Quantification of the degree of preference for different tissue products based on a hand-felt tissue test panel

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ABSTRACT: In this study, we successfully established a quantification model to determine the preference (PF) for different tissue products based on the results of a hand-felt tissue testing panel. The panel ascertained that products designed with four-ply tissues provided higher total tensile strength (TTS) and hand-felt surface softness (HSS) than did those of the three-ply, two-ply, and single-ply products.

When practically tested with a tissue softness analyzer (TSA), the four-ply tissue product had a softness (TSA-HF) advantage; however, in human panel tests, more than half of the participants could not be sure of the hand-felt bulk softness (HBS) of the four-ply tissue product. This was mainly because when using the four-ply tissue, the hand-held test pad gave an overall perception distinctly different from those of the hand-held two- or three-ply products, which also differed from the flattened state of test pieces used in the instrumental softness tests. Users could distinctly feel that a product was safer (better TTS) and more comfortable (higher hand-held surface softness). Thus, the four-ply tissue product was accorded a higher preference.

Application: The test method developed in this study can also be applied to other related industries that involve human perceptions or feelings. Based on the specific quality item, product adjustment and optimization could be carried out so that the products could gain the preference of specific consumer groups.

To humans, when we evaluate a commodity, there are many subjective perceptions of attributes in addition to price, such as taste, smell, visual, and tactile feelings, etc. In general, for products in an acceptable price range, users will base their choices on personal demands and preferences. For example, Kim et al. [1] used a test panel to investigate information on the preferences of consumers for chocolate milk containers; Hersleth et al. [2] also used a test panel in a questionnaire to investigate the effects of dining ambience on the responses of consumers to internal and external product attributes. These two reports inspired us to consider an important realm of tissue paper research; i.e., in pursuit of production technology, the sheet softness and sheet strength, which are negatively correlated, are often stressed. However, further investigation of preference (PF) evaluations would give us answers to what the options are for consumers in terms of sheet softness and sheet strength. Is there a production technology that can accommodate both?

In the past 10 years, our research team has applied panel testing to evaluate the hand-felt softness of tissue products and published three papers. The first, by Teng et al. [3], applied the reciprocal matrix of Saaty [4] and statistical analysis to successfully establish a method to evaluate hand-felt tissue softness. The second paper, by Perng et al. [5], overcame the original panel test specimen number limit of no more than nine items [6], and through conversion and calibration with respect to the standard samples, allowed ranking of test panel results conducted at different times, provided the specimen dimensions were the same. These findings also transcend the shortcoming of test panel results being individually independent and impossible to compare across different panel results, as noted by Patterson [7]. The third paper we published, by Perng et al. [8], was in reference to the theory of hand-felt surface softness (HSS) and hand-felt bulk softness (HBS) of Hollmark [9] and in conjunction with the use of a tissue softness analyzer (TSA). This paper successfully established technical curves between these two softness properties and the sheet total tensile strength (TTS). In these three serial studies, interrelationships and interactions among HSS, HBS, and TTS were investigated. For instance, the higher the softness of a product, the more easily a product will break, which affects the confidence of users in the product. On the other hand, a higher-strength product will have higher roughness, which affects the comfort as perceived by the user [10]. Thus, producers prefer tissue sheet production technology that will produce acceptable HSS or HBS, which influences equipment investment and chemical selection. If the product does not require high softness, only controlling the furnish and refiner for strength adjustment is sufficient; if the product is for cosmetic use, then investment of surface lotion coating facilities or internal addition of softening agent is required.

Henceforth, our research team drafted a plan to first investigate the feasibility of extending hand-felt perceptions to predict PFs. Second, based on the interrelationship between PFs and various paper properties, we investigated key qualities that affect PFs of specific consumer groups so process factors can be adjusted to satisfy the PFs of consumers.

EXPERIMENTAL PROCEDURES

The study was carried out in two stages. In the first stage, we organized panel 1 and conducted hand-felt softness and TSA softness (TSA-HF) evaluations on PFs of tissue samples. In the second stage, panels 2, 3, and 4 were organized, and in addition to sampling PFs and TSA-HF, the HBS and HSS evaluations were included.

First stage: establishing a PF evaluation and quantification method

Formation of the panelists

In the first stage, we recruited 11 university students, all of whom were inexperienced and were between 20 to 25 years of age, including 3 females and 8 males. They were basically not conversant with tissue production or quality control, and were merely tissue product consumers. The panelists followed the cue of a leader and completed the experiments according to a standard procedure. In particular, when conducting PF tests, they were asked to avoid preconceptions of softness (surface and bulk softness) that might influence their selection.

Preparation of the samples

In the study, 11 samples were prepared. All of them are commonly seen in Taiwanese markets and were provided by the Qing-shui Mill of Yuen-Foong-Yu Co. Ltd. (Qing-shui, Taiwan). Because of the two-stage study, each with different purposes, there were designs with different numbers of folds, and two groups resulted, as shown in **Table I**. In the first stage, sample group (SG-1) was used, which incorporated three varieties: single-ply, two-ply, and multi-ply (three or more plies). For the second stage study, we adjusted the grouping (SG-2) to two-ply and multi-ply (three or more plies). Therefore, of the sample groups, specimens designated as A to G were identical, and H and I were different.

In order to ensure the representativeness and repeatability of the experimental results, the two-stage experiments were all sampled from the same sample cluster, and their individual physical properties were measured. According to the sample preparation method of Teng et al. [3] and Perng et al. [5,8]: 1) the number of samples handled by a panel should not exceed nine items [6]; 2) test specimens must be free from holes, tear, and dead wrinkles, or other apparent defects; 3) a sufficient number of test specimens must be collected in sequence, and the number should allow completion of four sets of panels, TSA, and physical properties tests, i.e., 10~15 sheets for the panel tests, the next one for TSA tests, followed by one more for physical property tests; and 4) specimens should be folded such that one sheet has the use surface facing outward, and then double-folding the specimen into a square pad with four layers.

Determination of tissue physical properties

All physical property tests were carried out under a standard atmosphere of 50% ± 2.0% relative humidity at 23.0 ± 1.0°C (TAPPI Standard Test Method T 402 sp-21 "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products"). The following properties of the tissue specimens were measured according to the methods listed below:

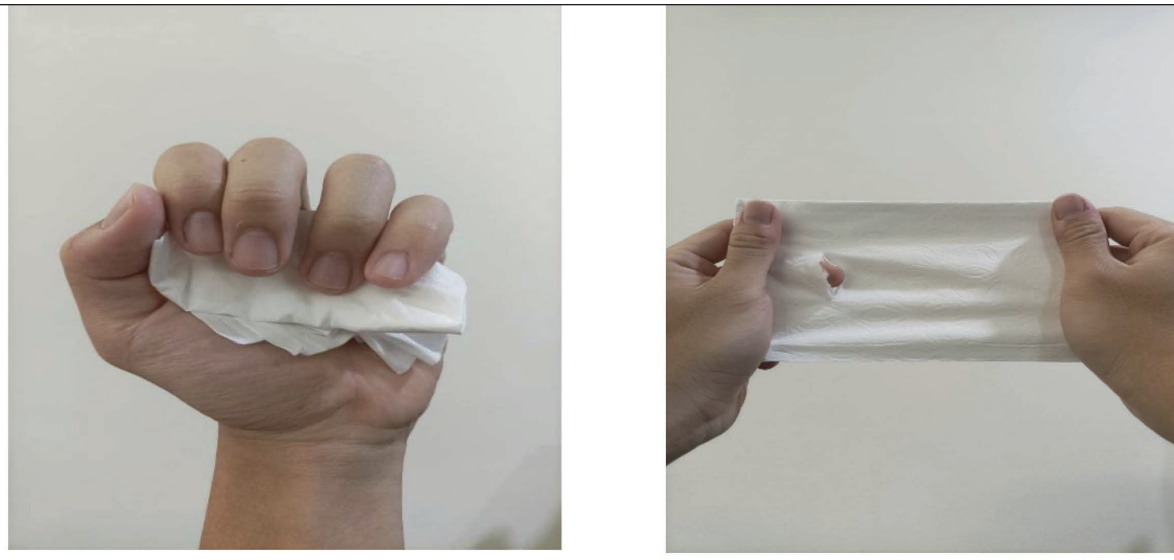
- Grammage: TAPPI T 410 om-19 "Grammage of paper and paperboard (weight per unit area)."
- Moisture: TAPPI T 412 om-22 "Moisture in pulp, paper and paperboard."
- Caliper: TAPPI T 580 pm-20 "Thickness (caliper) of towel, tissue, napkin and facial products," measured using an S/N 44692 Thwing Albert instrument (Thwing-Albert Instrument Company; West Berlin, NJ, USA).
- Tensile strength: TAPPI T 494 om-22, "Tensile properties of paper and paperboard (using constant rate of elongation apparatus)," measured along the machine direction (MD) and cross-machine direction (CD) using an EJA Vantage-10 Thwing-Albert instrument to provide MD tensile (MDT) and CD tensile (CDT) strengths.
- Total tensile strength: TTS was calculated using the equation $(MDT \times CDT)^{1/2}$.

TSA instrumental measurements

In this study, we also used measurements of a TSA (TSA-B0458) from Emtec (Leipzig, Germany) [11] to evaluate tissue softness. Sample sheets were cut into 10 cm × 10 cm square specimens for TSA-HF measurements. The TSA positions six thin scraper blades over the specimen surface. Then, the scrapers begin to rotate and produce a vibrational frequency. During testing, the TSA senses two frequency peaks, the first centered around 750 Hz, termed TS-750, and the second around 7000 Hz, termed TS-7. Subsequently, the probe of the instrument applies an increasing force from 0.1 to 0.6 N vertically on the specimen surface to measure the stiffness of the sheet, and the value obtained is termed the D-value. Finally, based on TS-750 and TS-7,

SG-1	A-2-ply	B-2-ply	C-2-ply	D-4-ply	E-2-ply	F-2-ply	G-3-ply	H-1-ply	I-1-ply
SG-2	A-2-ply	B-2-ply	C-2-ply	D-4-ply	E-2-ply	F-2-ply	G-3-ply	H-2-ply	I-4-ply

I. Sample mix (SG = sample group).



A. Feel the comfort *B. Feel the strength and security*

1. Schematic photos showing the correct hand-felt techniques.

the D-value, grammage, and caliper information, the TSA-HF is calculated, which has a value between 0 and 100.

Method of measuring and quantifying hand-felt tissue preferences

Quality control in tissue paper mills is mainly centered around sheet tensile strength and sheet softness. Therefore, guiding panel testers to make judgements of preference should be based on determinations of sheet strength (confident that the sample will not break or tear when in use) and sheet softness (providing a sense of comfort), so that meaningful feedback of parameter ranges can be produced for the production line.

During the test, a leader provided the panelists with pre-prepared specimen pairs. The testers picked up one specimen in each hand and made comparisons, and then the testers were advised to change hands and again make comparisons. The standard mode of the test was based on the habits of using a tissue, which are illustrated in **Fig. 1**: 1) first, feel the comfort when using the tissue; and 2) second, twist or poke the tissue with the fingers until it breaks to feel the strength and security; in other words, determine the level of safety from being dirtied when using the item.

The result of the same set of comparisons was scored according to the scale rules of **Table II**. The set of rules was successfully applied in prior studies [3,5,8], and we expected that these rules could be applied for the PF tests. As we were using the same pairwise specimen sets for the PF and smoothness tests, the PF test often cause damages to the specimens. Therefore, we asked the panelists to test surface smoothness first. Upon completing the test, specimens were retrieved by the leader, who ensured that there was no damage to the specimen, and then the same pairwise specimen sets were stored and served as the test specimens for the subsequent PF tests by the panelists. In addition to asking the tester to give PF differences, they were

Preferential No.	Paired Comparison Between Samples X_i and X_j
1	X_i and X_j are equal on PF (SS, BS).
3	X_i is slightly better than X_j on PF (SS, BS).
5	X_i is much better than X_j on PF (SS, BS).
7	X_i is very much better than X_j on PF (SS, BS).
9	X_i is absolutely better than X_j on PF (SS, BS).
2, 4, 6, 8	Even numbers can be assigned if the numbers listed above do not fully represent the difference.
Reciprocal	$X_i > X_j$, *then aij>0; aji=1/aij. (a=preferential nos. 1~9)*

PF =preference; SS = surface softness; BS = bulk softness.

II. Preferential numbers for scoring differences.

encouraged to discuss their insights and personal views.

Table III shows the procedure of quantification deduction: 1) a reciprocal matrix of the comparison results was constructed; 2) the reciprocal matrix was normalized; 3) elements in the matrix were transformed into normalized eigenvectors (*N-Ev*$_i$); 4) the logarithm value was taken, i.e., log(*N-Ev*$_i$) = W_i; and 5) based on the transformation equation (*Y=20X+70*) of Table III, values of W_i were transformed into a degree of preference, PF$_i$, for individual specimens.

Execution of preference evaluation and testing

In the first stage, the first sample group (SG-1) was comprised of A-2-ply, B-2-ply, C-2-ply, D-4-ply, E-4-ply, F-2-ply, G-3-ply, H-1-ply, and I-1-ply. Eleven students were chosen to conduct the hand-felt test.

Table IV shows results of the first stage test by the 11 students. The results all passed the *t*-test ($|t| > t_{0.025,7} = 2.365$). Although the 11th tester gave results that differed from all of others and were in a contradictory trend (*t*-value = -4.12), the overall trend of the panel was not affected. Upon discussion, the dissenting tester preferred coarser tissues and felt that those sheets had better cleaning power; while all of the other testers preferred softer, more-comfortable tissues, but still wanted the samples to have sufficient strength.

Table V provides basic information (TSA) and physical properties of sample group 1. **Table VI** is a rearrangement of average PF values in Table IV. It also summarizes the critical items (MDT, CDT, TTS, and TSA-HF) of Table V, and calculates significant difference values (2.0 for TSA-HF and 1.7 for PF), which are illustrated in **Fig. 2** and **Fig. 3**.

Figure 2 is a regression analysis of PF and TSA-HF. Line 1 indicates the overall trend of the nine specimens ($R^2 = 0.8713$). In a further perusal based on the specimen ply numbers, line 2 indicates the correlation coefficient (R^2) for two-ply specimens with $R^2 = 0.9392$. Line 3 indicates the same for multi-ply samples (three and four plies); and finally, line 4 shows results for one-ply samples.

Figure 3 shows the regressions of PF and TTS, in which line 1 indicates the overall trend of the nine samples ($R^2 = 0.3935$), which can be further differentiated into line 2 for two-ply samples ($R^2 = 0.9731$). Line 3 shows results of multi-ply samples, and finally, line 4 shows results of one-ply samples.

Details of the results are presented in the Results and Discussion section.

Brand	Reciprocal Matrix									*N-Ev*$_i$ (*n*=1)	*Log (N-Ev*$_i$*)= W*$_i$ (*n*=1)	PF$_i$ Data (*n*=1)
	A-2-ply	B-2-ply	C-2-ply	D-4-ply	E-2-ply	F-2-ply	G-3-ply	H-1-ply	I-1-ply			
A-2-ply	1.000	0.167	0.167	0.111	0.333	0.200	0.167	7.000	4.000	0.059	-1.23	45.3
B-2-ply	6.000	1.000	1.000	0.167	2.000	0.500	0.167	5.000	8.000	0.106	-0.97	50.5
C-2-ply	6.000	1.000	1.000	0.125	0.200	0.200	0.143	6.000	9.000	0.105	-0.98	50.5
D-4-ply	9.000	6.000	8.000	1.000	4.000	7.000	0.125	9.000	9.000	0.236	-0.63	57.5
E-2-ply	3.000	0.500	5.000	0.250	1.000	1.000	4.000	7.000	8.000	0.132	-0.88	52.4
F-2-ply	5.000	2.000	5.000	0.143	1.000	1.000	0.333	7.000	7.000	0.127	-0.90	52.1
G-3-ply	6.000	6.000	7.000	8.000	0.250	3.000	1.000	7.000	7.000	0.201	-0.70	56.1
H-1-ply	0.143	0.200	0.167	0.111	0.143	0.143	0.143	1.000	3.000	0.022	-1.65	37.0
I-1-ply	0.250	0.125	0.111	0.111	0.125	0.143	0.143	0.333	1.000	0.010	-1.98	30.4
Sum	33.417	10.126	22.310	14.180	14.226	6.001	4.718	45.000	47.000	1.000	--	--
Transfer formulation: *Y =20X+70Y=PFX= W*$_i$												
N-Ev$_i$ = normalized eigenvectors; W_i = logarithm of *N-Ev*$_i$; PF$_i$ = hand-felt preference.												

III. Reciprocal matrix of sample group 1 in the first phase.

Brand	N.1	N.2	N.3	N.4	N.5	N.6	N.7	N.8	N.9	N.10	N.11	PF (*n*=11)	
												Avg	SD
A-2-ply	45.3	52.1	49.3	42.0	48.2	39.9	45.1	42.7	46.7	49.0	56.2	46.9	4.7
B-2-ply	50.5	50.9	53.7	53.2	52.3	54.4	52.3	55.5	49.6	51.5	43.4	51.6	3.2
C-2-ply	50.5	50.2	45.3	51.8	47.8	51.1	47.7	50.9	47.6	48.1	51.4	49.3	2.1
D-4-ply	57.5	57.6	56.0	50.6	51.8	56.5	57.3	54.5	59.8	54.7	37.3	54.0	6.1
E-2-ply	52.4	49.7	54.7	50.0	54.9	49.6	52.7	53.8	49.6	56.1	40.9	51.3	4.2
F-2-ply	52.1	50.9	48.2	52.8	53.9	54.3	53.2	54.4	53.3	54.1	41.2	51.7	3.9
G-3-ply	56.1	55.2	55.9	57.4	56.8	53.6	54.6	52.2	50.4	52.8	46.0	53.7	3.3
H-1-ply	37.0	33.8	35.2	45.5	37.9	37.8	40.0	36.0	44.9	37.8	53.3	39.9	5.7
I-1-ply	30.4	33.5	38.6	44.4	31.1	42.5	37.5	36.0	44.0	33.8	60.3	39.3	8.5
R^2	0.963	0.900	0.862	0.579	0.908	0.770	0.960	0.919	0.610	0.914	0.708	--	--
$\|t\|>2.365$	13.42	7.943	6.624	3.105	8.310	4.836	12.93	8.907	3.308	8.611	**-4.12**	--	--

N.1~11 = 11 testers; PF = preference; *t*-test $|t|>$ t 0.025,7 = 2.365; Avg = average; SD = standard deviation.

IV. Panel preference testing by 11 testers of sample group 1 in the first phase.

Brand	Grammage (air-dried), g/m²/ply (*n*=10)	Tensile Strength, gf/1 in./1 sheet (*n*=10)			TSA-HF, ° (*n*=15)	TSA Frequency, dB (*n*=15)		TSA Stiffness, mm (*n*=15)
		MDT	CDT	TTS	HF	TS7	TS750	D-value
A-2-ply	15.97±0.38	554±60	324±32	422±24	71.0±1.2	18.5±1.1	15.5±3.0	2.4±0.1
B-2-ply	15.25±0.38	412±34	202±12	288±13	82.9±2.4	13.1±1.5	17.2±1.5	2.7±0.1
C-2-ply	14.23±0.35	542±73	264±23	377±25	77.4±1.7	15.6±1.4	21.1±5.1	2.6±0.2
D-4-ply	16.08±0.37	979±103	449±21	662±35	87.9±1.5	8.6±1.3	23.1±4.2	1.9±0.2
E-2-ply	15.40±0.45	463±38	198±16	302±17	84.9±1.5	11.8±0.8	21.5±3.5	2.7±0.1
F-2-ply	16.15±0.41	420±43	209±21	296±23	87.6±3.0	10.6±1.1	25.4±4.8	2.8±0.1
G-3-ply	15.29±0.46	718±31	317±42	475±27	83.6±2.0	11.3±0.7	23.4±5.4	2.3±0.2
H-1-ply	18.74±0.28	327±45	208±30	259±20	66.4±2.7	22.2±1.2	26.5±2.5	3.1±0.3
I-1-ply	17.70±0.39	279±26	138±17	196±17	68.5±4.2	21.7±1.5	25.7±5.8	3.2±0.3

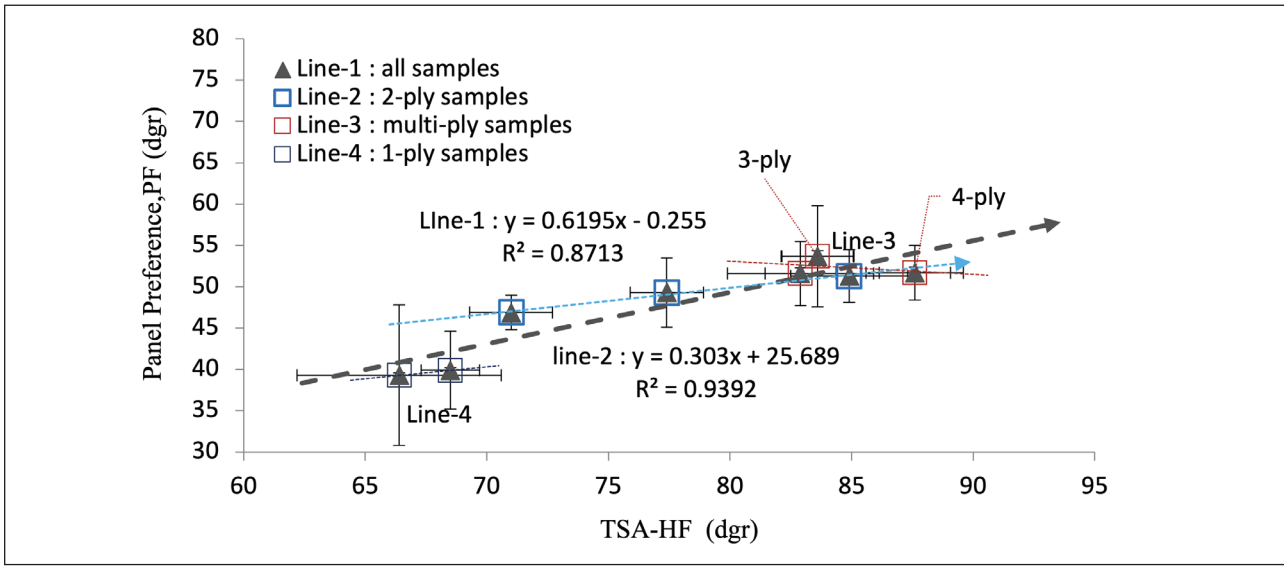
MDT = machine-direction tensile strength; CDT = cross-machine direction tensile strength; TTS = total tensile strength; gf = gram force; TSA-HF = softness; TS7 = fiber softness; dB = decibel, amplitude; TS750 = TSA smoothness; D-value = stiffness; moisture content % = 5.35%~7.5%.

V. Basic information (tissue softness analyzer, TSA) and physical properties of sample group 1 in the first phase.

Brand	Tensile Strength, gf/1 in./1 sheet (*n*=10)			TSA-HF, ° (*n*=15)		Panel PF-1, ° (*n*=19)	
	MDT	CDT	TTS	Avg	SD	Avg	SD
D-4-ply	979	449	662	87.9	1.5	54.0	6.1
G-3-ply	718	317	475	83.6	2.0	53.7	3.3
F-2-ply	420	209	296	87.6	3.0	51.7	3.9
B-2-ply	412	202	288	82.9	2.4	51.6	3.2
E-2-ply	463	198	302	84.9	1.5	51.3	4.2
C-2-ply	542	264	377	77.4	1.7	49.3	2.1
A-2-ply	554	324	422	71.0	1.2	46.9	4.7
I-1-ply	279	138	196	68.5	4.2	39.9	8.5
H-1-ply	327	208	259	66.4	2.7	39.3	5.7
Signi-diff.	--	--	--	> 2.0	--	> 1.7	--

MDT = machine-direction tensile strength; CDT = cross-machine direction tensile strength; TTS = total tensile strength; gf = gram force; TSA-HF = softness; PF = preference; Avg = average; SD = standard deviation; Signi-diff. = significant difference.

VI. Key information (tissue softness analyzer, TSA) and physical properties of sample group 1 in the first phase.



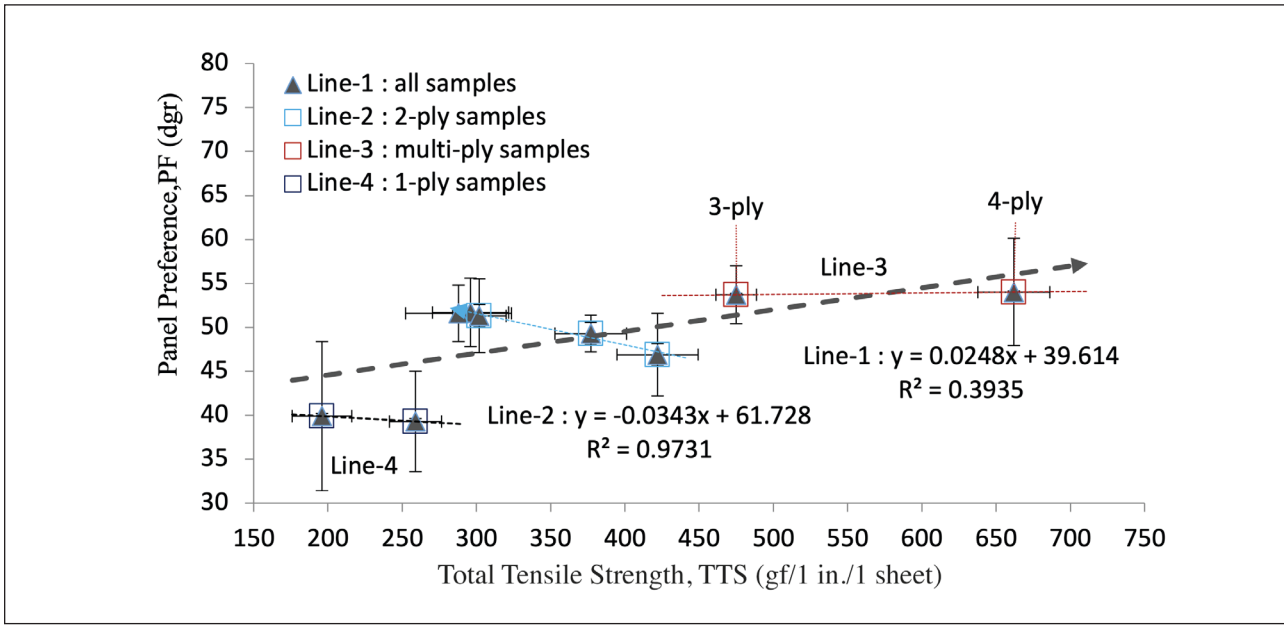
2. Regression between panel preferences and tissue softness analyzer (TSA) softness (TSA-HF).

Second stage experiments: investigation of user preferences, and surface and bulk softness of the samples

Before proceeding with the experiments, preparatory work for the panels had to be completed, which included forming the panel, preparing the samples, and conducting physical property tests of the samples and TSA tests.

Forming the panel

We retained three core experimenters (students N.1~N.3) and recruited another 16 students and members of the public for a total of 19 persons to serve as panelists in the second stage. The purpose of retaining three core students was to help judge whether the results could be repeated. Among the 19 panelists, seven were 20 to 30 years of age; two each were 30 to 40 and 40 to 50 years of age; six were 50 to 60 years of age; and two were 70 to 80 years of age.



3. Regression between panel preferences and TTS.

They consisted of 11 females and eight males. The testers had to follow the guidance of a leader to complete the hand-felt test in accordance with standard procedures. Particularly in the PF tests, the testers had to avoid the influence of preconceptions of surface and bulk softness of the samples.

Preparation of the test specimens and the TSA tests

In the first stage experiment, the H-1-ply and I-1-ply products had the least favorable preference, with scores of 39.9 and 39.4, respectively, and a minimum amount of production. Hence, in the second stage experiment, adjustments were made to substitute H-2-ply and I-4-ply products for the 1-ply ones. A second sample group (SG-2) of test specimens were used for the tests. They consisted of A-2-ply, B-2-ply, C-2-ply, D-4-ply, E-2-ply, F-2-ply, G-3-ply, H-2-ply, and I-4-ply commercial products. The physical properties and TSA tests were the same as those described for the first stage.

The experiments required preparation of two specimen sets, and the physical properties of individual spec-

Brand	Grammage (air-dried), g/m2/ply (*n*=10)	Tensile Strength, gf/1 in./1 sheet (*n*=10)			TSA-HF, ° (*n*=15)	TSA Frequency, dB (*n*=15)		TSA Stiffness, mm (*n*=15)
		MDT	CDT	TTS Set 1	HF Set 1	TS7	TS750	MDT
A-2-ply	14.80±0.19	593±56	291±24	415±27	71.4±2.6	18.4±1.1	16.4±1.6	2.5±0.2
B-2-ply	12.20±0.41	391±64	168±33	256±36	84.1±2.4	12.7±0.8	18.6±2.2	2.8±0.1
C-2-ply	13.05±0.34	525±31	266±30	372±24	75.8±2.1	16.5±1.2	23.1±2.4	2.6±0.1
D-4-ply	15.01±0.35	927±52	458±53	650±59	88.3±1.4	8.5±0.5	26.2±2.9	1.9±0.1
E-2-ply	14.51±0.25	506±32	176±27	298±28	83.6±2.2	12.5±1.2	21.7±3.7	2.7±0.1
F-2-ply	15.00±0.23	415±48	211±16	292±20	86.5±2.1	11.0±0.6	24.4±2.3	2.7±0.1
G-3-ply	14.30±0.24	585±70	279±34	403±31	85.0±1.4	11.2±0.8	24.2±2.2	2.3±0.1
H-2-ply	17.50±0.21	596±71	312±46	431±52	70.5±3.4	17.1±0.6	90.7±22.8	2.6±0.2
I-4-ply	15.90±0.37	910±76	513±58	683±40	89.4±1.4	7.8±0.5	27.0±3.1	1.9±0.1

MDT = machine-direction tensile strength; CDT = cross-machine direction tensile strength; TTS = total tensile strength; gf = gram force; TSA-HF = softness; TS7 = fiber softness; dB = decibel, amplitude; TS750 = TSA smoothness; D-value = stiffness; moisture content % = 5.4%~7.4%.

VII. Basic information (tissue softness analyzer, TSA) and physical properties of specimen set 1 in sample group 2 for preference testing

Brand	Grammage (air-dried), g/m²/ply (*n*=10)	Tensile Strength, gf/1 in./1 sheet (*n*=10)			TSA-HF, ° (*n*=15)	TSA Frequency, dB (*n*=15)		TSA Stiffness, mm (*n*=15)
		MDT	CDT	TTS Set 2	HF Set 2	TS7	TS750	D-value
A-2-ply	15.00±0.66	582±69	330±25	437±29	70.7±2.5	18.1±1.5	16.2±1.2	2.5±0.1
B-2-ply	14.45±0.47	408±47	190±20	277±25	83.3±2.4	12.8±0.5	19.8±5.8	2.7±0.2
C-2-ply	13.52±0.38	546±38	295±32	401±20	76.4±2.1	16.1±0.8	25.9±3.6	2.6±0.1
D-4-ply	15.30±0.33	889±62	470±53	646±47	88.6±1.3	8.3±0.9	28.2±3.8	1.9±0.2
E-2-ply	14.70±0.39	473±51	180±11	292±22	83.4±2.2	12.6±1.5	20.6±4.8	2.7±0.1
F-2-ply	15.30±0.35	451±72	184±60	288±46	86.4±2.1	10.9±0.5	24.1±5.2	2.7±0.2
G-3-ply	14.20±0.38	564±73	219±29	349±39	84.8±1.4	11.3±1.1	21.6±4.2	2.3±0.2
H-2-ply	17.52±0.15	615±36	376±22	480±28	69.0±3.3	18.2±1.2	88.8±16.3	2.6±0.4
I-4-ply	15.96±0.42	884±91	506±38	668±43	89.6±1.3	7.7±0.8	27.3±5.8	1.9±0.3

MDT = machine-direction tensile strength; CDT = cross-machine direction tensile strength; TTS = total tensile strength; gf = gram force; TSA-HF = softness; TS7 = fiber softness; dB = decibel, amplitude; TS750 = TSA smoothness; D-value = stiffness; moisture content % = 5.6%~7.5%.

VIII. Basic information (tissue softness analyzer, TSA) and physical properties of specimen set 2 in sample group 2 for hand-felt bulk and surface softness testing.

Brand	Tensile Strength, gf/1 in./1 sheet (*n*=10)			TSA-HF, ° (*n*=15)		
	TTS Set 1	TTS Set 2	TTS Avg	HF Set 1	HF Set 2	HF Avg
A-2-ply	415	437	426	71.4	70.7	71.1
B-2-ply	256	277	267	84.1	83.3	83.7
C-2-ply	372	401	387	75.8	76.4	76.1
D-4-ply	650	646	648	88.3	88.6	88.5
E-2-ply	298	292	295	83.6	83.4	83.5
F-2-ply	292	288	290	86.5	86.4	86.5
G-3-ply	403	349	376	85.0	84.8	84.9
H-2-ply	431	480	456	70.5	69.0	69.8
I-4-ply	683	668	676	89.4	89.6	89.5
R^2	0.9613	--	0.9949	--		
$\|t\|>2.365$	13.056	--	37.061	--		

TTS = total tensile strength; HF = TSA-HF (softness); gf = gram force; avg = average; *t*-test $|t| > t\ 0.025,7 = 2.365$.

IX. Key information for physical properties (TTS) and softness (TSA-HF) of specimen set 1 and set 2 in sample group 2.

Brand	Tensile Strength (gf/1 in./1 sheet) (*n*=10)	TSA-HF, ° (*n*=15)	Panel PF, ° (*n*=19)		Panel HBS (*n*=19)		Panel HSS (*n*=19)	
	TTS average	HF average	Avg	SD	Avg	SD	Avg	SD
I-4-ply	676	89.5	55.7	4.9	46.5	8.12	57.6	1.8
D-4-ply	648	88.5	55.3	5.2	47.2	7.95	57.3	1.4
G-3-ply	376	84.9	51.6	4.2	49.6	3.77	51.9	2.1
E-2-ply	295	83.5	49.8	2.8	51.9	3.47	48.8	1.8
F-2ply	290	86.5	49.6	3.9	53.9	2.18	50.6	2.5
B-2-ply	267	83.7	48.1	3.7	54.0	3.75	48.0	2.5
C-2-ply	387	76.1	43.8	3.5	48.8	4.63	43.2	2.1
A-2-ply	426	71.1	41.9	5.1	44.6	3.02	40.6	2.7
H-2-ply	456	69.8	41.8	5.9	44.8	5.47	38.8	2.9
Signif-diff.	--	**> 2.0**	**> 1.7**	--	**> 2.4**	--	**> 2.6**	--

TTS = total tensile strength; gf = gram force; TSA-HF = softness; PF = preference; HBS = hand-felt bulk softness; HSS = hand-felt surface softness; Avg = average; Signif-diff. = significant difference.

X. Key information for sample group 2.

imens had to be tested. **Table VII** shows the basic information based on the TSA and physical properties of specimen set 1 for use in preference testing by panel 2. **Table VIII** lists basic information for TSA and physical properties of specimen set 2 for HSS and HBS testing for use in panels 3 and 4.

Table IX presents key information (TTS and TSA-HF) summarized from Tables VII and VIII. The quality of test specimens for the two sets was quite similar, with R^2 = 0.9613 and *t*-value = 13.056 for TTS and R^2 = 0.9949 and *t*-value = 37.061 for HF. Henceforth, we used averages of TTS and HF as bases of subsequent analyses.

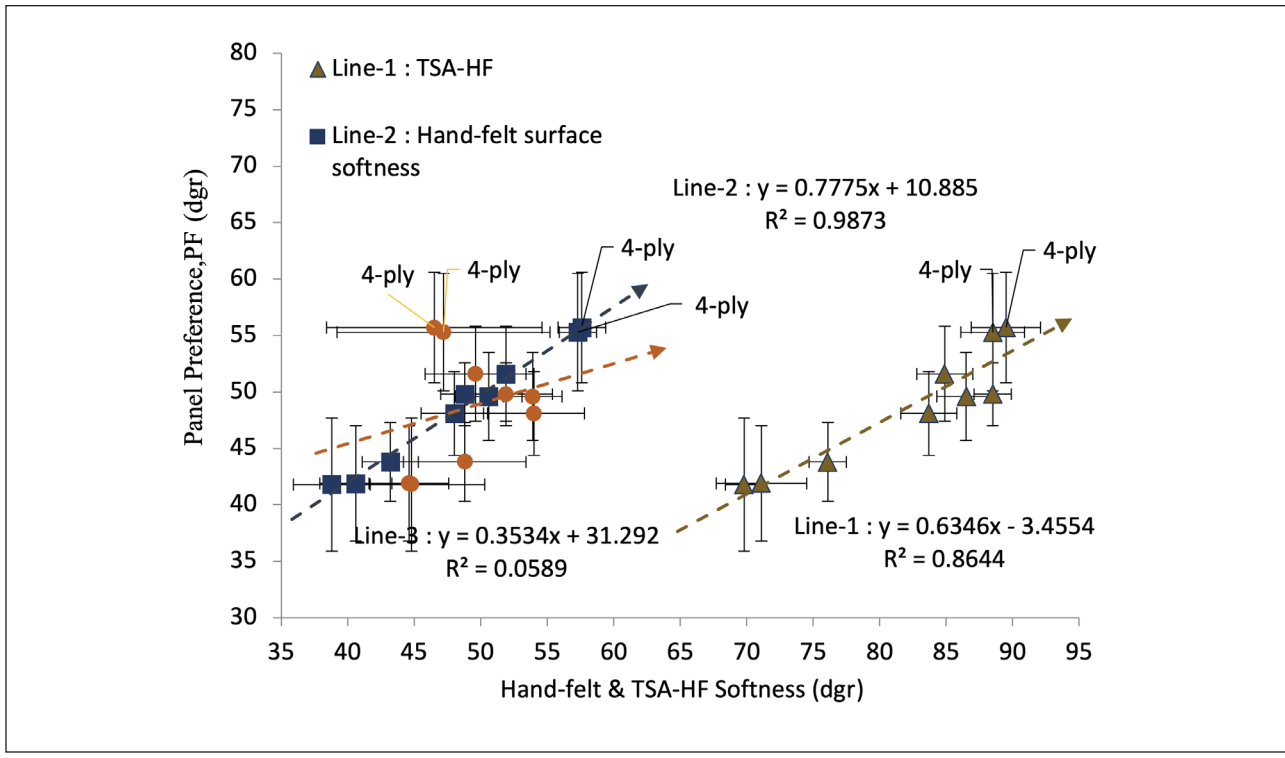
Panel tests

We completed three panel tests (panels 2, 3, and 4). In the first set of tests (specimen set 1), we used panel 2 to test for PF, with a method identical to the first stage. The second (specimen set 2) was first used for the HSS test of panel 3, and specimens were not damaged. After each paired test, the leader had to retrieve the specimens according to the original pairing for use in the HBS test by panel 4. Between the panel tests, a half-hour rest period was imposed.

Due to the large panel size (*n* = 19), a large amount of data was generated. In this stage, we only referenced averages and standard deviations (SDs) of the three panels for PF, HBS, and HSS, together with average TTS and TSA-HF values, which are listed in **Table X** and were ranked according to the PF. As shown in the footnotes to the table, we listed values of significant differences (2.0 for TSA-HF, 1.7 for PF, 2.4 for HBS, and 2.6 for HSS). Based on information in Table X, we accomplished analyses of **Figs. 4**, **5**, and **6**.

Figure 4 is a regression between panel preferences and softness (TSA-HF, HSS, and HBS). Of the lines, the PF trends of line 1 TSA-HF and line 2 HSS were nearly congruent (with R^2 = 0.8644 for TSA-HF, and R^2 = 0.9873 for HSS). Because the results of line 3 for HBS were obviously abnormal, with R^2 = 0.0589, we analyzed Fig. 5 and found that the PF for HBS was divided into two oppositely different groups, i.e., samples for two-ply and multi-ply with different trend slopes (slope = 0.8274 for two-ply samples and slope = -1.3789 for multi-ply samples).

Figure 6 is a regression between PF and TTS that illustrates the effects of paper strength on the PF of the products. Line 2 of the figure shows that due to decreased paper strength, the softness was better developed (slope = -0.0451), which also limited the PF for two-ply products. On the other hand, line 3 shows their increasing strength properties (slope = 0.0136), which made up for the weak strength properties of the two-ply samples and gained better PFs.



4. Regression between panel preferences and softness (hand-felt and TSA-HF).

RESULTS AND DISCUSSION

First stage objective: establishing a method for evaluating preferences

This stage is discussed in two units: 1) completion of the PF deduction model; and 2) multi-ply products having advantages in the PF evaluation.

1) Completion of the PF deduction model

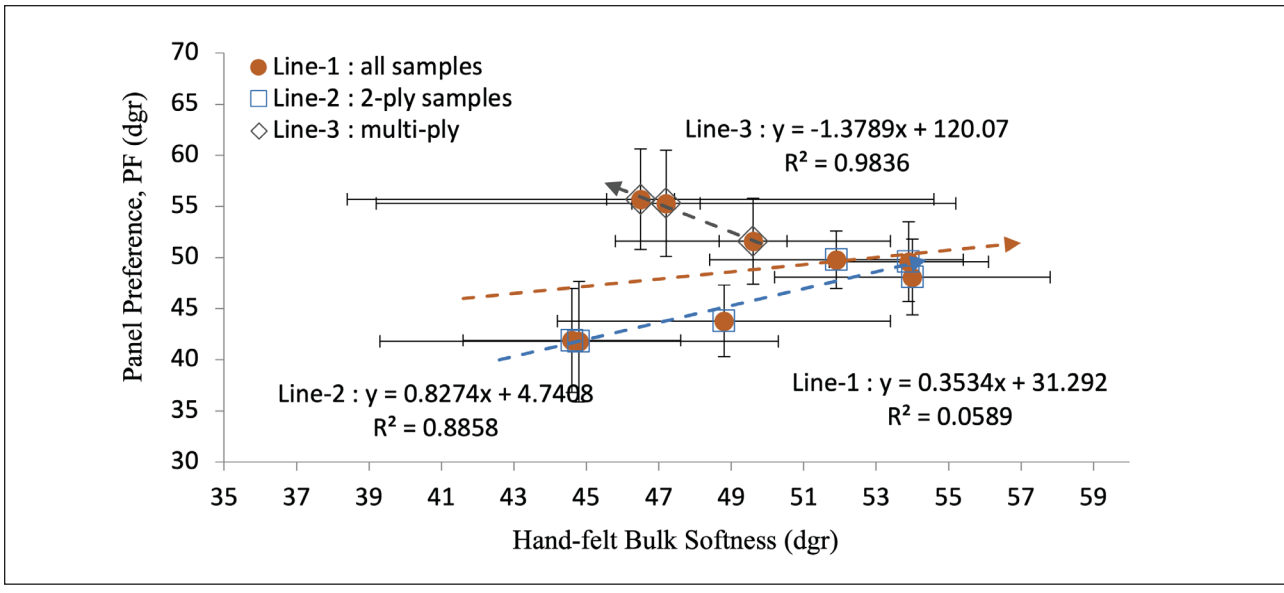
In the first stage experiment, panel 1 used Saaty's method of making pairwise sample comparisons and judging which one of a pair is preferred (Table II), and upon transformation of the reciprocal matrix method (Table III) [4], it was proven that this approach is applicable for evaluating HSS and HBS of tissues [3,5,8]. The 11 students in this panel proved that it is applicable for making PF evaluations (Table IV). The results again verify the advantages of Saaty's reciprocal matrix method, which includes: 1) capability of quantifying vague human perceptions; and 2) reducing the work load. For instance, using the n^2 method of comparing 9 specimens, 81 (9 x 9 = 81), pairwise comparisons are required; however, using Saaty's n(n-1)/2 method, the 9 specimens requires (9(9 -1)/2) = 36 times only, a reduction of 55.6%.

2) Advantages of PF choices for multi-ply products

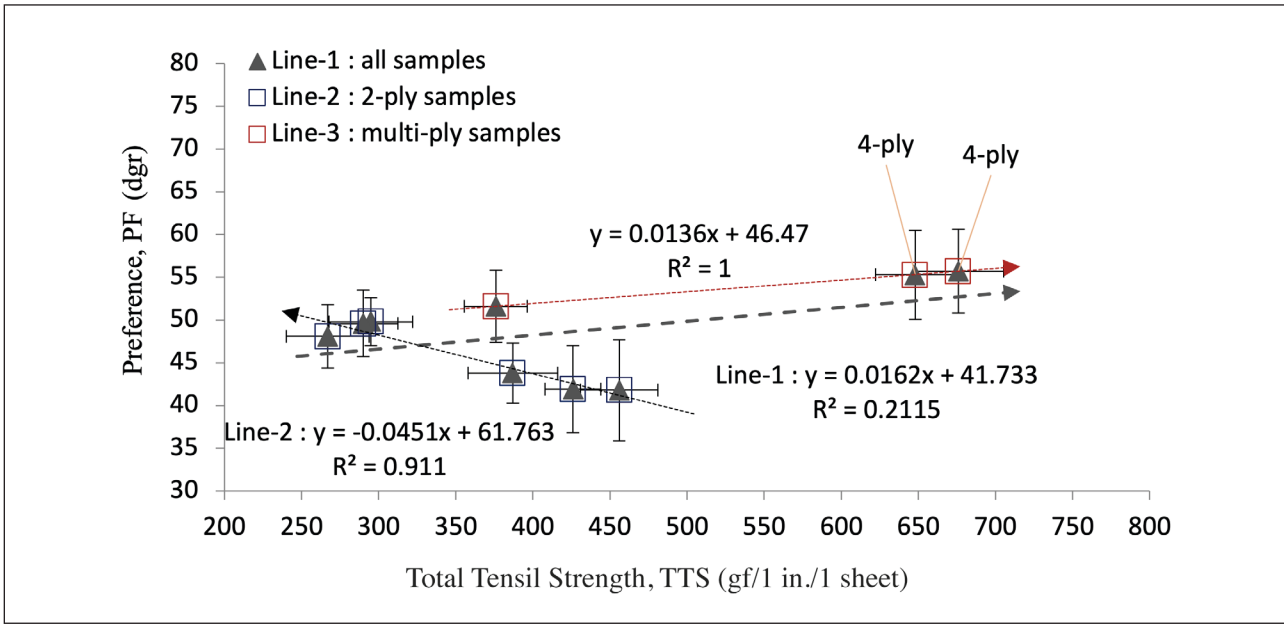
Figures 2 and 3 clearly show that three- and four-ply products possessed TSA-HF and TTS advantages over two-ply and single-ply products. These results are totally congruent with the oral descriptions and perceptions of the testers, i.e., tissue products with both comfort and strong strength gained higher preferences. These are specifically discussed as follows:

(i) *The advantage of multi-ply products in TSA-HF.* In Fig. 2 of PF and TSA-HF regressions, line 1 shows that PFs of all products were positively correlated with TSA-HF, with $R^2 = 0.8713$. In conjunction with Table VI, of the three product clusters, line 3 for multi-ply products had PFs of 53.7~54.0 > line 2 for two-ply products with PFs of 46.9~51.7 > line 4 for single-ply product (PFs = 39.3 and 39.9). Differences in the PFs of the three sample groups were all greater than the critical value of 1.7 for a significant difference. Respectively, the difference between G-3-ply and F-2-ply products was 2.0 (53.7 – 51.7 = 2.0), while the A-2-ply vs. I-1-ply difference was 7.0 (46.9 – 39.9 = 7.0).

(ii) *TTS advantage of multi-ply products.* Figure 3 shows the regression analysis of PF vs. TTS, in which line 1 indicates the regression of the assemblage of all nine samples with their TTS, and there is merely a hint of a correlation between the two parameters, with stronger samples having a trend of obtaining higher preferences, with $R^2 = 0.3935$. However, the *t*-test proved that the two were not correlated ($|t|=2.0491 < 2.3647$, ($t_{0.05/2\ ,\ 9\text{-}2} = 2.3647$)). Matching the data of Table VI, line 3 indicates that multi-ply samples had significantly improved TTS, and all gained higher PFs. For instance, the best four-ply sample (D-4-ply) had TTS = 662, TSA-HF = 87.9, and PF



5. Regression between panel preferences and hand-felt bulk softness.



6. Regression between panel preferences and TTS.

= 54.0 compared to the best two-ply sample (F-2-ply), which had TTS = 296, TSA-HF = 87.6, and PF= 51.7. The PF difference of the two was 2.3, which was far greater than the significance criterion of 1.7.

Second stage: related technical analyses

Results of this stage are discussed as five subunits: 1) proving the reproducibility of the PF deduction model; 2) comparing samples in different panels at the same scale; 3) four-ply products having different trends of HBS and TSA-HF; 4) four-ply products possessing advantages in both HSS and TTS of sheets; 5) re-examining the panelists; and 6) discussion on production technology aspects.

1) Proving the reproducibility of the PF deduction model

Table XI shows the reproducibility of the PF testing. Based on the four selected standard samples (D-4-ply, G-3-ply, C-2-ply, and A-2-ply), the first stage PF-1 and second stage PF-2 had a correlation coefficient R^2 of 0.9343, and *t*-value of 5.33 > 4.302, which successfully proves the reproducibility of the PF experiments.

2) Comparing samples in different panels at the same scale

According to the regression equation, $y = 0.5271x + 25.6$, derived from Table XI, the two stages of PF data could be calibrated to a correlated value (CV) for comparisons as shown in **Table XII**. When the significant difference cri-

Standard Sample	PF-1	PF-2	Regression Formula
D-4-ply	54.0	55.3	$y = 0.5271x + 25.6$ $R^2 = 0.9343$
G-3-ply	53.7	51.6	
C-2-ply	49.3	43.8	
A-2-ply	46.9	41.9	
t-test	$\|t\| \geq t\alpha/2$; n-2: 4.302		*t*-value = 5.33

PF-1 = preference test in phase 1; PF-2 = preference test in phase 2.

XI. Reproducibility of preference testing.

PF-panel	Brand	OV(x)	CV(y)	Regression Formula
PF-1	D-4-ply	54.0	54.0	$y = x$
	G-3-ply	53.7	53.7	
	F-2-ply	51.7	51.7	
	B-2-ply	51.6	51.6	
	E-2-ply	51.3	51.3	
	C-2-ply	49.3	49.3	
	A-2-ply	46.9	46.9	
	I-1-ply	39.9	39.9	
	H-1-ply	39.3	39.3	
PF-2	I-4-ply	55.7	55.0	$y = 0.5271x + 25.6$
	D-4-ply	55.3	54.7	
	G-3-ply	51.6	52.8	
	E-2-ply	49.8	51.8	
	F-2-ply	49.6	51.7	
	B-2-ply	48.1	51.0	
	C-2-ply	43.8	48.7	
	A-2-ply	41.9	47.7	
	H-2-ply	41.8	47.6	

OV(x) = original preference (PF) value (independent variables x); CV(y) = corrected PF value (dependent variables y).

XII. Correction of preference values.

I-4-ply	I-4ply										
D-4-ply	0.3	D-4-ply									
G-3-ply	2.2	1.9	G-3-ply								
E-2-ply	3.2	2.9	1.0	E-2-ply							
F-2-ply	3.3	3.0	1.1	0.1	F-2-ply						
B-2-ply	4.0	3.7	1.8	0.8	0.7	B-2-ply					
C-2-ply	6.3	6.0	4.1	3.1	3.0	2.3	C-2-ply				
A-2-ply	7.3	7.0	5.1	4.1	4.0	3.3	1.0	A-2-ply			
H-2-ply	7.4	7.1	5.2	4.2	4.1	3.4	1.1	0.1	H-2-ply		
I-1-ply	15.1	14.8	12.9	11.9	11.8	11.1	8.8	7.8	7.7	I-1-ply	
H-1-ply	15.7	15.4	13.5	12.5	12.4	11.7	9.4	8.4	8.3	0.6	H-1-ply

XIII. Preference difference for each paired sample.

terion of 1.7 was applied to judge whether there were significant differences in each pairwise comparison, then in conjunction with **Table XIII** to make each pairwise difference, we found the following four unique features.

(i) *Four-ply samples were better than three-ply samples.* The I-4-ply value of 55.0 was almost the same as the D-4-ply value of 54.7, which were better than the G-3-ply value of 52.8. The respective differences were 2.2 and 1.9, which were greater than the criterion of 1.7 for a significant difference.

(ii) *Four-ply samples were better than two-ply samples.* The two four-ply samples had respectively better PFs than the value for E-2-ply with differences of 3.2 and 2.9, which were both greater than the 1.7 value for a significant difference.

(iii) *Three-ply samples were not significantly preferred over two-ply samples.* The G-3-ply sample had a PF value of 52.8, which did not significantly differ from the E-2-ply and F-2-ply values with differences of 1.0 and 1.1, which were smaller than the 1.7 value required for a significant difference. However, they were significantly preferred over the other two-ply products.

(iv) *Improved products all showed significant increases in PF.* From 39.9 for the I-1-ply product to 55.0 for the I-4-ply product, a gain of 15.1 PF points was seen, and from 39.3 of the H-1-ply product to 47.6 of the H-2-ply product, a gain of 8.3 PF points was seen.

3) HBS of four-ply samples: different trends from TSA-HF counterparts

As noted before, because line 3 of Fig. 4 shows an abnormal HBS trend (R^2 = 0.0589), we therefore reanalyzed the abnormality, as shown in Fig. 5. Figure 5 illustrates two phenomena: The six samples of two-ply products (line 2) showed high positive correlations between PF and HBS, with R^2 = 0.8858 and slope = 0.8274. However, the three samples of multi-ply products showed a high correlation, but with the opposite trend (R^2 = 0.9836 and slope = -1.3789).

After discussions with the 19 panelists, we found that eight of them had different perceptions from the rest of the group; in testing HBS, the hand-held multi-ply products were thicker, bulkier pads that obviously differed from pads of two-ply samples, and greatly differed from TSA measurements of the planar states of the two-ply samples. The reason that the two four-ply samples were at the top of the PF list should be due to the HSS (line 2 for HSS in Fig. 4).

For the data analyses of this experiment, we did not exclude results from the eight abnormal testers as the original rules stipulated. Since the "so-called rules" are made by man, while abnormal performances often reflect other realities, there might be more opportunities to explore the consequences. For example, there is an opportunity to examine if HBS of multi-ply products gained no favor, then what constitutes the PF structural advantage of these products? This is discussed in the following section. Another opportunity is why did the overall test results of all testers conform to the theory, while when using the multi-ply products, half of the panel exhibited another state of perception? This phenomenon is discussed in the fifth section.

4) Co-occurring advantages of four-ply samples

Figure 5 together with Fig. 3 of the first stage results can be regarded as the best conclusion. Line 1 of both graphs for all samples indicates that the overall trend of the sam-

ples cannot be explained based on a theory of sheet softness, i.e., the trend for weaker sheets to have higher softness is rather obscure ($R^2 = 0.3935$ for Fig. 3, $R^2 = 0.2115$ for Fig. 6). The interfering factors are derived from there being products designed with four different plies in the experimental groups.

Line 2 of the two graphs shows that for two-ply samples, the slopes of the regression lines seemed to comply with the theory of the lower the sheet strength, the higher the softness ($R^2 = 0.9731$, slope = -0.0343 for Fig. 3; $R^2 = 0.911$, slope = -0.0451 for Fig. 6). It also shows the dilemma of development of the tissue sheet softness technical curve for quite some time.

When we incorporated the data analyses of Table X, it was apparent that two-ply products were in an inferior position, having HSS (38.8~50.6) and TTS (267~456), whereas four-ply products had advantages of both HSS (57.6 and 57.3) and TTS (676 and 648). The limitation of the two-ply products was thus resolved, and higher PFs were accorded. This, however, gave rise to a new thought, i.e., what is the limit of the advantages of four-ply products? This is an issue worthy of investigation in the future.

5) Re-examination of the testers

The softness values provided by the panelists were verified with *t*-test, which determined (statistically with 95% confidence interval) whether the data were linearly consistent. For instance, did the specimen A > B > C > D have stable correlations? Whenever the test results could not pass *t*-test, the tester was deemed an unqualified tissue softness quality control (QC) person and would be expelled from the panel. In this study, results of the 19 testers who hand-felt tested the HSS and TTS analyses all passed the *t*-test, which indicates that they had the same preference ranks for all nine samples of A to I. However, the same hand-felt perceptions could not produce consistent HBS rankings. This was due to perceptions that the thicker hand-held four-ply products differed from those of two-ply products, and also distinctly differed from the planar state of TSA specimens. This led us to become aware that although bulk softness is an important pursuit in tissue quality, four-ply products provide consumers with a comfortable feeling of tissue surface softness and a secure feeling that the products are not so easy to burst or break.

The rankings of PF were also subjected to *t*-test to ascertain the subjective preference of the tester, and we are expecting to further investigate the causes for the preference. Therefore, preferences for a product differed from one person to another, and all persons produced valuable referential information, excluding different perceivers, so using the statistical *t*-test to judge the testers was thus deemed inappropriate. As a consequence, the SD lines in Fig. 5 are particularly wide. We need to discern the main trend of the test panels, but also to further understand the feelings and needs of the dissenting minority.

6) Discussion on production technology aspects

(i) *Paper strength*: Regardless of the fiber genres or chemical used, with respect to paper property results, these are manifest in the physical properties and softness values. The established technical curve theory based on practical experience all indicated that the greater the paper strength, then the poorer paper softness became. When setting up the product-related specification, design must incorporate this theory. Therefore, we can adopt the expressed paper strength results based on a general mill production management allowing the findings of this study to be used for paper machines and also conforming to the usage status of the consumers.

(ii) *Variability*: From Figs. 2 to 6, we can perceive that household tissue products generally have fairly large standard deviations. Therefore, when using the average values for analysis, statistical verification must be applied. In our studies, *t*-test was used to verify our mean value analyses. In a broader sense, the measure would provide clear technical curves for the major variable trends. Based on our careful sampling process, these interrelations constructed out of the mean values had high value of reference, and reducing variability of the products is a persistent effort for which to strive.

(iii) *Furnish*: When producing a tissue with better softness, the furnish used would consider using fibers with lower coarseness. The long-fiber coniferous fiber to the short-fiber eucalyptus ratio would be 25%~35% vs. 75%~65%, and the proper physical properties would require refiner treatment to develop. After forming on the wire, the degree of beating would usually be adjusted according to the designed specifications of the product. Softness is controlled by the blade geometry on the Yankee dryer, which includes adjustment of blade angle together with the Yankee spray chemicals to facilitate creping of tissue.

(iv) *Chemicals*: In our study, all samples were produced by a single company, and we made sure that there was no addition of internal or surface softening agents. The tissue surface softness was developed during production of base paper accompanied by the bulk paper softness. According to Hollmark's theory [9], paper softness includes both surface and bulk softness; as the curves in Fig. 4 show, the four-ply products have first-place superiority. If, however, a surface smoothness agent was added to the products, there would be no bulk softness benefit. Although the chemicals are effective, they are not the point of contention in this study. The present study mainly focuses on the physical and softness properties that can be controlled on the production line and their effects on the product preference of consumers.

(v) *Model results*: The results of this model set us thinking that from the customer's perspective, in addition to tissue softness, this model helped point out that tissue strength should also emphasized, and from the cost perspective, if the four-ply products are deemed too expensive, some typ-

ical two-ply products can also meet the demand. For example, Table X shows that consumers liked E-2-ply, F-2-ply, and B-2-ply of the two-ply group. Thus, it is possible to examine their softness and strength to adjust product specifications. From the product development perspective, as Line 2 in Fig. 6 shows, the two-ply group of products has reached its developmental limits, with strength as their Achilles' heel. The four-ply products offer the opportunity for developing a new technical curve.

CONCLUSIONS

This study applied test panels to quantify preferences among a group of tissue products. After a two-stage experiment, we proved the reproducibility and consistency of this hand-held panel method. Through analyzing correlations of PFs with paper properties, such as TTS, TSA-HF, HBS, and HSS, we successfully identified critical factors that influence the PFs of a specific group of people, which should be helpful in adjusting certain qualities on the production line.

As tissue softness and physical properties have mutually negative correlations, products preferred by consumers are not mainly based on hand-felt softness, as softer products may sacrifice some strength properties; therefore, four-ply products that had advantages of both HSS and TSS were the preferred choices.

The testing method established in this study can be further developed for broader applications, such as differentiating consumers based on their age, region, sex, profession, etc.

ABOUT THIS PAPER

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About this journal

ABOUT THE AUTHORS

The study results presented here not only have proven that the experimental method has reproducibility and consistency, but have also successfully indicated the critical factors influencing the preference (PF) for tissue products of a specific consumer group, such as regional preference, whether they are especially picky about softness or are for a specific use, like cosmetics, where softness is definitely required. This research is an extension of a study in 2011 [3], 2019 [5], and 2021 [8], "Quantification of the degree of preference for different tissue products based on a hand-felt tissue testing panel." It will be helpful for mills in making adjustments to the production line so that product qualities fit the desires of consumers.

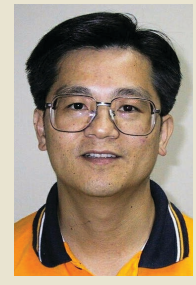
Study samples were provided by Ching-sui mill of Yuen-Foong-Yu Enterprises Ltd. We would like to stress that their careful specimen preparation work before the experiments was the most critical factor for a successful experiment. We want to thank the careful undertaking of the staff of Ching-sui mill for allowing the study to proceed smoothly. As the director and corresponding author of this research, I (Perng) want to also thank my professional team members, Tser-Ying Teng, Ching-Ho Chang, Shih-Sheng Chen, and Chao-Ben Gwo.

Through analyzing correlations of PFs with paper properties, such as TTS, TSA-HF, HBS, and HSS, we successfully identified critical factors that influence the preferences of a specific group of people, which should be helpful in adjusting certain qualities on the production line so that the resulting products will be better received in the marketplace. The testing method presented here can be further developed for broader applications, such as differentiating consumers based on their age, region, sex, profession, etc.

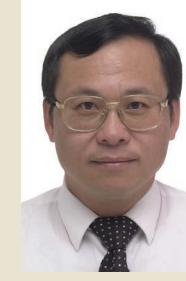
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ther applied to evaluations of preferences in different consumer groups of different ages, regions, sexes, professions, etc. Based on the outcomes of such studies, optimizing adjustments can be made to suit the preferences of specific consumer groups. **TJ**

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