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Watertown, Massachusetts

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ABSTRACT

The feasibility of utilizing several new armor materials in the development of combat helmets was demonstrated on the basis of laboratory tests for fragment protection capabilities and for durability. The materials considered were (1) phenolic/polyvinyl butyral bonded fabric of Kevlar, a high-strength, high-modulus aromatic polyamide fiber; (2) a rigid laminate of XP, a highly stretched polyolefin film; (3) polyester bonded glass fabric of LMLD, a low-modulus, low-density glass fiber; and (4) a composite system of XP encapsulated between laminated skins of polyester bonded glass fabric (GRP) and Kevlar fabric. Molding procedures were developed to obtain durable constructions without undue sacrifice of ballistic penetration resistance capabilities. The M-1 helmet shapes were molded from all these materials except for the LMLD, the processing for which is the same as for ordinary fiberglass.

These materials offer substantially improved protection capabilities against the broad weight range of anti-personnel munition fragments. In terms of V_{50} ballistic limit velocities obtained with four test projectiles, these materials surpass that in the standard M-1 helmet by up to 79 percent. The Kevlar system has the most promising combination of superior performance and a minimum of problems for combat helmet development. (Authors)

CONTENTS

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The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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INTRODUCTION

Three new materials are now simultaneously available for exploitation in personnel armor. They are (1) XP, a highly oriented polypropylene film; (2) LMLD - a low-modulus, low-density glass fiber; and (3) Kevlar - a high-modulus, high-strength aromatic polyamide fiber. All three are superior to the older armor materials in protection capabilities against munition fragments.[1]

The label "new" often signifies that a material has not been completely characterized and that actual use experience in product form is limited or non-existent. Further, if the new material has unusual properties, properties much different from prior materials, then its behavior may not be well understood, it may be difficult to process into desired forms and constructions, and its performance in the end product may not be as expected. Both XP and Kevlar fit into this category of new material. LMLD, on the other hand, and E glass fiber (ordinary fiberglass now used in armor) do not differ in properties tremendously. Both combine with the same polyester resins to make bonded fabric armor. Processing and fabrication for both are alike.

This report will consider only the XP and Kevlar materials and some problems posed by their "newness" and unusual characteristics in their application to helmets. The preparation of flat laminates and helmet constructions and their testing in several ways for "durability" and for fragment penetration resistance capabilities will be presented. The suitability of these materials and constructions thereof for helmets will be evaluated. Remaining problems to successful application will be identified.

PROBLEMS IN USING NEW MATERIALS FOR ARMOR

A. XP Film

XP is the first armor material in the form of a thin film. It is prepared from flat tubular polypropylene film by hot-stretching to about 12 times its original length and to a tube thickness of about 0.0015 inch.[2] Stretching changes the tensile strength from 4,300 to about 50,000 psi in the stretch direction and to practically no strength (40 psi) in the transverse direction. This highly orthotropic strength characteristic can be a problem in handling and assembling several hundred plies into armor since it splits easily. Also, it requires that alternate plies be cross-plied to be effective armor. Cross-plying is accomplished in a practical manner by the application of filament winding techniques. Eight-inch-wide film is wound at 45 degrees in alternate directions and a pad obtained by slitting the wound material longitudinally. Pads as large as 9x21 feet have been made. Pads may be secured by stitching around the perimeter and in horizontal and vertical rows at intervals. Film pads are converted to a rigid laminate by the simultaneous application of heat and pressure followed by cooling under pressure.[3] No adhesive or external bonding agent is used between the plies.

1. MASCIANICA, F. S. *Ballistic Technology of Lightweight Armor - 1973.* Army Materials and Mechanics Research Center, AMMRC TR 73-47, November 1973, Confidential Report.
2. KILL, S. A. *Scale Up and Quality Control Procedures for Flexible Armor Materials XP.* Phillips Scientific Corporation, Contract DAAG46-72-C-0804, Final Report, AMMRC CTR 72-5, April 1972, Confidential Report.
3. KILL, S. A. *Protection and Quality Control Procedures for Rigid Armor Material XP.* Phillips Scientific Corporation, Contract DAAG46-71-C-0032, Final Report, AMMRC CTR 74-12, February 1974, Confidential Report.

As normally made, molded XP has a tendency to delaminate partially when severely flexed or subjected to large temperature changes. Such behavior raises doubts as to the durability of an XP helmet in the field. Yet some capability for delamination under ballistic impact is necessary for a high degree of resistance to penetration. Complete fusion into a solid block will produce poor armor. Reconciling these opposing requirements is the problem.

Two approaches were taken in achieving a stable rigid structure without undue loss in protective capability. The first sought to determine whether the problem could be ameliorated to a satisfactory degree by careful selection of the molding temperature and pressure. The second encapsulates a pad of XP film between rigid skins of resin-bonded fabric laminates molded together at the edges to achieve a rigid structure that would be durable and equivalent to XP in protective capabilities.

B. Kevlar Fiber

Kevlar aromatic polyamide at present is made as three fibers having different strength properties that go up to 400,000 psi in tensile strength and 19×10^6 psi in modulus.[4] Fabrics made from these fibers differ a little in ballistic resistance; the better of these, Kevlar 29, is usually selected for armor applications.

Many bonding resins for Kevlar fabric armor have been examined by AMMRC and other laboratories. The consensus has selected the same phenolic/polyvinyl butyral resin used for the nylon fabric helmet liner. However, the interply bond strength using this resin is not always adequate. Molding temperature and pressure and precuring of the prepregged (resin impregnated) fabric were briefly investigated using flat panels before helmets were molded. Peel strength was used as the criterion for selecting the precure and molding conditions.

MOLDING OF TEST LAMINATES AND HELMETS

A. XP

Prior work indicated that temperature alone of the molding cycle variables could appreciably alter ballistic limits of laminated XP.[3] With increasing molding temperatures beyond about 325 F, ballistic limit decreased. However, no tests had been run to determine the effect of molding temperature on the susceptibility to delaminate. A series of 12x12-inch test panels weighing 40 oz/sq ft were made in a mold at temperatures between 315 F and 360 F (all molded for 20 minutes at 1000 psi) by the Phillips Scientific Corporation and tested at AMMRC for ballistic limit velocities. A duplicate set was cut into 6x6 inch panels and tested for delamination by temperature and humidity cycling and by water immersion.

A second series of test panels, 6x6 inches, weighing 56 oz/sq ft, were molded at AMMRC over the same temperature range using polished metal plates with 0.018-inch Teflon sheets between the XP and the metal plates to prevent adhesion. A

4. ALESI, A. L., et al. *Review of the Applications of Kevlar Fibers to Composite Structures.* Army Materials and Mechanics Research Center, AMMRC MS 74-11, October 1974.

thermocouple was inserted at mid-thickness in a corner to measure the molding temperature accurately inside the laminate rather than relying on a platen temperature. Molding at temperature was conducted for 30 minutes-sufficient to provide a minimum of 10 minutes at the indicated temperature for the center of the panel. Panels were cooled under pressure to an internal temperature of 100 F. The molding pressure was raised to about 2500 psi since higher pressures of this magnitude were needed for helmet molding and since partial internal delamination was observed on thermal stressing of the first series.

With one exception in each series, the AMMRC panels were translucent as shown in Figure 1 while the Phillips panels were striated, white, and opaque. When molded at the highest temperatures (356 to 360 F), both were yellow and hazy. The difference in appearance between the two sets of panels is attributed to the better removal of air between film plies at the higher pressure. Excessive flow of XP material occurred at the 356 F molding temperature as indicated by the flash that squeezed out around the edges.

Figure 1. Relative translucency of XP laminates. Left to right: Phillips panels molded at 1000 psi for 20 minutes at 360 F and 315 F; AMMRC panel molded at 2250 psi for 30 minutes at 347 F.

XP helmets were made using an M-1 helmet-shape, production-quality compression mold in a 300-ton press at the U.S. Army Natick Laboratories. This mold produced a helmet with a wall thickness of 0.2 inch that weighed about one pound. Although a 3-pound helmet was desired, this was the only compression mold available for demonstrating the molding process. Full press tonnage and the maximum temperature of 320 F obtainable from the steam supply was used. XP helmet preforms were put into the hot mold and pressed for 20 minutes, then cooled to room temperature under pressure. The size of the preform had to be made smaller than was indicated by helmet dimensions. The shear cut-off on the mold that operated satisfactorily when nylon fabric helmets were molded was unable to cut off any excess XP so that the mold did not fully close. The removal of about 1 to 1-1/2 inches from the perimeter of the preform corrected this. The XP flowed to fill the mold and produced a helmet with a finished rim.

Two styles of preforms were tried, an oval-shaped one and a "pinwheel" type shown in Figure 2 with either overlapping or butted "vanes." Sound helmets, that is, helmets bonded throughout, were obtained with both preform styles. One of the XP helmets is shown in Figure 3 together with helmets molded from the other materials.

B. Kevlar

Flat laminates consisting of 23 plies of Kevlar 29, 11 oz/sq yd plain weave fabric, preimpregnated with phenolic/polyvinyl butyral resin (22%) were prepared

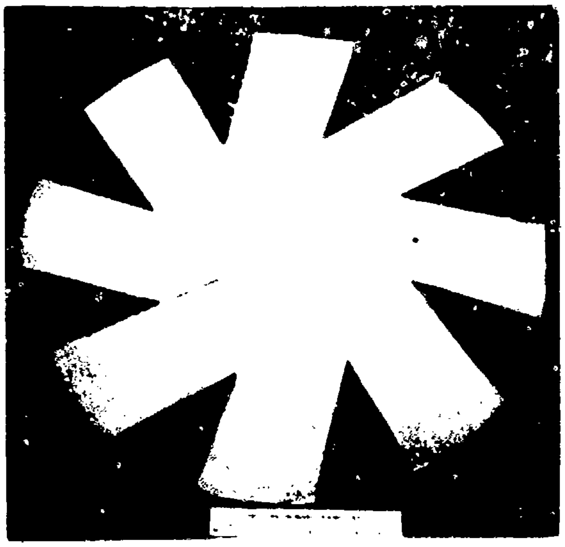

Figure 2 "Pinwheel" preform

by press molding under 45 tons at 330 F for 45 minutes, followed by cooling prior to removal from the press. Test panels, 12x12 inches, were molded for ballistic testing and 6x6 inch panels were cut from 12x12 inch panels for other tests. All panels had a 36 oz/sq ft areal density.

Helmet constructions of the standard M-1 helmet shape were prepared by conventional bag molding procedures in an autoclave at 330 F and 250 psi pressure for 80 minutes. The mold was a silicone rubber-coated, glass fabric-reinforced epoxy mold that was fabricated using a plaster cast made of the male half of the XP helmet compression mold. The mold was made so spacer liners could be inserted to obtain desired wall thicknesses. Two Kevlar 29 constructions evolved, one of 25 plies of 11 oz/sq yd plain weave fabric, and the other of 11 plies of 16 oz/sq yd woven roving weave fabric; both were preimpregnated with phenolic polyvinyl butyral resin (22 and 25 percent, respectively). Pinwheel preforms were laid up in an overlap pattern within the mold, the mold put into a polyvinyl alcohol film bag, and the bag evacuated (shown in Figure 4) prior to curing in the autoclave. The helmet made with 25 plies required three consecutive moldings of 9, 9 and 7 plies to achieve a smooth, wrinkle-free model with proper tapering along the helmet edge. However, 11 plies of woven roving fabric enabled the helmet to be molded in a single operation due to the fabric's better draping characteristics and lesser total bulk of the lay-up. This helmet and a test panel to provide specimens for a peel resistance test were molded at 350 F to obtain a greater resin cure and eliminate the strong residual odor of the 330 F molding. Helmets of both constructions weighed about 3 pounds each.

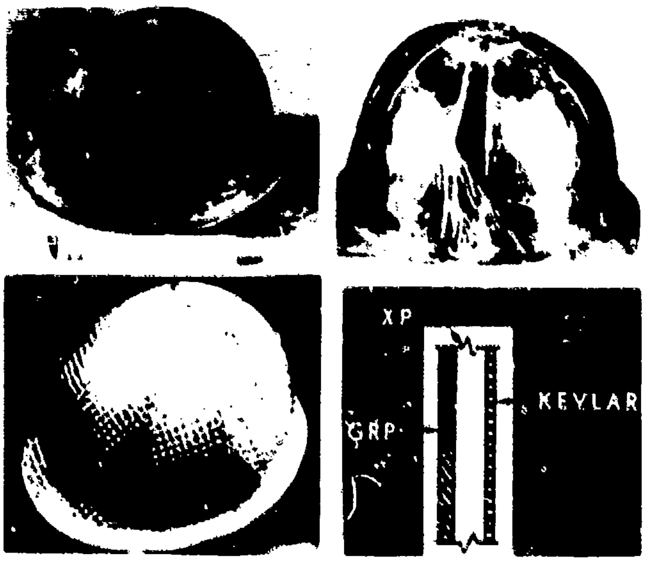

Figure 3 Helmets: Kevlar (upper left), XP (upper right), composite (lower left), composite helmet cross section (lower right)

Kevlar fabrics and laminates could not be cut cleanly by any of the usual means–scissors or rotary knives for fabrics, and band saws or circular saws for laminates.

C. GRP/XP/Kevlar Composite

Flat laminates were prepared by encapsulating 16 oz/sq ft XP film, 6x6 inches, between 4 plies of 8x10-inch conventional polyester prepregged woven roving glass fabric (GRP) and 6 plies of 8x10-inch polyester impregnated Kevlar 29 satin weave fabric (5 oz/sq yd). This composite was cured in the autoclave at 260 F under 75 psi pressure for 90 minutes employing conventional vacuum bag molding techniques. Under these conditions the XP film plies, as expected, remained unbonded.

Figure 4. Vacuum-bagged helmet preform in mold.
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In a similar manner, M-1 helmet-shaped composites were made in the same mold utilized for the Kevlar helmet. The core XP was tapered by progressively making the inner plies smaller with the largest ply ending an inch from the helmet edge so that the GRP and Kevlar bonded together to form a rigid double-wall shell sealed at the rim. Again a hand lay-up pinwheel overlap procedure for assembling the materials within the mold was employed. The helmets weighed about 3 pounds each.

TESTING PROCEDURES AND RESULTS

A. Ballistic Penetration Resistance

1. Helmet Materials

The ballistic resistance of the new helmet armor materials was determined using flat panels with four projectiles of different masses representative of the fragmenting munition threat (under 100 grains) to combat ground troops. The test projectiles were conventional Army fragment-simulating projectiles conforming to Military Specification MIL-P-46593. Testing was conducted in accordance with Military Standard MIL-STD-662, Ballistic Test Method for Personnel Armor Material. The test determines ballistic limit velocities, V_{50} denoting the projectile velocity where the probability of penetration is 0.50 and calculated by averaging an equal number of velocities within a range of 125 ft/sec that result in partial and complete penetrations. (Ballistic data now being acquired with munition fragments are confirming the superior resistance to penetration reported herein for these materials.)

The percent improvement in V_{50} values for the new materials over the standard M-1 helmet system (steel shell and laminated nylon fabric liner) is given in Table 1. It is readily apparent that all four materials exhibit substantially higher resistance to penetration than the M-1 helmet system. Kevlar and XP are best, closely followed by the GRP/XP/Kevlar composite. Their improvement over the M-1 helmet system is in the order of 30 to 80 percent.

2. Variation of V_{50} Ballistic Limit of Laminated XP With Molding Temperature

Only one intermediate caliber projectile was used. Figure 5 shows the combined data for the Phillips and AMMRC panels presented in terms of V_{50} ratios based on V_{50} value obtained for the lowest temperature (315 F). This ratio starts to decline rapidly after 345 F, indicating that the ballistic penetration resistance of laminated XP is being degraded at the higher temperatures.

B. Durability (Permanence) Tests

1. Temperature Cycling

All test panels were prepared with two adjacent edges cut with a band saw to obtain unsealed edges as well as molded edges. With XP this procedure produced partial delamination along the edges and some fusing of the cut surfaces.

TABLE 1. V_{50} BALLISTIC LIMITS OF NEW HELMET MATERIALS COMPARED TO THE STANDARD M-1 HELMET

	Percent Improvement*			
Material	A	B	C	D
KEVLAR	79	42	62	56
XP	66	36	69	77
GRP/XP/KEVLAR	64	33	56	75
LMLD	53	15	40	13

*Percent Improvement = $\frac{V_{50}\text{ (New Material)} - V_{50}\text{ (M-1 Helmet)}}{V_{50}\text{ (M-1 Helmet)}}$

A, B, C, D indicate fragment-simulating projectiles in increasing order of mass.
All comparisons are at an areal density of 16 oz/sq ft.
M-1 helmet includes Hadfield steel shell and nylon fabric-reinforced plastic liner.

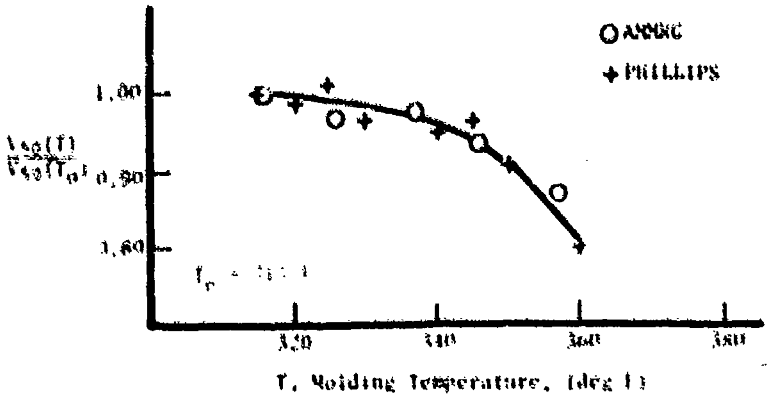

Figure 5 Effect of molding temperature on V_{50} ballistic limit of laminated XP.

The panels in an environmental test chamber were cycled from room temperature to -76 F, then to 176 F and back to room temperature within 8 hours. Two such cycles were run. Panels were inspected visually for changes after each cycle.

There were no changes in the appearance of the Kevlar and GRP/XP/Kevlar composite. The Phillips XP panels molded at 315 to 340 F delaminated around the cut edges to a depth of 1/8 to 3/8 inch. All panels molded at 315 to 350 F maintained their integrity and rigidity but were whiter in appearance than originally and felt slightly spongy when squeezed, indicating partial delamination. The 360 F panel warped and split partially along a curved surface of discontinuity that was visible before the test started.

AMMRC XP panels molded at 316 and 324 F turned white and split along the cut edges. The former puffed up to about 1-1/2" in thickness. The panels molded at 337, 347, and 356 F showed no change.

2. Humidity Cycling

This test was conducted in similar fashion to the temperature cycling test. The first part of the cycle was at 95 percent relative humidity and 176 F; the second part was at the same temperature but without the high humidity.

The behavior of the Phillips XP specimens submitted to humidity cycling was similar to those subjected to temperature cycling. It should be noted that humidity cycling also involves temperature cycling (room temperature to 176 F to room temperature). The panels molded at 315 F and 360 F split as before. All but the latter felt slightly spongy when squeezed. The AMMRC panels molded at 316, 326 and 338 F split with the frequency and extent of splitting decreasing with increasing temperature. The panels molded at 346 and 356 F did not change in appearance.

The Kevlar and GRP/XP/Kevlar composite panels did not change in appearance except that for the composite the Kevlar skin had puffed up away from the XP to a height of about 1/4 inch at the center.

3. Water Absorption

Water absorption for all the materials except the composite was conducted in accordance with procedures outlined in ASTM D570-63: Standard Method of Test for Water Absorption of Plastics The composite specimens consisted of 6x6-inch XP encapsulated within 8x10-inch GRP and Kevlar skins. Cuts to expose unsealed edges were made outside the XP are.

The 24-hour water absorption values determined were:

XP	None
Kevlar	2.5 Percent
GRP/XP/Kevlar composite	5.8 Percent

Water could be forced out of the composite specimens at the cut edges by shaking or tapping. Inspection of all edges showed that the Kevlar plies could be peeled from one another with very little effort. However, the Kevlar ply adjacent to the GRP was firmly bonded.

4. Impact Damage Resistance

To determine the relative impact resistance of M-1 shape helmet constructions, a 4-inch-diameter steel ball weighing 8 pounds was dropped from a height of 5 feet onto the crown of the helmet placed on a concrete floor. The amount of permanent deformation was measured and each helmet was closely examined for delamination or other damage.

No impact damage could be detected for either Kevlar helmet construction. The GRP/XP/Kevlar composite helmet suffered no permanent deformation but careful examination of the inside of the helmet revealed an area below the impact point, about 2 inches in diameter, that had a slightly altered appearance resulting presumably from the transient deformation of the helmet structure. Impact of the M-1 Hatfield steel helmet and nylon liner system produced a dent in the metal shell 7/16" deep and 1-7/8" in diameter. The XP helmet was also tested even though it was only 1/3 the weight of the others and it had been molded at a temperature too low for adequate bonding. Accordingly, it was not surprising that upon impact a dent 1-1/4 inches deep and 3-1/4 inches in diameter formed. The dented material had delaminated.

C. Peel Resistance

This test was conducted on Kevlar laminates only. The procedure followed was that of ASTM method D1876, Peel Resistance of Adhesives (T-Peel Test), except the bonded part of the specimens was 5 instead of 6 inches. Peel resistance of the laminates made with 11 oz/sq yd plain weave fabric and molded at 330 F and with 16 oz/sq yd woven fabric molded at 350 F was about 7 pounds per inch of width when pressed at 250 psi but only about 5-1/2 pounds at 2250 psi. Precuring the first fabric (prepregged) for 8 minutes at 235 F did not significantly change the peel strength. The peel strengths shown in Table 2 are considered adequate but not high for well-bonded durable laminates.

TABLE 2. PEEL RESISTANCE OF KEVLAR LAMINATES (lb/in.)

	Molding Temperature (F)	Molding Pressure (250 psi)	(2250 psi)
Not Precured	330*	7.3	5.7
	350†	7.0	-
Precured‡	330*	7.[illegible]	5.5

*Kevlar 29, 11 oz/sq yd plain weave fabric; 22% resin, phenolic/polyvinyl butyral.
†Kevlar 29, 16 oz/sq yd woven roving fabric, 25% resin, phenolic/polyvinyl butyral.
‡For 8 minutes at 235 F.

DISCUSSION OF RESULTS

A. Protective Capabilities

The 64 to 79 percent increase in V_{50} ballistic limit of the Kevlar and XP laminates and of the composite over the standard M-1 helmet system when tested with the projectile of least mass is especially significant. A major threat to ground troops are detonating munitions emitting small fragments traveling at high velocities. Kevlar and XP (or composite constructions having XP as the major component) helmets weighing 3 pounds (the same as the M-1 helmet system) are considered capable of stopping most and possibly all fragments at relatively short distances from burst. The M-1 helmet system is considered ineffective under these conditions.

B. XP Helmet

Molding of XP helmets, on the basis of experience with flat laminates, requires the selection of molding temperature of 340 to 350 F and a pressure of at least 2000 psi to insure removal of air between film plies, effect adequate bonding, and restrict the reduction in V_{50} ballistic limit to under 10 percent of the maximum attainable. The temperatures measured must be that of the XP, not that of the mold. Air removal appears to be a problem, and more positive measures are required. There appears to be wide latitude in preform design for XP helmets provided preforms are undersized (but not underweight) and of minimum bulk to allow the mold to close since any excess XP cannot be cut by the mold. Although molded XP helmets will require no cutting of the rim, piercing techniques with heated penetrators may be needed to make holes for mounting helmet suspensions without incurring local delamination of the XP.

Laminated XP when properly molded will not delaminate on thermal stressing, is dimensionally stable, and does not absorb water. The ability of 3-pound XP helmets to withstand low velocity impact as exemplified by the ball impact test remains to be determined.

Thermal stressing and exposure to varying humidity can distinguish between helmets molded under different conditions of temperature and pressure. As few as two cycles may suffice as a test. Translucency and color can also serve as visual guides to adequate molding. A yellowish tinge and good translucency indicate a satisfactory molding. Opaqueness with whiteness indicates too low molding temperatures and/or pressures. Very hazy yellowness indicates too high a temperature.

C. Kevlar Helmet

Kevlar fabric laminates using phenolic/polyvinyl butyral resin withstand thermal stressing and have low water absorption (2.5 percent in 24 hours). A molding pressure of 250 psi and temperature of 350 F are adequate. Heavy fabrics of good draping characteristics make molding of helmet shapes easier. A woven fabric of 15 oz/sq yd, and possibly up to 25 oz/sq yd, is satisfactory, and represents a lower cost fabric construction.

Kevlar fabrics and laminates of low resin content, 20 to 30 percent, were not able to be cut cleanly. Even helmets compression molded in matched steel dies (as they would be in production) will require some treatment of the as-molded fibrous edge to obtain a finished rim.

D. GRP/XP/Kevlar Composite Helmet

This composite construction was obviously not water proof, as evidenced by the accumulation of water between the skins. The entry point was apparently between Kevlar plies whose adhesion was quite poor. Polyester is evidently not a suitable bonding resin for Kevlar fabrics. Phenolic/polyvinyl butyral would be a better choice but its use would require some intermediate bonding medium to effect the bond with the GRP since the phenolic resin inhibits the cure of the GRP's polyester. If water also enters through the thickness of the skins, surface plies or all plies having somewhat higher resin contents would reduce or prevent this.

CONCLUSIONS

1. The feasibility of utilizing the new materials, Kevlar 29 fabric laminated with phenolic/polyvinyl butyral resin, and laminated XP polypropylene film, in the development of combat helmets has been demonstrated on the basis of laboratory tests for fragment protection capabilities and for durability. Some problems of secondary importance remain; obvious solutions for all but one are available.

2. Processing parameters have been defined for molding helmets weighing 3 pounds that are durable and possess at least 90 percent of the fragment protection capabilities of the material.

a) XP helmets are best molded at 345±5 F for a minimum for 30 minutes under a minimum pressure of 2000 psi. The specified temperature is that of the laminate and not a temperature measured somewhere in the mold metal. Procedures should be adjusted or modified to prevent the occlusion of air between film plies during molding. The making of holes in XP helmets for mounting suspension systems must be conducted with care using properly selected tools and techniques to insure that the new edges are sealed by fusion and no delamination occurs. Heated penetrators may be suitable hole-making devices.

b) There are no indications that the molding of laminated Kevlar 29 fabric helmets has any critical requirements. A molding pressure of 250 psi and a temperature of 350 F produced satisfactory helmets. Procedures or devices for cleanly cutting the helmet rim, or for removing frayed fibers and sealing the rim, or for binding the rim to form a finished edge are needed.

c) Polyester resins are not satisfactory bonding materials for Kevlar fabric in the GRP/XP/Kevlar composite helmet. Phenolic/polyvinyl butyral resin is recommended with the use of a polyester-compatible adhesive or resin-coated scrim ply between the GRP and Kevlar laminates. Resin contents of 30 percent (greater for surface plies) are recommended to reduce water absorption. Holes through the composite for mounting suspension hardware are expected to require the development of sealing methods to prevent the entry of water and possible separation of components.

3. Suitable types of tests for the quality of molded helmets are:

a) V_{50} ballistic limit velocity and falling ball impact for the three constructions.

b) Thermal stress and visual inspection of color and translucency for XP helmets.

c) Water absorption for GRP/XP/Kevlar composite helmets.

d) Peel strength for Kevlar 29 helmets.

4. Laminated Kevlar 29 fabric, laminated XP film, GRP/XP/Kevlar composite and LMLD offer substantially improved protection capabilities against the broad range of fragment masses inherent to anti-personnel munitions. In terms of V_{50} ballistic limit velocities for the range of test projectile masses utilized, the improvement over the standard M-1 helmet system is 42 to 79 percent for Kevlar, 36 to 77 percent for XP, 33 to 75 percent for the GRP/XP/Kevlar composite, and 13 to 53 percent for LMLD.

5. The development of a combat helmet can be successfully completed with any of the helmet systems examined. The Kevlar and LMLD helmet developments are the least difficult, XP is next, and the GRP/XP/Kevlar composite is the most difficult. The one having the most promising combination of superior performance and a minimum of problems in a Kevlar helmet.

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