V. Some Balloon Materials Testing Methods

Ray L. Hauser, Research Director
Hauser Research and Engineering Company
Boulder, Colorado

Abstract

Standard and novel test procedures that appear to be appropriate for balloon films are reviewed. The CRA and CRL test methods for axial breaking strength and breaking factor are compared. The apparatus for tensile and tear tests at -80°C is outlined. Current and future tests using biaxial stresses are described, and the projection is made regarding future quantitative tests of toughness at low temperatures.

1. INTRODUCTION

The intent of this paper is to review some of the current specification tests for balloon materials and to present some useful test variations.

The accumulated history of balloon failures has provided some insight into failure time, environment, and mechanism. In light of this information, there appear to be opportunities for developing some new balloon-material tests that should be of further value.

The properties that we are most concerned with, at the present time, are those of tensile strength at 25°C, elongation at -80°C, and tear initiation and tear propagation at both temperatures. The biaxial responses of balloon films to static stresses and to impact stresses at ambient and cold temperatures are also of keen interest.

2. TENSILE TESTS

MIL-P-4640A (USAF) states that tensile tests for balloon film are to be run at room temperature on samples taken from the machine and transverse direction. The test method is ASTM D-882-54, method C, which is now ASTM D-1923-61. The inclined plane or constant-rate-of-loading (CRL) testing machine is specified in this test method. A gauge length of 1 in. is used and the specimen may be as much as 3 in. wide according to the ASTM specification. The desired loading rate is 20,000 psi/min. Thus for a balloon film of 3000 psi tensile strength, the test is completed in a period of 9 sec. This is a very rapid loading of the sample, and it is unrealistic in terms of the very nearly static load application during most of the balloon flight.

A CRL type of testing machine is illustrated in Figure 1. In this test machine the table is tilted so that the constant weight, usually 10 lb, will exert a vertical component of force which increases at a linear rate with time. The force and elongation of the specimen are plotted on a chart near the center of the machine. There are very few of these instruments in existence that are appropriate for testing balloon films.

The constant rate of extension (CRE) type of test machine is most used throughout the balloon industry and the plastics industry in general. This type of tester, made by Instron, Wiedemann-Baldwin, Riehle and many others, applies a constant rate of elongation to the test specimen and the force is measured as the dependent variable. The loading rates are better controlled in this type of machine, and force measurements are much more accurate. The rate of elongation can normally be varied over very large extremes, if need be, so that a reasonable test time can be accomplished commensurate with proper load rate on the material.

Most of the balloon manufacturers have CRE type test machines or perhaps a cheaper variation, the constant rate of traverse (CRT) machine. Where a pendulum is used for load measurement, the machine is normally of the latter type, and traverse and elongation may differ by the amount of distance traveled by the upper or pendulum grip.

We feel that the CRE type of tensile test is most appropriate for balloon film.

Figure 1. The Scott Inclined Plane Testing Machine for Constant Rate of Loading

In tests we have made for evaluating a large number of candidate films, we have normally tested at the rate of 0.5 in./min, using a specimen with a 4-in.-gauge length. This is a very slow test for materials with high elongation, but it anticipates to some extent the problems of tensile creep. Quality control tests using the CRE type of test equipment should be made using 2- or 4-in.-gauge-length specimens and pulling at the rate of perhaps 10 or 20 in./min.

The CRE type of equipment permits testing at low temperatures and allows special inspection techniques much more easily than does the CRL type of equipment.

We used crossed Polaroid films for observing a number of balloon films, and found this technique helpful in identifying thickness and property variations within the test film. Our set-up merely uses a semi-cylinder of acrylic plastic with a small lamp and a Polaroid film set with its axis at 45 deg to the strain axis of the sample. This unit is attached to the cross-head behind the test specimen. We locate another Polaroid film in front of the test specimen, either permanently attached or held at the eye. This film is oriented to accomplish extinction of the light prior to the start of test.

Frequently gel particles and mechanical distortions may be apparent in the materials before testing is started. Nicks due to improper cutting of films may sometimes be apparent.

As the load is applied to the specimen, the birefringent response shows the strain patterns that occur in the plastic films, the areas of large thickness or material difference appear with distinct color patterns.

Two photographs were taken to show this type of inspection. Figure 2 is a sample of film with sworls and random quality variation. Figure 3 is a sample of film pulled in the transverse direction so that die thickness variations are readily apparent.

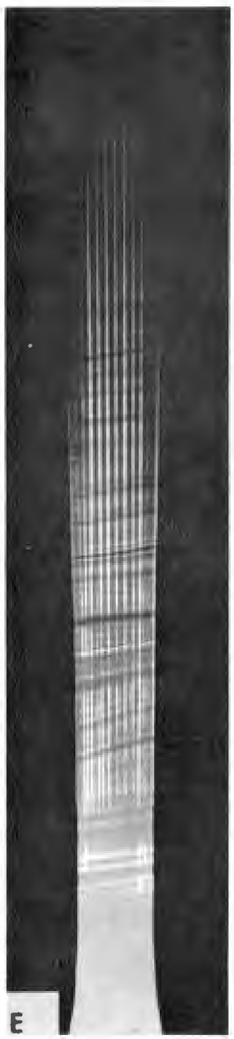

Figure 2. Photograph of 0.75-mil Balloon Film at About 100 Percent Elongation. Crossed Polaroids Accentuate the Appearance of Quality Variation

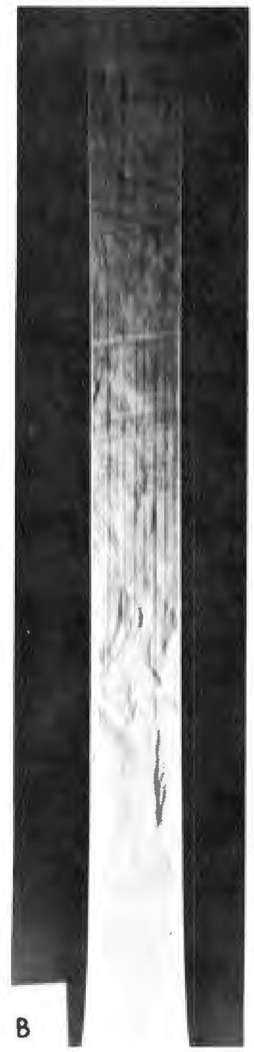

Figure 3. Polaroid Lighting and Inspection of 0.75-mil Balloon Film Accentuates Die Lines and Transverse Thickness Variations

These illustrations do not provide design information as such, and there are certainly many pros and cons throughout the industry regarding the value of Polaroid inspection of plastic materials. Frankly, we feel that this inspection is helpful and we refer to the ASTM specification D-882-61T, note 12, that states, "In the case of some materials, examination of specimens prior to and following testing under crossed Polaroid film provides a useful means of detecting flaws which may be or are responsible for premature failure."

3. LOW TEMPERATURE TESTS

We now know that scientific balloons must deploy at temperatures near -80°C. Thus we consider it appropriate to measure the properties of balloon films in this temperature region and to obtain quantitative measures of strength and elongation. Since the strength at -80°C is normally much higher than that at +25°C, we would not consider low-temperature strength to be a design criterion. However, the ultimate elongation of the material at low temperature may be very significant, since the opportunities for load distribution are largely evaluated in terms of ultimate elongation at operating temperatures. Tests of ultimate elongation at -80°C have predicted improved balloon performance with some balloon films developed during the past year (Hauser Res. and Eng. Co., 1964; NCAR, TN-5; NCAR, TN-9).

We tested the tensile strength, modulus, and elongation of a number of balloon films at -79 ± 2°C. Our equipment for this is very simple and the procedures are not difficult. Where a cross-head rate of 0.5 in./min is used in a tensile test, the time for tests at -80°C is less than the time required for a test at +25°C. Our test chamber is illustrated in Figure 4. It is merely two telescoping tubes, one of which is attached to the test machine and the other to the cross-head. Liquid carbon dioxide is injected into the lower section, and it sprays upward into the test chamber for the duration of the test. The specimen is in an environment of snowing dry ice. Thus, temperature uniformity is accomplished without separate electronic control systems, temperature sensors, or blowers. A baffle is sometimes used behind the test specimen and the injection nozzle is behind the baffle. This arrangement is made to minimize the effect of wind stresses on the film. Figure 5 shows the components and nature of hook-up to provide the low-temperature environment.

The equipment consists merely of a source of liquid carbon dioxide which the trade calls a syphon CO_2 bottle. Normally there are 50 lb of CO_2 per cylinder as received. The high-pressure line goes from the CO_2 bottle to a solenoid valve manufactured by Automatic Switch Company, and we use a simple 110-V on/off switch to control the valve. Downstream from this valve we use a 1/4-in. steel

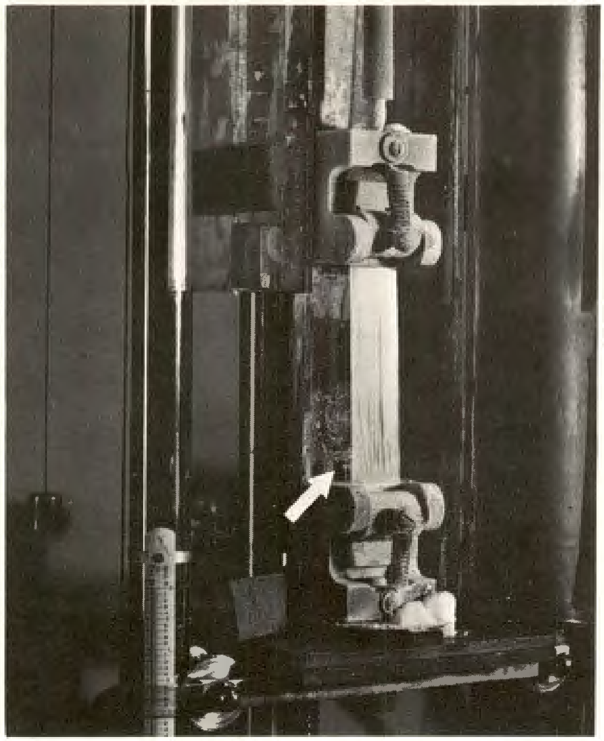

Figure 4. Telescoping Test Chamber Opened to Show Injection Nozzle (arrow) for Tests at -80^oC

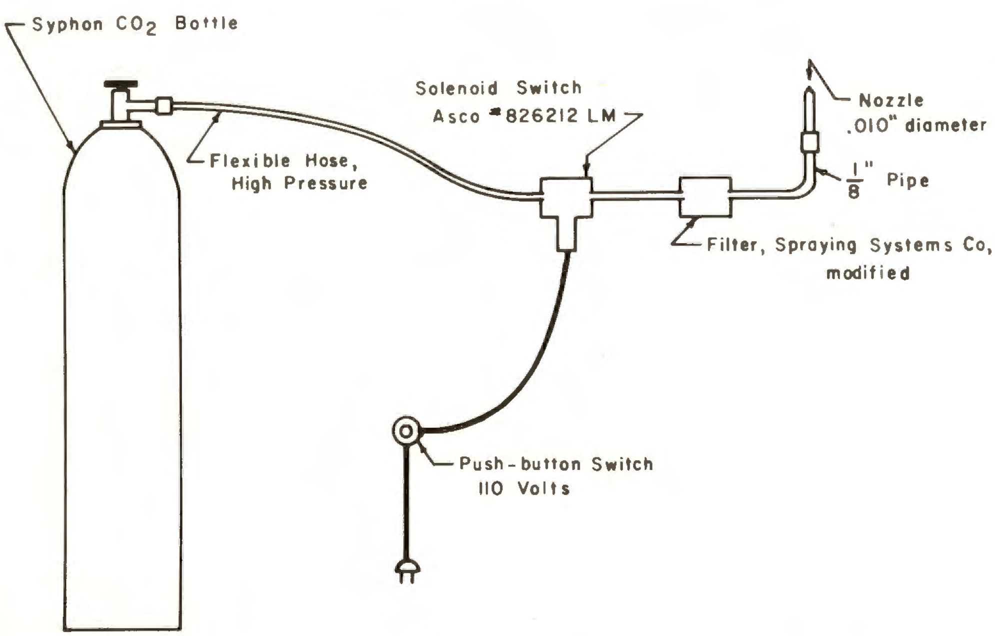

Figure 5. Components Used for Cooling the Telescoping Test Chamber

tubing, and a 10-mil hypodermic needle is soldered or brazed into the end of the tube to serve as an expansion nozzle for the carbon dioxide. This nozzle size provides an injection rate appropriate for our test chamber which is approximately 3 in. in diameter by 20 in. long.

The time for initial cool-down of the system is approximately 10 min, and we check temperature equilibrium with an alcohol thermometer located at the vent in the top portion of the test chamber. Subsequent tests are made with 2 to 3 min for cool-down. We usually obtain 10 to 12 tests per cylinder at a cost of 50 cents per test for the special environment.

Our telescoping test chamber is made of acrylic plastic tubing cut into half sections and hinged with brass hinges. Velcro material is used as a clamp closure. A thin layer of polystyrene foam insulation is bonded to the interior of each of the cylinders.

Although we at first anticipated the opportunity to view the test, we soon learned that the internal blizzard and the external frost obviated any chance of observation. Thus there is no need for the cylinders to be made of a transparent material. The grips for the low-temperature tests should preferably be of low heat capacity, and we did some modification of the lower grip in order to avoid a large amount of heat transfer into the cross-head. In our system the upper grip goes through a rod of glass-epoxy material and it stabilizes in temperature fairly quickly.

4. TEAR INITIATION AND PROPAGATION

We used the Graves tear test (ASTM D1004) for evaluating the initial tear strength of balloon films at +25°C and -80°C. We made a slight modification of the Graves test by adding a 1/16-in. razor slit at the apex of the specimen, as shown in Figure 6. Tear propagation forces were measured at both of the temperatures discussed above. Some materials showed very similar strength for both tear initiation and propagation. Other materials, notably biaxially oriented polypropylene, showed very high tear initiation strength but very low tear propagation strength at both temperatures.

We do not consider tear initiation or tear propagation to be a quantitative type of design allowable. We would certainly hope that the elongation of the balloon film would avoid initiation of any tears at stress concentrations. It can be expected that if a stress is large enough to initiate a tear, it will remain large enough to propagate the tear beyond the usefulness of the material.

We have seen no correlation between the ultimate elongation of the film with tear initiation or propagation strength among the many polyolefin and other types of balloon films we have tested (NCAR, FRB-1-64).

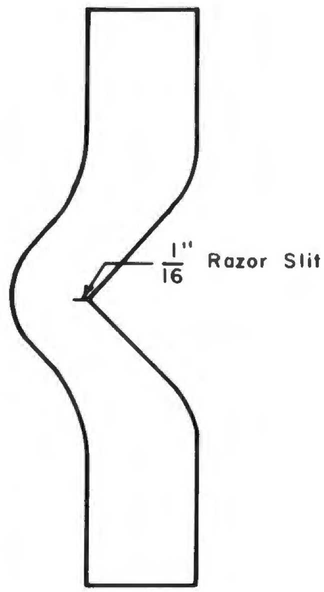

Figure 6. Graves Tear Test Specimen (ASTM D1004) Modified to Provide Tear Propagation Information

5. BIAXIAL TESTING

We are presently doing some biaxial testing of balloon films to provide a different type of information than is available from the uniaxial test discussed above. First of all, a biaxial test permits the use of a large sample, and sampling statistics may be improved considerably. There are opportunities for applying either balanced or unbalanced biaxial stresses to a film. If a circular diaphragm is used for an isotropic or orthotropic material, the stresses will be balanced as far as radii are concerned. If an elliptical diaphragm is tested using hydraulic or pneumatic pressure, the forces in the material will always be unbalanced. This type of test method appears to be very appropriate for evaluation of scrim-reinforced materials.

The manner of film failure in a biaxial test also appears to be of some interest. In preliminary tests to date, using both films and scrim-reinforced materials, we have sometimes observed a pin-hole type of failure in the film, frequently with a very small or a very large tear emanating from the pin hole. This type of failure could never be observed in a uniaxial type of test.

The equipment for these tests was designed and built by ourselves and the NCAR shop. As shown in Figure 7, it consists of a cylindrical base containing a chamber for hydraulic fluid and a circular hold-down clamp. Cooling and heating coils are contained within the base cylinder. A low- and high-pressure gauge is

Figure 7. Photograph of Biaxial Equipment Testing a Scrim-Reinforced Balloon Material

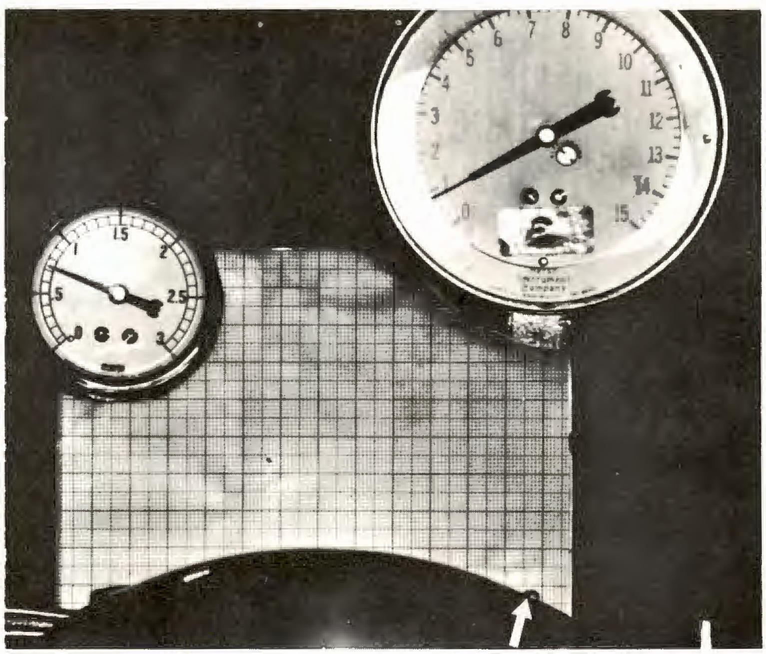

Figure 8. Profile of a Biaxial Film Test as Photographed by a Modified Aircraft Camera. This film has failed by a pin-hole, and the geyser has accumulated a drop of water on the film (arrow)

mounted on the pressure cylinder. A grid is in place for measuring coordinates to learn the radius of curvature of the test diaphragm.

We are currently using a modified aircraft camera with this equipment. It provides an illustration such as is shown in Figure 8, where the profile of the distended diaphragm is easily identified on the scale behind it. The hydraulic pressure against the diaphragm is measured on one of the gauges. Stress calculations are made from this pressure and the calculated radius at the crown of the distended film.

Further adaptations on this system provide for polar photography, looking down on the bubble. We hope to measure strain in the x and y coordinates, along with the present radius of curvature measurement in the z coordinate.

We are presently doing some development work toward strain gauges of very low modulus in relation to the modulus of the polyethylene film. These may be adapted in the biaxial test, either as accessories to or as replacement for photographic evaluation of the material properties.

Part of the background for the biaxial test relates to our anticipation that non-woven scrim reinforcement may provide greater strength per weight and better reliability in balloon materials of moderate cost.

6. COLD TOUGHNESS TESTS

We anticipate the opportunity of combining an impact toughness test with the present cold brittleness test. This would give a quantitative measure of the impact toughness of a cold balloon film and would concurrently show whether the failure mechanism was ductile or brittle.

We considered the photocell type of energy measurement as it is used in the toughness test of MIL-P-4640a. Alternatives are the rebound time or rebound height of the ball and the measurement of the ball's kinetic energy after it has perforated the film.

We are presently doing detail design of an apparatus that will accomplish vertical drop of a steel ball through a cabinet at approximately -80°C, through a diaphragm of balloon film, onto an impact bar.

Strain gauge instrumentation is anticipated for the impact bar which is to be made of 17-7 PH steel in the hard condition. Calibration will be accomplished by dropping the steel ball from a magnet at known heights with no film in the diaphragm clamp. This will relate impact energy to peak voltage output.

The chamber is to be cooled with liquid carbon dioxide to a temperature near -80°C. Intermediate temperatures can be used if necessary by adapting a Fenwal controller to the carbon dioxide supply. If lower temperatures are needed, liquid nitrogen injection will be used. A sketch of this equipment is shown in Figure 9.

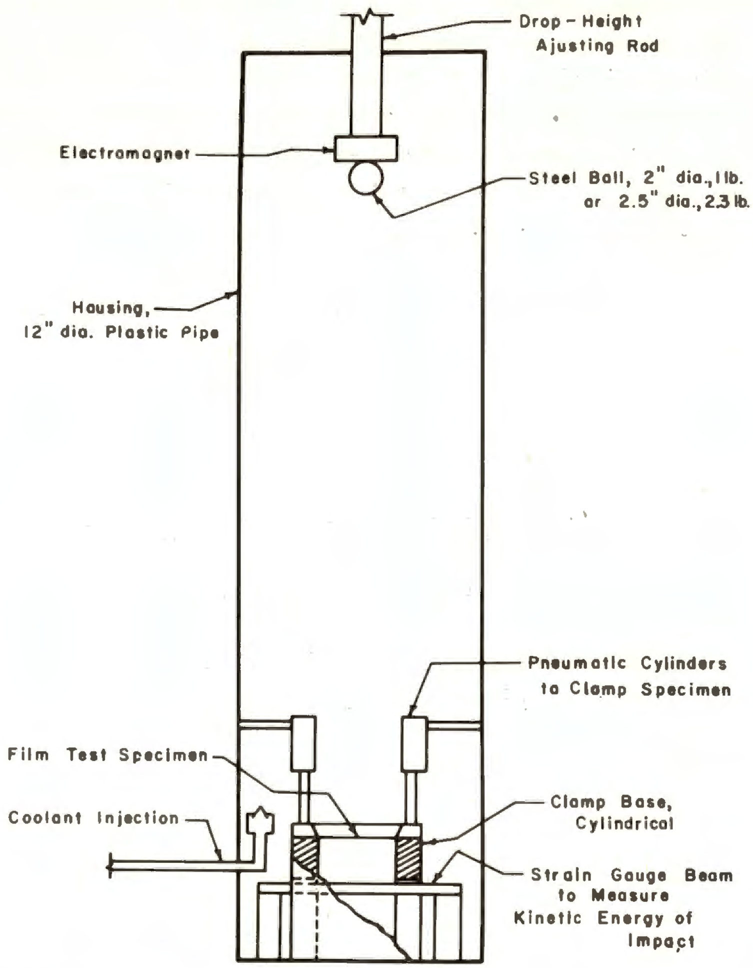

Figure 9. Equipment Planned for Measuring the Toughness of Balloon Films at Low Temperatures

The clamp mechanism will be designed so that the film can be placed at room temperature. Its thermal contraction will take place prior to actuation of the pneumatic clamping cylinders.

We see no advantage in using a "ski slide" type of ball drop with a vertical test specimen. The cabinet geometry can be simplified and its volume decreased considerably by using a straight-line drop. We are using a reinforced plastic pipe as the test cabinet for this system.

We hope to have test results from the cold toughness tests within a few months. At that time we may be able to obtain a better quantitative measure of what is now anticipated to be one of the most important properties of scientific balloon films.

7. CONCLUSIONS

In conclusion I'd like to mention that there is need for intelligent and discriminatory evaluation of balloon materials and for a continual pursuit of evaluation methods to provide information of maximum usefuleness in the scientific balloon program. We hope that the quality of the balloon materials and the reliability of the flight vehicles might be measurably increased by this type of support.

References

MIL-P-4640A (USAF) (1958) Plastic Film, Polyethylene, for Balloon Use, as amended 26 May 1958.

Hauser Research & Engineering Company (1964) Properties of Winzen StratoFilm, (report 5034-64-10, to be superseded by NCAR Tech Note TN-14.

NCAR Materials Strength Properties of Visqueen X-124 Film, Tech Note TN-5.

NCAR Materials Strength Properties of Startex SL1883 Film, Tech Note TN-9.

NCAR Tests of Balloon Materials, Facilities Report FRB-1-64.