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Article

Design and Development of High-Performance Light Weight Helmet for Fighter Aircraft Pilots

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ABSTRACT

The need for high-performance composites with superior properties tailored to the requirements of defense and aerospace applications led to the development of hybrid reinforcement systems in which two or more reinforcing fibers are combined with thermoset or thermoplastic based matrix. DEBEL has developed a series of aramid and UHMWPE based technical textiles, multiaxial fabric and hybrid fabrics intended for the development of lightweight helmets for fighter aircraft pilots. These are developed to meet good impact attenuation, resistance to drop penetration and most importantly to meet airworthiness requirements that include windblast test. Helmet shells were fabricated using the above fabrics in various combinations and tested for impact and drop penetration resistance as per the MIL87174 A standard. The Helmet shell developed from or combination of low modulus aramid fabric62 gsm and high modulus aramid fabric 170 gsm is lightweight (328 gm) and can withstand more than 48 Joules of impact energy. Efforts are also being made to use thermoplastic fiber based combinations using compression molding or injection molding to further reduce the weight without compromising its functional properties.

Key words: Aramid, UHMWPE, Multiaxial fabrics, Impact protection.

1. INTRODUCTION

The need for lightweight helmet becomes significant for fighter aircraft pilots as they experience high +G force during operations. Increase in +G force leads to increase in Helmet weight; which eventually leads to high neck load associated problems. For example, a helmet weighing 1.5 kg may weigh up to 21 kg as the +G force increases from +1G to +14G [1,2]. Technological advancement in composite materials, drive propulsion system, flight controls, mid-air refueling of aircrafts facilitate flying faster, higher, and longer flight operation endurance. These enhanced performance capabilities of modern aircraft expose the fighter pilot to increasingly significant occupational stresses and are pushing beyond the limits of current human physiological capability and endurance [3-6]. Helmet should also withstand impact energy (48J) and wind blast (600 KEAS) during emergency ejection from the aircraft. The developed helmet should be light in weight without compromising its functional and performance properties. Thus, development of lightweight helmets for fighter aircraft pilots is very challenging [7,8]. Hybrid textile composites structures help in achieving the desired properties at a lower weight. Cowoven technique can be used to produce woven structures from an array of high-performance fibers [9,10]. Most of the impact energy will be attenuated by the liner which is incorporated in the inner portion of the helmet. Expanded polystyrene (EPS) is the potential material, commonly used as a liner which withstands high impact energy [10-12].

2. EXPERIMENTAL

2.1. Materials

In the present study, high-performance polymer fabrics such as Dyneema (UHMWPE), aramid, Multiaxial made of Para-aramid/Glass yarn and also aramid/Dyneema hybrid fabrics are used for the development of helmet shells. The details of these fabrics are given in Tables 1-3.

2.2. Methodology

Hand layup technique assisted with vacuum bagging molding is used for fabricating helmet shells. Epoxy resin (Araldite® LY 5052) and Hardener (Aradur® 5052) from Huntsman are used in 100:38 ratio. The resin was applied on each layer, and sufficient number of layers was stacked so as to obtain shell thickness of 1.5 mm to 2.0 mm. Pressure of 1 bar is applied to compress the shell and is done under the vacuum to remove excess resin and minimize void formation in the helmet shell. Layup was then allowed to precure in the mold at room temperature for 24 h followed by post curing for 3 h at 120°C.

3. RESULTS AND DISCUSSION

3.1. Impact Resistance Test

Impact testing of helmet shells was performed at M/s. Vega Aviation Pvt. Ltd., Belagavi as per MIL-STD 87174A. According to the standard, following are the critical factors that need to be fulfilled by the helmet shells to pass the test.

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Table 1: Details of fabrics and construction.

Material	Warp	Weft	Weave structure	Linear density	Fabric thickness
Dyneema (95 gsm)	13/cm	8/cm	4 harness crowfoot satin	Warp and weft 44 Tex	0.2 mm
Aramid (62 gsm)	13/cm	13/cm	Plain weave	Warp and weft 22 Tex	0.06 mm
Aramid (170 gsm)	7/cm	7/cm	Plain weave	Warp and weft 127 Tex	0.25 mm
Aramid-Dyneema Co-woven hybrid fabric (84 gsm)	Aramid 17/cm	Dyneema 10/cm	4 end crow-foot satin	Warp=22 Tex Weft=44 Tex	0.17 mm
Weight of Dyneema (Weft): 46%					
Weight of aramid (Warp): 54%					
Multiaxial fabric (320 gsm)	-	-	-	-	0.4 mm

Table 2: Construction details of multiaxial fabric (top layer).

Construction	Nominal value	Tolerance	Supplier	Sizing	Titer	Filament diameter
+45°	45 g/m^2	±5.0%	M/s. Saertex®, Germany	2002	68 Tex	10.0 µm
+45°	87 g/m^2	±5.0%		Twaron 2200	121 Tex	-
−45°	45 g/m^2	±5.0%		1383	68 Tex	09.0 µm
−45°	87 g/m^2	±5.0%		Twaron 2200	121 Tex	-

Table 3: Construction details of multiaxial fabric (bottom layer).

Construction	Nominal value	Tolerance	Supplier	Titer
Sewing thread	6 g/m^2	1 g/m^2	PES	76 Tex

PES: Polyester

- Helmet shell must withstand minimum 48 joules impact energy.
- The acceleration recorded shall not exceed 150 g for not more than 6 ms, 200 g for 3 ms, or should not exceed 400 g.

Impact tests were carried out as per ANSI Z90.1 (MIL Specification 87174 A) by rigid anvil method using hemispherical impactor. EPS liner of 14 mm thickness and 60 densities is used as shock absorbing liners for all the helmet shells. Head form of 4.85 kg of circumference 580 mm is used for the impact measurement. The helmet shell is marked at four different places as front, back, left, and right sides of the helmet with exactly 10 cm distance from the crown. The impact tests are conducted at these four positions as well as at the crown position.

During the impact testing, the helmet is tightly fitted to the head form, and this pair is positioned in inverted manner. The helmet is then made to fall freely from a distance 1 m with a velocity 4.40 m/s (mono rail) onto the impactor. Three different helmet shells in the different combination of fabrics were made, and their impact resistance, as well as drop penetration tests, was done, and the results are presented here.

3.1.1. Helmet shell of aramid Dyneema combination by cowoven method

The helmet shell is developed using cowoven method with aramid filaments in warp direction and UHMWPE (Dyneema) filaments in weft direction, in the weight proportion of 54:46, respectively, using cowoven method. The UHMWPE is one of the highest specific strength materials available to date. However, their low surface energy and non-polar nature poses problems to use them with the commonly used resins like epoxy resin for composite preparation. The poor adhesion of UHMWPE to epoxy resin results to laminates of inferior quality which gets delaminated even with a moderately less force. The poor adhesion of the fabric also demands more resin which increases the weight of the helmet shell. In the present case, the helmet shell weighed 449 gm. This helmet exhibited poor impact resistance at left and back portions (Table 4).

3.1.2. Helmet shell of aramid 62 gsm and

3.1.2.1. Kevlar multiaxial 320 gsm combination

In this case, a single layer of multiaxial fabric (320 gsm) is used at the top layer of the helmet shell along with few layers of aramid 62 gsm fabric. The helmet shell weighed around 340 g. The use of multiaxial fabric on top surface helps to distribute the energy in multiple directions on encountering an impact. This helmet shell has passed the impact resistance test in all sides with maximum "g" encountered being 225 (back side).

3.1.3. Helmet shell of combination of aramid 62 gsm and 170 gsm

Here high and low modulus aramid fiber combination was used, and the helmet shell using this approach weighed around 328 g and withstands more than 50 joules of impact energy in all the five impact positions. This combination exhibited the best result by meeting all impact resistance criteria as per the MIL standard.

3.2. Drop Penetration Test

For drop penetration test, steel bob having mass of 0.46 kg and 60° included angle of tip radius 0.015″ (0.381 mm), having Rockwell

Table 4: Impact resistance test result for the optimized lightweight helmet shell (328 gsm).

Particulars	**Aramid 62 gsm+Aramid 170 gsm combination**				
Point of impact	**Front**	**Back**	**Crown**	**Left**	**Right**
Impactor shape	**Hemispherical**				
Speed (m/s)	4.22	4.19	4.22	4.24	4.17
Max peak (g)	175	65	54	111	213
Impact energy (joules)	53.32	52.61	53.5	54.05	52.08
Friction %	0.01	0.00	0.00	0.00	0.00
Head size	580 cm				
Head mass	4.85 kg				
SAM	EPS 14 mm				
Density SAM	60				
Helmet shell weight	328 g				
Result	Pass				

SAM: Shock absorbing material

hardness of C-60 is made to fall freely from a height of 3.05 m (10 ft) on these helmet surface. In all the three helmets drop penetration was found to be <6 mm and hence all the three helmets are qualified in drop penetration test.

4. CONCLUSION

In an effort to develop a lightweight helmet for fighter aircraft pilots various approaches have been tried out. Among these high and low modulus aramid fiber combination (aramid 62 and 170 gsm) exhibited excellent impact properties with the least weight. The helmet with the above fiber combination has met more than 50 joules impact resistance, and the highest maximum “g” observed was just 213 (right side). In drop penetration test, this helmet made of aramid 62 gsm and 170 gsm combination with EPS liner material (60 density and 14 mm thickness) shows <6.0 mm penetration depth. Thus, it has been proposed that the helmet made of combination of low and high modulus aramid fiber (62 gsm and 170 gsm) using EPS liner of 60 density has yielded better performance over other varieties and has been proposed as the optimum configuration for further performance tests.

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***Bibliographical Sketch**

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