

# A study on buckling behavior of composite sheets reinforced by hybrid woven fabrics

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## Abstract

To achieve a particular property, it is possible to mix two or more materials in form composites. In this study, to obtain superior characteristics, new composites are made with multi components reinforcement. In this study in order to improve the interface properties and brittleness of the Glass/Polyester composites, glass woven fabrics are modified with use of more elastic yarns of polyester. Polyester yarns are located either parallel to glass yarns or perpendicular to them. In this way a new fabric made of Glass and Polyester fibers are manufactured. Fabrics are manufactured in form of cross-ply or unidirectional plys in order to make superior hybrid laminated composites. A Comparison between the buckling behaviors of hybrid composites with glass woven composites shows that in similar conditions, use of hybrid fabrics increases the buckling strength increasingly. Also high resilience of polyester yarns in hybrid fabric composites returns the sample after failure nearly to its original shape.

**Keywords:** Composite Materials, Hybrid Woven Fabric, Buckling, Experiments

## 1. Introduction

The application of composite materials is increasing extensively. Among different fiber reinforcements, woven fabrics (bi-directional reinforcement) offer special properties. Equal and balanced properties in warp and weft directions, high stiffness and impact resistance of this kind of reinforcement make them superior in comparison with the unidirectional reinforcements. Methods of manufacturing can change the mechanical properties of the fabrics. For instance, using the weaving method in warp direction and knitting method in weft direction can increase the stiffness of the fabric the warp direction. Designers can change the mechanical properties of composite materials by selecting different reinforcements, matrices, and lay-ups. Carbon, Glass and Aramid fibers are used for different applications in composite industries [1-2]. Different fabrics made of different fibers and with various density per unit area present different properties, therefore various composite materials can be made by them.

Buckling is a very complicated phenomenon occurs in composite structures. Buckling can cause severe damage in the structure before the stresses pass the ultimate strengths. This phenomenon is studied by many researches [3-7]. In these articles in order to study the buckling behavior of composite materials, Ritz theory is modified by using FSDT (first-order shear deformation theory) and HSDT (higher-order shear order theory). Also the effects of edge grippers in the buckling behavior of the plates are studied [8]. In order to reach superior properties, the woven fabrics as reinforcement materials are also manufactured by mixing different materials. There are some researches in this field which can be mentioned in here. Using mixed chopped Glass and Nylon fibers [9-10], mixed continuous Glass and Polypropylene fibers [11], one layer of Glass fibers and one layer of banana fibers [12] are some examples. In some cases in order to improve the interface behavior between the matrix and the reinforcement a polyamide coating is used for the glass fibers [13] as shown in figure 1.

In the present research it is attempted to improve the brittle behavior of the glass fibers in a woven fabric by mixing it with polyester fibers. Using glass yarns and polyester yarns a hybrid woven fabric is manufactured. The mechanical behavior of the manufactured woven fabric as a reinforcement is studied. Using the hybrid woven fabrics and polyester resin laminated composite plates are manufactured. The mechanical properties of the hybrid composites are measured experimentally. The buckling behavior of the hybrid composite plates is also studied experimentally. Also using ABAQUS, as a finite element software [14] and the mechanical properties of the hybrid composite as the input, the buckling behavior of the hybrid composite is modeled and studied in detail.

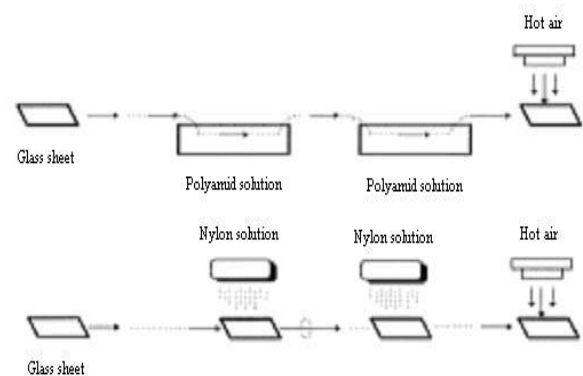


Fig. 1. Polyamid coating for the glass fibers

## 2. Manufacturing and mechanical characterization of Hybrid woven fabrics

A shuttle loom machine is used for weaving the glass woven fabric, polyester woven fabric and glass/polyester hybrid woven fabric. Suitable warp beam and pirn are provided for the machine. Also the let-off-mechanism, heddles, reed teeth, front rest and take-up-roller of the machine are modified. By changing the density of the weaving, two types of hybrid Glass/Polyester woven fabrics with the same density per unit area are manufactured. For the first hybrid woven fabric the warp and weft are made of Polyester and Glass, respectively. For the second

hybrid woven fabric threads in the warp are made of Glass and for the weft are made of 50% Glass and 50% Polyester. Polyester resin (GRP196) is used as the matrix and 5-layer composite plates with a  $[0_5]$  and symmetric x-ply  $[0/90]_5$  lay-ups are manufactured. The physical properties of the fabrics and composites are mentioned in Table 1. The constructions and the ply lay-ups of the composite plates are shown in Figure 2. In this figure  $G$  and  $P$  stand for Glass yarn, and Polyester yarn, respectively.

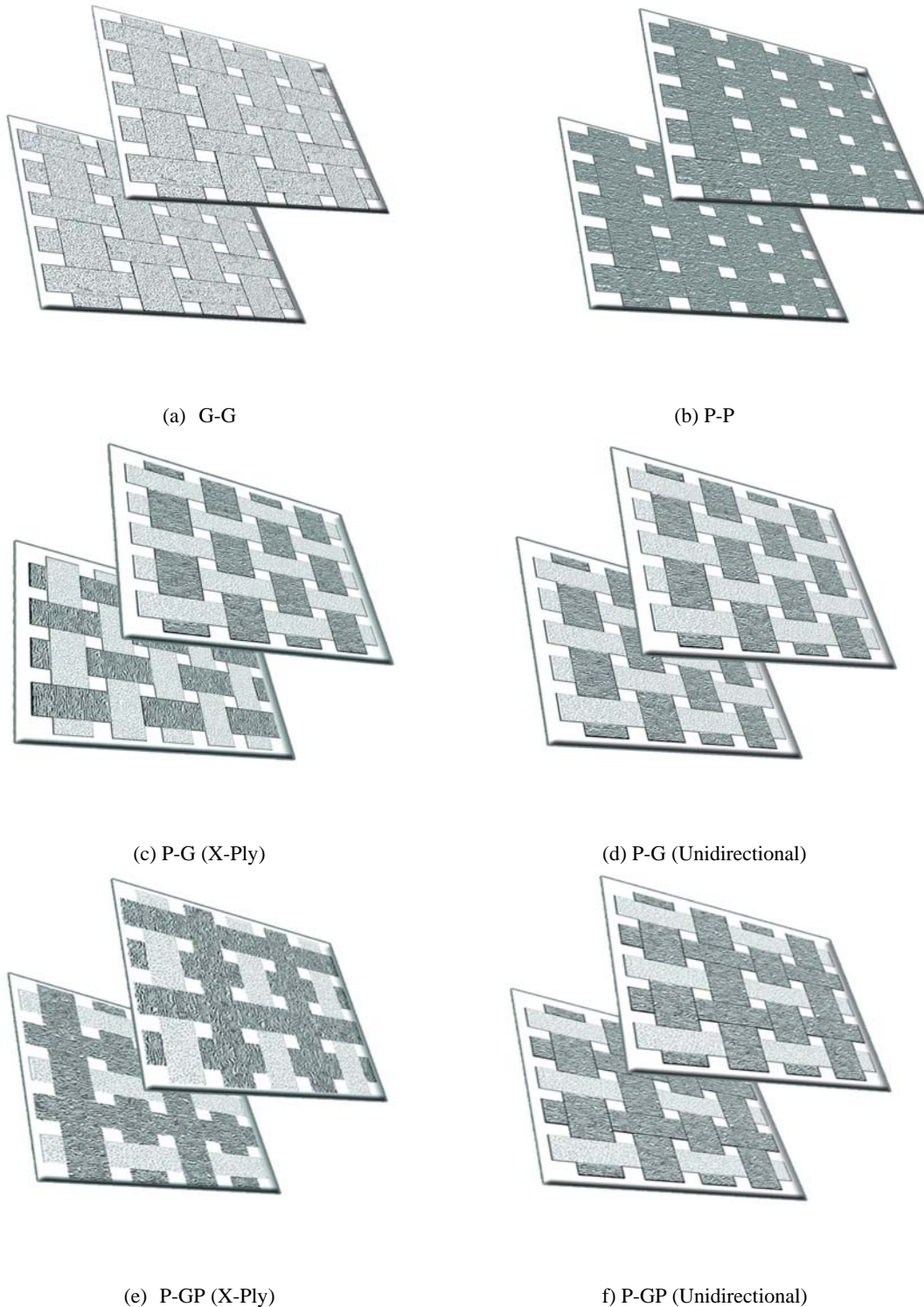


Fig. 2. Constructions and the ply lay-ups of the composite plates

Table 1. Physical Properties of the fabrics and the composites

Label	Fabrics						Composites			
	Warp	Weft	Warp (den/Cm)	Weft (den/Cm)	Weight in warp direction (g/m)	Weight in weft direction (g/m)	Weight ( $g / m^2$ )	Resin	Lay-up	Buckling loading direction
G-G	Glass (101 tex)	Glass (101 tex)	5	10	53.5	107	160.5	GRP 196	Unidirectional	G
									X-Ply	G
P-G	Polyester (150 den)	Glass (101 tex)	26	10.5	47.5	114	161.5	GRP 196	Unidirectional	G
									X-Ply	P
P-GP	Polyester (150 den)	Glass-Polyester	26	18	46	101+15.75	162.75	GRP 196	Unidirectional	G-P
									X-Ply	P

### 3. Material characterization

The fabrics and the composites are tested and the mechanical properties of them are listed in the following table. All tests for characterization of materials under tension, compression and shear loading conditions are performed based on ASTM standards [15-17]. All materials and lay-ups are tested and the

mechanical properties of them are characterized. The specimens under testing conditions are shown in Fig. 3. The results of experiments for Polyester-Glass fabric and Polyester resin composites are listed in Table 2.

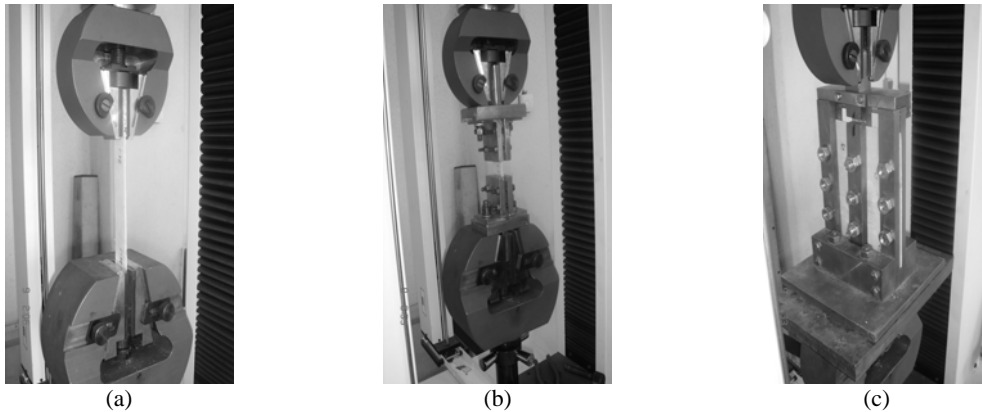


Fig. 3. Polyester-Glass fabric / polyester resin composites under a) tension, b) compression and c) shear tests

Table 2: Mechanical properties of Polyester-Glass fabric and Polyester resin composites

Lay-ups	Unidirectional	X-Ply
$E_x$ (kPa)	4058	3149
$E_y$ (kPa)	1495	1775
$G_{xy}$ (kPa)	1339	1217
$\nu_{xy}$	0.28	0.05
Tensile Strength in Glass direction (MPa)	189.4	130.7
Tensile Strength in Polyester direction (MPa)	10.8	63.9
Compressive Strength in Glass direction (MPa)	35.3	46.0
Compressive Strength in Polyester direction (MPa)	44.3	29.6
Shear Strength in Glass direction (MPa)	42.8	41.1
Shear Strength in Polyester direction (MPa)	43.7	60.3
thickness (mm)	2.05	2.10

The results obtained by experiments indicate that composites made of woven fabrics with the same density of the composites made of unidirectional plies show higher strength. The results obtained from the experiments are used as input data for simulation of the mechanical behavior of the composite plates under buckling loading conditions.

#### 4. Buckling tests

The composite plates are manufactured and equipped with tabs for buckling tests. A displacement control device for buckling loading tests is designed, manufactured and calibrated. This device is equipped with V-shaped grips for gripping the

specimens. The lower grip is fixed and the upper one moves with a speed of 1 mm/min. The device is equipped with a 500 kgf load cell and the precision of that is 50 grf. A micrometer can measure the displacement with a precision of 1/60 mm. The force and displacement data are transferred to a computer and logged in an output file. Figs. 4 shows a Polyester-Glass fabric and Polyester resin composite plate under buckling test and Fig. 5 shows the same sample after final damage. Fig. 6 shows the load-displacement of the samples under buckling loading conditions measured from the tests.

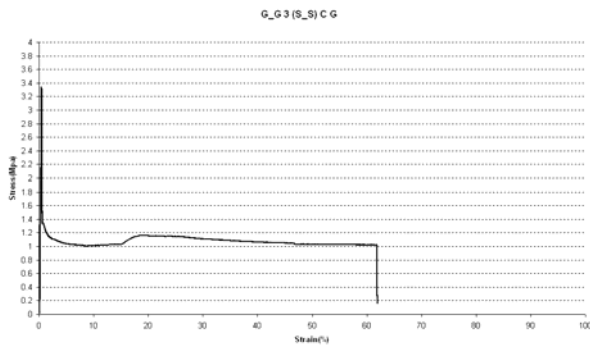
In Table 3 all data obtained from the experiments are listed. As shown in the table, seven tests for each case are performed.



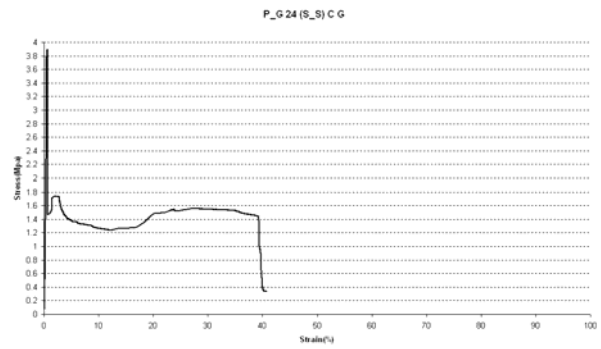
Fig. 4. A Polyester-Glass fabric and Polyester resin composite plate under buckling test



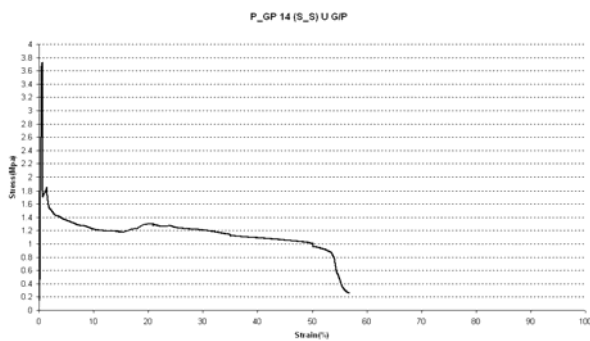
Fig. 5. A Polyester-Glass fabric and Polyester resin composite plate after final damage



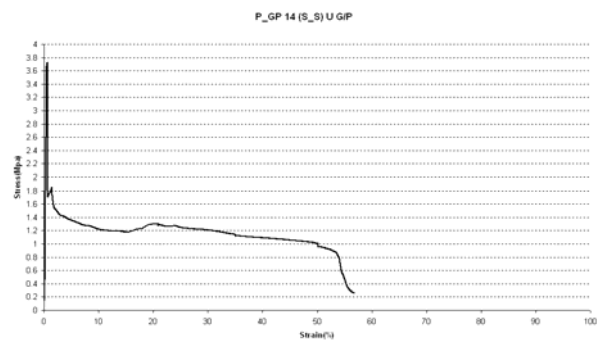
a) G-G (X-Ply)



b) P-G (X-Ply)



c) P-GP (Unidirectional)



d) P-P (X-Ply)

Fig. 6. Load-displacement of the samples under buckling loading conditions measured from the tests

Table 3. Data obtained from the buckling experiments for all composite specimens

Label	G-G		P-G		P-GP			
Lay-ups	Unidirectional	X-Ply	Unidirectional	X-Ply	Unidirectional	X-Ply		
Loading direction	G	G	G	P	P	GP	-	
$P_{cr}$ (kPa)	2447	2456	3220	1823	3908	1182	3727	3230
	2402	2487	3165	1898	3950	1156	3654	3258
	2398	2436	3302	1950	3896	1265	3697	3198
	2527	2390	3008	1876	3820	1175	3580	3248
	2512	2498	3195	1832	3960	1102	3610	3308
	2460	2350	3250	1980	3945	1235	3702	3080
	2650	2425	3188	1789	3879	1147	3631	3296

As shown in Table 3, the strength and strain to failure of hybrid composites are greater than those of the simple Glass/Polyester composites. Specially, Polyester-Glass yarns / Polyester resin composites show an excellent strength against buckling loads. The experiments show that these hybrid composites maintain its integrity after final failure. For the hybrid composites, polyester yarns help the damaged glass yarns and the specimen after buckling returns to its original shape before failure. Therefore, the integrity of the hybrid composites after buckling is maintained.

### 5. Modeling

In order to simulate the buckling behavior of the composite samples ABAQUS software [14] is used. The results obtained from the experiments based on ASTM standards for the composite material mentioned in Table 2 used as the input data. The loading and boundary conditions based on the experimental conditions are applied to the model. The V-shaped grip, used in the present research, is considered as a simply supported boundary condition and is modeled by a winding spring. Results obtained from the model for a Polyester-Glass yarns / Polyester resin cross ply composite plate and a Polyester-Glass yarns / Polyester resin unidirectional ply composite plate are shown in Figs. 7 and 8, respectively.

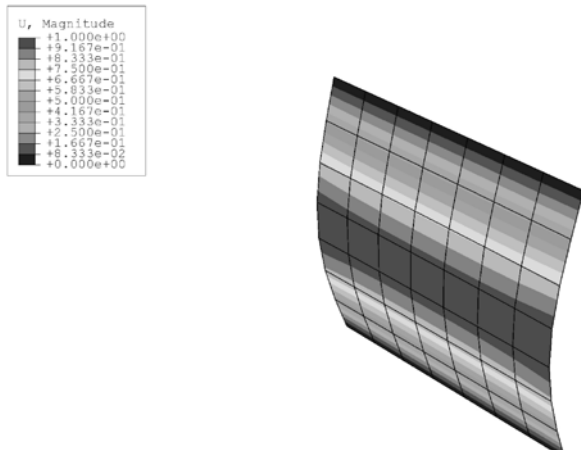


Fig. 7. Finite element result for a Polyester-Glass yarns / Polyester resin cross ply composite plate under buckling

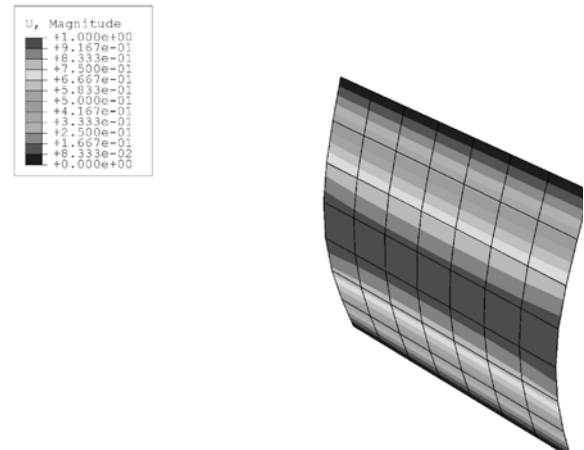


Fig. 8. Finite element result for a Polyester-Glass yarns / Polyester resin unidirectional ply composite plate under buckling

The average results obtained from the experiment for the critical buckling load for seven unidirectional composite plates is about 1291.1 N and this magnitude calculated from the software is 1249.2 N. The difference between the experimental result and the software is about % 3.3. Also the average results obtained from the experiment for the critical buckling load for seven cross-ply composite plates is about 985.9 N and this magnitude calculated from the software is 1156.6 N. The difference between the experimental result and the software is about % 17.2. The difference between the experimental results and the results obtained from the software show a very good agreement between them.

### 6. Summary and conclusion

Using Polyester yarns as well as glass yarns as reinforcements for polyester resin improved the buckling behavior of the hybrid composites. The results obtained from the present study show that:

1. The hybrid woven fabric made of Glass and polyester yarns increases the buckling strength of the composites made of this fabric and Polyester resin.
2. The hybrid composites show a greater strain to failure under buckling loading condition.
3. The hybrid composites show a better integrity after final failure with respect to Glass/Polyester composites. The experimental

results show that the damaged specimen buckling failure returns to its initial position.

4. Results of a finite element modeling for Polyester-Glass yarns and Polyester resin hybrid composites under buckling loading condition show a very good agreement between the simulation and the experimental results.

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