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Evaluation of the Fabric Formability by Concentrated Loading Method

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Abstract—**This work exploits the concentrated loading method (C.L.M) for the evaluation of woven fabric formability. A total of 21 randomly selected woven fabrics are tested by Lindberg and C.L.M methods and the results are compared. The correlation between calculated formability (bending rigidity/low initial modulus) and the measured features extracted from the concentrated loading curves indicates the possibility of measuring of formability of woven fabrics by C.L.M. Among the features extracted from the concentrated loading curves, the initial slope of the load extension curve (IS), the ending slope of the unloading curve of the concentrated loading method (ES) and the gap area below the buckling (GABB) are highly correlated to the calculated formability of the fabrics. The correlation results indicate that testing the fabric samples under C.L.M can be used for direct estimation of the formability of the woven fabrics without requiring two different laboratory testers (bending and tensile).**

Key words: Concentrated loading method, bending rigidity, shear deformation, fabric compressibility

I. INTRODUCTION

Fabric formability is introduced as fabric ability to cover surfaces of various curvatures that no wrinkles or folds are formed and is defined as the product of bending rigidity by longitudinal compressibility (compressional strain per unit applied load) sustained by fabric before it buckles. In other words, fabric formability is related to the maximum compression sustainable by a fabric before the onset of buckling [1].

The importance of this property comes from the fact that its determination enables clothing producers to formulate reliable equations to forecast tailor-ability and sew-ability [2]. In addition, knowledge of the effect of different parameters on formability will also help textile engineers to produce high quality products to satisfy the end-use requirements [3].

On the other hand, the evolution of textile and clothing industries from labor intensive to capital intensive tempts both industries to reduce their cost and increase the quality of their products. Increasing the quality and simultaneously decreasing the cost make the corresponding industries pay specific attention to the testing methods and their required laboratory equipment by choosing simple, cheap yet accurate lab equipment, especially in the case of low stress mechanical properties measurement which shows the quality, tailor-ability and performance characteristics of the fabrics. The leading accurate testers available to evaluate the property (in general, low stress mechanical properties) are Kawakawa and FAST set of instruments [4]. But regardless of which method is used to evaluate fabric formability, one has to use tensile and bending testers with an additional mathematical calculation. Therefore, introducing a simple method to evaluate fabric formability would be a help to the textile and clothing engineers and producers.

Furthermore, it has been shown that concentrated loading method can evaluate low stress shearing, bending and tensile behaviors of the woven fabrics [5]. In addition, it was claimed that, this method can be used to measure the formability too [6,7]. Therefore, the present work is planned to investigate the ability of the method for measuring the formability of the woven fabrics.

II. MATERIALS AND METHODS

A. *Materials*

A total of twenty one pieces of wool and polyester/wool blended suiting fabrics in mass per unit area ranging 180-260 g/m^2 in plain and twill weaves were selected for the present investigation. The sample specification details are shown in Appendix I.

B. *Test methods*

1) Conventional method

As earlier was mentioned, formability evaluation needs tow measurements (bending rigidity and initial modulus) as well as extra calculation.

a) Bending rigidity in warp and weft directions were calculated based on Peirce method according to ASTM D-1388-55T. For this purpose, five samples of dimensions $30\times3002\ mm^2$, in warp and weft directions were cut from each fabric. For each sample, the length of slacking part of sample was measured by the constant angle method. In this way, the value of bending length (for each direction) was the mean value of 20 readings.

b) The initial tensile modulus (ratio of force to elongation increment taking place in the initial linear shape of the load-extension curve) of the fabric in warp and weft directions was extracted from the low load tensile curves.

In order to find the value of initial tensile modulus, five samples were taken for those the bending rigidity was

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assessed. Fabric force-elongation curves were registered on the Testometric-Micro 350 Shirley development, load cell 2 Kg, speed 10mm/min.

c) Formability of samples was computed. In fact, formability in warp and weft directions of each sample (in mm^2) based on the ratio of bending rigidity (μN.m) and initial tensile modulus (N/m) of the corresponding direction was calculated (-B/IM-), where B stands for fabric bending rigidity and IM shows the initial modulus.

C. *Concentrated method*

As shown in Figure 1, the testing method was based on applying 200 gram force over a small portion of the edge of the rectangular specimen.

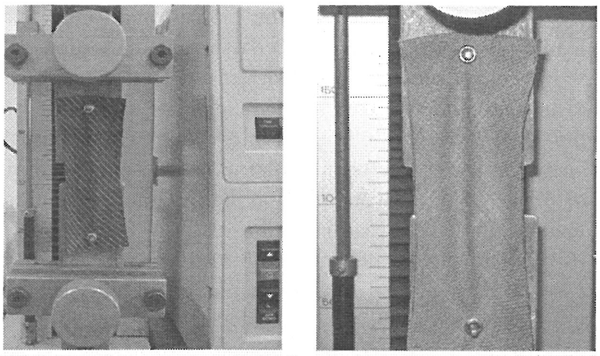
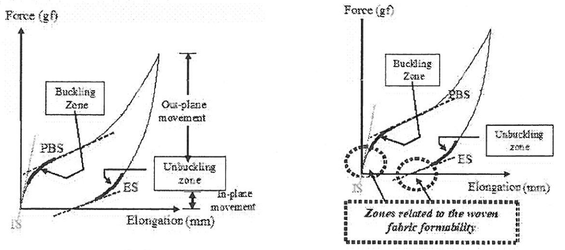


Fig. 1. The concentrated tensile loading

Three rectangular specimens, each 24 cm long and 5 cm wide, were cut from each fabric; one at an angle of 22.5° to the warp direction (which was 67.5° to the weft direction), one at 45° to the warp (which formed the same angle to the weft), and one 67.5° to the warp (which was 22.5° to the weft). The obtained strips were folded in half to form a double ply of face-to-face fabrics (12 cm long). The puncher inserted an eyelet of 1 cm from the ply ends opposite to the fold, and the second eyelet was inserted 10 cm away from the first one after any possible slack was removed. The eyelets were used to prevent the distortion of the fabric at the points of the load insertion. The length/width ratio of the sample was taken to be 2, due to the fact that the distribution of load at the distance equal to the width of the sample from the point of application of a concentrated force was very close to the condition of uniform loading [8]. It should be noted that doubling the strip frees the samples from any shear strain which could be developed under tensile stress.

As shown in Figure 1, the highly polished plates, ($5cm \times 7cm$ with a pin for sample mounting) was fixed on the jaws of the Shirley Testometric-Micro 350. Samples were mounted on the pins by the operator and were subjected to a single loading at a rate of 10 mm/min with 200 gf maximum, by using a simple attachment to the jaws of the Testometric-Tensile Tester with a 2 kg-load cell. Figure 2 shows the typical load extension curves of the concentrated loading method.

Despite the fact that all the loading–unloading curves of the new method are not the same, they do all have common zones among themselves. On the loading curve, a zone specifies the boarder of 'in-plane' and "out-of-plane" deformation (critical zone). On the unloading curve a zone which specifies the border between the "out-of-plane" return movement and the "in-plane" return movement (unbuckling zone) of the specimen. The zones are shown in Figure 2 and the features extracted from the curves are set out in Table I.



(a) (b)

Buckling zone location on the curve moves up as the fabric stiffness increases and consequently the zone prior to buckling is elongated.

Fig. 2. Concentrated loading unloading curves' zones (a) and those related to woven fabric formability (b).

TABLE I
THE FEATURES EXTRACTED FROM THE CONCENTRATED LOADING METHOD

Symbols	Specification	Unit
IS	Initial Slope of the loading curve	(N/mm)
PBS	Post buckling slope (20g load after buckling point)	(N/mm)
PSL	Peak slope for final 50g loading	(N/mm)
ES	Ending slope (final 20g of the unloading curve)	(N/mm)
LTL	Area under the return curve (last 20 gram load)	(N.mm)
ATH	Area under the loading curve, for 200g load	(N.mm)
TGA	Gap area between two curves	(N.mm)
EF	Strain at fifty gram load	(mm)
EH	Strain at hundred gram load	(mm)
EHF	Strain at hundred and fifty gram load	(mm)

III. RESULTS AND DISCUSSION

Table II shows the correlation between formability (in warp and weft directions) and the features extracted from the concentrated loading curves. Regardless of the values, the features have positive and negative signs of correlation. In both groups, the highest correlations belong to initial and ending slopes (IS and ES). More explicitly; as the formability increases the initial slope and ending slope also increase.

For those features with negative sign of correlation, the reciprocal values were introduced as new parameters and their correlations with formability were calculated and are shown in Table III.

Taking the new parameters into account, the highest value of correlation belongs to the reciprocal of the strain at fifty gram load (1/EF), and the reciprocal of the area under the last twenty gram of the un-loading curve (1/LTL). This means that, as the formability of the fabric increases, the elongation of the fabric due to the first 50 gram load and the actual value of the area under the last twenty gram of the un-loading curve both decrease.

Considering the correlation between features IS, 1/EF, ES, 1/LTL and formability, it could be seen that, the highest correlations belong to two areas which both are located at the bottom part of the loading-unloading curves where the in-plane movement of the fabric prior to buckling is registered (Figure 2). In other words, comparison of the correlations introduces two zones related to the formability:

1) Initial zone of the loading curve

This zone starts from zero to the boarder of in-plane and out-of-plane deformations and shows how a fabric under concentrated tensile load behaves to reach the buckling point (in-plane movement prior to buckling).

2) Ending zone located on the ending part of the unloading curve below unbuckling zone (Figure 2)

This zone also shows backward return movement of the deformed fabric to its origin (return in-plane movement of the fabric).

TABLE II

CORRELATION VALUES BETWEEN FABRIC FORMABILITY AND FEATURES EXTRACTED FROM THE LOADING-UNLOADING CURVES OF THE CONCENTRATED LOADING METHOD

Features*	Form$_{Warp}$	Form$_{Weft}$	Features*	Form$_{Warp}$	Form$_{Weft}$
IS_1	0.778	0.812	EF_1	-0.669	-0.656
IS_2	0.711	0.722	EF_2	-0.622	-0.630
IS_3	0.816	0.777	EF_3	-0.654	-0.622
PBS_1	0.727	0.708	EH_1	-0.669	-0.667
PBS_2	0.270	0.258	EH_2	-0.611	-0.617
PBS_3	0.546	0.421	EH_3	-0.605	-0.579
PSL_1	0.0045	0.029	EHF_1	-0.634	-0.638
PSL_2	-0.235	-0.248	EHF_2	-0.564	-0.569
PSL_3	-0.361	-0.36	EHF_3	-0.520	-0.484
ES_1	0.823	0.725	LTL_1	-0.659	-0.631
ES_2	0.754	0.717	LTL_2	-0.618	-0.607
ES_3	0.782	0.815	LTL_3	-0.613	-0.535
ATH_1	-0.489	-0.530	TGA_1	0.030	0.050
ATH_2	-0.32	-0.295	TGA_2	0.542	0.595
ATH_3	-0.096	-0.048	TGA_3	0.481	0.453

* Subscripts 1, 2 and 3 refer to 22.5, 45 and 67.5 degree from warp direction.

In general, the relation of the formability with the two elements located in the initial zone of the loading curve -IS and 1/EF- indicates that, the higher the formability is, the later the occurrence of the buckling phenomenon will be. This means that higher ration of load (bending stiffness) /elongation (in-plane modulus) prior to buckling yields to a better formability.

TABLE III

CORRELATION VALUES BETWEEN FABRIC FORMABILITY AND RECIPROCAL FEATURES EXTRACTED FROM THE LOADING-UNLOADING CURVES OF THE CONCENTRATED LOADING METHOD

Features	Form$_{Warp}$	Form$_{Weft}$	Features	Form$_{Warp}$	Form$_{Weft}$
$1/EF_1$	0.869	0.802	$1/EHF_1$	0.805	0.812
$1/EF_2$	0.854	0.867	$1/EHF_2$	0.694	0.704
$1/EF_3$	0.850	0.831	$1/EHF_3$	0.639	0.586
$1/EH_1$	0.789	0.751	$1/LTL_1$	0.838	0.791
$1/EH_2$	0.769	0.772	$1/LTL_2$	0.774	0.746
$1/EH_3$	0.747	0.713	$1/LTL_1$	0.742	0.607

The relation with two elements located in the last zone of the unloading curve (ES and 1/LTL) highlights the fact that the higher the formability is, the sharper and sooner the return in-plane movement of the fabric will be. The sharper ending slope (lower area under the last twenty gram load) means unity and modality of the fabric structure (a stable injunction and interaction between the fabric unit cells).

To analyze and realize the reasons of this relationship, it is worth considering the difference between the conventional tensile load and concentrated loading curves with the focus on initial parts of the two curves.

The initial region of the conventional curve shows the crimp removal and yarn straightening followed by a very rapid increase in the fabric stress. On the other hand, the loading curve of the new method (C.L.M.) shows an initial negative curvature, which turns positive upon further extension. Naturally, the differences between the curves are due to the response of the fabric to the method of loading (uniform loading applied over a small portion).

In the conventional method, tensile load is uniformly distributed and the implemented energy is used to deform the fabric in its own plane, but in concentrated loading, the energy is used to deform the fabric both in-plane and out-of-plane. In other words, in the case of the conventional loading, the whole load is used to deform the fabric in its own plane (no out of plane deformation), whereas in the case of concentrated loading, a portion of the energy is used to compress the fabric to reach to its buckling point and the rest is used for out-of-plane deformation (in-plane movements →buckling phenomenon →out of plane deformations).

Modality of the buckling phenomenon due to concentrated loading (style of fabric in-plane deformation prior to buckling) is another important point that to be considered. There are two different ways that a fabric in-plane deformation can occur:

a- Yarns in-plane movement leading to fabric buckling in a single smooth rounded curvature shape. At the buckled portion of the sample, yarns are brought together so close and tight, where there is no more room for them to migrate inside the fabric (they have only the chance to bulge out).

b- Yarns are bent and wrinkled before the fabric reaches its buckling point (low in-plane migration for the yarns in the fabric plane so that double curvature buckling zone is occurred). In other words, the fabric is not enough stiff to endure the smooth rounded curvature.

The formability of the first group is appreciated in comparison to the second group because, the first group yields higher compression sustained before the onset of buckling. This means that, fabrics with high bending rigidity and enough mobility (smooth in-plane shearing movement) will have high buckling point with high initial modulus and smooth rounded curvature at buckling point, or vice versa, loose fabrics in which the yarns bend easily will have low value of formability and under the concentrated load will buckle easily with low initial modulus and double curvatures.

In short, among the features, initial slopes (IS), the inverse value of the strain for fifty gram load (1/EF) and the ending slopes (ES) illustrate an acceptable correlation to the calculated formability. This is due to the fact that the initial slope and the elongation at fifty gram load indicate the sustainability of the fabric prior to buckling and the ending slope (ES) and the area under the last portion of the unloading curve (1/LTL) indicate the in-plan return movement of the woven fabric. The ending slope illustrates how freely and sharply the in-plane deformed elements return back to their origin (released from the extension-compression forces). All these four elements, i.e. IS, ES, EF and LTL show the response of the fabric to compression, extension, and shear deformations in the plane of the fabric prior to buckling.

Comparison of the correlations between values of the superior features (-IS and ES-) and formability in warp and weft directions (Table IV) also show that:

1- The initial slope of each direction shows higher correlation to the formability of the other direction. That is, initial slopes close to weft direction (-67.5° to the warp) show higher correlation with the fabric formability in the warp direction and the initial slope of the samples close to warp (-22.5° to the warp) shows a higher correlation with the formability in the weft direction. This is due to the manner of deformation which makes compression opposite to the extended direction.

In the first case, where the samples are cut close to the weft, the fabric is extended in the weft direction, implying lateral compression force on the warp direction and as a result, bending behavior of the fabric in warp direction plays an important role which makes the warp yarn properties more effective.

When 22.5° samples are tested, concentrated loading causes compression in weft direction, making wefts yarn properties to play an important role.

2- The ending slopes of the samples show higher correlation to the fabric formability in the same direction in which they were closer. This is due to the sample return deformation. At this stage the extended yarns are released and are returning back to their original condition. This phenomenon gives the yarns in the loaded direction a significant role to play.

3- The correlation values of 45° bias sample (Is or ES) which are not far from the correlation of the other two directions could also be used to judge and evaluate the formability of the fabric. This decreases the number of testing samples and has the advantage of saving time but requires more skill in sample preparation (cutting the sample) as well as testing operations.

TABLE IV

CORRELATION VALUES BETWEEN FABRIC FORMABILITY AND SUPERIOR FEATURES EXTRACTED FROM THE LOADING-UNLOADING CURVES OF THE CONCENTRATED LOADING METHOD

Features	$Form_{Warp}$	$Form_{Weft}$	Features	$Form_{Warp}$	$Form_{Weft}$
IS_1	**0.778**	0.812	**ES_1**	0.823	**0.725**
IS_2	**0.711**	**0.722**	**ES_2**	**0.754**	**0.717**
IS_3	0.816	**0.777**	**ES_3**	**0.782**	0.815

As an outstanding result of this study, the inverse values of the strain at fifty gram load (1/EF) show the highest correlation to the formability in all directions. So, this parameter could be suggested as the element to show the formability of these types of woven fabrics.

IV. CONCLUSIONS

Results of this experimental work show:

i- The concentrated loading method has the potential to evaluate the formability of woven fabric.

ii- Initial zone of the loading curve and ending portion of the unloading curve are related to the formability of the woven fabrics (zones are the keys to predict the behavior of the fabric during the sewing and tailoring processes).

iii- The initial slopes, ending slopes and the inverse value of the elongation at fifty gram load (the last one is the highest correlated parameter to formability) are recognized as parameters that indicate the formability of the woven fabrics.

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Appendix

THE FABRIC SAMPLE SPECIFICATIONS

Fab. No.	Polyester/ wool	Warp Count (Nm)	Warp Ends /cm	Weft Count (Nm)	Weft Picks /cm	Weight g/m^2	Formability (10^3) Warp (mm^2)	Formability (10^3) Weft (mm^2)
1	55/45	2/48	26	2/48	24	219	6.381	4.321
2	60/40	2/48	27	2/48	23	218	4.742	4.128
3	55/45	2/48	30	1/24	20	217	6.776	7.715
4	65/35	2/46	32	1/23	24	258	3.449	2.396
5	55/45	2/48	30	1/24	18	210	1.056	1.836
6	55/35	2/46	28	1/23	24	240	1.776	1.856
7	65/35	2/48	28	2/46	24	232	2.935	1.657
8	65/35	2/48	32	1/23	22	237	0.950	1.107
9	55/45	2/60	32	1/32	21	181	2.371	2.378
10	65/35	2/64	38	1/30	25	210	2.217	0.732
11	70/30	2/62	30	1/28	30	211	0.464	0.462
12	60/40	2/60	34	1/30	28	220	0.708	0.540
13	55/45	2/48	31	1/22	25	239	1.223	0.775
14	60/40	2/58	36	1/30	32	242	1.858	0.659
15	65/35	2/60	38	1/30	30	238	0.550	0.651
16	55/45	2/48	28	2/48	24	227	1.021	1.189
17	55/45	2/42	26	1/24	25	240	1.723	0.868
18	55/45	2/34	20	2/34	20	248	0.857	0.873
19	55/45	2/46	28	2/42	23	243	0.972	0.944
20	55/45	2/50	30	2/46	22	227	2.148	0.736
21	50/50	2/34	22	1/18	18	241	0.957	1.291