GHTMDD – 449
Received: May 4, 2004
Accepted: October 25, 2004

Bulletin of the Chemists and Technologists of Macedonia, Vol. **23**, No. 2, pp. 163–170 (2004)
ISSN 0350 – 0136
UDC: 678.742 : 53.083.3

Original scientific paper

BALLISTIC PROPERTIES OF BIDIRECTIONAL FIBER/RESIN COMPOSITES

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The aim of the research was to make evaluation of the ballistic strength of four different fiber/resin composites intended to be used in manufacturing of ballistic items for personal protection. Research has been performed on glass, ballistic nylon, aramid and HPPE (High Performance Polyethylene) plainly woven fabric based composites. As a matrix system, in all cases, polyvinylbutyral modified phenolic resin was used. For the investigation, areal weight range 2 – 9 kg/m^2 chosen was, which is applicable for personal ballistic protection and the ultimate resin content range 20 – 50 vol.%.

Ballistic test of the composites has shown that the best results exhibit HPPE based composites; aramid based composites have been the second best followed by the polyamide based composites. The worst results have been shown by the glass based composites.

All composites with lower resin content (20%) have performed much better than their counterparts with higher resin content (50 %). The plot of the ballistic strength (V_{50}) versus areal weight has shown a linear increase of V_{50} with the increase of areal weight.

The ballistic strength of the composites is highly dependant on the fiber/resin ratio and increases with the increase of fiber content.

Key words: ballistic composites; aramid; E-glass; polyamide; HPPE; fabrics; V_{50}

INTRODUCTION

Fabrics are an extremely important part of modern armors. Also extremely important are composite laminates made of fabric sheets stiffened with resin. Fibrous armor has importance for several reasons. Since man utilizes clothing in normal life, protective devices that can be incorporated into such clothing provide the most comfortable, compatible and inconspicuous method of providing such protection. The second reason fibers are important is that they provide the greatest strength and modulus properties that can be obtained from a given material. In the case of polymers, this is due, mainly, to the drawing operation which orients the molecules along the fiber axis increasing strength and stiffness and providing also a natural crack arresting mechanism [1].

Fiberglass is one of the best known, and in a way, the most unusual laminate prepared from glass fabric and used extensively in the construction industry, boats, etc. It is well-known in ballistic application because of the research conducted during World War II, which resulted in a fragmentation protective vest. It is an unusual laminate in that fiberglass, a fabric with poor impact resistance and with especially poor ballistic resistance unlaminated, when combined with polyester resin, another material with poor impact and ballistic resistance, results in a material with excellent ballistic resistance either alone or as a backup for a harder material. The resin although present in a small percentage (20%) mitigates the defects which can easily be introduced into glass and lower the strength.

Despite the existence of glass fabrics laminates (composites) before the World War II, the work of Carothers [2] at DuPont in the early 1930s was necessary to make fabric armor a reality. Carothers' research on macromolecules, recognizing the need for a molecular weight of at least 12000, a molecular length of 100 nm, and preferably a crystallizable morphology, led to nylon fibers which could be prepared uniformly and cheaply with high strength. The second laminate of longtime use by the military is that prepared from nylon fabric in combination with a phenolic resin. At that time, the main advantage of nylon laminates was in their excellent ballistic resistance and lower weight, compared to glass laminates.

The second breakthrough occurred in the early 1960s when DuPont scientists were experimenting with stiff polymers usually considered intractable. They came up with a new aramid fiber three times as strong as nylon and with a far higher modulus and heat resistance [3, 4]. Even though it had a higher modulus, the resulting fibers were so fine that the resulting fabric possesses flexibility and drape. The military seized upon this new material known as Kevlar 29 and produced vests with lighter weight and higher protection values that would have been imagined before.

Kevlar 29 is one of the most amazing man-made fibers. This para-aramid fiber is characterized by its high tenacity and modulus of elasticity, low density as well as high energy absorption [5].

Aramid fibers have been dominant fibers in ballistic applications until 1979 when the Dutch company DSM invented and patented super strong polyethylene fibers as well as the gel spinning process to produce it.

The basic theory about how to produce a super strong fiber from a polymer such as polyethylene is easy to understand. Polyethylene with an ultra high molecular weight (UHMW-PE) is used as the starting material. In normal polyethylene the molecules are not oriented and are easily torn apart. In the gel spinning process the molecules are dissolved in a solvent and spun through a spinneret. In the solution the molecules that form clusters in the solid state become disentangled and remain in that state after the solution is cooled to give filaments. As the fiber is drawn, a very high level of macromolecular orientation is attained resulting in a fiber with a very high tenacity and modulus [6,7]. Called Dyneema, this high performance polyethylene (HPPE) fiber is now available in different grades. It is characterized by a parallel orientation greater than 95% and a high level of crystallinity (up to 85%). This gives HPPE fiber its unique properties. The density is slightly less than one (0.97 g/cm^3), so the fiber floats on water. The tenacity is the highest in the world and can be up to 15 times that of a good quality steel [8]. The modulus is very high and is second only to that of a special carbon fibers grade. Elongation at break is as low for HPPE fibers as for other high performance fibers, but due to the high tenacity the energy to break is high.

EXPERIMENTAL

Materials

The resin matrix, for impregnation of the woven fabrics, was resol type phenolic modified with polyvinylbutyral. The properties of the reinforcing fabrics are presented in Table 1.

The prepreg material of all four fabrics was prepared on a semi-industrial, vertical impregnating machine. Two composite sets were manufactured, one with resin content of approx. 20%, and the other – 50 %, the volatiles content in both sets was kept less than 1.5%, and all the prepreg materials were manufactured with medium resin flow.

Table 1

Properties of the used fabrics

Property	Unit	Glass fabric	Nylon 6.6 fabric	Aramid fabric	HPPE fabric
Designation		7628	FG206/E	T713	5006
Weave		1×1	1×1	1×1	1×1
Areal weight	g/m^3	203±5	265±8	280±7	295±8
Thickness	mm	0.19	0.40	0.43	0.28
Yarn:					
warp		EC9 68 tex	120 tex	1260 dtex	SK76 1760
weft		EC9 68 tex	120 tex	1260 dtex	SK76 1760
Tread count:					
warp		12.5	15.0	11.0	8.0
weft		16.5	15.0	10.5	8.0
Tensile strength:	N/5cm				
warp		1700	4200	9500	19300
weft		2100	4200	10000	19300
Finish		Universal, compatible with phenolic resins	Universal, compatible with phenolic resins	No finish	No finish