LIGHTWEIGHT AIR SUPPORTED RADOME

MATERIALS DEVELOPMENT

"DACRALON"

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The work on radome materials development mentioned here was accomplished principally through contract with DeBell and Richardson, Inc., Hazardville, Connecticut, where Mr. Mac Mead, Mr. Wayne Turner and Mr. Fred Wiley were responsible engineers. Some prior work with Cornell Aeronautical Laboratory and Mr. Walter Bird is significant and is mentioned for its background importance. This development was administered through the Materials and Miniaturization Engineering Section of the Rome Air Development Center where Mr. James L. Briggs and Mr. S. C. Nilo were cognizant engineers. The author was fortunate, serving as Project Officer, and it is with the kind permission of the aforementioned that I proceed.

INTRODUCTION

The purposes of this development was to improve the performance of air supported radomes, principally by lightweighting the current radome techniques that use rubberized fabrics. The benefits were to be (1) greater mobility for ground radar systems and (2) reduction of the overall cost of radomes thru use of less materials, less fabrication time, less effort in handling and installation, less maintenance and longer service life in such structures.

In order to accomplish these goals the following requirements would have to be realized.

(1) A yarn of higher tenacity or strength than those previously available was needed for the strength compared to weight necessary in lightweighting.
(2) A yarn of improved resistance to the elements was required.
(3) Proofing or rubber coating materials of greater weather resistance than those presently known were required.
(4) Proofing materials were needed that were capable of stronger joints than those attainable by present techniques and materials.
(5) Designs utilizing more economic engineering were also required.

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These requirements and their engineering realization become the development contract undertaken by DeBell and Richardson, Inc., Hazardville, Connecticut on the 4th of January, 1954.

HISTORICAL BACKGROUND

The historical background for this development has a number of significant events, a few of which we might mention here. In 1946 the Air Defense Command and the Tactical Air Command imposed wind, temperature and ice loading requirements on radar systems that was about 400% of the design load for the antennas and pedestals. The need for environmental control was obvious.

Cornell Aeronautical Laboratory, Buffalo, New York, suggested to the Air Force in the fall of 1946 that an air supported radome could be used. Rubberized fabrics that were strong and flexible and fairly transparent to microwave energy at S and L band were to be fabricated into a truncated sphere that was internally inflated against external wind loads. A prototype structure, 50 feet in base diameter for the AN/CPS-6B Radar Set, was built by Cornell and erected in June, 1948 at Buffalo.

At the time of a demonstration, this prototype was damaged. It was repaired, re-erected and saw satisfactory service use for two years, which is fairly well for a prototype. The material used there was Fiberglas cloth proofed with Neoprene rubber. The need for improved materials arose early. Radomes using Fortisan rayon and Nylon in conjunction with Neoprene rubber were also proposed and these service tests items were manufactured. All were acceptable.

However, some shortcomings in performance were beginning to appear. Tear resistance was regarded as insufficient. Weathering had abominable effects on radomes in many cases. Materials were weakened at creases and folds. Artic use required a white structure. Radomes were heavy and bulky. Installation was not easy. In order to gain life against the elements in mid 1950, it was necessary to "beef up" the materials which detracted from reduced costs, improved electrical performance and related interests.

In 1951 Cornell undertook an Air Force contract to investigate improved materials for air supported radomes. Among the results there were two factors that were to be of great significance in the work that was to follow. It was learned that Hypalon synthetic rubber had promise for very good weather resistance, but it would require extensive development work before it could be commercially utilized in radome applications. Hypalon is a pigmented synthetic elastomer derived from chlorosulfonated polyethylene. The second factor was the possibility that the Dacron polyester type yarn could be made to have a rather high strength for its weight by hot-stretching or drawing the yarn. This high strength to weight ratio is important for lightweighting. But up until 1953 yarn drawing results had not been satisfactory. Any improved properties that were imparted to the yarn by drawing were lost in time recovery, or by shrinkage at ordinary fabric processing temperatures.

Air supported radomes could, in 1953, be made from Neoprene proofed fabrics of Fiberglas, Fortisan rayon, Nylon or Dacron. In the proofed or rubberized form, all of these materials had a unit strength of about 10-12 pounds/inch for each ounce/square yard of material. Each ounce of weight per square yard represents about 1 mil of thickness. A fifty foot radome uses a fabric of about 35 ounces to the square yard and it weighs over a ton. Weather resistance was insufficient. However there were serviceable items placed in Air Force inventory, which no doubt has played some part in our national security. However, with an eye to further improvement, it appeared desirable to try to reduce costs and to improve electrical and physical performance for the long run by lightweighting and by improving weather resistance. This would result in simplified handling and installation, minimized maintenance, greatly extended service life, reduced costs in fabrication and materials as well as providing better electrical and tactical performance of radar systems.

DEVELOPMENT OF DACRALON

The word "Dacralon" has been used in referring to proofed fabrics consisting of Hypalon rubber and Dacron fabric as further explained here. The problems confronting the development of lightweight weather resistant materials for air supported radomes were primarily in the field of high polymer technology and utilization, and in the engineering design of such radome structures. Certain properties of high polymers and the techniques for their commercial processing as applied to synthetic fibers and elastomeric coatings became the main area for this development with DeBell and Richardson, Incorporated.

It appeared that continuous filament Dacron showed the most promise in high tenacity and weathering ability. The problem was how could the yarn be further drawn or stretched to permanently gain the desired tenacity in a stable form thru processes that were adaptable to commercial production. The Hypalon synthetic elastomer had indicated very good weather resistance in an advantageously pigmentable and curable rubber stock. The problem was to adapt Hypalon to this requirement, especially in regards to adhesion, cure and fire resistance thru processes adaptable to commercial or production coating of the Dacron fabric. Weaving was to be a problem for the fabric required a strength to weight ratio that was unheard of in the industry. Since the lightweight, proofed fabric for the development was to be about six ounces/square yard total weight, the Dacron base fabric was seen as weighing 2 1/2 to 3 ounces and pulling at least 160 pounds/inch in tension before break. Design considerations for such structures involving the correlation of fundamental properties with radome performance, the evaluation of rip resistance, the plying of fabrics, the reduction of calculated strength in weaving and coating operations became important areas of the development.

YARN -

First development efforts concerned the yarn. Initial experiments produced yarn tenacities over eight grams/denier whereas the yarn as purchased had a tenacity of around six. The yarns were drawn or hot-stretched at about 400-420 F by contacting a hot plate and then "heat-set" by remaining at some elevated temperature for varying lengths of time as an effort to anneal the yarn. Fortunately a valuable discovery came early in the development. As the extent of drawing or stretching is increased, the time of heat setting or annealing became less and less important in removing any induced or built-in mechanical stresses. At 15% or more drawing, the heat-setting time appeared to no longer affect the residual shrinkage. Once the drawing is beyond 10 percent, annealing time from next to nothing up to 45 seconds had little or no effect on residual shrinkage. This discovery helped pave the way towards commercial production, for processing time in annealing was practically eliminated. The small shrinkage problem was thus transferred from the yarn to the fabric where familiar pre-shrinking techniques could be applied.

The polyethylene terephthalate resin used to manufacture Dacron yarn is probably as pure as possible for the production melt spinning process. Even then, some impurities, gel spots or gas bubbles are present and these points of discontinuity become areas of stress concentration under filament tension. It is generally agreed that filament breakage occurs at points of stress concentration at a much lower overall strength value than can be attributed to inter- and intra-molecular forces. When flaws are oriented in the stress field as is the case in hot stretching or drawing, they are less likely to facilitate premature failure for some stress can now be transmitted around the oriented flaws.

In experiments that followed, it was indicated that the drawing contact time was not nearly as important as the temperature level or the extent of drawing. Apparently one must go far enough to pull the yarn right thru its old elastic boundaries into a new crystalline alignment to gain any significant benefit by drawing. It was also discovered that the permanence of the increase in tenacity was better with yarn that had been freshly melt spun or manufactured, than with old yarn from the same polyethylene terephthalate resin. It could be that some of the crystallinity induced into the filament in the original fiber forming process was slowly replaced in time by more amorphous areas with subsequently more elastic behavior, which lowered the modulus and had to be overcome in the stretch-drawing operation. Some re-orientation of polymer molecules and of crystallite areas were no doubt brought about by the stretching, but all of this gain could not apparently be retained by the extremely high viscosity at room temperature and the yarns lost some orientation in time. Most of the increased tenacity could be accounted for by the reduced crossed section of the drawn yarn with its lessened denier. Yarn breaking strength was generally improved somewhat by the stretching which would indicate some improvement in filament orientation. The contribution of stretching or drawing to crystallinity and the effect of this on tenacity and yarn strength was not fully determined for unfortunately, such an evaluation was beyond the scope of the immediate problem.

Another significant processing discovery was made wherein by raising the drawing temperatures to just under the melting range of the polymer, 475 F in this case, one could attain tenacities of nine and over at only 14% draft or draw. Tenacities of nine were attained also at 28% draft. So it was an important finding that as long as the extent of drawing was sufficient to gain some mechanical orientation, it was far easier to process the yarn nearer to its melting range in order to gain strength without inducing filament breakage.

First samples of woven fabric were rather loose, or were too tight and it appeared desirable to have a yarn of intermediate denier. The DuPont Company was approached to supply a yarn of 300 or 150 denier. Sixty pounds of 162 denier, 68 filament, Type 5100 Dacron yarn were obtained with a tenacity of 6.4 and 9% elongation. The somewhat different properties of this yarn was believed to be due to a greater amount of drawing of the yarn by DuPont in the filament manufacture. After some minor difficulties, this yarn showed great promise for its high strength to weight ratio, and it was decided to use this 160 denier material.

A difficulty arose in that the DuPont Company decided not to make the 160 denier yarn available as a commercial item at the time that materials were being procured for the fabrication of the prototype structure, in the fall of 1955. It was then necessary to revert to 220 denier yarn, in a slightly heavier weave to avoid having any part of the development not commercially available.

WEAVING -

In weaving there were many difficulties to overcome in using flat, low twist yarns in a loose, flat, lightweight fabric. Filament breakage, lack of sizings, uneven weaving and poor handling properties were eventually overcome much to the credit of Stern and Stern Textiles, Inc., Hornell, N. Y.

First fabrics of 47 x 47 count, 220 denier yarn come off the loom with snags and slubs as well as reed marks and wrinkles. Fabrics with a 2 x 2 taffeta weave construction were woven with more success, especially by weaving with dual warp yarns and weaving two picks in the shed, which involves the passage of two fill shuttles through the warp shed for each motion of the heddles. However, the resultant fabric was too loose or sleazy for the coating operation. A compromise 2 x 1 taffeta weave was not entirely satisfactory in the desired weight. The need for a 150 or 300 denier yarn, as mentioned before, became evident. But since the desired yarn could not be obtained for production weaving and coating, the 220 denier yarn was used in a fabric that had a breaking strength of about 450 lbs/inch and a weight of about seven ounces/square yard. This fabric met the light weight requirement. The fabric construction and weight could be modified to fit the strength requirement of its intended end use.

COATING -

The use of Hypalon was decided for it possessed the desired properties, especially weather resistance. Of first consideration in this area was the use of precoats for (1) possibly enabling easier handling, (2) promoting adhesion of coating and (3) possibly reducing moisture absorption.

Precoats of MDI (4, 4' - diisocyanatodiphenyl methane) were seen to promote adhesion of Hypalon to Dacron fabric, particularly in lap joints at elevated temperatures. Fabrics were precoated by slashing thru a 4% solution of MDI in toluene and then coating as soon as solvent was lost to avoid moisture pick-up by the MDI. The adhesion was satisfactory in that peel strengths of about 10 lbs/inch were seen in cemented lap joints while the adhesion and shear strength was greater than fabric strength for the light weight fabrics.

Initial elastomer formulations for the Hypalon coating stock were those recommended by the supplier. A two component system was used, one containing the ball milled dispersion of elastomer, stabilizers and solvent, while the second part contained vulcanization accelerators, curing agents, pigments, etc. in a compatable dispersion. Laboratory coating runs gave satisfactory results that led to production coating techniques. The optimum cure of Hypalon was determined by tensile tests on unsupported films of cured elastomer. Commercial coating techniques have been used throughout the development.

Curing presented many problems, for the residul shrinkage often caused puckering and wrinkling while most interleavening agents promoting blocking of the coating during cure. Surface stainings and off-colors were manifold. However, colors showed little change after considerable exposure in weatherometers. Some modifications of the coating were needed. The accelerator MBTS, mercaptobenzothiazyl disulfide, was replaced with double amounts of Thiuram M, tetramethylthiuram disulfide,to give a more controllable cure. Lead acetate, used for acid buffering in cure, was eliminated to improve whiteness. This reduced the pot life of the coating but to no major consequence. Flame resistance in heavier fabrics had to be improved thru the use of more antimony trioxide at the expense of some titania pigment.

Normal coating technology lead to the incorporation of the isocyanate adhesion promoting compounds into the coating material at least for the first pass of the coating application. An outgrowth of this modified first coat was the use of a latex or a solution of unpigmented Hypalon rubber and MDI in toluene to impregnate the fabric and fill the voids and interstices with elastomer in an effort to reduce moisture absorption without loss of adhesion and thus increase radar transmission under rain exposure conditions. Moisture absorptions was cut to 1% or less even with immersed, unsealed edges. Wet transmission at about 10,000 Megacycles per second was 97% minimum; then dry it was 99% in such a Dacralon proofed fabric.

The joint or seam cement formulation was modified to effect a faster, stronger cure. The Thiuram M and phthalic acid which had been recommended were replaced with Neoprene accelerator No. 22, (2 - mercaptoimidazoline) and with

DOTG kicker (diorthotolyl quanidine). The coating dispersant was replaced with toluene solvent for a better cement. Tri basic lead maleate was the curing agent used to effect cross linking.

Two inch lap joints were cured in an oven for one hour at 250 F and generally had lap strength in excess of 200 lbs/inch. A loop of the coated, three ounce fabric usually broke at an area separated from the joint. A two hour cure enabled the joint to withstand four hours at 160 F under 120 lbs/inch load.

At this stage a significant achievement was noted since there had not previously been a cement available that would give satisfactory bonding of Hypalon coated surfaces especially at elevated temperatures. Joints had serrated edges with one inch deep V slots and the serrations were superposed to provide a continuous two inch lap joint.

Another significant discovery was that this proofed fabric, Dacralon, and its cement as developed, would lend itself to "heat sealing" techniques. Such a technique in proofed fabrics can save time and effort in fabrication, increase design latitudes and could allow new applications for the Dacralon proofed fabric. The Hypalon cement can be painted onto the surfaces to be joined and then allowed to air dry. Ten to fifteen minutes is generally sufficient for loss of solvent, however, satisfactory joints can be attained even if the "painted" surfaces are not joined for 72 hours. The surfaces are then sealed together with a hot iron. The joint at this stage is not completely cured, however, there is a high peel strength and the shear strength was seen to exceed 200 lbs/inch in a two inch serrated lap on a loop of five ounce fabric. The final and complete cure can be performed on the entire package in an oven.

TESTS AND DESIGN CONSIDERATIONS

Throughout this development numerous tests were performed to see what had been accomplished against specification requirements and for future guidance. Most tests were those common to the proofed fabrics trade and generally followed ASTM procedures. Strengths are reported on the ravelled strips and not by the grab method.

Burst tests are designed to give a strength figure for radome design. Fabric was clamped to a flat plate and inflated till it burst, providing a stress value according to the radius of curvature of the distorted fabric. Three ounce Dacron, coated with four ounces of Hypalon, (seven ounce Dacralon) was seen to have a burst strength of 120 lbs/inch and was regarded as satisfactory.

Weatherometers, sun lamps and natural weathering indicated that about three mils of Hypalon in a good coating was a minimum, for this permitted but a few percent loss of strength after extensive weathering.

Resistance to ripping in air supported structures is a valuable aspect, but it is difficult to accomplish and even more difficult to evaluate. Tongue and trapezoidal tear methods did not apply to biaxially stressed fabrics.

Puncture tests of samples stressed over a drum were difficult to correlate with radome performance. DeBell and Richardson conceived and built a device for applying a biaxial stress field that was not unlike a trampoline. In radomes of any size, a "test panel" can for some purposes be treated as a biaxially stressed, flat plate where the sample is progressively slit in the center until ripping ensues.

There arose in this regard a diametric situation where joint strength and rip resistance had requirements in opposite directions, since the ripping resistance in radomes seemed to require loose yarns of high strength that could move relative to one another, while the joints required extremely good adhesion of the yarns to coating. Since there was room for improvement in yarn strength and denier per end for each fabric, it appeared more logical to compensate for tearing characteristics through yarn strength and/or denier rather than sacrifice the unprecedented adhesion of coating and joints. Dacralon type fabrics performed better than Neoprene-Nylon on a given weight and construction basis.

The safety factors used in air supported radomes could be reduced from their value of about four or five, for the uncertainties in weathering effect and dead load fatigue could be greatly reduced in Dacralon fabrics.

Dacralon has an exceptional property in potential regard to accomodating stresses in a radome. The proof has an initially high modulus compared to related materials which gives its dimensional stability at normal conditions. Just above normal loads, Dacralon can yield elastically at medium stress levels to relieve stress concentrations. At higher loads the modulus is again high and continues high until break. The breaking strength is unpreceedented in materials of such light weight.

The unit strength of Dacralon proofed fabric is over 25 lbs/inch for each ounce of total weight as compared to about 12 for other types. In the bare uncoated fabric, there is breaking strength of about 65 lbs/inch for each ounce of fabric. Computing a cross-section and tensile from breaking strength, Dacralon has a tensile strength of over 25,000 psi even in thick samples. Twenty mil Dacralon pulls about 500 lbs/inch before breaking. Elongation is about 10-15%. Filaments of the hot stretched or drawn Dacron have a tensile strength of about 160,000, being considerably higher than most organics. Thus it is seen that Dacralon has an exceptionally high strength to weight ratio.

APPLICATIONS -

An extension of the work with DeBell and Richardson called for a prototype radome that would incorporate these improvements. It was decided to use a single ply Dacralon for this test structure with a crown of two ply Dacralon. The principal techniques of conventional radome design were utilized with those modifications necessary to adapt this new material to a prototype. This radome with 35 feet base diameter is now being fabricated by DeBell and Richardson, Inc. at Hazardville, Connecticut.

The heat sealing technique is being used in this fabrication. Each gore of fabric is being joined to the next by positioning and pressing together the lap with a hot iron on a contour form. The crown, crown plate, windows, etc. are being incorporated into the structure by similar techniques. The completed radome will then be cured as a whole in an oven to effect complete cure of the joints.

The Dacralon proofed fabric for the prototype weighs about 14 ounces/square yard. Such a Dacralon fabric is probably heavier than necessary for it would pull at least 450 pounds/inch before breaking. However, its use was considered expedient in this prototype for there could be further weight economics in subsequent items manufactured against specific end use requirements. Service life under normal conditions of five years minimum is anticipated. It is expected that the prototype fabrication will be completed for delivery to the Air Force this summer. A shipping container of heavier Dacralon material for the radome is also being fabricated.

Of concurrent interest in this regard, there was also developed through Rome Air Development Center by the B. F. Goodrich Company a radome maintenance coating using a modified, Hypalon based paint. The radome coating has been designated "Radolon" and is a blend of Hypalon and polyethylene in an air drying paint that can be brushed or sprayed. It is non-blocking, quick drying and can be made in a variety of permanent colors. It has excellent weather resistance, especially against ozone while samples are under stress. It has good shelf life and good adhesion to a variety of surfaces including laminar, reinforced plastics.

FURTHER USES FOR DACRALON

This Dacralon proofed fabric could lend itself to other designs and structures. Its use as a protective covering over framed structures of "geodesic" design might be interesting because of its strength and weathering ability as well as colorability and its fabrication techniques. The heat sealing technique of Dacralon could be utilized for fabricating a variety of air supported shapes and structures including inflated structural modules and large completed structures. Where necessary this technique might be used for on-the-spot fabrication of rather large structures where radiant energy of a variety of types including possibly infrared, microwave, gamma and beta energies might be used for curing the joint materials.

Radar antennas have been made of air inflated structures. Dacralon might be useable there for its high modulus, durability and fabrication techniques. Extremely high frequency radar, up to 30,000 megacycles per second, might use the Dacralon for its light weight or thinness, its dielectric properties, and moisture resistance. On the basis of preliminary tests, the dielectric constant for Dacralon approximates 3.5 and the loss tangent is about 0.02 at X band. Radar that requires minimum beam distortion and/or power reflection might possibly use Dacralon radomes.

There could be a variety of other applications that could benefit from the weather resistance, moisture proofness and light weight of Dacralon. Commercial tarpaulins and ice or wing covers might be possibilities. Portable housings, tents and shelters could be considered. Protective clothing might utilize the lightweight Dacralon for its resistance to moisture, acids and oxidizing agents and its impermeability. Possible use in airships, fuel cells, materials packaging containers and life rafts may be realized. The yarn or fabric may well be used for reinforcings in various plastics and rubber products where its high modulus, moisture resistance and chemical resistance could be advantageous.

In conclusion, there has been developed a proofed fabric of outstanding strength to weight ratio, exceptional weather resistance, and which is capable of unique applications for its excellent joint strength and simplified fabrication techniques.