EFFECTIVE FEATURES OF THE CONCENTRATED LOADING CURVES (WOVEN FABRIC OBJECTIVE MEASUREMENT)

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Abstract This paper deals with evaluation of the mechanical properties of woven fabrics. Method of evaluation is concentrated loading system. A total of 17 pieces of woven fabric is used. The most related parts of the curve to the properties are shown and as a result, effective features are lightened up.

Key Words Mechanical Properties, Woven Fabrics, Concentrated Loading System, Effective Features, Low Stress

چکیده ایـن مقالـه ارزشیابی خواص مکانیکی پارچه های تاری-پودی را مورد بررسی قرار داده است. روش سنجش بکار گرفته شده از نوع نیرو وارد کردن متمرکز می‌باشد. تعداد ۱۷ قطعه پارچه از نوع تاری-پودی بکار گرفـته شـده اسـت. قسـمتهائی از منحنی تنش- کرنش حاصل از آزمایش، مرتبط و همبسته با خواص مکانیکی شناخته شده و در نتیجه مرتبط ترین آنها (بعنوان پارامتر های سنجش خواص مکانیکی) نشان داده شده است.

1. INTRODUCTION

One of the major concerns of the textile and clothing industries is the low stress behavior of fabrics, while the cost and time consumption of the testing is also vital. Bishop [1] gives comprehensive surveys about different methods of evaluation together with discussions. Recently a new system called “Concentrated loading method” has been introduced [2,3,4]. This new method has the benefits of simplicity, and short duration of testing. The method is easily accessible and there is no need for sophisticated costly equipment.

This paper considers the ability of the concentrated loading method for measuring the basic low stress mechanical properties of woven fabric. Seventeen randomly selected woven fabrics were tested by two methods. First, the samples were tested by KES system [5] and the results were based as actual values for the evaluation and analyses of the concentrating loading method. Second, the specimens were also tested by the loading- unloading for 200-gram forces. The results show the ability of the method and introduce the parameters, which indicate the behavior of the woven fabrics.

2. BACKGROUND

Principles of the method are based on two behaviors of orthotropic sheets: the inter relations of in-plane properties; and buckling of flexible sheets under tension, when the external forces are not uniformly distributed [2,6,7]

Woven fabrics, like any other flat sheet can have three basic but independent forms of deformations (tensile (-extension or compression-), shear, and bending), plus buckling mode, which is a combination of the basic modes of deformations. Complex deformation of the woven fabrics (buckling due to the shearing, the compressive, and concentrating load), which are studied by Ly

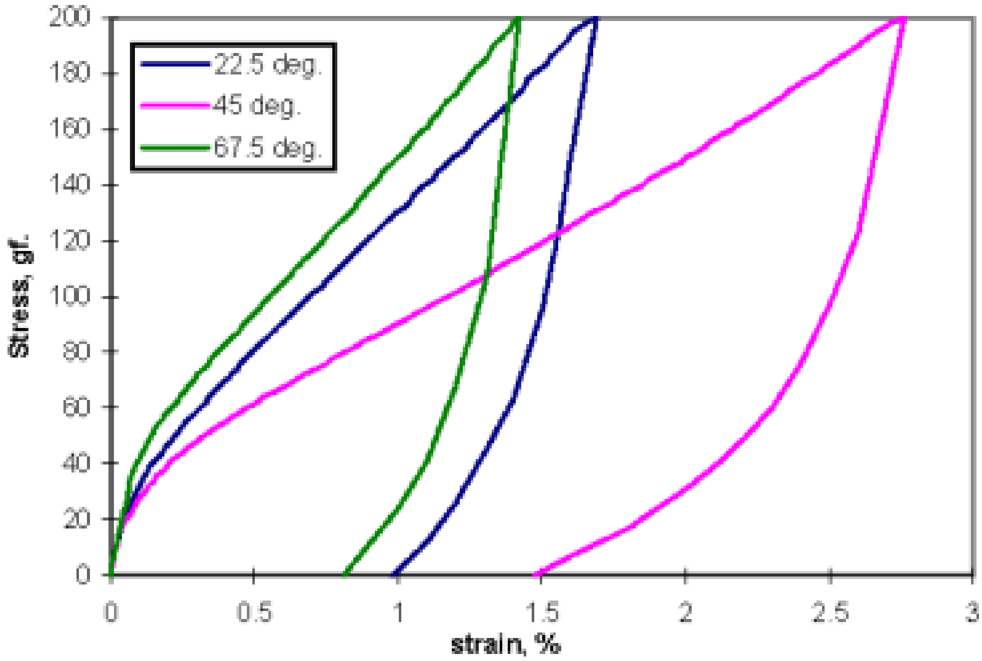


Figure 1. A sample of loading-unloading curves of the 3 bias specimens from each woven fabric**.**

and Dahlberg [10,11,12] Grosberg and Swani [13,14] and Amirbayat [6,7], are summarized and shown in reference number [8].

This new method has taken the advantages of the Buckling of woven fabrics due to the fact that when a concentrated load is applied on the boundary of a very large plate it will cause buckling which indeed is a combination of the three basic forms of deformations (- tensile, shear and bending-).

The method has been explained and well described in the publications [4,8]. It is shown that Ratio of the bending stiffness to the in-plane modulus, the Poisson's ratio, and the dimensions of the sheet are important factors in buckling under tension [6,7].

3. EXPERIMENTAL WORK

3.1. Materials A total of 17 woven fabrics with the specifications shown in Appendix 1 were randomly chosen for the experimental work. Fabrics included different structures, with wide range of materials, such as cotton, wool, jute, synthetics and blend of different fibers (weight range, 54-500 g/m^2 and thickness range, 0.1- 1.3 mm).

3.2. Test Specification

Size of the Specimen and Length/Width Ratio The length and the width of the samples were ten and five-cm respectively. The length/width ratio was taken to be two. This selection was due to the fact that the transverse stresses are compressive throughout the middle portions of the sample when the ratio Length/Width is greater than one and when the ratio is equal or greater than two the distribution of stress is close to the condition of the uniform loading [6].

Preparation of the Samples Three rectangular specimens, each 24cm long and 5cm wide were cut from every sample fabric, one at angle of 22.5°, to the warp direction, (which is 67.5° to the weft direction), one at 45° to the warp (which makes the same angle to the weft direction), and one 67.5° to the warp (which is 22.5° to the weft direction),

TABLE 1. The Correlation Between Kes Shearing Parameters and a Few Highest Correlated Features Extracted from the Curves.

	FEATURES							
	AGA	1/AGA	ECD	1/ECD	EML	1/EML	AAC	1/AAC
G	-0.637	0.964	-.442	0.832	-.674	0.927	-.691	0.934
2HG.5	-0.488	0.882	-.457	0.937	-.566	0.896	-.546	0.859
2HG5	-0.611	0.908	-.530	0.857	-.699	0.926	-.689	0.931

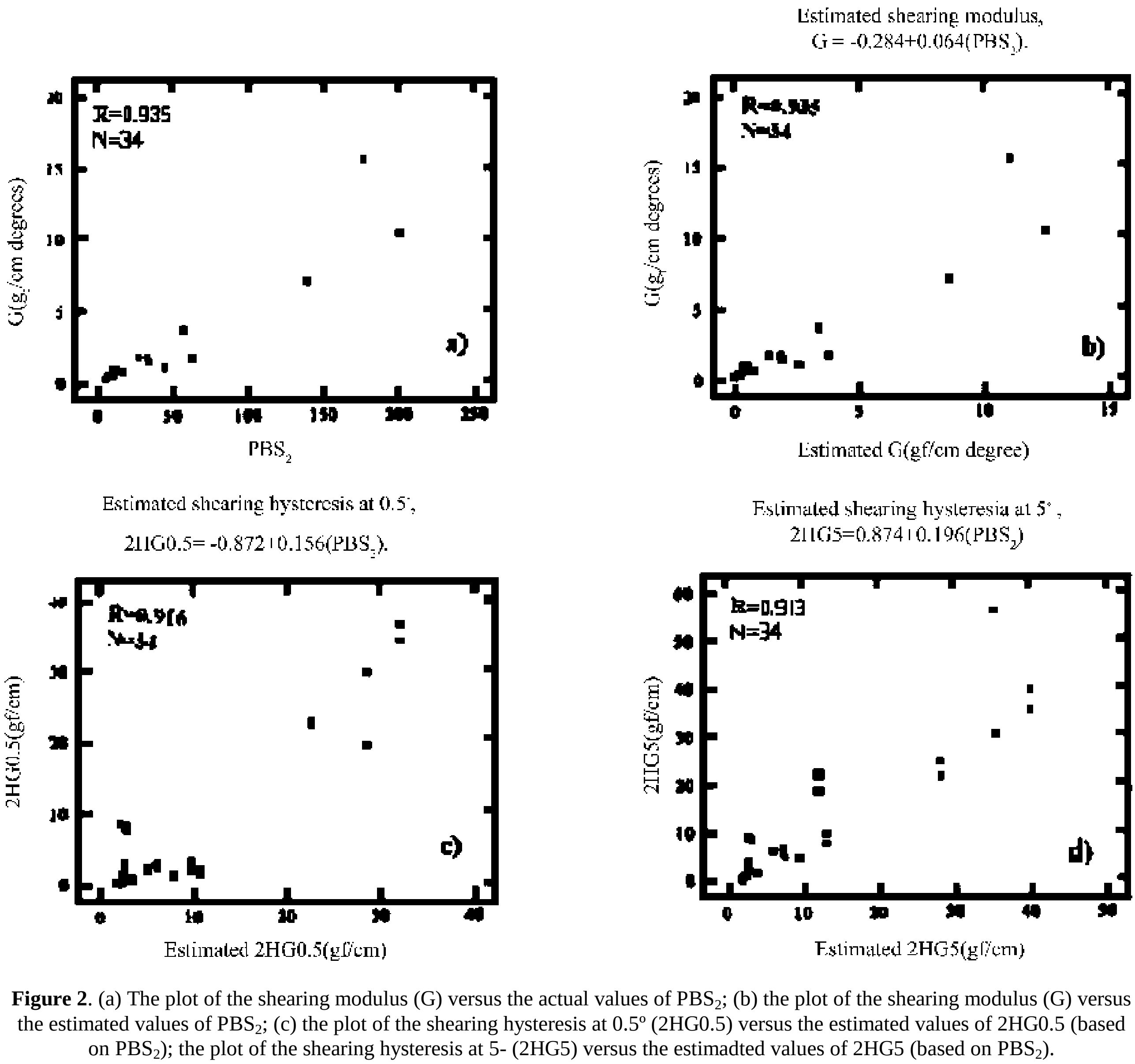


Figure 2. (a) The plot of the shearing modulus (G) versus the actual values of PBS_2; (b) the plot of the shearing modulus (G) versus the estimated values of PBS_2; (c) the plot of the shearing hysteresis at 0.5° (2HG0.5) versus the estimated values of 2HG0.5 (based on PBS_2); the plot of the shearing hysteresis at 5- (2HG5) versus the estimadted values of 2HG5 (based on PBS_2).

using a special template.

Since bias samples develop shear strain under tensile stress, the strips were folded in half to form a double ply of face-to-face fabrics 12cm long. An

TABLE 2. Correlation Coefficient Between Ending Slope and Initial Slope.

	ES1	ES2	ES3
IS1	0.674	0.406	0.488
IS2	0.712	0.766	0.712
IS3	0.488	0.406	0.674

eyelet was then punched 1cm from the ply ends opposite to the fold. The second eyelet was inserted 10cm far from the first one after any possible slack was removed. Preparation was done in the Testing lab and after 24 hours of conditioning [4].

3.3. Test Procedure The samples were subjected to a single loading-unloading cycle at a rate of 10mm/min with 200-gram maximum force using a simple attachment to the jaws of tensile tester (Testometric-micro 350 made in U.K. by Shirly developments with 10-kg load cell). Figure 1 shows a sample of the loading-unloading curves obtained by the new method.

4. FEATURES EXTRACTED FROM THE TESTS UNDER CONCENTRATED LOAD (LOAD-EXTENSION CURVES)

Thirty-five quantities (called Features) categorized in four groups of strains, stresses, area, and slopes were measured on each chart (Appendix 2). For more information about the features, please see References 4 and 8. Statistical analysis helped to find the correlation coefficients between the measured mechanical parameters (tested by KES method) and the characteristic factors (features) obtained by the concentrated loading method (Appendix 3). Effective features resulted to each mechanical parameters of the KES were selected and utilized for multiple linear regression. All correlations between the estimated and measured values of the properties are significant at 0.1 percent level.

5. ESTIMATION OF PROPERTIES FROM MEASURED QUALITIES

Figures 2 to 6 give plots of actual shearing tensile and bending properties measured by KES against the estimated values from the present set of tests.

Charts belonging to all different fabric properties contain 34 points, which is double the actual number of the fabrics tested. This is done by considering each fabric in its conventional sense and relating its warp properties to the parameters along 22.5°, 45°, and 67.5° from the warp direction.

Considering each fabric rotated through 90° and relating its weft properties to the parameters along 67.5°, 45° and 22.5° from direction of the warp.

As a result each property along a principal direction is related to the parameters (1) 22.5°, (2) 45° and (3) 67.5° from its direction.

6. RESULTS AND DISCUSSIONS

6.1. Shearing Properties For all the fabrics the curve corresponding to 45° shows the highest final extension (EML). This shows that ratio between

TABLE 3. Correlation Coefficient Between ET (Return Elongation From Unbuckling Point To Ending Point) and Elongation at Different Loading Points (Incremental Curve).

	EH1	EH2	EH3	EHF1	EHF2	EHF3	EML1	EML2	EML3
ET1	0.539	0.574	0.603	0.582	0.606	0.629	0.604	0.616	0.640
ET2	0.574	0.498	0.488	0.547	0.567	0.547	0.582	0.592	0.582
ET3	0.603	0.574	0.539	0.629	0.606	0.582	0.640	0.607	0.604

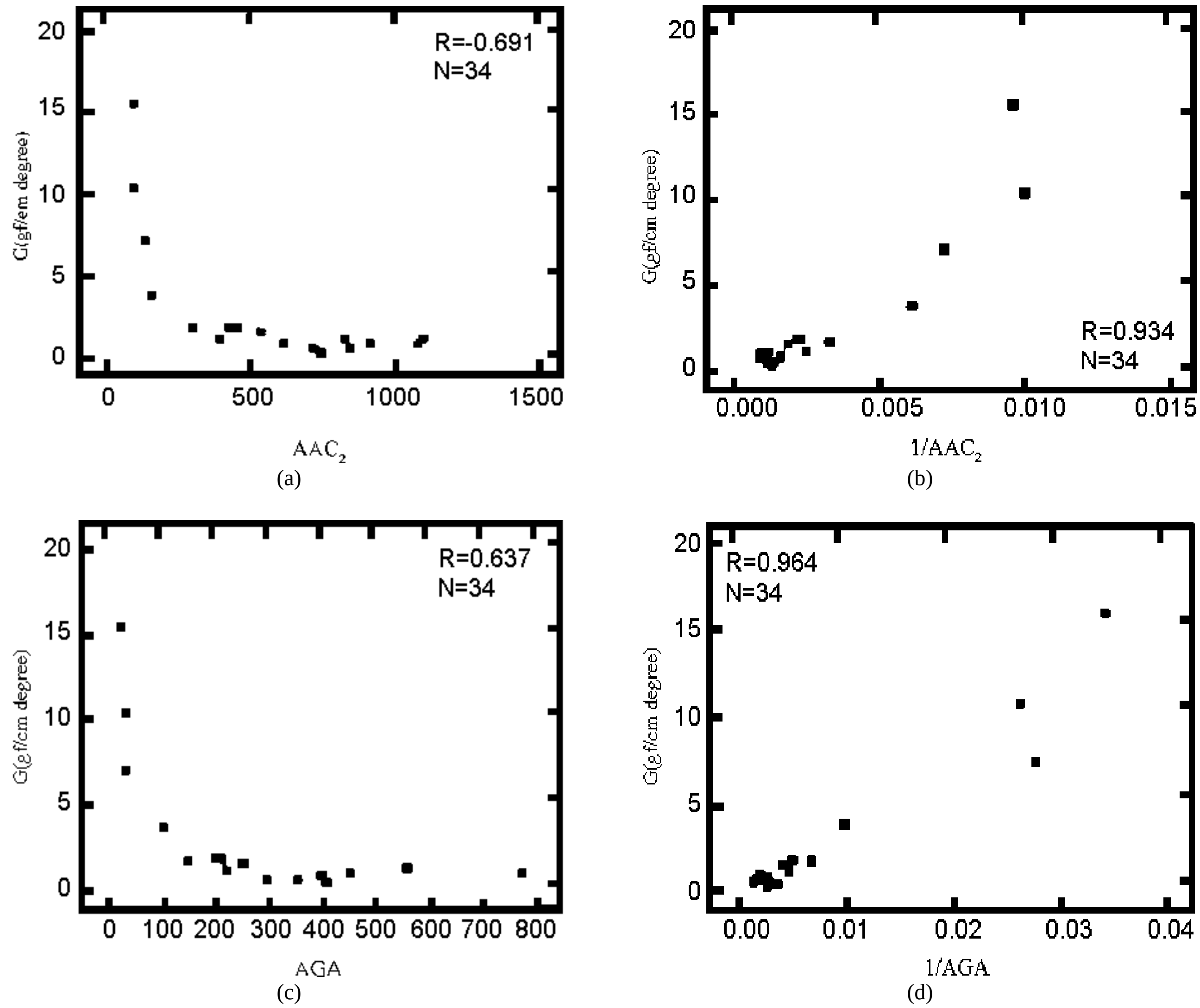


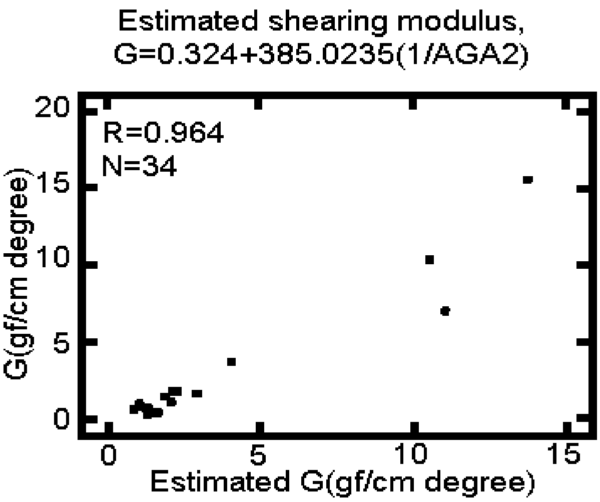
Figure 3. (a) The plot of the shearing modulus (G) versus the actual values of AAC_2; (b) the plot of the shearing modulus (G) versus the actual values of 1/ AAC_2; (c) The plot of the shearing modulus (G) versus the actual values of AGA_2; (d) the plot of the shearing modulus (G) versus the actual values of $1/AGA_2$.

Poisson's ratio and tensile rigidity reaches its maximum at 45°, which is in agreement with the work of Aalsawaf and the explanation of Amirbayat [9,2].

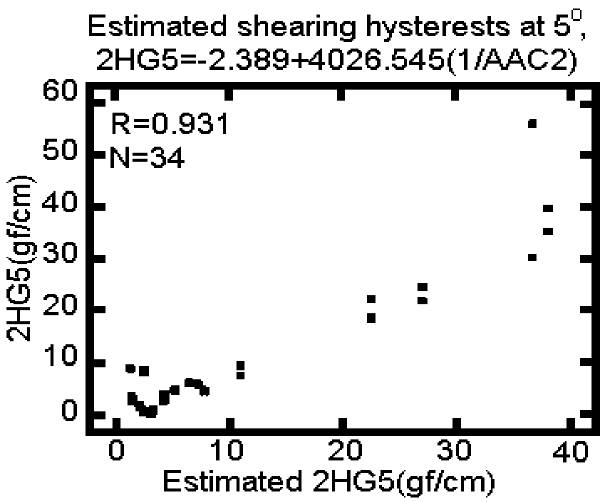
The measured shearing parameters (G- 2HG.5-2HG5) showed a very high correlation with the estimated factors showing that the method is able to evaluate the shearing properties perfectly.

Comparison between three sets of correlation results, shows that calculated features along the 45° bias sample (in contrast to the other two directions) had highest correlation with the shearing parameters specially shearing modulus, proving the fact that shearing modulus can be estimated from tensile properties along 45° bias. This is agreement with the explanation and work of Alamdar [15].

The correlation coefficients between features and the KES shearing parameters (Appendix 3, Table 1) show that post buckling slope had the highest value of correlation with the shearing parameters specially shearing modulus. It should also be noticed that highest correlation among the three sets (PBS22.5°, PBS45° and PBS67.5°)



(a)



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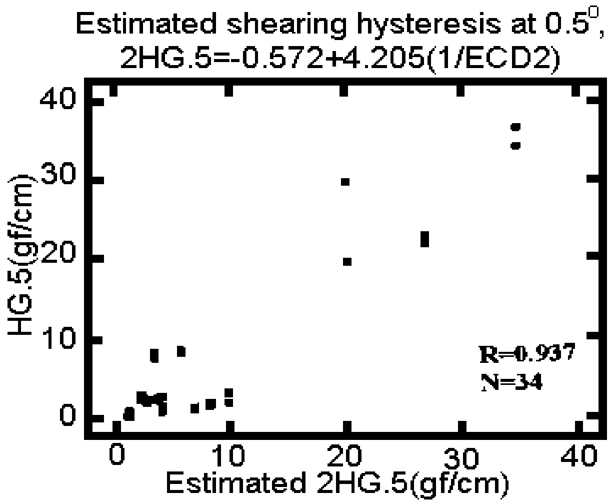


(c)

Figure 4. (a) The plot of the shearing modulus (G) versus the estimated values of G (based on 1/AGA_2); (b) the plot of the shearing hysteresis at 5° (2HG5) versus the estimated values of 2HG5 (based on 1/AAC_2); (c) the plot of the shearing hysteresis at 5° (2HG.5) versus the estimated values of 2HG0.5 (based on 1/ECD_2).

belongs to 45° bias samples indicating results similar to previous works [2,4,8].

The table of the correlation also indicates the importance of the ending slope and its relation to 2HG.5.

Figure 2 (a, b, c and d) shows the estimated equations and the plot of actual values of each shearing parameter versus its estimated values based on PBS2.

Some of the other features like AGA are negatively correlated to the shearing properties. The negative sign of the correlation values indicates that as the value of shearing parameters raises the value of extracted features decrease. In other words, if the inverse value of the extracted features (which are negatively correlated) were introduced as new parameters, the correlation would be positive. Therefore, reciprocal transformation is applied for some of the variables and the highest correlated features

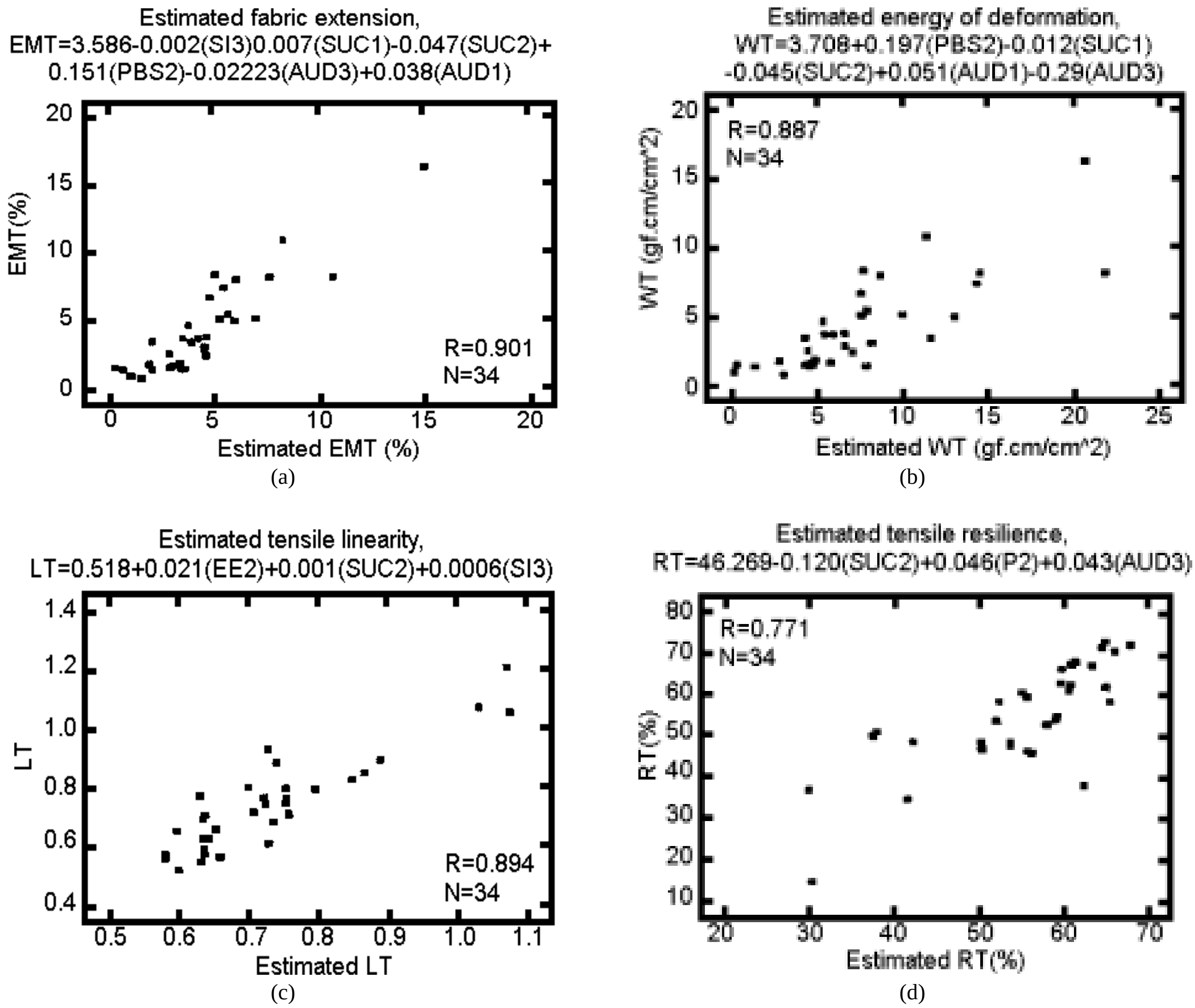


Figure 5. (a) The plot of the measured fabric extension versus the estimated values; (b) The plot of the measured energy of fabric extension versus the estimated values; (c) The plot of the measured linearity of tensile curve versus the estimated values; (d) The plot of the measured tensile resilience versus the estimated values.

are shown in Table 1.

Figure 3(a, b, c and d) gives the plots of measured shearing modulus against the actual and inverse values of AAC2 and AGA2.

The inverse values of the gap area between the loading and unloading curves (AGA) with positive sign are shown to be the most related feature to the shearing modulus (G). This quantitative feature (AGA) denotes the out of plane response of the fabric during loading and unloading. The relation between inverse value of AGA and shearing modulus is positive, informing that when shearing modulus is increased the area will be decreased. This is concluded that stiffer fabric (high shear modulus) would have lower extension due to the prefixed loading. Figure 4(a, b and c) shows the estimated equations and the plot of actual values of each shearing parameter versus its estimated values (based on the inverse values of the features).

However, it is concluded that shearing property could be easily evaluated by the behavior of the fabric during the loading. The initial movement (up to critical point), or movement during the

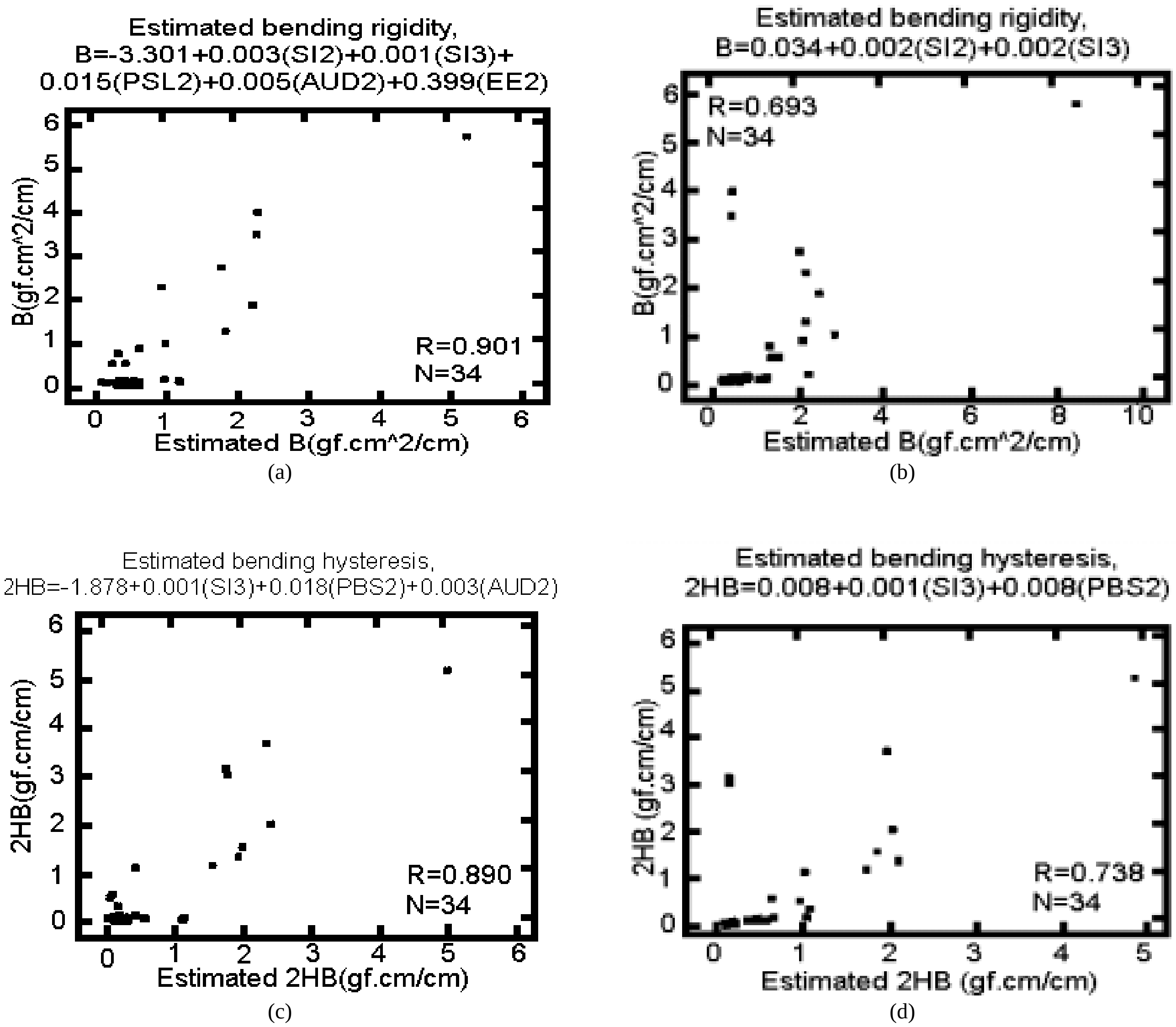


Figure 6. (a) The plot of the measured bending rigidly (B) versus the estimated values; (b) the plot of the measured bending rigidly (B) versus the estimated values; (c) the plot of the measured bending hysteresis (2HB) versus the estimated values; (d) the plot of the measured bending hysteresis (2HB) versus the estimated values.

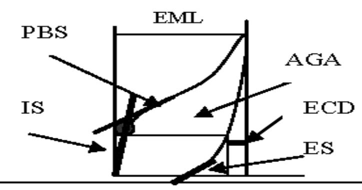
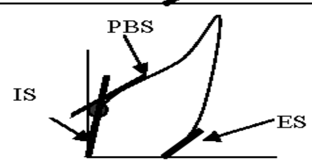
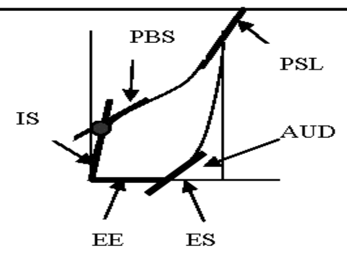
moment of buckling (initial out of plain movement) or the energy lost during loading and unloading (gap area between two curves) are the features which can show the shearing behavior. Figure 4 (a, b, & c) shows the plots of measured shearing parameters against the estimated values based on the inverse values of AAC, AGA & ECD).

6.2. Tensile Properties The correlation coefficients between features and the KES tensile parameters (Appendix 3, (Table 2)), as well as the regression analyses (Figure 5(a, b, c & d)) showed that tensile property, could be evaluated by this method. Initial movement, post buckling behavior,

TABLE 4. The Correlation Between KES Shearing, Tensile and Bending Parameters with Some Features Extracted from the Curves.

PRO.	SHEARING			BENDING		TENSILE			
	G	2HG.5	2HG5	B	2HB	LT	RT	WT	EMT
SI	------	------	------	0.664	0.663	------	-.607	0.425	------
SUC	____	0.921	0.903	0.589	0.647	0.824	-.678	------	------
PBS	0.935	0.916	0.913	0.522	0.656	0.760	-.667	------	------
ES	------	0.930	0.907	0.513	0.638	0.794	-.695	------	------
AUD	------	------	------	------	------	-.640	0.406	0.314	0.587
EBC	------	------	------	------	------	-.652	-.382	-.207	0.529
ECD	------	------	------	------	------	-.580	0.358	0.312	0.563
PSL	------	------	------	------	------	0.684	-.563	------	------
P	------	------	------	------	------	0.778	-.422	------	------
EE	------	------	------	------	------	------	------	-.459	-.404

TABLE 5. The In-Plane and Out of Plane Deformations, the Forces to be Overcome During the Deformations and the Features Related to the Properties.

<table>
<tr><th>Deformations</th><th>Forces to be overcome</th><th>Effective zones</th></tr>
<tr><td>(in-plane)
Shearing</td><td>Yarn friction at intersections, bending and twisting, in some cases.</td><td></td></tr>
<tr><td>(out of plane)
Bending</td><td>Intersection contact force and bending the yarn (- friction between fibers in the yarn-)</td><td></td></tr>
<tr><td>(in-plane)
Tensile</td><td>Longitudinal friction between the yarns and fibers.</td><td></td></tr>
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deformation for the last twenty gram load, (pick part of the curve) and the behavior of the fabric after releasing the load are the key points related to the property.

It is noticeable that fabrics, during unloading would have an unbuckling zone which sample leaves the buckling status and returns back to its plane form. This zone has its own specification and is able to serve enough information about the fabric behavior. In addition it makes the unloading curve to two parts which both are differently correlated to the properties.

1. Upper part, which is the return movement of the fabric from buckled form to plane (LAAC).
2. Lower part, which is the return in plane behavior (LABC).

APPENDIX 1. Specification of the Fabrics used in this Experimental Work.

F.no	ends/ cm.	warp count Nm	warp cri. %	Picks/ Cm.	Weft Count Nm	Wef Cri. %	Materi al	Fabric structu	Fab.w g/m^2	Fabric Thick Mm
1	40.0	180	3.6	28.0	095.0	04	Ac	Plain	054	0.110
2	46.0	130	10.0	25.0	100.0	10	Ac	Plain	067	0.140
3	60.0	086	08.0	30.0	086.0	10	P	Plain	114	0.200
4	37.4	034	02.0	16.5	010.5	03	Ac	Plain	270	0.620
5	23.0	028	12.0	18.0	028.0	15	P/C	Fanc.	167	0.335
6	78.0	088	12.0	44.0	077.0	20	P	Fanc.	167	0.380
7	22.0	019	04.0	19.5	019.0	07	C	Plain	230	0.420
8	23.0	020	03.0	16.5	020.0	06	Ac	Plain	207	0.340
9	20.0	44/2	20.0	22.0	052/2	08	P/W	Fancy	201	0.300
10	14.0	09.5	05.0	14.0	009.5	07	Ac	Plain	310	0.560
11	40.0	165.0	04.0	30.0	100.0	05	N	Plain	057	0.100
12	28.7	25.5	12.0	21.6	017.0	11	C/V	Velvet	340	0.750
13	30.3	32.0	11.0	14.2	018.0	14	C/V	Velvet	330	0.745
14	03.33	02.7	0.5	3.7	002.7	01	JU	Plain	258	1.300
15	20.0	07.9	05.0	25.0	015.2	10	C	Plain	450	1.070
16	29.0	09.5	11.0	18.0	009.0	08	C	Twill	500	0.930
17	20.0	07/2	06.0	10.0	009/2	11	C	Plain	406	0.950

Note: Ac.= acrylic C = cotton Ju.= jute N = nylon P = polyester V = viscose W = wool

However, it is found that area under the unloading curve, AUD (especially upper part, LAAC) is effective. The ECD, (which is the difference in strain between maximum load point and the unbuckling zone) and the EBC, (which is the difference in strain between maximum load point and end point) are also related to the tensile property.

The ending slope (ES) which is in one hand highly correlated to shearing property and in the other hand correlated to bending property, is also correlated to tensile property. Due to the fact that initial part of the incremental curve indicates the in-plane deformation of the specimen and the ending part of the unloading curve also indicates the return in-plane behavior, therefor the two parameters –IS & ES- should have a good correlation to each other. Table 2 shows the above fact.

Table 3 shows the correlation between in-plane return movements (fibers and yarns friction) when releasing the load and elongation at different loading points (incremental curve) due to fiber and yarn movements.

Appendix 3, (Table 3) shows the correlation and Figure 5(a, b, c, and d) shows the estimated equations and the plot of actual values of each KES parameter versus its estimated values.

6.3. Bending Properties The initial, post buckling and ending zone can serve enough information to evaluate bending deformation (Appendix 3, (Table 3)). Correlation between KES bending parameters and the features showed importance of the slopes. It also lightened up the weight of the initial zone of the loading curve plus the significance of the ending part of the unloading curve. Moreover, regression analyses revealed on the importance of the IS by selecting the initial slope of the curve as the most effective parameters among 35 measured features. Having a good correlation between the bending parameters and initial slope means that bending movement starts from the beginning of the loading especially for those, which have tight structures. Figure 6(a, b, c and d) shows the plots of the measured bending parameters versus the estimated values.

The features, which gave highest correlation to the properties, are summarized in Table 4.

APPENDIX 2. Features Extracted From the Curves.

Sym	Parameters	Units
AAC	Area under the loading curve, above the Critical Point	gf.
ABC	Area under the loading curve, below critical point	gf.
AF	Area under the loading curve, for 50-gram load	gf.
AGA	Gap area between two curves, above the critical point	gf.
AGL	Gap area between two curves, top 50-gram load	gf.
AH	Area under the loading curve, for 100-gram load	gf.
AHF	Area under the loading curve, for 150-gram l.	gf.
ALF	Area under the loading curve, final 50-gram load	gf.
ATH	Area under the loading curve, for 200-gram load	gf.
AUD	Area under the unloading curve	gf.
CPD	Strain at Critical point on the Unloading curve	%
EBC	Difference in strain between max. load & end point	%
EBCC	Strain between 2 curves at the Critical point	%
ECD	Difference. In strain between max. Load point & the point with the same load as the Critical point on the unloading curve	%
ECP	Strain at Critical point	%
EE	Strain at end point	%
EF	Strain at 50-gram load	%
EH	Strain at 100-gram load	%
EHF	Strain at 150 gram load	%
EMGD	Strain at the location of MG on the unloading curve	%
EMGL	Strain at the location of MG on the loading curve	%
EML	Strain at maximum load (200 g)	%
ES	Ending slope.(final 20-gram of the unloading curve)	gf.
ET	Difference .in strain between the Critical point on unloading curve and end point	%
LAAC	Area under the unloading curve, above Critical point	gf.
LABC	Area under the unloading curve, below the critical point	gf.
LAMG	Load at which maximum gap occurs	gf.
MG	Maximum distance (strain) between two curves	%
PBS	Post buckling slope(20-gram load after buckling point)	gf.
PSD	Peak. Slope (first 50-gram of the unloading curve)	gf.
PSL	Peak slope for final 50-gram loading	gf.
SCP	Load at Critical point	gf.
SI	Initial slope (first 10-gram loading) of the loading curve	gf.
SUC	Slope up to Critical point	gf.
TGA	Gap area between two curves	gf.

7. CONCLUSIONS

This experimental work shows, the mechanical properties of woven fabrics could be evaluated by concentrated loading system. The resultant curves of the method would show the bending, shearing and the tensile behaviors of the woven fabrics. Obviously the type of the curve is affected by the response of the fabric when load is inserted. As a result, each part of the curve resembles the behavior of the fabric during that deformation. The figures. in Table 5 show the forces to be over come, the effective parts of the curve and the features related to the properties.

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APPENDIX 3. Characteristic Factors (Features) Obtained by the Concentrated Loading Method.

	Shearing modulus			Shearing hyateresis at 0.5°			Shearing hyateresis at 5°		
PAR.	G_1	G_2	G_3	2HG.5$_1$	2HG.5$_2$	2HG.5$_3$	2HG5$_1$	2HG5$_2$	2HG5$_3$
SCP	0.548	0.766	0.548	0.597	0.789	0.556	0.641	0.742	0.587
ABC	-0.036	0.340	-0.036	0.010	0.365	-0.015	-0.004	0.323	-0.046
AF	-0.540	-0.553	-0.540	-0.466	-0.515	-0.467	-0.583	-0.607	-0.583
AH	-0.616	-0.670	-0.616	-0.479	-0.542	-0.480	-0.623	-0.678	-0.626
AHF	-0.645	-0.682	-0.645	-0.498	-0.541	-0.499	-0.647	-0.683	-0.651
ATH	-0.660	-0.687	-0.660	-0.511	-0.540	-0.512	-0.662	-0.686	-0.669
AAC	-0.656	-0.691	-0.656	-0.509	-0.546	-0.510	-0.660	-0.689	-0.664
ALF	-0.671	-0.677	-0.671	-0.521	-0.520	-0.523	-0.674	-0.670	-0.685
LAAC	-0.457	-0.479	-0.457	-0.462	-0.496	-0.461	-0.544	-0.571	-0.545
LABC	-0.155	0.006	-0.155	-0.092	0.039	-0.105	-0.127	0.006	-0.152
AUD	-0.485	-0.491	-0.485	-0.484	-0.506	-0.484	-0.571	-0.586	-0.575
TGA	-0.557	-0.566	-0.557	-0.369	-0.376	-0.371	-0.512	-0.510	-0.517
AGA	-0.599	-0.637	-0.599	-0.441	-0.488	-0.439	-0.582	-0.611	-0.581
AGL	-0.659	-0.632	-0.659	-0.491	-0.460	-0.492	-0.650	-0.611	-0.659
SI	0.693	0.830	0.693	0.391	0.720	0.545	0.469	0.779	0.775
SUC	0.795	0.825	0.795	0.580	**0.921***	0.694	0.677	0.839	**0.903***
PBS	0.807	**0.935***	0.807	0.674	**0.916***	0.719	0.774	**0.913***	0.892
PSI	0.769	0.872	0.769	0.581	0.757	0.620	0.742	0.892	0.854
PSU	0.414	0.677	0.414	0.358	0.720	0.362	0.473	0.731	0.545
ES	**0.838***	0.824	**0.838***	0.718	**0.930***	0.748	0.843	0.835	**0.907***
ECP	-0.265	-0.027	-0.265	-0.147	0.034	-0.173	-0.211	0.001	-0.257
EF	-0.503	-0.503	-0.503	-0.448	-0.479	-0.449	-0.556	-0.564	-0.556
EH	-0.591	-0.625	-0.591	-0.484	-0.540	-0.485	-0.618	-0.659	-0.620
EHF	-0.621	-0.659	-0.621	-0.501	-0.556	-0.501	-0.641	-0.686	-0.644
EML	-0.637	-0.674	-0.637	-0.510	-0.566	-0.511	-0.655	-0.699	-0.659
ECD	-0.421	-0.442	-0.421	-0.429	-0.457	-0.428	-0.506	-0.530	-0.505
EBC	-0.504	-0.513	-0.504	-0.487	-0.512	-0.485	-0.582	-0.596	-0.583
CPD	-0.489	-0.525	-0.489	-0.303	-0.342	-0.306	-0.433	-0.463	-0.439
EMGD	-0.586	-0.619	-0.586	-0.412	-0.446	-0.413	-0.557	-0.581	-0.561
EE	-0.396	-0.424	-0.396	-0.219	-0.246	-0.222	-0.332	-0.353	-0.336
EBCC	-0.486	-0.530	-0.486	-0.303	-0.349	-0.303	-0.432	-0.470	-0.434
MG	-0.522	-0.550	-0.522	-0.340	-0.370	-0.341	-0.476	-0.496	-0.478
EMGL	-0.380	-0.368	-0.380	-0.377	-0.384	-0.380	-0.445	-0.437	-0.451
LAMG	0.475	0.614	0.475	0.480	0.609	0.474	0.506	0.578	0.521
ET	-0.570	-0.614	-0.570	-0.455	-0.533	-0.455	-0.574	-0.633	-0.582

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