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TRIAXIALLY WOVEN FABRICS OF KEVLAR, DACRON POLYESTER AND HYBRIDS OF KEVLAR AND DACRON POLYESTER

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To provide data for possible LTA (Lighter Than Air) application, four triaxially woven fabrics were made using yarns of: (1) Kevlar aramid, (2) Dacron polyester and (3) hybrids of aramid and polyester. The woven triaxial fabrics were coated with urethane. The material samples were characterized by removal and test of specimens. The test matrix included creasing and environmental conditioning tests.

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The results of this evaluation indicate that some damage is done to the Kevlar aramid yarns during processing through the triaxial weaving process. The all aramid sample yielded the highest breaking strength when normalized on the bases of the uncoated fabric. Creasing, however, had a deleterious effect on the strength of the aramid warp samples.

On the basis of all around performance, the all aramid sample and the hybrid of polyester warp and aramid fill construction would be the best choices for use in LTA applications. Kevlar aramid fabrics, however, must avoid critical compressive loading which is accentuated at any small radius of curvature or point of concentrated pressure.

SUMMARY

To provide data for possible LTA (Lighter Than Air) application, four triaxially woven fabrics were made using yarns of (1) Kevlar aramid, (2) Dacron polyester and (3) hybrids of aramid and polyester. The woven triaxial fabrics were coated with urethane. The material samples were characterized by removal and test of specimens. The test matrix included creasing and environmental conditioning tests.

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INTRODUCTION

Recent interest in the Navy has developed concerning new uses for LTA vehicles such as reconnaissance, transportation, heavy lift operations, etc. Historically, the Navy abolished its LTA Program in 1961. No rigid airship has been built in the United States since 1934. The last non-rigid built for the Navy was constructed in 1959 - 1960.

Airships are pressure sensitive vehicles. Consequently, there is usually a need for at least part of the airship, whether rigid or non-rigid, to be capable of volume change and to be constructed of flexible material, reference (a). The classical rigid airship consisted of a framework structure, an external cover, interior gas cells and auxiliary structures. The external covers were cotton and acetate doped fabric to provide a smooth aerodynamic shape and to prevent environmental degradation of the airship system, reference (b). The non-rigid airship incorporates the load carrying structure and the external cover in a single flexible unit, stabilized by interior pressure and using air filled ballonets for pressure control. The following is a brief summary of yarn and fabric geometry usage for LTA applications.

Yarn Usage

Cotton and Fortisan yarns dominated early LTA applications for flexible units. These yarns became obsolete with the introduction of high strength nylon and Dacron polyester yarns. In addition to higher strength to weight, nylon and Dacron showed improved resistance to abrasion, heat and mildew.

A more recent development in yarns for high strength to weight applications are the aramids. Kevlar 29, one of the aramids, has been the most advanced structural yarn being used in aerostat applications. Typical mechanical properties of twisted Kevlar 29 are shown compared with other organic yarns in Figure 1. Kevlar has twice the strength of most organics.

Stress strain curves for most organic fibers show a linear portion at lower stresses, and non-linear at higher stresses. Kevlar is an exception in that it's stress strain curve is linear regardless of stress.

Materials which show no linearity on their stress-strain curve are not acceptable for use in the construction of airship envelopes. Uncontrolled stretch results in distortion of the envelope shape which affects the aerodynamic performance of the airship. It also produces severe problems with the rigid components which are attached to the envelope such as nose stiffening, suspension systems, cars, fins, etc. This is the reason why Dacron polyester yarns are usually preferred to the use of nylon; nylon has better tensile strength but greater stretch. The polyester fabrics, such as Dacron, demonstrate satisfactory elongation and are standard for use in (Goodyear) airships and tethered balloons today.

Fabric Geometry

Bias Ply Construction

Most woven fabrics are biaxial structures wherein two systems of yarns intersect and interlace at right angles to one another. These orthogonally woven fabrics are effective in transmitting stress in their respective directions, warp and fill, but not in any diagonal or bias direction. Such weaves are considered to be dimensionally unstable. The usual solution to providing the dimensional stability required for LTA applications was to bond two or more plies of fabric together such that one is oriented 45° to the other. This places a major axis in all directions and dimensional stability is achieved.

High Modulus Film With Single Ply

Another material construction which can be used to increase the dimensional stability of an orthogonal base fabric involves the lamination of an unsupported high modulus film to a base substrate. In this construction, the high modulus film is analogous to the bias ply previously described and must lock the fabrics rectangular weave geometry and prevent yarn slippage and distortion. The film provides a tensile member in the bias direction. To date however, only the higher efficiencies obtained from closely spaced filamentary materials, such as textiles appear to be satisfactory for non-rigid airships.

Triaxial Construction

A recently patented development, triaxial weave, provides for transfer of stresses in the bias direction with use of three systems of yarn. The three yarns intersect and interlace at 60° angles with one another and provide for a more uniform distribution of load during deformation, reference (c). The three systems of yarn are intermeshed in a single fabric to provide quasisotropic properties. Theoretically, this should make possible the construction of a single ply envelope.

DEVELOPMENT WORK

Potentially, Kevlar 29 and triaxial weave are very promising candidates for LTA applications. On this basis, they were selected for development work.

A series of candidate fabrics were fabricated for use in aerostats and partially tested under contract to N. F. Doweave, Inc. Doweave Inc., is no longer in business. Currently, Gentex Corp., using similar equipment is capable of weaving triaxial fabrics.

With a view toward the simplification of fabric design, it was decided to include two current production fabrics in the study; an all polyester (Dacron 52) sample in the basic weave pattern and an all aramid (Kevlar 29) sample in the biplain weave, reference (d). Two new constructions, both hybrids of polyester and aramid yarns, were made, one each of the basic weave and the biplain weave. Mechanical and physical tests were conducted by personnel from this Center and the Philadelphia College of Textiles and Science.

Triaxial Basic Weave

The basic weave, the simplest triaxial configuration, consists of two warp yarns in the machine direction. These are not interwoven but one lies over the other, Figure 2. The fill yarn (transverse direction) passes over one set of warp and under the other set thereby locking the yarns together in triangular intersections. The hexagonal holes in this open weave are about twice the yarn diameter.

Triaxial Biplain Weave

In the biplain weave construction, less porosity is achieved by weaving the horizontal or fill yarns over and under the two sets of warp yarns, Figure 2. The biplain weave may be considered one of the triaxial counterparts of the traditional plain weave, in which the fill yarn is woven over and under each warp yarn, one by one, reference (c). The biplain construction achieves closed structural fabric with exceptional dimensional stability.

Candidate Materials

Four candidate materials were woven on full scale production equipment. The fabric samples were identified as follows:

BP21P is a biplain triaxial fabric composed of 210 denier Dacron 52 yarns.

BP21PK is a biplain triaxial fabric with 210 denier Dacron 52 warp yarns and 200 denier Kevlar 29 filling yarn.

B20K is a basic triaxial fabric composed of 200 denier Kevlar 29 yarns.

B20KP is a basic triaxial fabric with 200 denier Kevlar 29 warp yarns and a 210 denier Dacron 52 filling yarn.

A description of the fabric samples is given in Table I.

Coating of Candidate Materials

Fabrics were coated with a urethane transfer film by Reeves Brothers Inc. The weight of the urethane was approximately 3 - 4 oz./sq. yd.

Test Methods

Tensile Strength

Fabric tensile strength was determined on uncreased, and creased specimens in the three major axes: machine (90^{o} to fill), transverse (filling) and in the bias direction using the grab breaking strength method (Federal Specification CCC-T-191b, Method 5100). Grab test specimens measure four inches by six inches and were tested with one inch jaws in an Instron Tensile Tester. Normally, textile tensile strength is tested with one inch by six inch specimens. In directions other than true warp or fill however, tensile deformation leads to anamolous results. For example, in the triaxial weave, very few yarns, if any, are gripped by both jaws during testing. Massive slippage occurs in addition to the closing of the trellis configuration at yarn intersections.

Crease Test

The crease test consisted of placing a Z fold in a tensile specimen. The Z fold consisted of two folds in an accordian fashion, with a one inch spacing between the folds. Each fold was a 180^{o} crease parallel to the four inch width of the tensile specimen. Each crease was individually "pressed in" by placing the test specimen on a flat surface and rolling the crease with a ten pound rod. This was done a total of 100 times on each specimen.

Environmental Exposure

The environmental exposure test consisted of 30 days at 95% relative humidity and $140^{o}F$ temperature.

Tear Strength

Tear strength was measured in the machine and crosswise directions by both the tongue (ASTM Standard D2261) and trapezoid methods. Tongue tear test specimens, six inches by eight inches, were cut so that the yarns to be ruptured lie in the short direction. A cut three inches in length is made along the longer centerline of the test specimen. This cut produces two-three inch by three inch tongues which were placed in the upper and lower jaws of an Instron Tensile Tester.

Trapezoid tear specimens, 8-1/2 inches by 5-3/8 inches, were cut with a one inch slit placed midway along the longer direction. The sample is inserted on the bias between the jaws of the Instron Tensile Tester. This test is entirely of a tension type and has little meaning in terms of the practical tearing characteristics of the fabric.

TEST RESULTS AND DISCUSSION

Tensile Strength

A comparison of breaking strength values for the triaxial fabric samples is given in Table II. The breaking strength is stated in lbs./in. (breaking load in pounds divided by jaw width). The breaking strength of the machine and transverse specimens of the all Kevlar sample (B20K) are about equal; 206 lbs./in. compared to 201 lbs./in. The bias strength is approximately 50% of these values; a marked improvement over biaxial fabrics which have practically no bias strength.

The replacement of the aramid fill yarn with a polyester yarn markedly affects the tensile strength in the transverse direction. The tensile strength decreases from 201 to 81 lbs./in., 60% decrease. The all polyester sample, BP21P, yielded the highest relative tensile strength of 333 lbs./in. in the machine (warp) direction.

Normalized breaking strength Table II, adjusts the data for differences in the total fabric weight and is presented in lbs./in. divided by oz./yd.^{2}

Tensile properties depend primarily on fiber properties. Because the base fabrics are not the same weight, the breaking strength is also normalized to adjust for differences in the base fabric weight and is presented in Table II. The anticipated effect of the higher strength to weight ratio of the aramid yarns is here reflected in the higher tensile strength of the basic triaxially woven fabrics (B20K and B20KP). The magnitude of this effect, however, is of a lesser degree than expected. The aramid Kevlar has over twice the breaking strength of polyester. The all aramid sample however is only 47% stronger than the all polyester sample; 137 lbs./in. compared to 93 lbs./in.

It is theorized that damage occurs in the passage of the aramid warp yarns through the triaxial weaving process. Little if any damage occurs in the manipulation of the polyester warp yarns. As a result, the initial advantage of the inherent high strength to weight ratio of the aramid yarn over the polyester yarn is partially lost during weaving.

The aramid warp samples show a greater loss in strength due to creasing. The strength of the polyester warp samples are unaffected by creasing but show approximately a 30% reduction in strength after environmental exposure.

Tear Strength

Tear properties depend not only on fiber properties but also on other factors such as fabric construction, coating, adhesion, etc. Because of the variations in these factors in this study, it is difficult to make a direct comparison in the interpretation of the results. Tongue and trapezoid tear strength is reported in pounds of tearing force or load. The tear strength data are also normalized to adjust for differences in fabric weight and are reported in pounds per ounce per square yard, Table III.

The aramid warp fabrics exhibit much greater resistance to tear than the polyester warp fabrics regardless of tear technique. The sample constructed of a polyester warp and Kevlar filling (BP21PK) would appear to be a compromise between the low tear strength of the all polyester sample and the higher values of the all Kevlar sample.

CONCLUSIONS

The results of this evaluation indicate that some damage is done to the Kevlar aramid yarns during processing through the triaxial weaving process. The all aramid sample (B20K) yielded the highest breaking strength when normalized on the bases of the uncoated fabric. Creasing, however, had a deleterious effect on the strength of the aramid warp samples.

On the basis of all around performance, the all aramid sample (B20K) and the polyester warp and aramid fill construction (BP21PK) would be the best choices for use in LTA applications. Perhaps Kevlar warp yarns can be sized and lubricated for improved manipulation through the triaxial machine. In addition to proper sizing, however, Kevlar aramid filaments must avoid critical compressive loading which is accentuated at any small radius of curvature or point of concentrated pressure.

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TABLE I

DESCRIPTION OF TRIAXIAL BASIC AND BIPLAIN FABRIC SAMPLES

	Basic		Biplain	
	B20K	B20KP	BP21P	BP21PK
Areal density, oz/yd.^{2}				
Base Fabric	1.5	1.6	3.6	2.7
Finished Fabric (Coated with Polyurethane)	4.35	4.86	7.5	6.25
Ends/inch yarns, denier	19R, 19L 200 Kevlar[1]	19R, 19L 200 Kevlar	40R, 40L 210 Dacron	37R, 37L 210 Dacron
Picks/inch yarns, denier	18 200 Kevlar	15 210 Dacron[2]	40 210 Dacron	26 200 Kevlar
Yarns/in.[2]	56	53	120	100

[1] Kevlar 29

[2] Dacron 52

TABLE II

BREAKING STRENGTH OF TRIAXIAL FABRIC SAMPLES

	B20K U	B20K C	B20K T	B20KP U	B20KP C	B20KP T	BP21P U	BP21P C	BP21P T	BP21PK U	BP21PK C	BP21PK T
Breaking Strength												
Machine	206	155	170	221	195	201	333	337	235	260	286	179
Transverse	201	127	104	81	80	75	198	204	187	185	205	195
Bias	104	-	-	125	123	-	252	235	-	235	273	-
Average	170	141	137	137	133	138	261	259	211	227	255	187
Fabric Weight (oz./yd.^{2})												
Base Fabric	1.5			1.6			3.6			2.7		
Coated Fabric	4.35			4.86			7.5			6.25		
Normalized Breaking Strength (lbs./inch)/(oz.yd.^{2} - Base Fabric)												
Machine	137	103	113	138	122	126	93	94	65	96	106	66
Transverse	134	85	69	51	50	47	55	57	52	69	76	72
Bias	69	-	-	78	77	-	70	65	-	87	101	-
Average	113	94	91	88	83	87	72	72	59	84	94	69
Normalized Breaking Strength (lbs./inch)/(oz./yd. 2 - Coated Fabric)												
Machine	47	36	39	46	40	41	44	45	31	42	46	29
Transverse	46	29	24	17	17	15	26	27	25	30	33	31
Bias	24	-	-	26	25	-	34	31	-	38	44	-
Average	39	32	32	30	27	28	35	34	28	36	41	30

U - Uncreased
C - Creased
T - After 30 days exposure to 95% R.H. and 140°F

TABLE III

TEAR STRENGTH OF TRIAXIAL FABRIC SAMPLES

	Tongue Tear				Trapezoid Tear			
	B20K	B20KP	BP21P	BP21PK	B20K	B20KP	BP21P	BP21PK
Tear Strength (lbs)								
Machine Direction	35	39	10	40	42	46	28	37
Crosswise Direction	33	19	10	39	35	54	48	73
Average	34	29	10	40	39	50	38	55
Coated Fabric Weight (oz./sq. yd.)	4.35	4.86	7.5	6.25	4.35	4.86	7.5	6.25
Normalized Tear Strength (lbs./(oz./sq.yd.))								
Machine Direction	8.0	8.0	1.3	6.4	9.7	9.5	3.7	5.9
Crosswise Direction	7.6	3.9	1.3	6.2	8.1	11.1	6.4	11.7
Average	7.8	6.0	1.3	6.3	8.9	10.3	5.1	8.8

Tear strength readings are the highest peak values in each of the first five centimeters of the Instron chart according to ASTM Standard D2261.

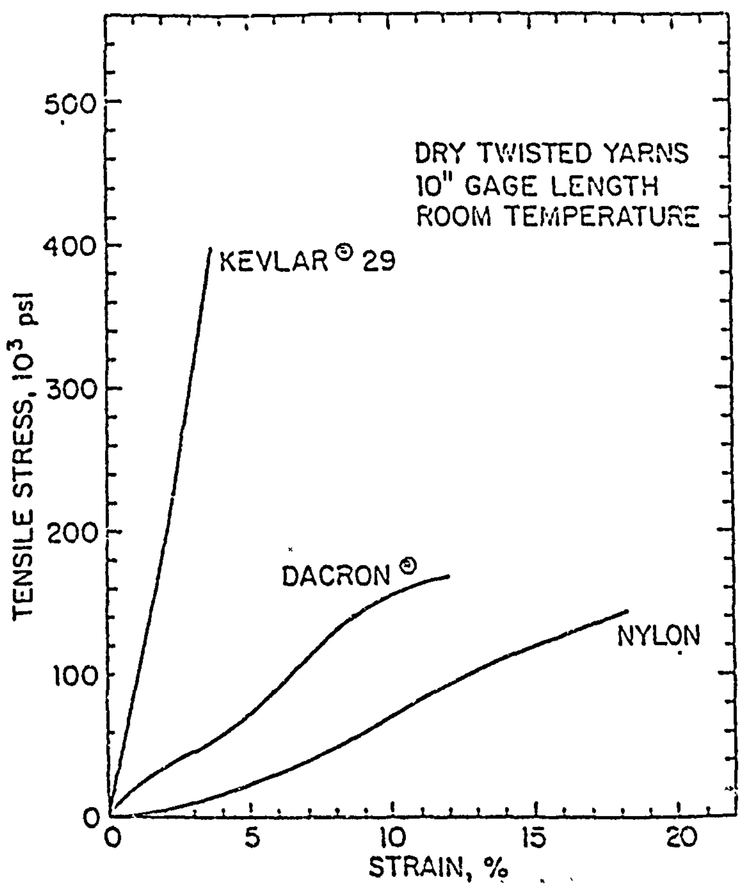
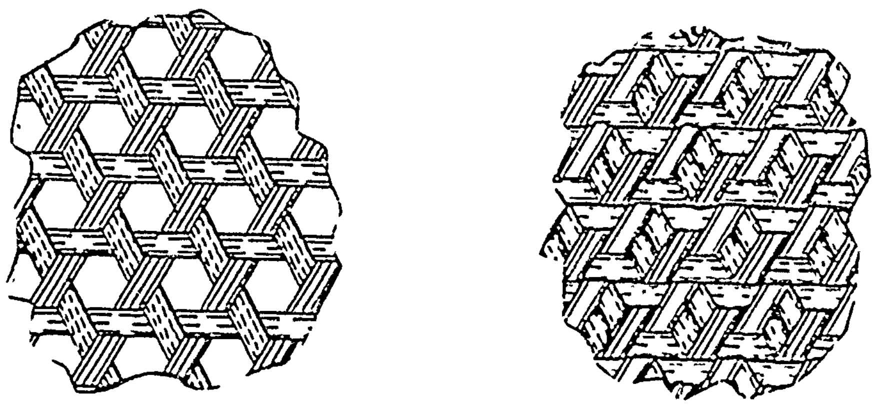


Figure 1. Yarn Stress Strain Curves of Dacron, Nylon and Kevlar



BASIC

BIPLANE

Figure 2. Basic and Biplane Triaxial Weave

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