A New Test Method to Characterize Torsional Behavior of Woven Fabrics

E. Hezavehi [i]; S. Shaikhzadeh Najar [ii]; Sh. Hoseini Hashemi [iii]; A.Rashidi[iv]

ABSTRACT

In this research, an apparatus was designed using data acquisition and micro-controller systems in order to measure torsional force of woven fabrics subjected to combined effects of torsional and compression strains. 6 different worsted wool blended fabric samples were used and then the torsional force of these fabrics were continuously measured along two warp and weft directions using 3 different spiral shafts with 25, 32, and 60 torsional angle degrees, respectively.

The results showed that the torsional force of worsted fabrics is significantly influenced by used fabric and spiral shaft types. It is shown that with the increase of torsional angle, the torsional force is increased along weft and warp directions. The results indicated that with a spiral shaft of 60 degrees, the torsional force of all fabric samples are almost similar particularly for fabric samples tested along weft direction. The result of this research suggests that using a spiral shaft of 32 degrees is preferable in measuring torsional behavior of worsted fabrics.

KEYWORDS

Worsted fabric, torsional force, torsional strain, data acquisition, micro-controller

1. INTRODUCTION

It has been considered that when a fabric undergoes the influence of external compression and torsional forces, the fabric will bend and buckle in different directions and hence wrinkle will be created into the fabric. Thus, torsional properties of fabric are important in clothing manufacturing, wear, washing and dry-cleaning processes.

There are a little studies that investigated the torsional behavior of worsted fabrics. Basset *et al.,* [1] reviewed the experimental methods for measuring fabric mechanical properties and discussed the proposed test methods for cylindrical specimens of permeable fabrics. Skelton and Freeston [2] designed an apparatus to measure the tangential force of cylindrical specimens subjected to an axial load against shear deformation for loom state, heat-set and coated fabrics. They related theoretically the shear stiffness of the fabric to the cylinder axial load, various geometrical parameters, angular rotating, and the tangential force. Shinohara *et al.,*[3] analyzed theoretically the buckling deformation of a woven fabric cylinder in axial compression.

In standard method of wrinkle recovery tester [4], the fabric is formed as a cylindrical shell and compressed and rotated under constants of axial load and rotational angle. However, in this method, it is not possible to measure the torsional force of worsted fabrics under the combined influences of compression and torsional strains. Therefore, the aims of this work are to investigate the torsional force of worsted woven fabric using a new developed test method and compare the statistical analysis results to indicate the effects of fabric type and torsional strain on fabric torsional behavior.

2. EXPERIMENTAL

A. MATERIAL

In this study, 6 different worsted fabrics with twill structure were used. Fabric thickness obtained by FAST

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tester [5] at 2 gf/cm load and 5 tests were done for each fabric sample. The general fabric specifications are shown in Table 1.

TABLE 1: FABRIC SPECIFICATIONS.

Fabric Code	Construction	Yarn count (Nm)	Fiber content %		Weight (g/m^2)	Yarn density		Thickness (mm)
						Picks/cm	Ends/cm	
A	T2/2	40/2	45w	55p	268	18	29	0.686
B	T2/1	40/2	20w	80p	260	18	28.5	0.586
C	T2/1	48/2	45w	55p	222	21	29	0.57
D	T2/1	48/2	20w	80p	221	19.5	28.8	0.67
E	T2/1	60/2	20w	80p	213	22	36	0.543
F	T3/1	60/2	45w	55p	225	26	34.5	0.59

B. Measurement of Fabric Mechanical Properties

The tensile elastic properties were obtained using Tensolab Mesdan tensile tester. In this test, the fabric width and length and test speed were adjusted at 5 cm , 15 cm. and 300 mm/min values, respectively. 5 tests were conducted for each fabric sample. In addition, the Poisson ratio was measured using a photography technique at strain levels of 6.66%, 13.3%, 20.00% and 26.6%, respectively and then the average level was calculated [6]. The extensibility of the fabrics at a sample loading of 5 gf/cm, 20 gf/cm, and 100 gf/cm width was measured by using FAST-3 (extension meter) [5] and 3 tests were conducted for each fabric sample. The value quoted (E-100) for fabric extensibility is that measured at 100 gf/cm. The extensibilities in the warp and weft directions measured at 5 gf/cm and 20 gf/cm are used to calculate fabric formability [5]. The bending rigidity of the fabrics was measured by using FAST-2 (bending meter) [5] and 6 tests were conducted for each fabric sample. The FAST system determines bending rigidity from the cantilever bending length of the fabric, measured using the principle described in BS: 3356 (1990), and fabric weight according to the following equation:

$$Bending\ Rigidity\ (B) = weight \times (bending\ length)^3 \times 9.807 \times 10^{-6}$$

where the bending rigidity is expressed in µN.m, the bending length in mm, and the fabric weight in g/m^2.

The shear rigidity of the fabrics was measured by using FAST-3 [5] and 6 tests were conducted for each fabric sample. In the FAST system, shear rigidity is calculated from bias extensibility of the fabric under a load of 5 gf/cm:

$$\text{Shear Rigidity } (G) = \frac{123}{\text{Bias Extensibility}}$$

where the shear rigidity is expressed in N/m and the bias extensibility as a percentage.

The FAST system uses the derived parameter, formability, in analysis of fabrics [5]. Formability is a measure of the extent to which a fabric can be compressed in its own plane before it will buckle. This parameter, as the product of the bending rigidity and the extensibility of the fabric at a low load, is defined in the FAST system as:

$$Formability\ (F) = Bending\ rigidity \times \frac{Extension\ (20) - Extension\ (5)}{14.7}$$

with formability in mm^2, bending rigidity in µN.m, and extension in %.

The suffixes 1 and 2 refer to the warp and weft directions, respectively.

The average results of fabric mechanical properties are also shown in Table 2. All experiments were performed under the standard conditions of 22 ± 2°c and 65 ± 2% r.h..

TABLE 2: FABRIC MECHANICAL PROPERTIES.

FABRIC	Formability (mm^2)		B_2 (µN.m)	B_1 (µN.m)	Shear Rigidity (N/m)	E_2 (N/mm)	E_1 (N/mm)	V_2	V_1	Extensibility (%)	
	F-1	F-2								E100-1	E100-2
A	0.87	0.36	11.4	17.5	31.8	2.38	1.83	0.55	0.6	2.74	2.40
B	0.76	0.29	11.6	19.6	41.5	3.89	1.75	0.56	0.59	1.90	1.70
C	0.47	0.40	11.1	17.2	51.6	1.86	1.5	0.62	0.8	1.60	2.30
D	0.26	0.42	8.7	19.4	31.8	1.54	3.09	0.6	1.22	1.00	2.90
E	0.35	0.18	16	22.2	73.1	1.13	3.27	0.74	0.85	1.10	1.10
F	0.53	0.29	14.3	18	41.2	3.56	1.2	0.67	0.75	2.00	1.30

C. EXPERIMRNTAL SET-UP

To investigate the fabric torsional properties, a new test method different from that of AATCC method is developed. A schematic diagram of this tester is shown in Figure 1. In this tester, the rectangular fabric specimen (with dimensions of 290 mm ×160 mm) formed into a cylinder shape and then mounted between two circular rings in 90 mm diameter.

The upper ring can rotate and move downwards over a spiral shaft through intermediate gears and a stepper motor (Model *Sanyo Denki*, Type *103H 89222-6341, 22 kg.cm).*

The speed rate and rotational direction of the stepper motor can be adjusted and controlled through the electronically intermediate boards and a Lab-view software Ver.6 (National Instrument Co.).

The speed of the stepper motor is kept constant at a rate of 4step/Sec. and its rotational direction is clockwise.

When the top ring is rotated and moved downwards, the load-cell (Model *BONGSHIN*, Type *DBBP-S-Beam,* 20 kg) measures the torsional resistance of the specimen. The output data in real time is transferred to a PC computer using the data acquisition system. A schematic control block diagram of torsional force tester is also shown in Figure 2. To analyze the data, MATLAB software is also used. In this work, 5 tests were performed for each fabric type. In order to create different rotational levels into the fabric, three different spiral shafts with spiral angles of 25, 32 and 60 degrees is used in this research. A typical diagram of the torsional force against torsional strain for one cycle loading is shown in Figure 3. The experimental result of fabric torsional test at maximum force is also shown in Table 3.

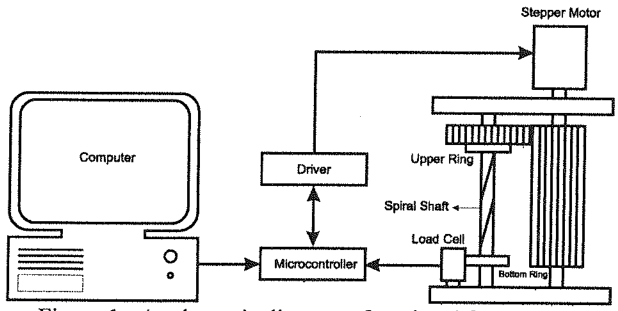

Figure 1: A schematic diagram of torsional force tester.

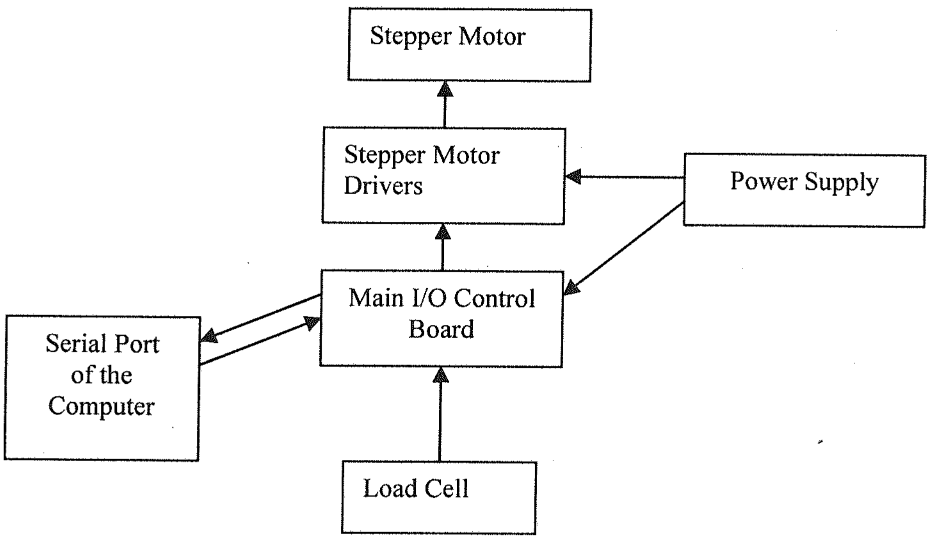

Figure 2: A schematic control block diagram of torsional force tester.

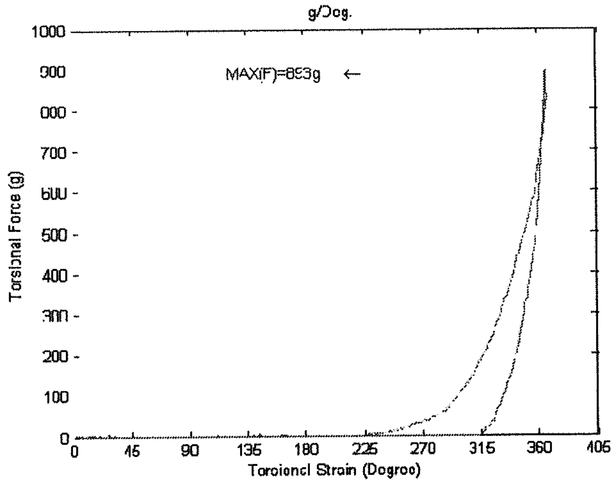

Figure 3: A typical diagram of torsional force against torsional strain for one cycle loading (Fabric Type A).

TABLE 3 : THE EXPERIMENTAL RESULTS OF THE TORSIONAL TESTER (MAXIMUM FORCE VALUE, N).

	Max Force (N) in $\alpha = 25^\circ$		Max Force (N) in $\alpha = 32^\circ$		Max Force (N) in $\alpha = 60^\circ$	
Fabric	Warp	Weft	Warp	weft	Warp	Weft
A	3.6(0.09)	2.37(0.05)	17.36 (0.21)	8.52(0.056)	17.85(0.09)	16.59(0.05)
B	4.81(0.29)	1.74(0.11)	13.90(0.61)	8.59(0.17)	16.95(0.04)	16.84(0.03)
C	2.64(0.17)	1.98(0.16)	10.44(0.3)	7.22(0.21)	16.91(0.05)	16.82(0.13)
D	2.73(0.05)	1.93(0.05)	15.22(0.19)	5.12(0.1)	16.84(0.03)	16.99(0.04)
E	2.23(0.04)	1.95(0.08)	9.73(0.34)	6.63(0.11)	16.89(0.05)	16.76(0.08)
F	1.13 (0.07)	0.75 (0.1)	10.31 (0.30)	7.28(0.19)	16.94(0.04)	16.88(0.05)

NOTE: THE DATA IN BRACKETS ARE SD VALUES.

3. RESULT AND DISCUSSION

In order to evaluate the effects of fabric type and torsional angle on fabric torsional force, two way analysis of variance (ANOVA) and Duncan test methods were used. The results will be discussed in detail.

A. *Maximum torsional force along warp direction*

Table 4 shows the ANOVA statistical analysis results of torsional force along warp direction in 5% confidence limit for different worsted fabrics at different torsional angle. As shown in this table, fabric type and torsional angle has significantly influenced maximum torsional force along warp direction. The Duncan test results is also represented in Tables 5 and 6. In these tables, the torsional force along warp direction are compared and classified according to fabric type and torsional angle. The variation of maximum torsional force along warp direction in terms of fabric type and torsional angle is also depicted in Figures 4 and 5. It is shown that fabric A has the highest torsional force amongst other fabric samples. As tabulated in Table 2, although this fabric exhibits a high extensibility and hence a high formability along warp direction, but this fabric has the highest thickness and weight amongst other samples which in turn leads to an increase of torsional force. In spite of a lower polyester fibre content compared with similar fabric with a higher polyester fibre content (fabric type B), the former fabric has a Twill 2/2 weave design that affects the number of warp and weft yarn interlacing at cross-over points and thus resulted to increasing torsional force. On the other hand, due to lower weight values, fabric types E and F have a low torsional force value.

As shown in Figure 5, with increasing the torsional angle or torsional strain, the torsional force of fabric is increased. This is because more torsional and compression strains imposed into the fabric while fabric is twisted and axially compressed. This causes fabric resists against torsional and compression deformations which in turn leads to an increase of torsional stress into the fabric. The results also indicates that at torsional angle of 60 degree value, the torsional force of all fabric samples are almost similar particularly for fabric samples tested along weft direction. This result is presumably attributed to the lower vertical displacement of the upper ring compared with its rotational speed. However, fabric samples tested with a spiral shaft of 32 degree along warp direction represents different torsional force values. For instance, fabric type D with a higher polyester fiber content exhibits the lowest extensibility and formability along warp direction amongst other samples and as a result represents a relatively high torsional force value.

TABLE 4: ANALYSIS OF VARIANCE OF MAXIMUM TORSIONAL FORCE IN WARP DIRECTION.
DEPENDENT VARIABLE: WARP MAX FORCE(N)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3462.106(a)	17	203.653	6743.495	.000
Intercept	10752.435	1	10752.435	356041.401	.000
ANGLE	3176.885	2	1588.443	52597.514	.000
TYPE	149.747	5	29.949	991.702	.000
ANGLE * TYPE	135.474	10	13.547	448.589	.000
Error	2.174	72	.030		
Total	14216.715	90			
Corrected Total	3464.280	89			

TABLE 5 : DUNCAN HOMOGENEOUS SUBSETS TEST OF MAXIMUM TORSIONAL FORCE OF WORSTED FABRICS IN WARP DIRECTION ACCORDING TO FABRIC TYPE (N).
Warp Max Force(N

	type of fabric	N	Subset				
			1	2	3	4	5
Duncan(a,b)	F	15	9.5242				
	E	15	9.6203				
	C	15		10.0010			
	D	15			11.6020		
	B	15				11.8910	
	A	15					12.9433
	Sig.		.134	1.000	1.000	1.000	1.000

TABLE 6 :DUNCAN HOMOGENEOUS SUBSETS TEST OF MAXIMUM TORSIONAL FORCE IN WARP DIRECTION ACCORDING TO ROTATIONAL ANGLE (N).
WARP MAX FORCE(N)

	ANGLE	N	Subset		
			1	2	3
Duncan(a,b)	a=25	30	2.8920		
	a=32.14	30		12.8312	
	a=60	30			17.0678
	Sig.		1.000	1.000	1.000

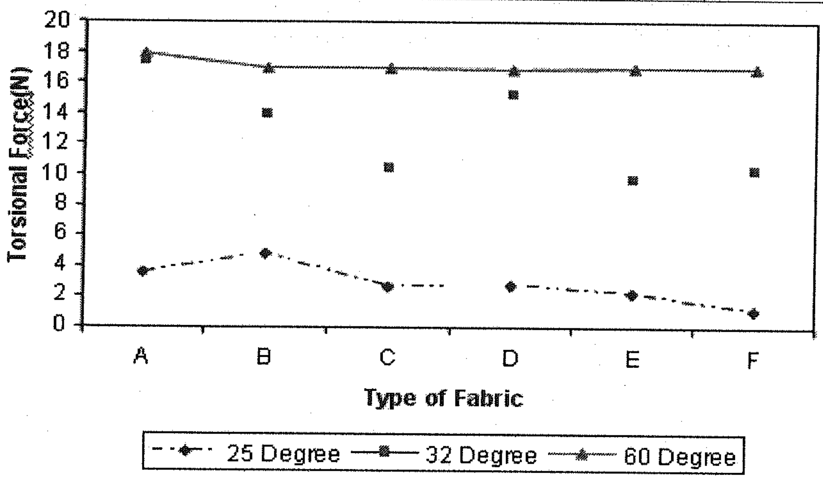

Figure 4: Comparison of maximum torsional force in different worsted fabrics (warp direction).

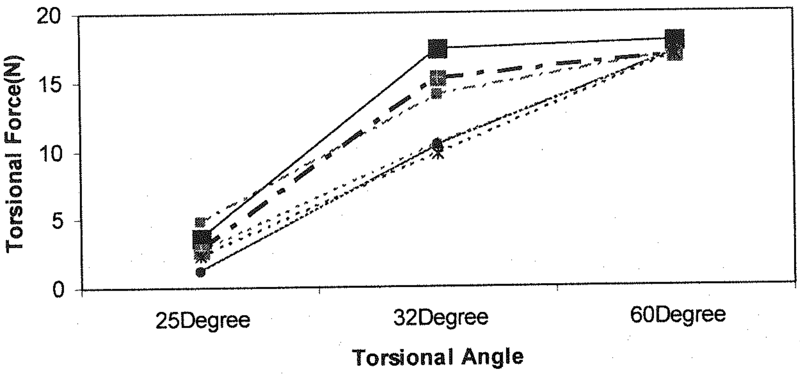

Figure 5: Comparison of maximum torsional force of fabrics with different torsional angles (warp direction).

B. Maximum torsional force along weft direction

Table 7 shows the ANOVA statistical analysis results of torsional force along weft direction in 5% confidence limit for different worsted fabrics at different torsional angle. As shown in this table, fabric type and torsional angle has significantly influenced maximum torsional force along weft direction. The Duncan test results are also represented in Tables 8 and 9. The maximum torsional force along weft direction in terms of fabric type and torsional angle is also depicted in Figures 6 and 7. Similar to previous findings, fabric type A exhibits the maximum torsional force between other worsted fabric samples. However, unlike the previous results along warp direction, fabric type D represents the lowest torsional force value along weft direction. As shown in Table 2, fabric type D has the highest extensibility along weft direction between other samples. This results in a high formability and hence is responsible for the lowest torsional value as obtained for fabric type D. The results of experiments show that the torsional force of fabric samples tested in weft direction is lower than in warp direction. It is reasonable to state that the lower bending rigidity and formability values obtained along weft direction are presumably attributed to this finding.

In general, it is indicated that the differences between the torsional force of worsted fabrics tested with a spiral shaft of 32 degree is clearly distinguishable compared with other spiral shafts. This result suggests that using a spiral shaft of 32 degree corresponding to AATCC wrinkle recovery tester [5] is preferable in measuring torsional behavior of worsted fabrics.

TABLE 7 ANALYSIS OF VARIANCE OF MAXIMUM TORSIONAL FORCE IN WEFT DIRECTION.
DEPENDENT VARIABLE: WEFT MAX FORCE(N)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3523.483(a)	17	207.264	15339.138	.000
Intercept	6677.325	1	6677.325	494174.378	.000
ANGLE	3473.885	2	1736.943	128547.354	.000
TYPE	14.705	5	2.941	217.651	.000
ANGLE * TYPE	34.893	10	3.489	258.239	.000
Error	.973	72	.014		
Total	10201.781	90			
Corrected Total	3524.456	89			

TABLE 8 DUNCAN HOMOGENEOUS SUBSETS TEST OF MAXIMUM TORSIONAL FORCE OF WORSTED FABRICS IN WEFT DIRECTION ACCORDING TO FABRIC TYPE (N).

WEFT MAX FORCE(N)

	type of fabric	N	Subset					
			1	2	3	4	5	6
Duncan(a,b)	D	15	8.0180					
	F	15		8.3091				
	E	15			8.4516			
	C	15				8.6779		
	B	15					9.0605	
	A	15						9.1638
	Sig.		1.000	1.000	1.000	1.000	1.000	1.000

TABLE 9 DUNCAN HOMOGENEOUS SUBSETS TEST OF MAXIMUM TORSIONAL FORCE IN WEFT DIRECTION ACCORDING TO ROTATIONAL ANGLE (N).

WEFT MAX FORCE(N)

	ANGLE	N	Subset		
			1	2	3
Duncan(a, b)	a=25	30	1.7920		
	a=32.14	30		7.2287	
	a=60	30			16.8199
	Sig.		1.000	1.000	1.000

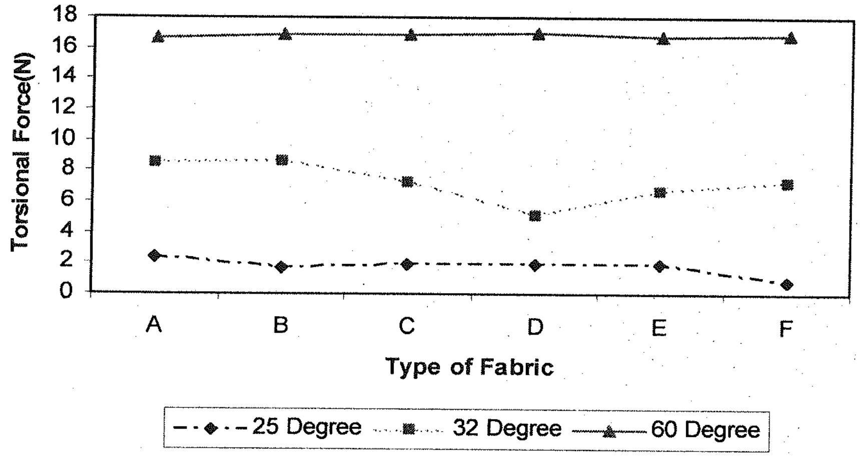

Figure 6: Comparison of maximum torsional force in different worsted fabrics (weft direction).

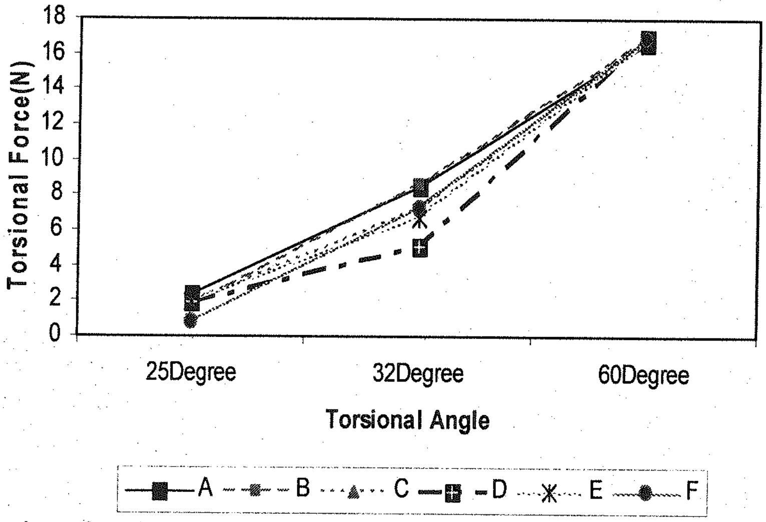

Figure 7: Comparison of maximum torsional force of fabrics with different torsional angles (weft direction).

4. CONCLUSION

The aim of this paper was to investigate the torsional behavior of woven fabrics. An apparatus was designed using data acquisition and micro-controller systems in order to measure torsional force of woven fabrics subjected to combined effects of torsional and compression strains. 6 different worsted wool blended fabric samples were used and then the torsional force of these fabrics were continuously measured along two warp and weft directions using 3 different spiral shafts with 25, 32, and 60 torsional angle degrees, respectively. The results showed that with the increase of torsional angle, the torsional force increased along weft and warp directions. The results indicated that with a spiral shaft of 60 degrees, the torsional forces of all fabric samples were almost similar particularly for fabric samples tested along weft direction. The result of this work revealed that the torsional force of worsted fabrics is interpreted in terms of formability and extensibility parameters derived by FAST method. The result of this research suggested that using a spiral shaft of 32 degrees corresponding to AATCC wrinkle recovery tester [5] is preferable in measuring torsional behavior of worsted fabrics. Further experimental works are needed to investigate and measure the effect of torsional strain rate on cyclic torsional behavior of woven fabrics.

5. ACKNOWLEDGMENT

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