Standard Test Method for
Burst Testing of Flexible Package Seals Using Internal Air Pressurization Within Restraining Plates[1]

1. Scope

1.1 These test methods cover the procedure for determining the minimum burst strength of a seal placed around the perimeter of a flexible package as it is internally pressurized and enclosed within restraining plates.

1.2 The test methods described herein are functionally similar to Test Methods F 1140 with the exception of the use of restraining plates. Test Methods F 1140 describes methods of burst testing that do not include the use of restraining plates and are suitable to determine a packages general ability to withstand pressurization stresses. Under Test Methods F 1140 the stresses are not distributed uniformly to all areas of the package seal. Under unrestrained conditions the stress on the package is highest at the middle of the pouch where it inflates to the packages maximum diameter; therefore, Test Methods F 1140 may not reliably detect the weakest area of the seal.

1.3 The burst test internally and increasingly pressurizes a package until an area of the package seal around the perimeter "bursts" open in response to pressurization. By placing the package within restraining plates during pressurization, the dimensional stability of the package is maintained in a manner that results in stresses applied more uniformly along the perimeter of the package, where seals are normally placed. This allows the test to have a higher probability of detecting the weakest area of the seal and provide a measurement of the pressure required to "burst" open the package.

1.4 This test only applies to flexible packages with seals placed around the perimeter of a flexible package (often referred to as a pouch). In particular it is intended as applicable to packages with seals that have a peelable seal feature (peeled open by end user to remove contents of package).

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Particular caution is advised where users of this procedure may be required to design and fabricate restraining plate fixtures. Reference Appendix X3 for further information regarding calculation of stress factors and structural design considerations.

2. Referenced Documents

2.1 *ASTM Standards:*
D 1898 Practice for Sampling of Plastics[2]
D 4332 Practice for Conditioning Containers, Packages, and Packaging Components for Testing[3]
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[4]
F 88 Test Method for Seal Strength of Flexible Barrier Materials[3]
F 1140 Test Methods for Failure Resistance of Unrestrained and Nonrigid Packages for Medical Applications[3]
F 1327 Terminology Relating to Barrier Materials for Medical Packaging[3]

3. Terminology

3.1 *Definitions*—For definitions and terms used in this test method, see Terminology F 1327.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *flexible package or pouch*, n—refers to a package in which at least one of the sealed materials is of a flexible structure (that is, paper, polyethylene, etc.).

3.2.2 *restraining plates*, n—refers to plates that are rigid in nature and configured to contact and limit the packages expandable surface area as the package is pressurized.

4. Summary of Test Method

4.1 Packages are tested in an apparatus that internally pressurizes the package until an area of the package ruptures (burst). For most applications the rupture (burst) will occur at one or more areas of the seal. The pneumatic supply and pressurization equipment need the capability to maintain an increasing pressure until the seal area fails. During pressurization, the package shall be enclosed between two rigid and parallel plates (restraining plates) that limit the expansion and dimensional distortion of the package but allow the seal perimeter area to be unrestricted. A sensor inside the package detects the internal pressure at the point at which the package ruptures (burst). Dependent on the application, two configurations of restraining plates are indicated for use with this test

[2] Discontinued. See *1998 Annual Book of ASTM Standards*, Vol 08.01.
[3] *Annual Book of ASTM Standards*, Vol 15.09.
[4] *Annual Book of ASTM Standards*, Vol 14.02.

method. Generally, these are described as follows:

4.1.1 *Open Package Configuration*—An open package configuration is used where there is a seal placed around three sides of the package perimeter and the fourth side is open. This configuration is generally used in the original package manufacture. See Fig. 1 for an illustration of the configuration used.

4.1.2 *Closed Package Configuration*—A closed package configuration is used where there is a seal placed around all four sides of the package. This configuration generally is used in operations where the purpose is to test the seal in it's finished, fully-sealed state. See Fig. 2 for an illustration of the configuration used.

5. Significance and Use

5.1 This test provides a rapid means of evaluating tendencies for package seal failure when the package is exposed to a pressure differential. Pressure differentials may occur during such processes as sterilization and transportation. This test method provides an indicator of the burst strength of a package, where the burst will normally occur in one or more areas of the seal. An indicator of the minimum burst strength may be of importance to the package manufacturer and end user in ensuring adequate package integrity. This test method cannot provide a measure of package seal uniformity. This test method also cannot provide an evaluation of overall package integrity or the burst strength of areas of the package that contact the surface of the restraining plates used. This test method should be combined with other methods of evaluating overall package integrity, uniformity of the package seal, or opening functionality, if so required.

5.2 This test frequently is used to quickly evaluate package seal strength during the manufacturing process and at various stages of the package's life cycle.

5.3 If correlations between pieces of test equipment are to be made it is important that all parameters of the test be equivalent. Typical parameters can include, but are not limited to the package size, material, type and configuration of seal, rate of air flow into the package, pressure detection sensing mechanism and sensitivity (machine response to pressure drop), position of test article, rigidity of restraining plates, and
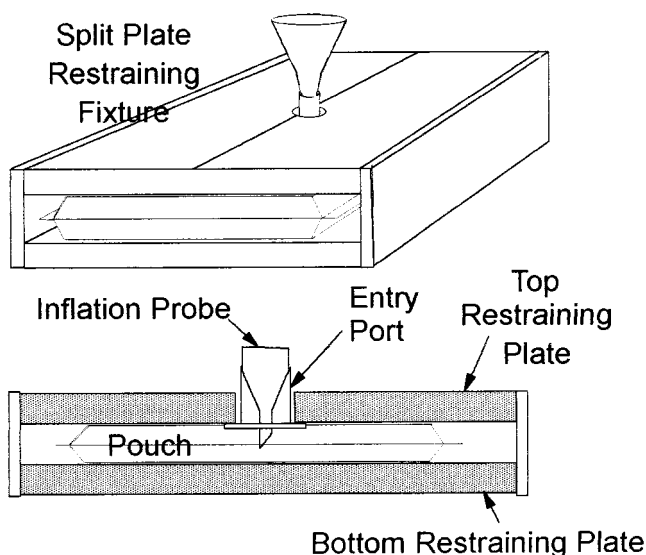

FIG. 2 Restraining Plates, Closed Package Configuration

distance between restraining plates. See Appendix X2 for further information.

5.4 This test may not necessarily provide correlation with package seal strength as typically measured using Test Methods F 1140 or F 88 (or equivalents).

6. Apparatus

6.1 Packages are tested under conditions described as follows:

6.1.1 *Open-Package Tester*—Open-package test fixtures are used to test flexible packages with one of the four sides of the package open (nonsealed). The package is pressurized with an inflation nozzle and pressure sensing mechanism inserted into the open end of the package. The open end then is sealed by a clamping mechanism for the duration of the test (see Fig. 1).

6.1.2 *Closed-Package Tester*—Closed-package test fixtures are used to test packages with all four sides of the package sealed. The closed package tester internally pressurizes the package utilizing a pressure nozzle and sensing mechanism
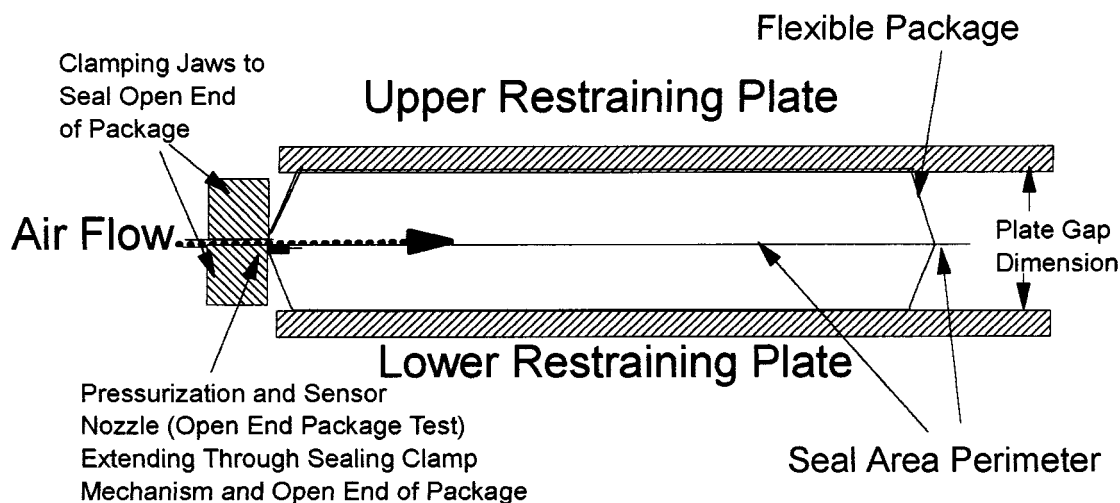

FIG. 1 Restraining Plates, Open Package Configuration

that is connected through a puncture in the package (see Fig. 2).

6.2 The test apparatus for both open and closed package testing shall include the following:

6.2.1 An air supply and pressure regulating mechanism that can produce sufficient air flow to pressurize the package to the point of package failure (burst);

6.2.2 A means of detecting a rapid pressure drop inside the package that signals that an area of the package is stressed to failure (burst);

6.2.3 A means of measuring the internal pressure at the point in which a rapid pressure drop occurs as the result of seal or other package failure (burst);

6.2.4 Two restraining plates that are configured similar to as shown in Fig. 1 or Fig. 2, is rigid to movement and flex, and contact the expandable surface area of the package for the duration of the test.

6.2.5 The following depending on type of test conducted.

6.2.5.1 Open-package test fixtures shall have a pressurization nozzle and sensor that is inserted into the open end of the package, and a clamping mechanism that seals the open end of the package, as well as creates an air tight seal around the pressurization nozzle and sensor; and

6.2.5.2 Closed-package test fixtures shall have a pressurization nozzle and sensor that inserts into a puncture of the body of the sealed package while maintaining an air tight seal around those mechanisms.

7. Sampling

7.1 *Sampling*[5]—Choose the number of test specimens to permit an adequate determination of representative performance. Practice D 1898 provides guidance to test specimen selection.

8. Conditioning

8.1 *Standard Test Conditions*—Condition and test package under standard laboratory atmosphere of 73.4°± 2°F (23° ± 1°C) and 50 ± 2 % relative humidity. Condition the packages for minimum of 72 h before performing testing. Reference Practice D 4332 for further information on standard conditioning.

8.2 Effects of environmental conditions other than the above standards have not been determined as they relate to the results of this test method and may depend on packaging materials used. Where comparisons or correlation's of test results may be a requirement, and the test is conducted in other than standard test conditions, record the conditioning factors and the temperature and relative humidity at the time of test.

9. Procedure

9.1 *Package Preparation*—The package may be tested with, if the package can fit within the restraining plates, or without product enclosed inside the package. Record the package test preparation, if applicable.

9.2 *Open-Package Test*:

9.2.1 Insert the package in a manner in which the body of the package is enclosed between the restraining plates. Place the package between the restraining plates in a manner which minimizes the unrestrained areas of the package during the test. It is advised to use some type of markings or fixturing that ensures consistent placement for all packages tested. Ensure plate gap dimension is set to appropriate gap setting. See Appendix X1 for recommendations on determining appropriate plate gap dimension settings.

9.2.2 Insert or otherwise place the pressurization and sensor nozzle inside the open end of the package.

9.2.3 Close the clamping mechanism to produce an air tight seal around the open end of the package including the area around the pressurization and sensor nozzle.

9.3 *Closed-Package Test*:

9.3.1 Insert the body of the package within the restraining plates and close the plates, if applicable, to the required plate gap dimension. See Appendix X1 for recommendations on determining appropriate plate gap dimension settings.

9.3.2 Carefully insert the pressurization and sensor nozzle entry device, and affix to the package so as to create an air tight seal. The center of the package is the preferred point of entry and may be fixtured as an attachment to the restraining plates (see Fig. 2).

9.4 Set the rate of pressurization and sensor sensitivity, if user selectable. Set the pressure failure sensor readout, if user selectable, to the desired units of measure, usually set to readout in pascal (Pa), kilopascal kPa), or inches of water units of measure for most package test resolutions required.

9.5 Begin test by initiating inflation process. Continue pressurization until a failure occurs. A failure in this context is when an area of the package ruptures (bursts) as the result of pressurization. The rupture (burst) is detected by the sensing mechanism as a rapid decrease in pressure within the body of the package, and the pressure reading device reports the pressure at the point in time just prior to the pressure drop.

9.6 Visually examine the tested package and note the position and type of failure, as well as the pressure at which the failure occurred. If the failure occurred in an area other than the seal the test may be voided depending on the purpose of the investigation.

10. Report

10.1 The report should include or have traceability to the following:

10.1.1 Test performed (open or closed package), apparatus used, test device machine settings chosen if operator adjustable (rate of pressurization and sensitivity of pressure drop detection sensor), and gap distance between restraining plates.

10.1.2 Packaging material types and other characteristics of package tested, that is, whether with or without package contents inside the package, seal type and configuration, etc., package lot number and source's name.

10.2 Include the date, time, location, and identification of the individual performing the test. The number of packages tested, the individual test values, and the units of measure that the sensing device is set to return as response values. Documentation also may include notations of failure mode, area of

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[5] Test equipment found to be satisfactory for this purpose is available from Carleton Corp., (Test-A-Pack System), Orchard Park, NY, and T.M. Electronics, Worcester, MA.

seal package failure, unusual test conditions and results.

10.3 The conditioning parameters and environmental conditions used at the time of test, if applicable.

10.4 A summary including comments or conclusions, the sample mean and standard deviation, should also be reported where appropriate.

11. Precision and Bias

11.1 A research report[6] describes a round robin conducted in 1999 in accordance with Practice E 691, involving ten laboratories testing four package sets for each of two material types. Materials tested are listed in Table 1[7] and statistical results are listed in Table 2 and Table 3. All samples were prepared at one source and then distributed to each of the laboratories participating in the study. Each laboratory performed ten replicate tests for each package set. All testing was conducted using restraining plates set to a gap height of 25.4 mm. Only the open package test configuration (see Figs. 1 and 2) was used for the round robin, precision is assumed to be similar for both open and closed package test configurations.

11.2 *Limitations and Considerations*—The test methods described herein are destructive in nature and do not allow repeat measurements on any given test specimen; therefore, by definition repeatability and reproducibility cannot be assessed as independent of the variability of the materials tested. Any estimate of test method precision in terms of repeatability or reproducibility will include some level of variability attribut-

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[6] Supporting data is available from ASTM Headquarters. Request RR:F02–1044.
[7] Tyvek is a registered trademark of DuPont.

TABLE 1 Descriptions of Package Sets Tested in Round-Robin Study

Package Set	Package ID Dimensions and Material Configurations[A]	Number of Samples Tested per Lab	Number of Labs
A	158.8 mm × 295.3 mm Spunbonded Olefin: PET/PE	10	10
B	139.7 mm × 231.8 mm Spunbonded Olefin: PET/PE	10	10
C	183.9 mm × 276.2 mm Spunbonded Olefin: PET/PE	10	10
D	133.4 mm × 224.8 mm Spunbonded Olefin: PET/PE	10	10
E	171.5 mm × 301.6 mm Paper: PET/PE	10	10
F	171.5 mm × 301.6 mm Paper: PET/PE	10	10
G	114.3 mm × 222.3 mm Paper: PET/PE	10	10
H	235.0 mm × 350.9 mm Paper: PET/PE	10	10

[A]All dimensions provided are nominal dimensions of width× length in millimeters, measured as internal dimensions from seal to seal within the packages tested. All packages tested are medical grade peelable seal pouches with 15 degree chevron style seal configuration. Materials listed are spunbonded olefin (1073B grade Tyvek) or medical grade paper sealed to PET/PE (polyester/ polyethylene) or PET/PP (polyester/polypropylene) laminated structures.[7]

TABLE 2 Summary of Interlaboratory Test Results by Package Set

Package Set	Average kPa	Standard Deviation of Lab to Lab Averages, kPa	Within Lab Repeatability Standard Deviation, kPa		Between Lab Reproducibility Standard Deviation, kPa	
				COV%	kPa	COV%
A	14.78	0.7221	4.89 %	1.3931	9.43 %	1.5060	10.19 %
B	18.58	1.5550	8.37 %	1.8825	10.13 %	2.3660	12.73 %
C	17.73	1.1346	6.40 %	1.5945	8.99 %	1.8910	10.66 %
D	15.73	0.8591	5.46 %	2.7499	17.48 %	2.7499	17.48 %
E	10.54	0.6198	5.88 %	0.8477	8.04 %	1.0153	9.63 %
F	9.06	0.8294	9.16 %	0.5974	6.60 %	1.0045	11.09 %
G	12.17	1.2560	10.32 %	1.5828	13.01 %	1.9576	16.09 %
H	8.84	0.4847	5.48 %	0.4197	4.75 %	0.6273	7.10 %

TABLE 3 Summary of Interlaboratory Test Results, Average COV for all Materials

Coefficient of Variation Basis	Average Value, %
Lab to lab averages	6.99
Within lab repeatability	9.80
Between lab reproducibility	11.87

able to the materials used. In addition, the selection of test parameters (flow rate, plate gap height, pressure drop sensor sensitivity, etc.) for any given package configuration (package size, materials used, bonding agents, seal area configuration, skirt area, etc.) will impact test results in terms of observed measurement values. Caution is advised where comparing test results conducted for different materials or test parameters.

11.3 Repeatability and reproducibility statistics in Table 2 include estimates of variance (standard deviations) and coefficients of variation (COV). Table 3 lists a summary of results which are average COVs for all package sets. Measurement units are in kilopascal (kPa). COVs are included based on the observation that the variability generally increases in proportion to the mean for any given set of test values. This relationship may or may not apply to other materials or materials tested at test parameters other than used for this study. Also included are estimates based on the standard deviations of the laboratory to laboratory (between laboratory) averages. This is included for the user to consider as an alternative estimate of test method reproducibility from laboratory to laboratory.

11.4 *Bias*—There are no recognized standards by which to estimate the bias of this test method.

12. Keywords

12.1 burst; closed-package; flexible packaging; inflation; medical packaging; open package; restraining plate method

APPENDIXES

(Nonmandatory Information)

X1. RECOMMENDATIONS FOR DETERMINING PLATE GAP DIMENSION

X1.1   Table X1.1 lists recommended maximum plate gap dimensions for varying package sizes as based on the rationale described in X1.3. Other plate gap dimensions may be used depending on the application and suitable rationale for their usage. Experimentation with plate gap settings should be conducted for any specific application to determine suitability for use. Selection of a gap dimension may be dependent on materials tested, or bonding mechanism, or both, as well as geometry of the seal. A pilot test of pouches at two or three gap dimensions, which can be correlated to seal strength tests (see Test Method F 88) to locate the weakest area of the pouch seal perimeter can guide user to select that gap, which provides the most consistency of indicating the weakest seal area. The rationale and recommendations described in the following sections are to be considered a guideline to use as a starting point for plate gap selection.

X1.2   As a precautionary warning regarding safety, it should be noted that reductions in plate gap dimensions will result in higher stresses acting upon the plates for any given package size and design. This should be factored into the structural design of any restraining plates. Reference Appendix X3 for further information regarding calculation of stress factors and structural design considerations.

X1.3   The rationale for recommended plate gap dimensions as listed in Table X1.1 is based on ensuring that a minimum of 60 % of the inflated package surface area fully contacts the plate surface. This is intended to ensure that the package is maintained in a state of restraint when fully inflated. Conceptually a very small gap dimension could be considered ideal for a given range of package sizes. Available data indicates that the plate gap should be minimized where possible. Ideally 90 % or more of the inflated surface area of the package should be in contact with the plates to increase the probability of bursts occurring at the weakest area of the seal; however this must be balanced against the consideration that a very small plate gap may also wholly or partially inhibit the seal area from peeling in a natural manner. Depending on the specifics of the package and seal design this could result in misclassification of test results.

X1.4   For most applications the recommendations for plate gap dimension listed in Table X1.1 are to be considered as a

starting point for determining the maximum plate gap setting. To determine the appropriate maximum plate gap dimension first measure the width (W) and length (L) dimensions of the package to be tested. These measurements shall be taken from the inner seal to seal positions as illustrated in Fig. X1.1. Using the minimum value of W or L determine to which row of column X the value corresponds. Then, select the corresponding gap dimension (D). For example, if $W = 63.5$ mm and $L = 127$ mm, X is the lesser of 63.5 and 127, and as such, $X = 63.5$ mm. If $X = 63.5$ mm, then X is in the range for the row marked ≥ 50.8 mm to < 101.6 mm and the corresponding gap dimension (D) is 12.7 mm.

X1.5   For reference and as an alternative to the tabled guidelines, the minimum surface area percentage (in contact with restraining plates) may be approximated with the following formula:

where:
W = Package width dimension (inner dimension from seal to seal),
L = Package length dimension (inner dimension from seal to seal),
D = Plate gap dimension selected,
x = The lesser value of W or L, and
π = 3.141593

Calculate z as the percentage of the inflated package surface that is in contact with the restraining plates as follows:

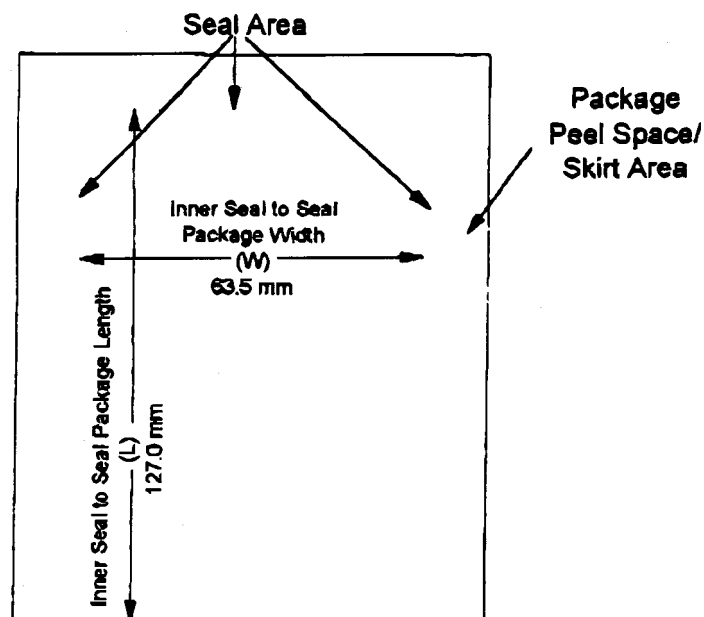$$Z = \left(\frac{\left(x - \left(\pi \times \dfrac{D}{2} \right) \right)}{x} \right) \times 100 \qquad \text{(X1.1)}$$

TABLE X1.1 Recommended Plate Gap Dimensions

X Package Seal to Seal Dimension (Minimum of Width or Length)	D Restraining Plate Maximum Gap Dimension	Z Minimum % of Inflated Package Surface in Contact with Restraining Plates
>= 101.6 mm	25.5 mm	>=60.73 %
>= 50.8 mm to < 101.6 mm	12.7 mm	>=60.73 %
>=25.4 mm to < 50.8 mm	6.5 mm	>=60.73 %

FIG. X1.1 Example for Determining W and L Dimensions

Example: Using the dimensions listed in Fig. X1.1 and a plate gap of 12.7 mm.

x = 63.5 mm

$$z = \left(\frac{\left(63.5 - \left(3.141593 \times \frac{12.7}{2} \right) \right)}{63.5} \right) \times 100 = 68.58 \ \%$$
(X1.2)

W = 63.5 mm
L = 127 mm
D = 12.7 mm

X2. FACTORS INFLUENCING TEST RESULTS BETWEEN LABORATORIES

X2.1   Use of this procedure may involve comparing test results from various laboratories. The methods outlined herein are applicable to a wide range of products. To obtain results that are consistent from one laboratory to another users should be aware of factors that influence test outcomes. As a general guideline to assist in understanding variables that influence the outcomes of test results the following should be considered.

X2.2   Restraining plate gap dimension should be controlled closely and identical when comparing test results between laboratories. As the gap dimension is reduced the volume inside the pouch or bag also is reduced, which will increase the observed pressure at the point in which the pouch or bag ruptures (bursts). Experimentation with varying gap dimensions may be used to determine a suitable gap for any given pouch type. In general, the gap dimension should be set so as to maximize the surface area of the flexible membrane surfaces that contacts the restraining plates and minimize distortions of the membrane during inflation.

X2.3   Rate of pressurization (flow rate) should be controlled closely and identical when comparing test results between laboratories. This is of particular concern where various pressure testing hardware may be used and each hardware manufacture may use a different method of design to control flow rates, that is, one design may be to set flow rate to a given constant while another may utilize a design in which the flow rate ramps up.

X2.4   Test results for various pouches or bags of varying dimensions or material combinations cannot be compared as identical. As a bag or pouch surface area increases the pressure load also is distributed over a larger surface area and the resultant pressure at the point in which the structure is observed to rupture (burst) will decrease. Materials used in the design of the structure or adhesives used to provide a seal bond also may affect the dynamics of how the seal separates and have a resultant effect on the observed pressure at burst.

X3. CALCULATING STRESSES AND FACTORS OF SAFETY FOR RESTRAINING PLATE FIXTURES IN INFLATION SEAL STRENGTH TESTS

X3.1   Calculation of the stresses and factors of safety to design restraining plates for inflation seal strength tests requires six basic steps.

X3.1.1 Define the applied load on the plates of the fixture.

X3.1.2 Calculate the applied loads given the maximum pressure applied to the pouch.

X3.1.3 Calculate the stress and deflection on the plates of defined size and materials.

X3.1.4 Calculate the applied loads on the fasteners.

X3.1.5 Calculate the fastener size and pre-load for a defined material.

X3.1.6 Calculate the factors of safety for the plates and fasteners.

X3.2   This process should be undertaken by a knowledgeable engineer or person skilled in the science. An example of this process follows. This example is for demonstration purposes only and cannot be used for a particular application.

X3.2.1 A pouch of dimensions 8 in. by 10 in., made from two poly film materials is heat-sealed on four sides. An experimental test shows that the burst pressure for this pouch is 10 psi when restrained at ½ in. The test apparatus can supply up to 50 psig maximum.

X3.2.1.1 The applied load area when the pouch is inflated will be less than the maximum area of the pouch. To be conservative the entire pouch area will be assumed to be inflated. The area is (8×10) 80 in.^{2}. The plates will be larger than the pouch to allow for fasteners. A plate of 10 in. $\times$ 12 in. is assumed.

X3.2.1.2 The applied load on each plate is as follows:

Force = Pressure $\times$ Area; $F = 10 \ \text{lb}_f/\text{in.}^2 \times 80 \ \text{in.}^2 = 800 \ \text{lb}_f$
(X3.1)

X3.2.1.3 The stress and deflection on the plates are derived from empirical formulae found in engineering text and depend on design and restraining conditions of the plates. We will assume a simple case for plates that are bolted in three places along the long axis of the fixture. In this case, we assume that the plate edges are simply supported and are free to rotate. In this case, the stress and deflection of the plates can be calculated by the following found in Rourke.[8]

Stress = $B \ w \ b^2/t^2$
(X3.2)

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[8] Roarke, R.J. *Formulas for Stress and Strain*, New York, NY, McGraw-Hill, 1965.

and

$$\text{deflection } Y = A\, w\, b^4/E\, t^3 \quad\quad (X3.3)$$

where:
A and B = constants,
b = plate width,
a = the plate length,
t = plate thickness,
w = applied pressure, and
E = Young's Modulus for the plate material.

X3.2.2 The constants A and B are found from Table X3.1 as provided in Rourke.[8] Using these formulae and tables we will assume that the load is uniformly distributed over the entire plate. The restraining plates will be larger than the pouch itself to accommodate the bolt fasteners. We will assume that the plate size is 10 in. × 12 in. × .375 in. thick. Then, the a/b ratio is 12/10 = 1.2. The calculations follow:

$$S = .3762 \times 10\text{ psi} \times (10)^2/(.375)^2 = 2675\text{ psi} \quad (X3.4)$$

$$Y = .0616 \times 10\text{ psi} \times (10)^4/E\,(.375)^3 \quad (X3.5)$$

Where for 2024 Aluminum $E = 10.6 \times 10^6$, then $Y = 11.2 \times 10^{-3}$ (.0112) in which is maximum at the center of the plate.

X3.2.3 Other conditions of pressure should be considered to allow for maximum loading conditions. For example, if the plate gap decreases then the pressures will be higher. The maximum pressure capability of the system is 50 psig. A calculation at this pressure will provide information at the maximum condition.

$$S = .3762 \times 50\text{ psi} \times (10)^2/(.375)^2 = 13\,375\text{ psi} \quad (X3.6)$$

$$Y = .0616 \times 50\text{ psi} \times (10)^4/10.6 \times 10^6\,(.375)^3 = 0.55\text{ in at the center} \quad (X3.7)$$

X3.2.4 Calculate the applied loads on the fasteners by first determining the number of bolts to be used. We will assume that six bolts will be used at the edges. For the 800 lb_f load on six bolts the load per bolt is 133 lb_f each. In the maximum case of 50 psi, the load is 50 psi × 80 in.^{2} = 4000 lb_f/6 = 667 lb_f per bolt.

X3.2.5 The bolt size is determined from calculation or a table of allowable loads that can be found in an engineering text, such as SME Tool and Manufacturing Engineers Hand-book (see Table X3.2).[9]

X3.2.5.1 The bolt is chosen so that the minimum tensile load is greater than the required resistance load. The maximum load should be considered to prevent bolt failure. In this case the 10–32 bolt could be chosen to assure strength at the maximum load of 667 lb_f.

X3.2.5.2 To prevent fatigue failure from repeated loads the bolt should be chosen so that when tightened to its proper preload the applied load is less than the preload value. In this case, the 133 lb_f is less than the 655 lb_f in a properly preloaded 10–32 bolt. This bolt size will function properly even if the loads are increased substantially.

X3.2.6 Once the plate stress and bolt load are calculated, the designer should calculate factors of safety. The factor of safety provides the extra margin of stress or loads for unanticipated situations that cannot be calculated. A factor of safety of at least 3–5 should be found. Sound engineering judgment must be exercised before the design is complete.

Factor of safety = allowable stress (or load)/actual stress (or load)
For the plate design in the working mode:
   Allowable stress for Al (2024-T4) is 42000 psi
   Actual stress calculated is 2675 psi
      FS = 42000/2675 = 15.7
   At maximum load of 50 psi
      FS = 42000/13375 = 3.1
Both are within design range.
For the bolts:
   Allowable load for 10–32 commercial steel bolt is 1092 lb_f
   Working load/bolt is 133 lb_f/bolt
      FS = 1092/133 = 8.2
   At maximum load of 667 lb_f/bolt
      FS = 1092/667 = 1.6
Since the factor of safety is lower than our target range, the designer may choose to use the next larger bolt.
   For the ¼-20 bolt the allowable load is 1750 lb_f
      FS = 1750/667 = 2.6

X3.2.7 While still lower than the target range for factors of safety, the designer may choose to exercise judgment on whether to continue to increase the bolt size or perhaps add more bolts to achieve the desired factor of safety.

[9] Daniels, D.B. (ed), Society of Manufacturing Engineers, *Tool and Manufacturing Engineers Handbook*, 3rd ed., New York, NY, McGraw-Hill, 1976.

TABLE X3.2 Bolt Sizes

Bolt Size	Stress Area	Min. Tensile Str (lb)	Torque @ 60 % (in./lb)	Preload @ 60 % (lb)
10–32	0.0199	1 092	41	655
¼–20	0.0317	1 750	53	1 050
⁵⁄₁₆–18	0.0522	2 850	107	1 710
⅜–24	0.0876	4 800	215	2 880
½–13	0.1416	7 800	468	4 680

TABLE X3.1 Constants A and B

a/b ratio	1.0	1.2	1.6	2.0	5.0
A	0.0444	0.0616	0.0906	0.1110	0.1417
B	0.2874	0.3762	0.5172	0.6102	0.7476