOVA based on Table 5, was conducted using tensile strength as the dependent variable and product and direction as fixed factors. The experimental design was balanced, with 40 observations for each product and 120 observations for each testing direction. The factorial analysis was based on the complete 240-observation dataset.

Table 5: Physical and mechanical properties of the six commercial tissue paper products, related to Table 1.

Product	Subsample	Specimen	Direction	Grammage	Absorbency	Tensile strength	Tensile Index	Work Capacity	Work to Rupture	Strain
1	A	1	MD	17,6	5	100,796	2,52	0,128	5,1	10,9
1	A	1	CD	17,6	5	28,303	0,708	0,007	0,3	
1	A	2	MD	17,6	5	126,416	3,16	0,144	5,7	9,3
1	A	2	CD	17,6	5	49,712	1,243	0,013	0,5	
1	A	3	MD	17,6	5	143,711	3,593	0,181	7,2	10,4
1	A	3	CD	17,6	5	43,636	1,091	0,016	0,6	
1	A	4	MD	17,6	5	111,777	2,794	0,143	5,7	10,6
1	A	4	CD	17,6	5	52,104	1,303	0,016	0,6	2,2
1	A	5	MD	17,6	5	114,783	2,87	0,145	5,8	10,6
1	A	5	CD	17,6	5	36,353	0,909	0,011	0,4	
1	A	6	MD	17,6	5	138,689	3,467	0,172	6,9	10
1	A	6	CD	17,6	5	50,647	1,266	0,016	0,6	5,4
1	A	7	MD	17,6	5	116,177	2,904	0,15	6	11
1	A	7	CD	17,6	5	42,59	1,065	0,017	0,7	
1	A	8	MD	17,6	5	121,38	3,034	0,144	5,8	9,2
1	A	8	CD	17,6	5	45,354	1,134	0,011	0,4	
1	A	9	MD	17,6	5	120,97	3,024	0,153	6,1	10,5
1	A	9	CD	17,6	5	40,135	1,003	0,014	0,6	
1	A	10	MD	17,6	5	130,27	3,257	0,155	6,2	9,7
1	A	10	CD	17,6	5	46,64	1,166	0,012	0,5	
1	B	1	MD	17,6	5	97,094	2,427	0,111	4,5	10,2
1	B	1	CD	17,6	5	41,105	1,028	0,012	0,5	
1	B	2	MD	17,6	5	155,715	3,893	0,205	8,2	11,3
1	B	2	CD	17,6	5	60,417	1,51	0,015	0,6	3
1	B	3	MD	17,6	5	141,153	3,529	0,172	6,9	10,5
1	B	3	CD	17,6	5	43,746	1,094	0,014	0,6	
1	B	4	MD	17,6	5	159,517	3,988	0,205	8,2	11,5
1	B	4	CD	17,6	5	58,531	1,463	0,017	0,7	3,5
1	B	5	MD	17,6	5	134,307	3,358	0,175	7	11,1
1	B	5	CD	17,6	5	44,072	1,102	0,016	0,6	
1	B	6	MD	17,6	5	153,28	3,832	0,196	7,8	10,8
1	B	6	CD	17,6	5	57,118	1,428	0,018	0,7	3
1	B	7	MD	17,6	5	157,768	3,944	0,206	8,3	11
1	B	7	CD	17,6	5	41,426	1,036	0,014	0,6	
1	B	8	MD	17,6	5	132,866	3,322	0,173	6,9	11,3
1	B	8	CD	17,6	5	54,159	1,354	0,016	0,6	2,6
1	B	9	MD	17,6	5	77,063	1,927	0,078	3,1	9,7
1	B	9	CD	17,6	5	54,707	1,368	0,015	0,6	3,3
1	B	10	MD	17,6	5	164,194	4,105	0,223	8,9	11,7
1	B	10	CD	17,6	5	42,148	1,054	0,014	0,6	
2	A	1	MD	18	8	221,157	5,529	0,137	5,5	4,8
2	A	1	CD	18	8	78,68	1,967	0,018	0,7	2,9

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2	A	2	MD	18	8	204,746	5,119	0,145	5,8	5,6
2	A	2	CD	18	8	62,65	1,566	0,012	0,5	2,7
2	A	3	MD	18	8	202,471	5,062	0,136	5,5	5,2
2	A	3	CD	18	8	64,445	1,611	0,013	0,5	1,6
2	A	4	MD	18	8	217,565	5,439	0,139	5,5	5,1
2	A	4	CD	18	8	78,858	1,971	0,019	0,8	1,8
2	A	5	MD	18	8	204,038	5,101	0,114	4,6	4,7
2	A	5	CD	18	8	77,574	1,939	0,022	0,9	3
2	A	6	MD	18	8	198,143	4,954	0,13	5,2	5,2
2	A	6	CD	18	8	77,096	1,927	0,021	0,8	2,6
2	A	7	MD	18	8	185,996	4,65	0,099	3,9	4,4
2	A	7	CD	18	8	58,742	1,469	0,012	0,5	2,5
2	A	8	MD	18	8	194,282	4,857	0,136	5,4	5,3
2	A	8	CD	18	8	63,948	1,599	0,015	0,6	3,4
2	A	9	MD	18	8	197,817	4,945	0,108	4,3	4,4
2	A	9	CD	18	8	75,435	1,886	0,019	0,8	2,6
2	A	10	MD	18	8	217,84	5,446	0,157	6,3	5,9
2	A	10	CD	18	8	64,068	1,602	0,013	0,5	1,6
2	B	1	MD	17,9	8	208,338	5,208	0,126	5	5,1
2	B	1	CD	17,9	8	62,378	1,559	0,012	0,5	1,6
2	B	2	MD	17,9	8	216,067	5,402	0,153	6,1	5,4
2	B	2	CD	17,9	8	71,485	1,787	0,019	0,8	2,6
2	B	3	MD	17,9	8	216,113	5,403	0,136	5,5	4,9
2	B	3	CD	17,9	8	69,144	1,729	0,014	0,6	1,5
2	B	4	MD	17,9	8	208,415	5,21	0,135	5,4	5,1
2	B	4	CD	17,9	8	76,57	1,914	0,018	0,7	3,3
2	B	5	MD	17,9	8	175,834	4,396	0,094	3,7	4,3
2	B	5	CD	17,9	8	73,988	1,85	0,017	0,7	3
2	B	6	MD	17,9	8	213,388	5,335	0,153	6,1	5,4
2	B	6	CD	17,9	8	63,802	1,595	0,012	0,5	1,5
2	B	7	MD	17,9	8	203,558	5,089	0,128	5,1	5
2	B	7	CD	17,9	8	68,353	1,709	0,014	0,6	2,6
2	B	8	MD	17,9	8	193,164	4,829	0,133	5,3	5,2
2	B	8	CD	17,9	8	72,213	1,805	0,015	0,6	2,4
2	B	9	MD	17,9	8	105,103	2,628	0,044	1,8	4,8
2	B	9	CD	17,9	8	62,227	1,556	0,012	0,5	1,7
2	B	10	MD	17,9	8	207,955	5,199	0,13	5,2	5,1
2	B	10	CD	17,9	8	67,602	1,69	0,015	0,6	3
3	A	1	MD	15,8	7	101,321	2,533	0,058	2,3	4,3
3	A	1	CD	15,8	7	47,413	1,185	0,015	0,6	
3	A	2	MD	15,8	7	50,77	1,269	0,016	0,6	3,6
3	A	2	CD	15,8	7	18,763	0,469	0,003	0,1	
3	A	3	MD	15,8	7	95,885	2,397	0,054	2,1	4,3
3	A	3	CD	15,8	7	44,912	1,123	0,014	0,5	
3	A	4	MD	15,8	7	66,751	1,669	0,033	1,3	4,4
3	A	4	CD	15,8	7	21,101	0,528	0,004	0,2	
3	A	5	MD	15,8	7	63,894	1,597	0,024	0,9	3,7
3	A	5	CD	15,8	7	46,78	1,17	0,014	0,6	
3	A	6	MD	15,8	7	102,183	2,555	0,061	2,4	5
3	A	6	CD	15,8	7	19,926	0,498	0,005	0,2	

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3	A	7	MD	15,8	7	67,238	1,681	0,024	1	2,7
3	A	7	CD	15,8	7	39,598	0,99	0,011	0,4	
3	A	8	MD	15,8	7	90,228	2,256	0,048	1,9	4,4
3	A	8	CD	15,8	7	46,256	1,156	0,015	0,6	
3	A	9	MD	15,8	7	98,18	2,455	0,057	2,3	4,5
3	A	9	CD	15,8	7	46,265	1,157	0,017	0,7	
3	A	10	MD	15,8	7	102,94	2,573	0,061	2,4	4,7
3	A	10	CD	15,8	7	44,958	1,124	0,014	0,6	
3	B	1	MD	15,9	7	101,288	2,532	0,054	2,2	4
3	B	1	CD	15,9	7	27,151	0,679	0,006	0,2	
3	B	2	MD	15,9	7	79,05	1,976	0,031	1,2	3,9
3	B	2	CD	15,9	7	44,734	1,118	0,016	0,6	
3	B	3	MD	15,9	7	114,659	2,866	0,066	2,6	4,3
3	B	3	CD	15,9	7	24,378	0,609	0,004	0,1	
3	B	4	MD	15,9	7	98,493	2,462	0,051	2	3,8
3	B	4	CD	15,9	7	22,929	0,573	0,004	0,1	
3	B	5	MD	15,9	7	93,944	2,349	0,047	1,9	3,9
3	B	5	CD	15,9	7	40,324	1,008	0,012	0,5	
3	B	6	MD	15,9	7	106,266	2,657	0,058	2,3	4,1
3	B	6	CD	15,9	7	30,762	0,769	0,007	0,3	
3	B	7	MD	15,9	7	80,579	2,014	0,033	1,3	3,4
3	B	7	CD	15,9	7	46,541	1,164	0,013	0,5	
3	B	8	MD	15,9	7	94,386	2,36	0,044	1,8	3,7
3	B	8	CD	15,9	7	44,536	1,113	0,017	0,7	
3	B	9	MD	15,9	7	101,095	2,527	0,057	2,3	4,3
3	B	9	CD	15,9	7	48,438	1,211	0,017	0,7	
3	B	10	MD	15,9	7	80,653	2,016	0,037	1,5	3,6
3	B	10	CD	15,9	7	21,182	0,53	0,004	0,1	
4	A	1	MD	17,5	7	92,895	2,322	0,05	2	4,5
4	A	1	CD	17,5	7	56,895	1,422	0,012	0,5	3,2
4	A	2	MD	17,5	7	125,522	3,138	0,067	2,7	4,4
4	A	2	CD	17,5	7	72,459	1,811	0,016	0,6	1,7
4	A	3	MD	17,5	7	116,543	2,914	0,059	2,3	4,2
4	A	3	CD	17,5	7	71,696	1,792	0,015	0,6	1,5
4	A	4	MD	17,5	7	108,215	2,705	0,066	2,6	4,6
4	A	4	CD	17,5	7	62,088	1,552	0,012	0,5	1,7
4	A	5	MD	17,5	7	147,876	3,697	0,107	4,3	5,5
4	A	5	CD	17,5	7	44,84	1,121	0,007	0,3	
4	A	6	MD	17,5	7	128,561	3,214	0,081	3,3	4,7
4	A	6	CD	17,5	7	65,838	1,646	0,012	0,5	1,4
4	A	7	MD	17,5	7	116,767	2,919	0,058	2,3	4,4
4	A	7	CD	17,5	7	48,328	1,208	0,01	0,4	
4	A	8	MD	17,5	7	103,4	2,585	0,05	2	4,4
4	A	8	CD	17,5	7	49,706	1,243	0,008	0,3	
4	A	9	MD	17,5	7	151,797	3,795	0,107	4,3	5,5
4	A	9	CD	17,5	7	56,125	1,403	0,008	0,3	1,5
4	A	10	MD	17,5	7	122,255	3,056	0,065	2,6	4,4
4	A	10	CD	17,5	7	49,739	1,243	0,013	0,5	
4	B	1	MD	17,6	7	175,536	4,388	0,138	5,5	6,1
4	B	1	CD	17,6	7	79,762	1,994	0,015	0,6	1,6

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4	B	2	MD	17,6	7	127,37	3,184	0,076	3	4,8
4	B	2	CD	17,6	7	76,074	1,902	0,013	0,5	1,3
4	B	3	MD	17,6	7	163,266	4,082	0,119	4,8	5,6
4	B	3	CD	17,6	7	45,796	1,145	0,008	0,3	
4	B	4	MD	17,6	7	122,25	3,056	0,064	2,6	4,5
4	B	4	CD	17,6	7	42,041	1,051	0,006	0,2	
4	B	5	MD	17,6	7	133,267	3,332	0,077	3,1	4,7
4	B	5	CD	17,6	7	45,317	1,133	0,01	0,4	
4	B	6	MD	17,6	7	179,414	4,485	0,143	5,7	6
4	B	6	CD	17,6	7	76,058	1,901	0,016	0,6	2,7
4	B	7	MD	17,6	7	153,377	3,834	0,107	4,3	5,4
4	B	7	CD	17,6	7	55,076	1,377	0,011	0,5	2,4
4	B	8	MD	17,6	7	139,394	3,485	0,082	3,3	4,8
4	B	8	CD	17,6	7	78,43	1,961	0,015	0,6	1,4
4	B	9	MD	17,6	7	133,114	3,328	0,072	2,9	4,6
4	B	9	CD	17,6	7	85,394	2,135	0,017	0,7	1,5
4	B	10	MD	17,6	7	159,573	3,989	0,115	4,6	5,4
4	B	10	CD	17,6	7	42,564	1,064	0,008	0,3	
5	A	1	MD	15,9	7	124,736	3,118	0,072	2,9	4,5
5	A	1	CD	15,9	7	39,582	0,99	0,009	0,4	
5	A	2	MD	15,9	7	112,328	2,808	0,064	2,6	4,5
5	A	2	CD	15,9	7	31,209	0,78	0,007	0,3	
5	A	3	MD	15,9	7	95,319	2,383	0,046	1,8	4,9
5	A	3	CD	15,9	7	29,16	0,729	0,006	0,2	
5	A	4	MD	15,9	7	54,967	1,374	0,018	0,7	3
5	A	4	CD	15,9	7	46,63	1,166	0,012	0,5	
5	A	5	MD	15,9	7	82,7	2,067	0,036	1,4	3,3
5	A	5	CD	15,9	7	26,812	0,67	0,005	0,2	
5	A	6	MD	15,9	7	93,296	2,332	0,044	1,8	3,8
5	A	6	CD	15,9	7	44,925	1,123	0,014	0,6	
5	A	7	MD	15,9	7	80,62	2,015	0,037	1,5	3,9
5	A	7	CD	15,9	7	26,235	0,656	0,004	0,2	
5	A	8	MD	15,9	7	105,646	2,641	0,057	2,3	4,5
5	A	8	CD	15,9	7	39,672	0,992	0,011	0,4	
5	A	9	MD	15,9	7	83,885	2,097	0,041	1,6	3,7
5	A	9	CD	15,9	7	17,036	0,426	0,003	0,1	
5	A	10	MD	15,9	7	80,951	2,024	0,039	1,6	3,9
5	A	10	CD	15,9	7	34,643	0,866	0,01	0,4	
5	B	1	MD	16,2	6	93,615	2,34	0,045	1,8	4,7
5	B	1	CD	16,2	6	25,135	0,628	0,007	0,3	
5	B	2	MD	16,2	6	112,174	2,804	0,06	2,4	4,2
5	B	2	CD	16,2	6	31,45	0,786	0,008	0,3	
5	B	3	MD	16,2	6	114,137	2,853	0,062	2,5	4,3
5	B	3	CD	16,2	6	44,7	1,117	0,012	0,5	
5	B	4	MD	16,2	6	55,332	1,383	0,016	0,6	2,3
5	B	4	CD	16,2	6	39,388	0,985	0,009	0,4	
5	B	5	MD	16,2	6	60,141	1,504	0,026	1	3,8
5	B	5	CD	16,2	6	44,176	1,104	0,014	0,6	
5	B	6	MD	16,2	6	120,369	3,009	0,068	2,7	4,4
5	B	6	CD	16,2	6	35,76	0,894	0,01	0,4	

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5	B	7	MD	16,2	6	117,311	2,933	0,062	2,5	4,2
5	B	7	CD	16,2	6	44,686	1,117	0,011	0,5	
5	B	8	MD	16,2	6	39,055	0,976	0,009	0,4	
5	B	8	CD	16,2	6	40,137	1,003	0,01	0,4	
5	B	9	MD	16,2	6	105,833	2,646	0,057	2,3	4,3
5	B	9	CD	16,2	6	17,163	0,429	0,004	0,1	
5	B	10	MD	16,2	6	111,7	2,793	0,057	2,3	4,1
5	B	10	CD	16,2	6	26,367	0,659	0,005	0,2	
6	A	1	MD	17,3	5	71,654	1,791	0,032	1,3	6
6	A	1	CD	17,3	5	61,902	1,548	0,012	0,5	2,7
6	A	2	MD	17,3	5	111,649	2,791	0,064	2,6	4,2
6	A	2	CD	17,3	5	46,453	1,161	0,014	0,6	
6	A	3	MD	17,3	5	112,64	2,816	0,067	2,7	5,1
6	A	3	CD	17,3	5	64,546	1,614	0,016	0,6	3,9
6	A	4	MD	17,3	5	105,728	2,643	0,055	2,2	4,5
6	A	4	CD	17,3	5	66,048	1,651	0,019	0,8	4,4
6	A	5	MD	17,3	5	124,206	3,105	0,078	3,1	4,8
6	A	5	CD	17,3	5	63,889	1,597	0,018	0,7	4,5
6	A	6	MD	17,3	5	120,439	3,011	0,072	2,9	4,7
6	A	6	CD	17,3	5	73,173	1,829	0,019	0,8	3,8
6	A	7	MD	17,3	5	112,97	2,824	0,064	2,6	4,8
6	A	7	CD	17,3	5	52,796	1,32	0,017	0,7	2,9
6	A	8	MD	17,3	5	129,254	3,231	0,078	3,1	4,7
6	A	8	CD	17,3	5	68,632	1,716	0,017	0,7	4,2
6	A	9	MD	17,3	5	116,448	2,911	0,066	2,6	5,1
6	A	9	CD	17,3	5	62,741	1,569	0,02	0,8	3
6	A	10	MD	17,3	5	130,972	3,274	0,085	3,4	4,8
6	A	10	CD	17,3	5	50,042	1,251	0,013	0,5	4,2
6	B	1	MD	17,2	5	100,016	2,5	0,055	2,2	5,1
6	B	1	CD	17,2	5	52,467	1,312	0,015	0,6	3,3
6	B	2	MD	17,2	5	112,354	2,809	0,064	2,6	4,5
6	B	2	CD	17,2	5	62,816	1,57	0,016	0,6	4,7
6	B	3	MD	17,2	5	124,707	3,118	0,077	3,1	5,3
6	B	3	CD	17,2	5	65,148	1,629	0,019	0,8	3,1
6	B	4	MD	17,2	5	140,38	3,51	0,1	4	5,3
6	B	4	CD	17,2	5	62,452	1,561	0,016	0,7	2
6	B	5	MD	17,2	5	130,624	3,266	0,095	3,8	5,4
6	B	5	CD	17,2	5	62,579	1,564	0,018	0,7	4
6	B	6	MD	17,2	5	123,636	3,091	0,077	3,1	4,5
6	B	6	CD	17,2	5	64,262	1,607	0,02	0,8	3,8
6	B	7	MD	17,2	5	119,449	2,986	0,07	2,8	4,7
6	B	7	CD	17,2	5	68,387	1,71	0,02	0,8	5,3
6	B	8	MD	17,2	5	124,827	3,121	0,074	3	4,7
6	B	8	CD	17,2	5	69,666	1,742	0,017	0,7	3,4
6	B	9	MD	17,2	5	111,056	2,776	0,069	2,7	5,4
6	B	9	CD	17,2	5	65,255	1,631	0,017	0,7	2,5
6	B	10	MD	17,2	5	117,517	2,938	0,075	3	5,5
6	B	10	CD	17,2	5	68,308	1,708	0,018	0,7	3,6

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The table in Figure 44 presented the descriptive statistical measures for the analyzed variables, together with bootstrap estimates used to assess the stability and uncertainty of these statistics.

Univariate Analysis of Variance		
Notes		
Output Created		05-SEP-2026 09:37:09
Comments		
Input	Data	C:\Users\kater\OneDrive\Έγγραφα\XARTIAYGEIAS120726.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	152010
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		UNIANOVA Tensile strength BY Product Direction /METHOD=SSTYPE(3) /INTERCEPT=INCLUDE /POSTHOC=Product(TUKEY) /PRINT ETASQ DESCRIPTIVE HOMOGENEITY OPOWER /CRITERIA=ALPHA(.05) /DESIGN=Product Direction Product*Direction.
Resources	Processor Time	00:00:32,69
	Elapsed Time	00:00:26,93

Between-Subjects Factors			
		Value Label	N
Product	1		40
	2		40
	3		40
	4		40
	5		40
	6		40
Direction	1,000	MD	120
	2,000	CD	120

Descriptive Statistics							
Dependent Variable: Tensile strength							
Product	Direction		Statistic	Bootstrapa			
				Bias	Std. Error	95% Confidence Interval	
						Lower	Upper
1	MD	Mean	129,89630	-,25747	5,09089	119,02098	139,43112
		Std. Deviation	23,045345	-,953341	3,519501	15,006278	28,681013
		N	20	0	4	13	29
	CD	Mean	46,64515	,01176	1,85639	42,80785	50,30797
		Std. Deviation	8,020970	-,328652	1,206634	5,568898	10,101790
		N	20	0	4	12	29

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	Total	Mean	88,27072	,00032	7,01097	75,11857	102,25887
		Std. Deviation	45,466413	-,774126	2,541715	39,727860	49,521168
		N	40	0	6	29	51
2	MD	Mean	199,59950	,22128	5,69213	186,03052	208,33583
		Std. Deviation	25,029058	-3,094946	9,842730	8,200990	40,647121
		N	20	0	4	12	29
	CD	Mean	69,46290	,10317	1,46601	66,75091	72,45364
		Std. Deviation	6,493034	-,164497	,631987	4,992403	7,514731
		N	20	0	4	12	29
	Total	Mean	134,53120	,03275	10,57107	113,08050	156,67290
		Std. Deviation	68,324077	-,849710	2,015704	62,687044	71,007039
		N	40	0	6	29	52
3	MD	Mean	89,49015	-,03038	3,75022	81,67007	96,46439
		Std. Deviation	16,773550	-,532191	2,690697	10,632926	21,239490
		N	20	0	4	12	29
	CD	Mean	36,34735	-,18555	2,51938	31,05249	40,81859
		Std. Deviation	11,400800	-,280224	,984928	8,811823	12,655605
		N	20	0	4	12	28
	Total	Mean	62,91875	-,16439	4,91264	53,24773	72,42950
		Std. Deviation	30,406159	-,346858	1,891406	26,198558	33,445605
		N	40	0	6	29	52
4	MD	Mean	135,01960	,31103	5,19311	125,24313	145,52857
		Std. Deviation	23,515406	-,756850	3,165450	16,132041	28,975588
		N	20	0	4	12	29
	CD	Mean	60,21130	-,09305	3,16233	53,75837	66,04750
		Std. Deviation	14,310401	-,457112	1,369731	10,788646	16,466540
		N	20	0	4	12	29
	Total	Mean	97,61545	,13742	6,87637	84,91005	111,36663
		Std. Deviation	42,474817	-,476478	3,125300	35,403269	47,874296
		N	40	0	6	28	51
5	MD	Mean	92,20575	,16360	5,48958	81,59742	102,51055
		Std. Deviation	24,650773	-,834108	3,492737	16,477365	30,157776
		N	20	0	5	12	30
	CD	Mean	34,24330	-,01932	2,13358	29,88906	38,24232
		Std. Deviation	9,180208	-,337181	1,172200	6,455122	11,078872
		N	20	0	4	12	29
	Total	Mean	63,22453	,24262	5,64449	52,21019	74,63053
		Std. Deviation	34,620009	-,421329	2,338540	29,277447	38,565131
		N	40	0	6	30	52
6	MD	Mean	117,02630	-,03274	3,16958	110,17705	123,11319
		Std. Deviation	14,336546	-,854100	3,635359	7,250639	20,492522
		N	20	0	4	12	29
	CD	Mean	62,57810	,06222	1,52312	59,57750	65,48480
		Std. Deviation	6,941881	-,306914	1,199817	4,076688	8,797019
		N	20	0	4	12	29
	Total	Mean	89,80220	-,13454	4,63171	80,73986	98,87753
		Std. Deviation	29,728198	-,475312	1,511053	26,055510	32,240432
		N	40	0	6	29	51

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Total	MD	Mean	127,20627	-,00971	3,80643	119,58635	134,97501
		Std. Deviation	42,456206	-,273403	2,618056	36,781803	47,251143
		N	120	0	8	105	135
	CD	Mean	51,58135	-,00938	1,51908	48,51183	54,48709
		Std. Deviation	16,486531	-,045360	,838175	14,776515	17,999961
		N	120	0	8	105	135
	Total	Mean	89,39381	-,02569	3,15744	83,08527	95,50980
		Std. Deviation	49,684930	-,159686	2,303277	44,786898	53,988590
		N	240	0	0	240	240
a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples							

Figure 44: Descriptive statistics with bootstrap estimates for the physical and mechanical properties of the tissue paper samples.

The Levene test (Figure 45), included in the two-way ANOVA output (Table 5), was significant, $F(11,228) = 5.392$, $p<0.001$, indicating heterogeneity of variance among the product x direction groups. This assumption violation should be acknowledged when interpreting the factorial ANOVA. However, the design was balanced and the observed effects were very large, making the principal patterns highly pronounced. The reported effect sizes should therefore be considered alongside, rather than independently of, this variance heterogeneity.

Levene's Test of Equality of Error Variances[a,b]					
		Levene Statistic	df1	df2	Sig.
Tensile strength	Based on Mean	5,392	11	228	,000
	Based on Median	4,285	11	228	,000
	Based on Median and with adjusted df	4,285	11	118,244	,000
	Based on trimmed mean	4,927	11	228	,000
Tests the null hypothesis that the error variance of the dependent variable is equal across groups.					
a. Dependent variable: Tensile strength					
b. Design: Intercept + Product + Direction + Product * Direction					

Figure 45: The Levene test.

The main effect of product in Figure 46 was statistically significant, $F(5,228)=99.221$, $p<0.001$, $\eta p^2=0.685$. That confirmed that tensile performance differed substantially among the six commercial products even after the testing direction was included in the model. That represented a large product effect, indicating that the commercial products differed substantially in their overall tensile performance. The overall factorial model (Figure 46), was highly significant, $F(11,228) =169.764$, $p<0.001$, with $\eta p^2=0.891$ and $R^2=0.891$. Thus, the fitted model explained approximately 89.1% of the variance in tensile strength in the analyzed dataset.

Tests of Between-Subjects Effects								
Dependent Variable: Tensile strength								
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	525796,506[a]	11	47799,682	169,764	,000	,891	1867,400	1,000
Intercept	1917900,712	1	1917900,712	6811,549	,000	,968	6811,549	1,000
Product	139686,709	5	27937,342	99,221	,000	,685	496,106	1,000
Direction	343147,681	1	343147,681	1218,711	,000	,842	1218,711	1,000
Product* Direction	42962,115	5	8592,423	30,517	,000	,401	152,583	1,000
Error	64197,055	228	281,566					
Total	2507894,273	240						
Corrected Total	589993,561	239						

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a. R Squared = ,891 (Adjusted R Squared = ,886)
b. Computed using alpha = ,05

Figure 46: Effect of product

The table in Figure 47 presented pairwise comparisons between group means, indicating the mean differences, standard errors, significance levels and confidence intervals. The results were used to identify statistically significant differences between groups following analysis of variance (ANOVA) with the Tukey HSD procedure controlling the family-wise error rate across multiple comparisons.

Post Hoc Tests						
Product						
Multiple Comparisons						
Dependent Variable: Tensile strength						
Tukey HSD						
(I) Product	(J) Product	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-46,26047*	3,752106	,000	-57,04447	-35,47648
	3	25,35197*	3,752106	,000	14,56798	36,13597
	4	-9,34473	3,752106	,131	-20,12872	1,43927
	5	25,04620*	3,752106	,000	14,26221	35,83019
	6	-1,53148	3,752106	,999	-12,31547	9,25252
2	1	46,26048*	3,752106	,000	35,47648	57,04447
	3	71,61245*	3,752106	,000	60,82846	82,39644
	4	36,91575*	3,752106	,000	26,13176	47,69974
	5	71,30667*	3,752106	,000	60,52268	82,09067
	6	44,72900*	3,752106	,000	33,94501	55,51299
3	1	-25,35197*	3,752106	,000	-36,13597	-14,56798
	2	-71,61245*	3,752106	,000	-82,39644	-60,82846
	4	-34,69670*	3,752106	,000	-45,48069	-23,91271
	5	-,30578	3,752106	1,000	-11,08977	10,47822
	6	-26,88345*	3,752106	,000	-37,66744	-16,09946
4	1	9,34473	3,752106	,131	-1,43927	20,12872
	2	-36,91575*	3,752106	,000	-47,69974	-26,13176
	3	34,69670*	3,752106	,000	23,91271	45,48069
	5	34,39093*	3,752106	,000	23,60693	45,17492
	6	7,81325	3,752106	,300	-2,97074	18,59724
5	1	-25,04620*	3,752106	,000	-35,83019	-14,26221
	2	-71,30667*	3,752106	,000	-82,09067	-60,52268
	3	,30578	3,752106	1,000	-10,47822	11,08977
	4	-34,39093*	3,752106	,000	-45,17492	-23,60693
	6	-26,57768*	3,752106	,000	-37,36167	-15,79368
6	1	1,53148	3,752106	,999	-9,25252	12,31547
	2	-44,72900*	3,752106	,000	-55,51299	-33,94501
	3	26,88345*	3,752106	,000	16,09946	37,66744
	4	-7,81325	3,752106	,300	-18,59724	2,97074
	5	26,57768*	3,752106	,000	15,79368	37,36167

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Based on observed means.
The error term is Mean Square (Error) = 267,020.
*. The mean difference is significant at the ,05 level.

Figure 47: Multiple comparisons using Tukey's honestly significant difference (HSD) test for the physical and mechanical properties of the tissue paper samples.

The table in Figure 48 presented the bootstrap results for pairwise group comparisons, providing estimates of the differences between group means and Information on their uncertainty. The bootstrap procedure was used to evaluate the stability and precision of the estimated differences, complementing the conventional multiple-comparison analysis.

Bootstrap for Multiple Comparisons						
Dependent Variable: Tensile strength						
Tukey HSD						
(I) Product	(J) Product	Mean Difference (I-J)	Bootstrap[a]			
			Bias	Std. Error	95% Confidence Interval	
					Lower	Upper
1	2	-46,26047	-,03243	12,59852	-73,43172	-21,55509
	3	25,35197	,16471	8,62787	8,98725	43,34130
	4	-9,34473	-,13710	10,08557	-28,50692	11,07586
	5	25,04620	-,24230	8,96468	7,56917	42,88109
	6	-1,53148	,13486	8,50697	-18,42782	15,30844
2	1	46,26048	,03243	12,59852	21,55509	73,43172
	3	71,61245	,19714	11,99769	47,70661	95,35428
	4	36,91575	-,10467	12,72520	12,18332	62,76972
	5	71,30667	-,20987	11,84803	48,39830	94,61250
	6	44,72900	,16729	11,56983	21,63928	69,15505
3	1	-25,35197	-,16471	8,62787	-43,34130	-8,98725
	2	-71,61245	-,19714	11,99769	-95,35428	-47,70661
	4	-34,69670	-,30181	8,29420	-51,89747	-18,65126
	5	-,30578	-,40701	7,68679	-16,12668	14,62254
	6	-26,88345	-,02985	6,69060	-40,45136	-13,32458
4	1	9,34473	,13710	10,08557	-11,07586	28,50692
	2	-36,91575	,10467	12,72520	-62,76972	-12,18332
	3	34,69670	,30181	8,29420	18,65126	51,89747
	5	34,39093	-,10520	8,86738	17,01341	52,18041
	6	7,81325	,27196	8,18157	-8,93164	24,95487
5	1	-25,04620	,24230	8,96468	-42,88109	-7,56917
	2	-71,30667	,20987	11,84803	-94,61250	-48,39830
	3	,30578	,40701	7,68679	-14,62254	16,12668
	4	-34,39093	,10520	8,86738	-52,18041	-17,01341
	6	-26,57768	,37716	7,42737	-40,69200	-10,61218
6	1	1,53148	-,13486	8,50697	-15,30844	18,42782
	2	-44,72900	-,16729	11,56983	-69,15505	-21,63928
	3	26,88345	,02985	6,69060	13,32458	40,45136
	4	-7,81325	-,27196	8,18157	-24,95487	8,93164
	5	26,57768	-,37716	7,42737	10,61218	40,69200
a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples						

Figure 48: Table of Bootstrap results for multiple comparisons.

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The table in Figure 49, grouped products with statistically comparable mean tensile strengths into homogeneous subsets at the 5% significance level (α=0.05). Products appearing within the same subset did not exhibit statistically significant differences in mean tensile strength according to the Tukey HSD procedure (Figures 50 & 51).

Homogeneous Subsets				
Tensile strength				
Tukey HSD[a,b]				
Product	N	Subset		
		1	2	3
3	40	62,91875		
5	40	63,22453		
1	40		88,27072	
6	40		89,80220	
4	40		97,61545	
2	40			134,53120
Sig.		1,000	,131	1,000
Means for groups in homogeneous subsets are displayed. Based on observed means. The error term is Mean Square(Error) = 281,566.				
a. Uses Harmonic Mean Sample Size = 40,000.				
b. Alpha = ,05.				

Figure 49: Homogeneous subsets of tensile strength for the six tissue paper products, identified using Tukey's honestly significant difference post-hoc test.

Univariate Analysis of Variance		
Notes		
Output Created		05-SEP-2026 09:43:10
Comments		
Input	Data	C:\Users\kater\OneDrive\Έγγραφα\XARTIAYGEIAS120726.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	240
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		UNIANOVA Tensile strength BY Product Direction /METHOD=SSTYPE(3) /INTERCEPT=INCLUDE /POSTHOC=Product(TUKEY BTUKEY) /EMMEANS=TABLES(Product) COMPARE ADJ(BONFERRONI) /EMMEANS=TABLES(Direction) COMPARE ADJ(BONFERRONI) /PRINT ETASQ DESCRIPTIVE HOMOGENEITY OPOWER /CRITERIA=ALPHA(.05) /DESIGN=Product Direction Product*Direction.

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Resources	Processor Time	00:00:00,09
	Elapsed Time	00:00:00,10

Between-Subjects Factors			
		Value Label	N
Product	1		40
	2		40
	3		40
	4		40
	5		40
	6		40
Direction	1,000	MD	120
	2,000	CD	120

Descriptive Statistics				
Dependent Variable: Tensile strength				
Product	Direction	Mean	Std. Deviation	N
1	MD	129,89630	23,045345	20
	CD	46,64515	8,020970	20
	Total	88,27072	45,466413	40
2	MD	199,59950	25,029058	20
	CD	69,46290	6,493034	20
	Total	134,53120	68,324077	40
3	MD	89,49015	16,773550	20
	CD	36,34735	11,400800	20
	Total	62,91875	30,406159	40
4	MD	135,01960	23,515406	20
	CD	60,21130	14,310401	20
	Total	97,61545	42,474817	40
5	MD	92,20575	24,650773	20
	CD	34,24330	9,180208	20
	Total	63,22453	34,620009	40
6	MD	117,02630	14,336546	20
	CD	62,57810	6,941881	20
	Total	89,80220	29,728198	40
Total	MD	127,20627	42,456206	120
	CD	51,58135	16,486531	120
	Total	89,39381	49,684930	240

Figure 50: Table of Descriptive Statistics.

Levene's Test of Equality of Error Variances[a,b]					
		Levene Statistic	df1	df2	Sig.
Tensile strength	Based on Mean	5,392	11	228	,000
	Based on Median	4,285	11	228	,000
	Based on Median and with adjusted df	4,285	11	118,244	,000
	Based on trimmed mean	4,927	11	228	,000
Tests the null hypothesis that the error variance of the dependent variable is equal across groups.					
a. Dependent variable: Tensile strength					
b. Design: Intercept + Product + Direction + Product * Direction					

Figure 51: Table of Levene's Test of Equality of Error Variances.

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The interaction between product and testing direction was also highly significant, F(5,228)=30.517, p<0.001, ηp2=0.401 (Figure 52). That finding was particularly important because it demonstrated that the influence of testing direction was not identical for all six commercial products. Although every product was stronger in MD than in CD, the magnitude of the MD-CD difference varied among products. Therefore, the product type influenced not only absolute tensile strength but also the degree to which tensile performance depended on orientation. The interaction therefore provided statistical support for the product-specific differences in anisotropy identified through the MD/CD ratios. Therefore product 2 actually combined the highest tensile strength with the highest observed MD/CD ratio, whereas product 6, displayed the lowest directional ratio.

Tests of Between-Subjects Effects								
Dependent Variable: Tensile strength								
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	525796,506[a]	11	47799,682	169,764	,000	,891	1867,400	1,000
Intercept	1917900,712	1	1917900,712	6811,549	,000	,968	6811,549	1,000
Product	139686,709	5	27937,342	99,221	,000	,685	496,106	1,000
Direction	343147,681	1	343147,681	1218,711	,000	,842	1218,711	1,000
Product * Direction	42962,115	5	8592,423	30,517	,000	,401	152,583	1,000
Error	64197,055	228	281,566					
Total	2507894,273	240						
Corrected Total	589993,561	239						
a. R Squared = ,891 (Adjusted R Squared = ,886)								
b. Computed using alpha = ,05								

Figure 52: Table of Subjects Effects.

Estimated Marginal Means

The estimated marginal means and their confidence intervals were presented in the factorial ANOVA output. The estimated marginal means were 88.27, 134.53, 62.92, 97.62, 63.22, and 89.80N/m for products 1-6, respectively (Figure 53). Product 2 had an estimated marginal mean of 134.53N/m, while products 3 and 5 had values of 62.92 and 63.22N/m respectively. Products 1, 4 and 6, occupied an intermediate range of 88.27-97.62N/m.

1. Product				
Estimates				
Dependent Variable: Tensile strength				
Product	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	88,271	2,653	83,043	93,499
2	134,531	2,653	129,303	139,759
3	62,919	2,653	57,691	68,147
4	97,615	2,653	92,388	102,843
5	63,225	2,653	57,997	68,452
6	89,802	2,653	84,574	95,030

Figure 53: Table of Estimates.

The corresponding pairwise comparisons in Figure 54 further confirmed the significant differences involving product 2 and the similarity between products 3 and 5 and among products 1, 4 and 6 (Figure 55).

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Pairwise Comparisons						
Dependent Variable: Tensile strength						
(I) Product	(J) Product	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-46,260*	3,752	,000	-57,391	-35,130
	3	25,352*	3,752	,000	14,222	36,482
	4	-9,345	3,752	,202	-20,475	1,786
	5	25,046*	3,752	,000	13,916	36,177
	6	-1,531	3,752	1,000	-12,662	9,599
2	1	46,260*	3,752	,000	35,130	57,391
	3	71,612*	3,752	,000	60,482	82,743
	4	36,916*	3,752	,000	25,785	48,046
	5	71,307*	3,752	,000	60,176	82,437
	6	44,729*	3,752	,000	33,599	55,859
3	1	-25,352*	3,752	,000	-36,482	-14,222
	2	-71,612*	3,752	,000	-82,743	-60,482
	4	-34,697*	3,752	,000	-45,827	-23,566
	5	-,306	3,752	1,000	-11,436	10,825
	6	-26,883*	3,752	,000	-38,014	-15,753
4	1	9,345	3,752	,202	-1,786	20,475
	2	-36,916*	3,752	,000	-48,046	-25,785
	3	34,697*	3,752	,000	23,566	45,827
	5	34,391*	3,752	,000	23,260	45,521
	6	7,813	3,752	,576	-3,317	18,944
5	1	-25,046*	3,752	,000	-36,177	-13,916
	2	-71,307*	3,752	,000	-82,437	-60,176
	3	,306	3,752	1,000	-10,825	11,436
	4	-34,391*	3,752	,000	-45,521	-23,260
	6	-26,578*	3,752	,000	-37,708	-15,447
6	1	1,531	3,752	1,000	-9,599	12,662
	2	-44,729*	3,752	,000	-55,859	-33,599
	3	26,883*	3,752	,000	15,753	38,014
	4	-7,813	3,752	,576	-18,944	3,317
	5	26,578*	3,752	,000	15,447	37,708
Based on estimated marginal means						
*. The mean difference is significant at the ,05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

Figure 54: Table of Pairwise Comparisons.

Univariate Tests								
Dependent Variable: Tensile strength								
	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	139686,709	5	27937,342	99,221	,000	,685	496,106	1,000
Error	64197,055	228	281,566					
The F tests the effect of Product. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.								
a. Computed using alpha = ,05								

Figure 55: Table of Univariate Tests.

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The estimated overall mean was 127.21N/m for MD and 51.58N/m for CD (Figure 56). The difference between directions was therefore approximately 75.63N/m (Figure 57). That very large effect confirmed that tissue-paper tensile strength was strongly direction-dependent. Thus, testing direction represented the largest modeled source of systematic variation in tensile strength.

2. Direction				
Estimates				
Dependent Variable: Tensile strength				
Direction	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
MD	127,206	1,532	124,188	130,225
CD	51,581	1,532	48,563	54,600

Figure 56: Table of Estimates

Pairwise Comparisons						
Dependent Variable: Tensile strength						
(I) Direction	(J) Direction	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
MD	CD	75,625*	2,166	,000	71,356	79,893
CD	MD	-75,625*	2,166	,000	-79,893	-71,356
Based on estimated marginal means						
*. The mean difference is significant at the ,05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

Figure 57: Table of Pairwise Comparisons.

Univariate Tests								
Dependent Variable: Tensile strength								
	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	343147,681	1	343147,681	1218,711	,000	,842	1218,711	1,000
Error	64197,055	228	281,566					
The F tests the effect of Direction. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.								
a. Computed using alpha = ,05								

Figure 58: Table of Univariate Tests.

The effect of testing direction (Figure 58), was the largest main effect in the model, $F(1,228)=1218.711$, $p<0.001$, $\eta p^2=0.842$.

Figures 50-59 contained the additional factorial-analysis outputs. Figure 51 was identified as an ANOVA table, Figure 52 as an estimated-marginal-means or related comparison display, and Figures 53-59 as post-hoc comparisons and homogeneous-subset outputs.

Product							
Multiple Comparisons							
Dependent Variable: Tensile strength							
	(I) Product	(J) Product	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	1	2	-46,26047*	3,752106	,000	-57,04447	-35,47648
		3	25,35197*	3,752106	,000	14,56798	36,13597
		4	-9,34473	3,752106	,131	-20,12872	1,43927

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		5	25,04620*	3,752106	,000	14,26221	35,83019
		6	-1,53148	3,752106	,999	-12,31547	9,25252
	2	1	46,26048*	3,752106	,000	35,47648	57,04447
		3	71,61245*	3,752106	,000	60,82846	82,39644
		4	36,91575*	3,752106	,000	26,13176	47,69974
		5	71,30667*	3,752106	,000	60,52268	82,09067
		6	44,72900*	3,752106	,000	33,94501	55,51299
	3	1	-25,35197*	3,752106	,000	-36,13597	-14,56798
		2	-71,61245*	3,752106	,000	-82,39644	-60,82846
		4	-34,69670*	3,752106	,000	-45,48069	-23,91271
		5	-,30578	3,752106	1,000	-11,08977	10,47822
		6	-26,88345*	3,752106	,000	-37,66744	-16,09946
	4	1	9,34473	3,752106	,131	-1,43927	20,12872
		2	-36,91575*	3,752106	,000	-47,69974	-26,13176
		3	34,69670*	3,752106	,000	23,91271	45,48069
		5	34,39093*	3,752106	,000	23,60693	45,17492
		6	7,81325	3,752106	,300	-2,97074	18,59724
	5	1	-25,04620*	3,752106	,000	-35,83019	-14,26221
		2	-71,30667*	3,752106	,000	-82,09067	-60,52268
		3	,30578	3,752106	1,000	-10,47822	11,08977
		4	-34,39093*	3,752106	,000	-45,17492	-23,60693
		6	-26,57768*	3,752106	,000	-37,36167	-15,79368
	6	1	1,53148	3,752106	,999	-9,25252	12,31547
		2	-44,72900*	3,752106	,000	-55,51299	-33,94501
		3	26,88345*	3,752106	,000	16,09946	37,66744
		4	-7,81325	3,752106	,300	-18,59724	2,97074
		5	26,57768*	3,752106	,000	15,79368	37,36167
Based on observed means.							
The error term is Mean Square (Error) = 281,566.							
*. The mean difference is significant at the ,05 level.							

Figure 59: Table of Multiple Comparisons.

Homogeneous Subsets

Tukey comparisons (Figure 60) showed that product 2 differed significantly from every other product. Products 3and 5 did not differ significantly, while products 1,4 and 6, formed an intermediate group with no significant differences among these three products. The products could broadly be classified into three tensile-performance groups. The lower-strength group comprising the products 3 and 5, the intermediate-strength group comprising products 1,4, and 6 and the highest-strength group comprising product 2.

Tensile strength					
	Product	N	Subset		
			1	2	3
Tukey HSD[a,b]	3	40	62,91875		
	5	40	63,22453		
	1	40		88,27072	
	6	40		89,80220	
	4	40		97,61545	
	2	40			134,53120
	Sig.		1,000	,131	1,000

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Tukey B[a,b]	3	40	62,91875		
	5	40	63,22453		
	1	40		88,27072	
	6	40		89,80220	
	4	40		97,61545	
	2	40			134,53120
Means for groups in homogeneous subsets are displayed. Based on observed means. The error term is Mean Square(Error) = 281,566.					
a. Uses Harmonic Mean Sample Size = 40,000.					
b. Alpha = ,05.					

Figure 60: Table of Homogeneous Subsets.

Finally, Figures 1-12 and Tables 1-3 demonstrated that the six commercial tissues were mechanically distinct despite their relatively narrow grammage range. The dominant characteristic was anisotropy. The two-way ANOVA confirmed this pattern statistically and showed that direction accounted for a very large proportion of the modeled variation. Product type exerted a substantial independent effect and the significant Product x Direction interaction demonstrated that the directional response depended on the particular commercial product. Product 2 illustrated that clearly, combining high absolute tensile strength with a high MD/CD ratio. Product 6, exhibited a lower MD/CD ratio, indicating a comparatively smaller directional difference. Products 3 and 5 showed similarly low overall tensile performance, while Products 1,4 and 6 occupied an intermediate range. The combined use of tensile strength, tensile index, MD/CD ratio, strain at break, work capacity and work-to-rupture provided a more complete mechanical characterization than any single parameter. The MD/CD ratio added structural information concerning directional dependence, while tensile index permitted comparison after accounting for basis weight and energy-related parameters characterized the behavior of the sheet up to failure.

Discussion

The most pronounced finding in this study was the strong anisotropy observed in every product. Mean tensile strength in MD was approximately 2.47 times the overall CD value. That behavior was consistent with the structural characteristics of paper, in which preferential fiber orientation developed during sheet formation and manufacturing. The large main effect of testing direction (ηp^2=0.842) provided strong statistical evidence for this anisotropic behavior. That effect was larger than the product effect alone, although product type also exerted a substantial influence (ηp^2=0.685). Consequently, both the identity of the product and the direction in which the sheet was loaded were important determinants of tensile performance. Product 2 was particularly distinctive. It showed the highest overall tensile strength, with a MD mean of 199.6N/m and a CD mean of 69.5N/m. Its average MD/CD ratio of 2.87 was also the highest among the six products. That combination suggested a strongly direction -dependent structure and a comparatively high level of mechanical reinforcement along the machine direction. At the opposite end of the tensile-strength scale, products 3 and 5, exhibited very similar means, 62.92N/m and 63.22N/m, respectively. The post-hoc analysis confirmed that these two products were not significantly different in overall tensile strength. Their similar performance indicated that differences in commercial formulation or manufacturing structure may have produced comparable mechanical outcomes even when the products were independently manufactured. Products 1, 4, and 6 formed an intermediate group. Their overall means ranged from approximately 88N/m to 98N/m, and pairwise comparisons did not reveal significant differences among these products. However, their directional behavior was not identical. Product 6 had the lowest MD/CD ratio, 1.87 while product 1 had a ratio of 2.78 and product 4 a ratio of 2.24.

Thus, two products with relatively similar overall tensile strengths may have had different degrees of anisotropy. That observation was reinforced by the statistically significant product x direction interaction. The interaction indicated that the effect of direction depended on the product. It was therefore insufficient to report only an overall MD-versus-CD difference; the directional response of each commercial product should also be considered. The MD/CD ratio was particularly useful in this context because it separated directional structure from absolute strength to some extent. A high ratio indicated a pronounced difference between MD and CD performance, whereas a lower ratio indicated a comparatively more balanced directional response. In the present study, product 6 had the lowest ratio, suggesting a relatively less anisotropic tensile response, whereas product 2 showed the highest ratio. The tensile-index results showed patterns consistent with the tensile-strength results. Because tensile index normalized tensile strength with respect to grammage, its use was useful when comparing tissue products whose basis weights were not identical. The results in the present study suggested that the major differences in tensile performance could not be attributed simply to small differences in basis weight. The products had relatively narrow grammage ranges, while their tensile properties differed substantially.

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The work-capacity and work-to-rupture results, also followed the general tensile-strength pattern. Products with greater tensile resistance generally exhibited greater energy absorption before rupture, although the magnitude of this relationship differed according to testing direction. This was physically reasonable because a tissue network capable of sustaining greater tensile stress over a deformation interval could generally absorb more mechanical energy before failure. Strain at break provided a complementary aspect of mechanical behavior. Unlike tensile strength, which described resistance to applied force, strain at break characterized the deformation experienced before failure. The results therefore indicated that tissue performance could not be adequately characterized by tensile strength alone. A tissue product may have possessed high tensile strength but a different deformation response from another product of comparable strength. An important statistical consideration was that the Levene test indicated significant heterogeneity of variance among the twelve product x direction groups. Consequently, the assumption of equal variances was not fully satisfied. Nevertheless, the experimental design was balanced, with 20 independent observations in every product x direction cell, and the observed effects were very large. The factorial ANOVA provided strong evidence for the existence of product, direction and interaction effects. The use of separate specimens for MD and CD was also important for interpretation. Because the two directions were not measured repeatedly on the same physical specimen, direction was appropriately treated as an independent between-specimen factor rather than as a repeated-measures factor.

That strengthened the suitability of the present factorial design for examining the independent and interactive effects of product and direction. Overall, the results indicated that commercial tissue papers should be regarded as structurally anisotropic materials whose mechanical performance depended strongly on both product characteristics and loading direction. The substantial differences observed between products despite relatively similar grammage demonstrated the importance of fiber-network structure and manufacturing history in determining tensile behavior [12].

Conclusion

The present study demonstrated differences in the mechanical behavior of six commercially available tissue paper products despite their relatively similar grammage. The experimental results obtained from 240 tensile observations showed a consistent and pronounced anisotropy, with tensile strength in the machine direction exceeding that in the cross direction for every investigated product. The overall mean tensile strength corresponded to an approximately 2.47-fold difference between the two testing directions. The individual product/subsample measurements presented in Figures 1-12 and summarized in Table 1 consistently demonstrated this directional behavior. The MD/CD tensile-strength ratio provided a useful quantitative descriptor of this anisotropy. As shown in Tables 2 and 3, the product-specific mean ratios ranged from 1.87 to 2.87.

The variation among products demonstrated that directional dependence was not uniform across commercial tissue papers and could therefore provide useful information concerning differences in sheet structure and fiber orientation. The statistical analyses further confirmed the observed differences. One-way ANOVA demonstrated significant differences among products for tensile strength, tensile index, work capacity, work to rupture and strain at break. The two-way factorial ANOVA demonstrated significant effects of product, testing direction and their interaction, with partial eta-squared values of 0.685, 0.842 and 0.401, respectively. The significant interaction was particularly important because it demonstrated that the magnitude of the MD-CD difference depended on the commercial product and could not be described solely by a common directional effect. The tensile-index, work-capacity and work-to-rupture results further showed that tensile strength should be considered together with deformation and energy-absorption characteristics. Products with greater tensile resistance, generally demonstrated greater capacity to absorb mechanical work before rupture, whereas strain at break revealed differences in extensibility that were not necessarily parallel to tensile strength. Finally, the study demonstrated that standardized tensile testing according to ISO 12625 provided an effective framework for differentiating commercial tissue papers and for characterizing their mechanical anisotropy. The combined evaluation of tensile strength, tensile index, MD/CD ratio, strain at break and work-to-rupture provided substantially more information about tissue performance than tensile strength alone. These parameters could therefore be useful for quality characterization, comparative product assessment and the interpretation of structural differences among commercial tissue papers..

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