The comparison between impact resistance of woven fabric composites and cross-ply unidirectional composites

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Abstract

The glass/polyester composite sheets reinforced with glass mat layers, are high strength but they are brittle. For example in boats and other parts made by these composites, the accident fracture due to intensive impact or after operation period, has been observed. Therefore this case reduces safety of devices made by them. Using woven textiles and yarns with higher flexibility, increases the residual impact resistance and accident fracture would be prevented. In present work, composite structures reinforced with woven fabrics by glass and polyester yarns in warp, weft, warp and weft directions manufactured and their mechanical properties (impact resistance and buckling after impact) were measured. Results show that application of more flexible yarns not only reduces the mechanical properties lost but also due to better interface properties with matrix, increase the initial resistance. The best samples provided by reinforcement fabrics, were woven by glass yarn in warp direction and polyester yarn in weft direction or vice versa.

Keywords: Composite, Impact resistance, Residual strength

1. Introduction

The composites are materials that included two or more initial materials. The properties of composite is not as same as initial materials but is affected by them .The study about composite materials is relatively new field but the application of composite structures in buildings, boats and metal alloys in old centuries are known.

However the composite materials in attention to their High ratio of strength to weight, easy production and formation, high rate of fatigue resistance and their high resistance against corrosion are already very important.

The polymeric composites reinforced by woven fabrics have most application in structures of airplanes, ships, High pressure tanks and car bodies. Woven fabric composites due to their good dimensional stability and easy formation are preference [1].

In comparison with unidirectional and non woven composites, the woven composites have advantages such as good impact resistance and better properties uniformity in different direction.

In studies carried out by NASA space organization [2] on the composites reinforced by textiles, the fabrics divided in to the five categories which are shown in figure 1.

In two dimensional structures the yarns plies in a sheet and the thickness of fabric in comparison with its length and width is very small. The two dimensional fabrics generally are un-isotropic and their in plane shear resistance are low. For increasing of isotropic characteristic and shear strength and other necessary properties, the three axial fabrics are used in inclined direction. In figures 2, 3, 4 and 5 the structure of different kind of fabrics that used in composites are shown.

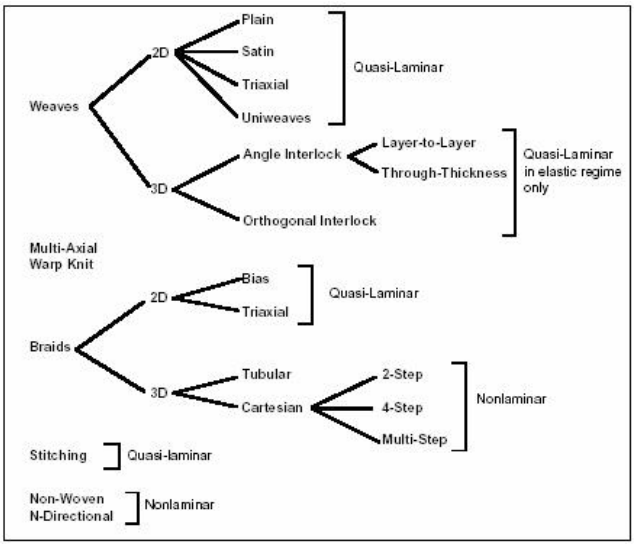

Fig. 1. Some of the textile fabrics available for high performance composite structures

In a fabric the initial modulus in warp and weft directions are different and with fabric elongation at 45 ^{o} the study of shear behavior of fabric would possible.

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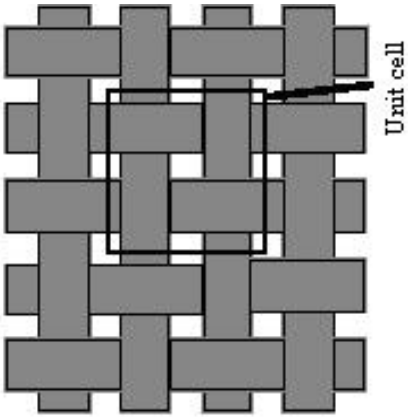

Fig. 2. Plain weave

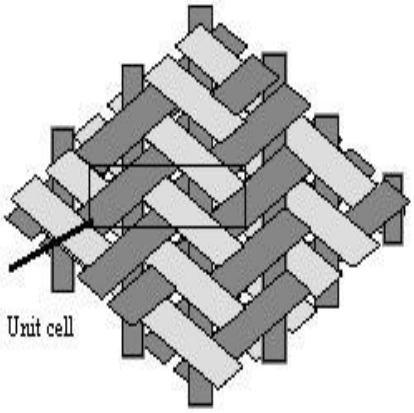

Fig. 4. Triaxial braid

In respect of high application rate of woven fabric composites and more complexity in study of their mechanical behavior, in this work the improvement of woven fabric composites has been studied.

The application of glass fabric composites is more than other kinds of fabric composites due to its low weight and high strength but its impact resistance is very low.

These composites are tight and very brittle in the way that the impacts with low inertia can make cracks in their structure and with impact repetition the whole structure would fail and be destroyed.

The existing reports about ships made of these composites or car bodies and flies and wings are evidences for this behavior. The first effect of initial impact is reduction of general strength of structure specially reduction in pressure strength. The effect of impact initially would be observed by matrix cracking, then delamination and finally fibre failure. There fore the effect of impact by residual strength under buckling can be study. Currently, in order to obtaining the best properties of composites materials, the reinforcement material is itself composed of two or more materials. In these cases many reinforcement material in different methods are plied in matrix material and plays their roles. Using of glass and nylon staple fibre blends [3], [4] and glass and polypropylene filament fibres in form of sheeth-core [5] and fabric layers in form of one by one from glass and banana fibres [6] are some examples. In some cases in order to improvement of matrix and reinforcement interface, the glass fabric is covered by polyamide cover [7]. Application of second or third part of reinforcement material can improve composite properties by improvement in reinforcement and resin interface properties.

The determination of composite materials, blending method and plying geometry is depended to composite properties that required by materials designer.

The considered mechanical property in this research is the impact resistance of glass fabric composites. The effect of dimensions [8], thickness [9], [10] and plying geometry of reinforcement layers [11], [12] on the impact resistance are studied in some papers. Also in other papers the fast reduction of residual strength composite due to initial low speed impacts has been studied [8].

The figure 6 shows this fast reduction of residual strength. In some cases non visible cracks and destroying can reduce even up to 50% of pressure strength.

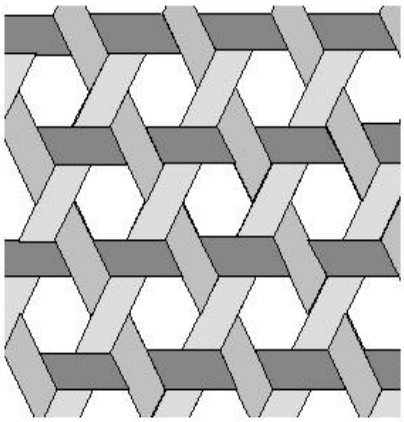

Fig. 3. Triaxial weave

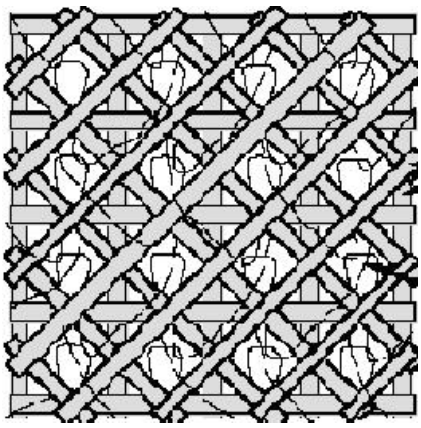

Fig. 5. Multi-axial warp knit

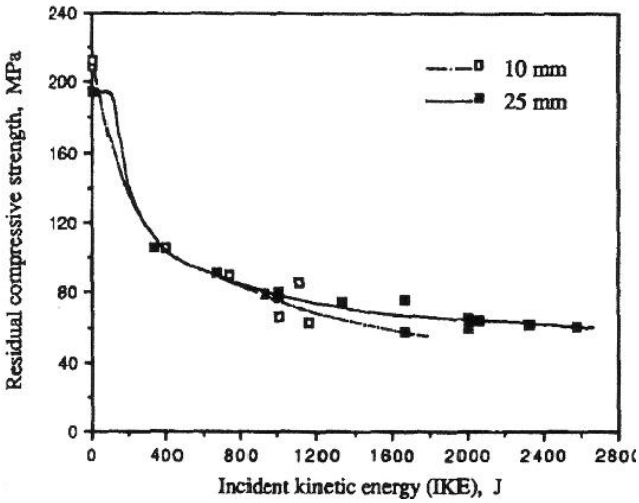

Fig. 6. Reduction of residual strength due to initial low speed impact

The destroyed area due to impact is also an important criteria for residual strength reduction. In this observation the woven fabric composites are much better than orthogonal uni-direction composites but the destroying due to impact in composites reinforced by glass fabrics are too considerable[1]. Figure 7 shows better control of destroyed region due to impact in woven fabric composites.

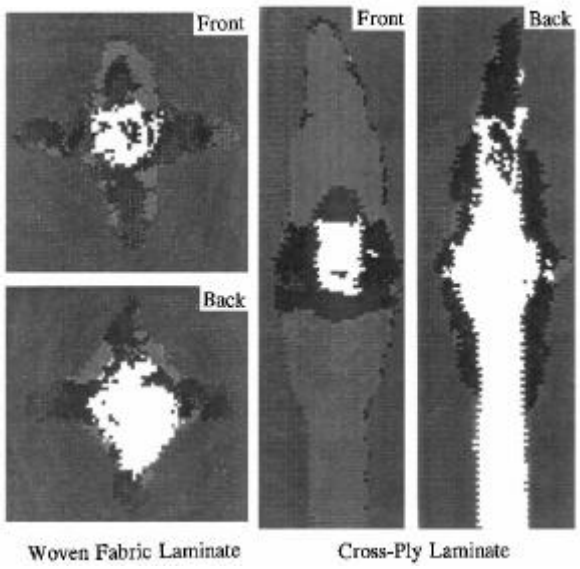

Fig. 7. Better control of impact destroy in woven fabric composites

However it seems that simultaneously application of more flexible yarns such as polyester yarns with glass yarns in woven fabrics, can make better binding between reinforcement material and resin in polyester composites and improves interface properties and also reduces the brittleness of final composite material.

2. Experiments

The glass filament yarn with count of 100 (tex) and polyester filament yarn with count of 150 (den) have chosen for weaving of samples and their tensile strength are measured. After warp beam and pirn preparation, the required fabric samples are woven on a shuttle loom.

in order to comparison between different samples, the weight of fabrics per area unit have taken constant by changing of weave density. The weaving of hybrid glass and polyester fabrics due to their different extensibility are required to more accuracy.

The composite plates with dimension of (15*15) centimeters are prepared by glass, polyester and hybrid glass-polyester fabric samples. The applied resin for all composite samples was polyester resin type GRP196. The 5 plying arrangement of composite samples are selected in form of unidirectional and cross ply, as shown in figure 8. Table 1 shows the fabrics structure and the kind of resin and composite sheets geometry. After appearance observation, coding and tab putting, the composite parts are prepared for impact test. The impact value have to be equal for all of the composite samples in Such a way effects of all samples but any sample should not be broken by impact. The impact test carried out by 1812 grams conical weight dropped from 25 centimeters altitude. The destroyed area due to impact is measured by c-scan test and image processing in MATLAB software media. This software with high accuracy contrast of color changing due to impact and considering the composite area in form of color contrast by a 0 and 1 matrix, can identify the destroyed area percent in respect of whole area. The figure 9 shows the form and destroyed area percent for three produced composite samples.

In order to measure the residual strength, carrying out buckling test is necessary and therefore all of composite samples, impacted and non- impacted, are tested for bucking.

The hounsfield apparatus and a 500 kilograms force measuring apparatus with 50 grams accuracy are used for buckling test. In buckling test the moveable jaw in form of simply support with speed of 1 milimeter per minute moved into fixed jaw. With this speed the breaking strain would be much more than high speed moving of jaws. For each 0.016 mm jaw movement, one set of required data is recorded by computer. Finally, the buckling curve and maximum buckling force of composite parts are obtained. Figures 10 and 11 show the some phases of these tests on a sample. The comparison between maximum buckling force of impacted sample and non-impacted sample from each kind of composite samples, can measure the strength reduction due to impact.

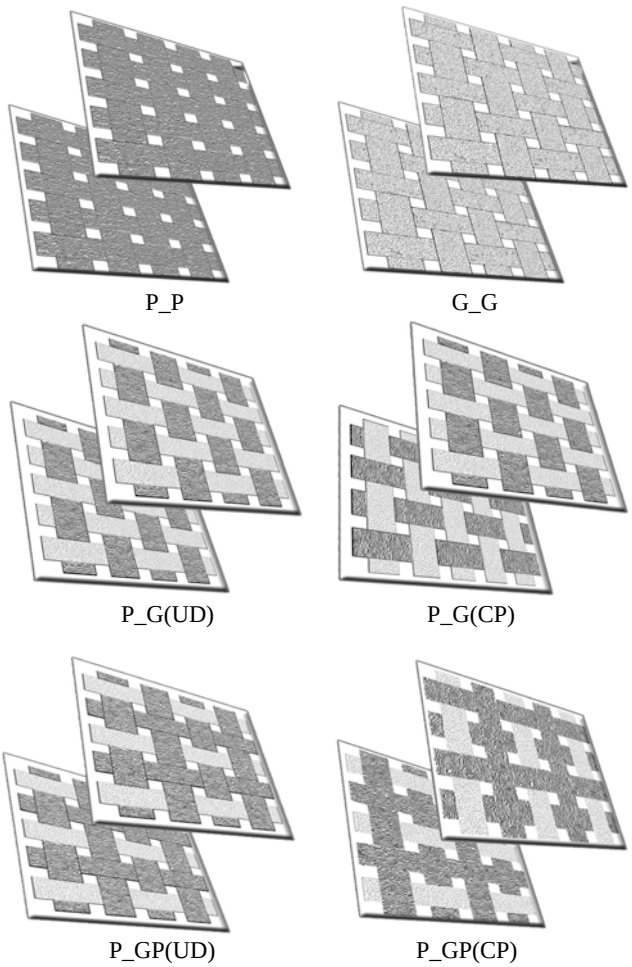

Fig. 8. Plying arrangement of fabrics in composite sheets

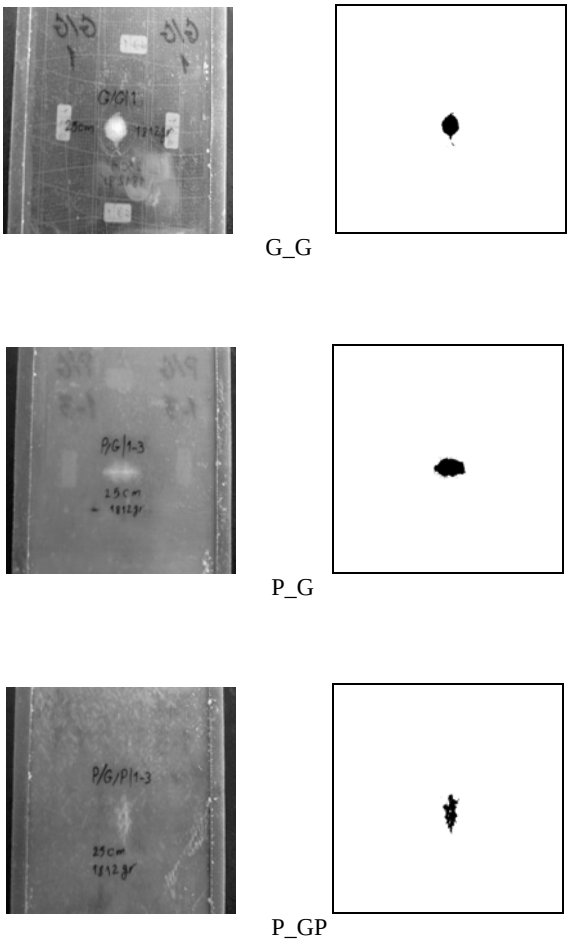

Fig. 9. Impact destroyed area identify

Table 1. Fabrics structure and used resin and composite sheets geometry

	Fabric							Resin	Composite	
Label	Warp	Weft	Warp den (/Cm)	Weft den (/Cm)	Weight in warp dir (g/m)	Weight in weft dir (g/m)	Weight (g / m^2)	Resin	Angular	Buckling dir
G_G	Glass (101 tex)	Glass (101 tex)	5	10	53.5	107	160.5	GRP 196	UD	G
									CP	G
P_G	Polyester (150 den)	Glass (101 tex)	26	10.5	47.5	114	161.5	GRP 196	UD	G
										P
									CP	-
P_GP	Polyester (150 den)	Glass-Polyester	26	18	46	101+15.75	162.75	GRP 196	UD	GP
										P
									CP	-

Fig. 10. Part buckling

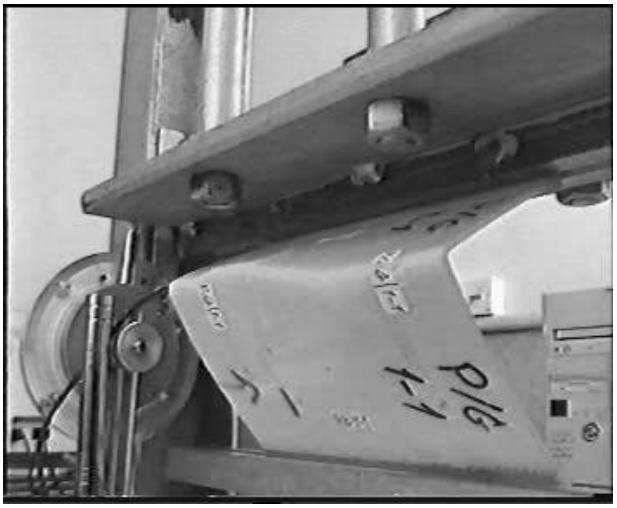

Fig. 11. Part after buckling failure

3. Results and discussion

The four parameters obtained from experimented tests are considered. These parameters are destroyed region form due to impact, destroyed area percent, destroyed modes and buckling stress reduction due to impact. By initial observation to destroyed region form due to impact, some interesting results are obtained. In composite reinforced by glass fabrics or polyester fabrics the form of destroyed region are nearly circular. For (P_P) composite samples only the first mode of destroying is observed but for (G_G) composite samples the destroying modes are going to the end. In composites reinforced by hybrid fabrics and unidirectional geometry (P_G(UD) and P_GP(UD)) the form of destroyed region are elliptical such a way that longer diameter is in glass yarns direction and shorter diameter is in polyester yarn direction. It means that matrix cracking in glass yarns direction is more extended. In hybrid parts only first mode of destroying in low intensity is visible especially for (P_GP) parts with cross ply arrangement.

In case of destroying region area except (P_G(UD) and P_GP(UD)), samples there are not significant difference between other composite types. in these parts with unidirectional playing the destroyed area due to impact significantly is more than other samples and it seems that more strain of polyester yarns under applied impacts increases of crack lengths in glass yarn direction although decreases the number of cracks. The most important mechanical parameter which is considerable is residual strength or pressure strength reduction percent of composite material. Regarding to impact and buckling test results which are given in table 2, it can concluded that the most decrease percent of pressure strength due to impact is for (G_G) composite samples and the least decrease percent is for composites which reinforced by hybrid fabrics. Also among hybrid composite samples, the least decrease percent of pressure strength is for (P_GP) composite sample with cross ply arrangement.

In other word it can concluded that by adding the polyester yarns to glass yarns in reinforcement fabric which used in composite material, the impact resistance of composite would be improved and more uniform distribution of glass and polyester yarns (such as one glass yarn and one polyester yarn side by side in warp and weft directions), has more effect of improvement.

In fact, the presence of polyester yarns between glass yarns, not only decreases of the brittleness of composite and increases of impact resistance, but also improves the binding between resin and reinforcement. The important point in comparison of maximum buckling stress is this point that replacement of glass yarns by polyester yarns, not only dos not decrease of pressure strength but also always increase it. The maximum pressure strength is belong to hybrid (P_G) composite with unidirectional plying in glass yarns direction.

4. Conclusion

The woven fabric composites in comparison with uni-direction composites have considerable advantages. In respect to high application of glass fabrics in woven composites, the attention to their brittleness and impact resistance is necessary. The simultaneously application of polyester yarns with high flexibility rate in glass fabric structure in addition to cost reduction, decreases the final composite brittleness. These yarns with better

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Table 2. Impact and buckling data for composite sheets

Label	Angular	Buckling dir	Impacted or Not	Impact area (%)	Buckling Strength	Impact Effect (%)
G_G	CP	G	NI	---	2447	-36.9
			I	0.75	1542	
P_G	UD	G	NI	---	3188	-27.7
			I	1.08	2304	
		P	NI	---	1832	-28.3
			I	1.08	1312	
	CP	G	NI	---	3893	-16.8
			I	0.82	3236	
		P	NI	---	1917	-19.7
			I	0.82	1538	
P_GP	UD	GP	NI	---	3727	-19.2
			I	1.15	3011	
		P	NI	---	1182	-13.7
			I	1.15	1019	
	CP	GP	NI	---	3230	-2.4
			I	0.78	3151	
		P	NI	---	1607	-8.6
			I	0.78	1468	
P_P	CP	P	NI	---	411	-25.5
			I	0.73	306	