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71-48-CE

BICOMPONENT AND BICONSTITUENT FIBERS IN BALLISTIC FABRIC FOR PERSONNEL ARMOR

by
M. W. Olsen
G. H. Brice

Uniroyal, Inc.
Wayne, New Jersey

Contract No. DAAG17-70-C-0032

April 1971

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing & Personal Life Support Equipment
Laboratory
TS-173

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FOREWORD

Except for minor frictional effects, the energy absorbing mechanism in ballistic nylon fabric body armor is the internal visco-elastic response of the fibers. Present fibers are nearly homogeneous; their response pattern is essentially uniform within the cross section, and their failure is normal fracture. As the strain rate is increased on a typical homogeneous fiber, it becomes more brittle and the resulting fracture limits the attenuation of energy. It is desired to explore additional mechanisms of energy absorption which might be developed within fibers.

One approach would be to evaluate the potential of combining within the individual fibers, materials of differing response characteristics as a means of creating interfacial shear effects within or along the fibers and possibly, larger fracture zones, which might increase energy absorption. Industry recently has developed technology to make biconstituent (dispersed fibril) fibers and bicomponent fibers in concentric and bilateral arrangements.

This project screens and evaluates the ballistic performance of several polymer combinations in the various biconstituent and bicomponent arrangements. It was initiated in September 1969 with Uniroyal, Inc., Wayne, New Jersey under Contract No. DAAG17-70-C-0032. The contract was administered under the direction of the Clothing and Personal Life Support Equipment Laboratory with Miss Barbara Hodam as Project Officer and Mr. Ronald Porter as Alternate.

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ABSTRACT

Experimental fibers have been spun from intimate mixtures of nylon, polypropylene and polyester plastics (biconstituent type) following an extensive screening program to determine compatibilities. Fibers of the bicomponent type (shell/core and bilateral) have also been spun from several combinations. A total of six combinations of both types plus a 100% nylon control have been spun in sufficient quantity to be woven into ballistic fabric and tested on a firing range. All seven fabrics showed an appreciably lower ballistic resistance (V_{50}) than a standard nylon ballistic fabric but processing difficulties during the spinning operation may have been responsible, at least in part, for the poor showing. When comparisons are made within the series there is evidence that a shell/core fiber made from nylon and polypropylene could be developed into an improved ballistic fabric.

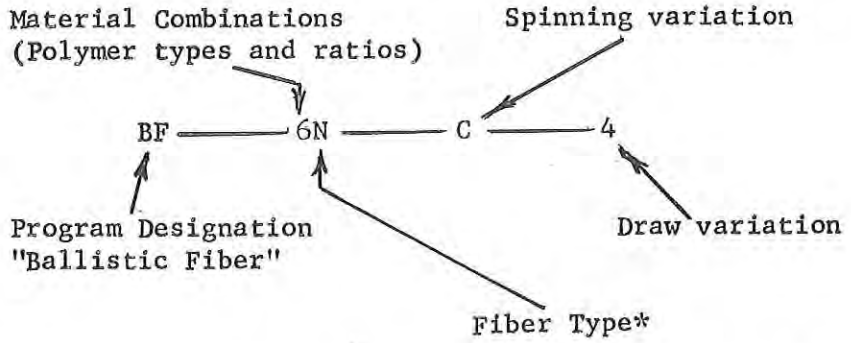
BICOMPONENT AND BICONSTITUENT FIBERS IN BALLISTIC FABRIC FOR PERSONNEL ARMOR

Introduction

The object of this work is to determine the potential improvement in armor fabric ballistic resistance which might be obtained in fabrics made from biconstituent and/or bicomponent fibers. The premises are that energy absorption ordinarily provided solely by fiber tenacity might be amplified by shear and interfacial separation effects within and along the complex fibers. It was hoped that this delaminating effect would extend well beyond the point of impact thus spreading the additional energy absorption over a large area of the fabric.

For the purpose of identification, a fiber comprised of two polymers wherein one exists as fibrils in a matrix of the other will be labeled a biconstituent fiber. A bicomponent fiber is one that contains two polymers, both of which are present in a continuous form. These can exist side by side as in a bilateral configuration, or with one surrounding the other as in a shell/core configuration.

A code system has been developed for identifying the various yarns that have been processed for this program. It is as follows:



*Fiber types are designated as follows: N - biconstituent made from bulk mixed material; P - biconstituent made from preblended material; S - bicomponent in shell/core configuration; B - bicomponent in bilateral configuration.

Material Selection

The materials selected for this program are listed in Table I.

Thermoplastic polyurethane and polyvinyl alcohol had also been considered during the planning stages of the program but were eliminated because of anticipated difficulties due to incompatibility. Since polyvinyl alcohol is processed by a unique wet spinning process, the possibility of successfully combining this material with hydro-

Table I

Candidate Plastics for Spinning into Fibers

Trade Name	Type	RV[1]	MV[1]	MV[5]	IV[1]	MV[6]	MF[1]
Plaskon 8205	Nylon 6	290	10,900				
Plaskon 8207	Nylon 6	70	2,100		1.27		
Plaskon 8202	Nylon 6	38			0.85		
Plaskon XP485[2]	Nylon 6	50	1,100				
Zytel 101[3]	Nylon 66	55					
Polytex	Polyester				0.93		
Vitel 316	Polyester				0.63		
Shell 5220	Polypropylene						0.6
Shell 5820	Polypropylene						12
Lexan 101	Polycarbonate			12,000			
Surlyn A-1559	Polyethylene/ methacrylic acid ionomer[4]					2200	

1. Melt viscosity in Poises @ 13.6 psi shear stress and 550°F.
2. Tire cord type polymer.
3. General purpose polymer.
4. Sodium cation.
5. Melt viscosity in Poises at 550°F, shear rate 650 $sec.^{-1}$
6. Melt viscosity in Poises at 500°F, shear rate 650 $sec.^{-1}$

Abbreviations: MV - melt viscosity, RV - relative viscosity, IV - intrinsic viscosity, MF - melt flow (ASTM D1238-65T).

phobic plastics in a hot melt appeared remote. Perfecting or developing a compatible wet spinnable nylon to combine with this material would be beyond the economic scope of this contract. A polyurethane elastomer that is melt spinnable in the temperature range of our nylon standard is not available commercially. The cost of running this combination, therefore, would also be too high to include this polymer as a candidate in a screening operation.

Plaskon 8205 type 6 nylon (RV 290) was first selected as the standard on which to base the various combinations, but it was found that this material had too high a viscosity to be processed in the equipment for spinning shell/core construction. Since Plaskon 8207 processed satisfactorily here, it was chosen as the common polymer for all combinations. Similarly, a lower molecular weight polypropylene (Shell 5820) was used to replace Shell 5220 in the polypropylene/nylon bilateral fiber when it was found that Shell 5220 was too viscous for the bilateral pack (manifested by immediate and repeated shear pin breakage in the gear pump under a variety of conditions).

Biconstituent Fiber Processing

Since a test of the spinnability of a large number of possible polymer combinations for biconstituent fibers was desired, a screening program was run on a small melt spin unit. This consisted of a 1-inch Modern Plastics Machinery type 100-20 extruder equipped with flow stabilizing gear pump and an 8-hole spinneret. Initially, bulk mixed granules of the two polymers were dried and fed directly to this machine. However, early in the program it was decided to try premixing to see if better physicals could be obtained. To accomplish this the combined pellets were melt extruded into a large-diameter monofilament, then chopped into pellets which were fed to the fiber spinning unit. Since no improvement could be detected over several runs the pre-mix procedure was abandoned. All yarns produced on the production-scale melt spin unit were spun from bulk mixed feeds. Combinations tried on the small screening unit are shown in Table II. In many cases several attempts were made on particular combinations either to obtain a successful run or to improve drawing characteristics and physicals. As soon as possible after spinning, the yarns were drawn; each yarn appeared to require a specific draw ratio to handle properly. Tensile tests were run following a successful draw to provide quantitative data on tenacity and elongation. Because of the limited nature of the program one can only safely say that specific material combinations mixed to a specific ratio did or did not run under the specific conditions imposed. Generally, however, the data did serve the purpose intended - that of acting as a guide for selecting combinations for the scale-up phase which would lead to fabric construction.

Table II

Combinations Tried on Small Melt Spin Unit for Biconstituent Fibers

Yarn Code No. BF-	2N	1N	10P	9P	12P	11P	16P	15P	34N	32N	35N	36N
Composition												
Nylon 6 (RV 290)	70	30	70	30	70	30	70	30				
Nylon 6 (RV 70)			30	70					70	30	70	30
Nylon 6 (RV 38)												
Nylon 66 (RV 55)												
Polyester (I.V. 0.93)									30	70		
Polyester (I.V. 0.63)	30	70										
Polypropylene (MF 0.6)					30	70	30	70			30	70
Polycarbonate												
Ionomer Copolymer							10	10				
Yarn Denier	151	72	108	85	(2)	(1)	127	86	(1)	63	(1)	(1)
Tenacity, g/den.	2.76	2.18	4.87	6.27	-	-	2.86	4.02	-	3.33	-	-
% Elongation	10	6	15	13	-	-	19	13	-	9.7	-	-
Selected for scale-up												

Notes (1) Not spinnable as run
(2) Could not be drawn
(3) Crosslinked in die

Table II (Cont'd.)

Yarn Code No. BF-	39N	38N	41N	43N	42N	44N	45N	29N	7N	30N	28N
Composition											
Nylon 6 (RV 290)											
Nylon 6 (RV 70)	70	30	30	70	30	70	30				
Nylon 6 (RV 38)											
Nylon 66 (RV 55)								70	30	70	30
Polyester (I.V. 0.93)				30	70					30	70
Polyester (I.V. 0.63)	30	70	70					30	70		
Polypropylene (MF 0.6)						30	70				
Polycarbonate											
Ionomer Copolymer			10	10	10	10	10				
Yarn Denier	(1)	76	(1)	(1)	(1)	(1)	(1)	163	78	(1)	(1)
Tenacity, g/den.	-	2.66	-	-	-	-	-	3.61	1.31	-	-
% Elongation	-	18.5	-	-	-	-	-	13.6	4	-	-
Selected for scale-up		x				x					

Notes (1) Not spinnable as run
(2) Could not be drawn
(3) Crosslinked in die

Table II (Cont'd.)

Yarn Code No. BF-	37N	47N	48N	49N	50N	51N
Composition						
Nylon 6 (RV 290)						
Nylon 6 (RV 70)	70	30	70	30	70	30
Nylon 6 (RV 38)			30	70	30	70
Nylon 66 (RV 55)						
Polyester (I.V. 0.93)						
Polyester (I.V. 0.63)						
Polypropylene (MF 0.6)						
Polycarbonate	30	70				
Ionomer Copolymer					10	10
Yarn Denier	(1)	(1)	82	98	81	88
Tenacity, g/den.	-	-	6.0	4.62	4.07	3.25
% Elongation	-	-	9.5	12.8	9.33	14.7
Selected for scale-up			x			

Notes (1) Not spinnable as run
(2) Could not be drawn
(3) Crosslinked in die

Two attempts were made to process a polycarbonate/nylon mixture but severe decomposition occurred in both cases.

Even though the 70/30 Nylon 6 (RV 70)/Polyester (I.V. 0.63) combination, Run No. 39N, could not be successfully spun on the small melt spin unit, it was tried on the large unit because Nylon 6 was desired as the major constituent of this combination. However, the lack of spinnability carried over to the large equipment, and it was necessary to settle for the reverse ratio combination, Run No. 38N, for processing into fabric.

The duPont ionic polymer, Surlyn A, was tried as a dispersing aid at the 10 parts level in many combinations. It proved to be of value only in nylon/polypropylene combinations where it improved spinnability and drawing characteristics sufficiently to permit production of a fiber.

A total of three biconstituent fibers plus a 100% nylon control were chosen to be produced for weaving into fabric. For these production runs the 2-1/2-inch Hartig extruder with a 140 hole spinneret was used. Material was fed into the spin pack with a flow stabilizing gear pump. The combinations successfully run are 70 polyester/30 nylon, 70 nylon/30 polypropylene, and 70 nylon (I.V. 1.27)/30 nylon (I.V. 0.85).

Bicomponent Fiber Processing

Bicomponent fibers were spun on a dual extruder setup. This comprises a 2-1/2-inch Hartig extruder and a Modern Plastics Machinery 1-inch extruder, each fitted with a flow stabilizing gear pump. Two 70 hole dual extrusion spinnerets were available. One produced a shell/core configuration and the other a bilateral configuration.

As mentioned before, Plaskon 8205 (RV 290) nylon could not be processed through the shell/core spin pack because of high viscosity; Shell 5220 (MF 0.6) polypropylene could not be processed through the bilateral spin pack for the same reason. Successful spinning production runs were made with combinations of Nylon 6 (RV 70)/Polypropylene (MF 0.6), Nylon 6 (RV 38)/Polypropylene (MF 0.6), and Nylon 6 (RV 70)/Nylon 6 (RV 38) in the shell/core construction and with combinations of Polypropylene (MF 12)/Nylon 6 (RV 70) and Nylon 6 (RV 70)/Nylon 6 (RV 38) in the bilateral construction. The Nylon 6 (RV 70)/Nylon 6 (RV 38)combinations have been completed through the drawing and twisting operation but will not be woven into fabric. All other combinations have been converted to fabric and tested.

Drawing, Twisting and Weaving

All production scale yarns were drawn on an apparatus designed to cover a large range of draw ratios in stepped increments. The equip-

ment included a thermostatically controlled, heated feed roll and a room temperature pull roll. A standard Ansonia take-up was used for spooling. The yarns were then given 3.5 turns per inch Z twist and respooled for the loom. Fabrics were woven into a 2x2 basket weave and scoured in accordance with specifications described in MIL-C-12369E.

Yarn and Fabric Properties

Table III presents data on the nine yarns and seven fabrics produced. Stress/strain curves were obtained on 140 filament yarns using an Instron at a crosshead speed of 10 in./min. The best yarn tenacity was obtained with the nylon control but even this figure (4.29 g/den.) is substantially lower than would be anticipated for a tire grade nylon. Generally, the biconstituent fibers gave the lowest yarn tenacities; the bilateral fiber made from a combination of the nylon control and polypropylene gave the best tenacity of any experimental combination.

The relatively high grab strength displayed by the nylon/nylon biconstituent fiber fabric (48N-D-2) when compared with that of the nylon/polypropylene biconstituent yarn (44N-F-2) and the nylon/polypropylene bilateral yarn (1B-D-1), both of which show higher tenacities in combination with equivalent or higher fabric weights, is an anomalous result which cannot be explained at present.

Even though several trial spinning and drawing runs were made for the control and for most experimental combinations, it is believed that further improvement in tenacities could have been made with more extensive development effort. The large number of variables present during a given run on the production scale melt-spin unit precluded optimization of each. Temperature changes alone required at least 60 minutes in most cases to reach an equilibrium condition. Also, it is thought that staged heating on the draw unit would have been helpful.

Figures 1 through 5 are photomicrographs of a cross sectional area of experimental yarns. Attempts to obtain electron micrographs (RCA model EMU-3) that would show any kind of phase distinction were unsuccessful. The shell/core construction, Figure 1, and the bilateral, Figure 2, definitely show two phases with lines of demarcation. Many of the bilateral fibers appear to have separated into their individual fibril components. Actually, there is no reason to expect nylon and polypropylene to adhere to one another by simple planar contact. Photomicrographs of the biconstituent fibers, Figures 3 and 4, fail to show any distinguishing features. Magnifications to 460X were tried but no phase distinctions could be observed. An attempt to slice the fibers longitudinally was unsuccessful. A photomicrograph of the nylon control, Figure 5, is included for comparative purposes.

Table III

Fiber and Fabric Properties

Code BF-	1B-D-1	2B-E-2	101S-D-1
Yarn			
Composition	50 LMW[2] polypropylene 50 HMW[2] nylon	50 HMW nylon 50 LMW nylon	50 HMW nylon 50 HMW polypropylene
Type Fiber	Bilateral	Bilateral	Shell/core
Tensile, g.	4390	3700	4130
% Elongation	30	12	35
Denier	1008	1020	1215
Evenness[1]	70.4	-	-
Tenacity, g./den.	4.07	3.63	3.40
Initial Modulus, g./den./%Elong.	0.306	0.443	0.168
Fabric		None Made	
Oz./sq. yd.	17.9		14.8
Width (in.)	10.93		11.95
Thickness (in.)	0.0564		0.0383
Ends/inch	47.7		47.0
Picks/inch	47.7		36.2
	Warp Fill		Warp Fill
Yarn Size (den.)	1248 1256		1296 1399
Take Up (%)	17.63 18.60		14.2 12.3
TPI Single "Z"	4.88 5.26		4.2 4.5
Grab strength (lb.)	818 930		723[3] 880
Grab Elong. @ Bk. (%)	111 132		61.0 109
Tear Resistance (lb.)	71.6 78.9		- -

1. Standard deviation calculated from ten samples taken from separate spools.
2. LMW: low molecular weight; HMW: high molecular weight.
3. Tore at jaw

Table III (Cont'd)

Code BF-	103S-B-1	105S-B-1	38N-G-1
Yarn			
Composition	50 LMW[2] nylon 50 HMW polypropylene	50 HMW nylon 50 LMW nylon	70 LMW polyester 30 HMW nylon
Type Fiber	Shell/core	Shell/core	Biconstituent
Tensile, g.	3310	3840	3320
% Elongation	27	21	8
Denier	986	1150	1060
Evenness[1]	24.8	-	79.8
Tenacity, g./den.	3.36	3.34	3.13
Initial Modulus, g./den./ % Elong.	0.129	0.315	0.449
Fabric		None Made	
Oz./sq. yd.	14.1		14.5
Width (in.)	11.60		10.96
Thickness (in.)	0.0441		0.0354
Ends/inch	48.3		47.3
Picks/inch	45.8		48.0

	Warp	Fill	Warp	Fill
Yarn size (den.)	1042	1003	1200	1040
Take Up (%)	14.1	13.6	6.72	13.79
TPI Single "Z"	4.2	4.6	5.04	5.54
Grab Strength (lb.)	692[3]	1069	580	595
Grab Elong. @ Br. (%)	80.0	130.0	46.6	60.3
Tear resistance (lb.)	-	-	41.8	46.3

1. Standard deviation calculated from ten samples taken from separate spools.
2. LMW: low molecular weight; HMW: high molecular weight.
3. Tore at jaw

Table III (Cont'd.)

Code BF-	44N-F-2		48N-D-2		19N-J-7	
Yarn						
Composition	70 HMW[2] nylon 30 HMW[2] polypropylene 10 Ionomer Copolymer		70 HMW nylon 30 LMW nylon		100 HMW nylon	
Type Fiber	Biconstituent		Biconstituent		Control	
Tensile, g.	4230		3110		5320	
% Elongation	31		15		30	
Denier	1360		1150		1240	
Evenness[1]	37.6		187.6		71.1	
Tenacity, g./den.	3.11		2.71		4.29	
Initial Modulus, g./den./% Elong.	0.217		0.295		0.329	
Fabric						
Oz./sq. yd.	17.0		16.8		15.1	
Width (in.)	11.98		11.1		11.48	
Thickness (in.)	0.0428		-		0.0378	
Ends/inch	35.8		23.0		45.3	
Picks/inch	37.7		22.8		43.5	
	Warp	Fill	Warp	Fill	Warp	Fill
Yarn Size (den.)	1596	1606	1266	1369	1410	1275
Take Up (%)	9.83	12.74	9.9	12.0	11.8	13.3
TPI Single "Z"	3.96	4.29	4.4	4.4	4.65	4.93
Grab Strength (lb.)	614	697	913	1150	1008	1416
Grab Elong. @ Bk. (%)	70.7	83.7	113	80.7	95.7	156.3
Tear resistance (lb.)	75.1	79.4	72.9	74.7	78.5	69.9

1. Standard deviation calculated from ten samples taken from separate spools.
2. LMW: low molecular weight; HMW: high molecular weight.

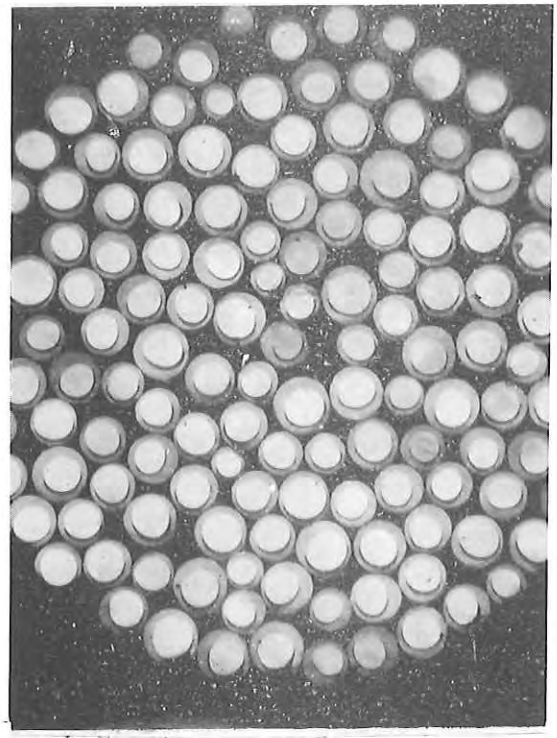


Fig. 1 - Photomicrograph (100 X) of Fiber Cross Sections (50 Polypropylene Shell, 50 Nylon Core)

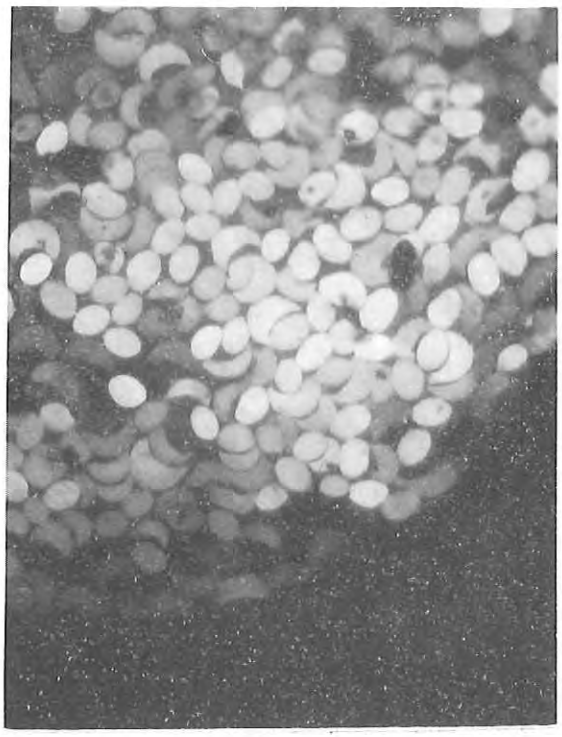


Fig. 2 - Photomicrograph (200 X) of Fiber Cross Sections (50 Polypropylene, 50 Nylon Bilateral)

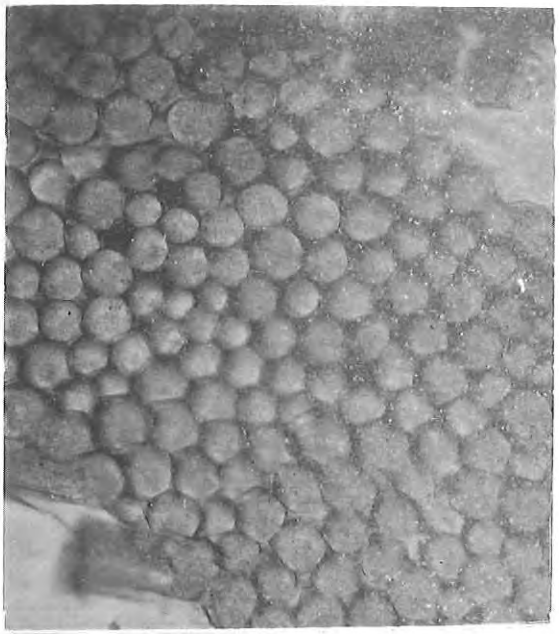


Fig. 3 - Photomicrograph (200 X) of Fiber Cross Sections (70 Polyester, 30 Nylon Biconstituent)

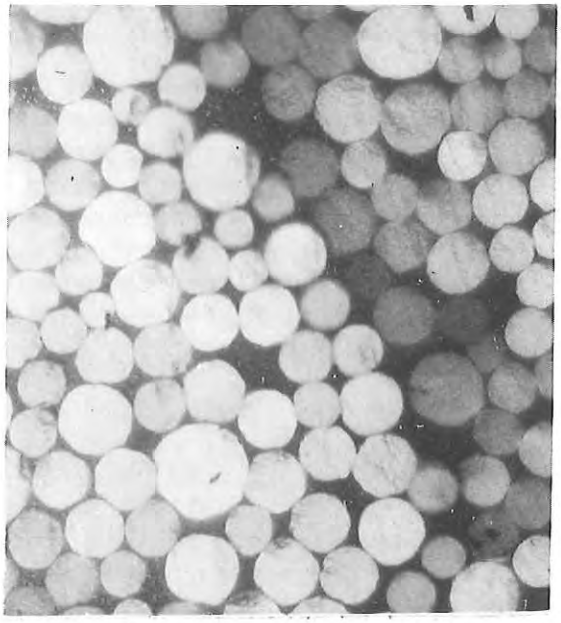


Fig. 4 - Photomicrograph (200 X) of Fiber Cross Sections (70 Nylon, 30 Polypropylene, 10 Surlyn A Biconstituent)

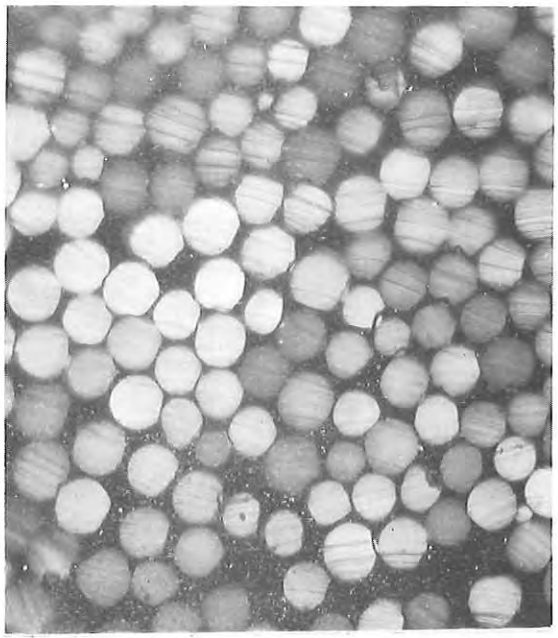


Fig. 5 - Photomicrograph (200 X) of Fiber Cross Sections (Nylon Control)

Ballistic Test Results

The fabrics were subjected to ballistic tests on a firing range at the Uniroyal Research Center in Wayne, N. J. The range was designed in accordance with instructions given in MIL-STD-1161, "Test Facility, Ballistic, For Personal Armor Material" while the method used to determine V_{50} followed the procedure given in MIL-STD-662A, "Ballistic Acceptance Test Method For Personal Armor Material." One important exception is that the test facility atmosphere was not controlled.

Since the fabrics were experimental they varied considerably in areal density and it was necessary to reduce the number of sheets in the test panel in some cases to more nearly approximate the weight of a standard test panel (12 sheets weighing 18.7 oz./ft.^{2}). Although V_{50} is not linearly related to fabric weight, calculated V_{50} values were then roughly corrected to compensate for the known differences by multiplying the actual V_{50} by the ratio of 18.7 to the measured panel areal density. The required number of sheets comprising a test panel were stapled together at the edges prior to mounting in the clamping frame. The surfaces of the clamping frame in contact with the fabric were faced with a coarse emery cloth to reduce bagging from projectile impact.

A new rifle was used to fire the standard 17-grain fragment simulating missile. Velocity was measured by an Electronics Associates, Inc. 6200-6202 counter. The accuracy of this instrument was checked with a type 564 Tektronix oscilloscope and found to be within specification. Standard ballistic fabric furnished by Natick was tested on each day that tests were run on experimental fabrics to maintain a control on the testing.

The data shown in Table IV indicate that an absolute improvement over standard nylon ballistic fabric has not been achieved. However, this may be due, at least in part, to the relatively low tenacities (as previously noted) of the experimental fibers. A more valid assessment of the value of bicomponent and biconstituent fibers in ballistic fabrics can be made by comparing them with the control which has been processed on the same equipment. If one examines the corrected V_{50} values it is apparent that only two of the experimental fabrics are as effective as that control, viz. BF-1B-D-1 and BF-101S-D-1. It will be noted that both of these are bicomponent fibers. Moreover, it may be seen that shell/core bicomponent fiber, 101S-D-1, exhibits the same V_{50} as the all-nylon control even though it shows a significantly lower tenacity (3.40 g/den. for the experimental fiber vs. 4.29 g/den. for the control). Presumably, if the tenacity could be improved a higher V_{50} might be realized. The shell/core construction, then, could serve as the basis for an extension of this program.

Table IV
Ballistic Tests

Code BF-	1B-D-1	101S-D-1	103S-B-1
Composition	50 LMW[3] polypropylene 50 HMW[3] nylon	50 HMW nylon 50 HMW polypropylene	50 LMW nylon 50 HMW polypropylene
Type Fiber	Bilateral	Shell/core	Shell/core
Yarn Tenacity g./den.	4.07	3.40	3.36
Fabric Wt., oz./sq. yd.	17.9	14.8	14.1
No. Sheets in Test Panel	10	11	12
Panel Areal Density, oz./sq. ft.	19.8	18.2	18.8
Actual V_{50}, ft./sec.	1176	1097	1007
Corrected V_{50}[1], ft./sec.	1110	1127	1000
V_{50}, Standard Fabric[2], ft./sec.	1290	1346	1320

1. Corrected to a test panel areal density of 18.7 oz./sq. ft.
2. Furnished by Natick and tested on same day as experimental fabric; 12 sheet panels, areal density 18.7 oz./sq. ft.
3. LMW: low molecular weight; HMW: high molecular weight.

Table IV (Cont'd.)

Code BF-	44N-F-2	48N-D-2	38N-G-1	19N-J-7
Composition	70 HMW[3] nylon 30 HMW polypropylene 10 Ionomer copolymer	70 HMW nylon 30 LMW[3] nylon	70 LMW polyester 30 HMW nylon	100 HMW nylon
Type Fiber	Biconstituent	Biconstituent	Biconstituent	Control
Yarn Tenacity, g./den.	3.11	2.71	3.13	4.29
Fabric Wt., oz./sq. yd.	17.0	16.8	14.5	15.1
No. Sheets in Test Panel	10	11	12	11
Panel Areal Density, oz./sq. ft.	18.9	20.5	19.3	18.5
Actual V_{50}	970	1045	1047	1113
Corrected V_{50}[1]	960	953	1013	1125
V_{50}, Standard Fabric[2]	1285	1285	1290	1300

1. Corrected to a test panel areal density of 18.7 oz./sq. ft.
2. Furnished by Natick and tested on same day as experimental fabric; 12 sheet panels, areal density 18.7 oz./sq. ft.
3. LMW: low molecular weight; HMW: high molecular weight.

SUMMARY AND CONCLUSIONS

Eight experimental fibers plus a nylon control have been prepared in quantity. Six of these plus the control have been woven into fabric and tested for ballistic resistance. All seven fabrics show an appreciably lower V_{50} than a standard nylon fabric furnished by U. S. Army Natick Laboratories. This may be explained by the generally low tenacities of all fibers produced under this contract. A more valid assessment of the value of bicomponent and biconstituent fibers in ballistic fabrics can be made by comparing them with the control which has been processed on the same equipment.

If one uses the control fabric for comparison and considers the fiber tenacities to be indicative of what may be anticipated with respect to ballistic resistance, then one of the experimental constructions, namely, the shell/core fiber prepared from nylon and polypropylene (BF-101S-D-1) is worthy of further consideration. Fabric made from this yarn showed the same V_{50} as the nylon control even though its tenacity was only 80% as high. Thus, the concept of increasing total energy absorption by adding a delaminating effect within or along these complex fibers to the basic strength of the fabric may have been demonstrated by this particular case. It is conceivable that refinements in processing to improve the overall tenacity could lead to a fabric with superior ballistic resistance.

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13. ABSTRACT

Experimental fibers have been spun from intimate mixtures of nylon, polypropylene and polyester plastics (biconstituent type) following an extensive screening program to determine compatibilities. Fibers of the bicomponent type (shell/core and bilateral) have also been spun from several combinations. A total of six combinations of both types plus a 100% nylon control have been spun in sufficient quantity to be woven into ballistic fabric and tested on a firing range. All seven fabrics showed an appreciably lower ballistic resistance (V_{50}) than a standard nylon ballistic fabric but processing difficulties during the spinning operation may have been responsible, at least in part, for the poor showing. When comparisons are made within the series there is evidence that a shell/core fiber made from nylon and polypropylene could be developed into an improved ballistic fabric.

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