



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.

SAE Technical Standards Board Rules provide that: “This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user.”

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2015 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE J2575_201504

SAE values your input. To provide feedback
on this Technical Report, please visit
http://www.sae.org/technical/standards/J2575_201504

Documents

Document Sharing Hub

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

1. Report on Steel Body Panel Performance Characteristics, vols. 1&2, Auto/Steel Partnership Dent Resistance Task Force, July 1991.
2. An Interim Report on the Development of Standard Procedures for Quasi-Static Denting, Auto/Steel Partnership, January 1994.
3. ASTM E-691-99 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method.
4. D. C. McCune, Updated Report on the MFD Round Robin on Tensile Properties of Low Carbon Sheet Steel, Memo to A. Pearson, and T. Mackie, A/SP, Southfield, MI, June 1997.
5. The Bake Hardening Steels for Automotive Outer Body Panels: Correlation Between BH Measurement and Dent Resistance, J. L. Christen, J. M. Rubianes, A. Col. 40th MWSP Conference Proceedings, ISS, pp. 77-81.
6. Bake Hardening Effect in Components, M. Blaimschein, K. M. Radlmayr, A. Pichler, E. Till, P. Stiaszny, 19th IDDRG Biennial Congress, Eger, June 1996, pp. 445-458.
7. An Analytical Investigation of Quasi-Static Denting in Sheet Steels, S. Sriram, D. K. Matlock, J. G. Speer. In preparation for submission to the International Journal of Mechanical Sciences.
8. Comparison of Dent Resistance and Shape Fixability Between Bake-hardenable and High r-value Type High Strength Sheet Steel, Y. Omiya, T. Kase, I. Tsukatani and Y. Okano, Sheet Metal Forming Beyond 2000, Proceedings of the IDDRG, 1998, pp. 415-422.
9. Dynamic Dent Resistance Performance of Steel and Aluminum, M. F. Shi, S. J. Zurdosky, SAE Paper 930786.
10. Effect of Prestrain on Aging and Bake Hardening of Cold-Rolled, Continuously Annealed Steel Sheets, W.C. Jeong, Metal. Trans. A, vol. 29A, Feb. 1998, pp. 463-467.
11. The Effects of Flow Stress on the Dent Performance of Sheet Steels, B. J. Allen, D. K. Matlock, S. Sriram, and J. G. Speer, 40th Mechanical Working and Steel Processing Conference, ISS, pp. 83-92.
12. Improvement of Dent Resistance of Auto Body Panels Taking Advantage of the Strain Hardening Properties of Steel Sheets, B. Dauby, P. Magain, R. Kergen, F. Beco, 19th IDDRG Biennial Congress, June 1996, pp. 65-74.

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 indentation 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 1.23×10^6 N/m (7×10^3 lbf/in) to more than 1.75×10^7 N/m (1×10^5 lbf/in) 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 μin). 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 $\pm$ 0.08466 mm per second (1.97in $\pm$ 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).