Shell Buckling Behavior of Fused Composite Worsted Fabrics

Behnam Namiranian, Saeed Shaikhzadeh Najar and Ali Salehzadeh Nobary

Abstract—**The aim of this paper is investigation of some important parameters in shell buckling of fused interlining worsted fabric with different weight and considering five different relative orientation angles (0°, 22.5°, 45°, 67.5°, 90°) according to the machine direction of non-woven fusible interlining and a face fabric. The formability of the prepared fused fabric composite based on shell buckling curves and Lindberg's hypothesis is also reported. The shell buckling compression behavior of fused fabric composite is investigated using a special corrugated clamp based to Dahlberg's test method.**

The result show that with increasing the interlining relative orientation angle, buckling loads and buckling energy parameters decrease, whereas, hysteresis and compression remaining increase. The fused fabric composites exhibit the highest formability at 67.5° relative orientation angle. The results show that at 0° relative orientation angle, the lowest buckling hysteresis, compressibility and compression remaining are obtained.

Keywords: Shell buckling, relative orientation angle, mechanical properties, interlining, fused fabric composite

I. INTRODUCTION

In practical use, textile fabrics are subjected to a wide range of complex deformations. Among these, various forms of buckling has been given considerable attentions. In fact, buckling is a very common phenomenon during the use of fabrics in garments [1]. For instance, the bending of a sleeve produces a form of wave at right angles to direction of the bending and as a result shell buckling would be created [3, 4]. Lindberg *et al.* [1] suggested this type of shell buckling in which the specimen consists of a corrugated sheet. It is deduced that joining of sleeve into the head shoulder during sleeve insertion process produces such a corrugated sheet [1, 5]. Thus, during shell buckling procedure, fabric is subjected to the double curvature and in shell buckling, both bending and compression occur in different directions [2]. The deformation pattern in shell buckling is very similar to the pattern obtained when a sleeve is buckled. The shell buckling load would be more closely related to the handle of a fabric than is plate buckling load or bending stiffness [1-2].

The buckling of these types of shells produces bending in many directions in the cloth which in turn the fabric sheer properties are involved [9]. It is interesting to note that Lindberg and his coworkers [1] empirically found that the ratio of plate buckling to shell buckling loads is non-linearly proportional to the shear modulus.

Buckling behavior of the fused interlining fabric is the most significant property which characterizes the shape of cuff and collar [4]. The buckling behavior of the fused fabric also influences the overfeed in stitching of garments and the resultant quality [3].

Lindberg *et al.* [1] described an apparatus which can be used for measuring both plate and shell buckling, and evaluated the influence of deformation rate, sample length and corrugation radius on buckling compressibility of several fabrics in different directions. However, there is little available research on shell buckling properties of fused fabrics. In a recent study, it is shown that relative orientation angle of fusible interlining do significantly influence on plate buckling behavior of fused fabric composite [6]. Kim and his coworkers [7] also predicted the bending rigidity of fused fabric by a laminate model with considering tensile and in-plane compressive modulus.

The current study is the extension of previous study [6] and is aimed to investigate the shell compression buckling behavior of fused composite fabrics with different interlining relative orientation angles.

II. MATERIALS AND METHODS

A. *Sample preparation*

Three different worsted fabrics (coded by A, B and C) and one dot-coated non-woven fusible interlining (I) samples were used in this research [4]. The specifications of employed fabrics are shown in Table I. The fusible interlining fabric was placed over face fabric at five different relative orientation angles (0°, 22.5°, 45°, 67.5° and 90°). The fusing process was carried out in a HASHIMA HP-30PS machine according to straight linear creasing press method (temp=185 °C, pressure=6 bar and time=10 Sec). To study the effect of resin spreading during fusing, the interlining samples were fed to the fusing machine along with the aluminum sheet. The fused interlinings were then peeled off from the Aluminum sheets for testing (IF).

B. *Mechanical properties testing*

The FAST system [8, 9] was used to measure the bending rigidity and extensibility of the worsted fabrics,

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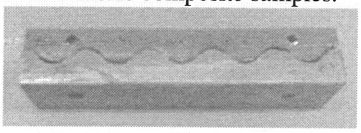
TABLE I
FABRIC SAMPLES CHARACTERISTICS

Sample code	Weight (g/m²)	Thickness(mm)	Weave	Fabric density(cm⁻¹)		Fiber content
				Warp	Weft	
A	253 (2.19)*	0.57 (0.005)♦	Twill2/1z	25	19	20% Wool/80% Polyester
B	216 (2.13)	0.46 (0.007)	Twill2/1z	31	25	20% Wool/80% Polyester
C	196 (0.53)	0.39 (0.01)	Twill2/1z	30	22	20% Wool/80% Polyester
I	70 (5.85)	0.26 (0.005)	Non-Woven (thermo-bounded)			100% Polypropylene
IA	317 (2.31)	0.89 (0.004)				
IB	281 (3.87)	0.78 (0.004)				
IC	264 (2.15)	0.73 (0.016)				
IF	220 (2.30)	0.69 (0.004)				

Note: The data in the brackets are SD values; * unit is (g/m²) ♦ unit is (mm)

fusible interlining and fused fabric composites. All tests were conducted in a standard conditions (20°C and 65%RH) according to the standard procedure specified in the FAST manual [8]. The bending properties of fused fabric composites were carried out in both up-ward and back-ward views respectively with different interlining's relative orientation angle. Table II lists the mechanical properties of fused fabric composite samples.



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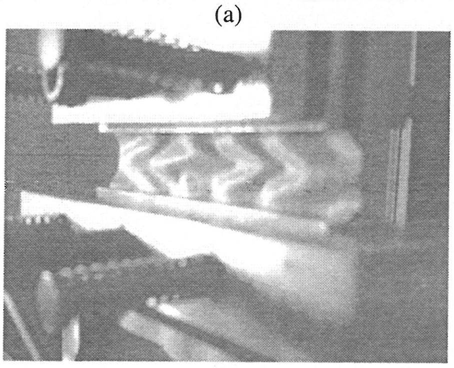


(b)

Fig. 1. a) Shell buckling tester clamps. b) Experimental region.

C. Shell buckling test

The plate buckling test method for fused fabric composite was explained in previous study [6]. The general principles of shell buckling test method were similar to the plate buckling test as shown in Fig. 1(b). However some modifications were needed to perform this test method. As shown in Fig. 1(a), for this purpose, a special clamp was designed and constructed. The radius of the half-circles which make-up the corrugation was 0.5cm. The specimen had to be performed as a corrugated sheet. The experimental load-deflection curves during shell buckling for worsted fabrics, fusible interlining and fused worsted fabric composites were obtained using an Instron tensile tester (Model 5566) employing a designed attachment explained in previous study [6]. The materials were cut into a strip of 10 cm×11.4 cm for shell buckling test. Before starting the test, the lower clamp was aligned with upper one in vertical position. The instrument was calibrated, and then the sample was first positioned in the upper clamp at a pre-determined pre-tension. Then, the sample clamped between the jaws initially separated at the desired distance (l=2.5 cm). When the upper cross head was moved downwards at a constant speed of 1 cm/min, the buckling force was registered by the load cell (L.C). A recovery graph was obtained by reversing the cross head movement at a given deflection of 40%. In this research work, five tests were performed for each specimen.

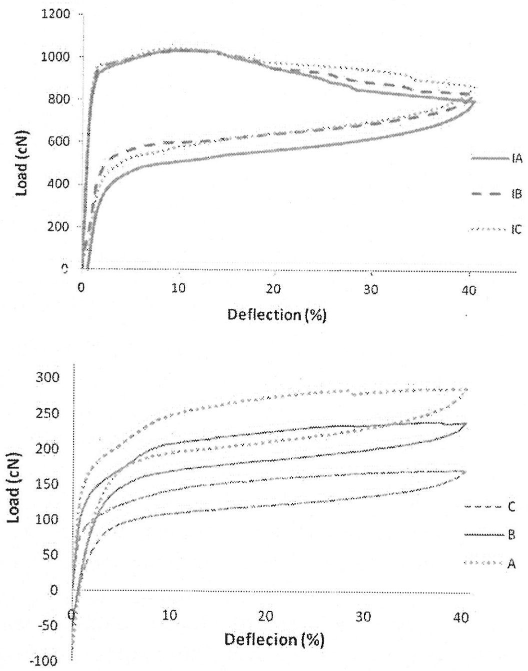


Fig. 2. One cycle of shell buckling test. a) Fused fabric composite. b) Face fabric.

D. Shell buckling behavior of fused interlining fabric

The shell buckling curves of fused composite, face, fusible interlining and fused interlining fabrics for one cycle loading are depicted in Figs. 2 and 3. It is shown that the shell buckling curves are different from plate buckling curves as represented in previous work [6]. The slope of the curve at the beginning represents the compressibility of fused fabric composite, face fabric, fusible interlining and fused interlining. All curves after starting points rise up to the highest point or critical buckling load. Then, with

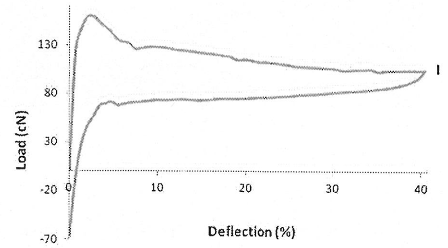
TABLE II
FABRIC MECHANICAL PROPERTIES

Sample code	Extensibility at 5 gf/cm Load (%)	Extensibility at 20 gf/cm Load (%)	Extensibility at 100 gf/cm Load (%)	Bending rigidity (μ N. m)	Harmonic mean*
■IA^{0}	0.0(0.0)	0.06(0.05)	0.5(0.00)	214.65♦(4.59) 177.73•(7.79)	97.22
IA$^{22.5}$	0.06(0.05)	0.23(0.05)	1.4(0.05)	139.33♦(6.99) 161.62•(16.29)	74.82
IA^{45}	0.0(0.0)	0.1(0.0)	0.9(0.00)	164.23♦(0.00) 177.73•(0.00)	85.35
IA$^{67.5}$	0.06(0.05)	0.16(0.05)	0.7(0.05)	206.89♦(4.37) 199.32•(33.60)	101.51
IA^{90}	0.0(0.0)	0.3(0.0)	1.5(0.11)	122.40♦(0.00) 145.30•(3.44)	66.43
IB^{0}	0.0(0.0)	0.03(0.05)	0.5(0.00)	234.83♦(11.13) 123.33•(19.63)	80.86
IB$^{22.5}$	0.03(0.05)	0.26(0.05)	1.4(0.05)	171.19♦(10.40) 121.26•(6.08)	70.98
IB^{45}	0.03(0.05)	0.16(0.11)	1.0(0.20)	157.31♦(2.78) 140.77•(6.82)	74.29
IB$^{67.5}$	0.03(0.05)	0.1(0.1)	0.7(0.1)	213.12♦(19.16) 163.52•(13.14)	92.52
IB^{90}	0.03(0.05)	0.36(0.05)	1.7(0.1)	124.37♦(14.46) 113.20•(0.00)	59.26
IC^{0}	0.0(0.05)	0.03(0.05)	0.5(0.05)	206.40♦(21.62) 172.45•(3.64)	93.95
IC$^{22.5}$	0.0(0.0)	0.23(0.05)	1.3(0.00)	131.49♦(16.01) 122.13•(10.48)	63.31
IC^{45}	0.0(0.0)	0.13(0.05)	0.9(0.05)	148.14♦(21.21) 145.84•(36.36)	73.49
IC$^{67.5}$	0.03(0.05)	0.1(0.01)	0.6(0.05)	199.28♦(11.76) 159.99•(15.83)	88.74
IC^{90}	0.03(0.05)	0.26(0.11)	1.35(0.11)	111.30♦(2.79) 94.14•(19.03)	51.00

♦ The face fabric is on the outer or convex side of the bent curve (B_1), * The face fabric is on the inner or concave side of the bent curve (B_2). ■ Fused fabric composite (IA, IB, IC).
Note: The data in the brackets are SD values. Extensibility' s SD value unit is (%), and Bending Rigidity is (μ N.m). * Harmonic mean values are calculated by $(B_1*B_2)/(B_1+B_2)$

increase of deflection up to 10%, the buckling load in the post-buckling zone become more or less un-variant with some fluctuation. After this point, the load has decreased. However, the trend of load variation against deflection is not uniform particularly for fused interlining fabrics with lower weights. Obviously, it can be noticed that critical buckling load of fused fabric composite is more than face, fusible interlining and fused interlining fabric. It may be considered that up to 4% deflection, a non-linearity trend is observed in post-buckling curve for fused fabric composite and its components. However, the compression buckling curves for face fabric is different. As shown in Fig. 2(b), for fabric A with a higher weight, the load in post buckling zone is increased with compression deflection. For fabrics B and C with lower weights, the compression load in this zone gradually has increased with compression deflection.

In the case of fusible interlining (I) and fused interlining (IF) the curve in post buckling zone shows a decrease in load with compression deflection. As Fig 3(b) shows, after 40% deflection, when the load is removed, recovery curve is obtained and a clear hysteresis is particularly detectable for fused fabric composite. In general, the trend of shell buckling for fusible interlining and fused interlining fabric are partially similar to that of fused fabric composite.



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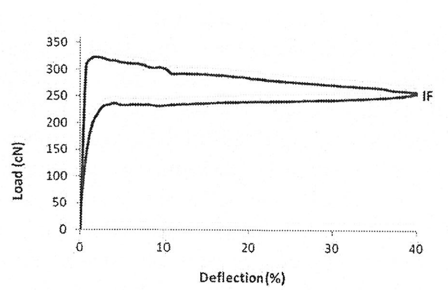


(b)

Fig. 3. One cycle of shell buckling test. a) Fusible Interlining and b) Fused interlining.

However, for the case of fused interlining fabric, the load in the post-buckling zone is higher and uniformly has decreased with compression deflection in comparison to fusible interlining. To evaluate the shell buckling behavior of fused fabric composites, some important parameters similar to those introduced in previous research work [6] were extracted from post-buckling compression curves. These parameters included the critical buckling load (Pc), load at 5% and 20% (P20) deflections, shape index (The ratio of load at 20% deflection to critical buckling load), shell buckling energy, hysteresis, the compressibility (the inverse slope of the linear portion of the curve) and compression remaining. It is noted that at the load 5%, deflection has the lowest coefficient of variation amongst all loads and all fused fabric composite samples. Table III shows shell buckling parameters for fused fabric composite samples.

III. Formability Evaluation

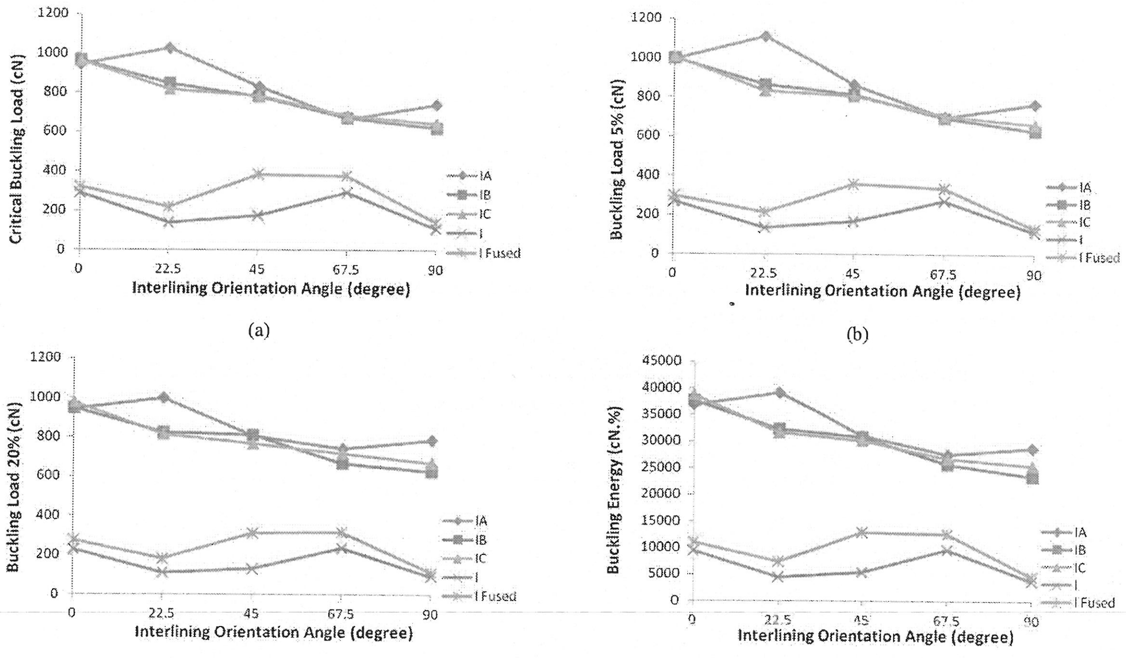
In shell buckling, the buckling load is much higher than plate buckling and therefore, the compression can be recorded over larger loads [12, 13]. Thus, determining of compressibility through shell buckling curve (inverse slope of the first portion of the buckling curve) could improve the accuracy of results [11]. Therefore, the formability is determined according to Lindberg hypothesis as well as FAST method as described in details in [6, 11]. The results of formability evaluation are listed in Table IV.

IV. Results and Discussion

In order to evaluate the effects of fusible interlining relative orientation angle and face fabric weight on shell buckling behavior, the results of experiments were statistically analyzed using one-way ANOVA and LSD test methods at 95% confidence limit. These results are discussed in detail as follow.

A. Effect of fusible interlining relative orientation angle on shell buckling parameters

A summary of ANOVA statistical result of shell buckling parameters for 3 fused fabric composites at different fusible interlining relative orientation angles is presented in Table V. It is shown that relative orientation angle significantly affected almost all shell buckling parameters for different fused fabric composites. It can be seen that the effect of interlining relative orientation angle on all shell buckling parameters for fused fabric composite IB is highly significant (P-value=0.00). The results for fused fabric composite, IA is similar to IB fabric composite, except for buckling load at 20% deflection (P-value=0.033). However, the values of significant level for fused fabric composite, IC, are much lower than fabric types IA and IB particularly for buckling load at 20% deflection. This result is attributed to the lower fused fabric composite bending rigidity (type IC) in comparison to other fabric types which are explained as follows. It was observed that during shell buckling procedure, the fused fabric composite is bent in both convex and concave sides. This means that, the face and interlining composites are bent in both sides accordingly. The harmonic mean of bending rigidity values of fused fabric composites for those two sides of bending are listed in Table II. It may be deduced that fused fabric composite IC, has the lowest bending rigidity amongst other composite fabrics. This means that a more flexible fused fabric composite exhibits a lower frictional bending couple which in turn causes the fused fabric composite to be easily bent at different



(a) (b) (c) (d)

Fig. 4. a), b) and c) Effects of interlining relative orientation angle on shell buckling load. d) Buckling energy.

interlining relative orientation angles for both sides of the bending curve.

The results of buckling parameters for fused fabric composite at different interlining relative orientation angles are shown in Table VI. According to LSD test, all buckling parameters at the level of 0° relative orientation angle are significantly different from 67.5° and 90° levels for all fused fabric composites. However, the difference between 0° level with 22.5° and 45° relative orientation angle levels are statistically insignificant for fused fabric composite IA and IC types. For the fused fabric composite IB, the 0° relative orientation angle is partially invariant

TABLE III
SHELL BUCKLING CHARACTERISTICS FOR FUSED FABRIC COMPOSITE

Sample code	Critical Buckling Load (cN)	Load at 5% deflection (cN)	Load at 20% deflection (cN)	Shape Index (P_{20}/P_c)	Buckling Energy (cN.%)	Hysteresis (%)	Compressibility %/cN	Compression remaining (%)
IA [*,a]	944	994.21	945.66	1.00	36925.2	39.73	0.0009	0.7
	(103.76)	(114.27)	(168.45)	(1.62)	(6343.69)	(2.89)	(0.0001)	(0.23)
IA [b]	1027	1109.13	998.06	0.97	39181.75	44.86	0.0007	0.8
	(94.04)	(104.95)	(178.44)	(1.89)	(6094.6)	(4.60)	(0.0001)	(0.13)
IA [c]	832.8	866.11	807.26	0.96	31143.47	43.39	0.0012	0.9
	(118.2)	(132.8)	(92.8)	(0.78)	(4881.07)	(4.4)	(0.0002)	(0.21)
IA [d]	666	697.70	743.02	1.11	27611.34	57.88	0.0015	1.66
	(75.45)	(70.2)	(73.2)	(0.97)	(1786.0)	(2.5)	(0.0005)	(0.29)
IA [e]	741.6	765.85	785.93	1.05	28838.75	59.95	0.0017	2.4
	(149.0)	(118.1)	(137.18)	(0.92)	(4524.3)	(8.6)	(0.0001)	(0.67)
IB [a]	967	998.09	949.51	0.98	37623.04	32.09	0.0008	0.52
	(87.7)	(82.7)	(121.4)	(1.38)	(4136.2)	(4.3)	(0.0001)	(0.16)
IB [b]	845.6	864.41	824.06	0.97	32375.28	34.33	0.001	0.58
	(36.8)	(30.0)	(15.8)	(0.42)	(743.1)	(3.3)	(0.00)	(0.13)
IB [c]	783.4	814.91	811.33	1.03	30805.89	39.82	0.0013	0.8
	(50.8)	(48.3)	(66.7)	(1.31)	(2391.7)	(2.3)	(0.00)	(0.12)
IB [d]	674.6	696.13	666.89	0.98	25728.28	44.35	0.0015	0.8
	(48.5)	(40.3)	(89.8)	(1.85)	(3130.1)	(3.5)	(0.0008)	(0.14)
IB [e]	624.4	631.39	625.64	1.00	23518.15	49.11	0.0017	1.22
	(137.8)	(136.4)	(145.6)	(1.05)	(5053.9)	(8.8)	(0.0002)	(0.24)
IC [a]	962.2	1007.22	975.37	1.01	38700.75	34.38	0.0007	0.56
	(119.09)	(96.15)	(164.7)	(1.38)	(5726.2)	(3.3)	(0.0001)	(0.08)
IC [b]	817.4	833.28	813.67	0.99	31593.49	40.34	0.001	0.7
	(46.0)	(44.4)	(75.13)	(1.63)	(2388.4)	(2.3)	(0.0001)	(0.23)
IC [c]	784.8	806.55	765.76	0.97	30177.26	37.41	0.001	0.68
	(206.9)	(214.3)	(210.4)	(1.01)	(8096.4)	(8.2)	(0.0001)	(0.17)
IC [d]	682.6	704.75	716.05	1.04	26865.26	45.16	0.001	0.92
	(151.9)	(157.8)	(116.0)	(0.76)	(4977.4)	(6.6)	(0.0002)	(17)
IC [e]	644	663.08	668.43	1.03	25484.29	46.32	0.001	1.2
	(159.5)	(147.4)	(152.5)	(0.95)	(5403.1)	(8.6)	(0.0003)	(0.50)

** Interlining relative orientation angle, a: 0□, b: 22.5□, c: 45□, d: 67.5□, e: 90□.*

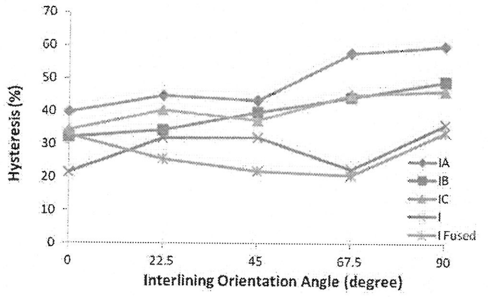
Note: The data in the brackets are SD values. Load' s SD value unit is (cN), Buckling Energy is (cN.%), Hysteresis is (%), Compressibility is (%/cN), Compression remaining is (%).

Note: Parameter P_{20} is load at 20% deflection and Pc is critical buckling load.

TABLE IV
RESULT OF FORMABILITY FOR FUSED FABRIC COMPOSITE ACCORDING TO FAST (F) AND LINDBERG (FC) METHODS

Fabric code	Relative orientation angle									
	Warp		22.5°		45°		67.5°		Fill	
	F (mm^2.%)	F_C (mm^2.%)	F (mm^2.%)	F_C (mm^2.%)	F (mm^2.%)	F_C (mm^2.%)	F (mm^2.%)	F_C (mm^2.%)	F (mm^2.%)	F_C (mm^2.%)
IA	0.72	0.87	2.85	0.52	1.20	1.02	1.35	1.52	2.96	1.12
	(0.2)	(0.1)	(0.05)	(0.1)	(0.05)	(0.4)	(0.1)	(0.1)	(0.2)	(0.1)
IB	0.25	0.64	1.89	0.70	1.24	0.96	0.77	1.38	2.54	1.00
	(0.1)	(0.2)	(0.6)	(0.0)	(0.5)	(0.2)	(0.7)	(0.1)	(0.7)	(0.2)
IC	0.35	0.65	1.91	0.63	1.28	0.73	0.76	0.88	1.47	0.51
	(0.1)	(0.2)	(0.6)	(0.1)	(0.6)	(0.2)	(0.6)	(0.4)	(0.4)	(0.2)

from 22.5° orientation angle level while in comparison to 45° orientation angle level, all buckling parameters are more or less different. This result indicates that the effect of relative orientation angle on buckling parameters for fused fabric composite IB is more noticeable in comparison to other fused composite samples as can be observed in Table V. On the other hand, it can be deduced that the role of relative orientation angle on buckling parameters for fused fabric composite IC is much lower than other fabric samples as are shown in Tables V and VI.



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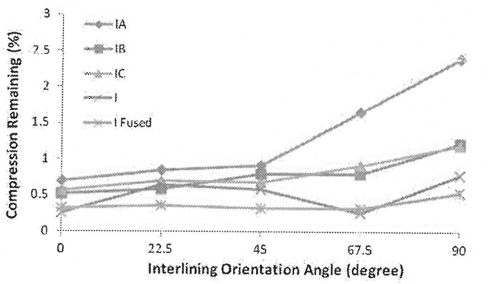


(b)

Fig. 5. a) Effects of interlining relative orientation angle on hysteresis. b) Compression remaining.

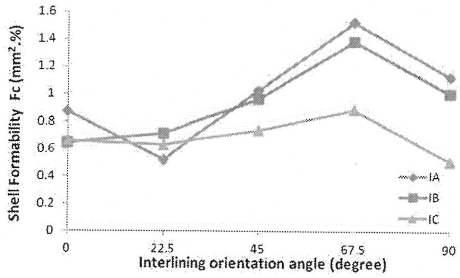
As shown in Fig. 4, with increase of relative orientation angle from 0° to 90°, buckling loads at different deflection and total buckling energy gradually decrease for all fused fabric composites as well as fusible interlining samples. It can be observed that the values of buckling load (critical, load at 20% and 40% deflection) and buckling energy for fused fabric composite are more than those of fused interlining (IF) as well as fusible interlining (I) fabrics.

TABLE V
THE ANOVA TEST RESULT OF FUSED FABRIC BUCKLING PARAMETERS OF 3 DIFFERENT FUSED FABRIC COMPOSITES FOR INTERLINING RELATIVE ORIENTATION ANGLE (P-VALUE=0.05)

Subject	P-Value		
	IA	IB	IC
Critical buckling load	0.000	0.000	0.022
Buckling load at 5% deflection	0.000	0.000	0.013
Buckling load at 20% deflection	0.033	0.000	0.040
Buckling energy	0.005	0.000	0.012
Hysteresis	0.000	0.000	0.037
Compressibility	0.000	0.000	0.000
Compression remaining	0.000	0.000	0.013
Formability	0.003	0.001	0.032

As depicted in Fig. 5, unlike to buckling load and energy, the buckling hysteresis for fused fabric composite nonlinearly increase with relative orientation angle. Similar trend is found for compression remaining as shown in Fig. 5. The energy loss manifests itself in the form of hysteresis.

As buckling hysteresis increases, it is clear that more wrinkles are left at the end of cycling load. This means that, wrinkle values increase. The LSD test results given in Table VI reveals that the level of 90° relative orientation angle for buckling hysteresis is significantly different from 45°, 22.5° and 0° levels at 5% confidence limit for IA and IB types. However, for fabric IC type, the buckling hysteresis value at 90° relative orientation angle is significantly different from 0° relative orientation angle and is partially different from 45°.



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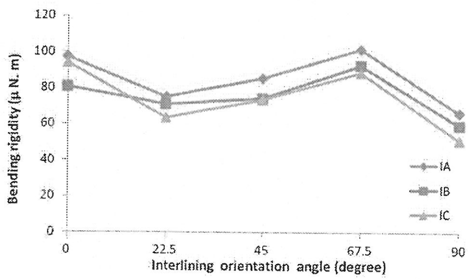

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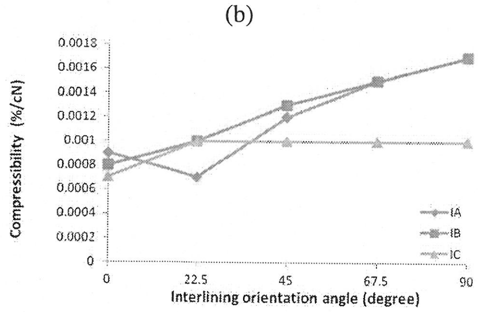

(c)

Fig. 6. Effects of interlining relative orientation angle on formability obtained from a) shell, b) bending rigidity and c) compressibility.

B. Formability

Figure 6 shows the variation trend of formability, bending rigidity and compressibility values obtained from shell buckling curves against fusible interlining relative orientation angle. As shown in Fig. 6(a), and Table VI, the formability of all fused fabric composite samples at 67.5° relative orientation angle level is significantly higher than other relative orientation angle levels. This results is attributed to the increase of both bending rigidity and compressibility at 67.5° relative orientation angle.

TABLE VI
SUMMARY OF LSD TEST RESULTS FOR BUCKLING PARAMETERS OF FUSED FABRIC COMPOSITE AT DIFFERENT INTERLINING RELATIVE ORIENTATION ANGLE

Dependent variable	Interlining direction		Critical buckling load	Load at 5% deflection	Load at 20% deflection	Buckling energy	Hysteresis	Compressibility	Compression remaining	Formability
IA	0	22.5	.251	.123	.550	.484	.128	.320	.550	.075
		45	.129	.088	.124	.082	.271	.044	.351	.906
		67.5	.001	.000	.029	.008	.000	.000	.000	.004
		90	.009	.005	.079	.019	.000	.000	.000	.966
	22.5	0	.251	.123	.550	.484	.128	.320	.550	.075
		45	.012	.003	.039	.019	.653	.005	.732	.062
		67.5	.000	.000	.008	.002	.001	.000	.002	.000
		90	.001	.000	.023	.004	.000	.000	.000	.081
	45	0	.129	.088	.124	.082	.271	.044	.351	.906
		22.5	.012	.003	.039	.019	.653	.005	.732	.062
		67.5	.027	.029	.465	.277	.000	.017	.004	.005
		90	.208	.176	.807	.474	.000	.044	.000	.872
	67.5	0	.001	.000	.029	.008	.000	.000	.000	.004
		22.5	.000	.000	.008	.002	.001	.000	.002	.000
		45	.027	.029	.465	.277	.000	.017	.004	.005
		90	.294	.351	.624	.702	.530	.655	.004	.004
	90	0	.009	.005	.079	.019	.000	.000	.000	.966
		22.5	.001	.000	.023	.004	.000	.000	.000	.081
		45	.208	.176	.807	.474	.000	.044	.000	.872
		67.5	.294	.351	.624	.702	.530	.655	.004	.004
IB	0	22.5	.028	.012	.058	.025	.490	.162	.578	.669
		45	.002	.001	.039	.005	.025	.007	.016	.145
		67.5	.000	.000	.000	.000	.001	.000	.016	.000
		90	.000	.000	.000	.000	.000	.000	.000	.127
	22.5	0	.028	.012	.058	.025	.490	.162	.578	.669
		45	.240	.317	.841	.477	.100	.134	.051	.071
		67.5	.003	.002	.021	.006	.005	.003	.051	.000
		90	.000	.000	.005	.001	.000	.000	.000	.062
	45	0	.002	.001	.039	.005	.025	.007	.016	.145
		22.5	.240	.317	.841	.477	.100	.134	.051	.071
		67.5	.047	.023	.032	.030	.169	.089	1.000	.001
		90	.006	.001	.008	.003	.008	.000	.001	.935
	67.5	0	.000	.000	.000	.000	.001	.000	.016	.000
		22.5	.003	.002	.021	.006	.005	.003	.051	.000
		45	.047	.023	.032	.030	.169	.089	1.000	.001
		90	.340	.195	.517	.320	.150	.009	.001	.001
	90	0	.000	.000	.000	.000	.000	.000	.000	.127
		22.5	.000	.000	.005	.001	.000	.000	.000	.062
		45	.006	.001	.008	.003	.008	.000	.001	.935
		67.5	.340	.195	.517	.320	.150	.009	.001	.001
IC	0	22.5	.134	.075	.106	.059	.155	.163	.436	.194
		45	.070	.043	.040	.026	.462	.011	.503	.817
		67.5	.007	.004	.013	.003	.015	.000	.054	.036
		90	.003	.001	.004	.001	.008	.000	.002	.550
	22.5	0	.134	.075	.106	.059	.155	.163	.436	.194
		45	.729	.776	.621	.695	.476	.192	.911	.275
		67.5	.162	.181	.319	.199	.245	.014	.226	.003
		90	.076	.081	.144	.101	.153	.001	.010	.456
	45	0	.070	.043	.040	.026	.462	.011	.503	.817
		22.5	.729	.776	.621	.695	.476	.192	.911	.275
		67.5	.284	.285	.608	.363	.069	.192	.188	.024
		90	.145	.137	.320	.202	.039	.017	.008	.711
	67.5	0	.007	.004	.013	.003	.015	.000	.054	.036
		22.5	.162	.181	.319	.199	.245	.014	.226	.003
		45	.284	.285	.608	.363	.069	.192	.188	.024
		90	.682	.658	.623	.702	.777	.224	.127	.013
	90	0	.003	.001	.004	.001	.008	.000	.002	.550
		22.5	.076	.081	.144	.101	.153	.001	.010	.456
		45	.145	.137	.320	.202	.039	.017	.008	.711
		67.5	.682	.658	.623	.702	.777	.224	.127	.013

However, the variation of formability of fabric samples at 0°, 22.5°, 45° and 90° relative orientation angles are insignificant. As it is expected, the formability of fused fabric composite IC is much lower than those of fused fabric composites IA and IB. This behavior is more related to lower compressibility of IC fabric in comparison to other samples as depicted in Fig. 6(c).

V. CONCLUSION

The aim of this work was to investigate the effects of fusible interlining relative orientation angle on shell buckling behavior of fused fabric composites produced with different face fabrics. In this research, three different worsted fabrics were fused at five different relative orientation angles (0°, 22.5°, 45°, 67.5° and 90°) using a non-woven fusible interlining. The most important fabric mechanical properties, i.e. bending rigidity, extensibility and formability were measured using FAST method. Then, the buckling test was performed on an Instron tensile tester under one cycle of compression loading using a special designed clamp. Different buckling parameters including critical buckling load, buckling loads at 5% and 20% deflection, buckling energy, hysteresis, compressibility and compression remaining were obtained. The formability of fused fabric composites was also determined according to Lindberg's hypothesis. Statistical analysis was performed on the results using ANOVA and LSD test methods.

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