SAE INTERNATIONAL

SURFACE VEHICLE STANDARD

J2575 APR2015

Issued 2004-06
Reaffirmed 2015-04

Superseding J2575 JUN2004

Standardized Dent Resistance Test Procedure

RATIONALE

J2575 has been reaffirmed to comply with the SAE five-year review policy.

1. Scope

These test procedures were developed based upon the knowledge that steel panel dent resistance characteristics are strain rate dependent. The “quasi-static” section of the procedure simulates real world dent phenomena that occur at low indenter velocities such as palm-printing, elbow marks, plant handling, etc. The indenter velocity specified in this section of the procedure is set to minimize material strain rate effects. The dynamic section of the procedure simulates loading conditions that occur at higher indenter velocities, such as hail impact, shopping carts, and door-to-door parking lot impact.

Three dent test schedules are addressed in this procedure. Schedule A is for use with a specified laboratory prepared (generic) panel, Schedule B is for use with a formed automotive outer body panel or assembly, and Schedule C addresses end product or full vehicle testing. These schedules are targeted at sheet steel samples obtained at different points in an auto/steel product development cycle. A multiple schedule approach has been utilized to maximize dent test method flexibility and thereby allow both the steel producers and end users to benefit from a standardized approach. Extrapolating results from one schedule to another, however, may not be valid and could result in erroneous conclusions.

For “quasi-static” testing, each test schedule provides a load-displacement curve for a given material, either as-stamped or after assembly, under a prescribed set of conditions such as specified strain state, specimen geometry, boundary conditions, indenter type, etc. In order to obtain the most information about dynamic denting behavior comparable in scope to the quasi-static testing, it is necessary to use high speed measuring and recording equipment. If use of this equipment is cost-prohibitive, other dynamic dent evaluations use a drop weight, pendulum, or air gun to fire a projectile at the test surface. For this latter type of dynamic testing, only the impact energy is calculated and the dent depth measured after impact. This information may be sufficient to measure some aspects of dent resistance in the absence of high-speed measuring and recording equipment, but the indenter speed/energy interaction will not be captured. Uniform methods for calculating panel property characteristics such as stiffness and oil canning load are presented. A format for reporting test results is suggested. Using this procedure, reproducible values of “dent resistance” should be obtained in different laboratories.

1.1 Purpose

The test methods and definitions presented in this procedure are for the mechanical dent testing of sheet steel products. Both quasi-static (low velocity) and dynamic (higher velocity) indenting conditions are discussed. The objective of these methods is to provide reproducible and comparable dent test results.

2. References

2.1.1 OTHER PUBLICATIONS

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13. Material and Design Factors Influencing the Quasi-Static Dent Resistance of Steel Body Panels", S. Sriram, J. G. Speer, and D. K. Matlock, SAE Paper 1999-01-0025.
14. The Comparison in Dent Resistance Between High Strength Steels with Excellent Formability and Bakehardenable steel", Y. Hirose, M. Nakata, N. Kojima, and N. Mizui, Sheet Metal Forming Beyond 2000,Proceedings of the IDDRG, 1998

3. Definitions

3.1 Body Assembly (partial)

Refers to one or more outer sheet metal parts intended for a vehicle component (door, hood, etc.) Which may be in an untrimmed state. No supporting inner panel is present. The part must have been exposed to a paint bake cycle to assure that all strain aging and adhesive curing has taken place, unless the intent of the test is to evaluate in-plant handling of partially finished body assemblies. Such intent must be specifically called out and recorded on all affected data sheets.

3.2 Body Assembly (unfinished)

Refers to all automotive sheet metal parts of a particular vehicle component (door, hood, etc.) Welded together and including all structural supports, adhesives, and structural sealing. The part must have been exposed to a paint bake cycle to assure that all strain aging and adhesive curing has taken place, unless the intent of the test is to evaluate in-plant handling of partially finished body assemblies. Such intent must be specifically called out and recorded on all affected data sheets.

3.3 Body Assembly (finished)

Refers to all automotive sheet metal parts of a particular vehicle component, such as a door, a hood, etc., welded together and including all panel hardware, glass, structural supports, adhesives, and sealing components. The part must be painted and must have been exposed to a paint bake cycle to assure that all strain aging and adhesive curing has taken place.

3.4 Deflection Under Load

Is the total displacement occurring when a panel is loaded to a particular force.

3.5 Dent

Is a permanent plastic deformation, localized at the point of loading, which is not the intent of the product design.

3.6 Dent Area

Is the area around the dent that is deformed, and hence affected, by the denting process.

3.7 Dent Depth

Is the difference between (a) the panel position at the denting location at pre-load prior to the loading cycle and (b) the panel position at the denting location at pre-load after the loading cycle has been conducted.

3.8 Dent Depth, First Visible

Is the dent depth at which the consumer first will notice, and therefore object to, a dent. This depth depends on many factors, such as paint color, local panel curvature, and affected area of the dent. First visible dent depths, or fvdds, in the range of 0.02 to 0.1 mm (0.0008 to 0.0039 in) have been used in the literature.

3.9 Dent Initiation Load

Is the applied load that results in the formation of a dent of a given depth. The first visible dent depth is typically used. It quantifies a panel's relative dent resistance.

3.10 Dent Resistance

Is the ability of a panel to withstand denting.

3.11 Dent Volume

Is the volume created by the movement of the panel between the as-received and dented condition.

3.12 Denting, Dynamic

Is the process of producing a dent at a high strain rate. The strain rate would be equivalent to typical indenter velocities of at least 894 mm per second (894 mm per second = 2112 in per minute = 2 miles per hour).

3.13 Denting, Quasi-static

Is a process of producing a dent at a low strain rate. The strain rate would be equivalent to typical indenter velocities of at most 2.116 mm per second (5 in per minute). This procedure recommends an indenter velocity of 0.846 mm per second (2 in per minute).

3.14 Nodal Point

Is the localized boundary zone (usually circular) about the denting location.

3.15 Oil Canning

Is the recoverable localized reversal of panel curvature.

3.16 Oil Canning Load

Is the minimum load at which oil canning occurs. For hard oil canning, it is defined by the point where the slope of the load-displacement curve first reaches a value of zero. For soft oil canning, it is defined at the point where the slope of the load-displacement curve reaches a minimum.

3.17 Oil Canning, Hard

Is a buckling event that results in a drop in the required load for further displacement after some initial deflection accompanied by a monotonically increasing load.

3.18 Oil Canning, Soft

Is a buckling event less severe than hard oil canning in which the slope of the load-displacement curves exhibits a local minimum but remains positive.

3.19 Panel Attachment Hardware

Include the hinges, latches, strikers, and over-slam bumpers that are used to connect the body panel component, such as a hood, door, or rear compartment lid to the body-in-white.

3.20 Post-load

Is the load applied after completion of dent resistance testing to determine dent depth.

3.21 Reference Load / Pre-load

Is the load that defines the displacements off of the load-displacement curves which are used to determine dent depths.

3.22 Sample Envelope

Is the smallest length, width and height dimensions which will fully enclose the specimen being tested, including panel motion during the denting process.

3.23 Stiffness, Initial

Is the slope of the initial linear portion of the load-displacement curve of a given panel.

3.24 X, Y, Z axes (Orientation of test equipment with respect to panel specimen)

- For Schedules A and B, the XY plane is defined as the bed upon which or to which the panel specimen is secured.
- For Schedule C, the XY plane is defined as the horizontal plane for hoods, roofs, and rear compartment lids, and the vertical plane for all other panels.
- In all cases, the Z axis is defined as perpendicular to the XY plane using the standard right-hand rule.

4. Quasi-Static Dent Evaluations: General Requirements and Test Procedure

4.1 Quasi-Static Load Displacement Curves

The shape of the load-displacement curve produced during indention of a sheet metal panel is a function of a number of factors, both geometry- and material-based. See Appendix A for examples of typical load-displacement curves obtained during denting evaluations.

4.2 General Requirements for Quasi-Static Testing

4.2.1 TEST FRAME

The frame must enclose the sample envelope with minimal deflection or rotation due to its weight or during test loading.

The actuator must be able to be positioned at any desired location on the test sample normal to the panel surface at the point of contact.

4.2.2 TEST ACTUATOR

The actuator should have a minimum total travel at least as large as the maximum deflection that would occur when the test specimen is loaded to 355 N (80 lbf). Note that for some automotive body panels, this deflection may be greater than 51 mm (2 in) The test actuator shall support the weight of the load cell, displacement transducer, and the indenter as well as all loads applied to any panel in Schedule A, B, and C.

4.2.3 SYSTEM STIFFNESS

The system must be sufficiently rigid to minimize deflection at a load of 222 N (50 lbf). Round robin testing of generic experimental panels using frames with stiffness values ranging from 1.23 x 106 N/m (7 x 103 lbf/in) to more than 1.75 x 107 N/m (1 x 105 lbf/) produced satisfactory results. If the test frame stiffness is suspect, then an external reference point must be used for panel deflection measurements.

4.2.4 INDENTER DESCRIPTION

Indenters shall be of two types, as follows (see Figure 1):

4.2.4.1 Type I (hard indenter)

A type I indenter shall be used in all three schedules. The type I indenter is hemispherical shaped and 25.4 mm (1 in) diameter. It is composed of steel with a nominal hardness of Rc 55 and a nominal average surface roughness (Ra) of 0.254 μm (10 μ in). Typical applications for this indenter are to simulate elbow marks, luggage rack damage, thumbprint, and other quasi-static in-service damage.

4.2.4.2 Type II (soft indenter)

The use of a rubber indenter is optional. This type of indenter should be used to test only Schedule B and C level specimens. Historically, the development and use of rubber indenters has varied significantly from company to company. Rubber indenters have been used to simulate quasi-static palm, knee, hip, and large object panel denting. Type II indenters have been used in subjective (jury based) panel performance evaluations and, to a limited extent, in some quantitative studies. Neither the test methodology nor the rubber indenter design have been specified as a part of this procedure. Companies choosing to use soft style indenters should develop an indenter geometry based upon the specific body panels to be dented and then study the test repeatability of each respective soft indenter design. Dent Project work relating to the development of a general (all body panel) soft rubber indenter utilized a flat faced 50.8 mm (2 in) diameter cylinder indenter composed of a nominal 50 durometer rubber pad attached to a steel base. Dent test repeatability using this indenter design for general applications has not been assessed.

4.2.5 SPEED OF TESTING

A constant actuator speed of 0.834 mm ± 0.08466 mm per second (1.97in ± 0.20 inper minute) will be used during both the loading and unloading portions of the test and will be recorded.

4.2.6 SYSTEM PERFORMANCE

The test system shall be capable of recording the total load-displacement curve, both the loading and unloading segments. If desired, recording of the unloading segment may be terminated after sufficient data is obtained to identify the true end of the loading cycle.

The angle of load input to the panel shall be perpendicular to the surface at the point of first contact within 2.5 degrees, and continue on this angle throughout the test without shifting or skidding along the surface of the panel. A measurement system such as a magnetic protractor shall be used to establish loading angle.

To minimize bending loads placed on the load cell, the distance between the load cell and the panel shall be as small as practical.

4.2.7 LOAD CELL TRANSDUCER

The load cell transducer and recording equipment shall have a resolution of 1.33 N (0.3 lbf) or better for quasi-static indenting.

4.2.8 DISPLACEMENT TRANSDUCER

The displacement transducer and recording equipment shall have a resolution of 0.013 mm (0.0005 in) or better for quasi-static indenting. It is preferred that the resolution be on the order of 10% of the critical dent depth, but transducers capable of resolving 6 μm (as would be needed for a 0.06 mm critical dent depth) may be cost prohibitive.

4.2.9 CALIBRATION

There shall be a system calibration conducted periodically in accordance with the latest revision of ASTM E 4 Standard Practices for Load Verification of Testing Machines, Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, PA. Calibration at 5.0 N (1.12 lbf) shall be within the system resolution.

4.2.10 ADDITIONAL HARDWARE REQUIRED

Deflection of the panel at the point of loading shall be continuously measured throughout the test using appropriate hardware to digitally store the data for subsequent computer analyses. Data collection at a resolution at least as large as that of the transducers shall be possible for a minimum travel of 25 mm (0.98 in). The sampling rate shall be sufficient to capture a minimum of 2500 data points for every 25 mm (0.98 in) of deflection.

4.3 General Test Procedure for Quasi-Static Denting

4.3.1 INCREMENTAL DENT RESISTANCE EVALUATION TEST SEQUENCE (FIGURE. 2)

1. Calibrate testing system as required (see 6.1.9).
2. Mount test specimen (body panel) in test frame.
3. Mark test location on test specimen.
4. Wipe the test location using a clean cloth to remove any extraneous dirt from the test location.
5. Align actuator normal to surface at test location (see 6.1.6).
6. Apply the following series of sequential loads. (Notes 1, 3 and 4 below)

    a. Apply a preload to 7 N (1.57 lbf) and record the load-displacement history. This loading sequence establishes the displacement, which is the reference value from which all other displacement readings are determined. Unload back to zero N (0 lbf). (see Note 2).
    b. Record load versus displacement history as sample is loaded to 50 N (11.2 lbf) and unloaded back to zero N (0 lbf).
    c. Record load versus displacement history as sample is loaded to 70 N (15.7 lbf) and unloaded back to zero N (0 lbf).
    d. Record load versus displacement history as sample is loaded to 90 N (20.2 lbf) and unloaded back to zero N (0 lbf).

e. Record load versus displacement history as sample is loaded to 110 N (24.7 lbf) and unloaded back to zero N (0 lbf).
f. Record load versus displacement history as sample is loaded to 130 N (29.2 lbf) and unloaded back to zero N (0 lbf).
g. Record load versus displacement history as sample is loaded to 150 N (33.7 lbf) and unloaded back to zero N (0 lbf).
h. Record load versus displacement history as sample is loaded to 170 N (38.2 lbf) and unloaded back to zero N (0 lbf).
i. Record load versus displacement history as sample is loaded to 190 N (42.7 lbf) and unloaded back to zero N (0 lbf).
j. Record load versus displacement history as sample is loaded to 210 N (47.2 lbf) and unloaded back to zero N (0 lbf).
k. Apply a post-load to at least 7 N (1.57 lbf).

NOTE 1—This loading sequence listed (7, 50, 0, 70, 0, 90, 0, 110, 0, 130, 0, 150, 0, 170, 0, 190, 0, 210, 0, and 7 N) is only a suggestion. The loads within a given sequence should encompass both the low and high loads that are of interest to the user. At a minimum, the gap between increments should be 20 N as shown in this sequence. It is preferred that the gap is 10 N. The minimum load of the first stroke is 30 N.

NOTE 2—Starting with a pre-load sequence to 7 N is optional. The user can instead initialize data collection from the 5 N load determined from the 50 N loading cycle. However, returning back to an unloaded condition after each cycle and finishing with a post-load of at least 7 N are needed for accurate data interpretation.

NOTE 3—If it is desired, a displacement sequence (i.e., loading until 1.25, 2.5, 3.75, 5.0, 6.25, 7.5, 8.75, and 10.0 mm [0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, and 0.40 in] maximum displacements) may be used instead of a loading sequence.

NOTE 4—If the dent depth after one specific loading increment is desired, a single load cycle is sufficient provided a preload and post-load are also used to determine dent depth.

NOTE 5—The effects of a painted rather than an unpainted sample surface on the test results are not known. In addition, the effect of the paint thickness on the test results is not known. However, there are cases where a painted surface is desired (see 4.5.2.1).

4.3.2 HARD OIL CAN EVALUATION TEST: TEST SEQUENCE

1. Calibrate testing system as required (see 6.1.9).
2. Mount test specimen (body panel) in test frame.
3. Mark test location on test specimen.
4. Wipe the test location using a clean cloth to remove any extraneous dirt from the test location.
5. Align actuator normal to surface at test location (see 6.1.6).
6. Apply the following series of sequential loads.
   a. On the first replicate specimen:
      1) Follow the Incremental Dent Test loading sequence using a 10 N load increment to determine the minimum load necessary to achieve a hard oil can response.
   b. On subsequent replicate specimens:
      1) Apply a preload to 7 N (1.57 lbf) and record the load-displacement history. This loading sequence establishes the displacement that is the reference value from which all other displacement readings are determined. Unload back to zero N (0 lbf). (see Note).

2) Record load versus displacement history as sample is loaded, to at least the minimum load determined in the previous step, and unloaded back to zero N (0 lbf).
3) Apply a post-load to at least 7 N (1.57 lbf).

NOTE—Starting with a pre-load sequence to 7 N is optional. The user can instead initialize data collection from the 5 N load determined from the primary oil can loading cycle. However, returning back to an unloaded condition after each cycle and finishing with a post-load of at least 7 N are needed for accurate data interpretation.

4.4 Data Analysis

4.4.1 INCREMENTAL DENT RESISTANCE EVALUATION TEST

4.4.1.1 Determination of "Zero" Displacement at 5 N

The displacement associated with the 5 N load obtained during the preload sequence is defined as the reference displacement value. During the post load sequence this value is defined as the zero displacement. The actual displacement value for the 5 N load will be determined by linearly interpolating displacement values between all data point pairs collected between 3 N and 7 N.

4.4.1.2 Determination of Resulting Dent Depth (see Section 3 [Definitions] and Figure 2)

The total dent depth on any given loading cycle is obtained as the difference between the reference displacement and the zero displacement. For any given loading cycle, the reference displacement is determined on the preload cycle described in 6.2.1 Step 6b, and the zero displacement is determined on the post-loading cycle following the loading cycle under consideration. To illustrate this procedure:

1. total dent depth from the 50 N (11.2 lbf) loading cycle is the difference between the zero displacement on the loading portion of the 70 N (15.7 lbf) loading cycle and the reference displacement obtained during the preload cycle.
2. total dent depth from the 70 N (15.7 lbf) loading cycle is the difference between the zero displacement on the loading portion of the 90 N (20.2 lbf) loading cycle and the reference displacement obtained during the preload cycle.
3. total dent depth from all other loading cycles is obtained in a similar fashion as the 50 N and the 70 N loading cycles.
4. total dent depth from the 210 N (47.2 lbf) loading cycle is the difference between the zero displacement obtained in the post-load cycle and the reference displacement obtained during the preload cycle.

4.4.1.3 Interpretation of Critical Denting Load (Dent Initiation Load)

1. For all loading cycles, list maximum load and resultant total dent depth.
2. Compare with company/platform numerical criterion of First Visible Dent Depth.
3. Using the first maximum load/resultant total dent depth pair having a total dent depth greater than the First Visible Dent Depth and the last maximum load/resultant total dent depth pair having a total dent depth less than the First Visible Dent Depth, perform a linear regression of maximum load against resultant total dent depth.

NOTE—This linear regression will be performed on a total of two maximum load / resultant total dent depth pairs determined from testing. These two pairs are chosen so that the company/platform definition of First Visible Dent Depth is in the center of the two values of resultant total dent depth.

4. Using the equation generated from the linear regression, estimate the dent initiation load using the company/platform definition of First Visible Dent Depth.

4.4.1.4 Deflection Under Load

The deflection under load shall be measured at loads of 50 N, 100 N, and 150 N. The deflection under load shall be measured as the difference in the associated displacement readings obtained at the 5 N and (50 N, 100 N, or 150 N) load values from the (50 N, 100 N, or 150 N) loading cycle. If the data recorded does not capture displacement values at exactly 5 N and (50 N, 100 N, or 150 N), linearly interpolate the displacement value using the data point pair above and below the 5 N and/or the (50 N, 100 N, or 150 N) load reading.

4.4.1.5 Initial Stiffness

The initial stiffness shall be determined by a linear least squares fit to the load-displacement data from loads between 10 and 25 N, inclusive, on the 50 N loading cycle (see Figure 3).

4.4.1.6 Load at Minimum Slope

1. Compute first derivative of load versus displacement curve against displacement (i.e, $dF/d\delta$ versus δ) (see Figure 4B).
2. The load corresponding to the minimum value on the $dF/d\delta$ versus δ curve is the Load at Minimum Slope.

4.4.2 HARD OIL CAN EVALUATION TEST

Two types of “oil canning” behavior are recognized. In the first type of oil canning, as the indenter is pressed into a panel, after some initial deflection accompanied by a monotonically increasing load, a drop in the load required for a further deflection may occur (Figure 4A, Curve A). This is referred to as "hard” or “snap-through” oil can, and the oil canning load is defined by the point where the slope of the load-displacement curve (that is, the instantaneous stiffness) first reaches a value of zero.

In the second type of oil canning the slope of the load-displacement curve exhibits a local minimum but remains positive (Figure 4A, Curve B). This is referred to as "soft" oil can, and the oil canning load is defined by the point where the slope of the curve reaches the minimum.

Oil canning is known to be a phenomenon that is dependent on the part geometry, stiffener placement, and panel support. For these reasons, an oil canning load determined on a generic laboratory panel as described in Section 7 may not be similar to one determined on an assembly or a full vehicle. Furthermore, to ensure that any permanent deformation occurring in incrementally loaded panels does not affect measured oil canning loads, it is suggested that only a single-load cycle be used when determining oil canning loads.

When triplicate samples are available, an incremental loading cycle applied to one panel can be used to determine the location and maximum load to be used for the single-load cycle evaluation on subsequent panels. The maximum load for the single-load cycle will be that load determined from the incremental loading cycle that is sufficiently high to capture the oil canning event. When triplicate samples are not available, hard oilcan results from incremental loading cycles will be reported.

Frequently some type of data smoothing technique (such as the spline or Loess techniques) may be necessary to obtain a clearly defined derivative function for the load-stroke curve. If so, the particular technique used should be noted.

4.4.2.1 Initial Stiffness

The initial stiffness shall be determined by a linear least squares fit to the load-displacement data from loads between 10 and 25 N, inclusive, on the 50 N loading cycle (see Figure 3).

4.4.2.2 Determination of Oil Canning Load:

1. Compute first derivative of load versus displacement curve against displacement (i.e, $dF/d\delta$ versus δ) (see Figure 4B).
2. If the minimum value on the $dF/d\delta$ versus δ curve is negative, then the load at which this curve first crosses the horizontal axis (the lowest displacement where $dF/d\delta = 0$) is the oil canning load. This is called a "hard" oil can.
3. If the minimum value on the $dF/d\delta$ versus δ curve is never negative, then the load corresponding to the minimum value on the $dF/d\delta$ versus δ curve is the oil canning load. This is called a "soft" oil can.
4. To determine severity of soft oil can, determine "X" as per instructions in Appendix B.
5. Some panels will oil can at more than one load. All oil canning events should be reported.

4.5 Full Dent Characterization

Studies have shown that dent depth and customer visual perception of a dent do not always correlate. Customer perception of a dent is related to numerous factors such as local panel curvature, paint color, dent area, and dent volume, in addition to the dent depth. Since panel curvature and paint color are usually fixed, full dent characterization should include the determination of dent depth, area, and volume. Use of a coordinate measuring machine (CMM) is a costly, slow method to achieve dent characterization. A preferred method is to generate a three-dimensional non-contact optical profile of the dent. This method allows for accurate, objective, and repeatable measurements of the entire dent, not just the dent depth.

4.5.1 THREE - DIMENSIONAL DENT PROFILING EQUIPMENT - SYSTEM REQUIREMENTS

Minimum Diameter of Analysis area:	102 mm (4 in)
Resolution in direction of indentation:	< 0.013 mm (0.0005 in)
Accuracy in direction of indentation:	0.010 mm (0.0004 in)
Resolution in plane normal to indentation:	< 0.38 mm (0.015 in)
Accuracy in plane normal to indentation:	± 0.13 mm (0.005 in)

4.5.2 PANEL PREPARATION

Laser systems have the best resolution when the detector receives the greatest signal back from the sample surface. Some laser systems work best if the sample surface is painted white, while painted black surfaces work best with other systems. As such, the user should first determine the appropriate paint color for laser surface analysis and prepare test samples accordingly. The surfaces to be analyzed with a laser-based system should be cleaned and painted before the initial dent is made on the panel. If production paint facilities are not available, it is acceptable to apply a light uniform spray coating (using, for example, Krylon™) to the surface. The paint method and paint color should be noted in the test report (see 4.6).

4.5.2.1 Effect of Paint on the Denting Process

Although a painted surface is preferred for optical analysis of the dent, the actual effect of the paint on the denting process is not known. The properties of all coatings above the cold rolled steel surface (including the layers of galvanized zinc/zinc alloy, phosphate, electroprimer, color-coat, and clear-coat) will likely affect denting results in an as-yet undetermined manner. As such, a valid comparison of denting parameters between two panels is possible only under similar panel coating conditions.

4.5.3 ANALYSIS AREA

For dent characterization using a laser based system, an analysis area of 102 mm x 102 mm (4 in x 4 in) shall be used.

4.6 Records and Reports

A typical test report meeting all requirements of this standard is shown in Table 1. This report shall include pertinent denting parameters (noting if these parameters were obtained using in-situ measurements from load cells and displacement transducers or during post-test evaluations using a laser-based system), mechanical properties (both from the initial [unformed] blank and from the formed [and baked, if appropriate] part), and paint application parameters (e.g., spray can application versus production paint cycle, and paint color).

TABLE 1—SAMPLE TEST REPORT

Dent Test Information

Type of sample:	Generic pan, outer skin, assembly, full vehicle
Sample fixturing technique:	Recommended generic pan fixture, body panel cradle, hard-fixtured to rigid surface, panel attachment hardware to rigid surface.
Test speed:	0.1 inper minute to 100 miles per hour.

Dent Test Parameter	How Measured?	Load Cycle 1	Load Cycle 2	Load Cycle 3	Load Cycle 4
Load (lbf)	LC	15	30	45	60
Dent Depth (in)	DT	0.003	0.006	0.009	0.012
Maximum Displacement (in)	DT	0.098	0.213	0.302	0.393
Initial Stiffness (lbf/in)	LC/DT	652	628	610	598
Oil Canning Load (lbf)	LC/DT	N/A	19	20	20
Secondary Stiffness (lbf/in)	LC/DT	N/A	153	175	164
Final Stiffness (lbf/in)	LC/DT	522	442	490	521
Energy Applied (in-lb)	LC/DT	2.6	4.0	6.4	8.3
Energy Absorbed (in-lb)	LC/DT	0.3	0.5	0.9	1.2
Dent Area (in2)	NCSC	0.063	0.148	0.212	0.563
Dent Volume (in3)	NCSC	0.00019	0.00067	0.00142	0.00528

LC = Load cell; DT = Displacement transducer; NCSC = Non-contact surface contour

Mechanical Properties	Initial (flat) blank	Formed
Orientation with respect to rolling or stamping direction	longitudinal	longitudinal
Gauge (in)	0.031	0.028
Surface Strain (%, major x minor)	N/A	2.3 x 2.1
Yield Strength (ksi)	31.2	49.7
Tensile Strength (ksi)	52.6	55.6
Total Elongation (%)	36.5	22.4
Uniform Elongation (%)	20.7	5.6
Yield Point Elongation (%)	0.0	0.0
Normal Plastic Anisotropy (R-Value)	1.97	n/a
Strain Hardening Exponent (n-Value)	0.207	n/a
n-Value Determination (e.g., full curve, 10%-20%, etc.)	10% to unif. elong.	n/a
Strength Coefficient [K-Value] (ksi)	97.1	n/a

Painting Information

Production paint cycle or spray painted?	production paint cycle
Paint Color	white
Material layers on top of steel surface	electrozinc, phosphate, electrodeposited primer (ELPO), white basecoat paint, clear topcoat

5. Dynamic Dent Evaluations: General Requirements and Test Procedure

5.1 Discussion of Dynamic Indenting Conditions

There are only limited dent evaluation facilities in existence that have the capability of recording the entire load-displacement cycle during a dynamic impact occurring at velocities greater than 2 miles per hour. As a result, most locations interested in dynamic dent evaluations will use a drop weight, pendulum, or air gun to fire a projectile at the test surface. Although this type of testing does not facilitate measuring and recording the complete load-displacement cycle, the impacting energy is known or can be calculated, and it is possible to measure the dent depth after impact.

It is known that sheet steels are strain rate sensitive and the strength of sheet steels increases when the deformation rate increases. Therefore, the dent resistance of sheet steels depends upon the indenting speed used in the test. The same amount of energy generated at different indenting speeds would result in different dent depths. In order to minimize the strain rate effect during dent tests, a constant speed should be maintained when the purpose of dent tests is not to study the dent testing speed effect.

Although dynamic denting characteristics may be evaluated using either a simple drop weight test or a hydraulically controlled test machine coupled with a high speed data acquisition system recording load and displacement data, it is important to distinguish differences between the two approaches. The energy generated in the drop-weight test or the air gun type of test is kinematic energy which depends upon the velocity and indenter mass. Usually, different amounts of energy are achieved (through changes in the indenter velocity) by varying the drop heights in the drop weight test or varying the air-pressures in the air-gun test. When the drop-weight test or the air-gun test is used for the evaluation of dent resistance, it is recommended that different indenter masses be used to achieve different amounts of energy instead of the drop heights or air pressures in order to minimize the speed effect mentioned above.

In hydraulically controlled test machines, the applied energy is calculated from the area under the load-displacement curve, with the applied load directly relating to the deformation work involved in making the dent. In drop-weight and air gun tests, much of the applied energy is converted to the deformation work that causes a dent in the test specimen. However, a percentage of the applied energy in drop-weight or air gun tests is also dissipated as heat. Unless the portion of the impact energy that contributes to deformation work can be isolated, users of dynamic dent test data are cautioned against doing a direct comparison of results obtained from different test methods.

5.2 General Requirements for Dynamic Denting

5.2.1 TEST FRAME

See 4.2.1.

5.2.2 TEST ACTUATOR

5.2.2.1 Testing on Equipment Which Can Measure and Record Complete Load-Displacement Loading and Unloading Cycle

See 4.2.2.

5.2.2.2 Testing on Equipment Which Can Measure and Record Only Impacting Energy and Final Dent Depth

Not applicable.

5.2.3 SYSTEM STIFFNESS

The system must be sufficiently rigid to minimize deflection at a load of 222 N (50 lbf). Round robin testing of generic experimental panels under quasi-static conditions using frames with stiffness values ranging from 1.23 N/m x 106 N/m (7 lbf/in x 103 lbf/in) to more than 1.75 N/m x 107 N/m (1 lbf/in x 105 lbf/in) produced satisfactory results. If the test frame stiffness is suspect, then an external reference point must be used for panel deflection measurements.

5.2.4 INDENTER DESCRIPTION

5.2.4.1 Testing on Equipment Which Can Measure and Record Complete Load-Displacement Loading and Unloading Cycle

A Type I hard indenter (see 4.2.4.1) may be considered typical. Alternative indenter shapes may also be used to address specific real-world denting phenomena.

5.2.4.2 Testing on Equipment Which Can Measure and Record Only Impacting Energy and Final Dent Depth

Alternative (shape, material, and mass) indenters may be used to generate different energy levels for a drop weight, pendulum, or air gun type test.

5.2.5 SPEED OF TESTING

5.2.5.1 Testing on Equipment Which Can Measure and Record Complete Load-Displacement Loading and Unloading Cycle

A constant actuator speed greater than 894 mm ± 90 mm per second (2 mile/hour or 35.2 in± 3 inper second) will be used during both the loading and unloading portions of the test and will be recorded.

5.2.5.2 Testing on Equipment Which Can Measure and Record Only Impacting Energy and Final Dent Depth

The impacting energies within a given sequence should encompass both the low and high energy levels that are of interest to the user (see 5.3.2, Note 1).

5.2.6 SYSTEM PERFORMANCE

5.2.6.1 Testing on Equipment Which Can Measure and Record Complete Load-Displacement Loading and Unloading Cycle

See 4.2.6.

5.2.6.2 Testing on Equipment Which Can Measure and Record Only Impacting Energy and Final Dent Depth

The angle of load input to the panel shall be perpendicular to the surface at the point of first contact within 2.5 degrees, and continue on this angle throughout the test without shifting or skidding along the surface of the panel.

5.2.7 DISPLACEMENT TRANSDUCER

5.2.7.1 Testing on Equipment Which Can Measure and Record Complete Load-Displacement Loading and Unloading Cycle

See 4.2.8.

5.2.7.2 Testing on Equipment Which Can Measure and Record Only Impacting Energy and Final Dent Depth

The displacement transducer used to measure dent depth shall have a resolution of 0.013 mm (0.0005 in) or better.

5.2.8 CALIBRATION

See 4.2.9.

5.2.9 ADDITIONAL HARDWARE REQUIRED

5.2.9.1 Testing on Equipment Which Can Measure and Record Complete Load-Displacement Loading and Unloading Cycle

See 4.2.10.

5.2.9.2 Testing on Equipment Which Can Measure and Record Only Impacting Energy and Final Dent Depth

Not applicable.

5.3 General Test Procedure - Dynamic Dent Testing

5.3.1 TESTING ON EQUIPMENT WHICH CAN MEASURE AND RECORD COMPLETE LOAD-DISPLACEMENT LOADING AND UNLOADING CYCLE: TEST SEQUENCE (SEE ALSO FIGURE 2)

1. Calibrate testing system as required (see 5.2.8).
2. Mount test specimen (e.g., body panel) in test frame.
3. Mark test location on test specimen.
4. Wipe the test location using a clean cloth to remove any extraneous dirt from the test location.
5. Align actuator normal to surface at test location (see 6.1.6).
6. Apply a preload to 7 N (1.57 lbf) and record the load-displacement history. This loading sequence establishes the displacement, which is the reference value from which all other displacement readings are determined. Unload back to zero N (0 lbf).
7. Record load versus displacement history as sample is indented with 0.2 J (1.77 in-lbf) impact energy at a constant speed and retracted back to zero J.
8. Apply a post load to 7 N (1.57 lbf) at a speed of 50.4 mm (2 in) per minute and record load-displacement history. Unload back to zero N (0 lbf).
9. Record load versus displacement history as sample is indented with 0.3 J (2.66 in-lbf) impact energy at a constant speed and retracted back to zero J.
10. Apply a post load to 7 N (1.57 lbf) at a speed of 50.4 mm (2 in) per minute and record load-displacement history. Unload back to zero N (0 lbf).
11. Record load versus displacement history as sample is indented with 0.4 J (3.54 in-lbf) impact energy at a constant speed and retracted back to zero J.
12. Apply a post load to 7 N (1.57 lbf) at a speed of 50.4 mm (2 in) per minute and record load-displacement history. Unload back to zero N (0 lbf).
13. Record load versus displacement history as sample is indented with 0.5 J (4.43 in-lbf) impact energy at a constant speed and retracted back to zero J.
14. Apply a post load to 7 N (1.57 lbf) at a speed of 50.4 mm (2 in) per minute and record load-displacement history. Unload back to zero N (0 lbf).

NOTE 1—This indenting sequence listed (0.2, 0.3, 0.4, and 0.5 J) is only a suggestion. The impacting energies within a given sequence should encompass both the low and high energy levels that are of interest to the user.

NOTE 2—If it is desired and possible with the equipment in use, a displacement sequence (i.e., impacting until 2.5, 5.0, 7.5, and 10.0 mm [0.10 in, 0.20 in, 0.30 in, and 0.39 in] maximum displacements) may be used instead of an energy sequence.

NOTE 3—If the dent depth after one specific energy increment is desired, a single impact cycle is sufficient providing a preload and post load are also used to determine dent depth. A slow speed must be used in pre- and post-loading to avoid dynamic effects.

NOTE 4—The effects of a painted rather than an unpainted sample surface on the test results are not known. In addition, the effect of the paint thickness on the test results is not known. However, there are cases where a painted surface is desired (see 4.5.2.1).

5.3.2 TESTING ON EQUIPMENT WHICH CAN MEASURE AND RECORD ONLY IMPACTING ENERGY AND FINAL DENT DEPTH: TEST SEQUENCE (SEE ALSO FIGURE 2)

1. Calibrate testing system as required (see 5.2.8).
2. Mount test specimen (e.g., body panel) in test frame.
3. Mark test location on test specimen.
4. Wipe the test location using a clean cloth to remove any extraneous dirt from the test location.
5. Measure panel height on test location. This height is the reference value from which all dent depth readings are determined.
6. Align panel such that the surface at the test location is normal to the path of the indenter (see 6.1.6).
7. Use a ball/pendulum/air gun to impact the sample with an indenting energy of 0.2 J (1.77 in-lbf). If possible, measure and record the rebound energy. Do not allow the indenter to strike the panel a second time.
8. Measure and record the dent depth from the 0.2 J impact.
9. Use a ball/pendulum/air gun to impact the sample with an indenting energy of 0.3 J (2.66 in-lbf). If possible, measure and record the rebound energy. Do not allow the indenter to strike the panel a second time.
10. Measure and record the dent depth from the 0.3 J impact.
11. Use a ball/pendulum/air gun to impact the sample with an indenting energy of 0.4 J (3.54 in-lbf). If possible, measure and record the rebound energy. Do not allow the indenter to strike the panel a second time.
12. Measure and record the dent depth from the 0.4 J impact.
13. Use a ball/pendulum/air gun to impact the sample with an indenting energy of 0.5 J (4.43 in-lbf). If possible, measure and record the rebound energy. Do not allow the indenter to strike the panel a second time.
14. Measure and record the dent depth from the 0.5 J impact.

NOTE 1—This indenting sequence listed (0.2, 0.3, 0.4, and 0.5 J) is only a suggestion. The impacting energies within a given sequence should encompass both the low and high energy levels that are of interest to the user. The lowest impact energy used should be the energy that first creates a measurable dent. Limited testing on one specific geometry and material has found this energy to be approximately 0.2 to 0.3 J.

NOTE 2—If the dent depth after one specific impacting increment is desired, a single impact at a given energy level is sufficient.

NOTE 3—The effects of a painted rather than an unpainted sample surface on the test results are not known. In addition, the effect of the paint thickness on the test results is not known. However, there are cases where a painted surface is desired (see 4.5.2.1).

5.4 Data Analysis

5.4.1 Testing On Equipment Which Can Measure And Record Complete Load- Displacement Loading and Unloading Cycle

The techniques to calculate panel performance characteristics (dent depth, initial stiffness, load at minimum slope, applied energy and absorbed energy) under dynamic impacting conditions where the complete load/displacement curve is measured and recorded are the same techniques described in 6.3 for quasi-static denting, incremental dent resistance evaluation. A data noise reduction procedure such as the Fourier Transform method may be helpful to reduce or eliminate the noise in the data for the calculation of the load at minimum slope and the various stiffness parameters.

5.4.1.1 Determination of "Zero" Displacement at 5 N

The displacement associated with the 5 N load obtained during the preload sequence is defined as the reference displacement value. During the post load sequence this value is defined as the zero displacement. The actual displacement value for the 5 N load will be determined by linearly interpolating displacement values between all data point pairs collected between 3 N and 7 N.

5.4.1.2 Determination of Resulting Dent Depth

(See Section 3 [Definitions])

The total dent depth on any given impact cycle is obtained as the difference between the reference displacement and the zero displacement. For any given impact cycle, the reference displacement is determined on the preload cycle described in 6.2.1 Step 6, and the zero displacement is determined on the post-loading cycle following the impact cycle under consideration.

5.4.2 Testing On Equipment Which Can Measure And Record Only Impacting Energy And Final Dent Depth

The only panel performance parameters that can be measured are dent depth and impacting energy. If the rebound height was measured, then the absorbed energy can be calculated.

5.5 Full Dent Characterization

See 4.5.

5.6 Records and Reports

See 4.6

6. Procedure Specifics for Laboratory Prepared Panel

6.1 Test Description

The laboratory panel for the quasi-static and dynamic dent performance procedures includes the effects of both geometry (i.e., curvature) and material properties. The panel geometry was selected in order to include the important elastic response characteristics that are necessary for correlation to automotive body panel performance. Based on the known geometry dependence of oil canning load determination, it is not recommended to use these laboratory prepared panels to obtain an oil canning load for real-world application. The oil canning load obtained from the laboratory prepared panel should just be used for ranking of materials.

6.2 Sample Envelope (X x Y x Z)

6.2.1 INCREMENTAL DENT RESISTANCE EVALUATION TEST

305 mm x 305 mm x 51 mm (12 in x 12 in x 2 in)

6.2.2 HARD OIL CAN EVALUATION TEST

305 mm x 127 mm x 51 mm (12 in x 5 in x 2 in)

6.3 Specimen Description

Rectangular blank specimens shall be obtained from flat sheet material. Specimen length is 305 mm (12 in). The Incremental Dent Resistance specimen is 305 mm (12 in) wide (fully constrained) while the Hard Oil Can Evaluation specimen is 127 mm (5 in) wide. The flat sheet specimen shall be stamped into general shallow panel samples using the tooling described below.

6.3.1 PANEL FABRICATION

The Incremental Dent Resistance specimen panel will be stamped in the fully locked out condition with a punch having 940 mm (37 in) radius of curvature to achieve a 2% biaxial stretch. All punch and die radii shall be 13 mm. A formed generic panel is presented in Figure 5A with dimensions presented in Figure 5B. The degree of biaxial stretch in the stamping is established by a 100 mm circle scribed in the center of the blank.

The Hard Oil Can Evaluation specimen panel is produced on the same punch as the Incremental Dent Resistance specimen panel. The panel is centered over the punch and stamped to the same punch depth setting as determined necessary to achieve the 2% biaxial stretch for the Incremental Dent Resistance specimen panel.

6.3.1.1 Blank Dimensions

If “stinger” gripper beads are used to lock the panel (see 6.3.1.2), then a blank having dimensions of 305 mm (12 in) x 305 mm (12 in) is sufficient. Other bead designs may require larger blanks to accommodate the specific locking bead design.

6.3.1.2 Achieving Complete Panel Lockout

Although complete panel lockout can be achieved with various bead configurations (such as square, “V”, or step) this procedure recommends, but does not require, the use of “stinger” gripper beads. The advantages of this bead over other bead configurations are that panels made using stinger beads will not have wrinkles, are easier to clamp, and may allow for the use of smaller blanks.

The stinger beads are described in detail in United States Patent No. 4,576,030

For either a stinger bead design or the more conventional bead geometry (i.e., square, “V”, or step), a blank holder force of approximately 60 tons is required to achieve complete lockout of the panel described in Figure 5.

6.3.1.3 Biaxial Stretch as a Function of Draw Depth

It is possible to change the panel stiffness and formed strength by changing the punch shape and draw depth. Table A2 is provided for information only to aid in future studies that may vary punch shape and draw depth to obtain different panel characteristics and, as a result, different denting behavior.

The values in Table A2 were developed from a two-dimensional finite element computer model and are valid only for the panel shape shown in Figures 5 & 6 (940 mm punch radius, 13 mm internal radii). The strain values listed in Table A2 are approximations only, with deviations from this table possibly due to changes in tooling, friction, lubrication, etc. compared with the conditions assumed for the model. It is recommended that the 100 mm circular scribe on the flat blank be used in all cases to establish the degree of biaxial stretch as a function of punch depth (see 6.3.1).

6.3.2 TOOLING DESCRIPTION

The surface of the punch, radii, and beads shall have at least a 400 grit emery finish.

Engineering drawings of the tooling required to produce the generic panels are presented in Figure 5.

6.4 Number of Replicate Tests

It is recommended that the minimum sample size consists of three replicates.

6.5 Boundary Conditions

The standard specimen shall be firmly clamped along the flat region just inside the stinger beads or the lock beads. This may be accomplished using a ring that fits within the flat region, but DOES NOT come in contact with the side wall of the standard specimen (see Figure 8). This ring can then be clamped onto a solid, flat surface during the testing sequence. The supporting table for the specimen shall be sufficiently rigid to ensure that there is no measurable contribution to the overall displacement of the specimen during the test (see 5.3). If the sample is properly clamped, the stinger/lock beads and the flanges will not move during the dent testing.

This sample has a flat binder, and when clamped around the periphery, may cause an air pocket to be formed under the sample. To be sure that the fixed air volume does not contribute additional resistance that can affect dent resistance, a vent hole should be drilled in the clamping surface to allow for equalization of air pressure during the test.

6.6 Testing Location

The load/displacement characteristics for the generic panel shall be determined by applying the load at the center of the panel. Loading is required to be directed normal to the surface at this location (see 5.3).

It is recommended that surface strains be recorded to aid in the comparison of dent resistance of materials. Whenever possible, surface strain analysis using a 100 mm diameter circle should be performed at the dent test location to confirm that a 2% biaxial stretch was achieved. A less desirable alternative is to use ultrasonic thickness measurements taken at the pole and flange positions to compute the thickness strain of the formed panel. However it is possible to compare two specific panels on a relative basis without performing the surface strain analysis.

6.7 Loading Sequence

A suggested loading sequence for the laboratory prepared panels is nine loading/unloading cycles with maximum loads of 50, 70, 90, 110, 130, 150, 170, 190, and 210 N (11.2, 16.9, 22.5, 28.1, 33.7, 39.3, 45.0, and 50.6 lbf), respectively.

7. Procedure Specifics for Automotive Components

7.1 Test Description

This procedure covers the evaluation of quasi-static and dynamic dent performance of fully formed automotive body panels and assemblies. It is intended for use as an aid in integrating and optimizing design, structure, and material panel considerations early in the vehicle design cycle.

7.2 Typical Sample Envelopes (X x Y x Z)

As needed to accommodate vehicle component and support cradle (approximately 1830 mm x 1830 mm x 610 mm [72 in x 72 in x 24 in).

7.3 Number of Replicate Tests

This schedule is typically used to evaluate advanced prototypes. Specimen availability and cost usually limits testing to a single sample of each design configuration. Testing of triplicate samples is recommended whenever possible.

7.4 Test Locations

Multiple locations will be tested on most body panels. Care must be taken that panel deformation around one dent location does not affect the out come of a dent test elsewhere on the panel. Distance between test locations may be as small as 2 in or as large as 10 in and must be assessed on a case by case basis.

The specific test locations will be chosen based on unique specimen geometry requirements and the likelihood that a given area will be dented by a customer in service. Examples are:

Door handle areas:	Thumb or palm printing
Mid quarter panel:	Shopping cart or plant handling damage areas
Front hood or decklid:	Palm pressure areas used when closing
Fender top:	Mechanic elbow marks
Door panels:	Areas likely to receive hip closing loads

7.5 Additional Hardware Required

7.5.1 BOUNDARY CONDITIONS

Closely controlling panel boundary conditions results in improved part-to-part test repeatability. Three recommended methods of sample fixturing are described in this section. No single laboratory test condition on a body component can truly represent conditions that the end customer will encounter on a full in-service vehicle. The test engineer is therefore required to choose the laboratory test set-up that best meets the specific test goals. Multiple means of supporting the test specimen are provided so that similar fixture methods may be used given the same type of test component and available supporting hardware. In all cases, the fixtured component should be supported against a rigid surface that will not allow the fixtures to degrade the overall test system stiffness (see 5.2.3).

7.5.2 FIXTURING A BODY ASSEMBLY (PARTIAL)

This method assumes that the test component is a partial assembly (i.e., untrimmed / unassembled outer body panel or assembly without internal attachment components) and can not be supported from actual body mount or seal surface locations. Outer panel specimens should be attached to a cradle at representative weld flange areas using screws to simulate spot welds at all design intent spot weld locations. If applicable, MIG (metal inert gas) braze, spot welds and/or adhesive may also be used as a means of fastening the panel to the cradle. Untrimmed outer panels should be attached to a cradle using screws approximately every 2 inadjacent to the first design intent break in the panel. Typically the support cradle is made of hard wood or steel and utilizes a plastic splash to allow a continuous cradle-to-panel contact where applicable. Assemblies which have both inner and outer panels (but are internally incomplete) are to be supported from the inner panel side of the assembly allowing the outer "test" panel to move unrestrained by the cradle.

7.5.3 FIXTURING A BODY ASSEMBLY (UNFINISHED) OR BODY ASSEMBLY (FINISHED) USING HARD FIXTURING

This method assumes that the test component (i.e, door, hood, decklid etc.) has all design intent attachment points available, but representative attachment hardware is not used. "Hard fixturing" refers to metal-to-metal contact between the test component, fabricated fixture brackets and the bedplate. With this fixturing method no possibility for metal motion relative to panel attachment is possible in any direction. The elimination of the effects of panel attachment hardware (i.e, hinges and striker) allows for an improved comparison of materials and component assembly construction.

7.5.4 FIXTURING A BODY ASSEMBLY (FINISHED) USING ATTACHMENT HARDWARE

The finished body panel assembly shall be supported by design intent hardware at the panel attachment points (i.e, use latches at the latch points, hinges at the hinge points and over slam bumpers where appropriate). The body side of the hardware shall be rigidly affixed to fixtures which position the panel parallel to the bed plate (i.e, ground plane). Design intent fasteners shall be used on the test panel side of the hardware. Nominal fastener torque levels should be used. To improve test repeatability it is important that body panel positioning adjustments be done as consistently as possible (i.e, proper over slam bumper height and hardness, as well as latch clearance adjustment)

7.6 Test Procedure (5.3 and 7.1)

If the test panel is built into an assembly (i.e, door, rear compartment lid or hood assembly), the test specimen should be equipped with all applicable structural components, adhesives, sprayable stiffeners and expandable sealants to represent the design level being evaluated. Unless the test is to evaluate an in-process level specimen, for plant handling applications, the assembly should received the proper bake cycle and curing cycle to simulate proper responses of bake-hardenable steels and adhesives incurred in normal production.

7.7 Report

Disclose in the comments section of the report any supplemental structural materials (i.e, sprayable stiffeners, braces or beta patches) which were used on any of the samples tested.

8. Procedure Specifics for Full Vehicles

8.1 Test Description

This procedure covers the evaluation of quasi-static and dynamic dent performance from a systems or end user point of view. It is intended for use as a means of validating a given overall product design and predicting customer dent resistance quality perceptions based on a quantifiable test method.

8.2 Specimen Description

A fully trimmed and painted passenger car or light truck. All exterior body panels should be evaluated (i.e., hoods, decklids, roofs, fenders, rear quarters, doors, tailgates, and cargo boxes). A high gloss black production painted finish is recommended for all panels that will be used for subjective comparisons. If an optical method will be used to analyze the panel, a high gloss white production painted finish is recommended.

8.3 Typical Sample Envelope (X x Y x Z)

As needed to accommodate full size test surfaces mounted to a representative test vehicle. A full size light truck or van would require an area approximately 5320 mm x 2030 mm x 1520 mm (210 in 80 in x 60 in). Full vehicle dent test systems require compound angular mounting adjustment for the test actuator.

8.4 Number of Replicate Tests

Due to the high cost associated with full vehicle testing, a sample size of one panel specimen (of each particular panel type) is typical. It is recommended that an effort be made to maximize the number of data points tested per vehicle. Each dent location on a given vehicle should be viewed as unique. Symmetrical right and left side dent test points are sometimes improperly grouped or compared resulting in high part-to-part test variability. Left and right side body panels are stamped on different tooling, at different times, usually on different presses, from different material stockpiles and often have asymmetrical design characteristics (fuel tank filler access holes, radio antenna hardware and passenger side sliding doors). Do not assume that a right and left side body panel or the right and left sides of a hood or deck lid are simple mirror images of each other. Substructure differences (i.e, asymmetrical inner panel designs or gum drop patterns) can effect results. For tests repeated on multiple panel specimens, test locations shall be reproduced on the surface of the subsequent panels accurate to 3 mm (0.125 in) radially, relative to the panel edges.

8.5 Boundary Conditions

This is a full vehicle test. Panels should be fully assembled and then installed onto a fully cured and painted representative test vehicle using design intent manufacturing processes, hardware, fasteners, glass, seals, adhesive, sealants, trim and all related sub-components. To eliminate suspension compliance the test vehicle should be rigidly supported such that all wheels are off the ground (e.g., on blocks). Trucks and other vehicles with frames, should be positioned on support blocks located below the body sills. Positioning the blocks under the body rather than the frame eliminates body mount compliance. All panel assemblies should be tested in the closed position with the glass, if applicable, fully raised. All test assemblies should be adjusted for proper body fit-up (i.e, body gaps, hardware alignment and over slam bumper adjustments) before testing.

8.6 Additional Hardware Required

Vehicle options if significant to panel stiffness (luggage racks, spoilers, sunroofs, etc.).

9. Verification of Standard Test Procedures - Stiffness and Dent Load

Round robin evaluations were done using generic panels for the steels listed in Table 3.

TABLE 3—MECHANICAL PROPERTIES OF THE STEELS USED IN THE DENTABILITY R&R.

Description	Thickness	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (ASTM %)	Luders Elongation (ASTM %)	N-value	r-bar
Drawing Steel-1; EG (“DS-1”)	0.625mm/0.65	185	316	41.0	0.0	0.222	1.55
Drawing Steel-2; EG (“DS-2”)	0.78mm/0.846	175	319	43.3	0.0	0.224	1.58
BH250; EG (“BH250”)	0.673mm	n/a	n/a	n/a	n/a	n/a	n/a
IF-Rephos; GA (“IF-R”)	0.739mm/0.71 0.762mm	213	365	36.2	0.0	0.202	1.87

All pie-pans were formed at the same time using the same tooling. The samples were then randomized and sent through a paint-bake cycle (175°C for 20 minutes) to simulate the paint bake cycle process in automotive closure panels. Samples were again randomized and distributed to member companies for dent test evaluations. The latest version of the Standard Procedures was used as the controlling document. Load and deflection were recorded and the parameters calculated included the initial stiffness, the load to generate a 60 µm dent, the load to generate a 100µm dent. In addition, the participating companies reported the displacements at 50 N, 100 N and 150 N. The stiffness and the dent loads are important panel characteristics, while the displacement under load were intended as a check of raw data and overall test repeatability. ASTM Standard E 691 [3] (Standard Procedure for the Determination of the Precision of a Test Method) was used to generate values for Repeatability (r) and Reproducibility (R). Note that "r", the Repeatability Interval, is that interval which can be expected to contain 95% of future differences between two test results obtained within a single laboratory. "R", the Reproducibility Interval, is that interval which can be expected to contain 95% of future differences between two test results from two different laboratories. The complete statistical analysis is presented in the Appendix. A summary of the Repeatability and Reproducibility values is shown in the following table. Note that "r" and "R" values are also presented as a percentage of the average parameter value.

TABLE 4—SUMMARY R&R RESULTS FOR DENTABILITY

RESPONSE	MATERIAL	AVERAGE	r	% r	R	%R
Initial Stiffness	DS-1	144.877	21.159	14.6	40.229	27.8
Initial Stiffness	DS-2	243.255	33.568	13.8	55.174	22.7
Initial Stiffness	BH250	178.590	14.856	8.3	45.854	25.7
Initial Stiffness	IF-R	208.970	36.429	17.4	65.214	31.2
60µm Dent Load	DS-1	81.102	13.890	17.1	15.178	18.7
60µm Dent Load	DS-2	138.952	18.214	13.1	25.624	17.1
60µm Dent Load	BH250	135.768	18.014	13.3	24.491	18.0
60µm Dent Load	IF-R	126.962	16.686	13.1	25.468	20.1
100µm Dent Load	DS-1	93.185	12.875	13.8	16.095	17.3
100µm Dent Load	DS-2	156.720	11.192	7.1	17.413	11.1
100µm Dent Load	BH250	165.611	18.958	11.4	25.855	15.6
100µm Dent Load	IF-R	144.414	15.757	10.9	18.087	12.8

From Table 2, it can be seen that the repeatability of the stiffness and dent load parameters within an individual lab ("%r") for all materials is on the order of 10% to 15%. The reproducibility of the dent load parameter between two different labs ("%R") is on the order of 15% to 20% while that for stiffness is 25% to 30%. The higher value for the stiffness reproducibility may be associated with one of the labs not strictly adhering to the calculation algorithm at is appears in the Standard Procedure.

Oil Canning Load

Because of its geometry, the generic panel did not undergo oil-canning under typical loading conditions. Testing was done to determine a panel design that would result in a sample that does oil can, and could still be produced on the same set of tools that is used for the dent panels. This design takes the 305 mm x 305 mm square blank used for dent testing, and reduces the width of one of the dimensions to 125 mm. This 125 mm x 305 mm blank is centered in the tooling, and produces a panel similar to a Limiting Dome Height (LDH) sample. This formed generic panel is loaded in the same manner as the dent panels. The resulting data of applied load and resulting displacement can be used to generate an oil-canning load, as shown in the Standard Procedures.

Four materials were used to verify the oil canning load procedure. The complete results for this testing can be found in the Appendix. A summary of the Repeatability and Reproducibility values is shown in the following table. Note that “r” and “R” values are also presented as a percentage of the average parameter value.

TABLE 5—MECHANICAL PROPERTIES OF THE STEELS USED IN THE HARD OIL-CANNING R&R.

Description	Thickness	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (ASTM %)	Luders Elongation (ASTM %)	N-value	r-bar
ULC IF	0.7mm	158	317	42	0.0	0.228	2.04
ULC IF	0.8mm	159	310	41.6	0.0	0.228	1.92
DR210 (non BH)	0.75mm	232	375	35.4	0.0	0.205	1.64
DR210 (non BH)	0.8mm	247	384	35.2	0.0	0.204	1.58

TABLE 6—SUMMARY R&R RESULTS FOR HARD OIL-CANNING

RESPONSE	MATERIAL	AVERAGE	R	% r	R	%R
Oil Canning Load	0.7mm ULC	98.59	16.48	16.7	18.83	19.1
Oil Canning Load	0.8mm ULC	150.51	5.41	3.6	7.34	4.9
Oil Canning Load	0.75mm DR210	136.98	3.58	2.6	6.96	5.1
Oil Canning Load	0.8mm DR210	156.37	4.66	3.0	6.83	4.4

From Table 6, excluding material #1, it is seen that the repeatability of the hard oil-canning load within an individual lab (“%r”) for all materials is on the order of 5%, and the reproducibility of the oil canning load parameter between two different labs (“%R”) is approximately 7%. Stamping variability could cause the high % r and % R for material #1.

To put these numbers into perspective, a detailed evaluation of tensile testing was conducted by General Motors in 1997, in which 40 different laboratories participated [4]. The summary results for %r and %R from that report are given in Table 7.

TABLE 7—SUMMARY R&R RESULTS FOR TENSILE PROPERTIES [4]

RESPONSE	MATL. SET	% r	%R
Yield strength	#1	10.4	14.2
Yield strength	#2	10.8	14.3
Yield Strength	#3	11.1	13.1
Tensile Strength	#1	1.5	4.6
Tensile Strength	#2	1.6	4.7
Tensile Strength	#3	1.4	4.3
Total Elong.	#1	7.8	14.2
Total Elong.	#2	5.3	13.7
Total Elong.	#3	6.9	14.5
n-value	#1	5.5	9.8
n-value	#2	6.1	11.2
n-value	#3	6.1	12.6

Comparing Tables 3, 6 and 7 it can be seen that the repeatability and reproducibility of the 0.1 mm dent load is as good as that for the yield strength, which is a commonly accepted material property. A similar comparison for the hard oil-canning load indicates that for the most part, the repeatability and reproducibility is similar to that of tensile strength. As mentioned before, there was significant inter-lab variability in measuring (and calculating) the initial stiffness. During this R&R, it was discovered that one of the labs was not using the most updated procedure. Also, the stiffness determination could be more sensitive to small thickness variations caused by inherent material variability and differences during stamping.

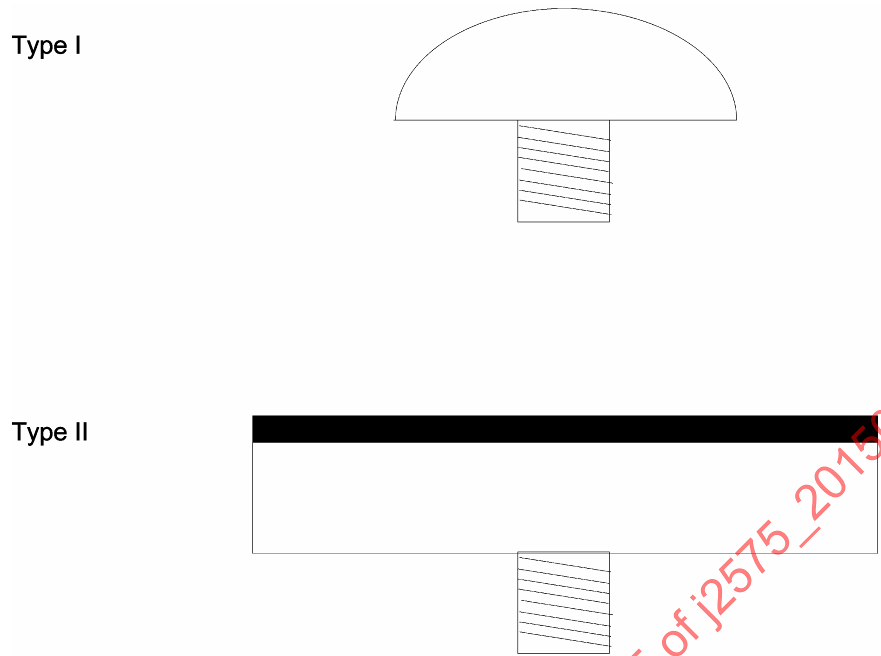

FIGURE 1—TWO TYPES OF INDENTORS

Type I: 25.4 mm (1 in) diameter hemispherical steel ball. Nominal hardness: R_c 55. Nominal average surface roughness: 0.254 µm (10 µ in)

Type II: 50.8 mm (2 in) diameter indenter composed of 6.4 mm (0.25 in) thick 50 durometer pad on top of a steel cylinder.

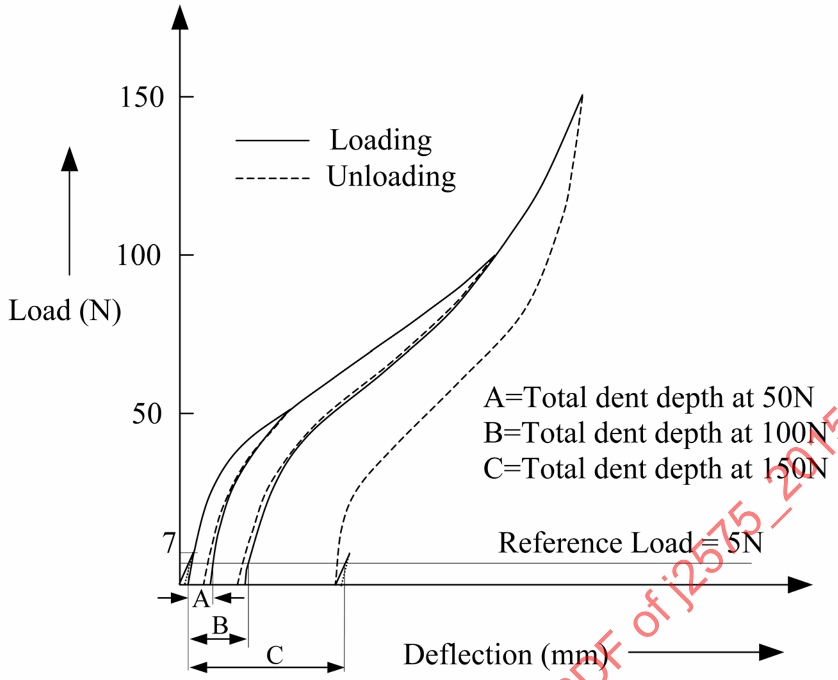

FIGURE 2—SCHEMATIC OF DENT TEST SEQUENCE WHICH CONSISTS OF A PRE-LOAD, THREE LOADING AND UNLOADING CYCLES, AND A POST-LOAD CYCLE. DETERMINATION OF TOTAL DENT DEPTH FOR EACH PRIMARY CYCLE IS ILLUSTRATED.

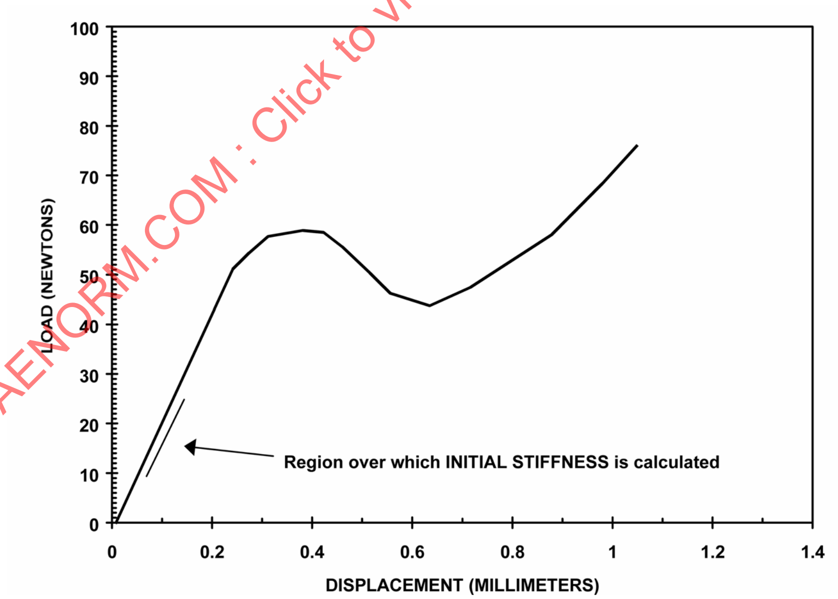

FIGURE 3—SCHEMATIC LOAD-DISPLACEMENT CURVE WHICH HIGHLIGHTS THE REGION OVER WHICH INITIAL STIFFNESS IS CALCULATED. SEE 4, 6.3.1 AND 4.4.2.

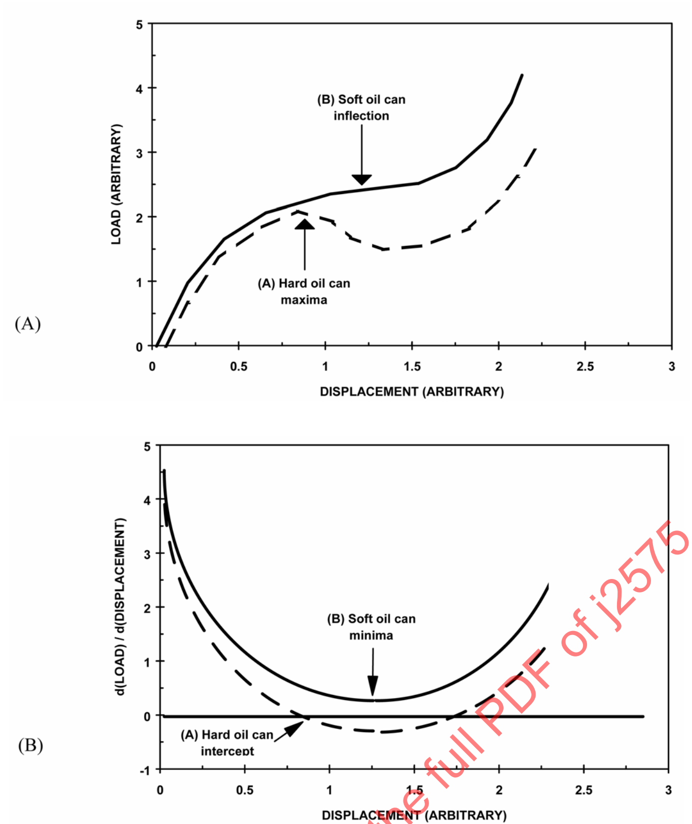

FIGURE 4—SCHEMATIC LOAD-DISPLACEMENT CURVES AND CORRESPONDING DERIVATIVE FUNCTIONS ILLUSTRATING (A) HARD AND (B) SOFT OIL CANNING. SEE 4.4.2.

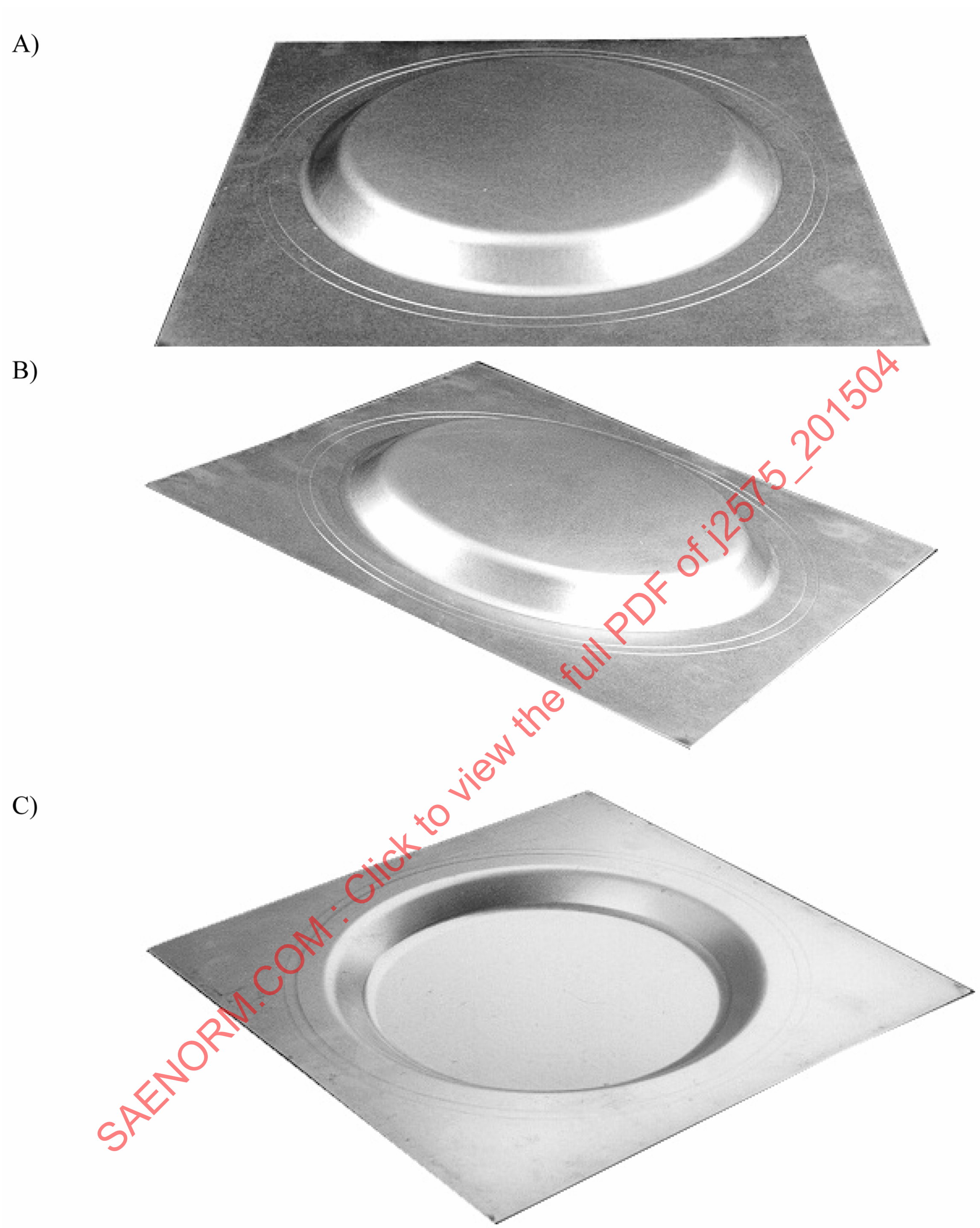

FIGURE 5—LABORATORY-PREPARED GENERIC PANEL.
VIEWS: A) TOP, B) SIDE, C) BOTTOM

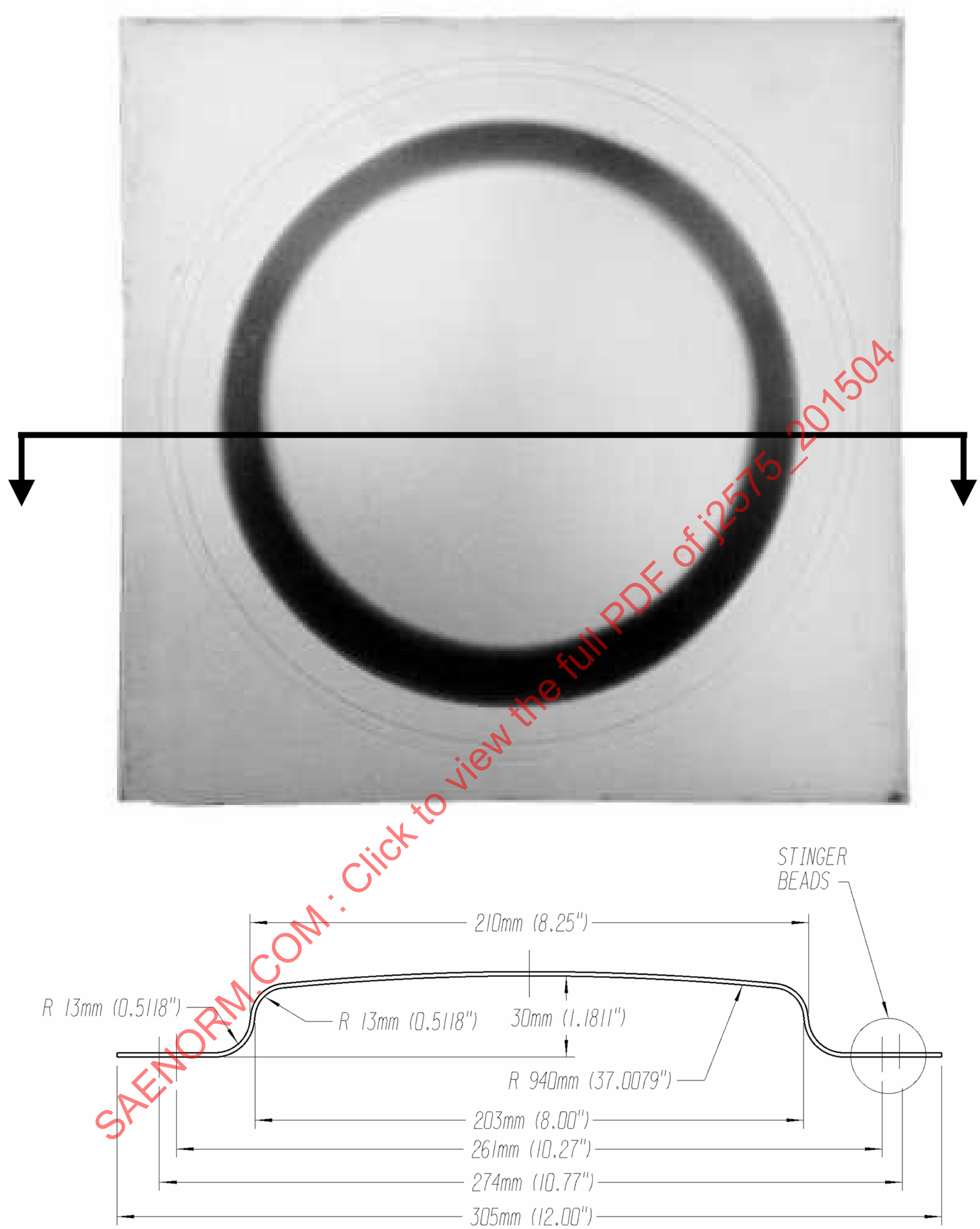

FIGURE 6—DIMENSIONS OF LABORATORY-PREPARED GENERIC PANEL