NASA/TM—2020-220451

DOT/FAA/TC–19/40

# Impact Testing of Inconel 718 for Material Impact Model Development

*J. Michael Pereira, Duane M. Revilock, and Charles R. Ruggeri*
*Glenn Research Center, Cleveland, Ohio*

June 2020

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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## Acknowledgments

The authors would like to thank both Mr. Bill Emmerling (Federal Aviation Administration (FAA), retired) and Dr. Dan Cordasco (FAA) for providing the raw materials for this study and their technical support and advice.

This work was sponsored by the Advanced Air Vehicle Program at the NASA Glenn Research Center



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National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

## Summary

One of the difficulties with developing and verifying accurate impact models is that parameters such as high strain-rate material properties, failure modes, static properties, and impact test measurements are often obtained from a variety of different sources using different materials, with little control over consistency among the different sources. In addition, there is often a lack of quantitative measurements in impact tests to which the models can be compared.

To alleviate some of these problems, a project is underway to develop a consistent set of material property, impact test data, and failure analysis for a variety of aircraft materials that can be used to develop improved impact failure and deformation models. This project is jointly funded by the NASA Glenn Research Center and the Federal Aviation Administration (FAA) William J. Hughes Technical Center. Unique features of this set of data are that all material property and impact test data are obtained using traceable material, the test methods and procedures are extensively documented, and all of the raw data is available. Four parallel efforts are currently underway. The Ohio State University conducts both measurement of material deformation and failure response over a wide range of strain rates and temperatures and failure analysis of material property specimens and impact test articles. The George Mason University conducts the development of improved numerical modeling techniques for deformation and failure. Glenn conducts the impact testing of flat panels and substructures.

This report describes impact testing performed on Inconel 718 sheet and plate samples of different thicknesses with different types of projectiles, one a regular cylinder and one with a more complex geometry incorporating features representative of a jet engine fan blade. Data from this testing will be used in validating material models developed under this program. The material tests and the material models developed in this program will be published in separate reports.

## Nomenclature

| | |
|---|---|
| DIC | digital image correlation |
| FAA | Federal Aviation Administration |
| NGFBF | NASA Generic Fan Blade Fragment |
| $V_{50}$ | velocity at which the probability of penetration is 50 percent |

## 1.0 Introduction

Numerical simulation of dynamic impact events has reached a level of maturity at which it is commonly used as a design tool for a wide variety of aerospace structures such as jet engine containment systems, fan blades, radomes, cowling wings, and empennages. However, current efforts require extensive testing in parallel with modeling and it is often necessary to adjust model parameters somewhat arbitrarily in order that the model fit the test results. Explicit transient finite element modeling of even the simplest of problems, such as a regularly shaped projectile impacting a flat plate can result in widely varying results, depending on the material and failure models, available material properties, the contact models, the mesh density, and a number of different numerical parameters that must be specified in the computer codes.

One of the difficulties with developing and verifying accurate impact models is that parameters such as high strain-rate material properties, failure modes, static properties, and impact test measurements are often obtained from a variety of different sources using different materials, with little control over consistency among the different sources. In addition, there is often a lack of quantitative measurements from impact tests to which the models can be compared.

To alleviate some of these problems, a project is underway to develop a consistent set of material property and impact test data and failure analysis for a variety of materials that can be used to develop improved impact failure and deformation models. This project is jointly funded by the NASA Glenn Research Center and the Federal Aviation Administration (FAA) William J. Hughes Technical Center. Unique features of this set of data are that all material property and impact test data are obtained using traceable material, the test methods and procedures are extensively documented, and all of the raw data is available. Four parallel efforts are currently underway: measurement of material deformation and failure response over a wide range of strain rates and temperatures; development of improved numerical modeling techniques for deformation and failure; ballistic impact testing of flat panels and substructures; and failure analysis of material property specimens and impact test articles.

This report describes impact testing conducted on Inconel 718 sheet and plate samples of different thicknesses and with different types of projectiles, one a regular cylinder and one with a more complex geometry incorporating features representative of a generic jet engine fan blade fragment called the NASA Generic Fan Blade Fragment (NGFBF). The test program described in this report is similar to one conducted on Al 2024 and Ti-6Al-4V sheet and plate samples described in Reference 1. Procedures and results are reported in detail, and information about obtaining raw data is provided. The material properties of this material, measured over a range of temperatures and strain rates will be provided in a separate report.

## 2.0 Methods

Impact tests were conducted on precipitation-hardened Inconel 718 panels with two different areal dimensions, 24- by 24-in. large panel and 15- by 15-in. small panel. The smaller panels were impacted in a normal direction with cylindrical projectiles ranging in diameter from 0.375 to 0.75 in. The larger panels were impacted by the NGFBF as a simplified simulation of a blade impacting a containment structure in an oblique orientation. Different test setups were used for the two sets of impact tests, as described in the following sections. Strains and displacements were measured on the backside of the panels using digital image correlation (DIC) techniques, providing data useful for validating numerical impact models.

### 2.1 Materials

Impact tests for both the small and large panels were conducted on precipitation-hardened Inconel 718 sheet and plate material of the thicknesses shown in Table I. The nominal thickness in the table is the thickness stated on the certification sheet and the actual thickness is based on averages of multiple measurements of the as-received material. The material certification sheets are given in Appendix A. For consistency, future reference to target thickness in this report refers to the nominal thickness of the material.

TABLE I.—TEST SPECIMEN NOMINAL AND MEASURED THICKNESSES

| Thickness | Panels | | | | | | |
|---|---|---|---|---|---|---|---|
| | Small | | | | | Large | |
| Nominal, in. | 0.0500 | 0.08 | 0.125 | 0.250 | 0.50 | 0.0500 | 0.125 |
| Actual, in. | .0495 | .08 | .126 | .263 | .53 | .0495 | .126 |

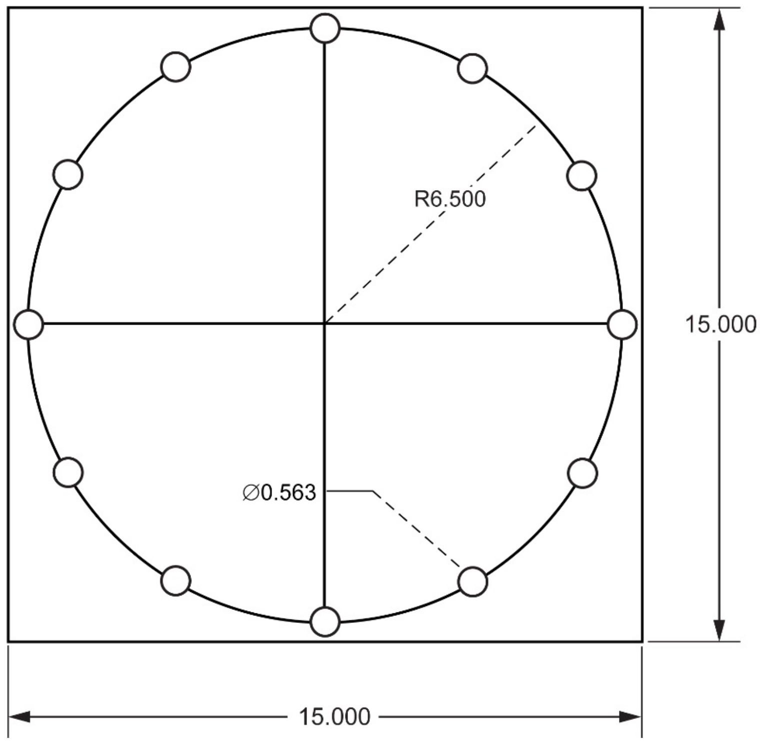



Figure 1.—Small panel test specimen. Dimensions in inches.

The sheet and plate material was received in the annealed condition and precipitation hardened according to the following schedule:

1. Heat to 1,325 °F (718 °C) and hold for 8 h in inert environment.
2. Furnace cool at 100 °F (55 °C) per hour to 1,150 °F (621 °C). Hold for 8 h.
3. Cool in air or argon.

The heat treatment resulted in a hardness of HRC 44 (certification sheet, Appendix B).

## 2.2 Small Panel Test Setup

A minimum of seven ballistic impact tests were conducted on each of the different thickness target panels shown in Table I. The test specimens were cut in squares, 15 in. on a side, with through holes for mounting bolts as shown in Figure 1. The through holes were 9/16 in. in diameter on a 13-in.-diameter bolthole circle. They were held in massive steel fixtures with a 10-in.-circular aperture as shown in Figure 2. The two parts of the fixture were 1.5-in.-thick steel.

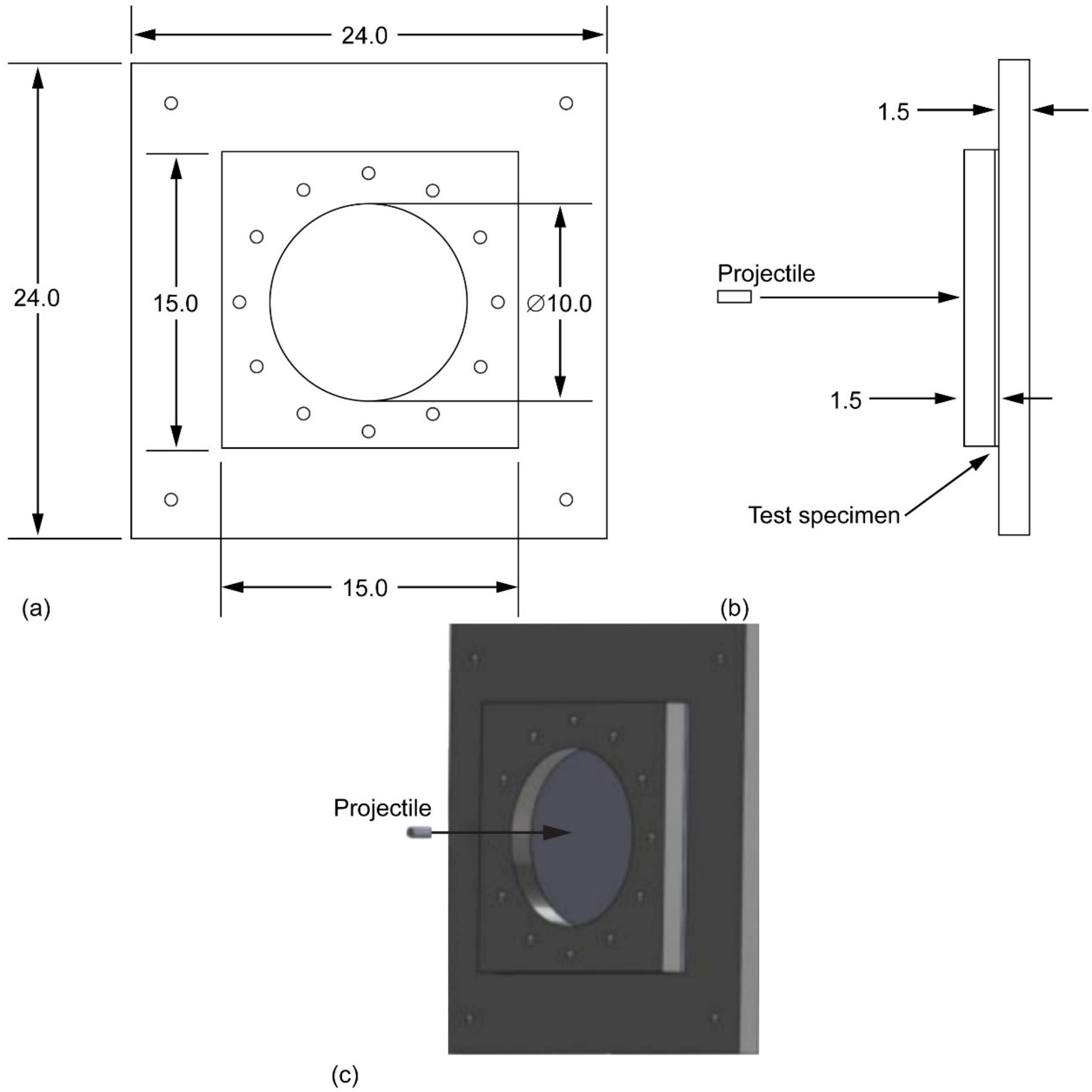


Figure 2.—Test fixture assembly. Dimensions in inches. (a) Front view. (b) Side view. (c) Clamp fixture assembly.

The projectiles were cylindrical with a large radius front face and impacted the plates in a normal orientation at the center of the plate. The only exception to this was with one of the 0.5-in. specimens, tests DB266 through DB268. These were conducted on the same panel at locations at least 3 in. away from each other. Conducting multiple tests on a single 0.5-in.-thick panel was considered acceptable as the damage in plates of this thickness was highly localized. The tests were designed such that the ballistic limit velocity for the particular combinations of projectiles and panels was in the range of 600 to 900 ft/s. This corresponds to the high-speed range of the center of mass of a typical uncontained engine fan blade fragment. The impact tests were conducted at speeds above and below the ballistic limit so that some projectiles penetrated and some did not.

TABLE II.—PROJECTILE MATERIAL AND DIMENSIONS FOR DIFFERENT SPECIMEN THICKNESSES

| Panel thickness, in. | Projectile material | Projectile length, in. | Projectile diameter, in. | Average mass, g |
|---|---|---|---|---|
| 0.05 | S7 tool steel | 0.75 | 0.375 | 11.2 |
| 0.08 | S2 tool steel | .86 | .5 | 21.2 |
| 0.125 | S2 tool steel | .86 | .5 | 21.2 |
| 0.25 | S2 tool steel | 1.0 | .5 | 21.2 |
| 0.5 | A2 tool steel | 2.245 | .75 | 126.4 |

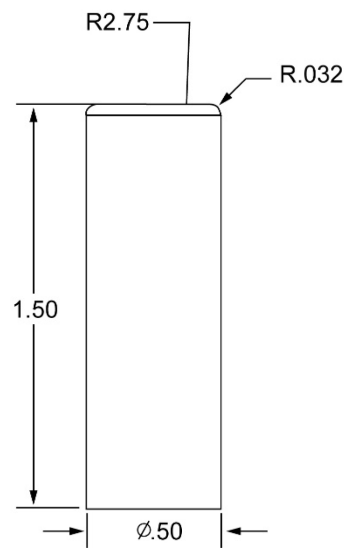


Figure 3.—Sample small panel projectile. Length and diameter vary depending on test specimen thickness and material. Dimensions in inches.

### 2.2.1 Projectiles

The projectiles used for the small panel testing were hardened tool steel cylindrical rods with varying length, diameter, and material as shown in Table II. They had a relatively large nose radius of 2.75 in., which allowed a slight deviation in the normal orientation of the projectile without a front edge impact (Figure 3). The edge of the front face was “broken” with a 1/32-in. radius. The projectiles were hardened to a minimum of Rockwell 55C.

### 2.2.2 Gas Gun

The cylindrical projectiles were accelerated with a helium-filled gas gun connected to a vacuum chamber, shown in Figure 4. The gun barrel had a length of 12 ft and a bore of 2.0 in. The pressure vessel was made up of sections as shown in Figure 5, with a total volume of 681 $in^3$. The projectile was carried down the gun barrel supported by rigid foam in a cylindrical polycarbonate sabot shown in Figure 6. The gun barrel protruded into the vacuum chamber, which held the fixture for the specimens. The sabot was stopped at the end of the gun barrel by a stopper plate with a through hole large enough to allow the projectile to pass through. This stopper system was designed such that the bottom of the sabot, including the O-rings, remained in the gun barrel and formed a seal, which prevented the gas pressure behind the sabot from affecting the pressure in the vacuum chamber.

Figure 4.—Large vacuum gas gun. Shown with 3-in.-diameter gun barrel.

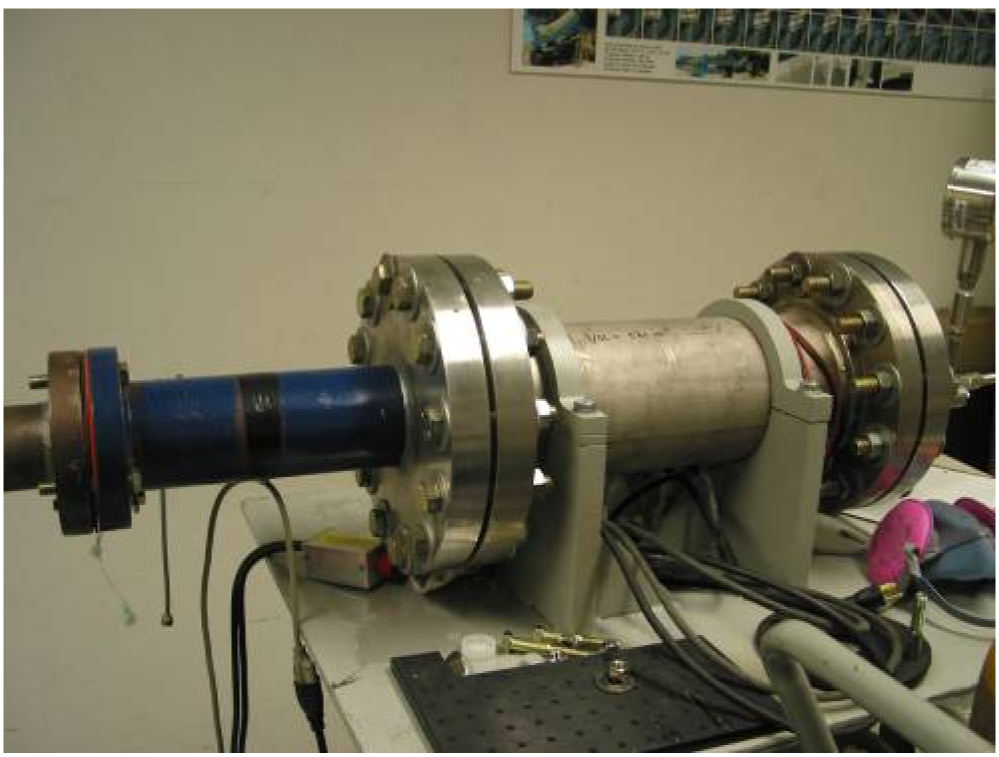


Figure 5.—Pressure vessel.

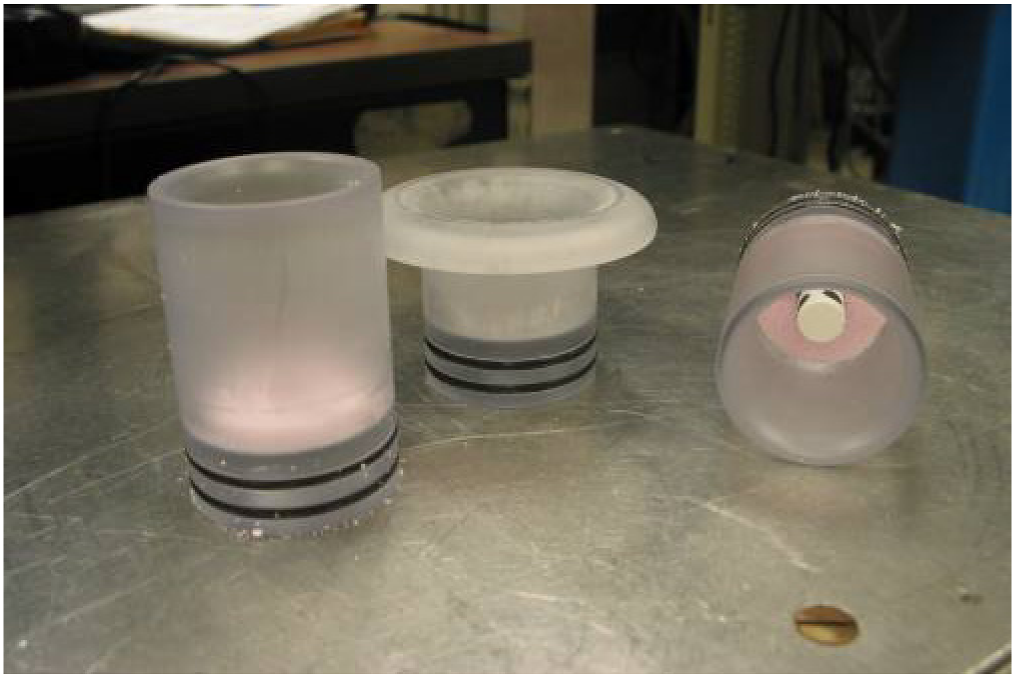


Figure 6.—Sabots used to transport projectile down gun barrel. Posttest sabot shown in center.

### 2.2.3 Instrumentation

Data acquired from the impact tests included measurements of the impact velocity, post-impact velocity (if penetration occurred), projectile orientation prior to impact, and full-field backside strain and displacement measurements using a DIC system. In addition, high-speed cameras provided qualitative observations of each test.

Seven high-speed digital cameras were used for each test. These cameras provided a side view of the front of the panel and two views of the rear of the panel (side and top) for post-impact velocity measurement. In addition, a calibrated pair of cameras located above and in front of the panel were used to measure impact velocity and projectile orientation, and a calibrated pair of cameras viewing the backside of the panel were used to compute the backside displacement and strain. The locations of these cameras are shown schematically in Figure 7.

The speed and orientation of the projectile were measured by tracking the position of markers on the projectile and the position of three fixed points, which defined the fixed laboratory coordinate system. The point tracking was accomplished with the use of a calibrated pair of high-speed cameras (Phantom V7.3, Vision Research, Inc.) and the PONTOS point tracking software system (GOM). The three fixed points were located on a metal plate mounted to the specimen fixture in a horizontal plane directly below the path of the projectile as shown in Figure 8. The three points defined a coordinate system with the x-axis pointing in the opposite direction of the direction of travel of the projectile, the z-axis vertically upward, and the y-axis in the horizontal plane and in a direction defined by the vector product of unit vectors in the z and x directions, respectively (Figure 8). The origin of the coordinate system was at point 1 shown in Figure 8. All positions reported for the projectile and the impact point were computed with respect to this coordinate system.

For tests in which the projectile penetrated the panel, the exit velocity of the projectile was measured using a second pair of calibrated Phantom V7.3 cameras and the PONTOS point tracking system.

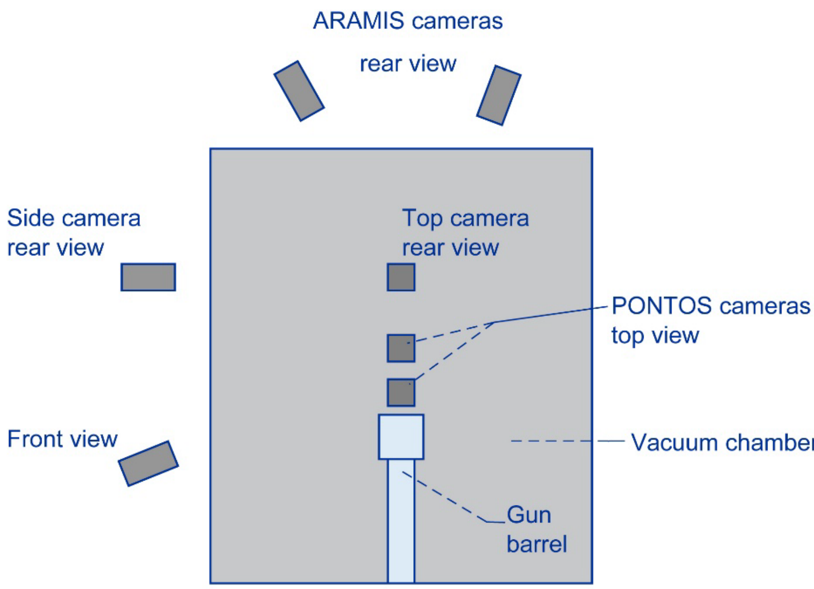



Figure 7.—Top view of vacuum chamber showing high-speed camera locations. PONTOS and ARAMIS made by GOM.

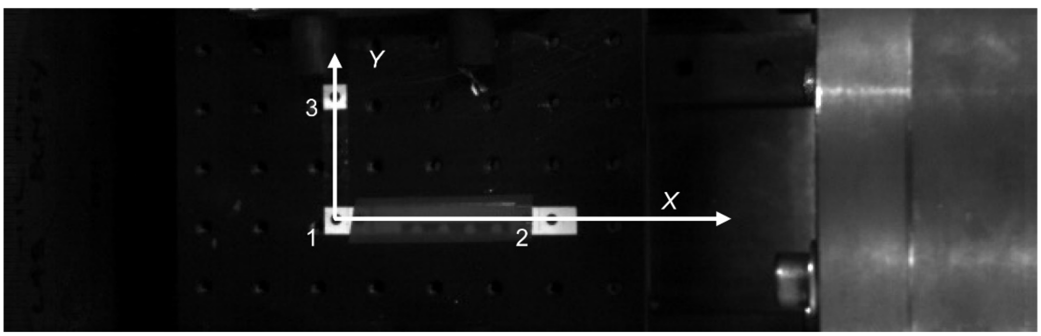



Figure 8.—Points used to define laboratory coordinate system.

Full-field displacement and strain measurements were obtained using a calibrated pair of high-speed digital cameras (Photron model SA1.1, Photron USA) and a DIC software package (ARAMIS, GOM). The cameras were located on the outside of the vacuum chamber and viewed the backside of the panel through two viewports. The distance from the cameras to the panel was approximately 36 in. and between the cameras was approximately 16 in. The cameras were set with a resolution of 256 × 216 pixels, an exposure of 5 µs and a frame rate of 150,000 frames per second. The backside of each panel was painted with a random set of black dots on a white background as required by the ARAMIS software. From the images, the software computed the displacements in three directions at any point in the view for every recorded frame. In-plane strains on the back surface of the panel were computed from the displacements.

## 2.3 Large Panel Test Setup

Impact tests were conducted on large panels with two different thicknesses. These tests were designed to involve a more realistic projectile and non-normal impact orientation to provide data for validation of numerical models under conditions more complex than the small panel tests. It also is a better representative laboratory test for a turbine-engine blade release event. Since the release of an engine blade is tangential, as the blade is released the tip makes contact in such a way that it tends to bend, as opposed to a blade exiting in a purely radial direction. This creates a moment and the blade rotates after initial contact, with the heavier root section often being the part of the blade that penetrates the engine case. This test is a simple rig test to try to more accurately represent this type of impact.

### 2.3.1 Test Specimens

The test specimens were 24-by 24-in. precipitation-hardened Inconel 718 with a nominal thicknesses of 0.125 in. These specimens were cut from the same sheet material as the small panel test specimens. Actual thicknesses are shown in Table I. The panels were held at a 45° angle in a square fixture with a 20-by 20-in. aperture as shown in Figure 9. The panels were through-bolted with twenty-four 0.5-in. bolts equally spaced around the sides, 1 in. from the edges, and they were mounted such that the rolling direction of the sheet was in the vertical direction.

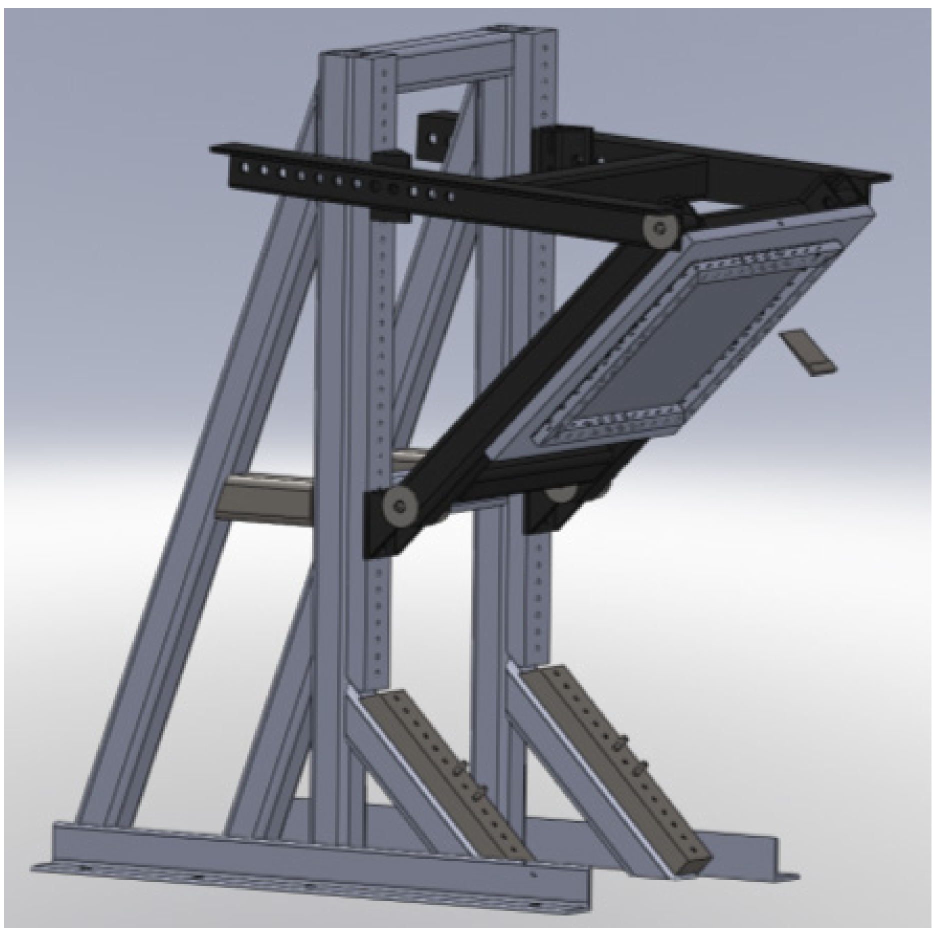


Figure 9.—Large panel test setup showing orientation of projectile and test specimen.

### 2.3.2 Projectile

Two NGFBF projectiles were used for the large panel tests, designated thick and thin, as shown in Figure 10 and Figure 11. The two were similar in shape but differed in the thickness dimension. The projectiles were Ti-6Al-4V, AMS 4911, with nominal masses of 340 and 430 g for the thin and thick projectiles, respectively. The desired orientation of the projectile at impact was at a 45° angle from vertical such that the flat plane of the projectile was at a 90° angle to the plane of the test specimen. A still image from a high-speed video of an impact test, directly before impact is shown in Figure 12.

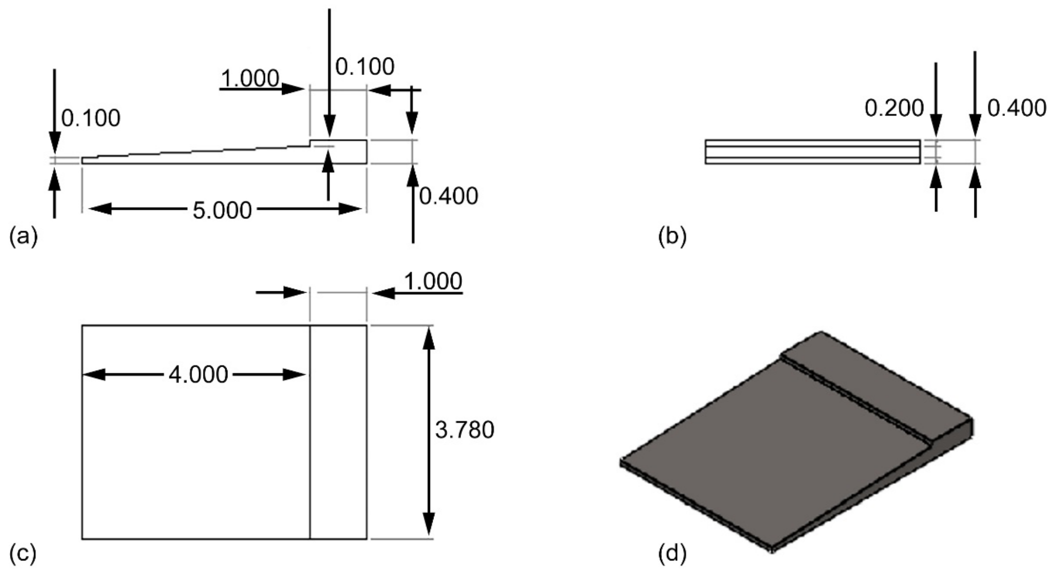



Figure 10.—Thin generic fan blade fragment. Dimensions in inches. (a) Side view. (b) Front view. (c) Top view. (d) View of model.

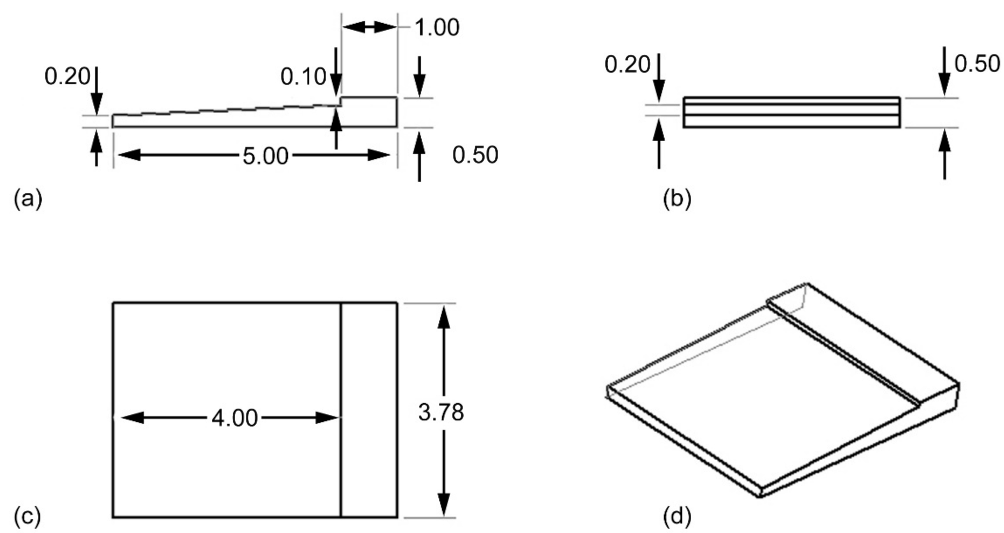



Figure 11.—Thick generic fan blade fragment. Dimensions in inches. (a) Side view. (b) Front view. (c) Top view. (d) View of model.

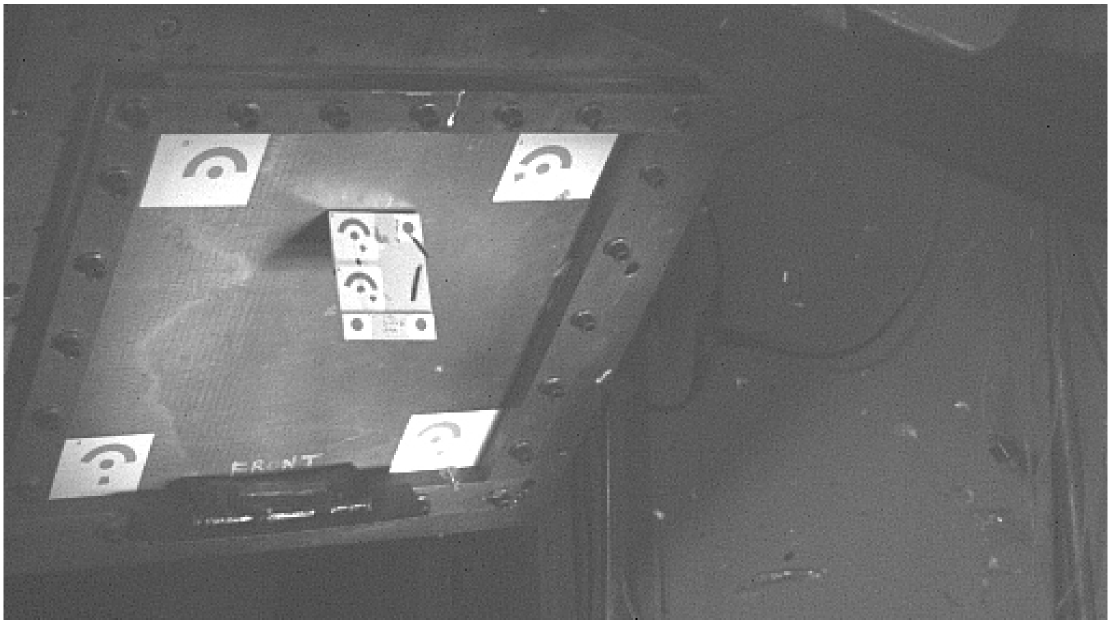



Figure 12.—Still image from high-speed movie of impact test taken directly before impact.

### 2.3.3 Instrumentation

Full field displacement data on the backside of the impacted panels were obtained using a pair of calibrated Phantom V7.3 high-speed cameras and a DIC system, similar to the small panel tests.

To measure the projectile linear and angular position and velocity, a pair of calibrated Photron SA-X2 cameras and the PONTOS point tracking software were used to track the position of individual markers on the projectile. These were used to establish the projectile coordinate system and calculate velocity and orientation relative to the fixed laboratory coordinate system.

The fixed laboratory coordinate system was specified with the origin at the center of the impact face of the test panel with the x direction in the direction of the axis of the gun barrel. The y direction was to the right when looking toward the test specimen from the gun barrel and the z direction was vertically downward.

The projectile coordinate system is shown in Figure 13. The origin of the coordinate system was located at a point on the root of the blade 0.5 in. from the bottom edge and 0.5 in. from the side, as shown in the figure. The y-axis of the coordinate system was pointed to the right, parallel to the bottom edge. The x-axis was parallel to the edge of the projectile and pointed from the origin to another point along the top face of the projectile located an absolute distance $L$ from the origin.

To report the position, velocity, and orientation of the projectile, the position and velocity of the origin of the projectile local coordinate system are given with respect to the fixed laboratory coordinate system. The angular position and velocity are given as a set of Euler angles and angular velocities with respect to the moving coordinate system. The Euler angles are defined as a rotation about the fixed laboratory x-axis (roll), followed by a rotation about the once-rotated local y-axis (pitch), followed by a rotation about the twice-rotated local z-axis (yaw).

In addition to the above cameras, a Phantom V7.3 camera oriented normal to the path of the projectile from the side was used for a redundant velocity measurement, and a Phantom V7.3 camera viewing from above was used to measure the velocity of the projectile if it penetrated the panel.

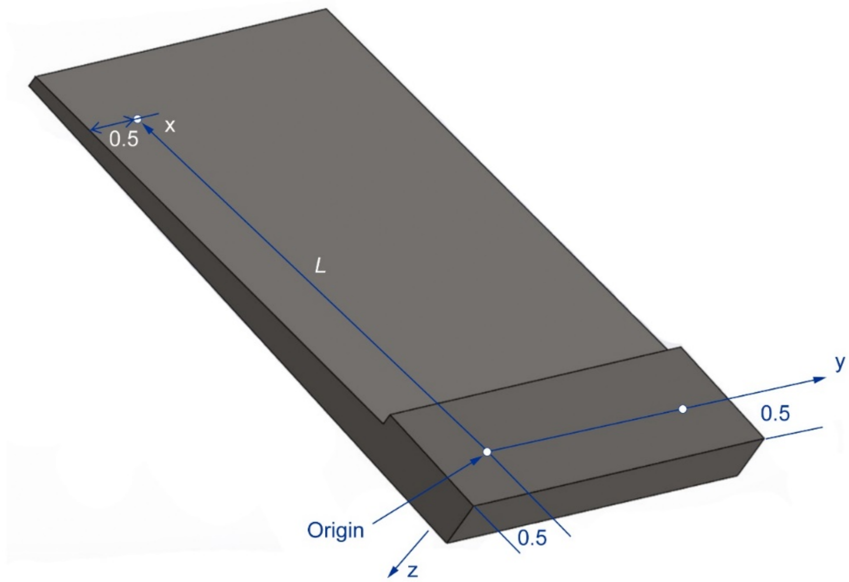



Figure 13.—Projectile local coordinate system. Dimensions are in inches.

For the tests on the 0.125-in. material, the backside DIC cameras were operating at a frame rate of 20,000 frames per second, an exposure of 4 µs, and a resolution of 352 × 368 pixels. The front-side photogrammetry cameras were operating at 60,000 frames per second with an exposure of 2.5 µs and a resolution of 768 × 256 pixels.

For the tests on the 0.05-in. material, the backside DIC cameras were operating at a frame rate of 20,000 frames per second, an exposure of 4 µs and a resolution of 384 × 344 pixels. The front-side photogrammetry cameras were operating at 40,000 frames per second with an exposure of 2.5 µs and a resolution of 768 × 392 pixels.

For all tests, the side camera was operating at a rate of 32,000 frames per second, an exposure of 10 µs, and a resolution of 608 × 96 pixels. The top camera was operating at a rate of 10,000 frames per second, an exposure of 25 µs and a resolution of 400 × 600 pixels.

#### 2.3.4 Test Configuration

The desired orientation of the projectile at impact was 0° about the x-axis (roll), 45° about the projectile y-axis (pitch), and 0° about the (rotated) projectile z-axis (yaw). In this orientation, the angle between the projectile and the test panel was 90°. This orientation was not achieved exactly in all tests, but the actual orientations (Euler angles) were measured and recorded.

## 3.0 Results and Discussion

Fifty instrumented impact tests were conducted in total for the two different size test specimens. The following sections describe and discuss the test results.

## 3.1 Small Panel Impact Tests

A total of 40 small panel impact tests were conducted on five different specimen thicknesses. The tests were conducted at velocities that bracketed the penetration threshold velocity of the panel. The projectile size and mass were different for each panel size to maintain a penetration threshold in the 600 to 900 ft/s range. The results of the tests are summarized in Table III. In a number of instances, the size of the projectile was changed after the first test of a given specimen thickness. This occurred with the 0.05- and 0.08-in.-thick specimens.

Figure 14 through Figure 18 plot the penetration (0 or 1) against the projectile impact velocity. For tests on the 0.05-, 0.08-, and 0.125-in. specimens, there was no overlap in the results, meaning that the lowest velocity where penetration occurred was higher than the highest nonpenetrating test velocity. For the 0.25- and 0.5-in. specimens, there is some overlap. For cases in which there is an overlap, a logistic regression analysis was used to compute the probability of penetration and the velocity at which the probability of penetration is 50 percent, termed the $V_{50}$. For cases in which there is no overlap, it is not possible to compute the probability, so the $V_{50}$ is assumed to be the average of the highest nonpenetrating velocity and the lowest penetrating velocity. The $V_{50}$ of the different thickness panels is shown in Table IV.

TABLE III.—SMALL PANEL IMPACT TEST RESULTS

| Test | Panel thickness, in. | Projectile | | | Impact velocity | | Kinetic energy (KE), J | Exit velocity | | Exit KE, J | Penetrate | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dimensions, length × diameter, in. | Material | Mass, g | ft/s | m/s | | ft/s | m/s | | | |
| DB232 | 0.0495 | 1.00×0.375 | S7 | 14.94 | 806.0 | 245.7 | 450.8 | 660.1 | 201.2 | 302.4 | 1 | Penetrate |
| DB234 | 0.0495 | 0.75×0.375 | S7 | 11.19 | 485.0 | 147.8 | 122.3 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and no crack |
| DB235 | 0.0495 | 0.75×0.375 | S7 | 11.20 | 517.0 | 157.6 | 139.1 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and no crack |
| DB236 | 0.0495 | 0.75×0.375 | S7 | 11.21 | 593.0 | 180.7 | 183.1 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate but produced a crack |
| DB237 | 0.0495 | 0.75×0.375 | S7 | 11.22 | 553.6 | 168.7 | 159.7 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and through crack around perimeter of impact |
| DB238 | 0.0495 | 0.75×0.375 | S7 | 11.21 | 660.5 | 201.3 | 227.2 | 248.8 | 75.8 | 32.2 | 1 | Penetrated; and flap separated from panel |
| DB239 | 0.0495 | 0.75×0.375 | S7 | 11.19 | 620.0 | 189.0 | 199.8 | 363.0 | 110.6 | 68.5 | 1 | Penetrated; and clean hole in panel |
| DB240 | 0.0495 | 0.75×0.375 | S7 | 11.22 | 773.0 | 235.6 | 311.4 | 621.0 | 189.3 | 201.0 | 1 | Penetrated |
| DB241 | 0.0800 | 0.853×0.500 | S2 | 21.16 | 763.0 | 232.6 | 572.2 | 515.0 | 157.0 | 260.7 | 1 | Penetrated |
| DB242 | 0.0800 | 0.86×0.50 | S2 | 21.16 | 632.0 | 192.6 | 392.6 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and no crack |
| DB243 | 0.0800 | 0.86×0.50 | S2 | 21.26 | 647.0 | 197.6 | 413.4 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and no crack |
| DB244 | 0.0800 | 0.86×0.50 | S2 | 21.20 | 694.1 | 211.6 | 474.4 | 146.2 | 44.6 | 21.0 | 1 | Penetrated; and flap stayed connected to panel |

TABLE III.—Continued.

| Test | Panel thickness, in. | Projectile | | | Impact velocity | | Kinetic energy (KE), J | Exit velocity | | Exit KE, J | Penetrate | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dimensions, length × diameter, in. | Material | Mass, g | ft/s | m/s | | ft/s | m/s | | | |
| DB245 | 0.0800 | 0.86×0.50 | S2 | 21.23 | 683.0 | 208.2 | 460.0 | 259.0 | 78.9 | 66.2 | 1 | Penetrated; and flap separated from panel |
| DB246 | 0.0800 | 0.86×0.50 | S2 | 21.23 | 653.3 | 199.1 | 420.9 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and through crack at bottom |
| DB247 | 0.0800 | 0.86×0.50 | S2 | 21.24 | 661.0 | 201.5 | 431.1 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and crack around approximately half of perimeter at top |
| DB248 | 0.0800 | 0.86×0.50 | S2 | 21.25 | 823.6 | 251.0 | 669.6 | 609.0 | 185.6 | 366.1 | 1 | Fully penetrated; and plug velocity 697 ft/s |
| DB249 | 0.0800 | 0.86×0.50 | S2 | 21.23 | 846.0 | 257.9 | 705.8 | 632.0 | 192.6 | 393.9 | 1 | Fully penetrated |
| DB250 | 0.1260 | 0.86×0.50 | S2 | 21.23 | 853.0 | 260.0 | 717.5 | 549.5 | 167.5 | 297.8 | 1 | Fully penetrated; and plug velocity 652 ft/s |
| DB259 | 0.1270 | 0.86×0.50 | S2 | 21.30 | 657.0 | 200.3 | 427.1 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and through crack in part of perimeter |
| DB260 | 0.1270 | 0.86×0.50 | S2 | 21.31 | 685.6 | 209.0 | 465.3 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and crack around approximately half of perimeter |
| DB261 | 0.1270 | 0.86×0.50 | S2 | 21.28 | 739.9 | 225.5 | 541.1 | 0.0 | 0.0 | 0.0 | 0 | Perforation hole; and projectile did not penetrate. Plug ejected on backside |
| DB262 | 0.1270 | 0.86×0.50 | S2 | 21.30 | 776.0 | 236.5 | 595.8 | 429.9 | 131.0 | 182.9 | 1 | Penetrated |
| DB263 | 0.1270 | 0.86×0.50 | S2 | 21.28 | 770.6 | 234.9 | 587.0 | 373.7 | 113.9 | 138.0 | 1 | Penetrated |
| DB264 | 0.1270 | 0.86×0.50 | S2 | 21.29 | 709.1 | 216.1 | 497.3 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and created a flap |
| DB265 | 0.1270 | 0.86×0.50 | S2 | 21.30 | 639.0 | 194.8 | 404.0 | 0.0 | 0.0 | 0.0 | 0 | No penetration or cracking |
| DB251 | 0.2630 | 0.86×0.50 | S2 | 21.27 | 861.0 | 262.4 | 732.4 | 0.0 | 0.0 | 0.0 | 0 | Did not penetrate; and plug velocity 157 ft/s |

TABLE III.—Concluded.

| Test | Panel thickness, in. | Projectile | | | Impact velocity | | Kinetic energy (KE), J | Exit velocity | | Exit KE, J | Penetrate | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dimensions, length × diameter, in. | Material | Mass, g | ft/s | m/s | | ft/s | m/s | | | |
| DB252 | 0.2630 | 1.00×0.50 | S2 | 24.57 | 867.3 | 264.4 | 858.5 | 170.7 | 52.0 | 33.3 | 1 | Fully penetrated |
| DB253 | 0.2630 | 1.00×0.50 | S2 | 24.52 | 822.0 | 250.5 | 769.6 | N/A | 0.0 | 0.0 | 0 | Projectile was captured; and plug exited hole |
| DB254 | 0.2630 | 1.00×0.50 | S2 | 24.57 | 761.0 | 232.0 | 661.0 | 123.5 | 37.6 | 17.4 | 1 | Projectile fully penetrated panel |
| DB255 | 0.2630 | 1.00×0.50 | S2 | 24.88 | 760.0 | 231.6 | 667.5 | N/A | 0.0 | 0.0 | 0 | Projectile was captured |
| DB256 | 0.2630 | 1.00×0.50 | S2 | 24.86 | 570.8 | 174.0 | 376.2 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and no crack |
| DB257 | 0.2630 | 1.00×0.50 | S2 | 24.80 | 652.2 | 198.8 | 490.0 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and no crack |
| DB258 | 0.2630 | 1.00×0.50 | S2 | 24.80 | 719.5 | 219.3 | 596.4 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and through crack around most of perimeter |
| DB266 | 0.5300 | 2.245×0.750 | A2 | 126.30 | 668.7 | 203.8 | 2,623.4 | 172.4 | 52.5 | 174.4 | 1 | Penetrated; and plug exit velocity 216 ft/s |
| DB267 | 0.5300 | 2.245×0.750 | A2 | 126.32 | 528.1 | 161.0 | 1,636.5 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and created a dent but no visible crack |
| DB268 | 0.5300 | 2.245×0.750 | A2 | 126.31 | 626.0 | 190.8 | 2,299.3 | 179.0 | 54.6 | 188.0 | 1 | Penetrated; and plug exit velocity 220 ft/s |
| DB269 | 0.5300 | 2.245×0.750 | A2 | 126.39 | 591.8 | 180.4 | 2,056.2 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and no visible crack |
| DB270 | 0.5300 | 2.245×0.750 | A2 | 126.39 | 602.9 | 183.8 | 2,134.0 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and no visible crack |
| DB271 | 0.5300 | 2.245×0.750 | A2 | 126.41 | 620.5 | 189.1 | 2,260.8 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and no visible crack |
| DB272 | 0.5300 | 2.245×0.750 | A2 | 126.47 | 642.0 | 195.7 | 2,421.3 | N/A | 0.0 | 0.0 | 0 | Did not penetrate; and no visible crack |

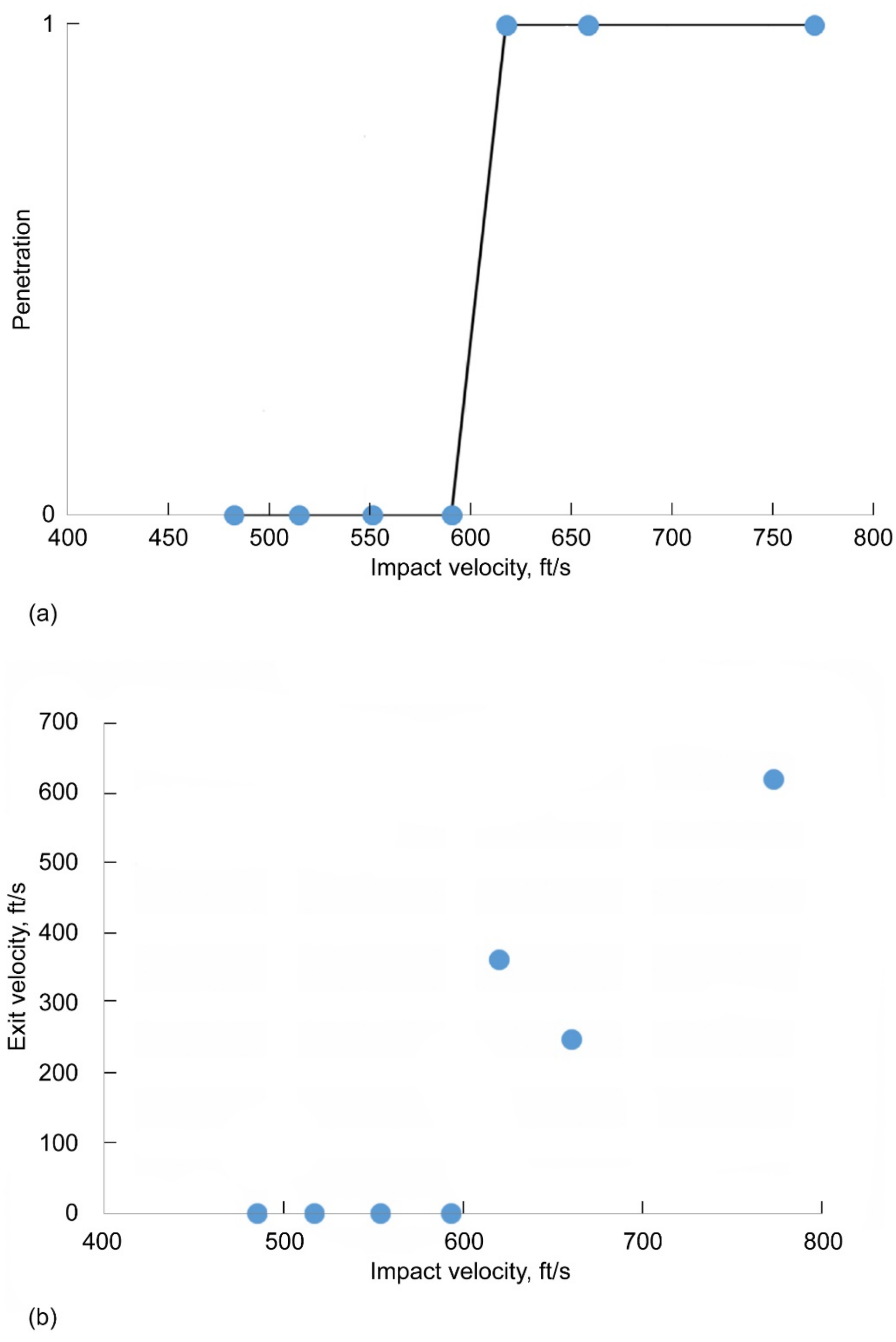
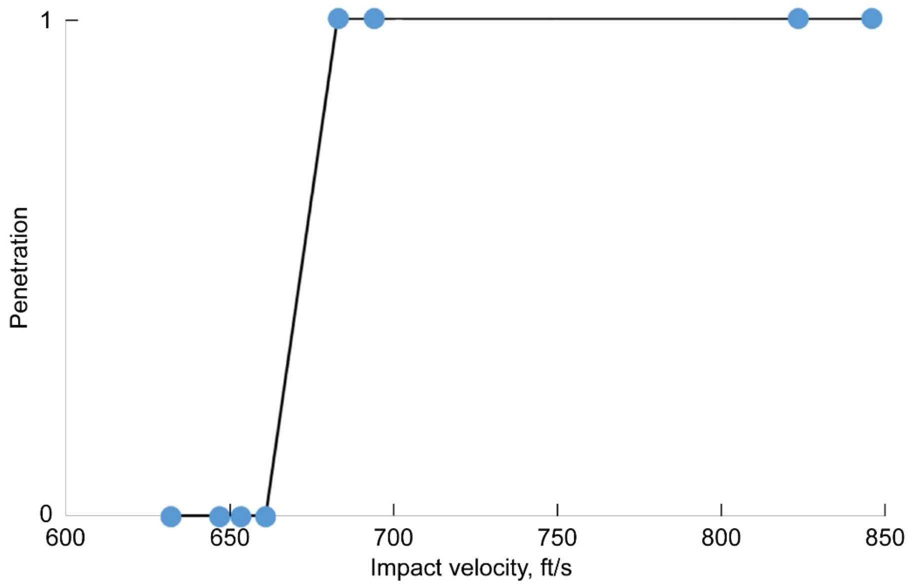
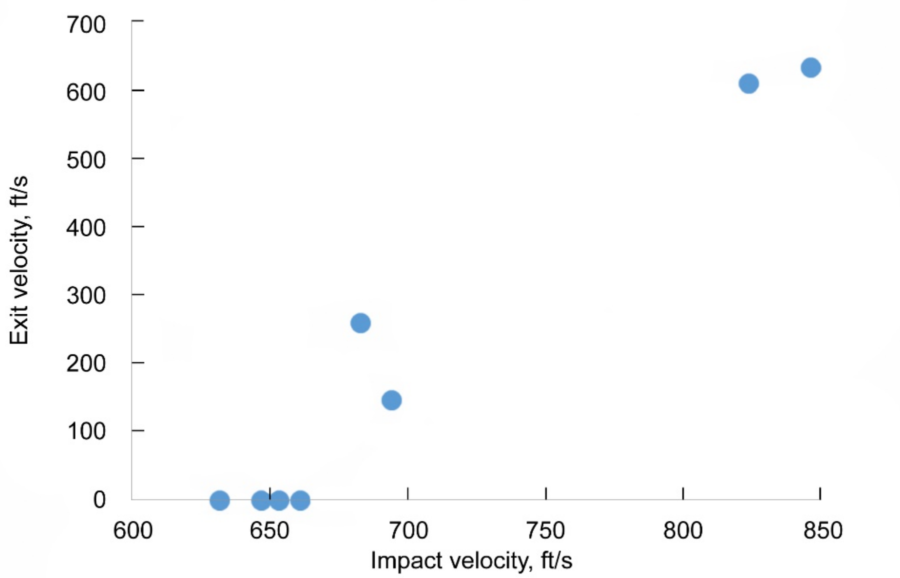



Figure 14.—Penetration results for 0.05-in. (nominal) small panels. (a) Penetration (1 = yes, 0 = no). (b) Exit velocity versus impact velocity. Velocity at which probability of penetration is 50 percent, $V_{50}$, was 607 ft/s.




(a)




(b)

Figure 15.—Penetration results for 0.08-in. (nominal) small panels. (a) Penetration (1 = yes, 0 = no). (b) Exit velocity versus impact velocity. Velocity at which probability of penetration is 50 percent, $V_{50}$, was 672 ft/s.

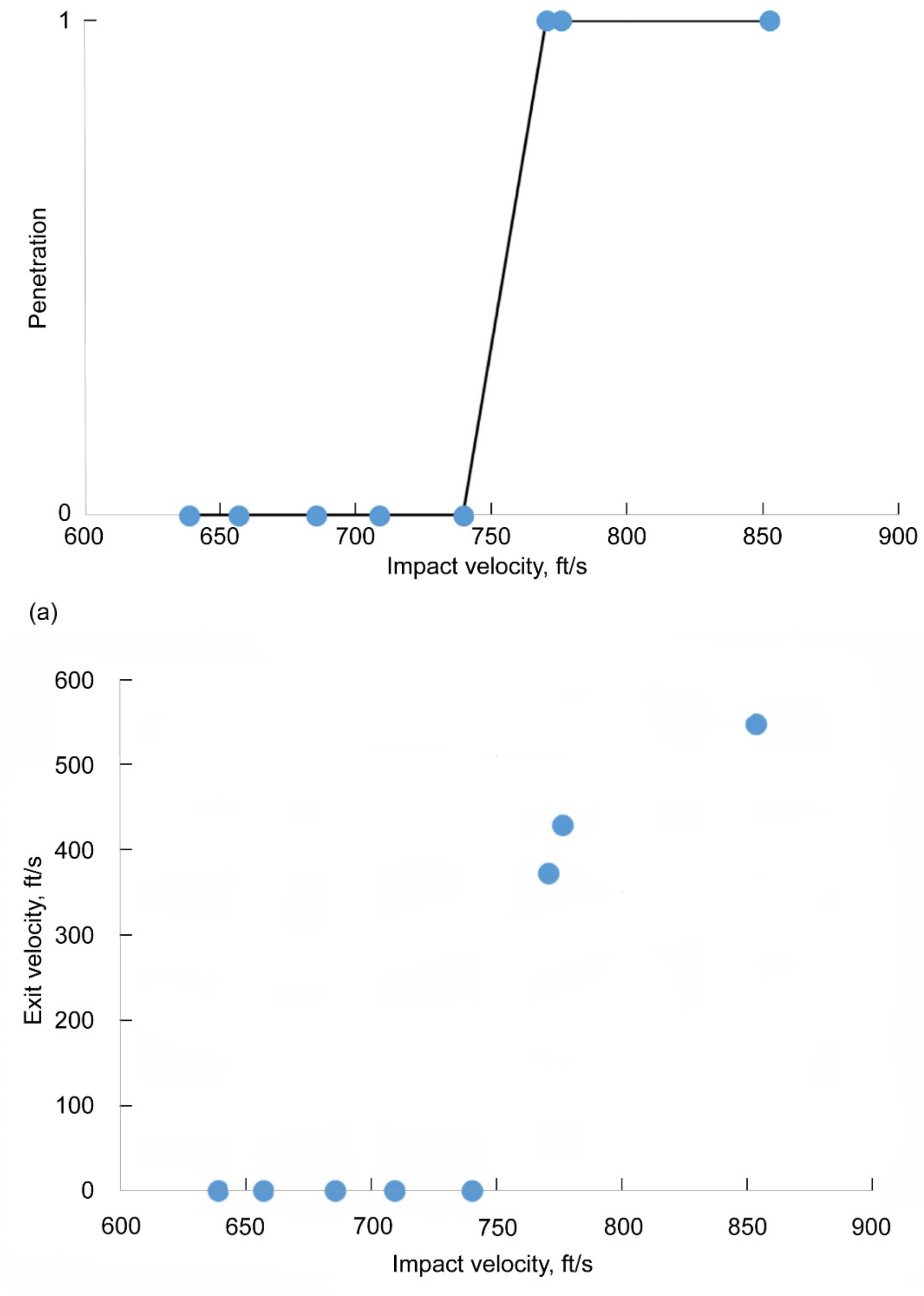



Figure 16.—Penetration results for 0.125-in. (nominal) small panels. (a) Penetration (1 = yes, 0 = no). (b) Exit velocity versus impact velocity. Velocity at which probability of penetration is 50 percent, $V_{50}$, was 655 ft/s.

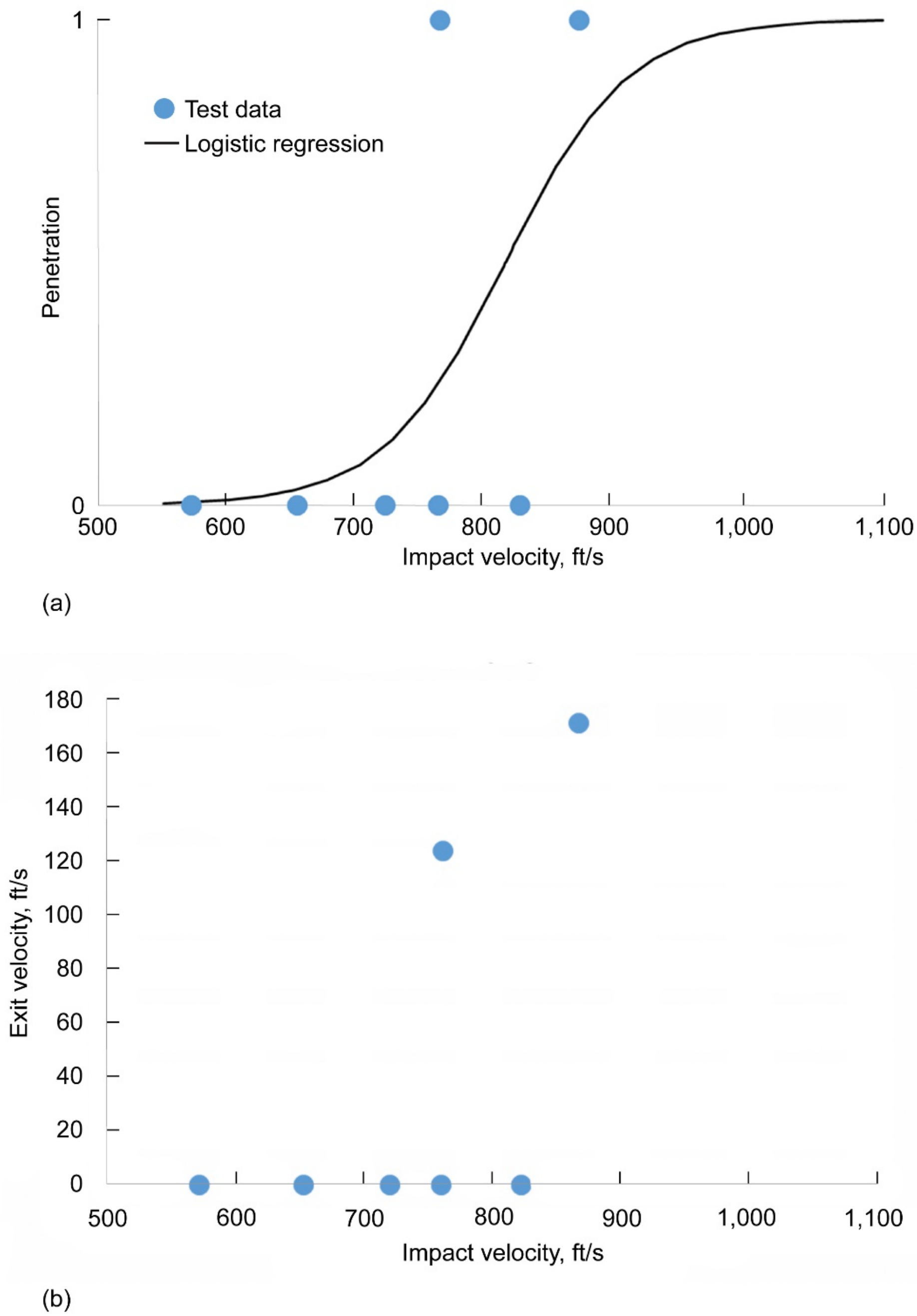
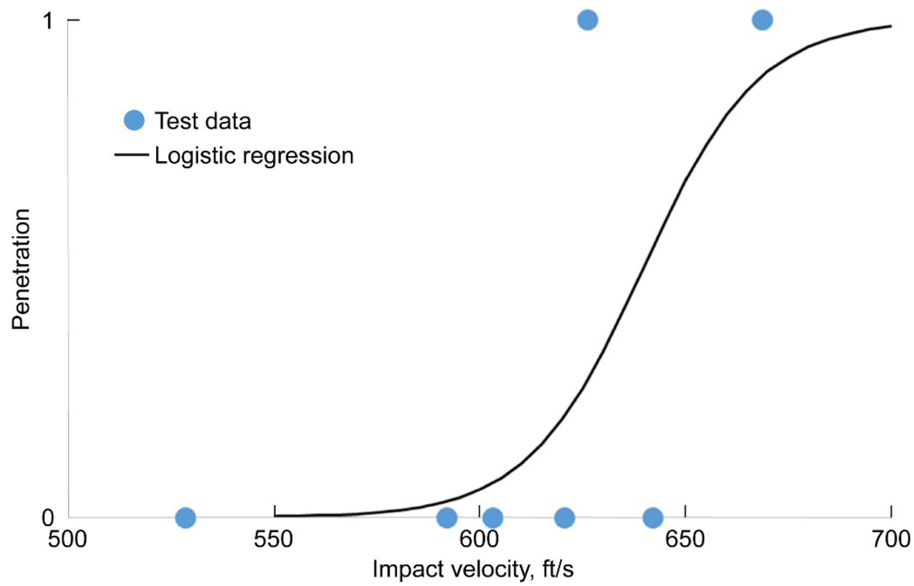
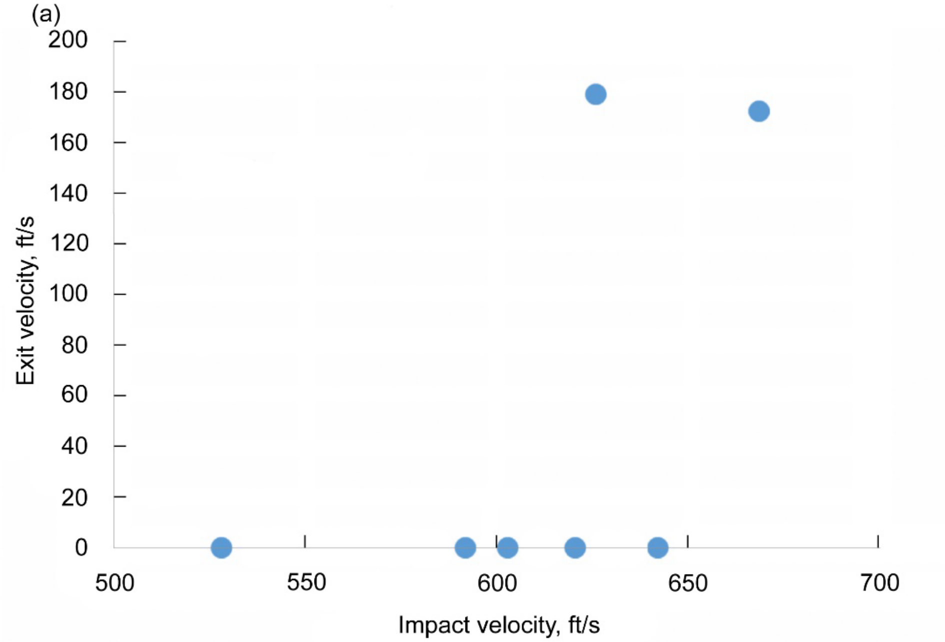



Figure 17.—Penetration results for 0.25-in. (nominal) small panels. (a) Probability of penetration. (b) Exit velocity versus impact velocity. Velocity at which probability of penetration is 50 percent, $V_{50}$, was 812 ft/s.




(a)




(b)

Figure 18.—Penetration results for 0.5-in. (nominal) small panels. (a) Probability of penetration. (b) Exit velocity versus impact velocity. Velocity at which probability of penetration is 50 percent ,$V_{50}$, was 640 ft/s.

TABLE IV.—$V_{50}$ MEASUREMENTS FOR DIFFERENT PANEL THICKNESSES

| Panel thickness, in. | $V_{50}$, ft/s |
|---|---|
| 0.05 | 607 |
| 0.08 | 672 |
| 0.125 | 655 |
| 0.25 | 812 |
| 0.8 | 640 |

Photographs and deformation response from the small panel tests are given in Appendix C.

TABLE V.—LARGE PANEL IMPACT TEST RESULTS

| Test | Panel thickness, in. | Projectile | | | Impact velocity of blade center of mass | | Translational kinetic energy, J | Exit Velocity (ft/s) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | Thickness | Material | Mass, g | ft/s | m/s | | | |
| LG1110 | 0.08 | Thin | Ti-6Al-4V | 311 | 913 | 278.3 | 12,044 | 0 | Did not penetrate |
| LG1111 | 0.08 | Thin | Ti-6Al-4V | 325 | 1,120 | 341.4 | 18,940 | 0 | Did not penetrate |
| LG1113 | 0.08 | Thick | Ti-6Al-4V | 431 | 1,112 | 338.9 | 24,751 | 0 | Complete perforation initiated at tip; large piece separated from panel; and blade fractured but did not completely penetrate the panel. |
| LG1114 | 0.08 | Thick | Ti-6Al-4V | 445 | 895 | 272.8 | 16,558 | 0 | Complete perforation initiated at tip; large piece of panel ripped away but remained attached; and blade fractured but did not completely penetrate panel |
| LG1115 | 0.08 | Thick | Ti-6Al-4V | 444 | 720 | 219.5 | 10,696 | 0 | Blade tumbled; did not penetrate or crack specimen; and incorrect blade orientation |
| LG1116 | 0.08 | Thick | Ti-6Al-4V | 445 | 741 | 225.9 | 11,354 | 0 | Did not penetrate or crack specimen |
| LG1125 | 0.05 | Thin | Ti-6Al-4V | 328 | 634 | 193.2 | 6,122 | 176 | Penetrated; tip impacted and slide down; and heavier root section penetrated |
| LG1126 | 0.05 | Thin | Ti-6Al-4V | 327 | 378 | 115.2 | 2,170 | 140 | Penetrated; tip impacted and slide down; and heavier root section penetrated. |
| LG1127 | 0.05 | Thin | Ti-6Al-4V | 326 | 261 | 79.6 | 1,033 | 0 | Did not penetrate |
| LG1128 | 0.05 | Thin | Ti-6Al-4V | 331 | 322 | 98.1 | 1,593 | 0 | Did not penetrate |

## 3.2 Large Panel Impact Tests

Six tests were conducted on the 0.08-in.-thick large Inconel 718 heat-treated panels, two with the thin projectile (Figure 10) and four with the thick projectile (Figure 11). Four tests were conducted on the 0.05-in.-thick large panels with the thin projectile (Figure 10). For the 0.08-in.-thick panels, neither of the tests with the thin projectile resulted in penetration. Two tests with the thick projectile resulted in full perforation of the panel but the projectile itself did not penetrate through the panel. It should be noted that the energy required to fully perforate the panel in test LG1114 was less than that of test LG1111, in which there was no perforation. This may be due to the fact that the thicker blade used in test LG1114 was less likely to bend, presenting a stiffer impact surface. While the projectiles in both tests, LG1113 and LG1114, completely fractured, there was less bending in the tip. For the 0.05-in.-thick panels, two tests resulted in penetration and the penetration velocity was bounded between 322 and 378 ft/s. The results for the large panel tests are summarized in Table V. The linear and angular positions and velocities of the blade local coordinate system at the time of impact are presented in Table VI. Note that the velocities of the local coordinate system origin differ from those of the center of mass shown in Table V. Photographs and deformation response from the large panel tests are presented in Appendix D.

TABLE VI.—LINEAR AND ANGULAR POSITION AND VELOCITY OF THE PROJECTILE LOCAL COORDINATE SYSTEM AT THE TIME OF IMPACT

[The projectile x-axis dimension refers to the dimension, $L$, given in Figure 13. Note in test LG1113, the photogrammetry cameras did not trigger so position and velocity data were not obtained.]

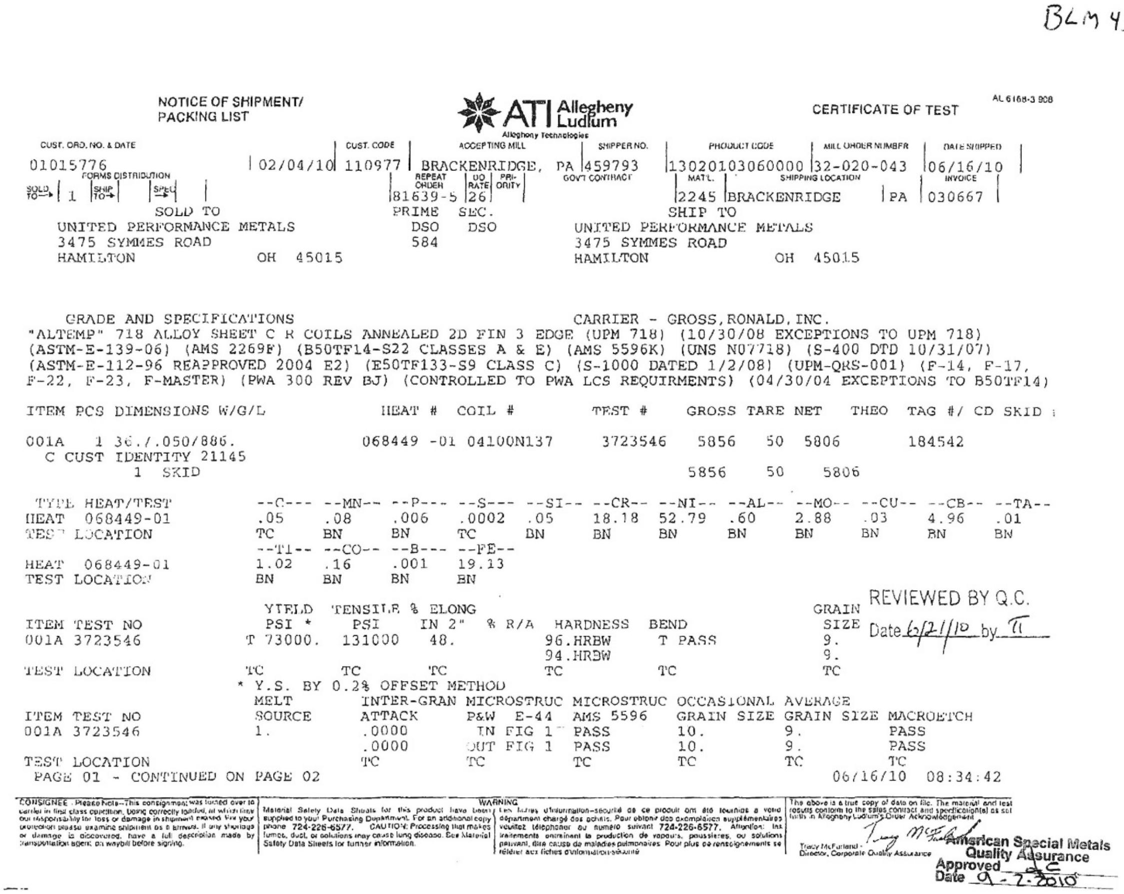
| Test Number | Projectile position and orientation | | | | | | Projectile linear and angular velocity | | | | | | Projectile x-axis dimension, $L$, in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X, in. | Y, in. | Z, in. | Roll, deg | Pitch, deg | Yaw, deg | X, ft/s | Y, ft/s | Z, ft/s | Roll, deg/s | Pitch, deg/s | Yaw, deg/s | |
| LG1110 | –5.8 | –1.0 | 0.4 | –2.7 | 64.2 | 3.4 | 935.9 | 6.3 | –9.0 | –75.3 | 7,152.8 | 1,283.6 | 2.74 |
| LG1111 | –6.9 | –1.2 | –0.5 | –1.5 | 58.0 | –1.0 | 1,149.8 | 11.4 | –17.8 | 198.7 | 7,216.8 | –275.8 | 3.56 |
| LG1113 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| LG1114 | –6.4 | –0.8 | 0.1 | –2.0 | 59.3 | 0.2 | 939.0 | 0.6 | –20.5 | –1,315.5 | 4,167.6 | 1,597.0 | 3.85 |
| LG1116 | –5.9 | –1.6 | 0.9 | 0.8 | 66.5 | –0.5 | 773.4 | –39.2 | –10.6 | 296.4 | 4,617.8 | 929.3 | 3.84 |
| LG1125 | –5.8 | –1.4 | –0.4 | 7.6 | 77.0 | 4.8 | 640.8 | 10.3 | –8.3 | 64.5 | 6,566.8 | 511.1 | 4.02 |
| LG1126 | –6.1 | –1.3 | –0.2 | –0.4 | 68.2 | 3.6 | 384.8 | 5.5 | –4.6 | –73.6 | 2,861.2 | 47.9 | 3.89 |
| LG1127 | –2.7 | –1.1 | –0.8 | 2.2 | 118.4 | –5.8 | 264.7 | 3.7 | –7.6 | –146.8 | 4,241.9 | –299.1 | 3.97 |
| LG1128 | –4.1 | –1.2 | –0.1 | 1.2 | 98.5 | –3.1 | 327.2 | 4.4 | –5.3 | –63.8 | 4,317.0 | –153.0 | 3.94 |

# 4.0 Concluding Remarks

This report provides results of instrumented impact tests on 15-in.-square Inconel 718 panels of different thicknesses impacted in a normal direction by a cylindrical projectile and 24-in.-square panels of the same materials impacted at a 45° angle by a more complex projectile having bladelike features. In the small panel tests, the thinner panels (0.05-, 0.08-, and 0.125-in.) had a well-defined ballistic threshold velocity while there was some overlap in the thicker panels (0.25- and 0.5-in.). These results are similar to those obtained in a previous study on Al 2024 and Ti-6Al-4V materials (Ref. 1). As in the previous study, it is postulated that irregular results obtained for the thicker materials may be due to a high sensitivity to frictional effects. The data provided in this report is useful for validation of numerical and empirical impact models for metals. Unique features of the data provided include extensive documentation of test procedures and results, traceable materials used for both material characterization and impact testing, and extensive instrumentation results. This report provides a set of data, which can be used for developing and validating computational and empirical high strain rate and impact deformation and failure models. Although it is impossible to report all data in a single report, they are archived and available through the authors.

# Appendix A.—Material Certification Sheets

Material certification sheets for the various Inconel 718 sheet thicknesses are found in Figure A.1 to Figure A.4.



BLM 43

NOTICE OF SHIPMENT/ PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01015776 | 02/04/10 | 110977 | BRACKENRIDGE, PA | 459793 | 13020103060000 | 32-020-043 | 06/16/10 |

FORMS DISTRIBUTION: SOLD TO 1 | SHIP TO | SPEC

REPEAT ORDER 81639-5 | UO RATE 26 | PRIORITY | GOV'T CONTRACT | MAT'L. 2245 | SHIPPING LOCATION BRACKENRIDGE PA | INVOICE 030667

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS

CARRIER - GROSS,RONALD,INC.

"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/31/07) (ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

| ITEM | PCS | DIMENSIONS W/G/L | HEAT # | COIL # | TEST # | GROSS | TARE | NET | THEO | TAG #/ CD SKID |
|---|---|---|---|---|---|---|---|---|---|---|
| 001A | 1 | 36./.050/886. | 068449 -01 | 04100N137 | 3723546 | 5856 | 50 | 5806 | | 184542 |
| C CUST IDENTITY 21145 | | | | | | | | | | |
| 1 SKID | | | | | | 5856 | 50 | 5806 | | |

| TYPE HEAT/TEST | C | MN | P | S | SI | CR | NI | AL | MO | CU | CB | TA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEAT 068449-01 | .05 | .08 | .006 | .0002 | .05 | 18.18 | 52.79 | .60 | 2.88 | .03 | 4.96 | .01 |
| TEST LOCATION | TC | BN | BN | TC | BN | BN | BN | BN | BN | BN | BN | BN |

| | TI | CO | B | FE |
|---|---|---|---|---|
| HEAT 068449-01 | 1.02 | .16 | .001 | 19.13 |
| TEST LOCATION | BN | BN | BN | BN |

| ITEM TEST NO | YIELD PSI * | TENSILE PSI | % ELONG IN 2" | % R/A | HARDNESS | BEND | GRAIN SIZE |
|---|---|---|---|---|---|---|---|
| 001A 3723546 | T 73000. | 131000 | 48. | | 96.HRBW | T PASS | 9. |
| | | | | | 94.HRBW | | 9. |
| TEST LOCATION | TC | TC | TC | | TC | TC | TC |

* Y.S. BY 0.2% OFFSET METHOD

REVIEWED BY Q.C.
Date 6/21/10 by TI

| ITEM TEST NO | MELT SOURCE | INTER-GRAN ATTACK | MICROSTRUC P&W E-44 | MICROSTRUC AMS 5596 | OCCASIONAL GRAIN SIZE | AVERAGE GRAIN SIZE | MACROETCH |
|---|---|---|---|---|---|---|---|
| 001A 3723546 | 1. | .0000 | IN FIG 1 | PASS | 10. | 9. | PASS |
| | | .0000 | OUT FIG 1 | PASS | 10. | 9. | PASS |
| TEST LOCATION | | TC | TC | TC | TC | TC | TC |

PAGE 01 - CONTINUED ON PAGE 02

06/16/10 08:34:42

CONSIGNEE - Please Note—This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

WARNING
Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy phone 724-226-6577. CAUTION: Processing that makes fumes, dust, or solutions may cause lung disease. See Material Safety Data Sheets for further information.

Les fiches d'information–sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des exemplaires supplémentaires veuillez téléphoner au numéro suivant 724-226-6577. Attention: les traitements entraînant la production de vapeurs, poussières, ou solutions peuvent être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland - Director, Corporate Quality Assurance

American Special Metals Quality Assurance
Approved
Date 9-2-2010

Figure A.1.—Material certification for test number G210041.

NOTICE OF SHIPMENT/
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Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01015776 | 02/04/10 | 110977 | BRACKENRIDGE, PA | 459793 | 13020103060000 | 32-020-043 | 06/16/10 |

| FORMS DISTRIBUTION SOLD TO | SHIP TO | SPEC | REPEAT ORDER | DO RATE | PRI-ORITY | GOVT CONTRACT | MATL | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 81639-5 | 26 | | | 2245 | BRACKENRIDGE | PA | 030667 |

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UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
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3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS CARRIER - GROSS, RONALD, INC.
"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/31/07) (ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

| ITEM TEST NO | P&W E-25 TRAN BEND |
|---|---|
| 001A 3723546 | 2. |

TEST LOCATION TC
METALLOGRAPHIC MAGNIFICATION: 100X ETCHANT USED: HC1/CHROMIC ACID

GRADE VERIFICATION WAS CARRIED OUT SPECTROSCOPICALLY

INTERGRANULAR ATTACK MAGNIFICATION: 500X

ALLEGHENY LUDLUM DOES NOT USE MERCURY IN THE TESTING OR PRODUCTION OF ITS PRODUCTS. TO THE BEST OF ALLEGHENY LUDLUMS KNOWLEDGE, UNDERSTANDING, AND BELIEF, THIS MATERIAL WAS NOT CONTAMINATED BY MERCURY WHILE IT WAS BEING PRODUCED IN OUR FACILITIES.

NO WELDS/WELD REPAIRS PERFORMED.

THE PRODUCT WAS SOLUTION HEAT-TREATED WITHIN THE RANGE 1725F - 1825F +/- 25F (941C - 996C +/- 14C) FOR A TIME COMMENSURATE WITH THICKNESS AND COOLED AT A RATE EQUIVALENT TO AIR OR FASTER.

ALLEGHENY LUDLUM DOES NOT USE MERCURY IN THE TESTING OR PRODUCTION OF ITS PRODUCTS.

PAGE 02 - CONTINUED ON PAGE 03 06/16/10 08:34:42

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WARNING
Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy phone 724-226-6577. CAUTION: Processing that makes fumes, dust, or solutions may cause lung disease. See Material Safety Data Sheets for further information.

Les fiches d'information-sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des exemplaires supplémentaires veuillez téléphoner au numéro suivant 724-226-6577. Attention: les traitements entraînant la production de vapeurs, poussières, ou solutions peuvent être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved AC
Date 9-2-2010

Figure A.1.—Continued.

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CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01015776 | 02/04/10 | 110977 | BRACKENRIDGE, PA | 459793 | 13020103060000 | 32-020-043 | 06/16/10 |

| FORMS DISTRIBUTION SOLD TO | SHIP TO | SPEC | REPEAT ORDER | DO RATE | PRIORITY | GOV'T CONTRACT | MAT'L | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 81639-5 | 26 | | | 2245 | BRACKENRIDGE | PA | 030667 |

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS CARRIER - GROSS,RONALD,INC.
"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/31/07) (ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

THE NUMERIC CODES SHOWN UNDER MELT SOURCE CAN BE INTERPRETED AS FOLLOWS:
1. - MATERIAL MELTED, ROLLED AND TESTED IN THE UNITED STATES.
2. - FOREIGN MELT; ROLLED AND TESTED IN THE UNITED STATES.

THIS DIN EN 10204:2005 - 3.1 CERTIFICATE OF TEST SHALL NOT BE REPRODUCED EXCEPT IN FULL. FEDERAL LAW PROHIBITS THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THE CERTIFICATE AND MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL LAW. MATERIAL WAS MANUFACTURED IN ACCORDANCE WITH THE ALC QUALITY MANUAL REVISION 18 DATED 08/05/2009. ALC HOLDS SEVERAL QUALITY CERTIFICATIONS THAT INCLUDE ISO-9001 AND AS9100. TESTING WAS PERFORMED AT ALC NADCAP AND ISO/IEC 17025 APPROVED LABORATORIES LOCATED AT THE NATRONA HEIGHTS, BRACKENRIDGE, LATROBE, AND MIDLAND, PA FACILITIES OR AT A NADCAP AND ISO/IEC 17025 ACCREDITED COMMERCIAL LABORATORY.

DIN EN 10204:2005 - 3.1 CERTIFICATE DOES NOT INDICATE PED APPROVAL FOR THIS MATERIAL.

ATI-ALLEGHENY LUDLUM HOLDS SEVERAL QUALITY AND LABORATORY CERTIFCATIONS THAT INCLUDE ISO-9001:2000, AS9100, AD 2000-MERKBLATT WO, AND EU PRESSURE EQUIPMENT DIRECTIVE 97/23/EC, NADCAP MATERIALS TESTING, ISO/IEC 17025, GEAE S400, GEAE S-1000. REFER TO WWW.ALLEGHENYLUDLUM.COM TO ACCESS THE CURRENT ATI-AL QUALITY CERTIFICATIONS.

ALLEGHENY LUDLUM WORKS TO THE ROLLS ROYCE RR9000:SABRE REQUIREMENTS.

MATERIAL TESTED AT ALLEGHENY LUDLUM GEAE S400 (DATED 10/31/07) APPROVED FACILITIES (T1225): NATRONA HEIGHTS TECHNICAL CENTER AND BRACKENRIDGE, PA.

PAGE 03 - CONTINUED ON PAGE 04 06/16/10 08:34:42

CONSIGNEE--Please Note--This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

WARNING
Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy phone 724-226-6577. CAUTION: Processing that makes fumes, dust, or solutions may cause lung disease. See Material Safety Data Sheets for further information.

Les fiches d'information-sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des exemplaires supplémentaires veuillez téléphoner au numéro suivant 724-226-6577. Attention: les traitements entraînant la production de vapeurs, poussières, ou solutions peuvent être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFalland
Tracy McFalland - Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved LC
Date 9-2-2010

Figure A.1.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01015776 | 02/04/10 | 110977 | BRACKENRIDGE, PA | 459793 | 13020103060000 | 32-020-043 | 06/16/10 |

| FORMS DISTRIBUTION SOLD TO | SHIP TO | SPEC | REPEAT ORDER | DO RATE | PRI-ORITY | GOV'T CONTRACT | MAT'L | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 81639-5 | 26 | | | 2245 | BRACKENRIDGE | PA | 030667 |

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS CARRIER - GROSS,RONALD,INC.
"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718)
(ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/31/07)
(ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17,
F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

ALLEGHENY LUDLUM PERFORMS CHEMICAL ANALYSIS BY THE FOLLOWING TECHNIQUES:
C, S BY COMBUSTION/INFRARED
N, O, H BY INERT FUSION/THERMAL CONDUCTIVITY
MN, P, SI, CR, NI, MO, CU, CB, CO, V BY WDXRF
B BY OES
AL AND TI (>=0.10%) BY WDXRF, OTHERWISE BY OES
PB, BI, AG BY GFAA

TESTING WAS PERFORMED AT THE FOLLOWING LOCATIONS:
BN = ATI-ALLEGHENY LUDLUM; 100 RIVER ROAD; BRACKENRIDGE, PA 15014
TC = ATI-ALLEGHENY LUDLUM; 1300 PACIFIC AVENUE; NATRONA HEIGHTS, PA 15065

AMERICAN SPECIAL METALS, CORP.
CERTIFICATION OF COMPLIANCE
We certify that this material conforms to the applicable specifications as shown on this purchase order.
Customer FAA
Customer PO# DTFACT-10-P-00240
ASM Work Order# 2010-H-12711
Qty 6 Pieces
AC 9-2-2010
Q.C. Certification Clerk Date

<<<<<<<< FOR ACCESS TO ONLINE CERTIFICATES OF TEST >>>>>>
<<<<<<<< REGISTER AT WWW.ALCEXTRA.COM >>>>>>

PAGE 04 - CONTINUED ON PAGE 05 06/16/10 08:34:42

CONSIGNEE Please Note - This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

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The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.
Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

Figure A.1.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 R08

INVOICE NO 30667
SHIP DATE 6/16/2010

TEST NO 3723546

| SPECIFICATION | | YIELD (PSI) | TENSILE (PSI) | ELONGATION IN 2" | HARDNESS | STRESS RUPTURE |
|---|---|---|---|---|---|---|
| B50TF14-S22 * | | | | | | |
| HEAT TREAT | (1) | 170000 | 201000 | 20 | 45HRC | |
| ELEVATED TEMP | (3) | 145000 | 162000 | 16 | | |
| STRESS RUPTURE | (2) | | | | | 20.2 HOURS DISCONTINUED |
| AMS 5596K * | | | | | | |
| HEAT TREAT | (4) | 180000 | 205000 | 19 | 46HRC | |
| ELEVATED TEMP | (3) | 152000 | 166000 | 12 | | |
| STRESS RUPTURE | (2) | | | 23 | | 145.3 HOURS BROKE |

GRAIN STRUCTURE: UNIFORM LARGEST GRAIN SIZE: 9

* TRANSVERSE TEST-Y.S. BY 0.2% OFFSET METHOD

(1) HEAT TO 1750F +/- 25F (954C +/- 14C) AND HOLD FOR ONE HOUR. COOL TO ROOM TEMPERATURE. HEAT TO 1325F +/- 25F (718C +/- 14C) AND HOLD FOR EIGHT HOURS. FURNACE COOL TO 1150F +/- 25F (621C +/- 14C) FOR EIGHT HOURS. COOL TO ROOM TEMPERATURE.

(2) 1200F +/- 3F (649C +/- 2C), 100,000 PSI (689 MPA).

(3) HEAT TENSILE TO 1200F +/- 5F (649C +/- 3C), HOLD AT HEAT 20-30 MINUTES, TEST AT 1200F +/- 5F (649C +/-3C).

(4) HEAT TO 1325F +/- 15F (718C +/- 8C), HOLD AT HEAT FOR 8 HOURS +/- .5 HOURS; COOL AT RATE OF 100F +/- 15F (38C +/- 8C) PER HOUR, TO 1150F +/- 15F (621C +/- 8C); HOLD AT 1150F +/- 15F (621C +/- 8C) FOR 8 HOURS, AIR COOL.

BY CERTIFYING TO B50TF14-S22 CLASS E, WE HAVE CERTIFIED THAT THIS MATERIAL IS CAPABLE OF MEETING CLASS F, WHEN HEAT TREATED IN ACCORDANCE WITH THE CLASS F REQUIREMENTS OF PARAGRAPH 3.6.1. HEAT TREATED PROPERTIES REPORTED ON OUR CERTIFICATE OF TEST, INDICATED BY (1) ABOVE, SHOW THE RESULTS AFTER SAMPLES WERE HEAT TREATED TO THE REQUIREMENT OF CLASS F. ACTUAL COIL WAS SUPPLIED IN THE MILL ANNEALED CONDITION IN ACCORDANCE WITH CLASS E.

ELEVATED TEMPERATURE TENSILE TESTING WAS PERFORMED AT WESTMORELAND MECHANICAL TESTING & RESEARCH, INC., YOUNGSTOWN, PA., CERTIFICATE #122335, EXPIRATION DATE 04/30/2010.

ISSUED BY ALLEGHENY LUDLUM - 06/16/2010 13:09
CARRIE MCFALL / QUALITY ASSURANCE DEPT

PAGE 05 - FINAL PAGE

CONSIGNEE Please Note--This consignment was turned over to carrier in first class condition, being correctly loaded at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

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Tracy McFarland
Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved AC
Date 9-2-2010

Figure A.1.—Concluded.

BLM 43

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016216 | 04/19/10 | 110977 | BRACKENRIDGE, PA | 464071 | 13020103060000 | 32-040-092 | 07/29/10 |

FORMS DISTRIBUTION: SOLD TO 1 | SHIP TO | SPEC
REPEAT ORDER 81639-9 | DO RATE 26 | PRIORITY
GOV'T CONTRACT
MAT'L 2245 | SHIPPING LOCATION VANDERGRIFT PA | INVOICE 650416

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS

CARRIER - CLAY TRANSPORT, INC.

"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

| ITEM | PCS | DIMENSIONS W/G/L | HEAT # | COIL # | TEST # | GROSS | TARE | NET | THEO | TAG #/ CD SKID # |
|---|---|---|---|---|---|---|---|---|---|---|
| 001A | 1 | 36.02/.080/551. | 068623 -02 | 06190N502 | G210041 | 5620 | 50 | 5570 | | 721872 |
| C CUST IDENTITY 14084 | | | | | | | | | | |
| | 1 SKID | | | | | 5620 | 50 | 5570 | | |

| | --C-- | --MN-- | --P-- | --S-- | --SI-- | --CR-- | --NI-- | --AL-- | --MO-- | --CU-- | --CB-- | --TA-- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEAT 068623-02 | .05 | .12 | .008 | .0001 | .07 | 18.21 | 52.54 | .55 | 2.90 | .06 | 5.00 | .01 |
| TEST LOCATION | TC | BN | BN | TC | BN | BN | BN | BN | BN | BN | BN | TC |

| | --TI-- | --CO-- | --B-- | --FE-- |
|---|---|---|---|---|
| HEAT 068623-02 | 1.00 | .30 | .002 | 19.05 |
| TEST LOCATION | BN | BN | BN | BN |

| ITEM TEST NO | YIELD PSI * | TENSILE PSI | % ELONG IN 2" | % R/A | HARDNESS | BEND | GRAIN SIZE |
|---|---|---|---|---|---|---|---|
| 001A G210041 | T 62000. | 128000 | 53. | | 93.HRBW | T PASS | 9. |
| | | | | | 93.HRBW | | 9. |
| TEST LOCATION | TC | TC | TC | | TC | TC | TC |

REVIEWED BY Q.C.
Date 8/3/10 by

* Y.S. BY 0.2% OFFSET METHOD

| ITEM TEST NO | MELT SOURCE | INTER-GRAN ATTACK | MICROSTRUC P&W E-44 | MICROSTRUC AMS 5596 | OCCASIONAL GRAIN SIZE | AVERAGE GRAIN SIZE | MACROETCH |
|---|---|---|---|---|---|---|---|
| 001A G210041 | 1. | .0000 | IN FIG 1 | PASS | 9. | 9. | PASS |
| | | .0000 | OUT FIG 1 | PASS | 9. | 9. | PASS |
| TEST LOCATION | | TC | TC | TC | TC | TC | TC |

PAGE 01 - CONTINUED ON PAGE 02

07/29/10 11:54:35

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The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved AC
Date 9-2-2010

Figure A.2.—Material certification for test number 3723546.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016216 | 04/19/10 | 110977 | BRACKENRIDGE, PA | 464071 | 130201030600000 | 32-040-092 | 07/29/10 |

| FORMS DISTRIBUTION: SOLD TO | SHIP TO | SPEC | REPEAT ORDER | DO DATE | PRI-ORITY | GOV'T CONTRACT | MAT'L | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 81639-9 | 26 | | | 2245 | VANDERGRIFT | PA | 650416 |

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS

CARRIER - CLAY TRANSPORT, INC.

"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

| ITEM TEST NO | P&W E-25 TRAN BEND |
|---|---|
| 001A G210041 | 2. |

TEST LOCATION TC
METALLOGRAPHIC MAGNIFICATION: 100X ETCHANT USED: HCl/CHROMIC ACID

GRADE VERIFICATION WAS CARRIED OUT SPECTROSCOPICALLY

INTERGRANULAR ATTACK MAGNIFICATION: 500X

ALLEGHENY LUDLUM DOES NOT USE MERCURY IN THE TESTING OR PRODUCTION OF ITS PRODUCTS. TO THE BEST OF ALLEGHENY LUDLUMS KNOWLEDGE, UNDERSTANDING, AND BELIEF, THIS MATERIAL WAS NOT CONTAMINATED BY MERCURY WHILE IT WAS BEING PRODUCED IN OUR FACILITIES.

NO WELDS/WELD REPAIRS PERFORMED.

THE PRODUCT WAS SOLUTION HEAT-TREATED WITHIN THE RANGE 1725F - 1825F +/- 25F (941C - 996C +/- 14C) FOR A TIME COMMENSURATE WITH THICKNESS AND COOLED AT A RATE EQUIVALENT TO AIR OR FASTER.

ALLEGHENY LUDLUM DOES NOT USE MERCURY IN THE TESTING OR PRODUCTION OF ITS PRODUCTS.

PAGE 02 - CONTINUED ON PAGE 03 07/29/10 11:54:35

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Tracy McFarland -
Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved LC
Date 9-2-2010

Figure A.2.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016216 | 04/19/10 | 110977 | BRACKENRIDGE, PA | 464071 | 13020103060000 | 32-040-092 | 07/29/10 |

| FORMS DISTRIBUTION | | | REPEAT ORDER | DO RATE | PRIORITY | GOVT CONTRACT | MAT'L | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| SOLD TO 1 | SHIP TO | SPEC | 81639-9 | 26 | | | 2245 | VANDERGRIFT | PA | 650416 |

| SOLD TO | PRIME | SEC. | SHIP TO |
|---|---|---|---|
| UNITED PERFORMANCE METALS<br>3475 SYMMES ROAD<br>HAMILTON OH 45015 | DSO<br>584 | DSO | UNITED PERFORMANCE METALS<br>3475 SYMMES ROAD<br>HAMILTON OH 45015 |

GRADE AND SPECIFICATIONS CARRIER - CLAY TRANSPORT, INC.
"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

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2. - FOREIGN MELT; ROLLED AND TESTED IN THE UNITED STATES.

THIS DIN EN 10204:2005 - 3.1 CERTIFICATE OF TEST SHALL NOT BE REPRODUCED EXCEPT IN FULL. FEDERAL LAW PROHIBITS THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THE CERTIFICATE AND MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL LAW. MATERIAL WAS MANUFACTURED IN ACCORDANCE WITH THE ALC QUALITY MANUAL REVISION 19 DATED 06/09/2010. ALC HOLDS SEVERAL QUALITY CERTIFICATIONS THAT INCLUDE ISO-9001 AND AS9100. TESTING WAS PERFORMED AT ALC NADCAP AND ISO/IEC 17025 APPROVED LABORATORIES LOCATED AT THE NATRONA HEIGHTS, BRACKENRIDGE, LATROBE, AND MIDLAND, PA FACILITIES OR AT A NADCAP AND ISO/IEC 17025 ACCREDITED COMMERCIAL LABORATORY.

DIN EN 10204:2005 - 3.1 CERTIFICATE DOES NOT INDICATE PED APPROVAL FOR THIS MATERIAL.

ATI-ALLEGHENY LUDLUM HOLDS SEVERAL QUALITY AND LABORATORY CERTIFCATIONS THAT INCLUDE ISO-9001:2000, AS9100, AD 2000-MERKBLATT WO, AND EU PRESSURE EQUIPMENT DIRECTIVE 97/23/EC, NADCAP MATERIALS TESTING, ISO/IEC 17025, GEAE S400, GEAE S-1000. REFER TO WWW.ALLEGHENYLUDLUM.COM TO ACCESS THE CURRENT ATI-AL QUALITY CERTIFICATIONS.

ALLEGHENY LUDLUM WORKS TO THE ROLLS ROYCE RR9000:SABRE REQUIREMENTS.

MATERIAL TESTED AT ALLEGHENY LUDLUM GEAE S400 (DATED 10/31/07) APPROVED FACILITIES (T1225): NATRONA HEIGHTS TECHNICAL CENTER AND BRACKENRIDGE, PA.

PAGE 03 - CONTINUED ON PAGE 04 07/29/10 11:54:35

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WARNING
Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy phone 724-226-6577. CAUTION: Processing that makes fumes, dust, or solutions may cause lung disease. See Material Safety Data Sheets for further information.

Les fiches d'information-sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des exemplaires supplémentaires veuillez téléphoner au numéro suivant 724-226-6577. Attention: les traitements entraînant la production de vapeurs, poussières, ou solutions peuvent être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved JC
Date 9-2-2010

Figure A.2.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016216 | 04/19/10 | 110977 | BRACKENRIDGE, PA | 464071 | 13020103060000 | 32-040-092 | 07/29/10 |

| FORMS DISTRIBUTION SOLD TO | SHIP TO | SPEC | REPEAT ORDER | DO RATE | PRI-ORITY | GOV'T CONTRACT | MAT'L | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 81639-9 | 26 | | | 2245 | VANDERGRIFT | PA | 650416 |

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS

CARRIER - CLAY TRANSPORT, INC.

"ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UPM 718) (10/30/08 EXCEPTIONS TO UPM 718) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (ASTM-E-112-96 REAPPROVED 2004 E2) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

ALLEGHENY LUDLUM PERFORMS CHEMICAL ANALYSIS BY THE FOLLOWING TECHNIQUES:
C, S BY COMBUSTION/INFRARED
N, O, H BY INERT FUSION/THERMAL CONDUCTIVITY
MN, P, SI, CR, NI, MO, CU, CB, CO, V BY WDXRF
B BY OES
AL AND TI (>=0.10%) BY WDXRF, OTHERWISE BY OES
PB, BI, AG BY GFAA

TESTING WAS PERFORMED AT THE FOLLOWING LOCATIONS:
BN = ATI-ALLEGHENY LUDLUM; 100 RIVER ROAD; BRACKENRIDGE, PA 15014
TC = ATI-ALLEGHENY LUDLUM; 1300 PACIFIC AVENUE; NATRONA HEIGHTS, PA 15065

<<<<<<<< FOR ACCESS TO ONLINE CERTIFICATES OF TEST >>>>>>>>
<<<<<<<< REGISTER AT WWW.ALCEXTRA.COM >>>>>>>>

AMERICAN SPECIAL METALS, CORP.
CERTIFICATION OF COMPLIANCE
We certify that this material conforms to the applicable specifications as shown on this purchase order.
Customer FAA
Customer PO# DTFACT-10-P-00240
ASM Work Order# 2010-H-12711
Qty 6 Pieces
JC 9-2-2010
Q.C. Certification Clerk Date

PAGE 04 - CONTINUED ON PAGE 05

CONSIGNEE - Please Note - This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

WARNING

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The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

Figure A.2.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

INVOICE NO 650416
SHIP DATE 7/29/2010

TEST NO G210041

| SPECIFICATION | | YIELD (PSI) | TENSILE (PSI) | ELONGATION IN 2" | HARDNESS | STRESS RUPTURE |
|---|---|---|---|---|---|---|
| B50TF14-S22 * | | | | | | |
| HEAT TREAT | (1) | 169000 | 201000 | 19 | 47.HRC | |
| ELEVATED TEMP | (3) | 142000 | 162000 | 20 | | |
| STRESS RUPTURE | (2) | | | | | 20.2 HOURS DISCONTINUED |
| AMS 5596K * | | | | | | |
| HEAT TREAT | (4) | 174000 | 203000 | 20 | 48.HRC | |
| ELEVATED TEMP | (3) | 143000 | 164000 | 19 | | |
| STRESS RUPTURE | (2) | | | 13 | | 98.9 HOURS BROKE |

GRAIN STRUCTURE: UNIFORM LARGEST GRAIN SIZE: 9

* TRANSVERSE TEST-Y.S. BY 0.2% OFFSET METHOD

(1) HEAT TO 1750F +/- 25F (954C +/- 14C) AND HOLD FOR ONE HOUR. COOL TO ROOM TEMPERATURE. HEAT TO 1325F +/- 25F (718C +/- 14C) AND HOLD FOR EIGHT HOURS. FURNACE COOL TO 1150F +/- 25F (621C +/- 14C) FOR EIGHT HOURS. COOL TO ROOM TEMPERATURE.

(2) 1200F +/- 3F (649C +/- 2C), 100,000 PSI (689 MPA).

(3) HEAT TENSILE TO 1200F +/- 5F (649C +/- 3C), HOLD AT HEAT 20-30 MINUTES, TEST AT 1200F +/- 5F (649C +/-3C).

(4) HEAT TO 1325F +/- 15F (718C +/- 8C), HOLD AT HEAT FOR 8 HOURS +/- .5 HOURS; COOL AT RATE OF 100F +/- 15F (38C +/- 8C) PER HOUR, TO 1150F +/- 15F (621C +/- 8C); HOLD AT 1150F +/- 15F (621C +/- 8C) FOR 8 HOURS, AIR COOL.

BY CERTIFYING TO B50TF14-S22 CLASS E, WE HAVE CERTIFIED THAT THIS MATERIAL IS CAPABLE OF MEETING CLASS F, WHEN HEAT TREATED IN ACCORDANCE WITH THE CLASS F REQUIREMENTS OF PARAGRAPH 3.6.1. HEAT TREATED PROPERTIES REPORTED ON OUR CERTIFICATE OF TEST, INDICATED BY (1) ABOVE, SHOW THE RESULTS AFTER SAMPLES WERE HEAT TREATED TO THE REQUIREMENT OF CLASS F. ACTUAL COIL WAS SUPPLIED IN THE MILL ANNEALED CONDITION IN ACCORDANCE WITH CLASS E.

ELEVATED TEMPERATURE TENSILE TESTING WAS PERFORMED AT WESTMORELAND MECHANICAL TESTING & RESEARCH, INC., YOUNGSTOWN, PA., A NADCAP CERTIFIED LABORATORY.

American Special Metals
Quality Assurance
Approved AC
Date 9-2-2010

PAGE 05 - FINAL PAGE.

ISSUED BY ALLEGHENY LUDLUM - 07/29/2010 15:56
TERESA A.STUMPF - QUALITY ASSURANCE DEPT

CONSIGNEE: Please note: This consignment was turned over to carrier in first class condition, being correctly loaded at which time our responsibility for loss of damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

WARNING

Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy phone 724-226-6577. CAUTION: Processing that makes fumes, dust, or solutions may cause lung disease. See Material Safety Data Sheets for further information.

Les fiches d'information–sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des exemplaires supplémentaires veuillez téléphoner au numéro suivant 724-226-6577. Attention: les traitements entraînant la production de vapeurs, poussières, ou solutions peuvent être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

The above is a true copy of data on file. This material ... results conform to the sales order ... Allegheny Ludlum ...

Tracy McFarland
Director Corporate Quality Assurance

Figure A.2.—Concluded.

BLM43

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016426 | 05/21/10 | 110977 | BRACKENRIDGE, PA | 465610 | 13010103060000 | 32-050-144 | 08/12/10 |

FORMS DISTRIBUTION: SOLD TO → 1 | SHIP TO → | SPEC →

REPEAT ORDER 87110-0 | DO RATE 26 | PRI-ORITY | GOVT CONTRACT | MATL 2245 | SHIPPING LOCATION BRACKENRIDGE PA | INVOICE 030899

| SOLD TO | PRIME | SEC. | SHIP TO |
|---|---|---|---|
| UNITED PERFORMANCE METALS | DSO | DSO | UNITED PERFORMANCE METALS |
| 3475 SYMMES ROAD | 584 | | 3475 SYMMES ROAD |
| HAMILTON OH 45015 | | | HAMILTON OH 45015 |

GRADE AND SPECIFICATIONS CARRIER - GROSS,RONALD,INC.
"ALTEMP" 718 ALLOY SHEET C R CUT LENGTHS ANNEALED 2D FIN 3 EDGE (UPM 718) (ASTM-E-112-96 REAPPROVED 2004 E2) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (10/30/08 EXCEPTIONS TO UPM 718) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

| ITEM | PCS | DIMENSIONS W/G/L | HEAT # | COIL # | TEST # | GROSS | TARE | NET | THEO | TAG #/ CD SKID # |
|---|---|---|---|---|---|---|---|---|---|---|
| 001A | 16 | 36./.125/120. | 068645 -02 | 07020N260A | 3723828 | 2833 | 249 | 2584 | | 134855 |
| | 16 | 36./.125/120. | 068645 -02 | 07020N260B | 3723828 | 2883 | 291 | 2592 | | 134856 |
| | 10 | 36./.125/120. | 068645 -02 | 07020N260C | 3723828 | 1917 | 295 | 1622 | | 134857 |
| C CUST IDENTITY 14050 | | | | | | | | | | |
| | 3 | SKIDS | | | | 7633 | 835 | 6798 | | |

| TYPE HEAT/TEST | --C-- | --MN-- | --P-- | --S-- | --SI-- | --CR-- | --NI-- | --AL-- | --MO-- | --CU-- | --CB-- | --TA-- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEAT 068645-02 | .05 | .07 | .007 | .0002 | .06 | 18.27 | 52.20 | .59 | 2.89 | .04 | 5.04 | .01 |
| TEST LOCATION | TC | BN | BN | TC | BN | BN | BN | BN | BN | BN | BN | TC |

| | --TI-- | --CO-- | --B-- | --FE-- |
|---|---|---|---|---|
| HEAT 068645-02 | 1.02 | .16 | .002 | 19.62 |
| TEST LOCATION | BN | BN | BN | BN |

| ITEM TEST NO | YIELD PSI * | TENSILE PSI | % ELONG IN 2" | % R/A | HARDNESS | BEND | GRAIN SIZE |
|---|---|---|---|---|---|---|---|
| 001A 3723828 | T 65500. | 129000 | 49. | | 98.HRBW | T PASS | 9. |
| | | | | | 95.HRBW | | 9. |
| TEST LOCATION | TC | TC | TC | | TC | TC | TC |

* Y.S. BY 0.2% OFFSET METHOD

REVIEWED BY Q.C.
Date 8/16/10 by TI

PAGE 01 - CONTINUED ON PAGE 02 08/12/10 14:34:27

CONSIGNEE - Please Note - This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

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The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved AC
Date 9-2-2010

Figure A.3.—Material Certification for test number 3723828.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO. | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016426 | 05/21/10 | 110977 | BRACKENRIDGE, PA | 465610 | 13010103060000 | 32-050-144 | 08/12/10 |

| FORMS DISTRIBUTION | | | REPEAT ORDER | DO RATE | PRIORITY | GOV'T CONTRACT | MAT'L | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| SOLD TO→ 1 | SHIP TO→ | SPEC → | 87110-0 | 26 | | | 2245 | BRACKENRIDGE | PA | 030899 |

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS

CARRIER - GROSS,RONALD,INC.

"ALTEMP" 718 ALLOY SHEET C R CUT LENGTHS ANNEALED 2D FIN 3 EDGE (UPM 718) (ASTM-E-112-96 REAPPROVED 2004 E2) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (10/30/08 EXCEPTIONS TO UPM 718) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

| ITEM TEST NO | MELT SOURCE | INTER-GRAN ATTACK | MICROSTRUC P&W E-44 | MICROSTRUC AMS 5596 | OCCASIONAL GRAIN SIZE | AVERAGE GRAIN SIZE | MACROETCH |
|---|---|---|---|---|---|---|---|
| 001A 3723828 | 1. | .0000 | IN FIG 1 | PASS | 9. | 9. | PASS |
| | | .0000 | OUT FIG 1 | PASS | 9. | 9. | PASS |
| TEST LOCATION | | TC | TC | TC | TC | TC | TC |

| ITEM TEST NO | P&W E-25 TRAN BEND |
|---|---|
| 001A 3723828 | 2. |
| TEST LOCATION | TC |

METALLOGRAPHIC MAGNIFICATION: 100X ETCHANT USED: HCl/CHROMIC ACID

GRADE VERIFICATION WAS CARRIED OUT SPECTROSCOPICALLY

INTERGRANULAR ATTACK MAGNIFICATION: 500X

ALLEGHENY LUDLUM DOES NOT USE MERCURY IN THE TESTING OR PRODUCTION OF ITS PRODUCTS. TO THE BEST OF ALLEGHENY LUDLUMS KNOWLEDGE, UNDERSTANDING, AND BELIEF, THIS MATERIAL WAS NOT CONTAMINATED BY MERCURY WHILE IT WAS BEING PRODUCED IN OUR FACILITIES.

NO WELDS/WELD REPAIRS PERFORMED.

THE PRODUCT WAS SOLUTION HEAT-TREATED WITHIN THE RANGE 1725F - 1825F +/- 25F (941C - 996C +/- 14C) FOR A TIME COMMENSURATE WITH THICKNESS AND COOLED AT A RATE EQUIVALENT TO AIR OR FASTER.

PAGE 02 - CONTINUED ON PAGE 03 08/12/10 14:34:27

CONSIGNEE - Please Note—This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

WARNING
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The above is a true copy of data on file. The material and test results conform to the cated contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved
Date 9-2-2010

Figure A.3.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6168-3 808

| CUST. ORD. NO & DATE | | CUST CODE | ACCEPTING MILL | SHIPPER NO | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016426 | 05/21/10 | 110977 | BRACKENRIDGE, PA | 465610 | 13010103060000 | 32-050-144 | 08/12/10 |

FORMS DISTRIBUTION: SOLD TO→ 1 | SHIP TO→ | SPEC→

| REPEAT ORDER | DO RATE | PRI-ORITY | GOV'T CONTRACT | MAT'L | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|
| 87110-0 | 26 | | | 2245 | BRACKENRIDGE | PA | 030899 |

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS

CARRIER - GROSS,RONALD,INC.

"ALTEMP" 718 ALLOY SHEET C R CUT LENGTHS ANNEALED 2D FIN 3 EDGE (UPM 718) (ASTM-E-112-96 REAPPROVED 2004 E2) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (10/30/08 EXCEPTIONS TO UPM 718) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIRMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

ALLEGHENY LUDLUM DOES NOT USE MERCURY IN THE TESTING OR PRODUCTION OF ITS PRODUCTS.

THE NUMERIC CODES SHOWN UNDER MELT SOURCE CAN BE INTERPRETED AS FOLLOWS:

1. - MATERIAL MELTED, ROLLED AND TESTED IN THE UNITED STATES.
2. - FOREIGN MELT; ROLLED AND TESTED IN THE UNITED STATES.

THIS DIN EN 10204:2005 - 3.1 CERTIFICATE OF TEST SHALL NOT BE REPRODUCED EXCEPT IN FULL. FEDERAL LAW PROHIBITS THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THE CERTIFICATE AND MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL LAW. MATERIAL WAS MANUFACTURED IN ACCORDANCE WITH THE ALC QUALITY MANUAL REVISION 19 DATED 06/09/2010. ALC HOLDS SEVERAL QUALITY CERTIFICATIONS THAT INCLUDE ISO-9001 AND AS9100. TESTING WAS PERFORMED AT ALC NADCAP AND ISO/IEC 17025 APPROVED LABORATORIES LOCATED AT THE NATRONA HEIGHTS, BRACKENRIDGE, LATROBE, AND MIDLAND, PA FACILITIES OR AT A NADCAP AND ISO/IEC 17025 ACCREDITED COMMERCIAL LABORATORY.

DIN EN 10204:2005 - 3.1 CERTIFICATE DOES NOT INDICATE PED APPROVAL FOR THIS MATERIAL.

ATI-ALLEGHENY LUDLUM HOLDS SEVERAL QUALITY AND LABORATORY CERTIFCATIONS THAT INCLUDE ISO-9001:2000, AS9100, AD 2000-MERKBLATT WO, AND EU PRESSURE EQUIPMENT DIRECTIVE 97/23/EC, NADCAP MATERIALS TESTING, ISO/IEC 17025, GEAE S400, GEAE S-1000. REFER TO WWW.ALLEGHENYLUDLUM.COM TO ACCESS THE CURRENT ATI-AL QUALITY CERTIFICATIONS.

ALLEGHENY LUDLUM WORKS TO THE ROLLS ROYCE SABRE QUALITY MANAGEMENT SYSTEM.

PAGE 03 - CONTINUED ON PAGE 04

08/12/10 14:34:27

CONSIGNEE - Please Note - This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

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The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved AC
Date 9.2.2010

Figure A.3.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

AL 6109-3 908

| CUST. ORD. NO. & DATE | | CUST. CODE | ACCEPTING MILL | SHIPPER NO | PRODUCT CODE | MILL ORDER NUMBER | DATE SHIPPED |
|---|---|---|---|---|---|---|---|
| 01016426 | 05/21/10 | 110977 | BRACKENRIDGE, PA | 465610 | 13010103060000 | 32-050-144 | 08/12/10 |

| FORMS DISTRIBUTION SOLD TO | SHIP TO | SPEC | REPEAT ORDER | DO RATE | PRIORITY | GOVT CONTRACT | MATL. | SHIPPING LOCATION | | INVOICE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 87110-0 | 26 | | | 2245 | BRACKENRIDGE | PA | 030899 |

SOLD TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

PRIME SEC.
DSO DSO
584

SHIP TO
UNITED PERFORMANCE METALS
3475 SYMMES ROAD
HAMILTON OH 45015

GRADE AND SPECIFICATIONS CARRIER - GROSS,RONALD,INC.
"ALTEMP" 718 ALLOY SHEET C R CUT LENGTHS ANNEALED 2D FIN 3 EDGE (UPM 718) (ASTM-E-112-96 REAPPROVED 2004 E2) (ASTM-E-139-06) (AMS 2269F) (B50TF14-S22 CLASSES A & E) (AMS 5596K) (UNS N07718) (S-400 DTD 10/10/2008) (10/30/08 EXCEPTIONS TO UPM 718) (E50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIREMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

MATERIAL TESTED AT ALLEGHENY LUDLUM GEAE S400 (DATED 10/31/07) APPROVED FACILITIES (T1225):
NATRONA HEIGHTS TECHNICAL CENTER AND BRACKENRIDGE, PA.

ALLEGHENY LUDLUM PERFORMS CHEMICAL ANALYSIS BY THE FOLLOWING TECHNIQUES:
C, S BY COMBUSTION/INFRARED
N, O, H BY INERT FUSION/THERMAL CONDUCTIVITY
MN, P, SI, CR, NI, MO, CU, CB, CO, V BY WDXRF
B BY OES
AL AND TI (>=0.10%) BY WDXRF, OTHERWISE BY OES
PB, BI, AG BY GFAA

TESTING WAS PERFORMED AT THE FOLLOWING LOCATIONS:
BN = ATI-ALLEGHENY LUDLUM; 100 RIVER ROAD; BRACKENRIDGE, PA 15014
TC = ATI-ALLEGHENY LUDLUM; 1300 PACIFIC AVENUE; NATRONA HEIGHTS, PA 15065

<<<<<<<< FOR ACCESS TO ONLINE CERTIFICATES OF TEST >>>>>>>>
<<<<<<<< REGISTER AT WWW.ALCEXTRA.COM >>>>>>>>

AMERICAN SPECIAL METALS, CORP.
CERTIFICATION OF COMPLIANCE
We certify that this material conforms to the applicable specifications as shown on this purchase order.
Customer FAA
Customer PO# DTFACT-10-P-00240
ASM Work Order# 2010-H-12711
Qty 6 Pieces
AC 9-2-2010
Q.C. Certification Clerk Date

PAGE 04 - CONTINUED ON PAGE 05.

CONSIGNEE - Please Note - This consignment was turned over to carrier in first class condition, being correctly loaded at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

WARNING
Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy phone 724-226-6577. CAUTION: Processing that makes fumes, dust, or solutions may cause lung disease. See Material Safety Data Sheets for further information.

Les fiches d'information-sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des exemplaires supplémentaires veuillez téléphoner au numéro suivant 724-226-6577. Attention: les traitements entraînent la production de vapeurs, poussières, ou solutions peuvent être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

The above is a true copy of data on file. The material and test results conform to the sales contract and specification(s) as set forth in Allegheny Ludlum's Order Acknowledgement.

Tracy McFarland -
Director, Corporate Quality Assurance

Figure A.3.—Continued.

NOTICE OF SHIPMENT/
PACKING LIST

ATI Allegheny Ludlum
Allegheny Technologies

CERTIFICATE OF TEST

INVOICE NO 30899
SHIP DATE 8/12/2010

TEST NO 3723828

| SPECIFICATION | | YIELD (PSI) | TENSILE (PSI) | ELONGATION IN 2" | HARDNESS | STRESS RUPTURE |
|---|---|---|---|---|---|---|
| B50TF14-S22 * | | | | | | |
| HEAT TREAT | (1) | 168000 | 201000 | 20 | 46.HRC | |
| ELEVATED TEMP | (3) | 144000 | 163000 | 17 | | |
| STRESS RUPTURE | (2) | | | | | 20.5 HOURS DISCONTINUED |
| AMS 5596K * | | | | | | |
| HEAT TREAT | (4) | 179000 | 206000 | 18 | 47.HRC | |
| ELEVATED TEMP | (3) | 144000 | 163000 | 16 | | |
| STRESS RUPTURE | (2) | | | 12 | | 109.5 HOURS BROKE |

GRAIN STRUCTURE: UNIFORM LARGEST GRAIN SIZE: 9

* TRANSVERSE TEST-Y.S. BY 0.2% OFFSET METHOD

(1) HEAT TO 1750F +/- 25F (954C +/- 14C) AND HOLD FOR ONE HOUR. COOL TO ROOM TEMPERATURE. HEAT TO 1325F +/- 25F (718C +/- 14C) AND HOLD FOR EIGHT HOURS. FURNACE COOL TO 1150F +/- 25F (621C +/- 14C) FOR EIGHT HOURS. COOL TO ROOM TEMPERATURE.

(2) 1200F +/- 3F (649C +/- 2C), 100,000 PSI (689 MPA).

(3) HEAT TENSILE TO 1200F +/- 5F (649C +/- 3C), HOLD AT HEAT 20-30 MINUTES, TEST AT 1200F +/- 5F (649C +/-3C).

(4) HEAT TO 1325F +/- 15F (718C +/- 8C), HOLD AT HEAT FOR 8 HOURS +/- .5 HOURS; COOL AT RATE OF 100F +/- 15F (38C +/- 8C) PER HOUR, TO 1150F +/- 15F (621C +/- 8C); HOLD AT 1150F +/- 15F (621C +/- 8C) FOR 8 HOURS, AIR COOL.

BY CERTIFYING TO B50TF14-S22 CLASS E, WE HAVE CERTIFIED THAT THIS MATERIAL IS CAPABLE OF MEETING CLASS F, WHEN HEAT TREATED IN ACCORDANCE WITH THE CLASS F REQUIREMENTS OF PARAGRAPH 3.6.1. HEAT TREATED PROPERTIES REPORTED ON OUR CERTIFICATE OF TEST, INDICATED BY (1) ABOVE, SHOW THE RESULTS AFTER SAMPLES WERE HEAT TREATED TO THE REQUIREMENT OF CLASS F. ACTUAL COIL WAS SUPPLIED IN THE MILL ANNEALED CONDITION IN ACCORDANCE WITH CLASS E.

ELEVATED TEMPERATURE TENSILE TESTING WAS PERFORMED AT WESTMORELAND MECHANICAL TESTING & RESEARCH, INC., YOUNGSTOWN, PA., A NADCAP CERTIFIED LABORATORY.

American Special Metals
Quality Assurance
Approved AC
Date 9. 7. 2010

ISSUED BY ALLEGHENY LUDLUM - 08/12/2010 16:01
TERESA A. STUMPF - QUALITY ASSURANCE DEPT

PAGE 05 - FINAL PAGE.

CONSIGNEE Please Note: This consignment was turned over to carrier in first class condition, being correctly loaded, at which time our responsibility for loss or damage in shipment ceased. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, have a full description made by transportation agent on waybill before signing.

WARNING

Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy phone 724-226-6577. CAUTION Processing that makes fumes, dust, or solutions may cause lung disease. See Material Safety Data Sheets for further information.

Les fiches d'information sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des exemplaires supplémentaires veuillez téléphoner au numéro suivant 724-226-6577. Attention: les traitements entraînant la production de vapeurs, poussières, ou solutions peuvent être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information sécurité.

Tracy McFarland
Director Corporate Quality Assurance

Figure A.3.—Concluded.

JS0286A-1 200

**ATI Allegheny Ludlum**
Allegheny Technologies

500 Green Street
Washington, PA 15301

CERTIFIED MATERIAL TEST REPORT
CERTIFICATE OF CONFORMANCE

| | | |
|---|---|---|
| OUR ORDER NO. | PW0386770 | BLM |
| YOUR ORDER NO. | T74040 | 43 |
| MEMO NO. | 361748-01 | |
| DATE | 05/26/2010 | |
| SALESMAN NO. | 424 | |

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

48182 32

ALTEMP 718 HRAP
ASTM B670 02 AMS 5596 K GE B50TF14 S22 CLASS A & E
2.4668; NACE MR0175; RR9000:SABRe;
S1000E; S400E; UNS N07718

TRACER # Below

| Heat | Matl ID | Slip | Sid | Lot No | Size(Inches) | Pcs | Weight(lb) |
|---|---|---|---|---|---|---|---|
| 068516L03 | 03 | 15012 | AAA | 234006 | .5000 x 48.0000 x 260.0000 | 1 | 1909 TN 209304 |
| 068516L03 | 03 | 15012 | AAB | 234007 | .5000 x 48.0000 x 258.0000 | 1 | 1895 TN 209305 |

| Heat | C | MN | P | S | SI | NI | CR | MO | CO | CU | AL | TI | CB | B | FE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 068516L03 | .048 | .083 | .008 | .0001 | .072 | 52.60 | 18.32 | 2.87 | .20 | .034 | .54 | 1.02 | 4.94 | .0029 | 19.25 |

| Heat | TA |
|---|---|
| 068516L03 | .010 |

| Lot No | Gauge | Cond. | Cond. Test | Yield Strength | Tensile Strength | Elong % | Red. of Area % | Hardness | Bend | Corrosion | Grain Size |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 234006 | .5000 | TRANS | ANNEAL | 62.8 KSI | 128.8 KSI | 52.0 | 60.0 | B091 | | | 8 |
| | | TRANS | (A) | 167.7 KSI | 204.5 KSI | 25.0 | | C044 | | | |
| | | TRANS | (A&C) | 140.2 KSI | 166.1 KSI | 28.0 | | | | | |
| | | TRANS | (B) | 160.8 KSI | 200.2 KSI | 27.0 | | C044 | | | |
| | | TRANS | (B&C) | 129.3 KSI | 156.0 KSI | 27.0 | | | | | |
| 234007 | .5000 | TRANS | ANNEAL | 64.0 KSI | 130.8 KSI | 51.0 | 57.0 | B093 | | | 8 |
| | | TRANS | (A) | 163.9 KSI | 202.2 KSI | 26.0 | | C043 | | | |
| | | TRANS | (A&C) | 139.8 KSI | 164.9 KSI | 29.0 | | | | | |
| | | TRANS | (B) | 172.5 KSI | 204.6 KSI | 24.0 | | C043 | | | |

American Special Metals
Quality Assurance
Approved AC
Date 9-2-2010

PAGE 1 CONTINUE ON PAGE 2

REVIEWED BY Q.C.
Date 8/30/10 By

THIS CERTIFICATE OF TEST SHALL NOT BE REPRODUCED IN FULL WITHOUT THE WRITTEN APPROVAL OF THE COMPANY. THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THE CERTIFICATE MAY BE PUNISHED AS A FELONY UNDER FEDERAL LAW. TESTING WAS PERFORMED AT ALC NADCAP AND ISO/IEC 17025 APPROVED LABORATORIES LOCATED AT NATRONA HEIGHTS, BRACKENRIDGE, LATROBE, MIDLAND, AND LEECHBURG, PA FACILITIES OR A NADCAP AND ISO/IEC 17025 ACCREDITED LABORATORY. EN 10204 - 3.1 ALLEGHENY LUDLUM IS APPROVED AS MANUFACTURER ACCORDING TO AD-MERKBLATT WO/TRD 100 AND THE PRESSURE EQUIPMENT DIRECTIVE PED 97/23/EC.

ALLEGHENY LUDLUM PERFORMS CHEMICAL ANALYSIS BY THE FOLLOWING TECHNIQUES: C, S BY COMBUSTION/INFRARED. N, O, H BY INERT FUSION/THERMAL CONDUCTIVITY. MN, P, SI, CR, NI, MO, CU, CB, CO, V, BY WDXRF. B BY OES. AL AND TI (>=0.10%) BY WDXRF. OTHERWISE BY OES. PB, BI, AG BY GFAA

CERTIFICATE OF TEST STATEMENT & CHEMISTRY STATEMENT EXCEPT AS OTHERWISE NOTED, THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH THE LISTED SPECIFICATIONS AND RESULTS CONFORM TO THE SPECIFICATION AND ORDER REQUIREMENTS.

Figure A.4.—Certificate of conformance.

JS0288A-1 200

ATI Allegheny Ludlum
Allegheny Technologies

500 Green Street
Washington, PA 15301

CERTIFIED MATERIAL TEST REPORT
CERTIFICATE OF CONFORMANCE

| | |
|---|---|
| OUR ORDER NO. | PW0386770 Page 2 |
| YOUR ORDER NO. | T74040 |
| MEMO NO. | 361748-01 |
| DATE | 05/26/2010 |
| SALESMAN NO. | 424 |

Tracy McFarland
Tracy McFarland - Director, Corporate Quality Assurance

48182 182

| Lot No | Gauge | Cond. | Cond. Test | Yield Strength | Tensile Strength | Elong % | Red. of Area % | Hardness | Bend | Corrosion | Grain Size |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TRANS | (B&C) | 145.0 KSI | 167.8 KSI | 22.0 | | | | | |

Lot No: 234006 (D) STRESS RUPTURE - HRS BROKE 67.0 ELONG 8.0
Lot No: 234006 (E) STRESS RURTURE - HRS BROKE 91.5 ELONG 6.0
Lot No: 234006 MICROSTRUCTURE UNIFORM
Lot No: 234006 FINAL STRESS RUPTURE LOAD - (D) 130 KSI; (E) 130 KSI
Lot No: 234007 (D) STRESS RUPTURE - HRS BROKE 64.9 ELONG 8.0
Lot No: 234007 (E) STRESS RUPTURE - HRS BROKE 93.9 ELONG 7.0
Lot No: 234007 MICROSTRUCTURE UNIFORM
Lot No: 234007 FINAL STRESS RUPTURE LOAD (D) 130 KSI; (E) 130 KSI

MATERIAL WAS NOT WELD REPAIRED
MATERIAL WAS PRODUCED WITHOUT KNOWN CONTACT WITH MERCURY
DIN EN 10204:2005 3.1 CERTIFICATE
MATERIAL IS OF USA MELT AND MANUFACTURE
(A) SOLUTION TREATED & AGED PER GE B50TF14 (ABOVE REVISION) CLASSES B & F
(B) PRECIPITATION HARDENED PER AMS 5596 AND ASTM B670 (ABOVE REVISIONS)
(C) HEAT TO 1200 DEG F, HOLD AT HEAT 20/30 MIN., TEST AT 1200F +/- 5F
(D) STRESS RUPTURE PER G.E. B50TF14 - 1200F, UPLOAD 5 KSI/8-10 HRS AFTER 23 HRS
(E) STRESS RUPTURE PER AMS 5596 & ASTM B670; UPLOAD 5 KSI/8-10 HRS AFTER 48 HRS
NADCAP CERT #124317 ALLEGHENY LUDLUM BRACKENRIDGE, PA EXPIRES 10/31/2010
HEAT TREATED IN RANGE OF 1725-1825F AND COOLED AT RATE EQUAL TO AIR OR FASTER
INITIAL STRESS RUPTURE LOAD - 100 KSI
MECHANICAL & ELEVATED TEMP TESTS PERFORMED AT WMTR; CHEMICAL TESTING PERFORMED AT ALLEGHENY LUDLUM

PAGE 2 CONTINUE ON PAGE 3

American Special Metals
Quality Assurance
Approved AC
Date 9.2.2010

THIS CERTIFICATE OF TEST SHALL NOT BE REPRODUCED IN FULL WITHOUT THE WRITTEN APPROVAL OF THE COMPANY. THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THE CERTIFICATE MAY BE PUNISHED AS A FELONY UNDER FEDERAL LAW. TESTING WAS PERFORMED AT ALC NADCAP AND ISO/IEC 17025 APPROVED LABORATORIES LOCATED AT NATRONA HEIGHTS, BRACKENRIDGE, LATROBE, MIDLAND, AND LEECHBURG, PA FACILITIES OR A NADCAP AND ISO/IEC 17025 ACCREDITED LABORATORY. EN 10204 - 3.1 ALLEGHENY LUDLUM IS APPROVED AS MANUFACTURER ACCORDING TO AD-MERKBLATT WO/TRD 100 AND THE PRESSURE EQUIPMENT DIRECTIVE PED 97/23/EC.

ALLEGHENY LUDLUM PERFORMS CHEMICAL ANALYSIS BY THE FOLLOWING TECHNIQUES: C, S BY COMBUSTION/INFRARED. N, O, H BY INERT FUSION/THERMAL CONDUCTIVITY. MN, P, SI, CR, NI, MO, CU, CB, CO, V, BY WDXRF. B BY OES. AL AND TI (>=0.10%) BY WDXRF, OTHERWISE BY OES. PB, BI, AG BY GFAA
CERTIFICATE OF TEST STATEMENT & CHEMISTRY STATEMENT EXCEPT AS OTHERWISE NOTED, THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH THE LISTED SPECIFICATIONS AND RESULTS CONFORM TO THE SPECIFICATION AND ORDER REQUIREMENTS.

Figure A.4.—Continued.

B4M 43

**CERTIFICATION OF TESTS • RAPPORT D'ESSAIS CERTIFIE • WERKSZEUGNIS**

| Sales Order No / Reference Commande / Bestellungs Nr | Date Entered / Date De Commande / Bestelldatum | Customer Reference / Reference Client / Kundenbestelldaten | Report No. / Rapport No / Zeugnis Nr | Pages of Pages / Page de Pages / Anzahl der Seiten |
|---|---|---|---|---|
| 580571001-0 | 03/18/10 | T74082 | 20100821006 | 1 Of 3 |

CUSTOMER COPY

**HAYNES International**

Haynes International
1020 West Park Avenue
PO Box 9013
Kokomo, Indiana, 46902

Product Description • Description Produit • Material Beshreibung

**0.250 x 48 x 240**

**HAYNES(R) 718 ALLOY PLATE - PLATE**
**Nadcap CERTIFICATE NUMBER 126994**
**GE# 19762, S400 10/10/2008, S1000 3/2/2010, EN 10204 3.1, AS9100**

| Specification • Specification • Spezifikation | Quantity Ordered / Quantite Commandee / Bestellemenge | Quantity Shipped / Quantitie Expediee / Liefermenge |
|---|---|---|
| AMS 5596, K; B50TF14, S22, CL A TESTED CL. B; B50TF14, S22, CL E TESTED CL. F; ASTM-B-670, 02, UNS# N07718; MR0175-2003, A; RR9000:SABRe | 4 PC | 4 PC |

Chemical Analysis • Analyse Chimique • Chemische Analyse

| Heat Number / Numero De Coulee / Charge Nr | Al | B | C | Cb+Ta (Nb+Ta) | Co | Cr | Cu | Fe | Mn | Mo | Ni | P | S | Si | Ti | V | W | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2180 0 9812 | 0.53 | 0.003 | 0.051 | 5.17 | 0.27 | 18.10 | 0.05 | 18.90 | 0.21 | 3.09 | 52.90 | <0.005 | <0.002 | 0.08 | 0.92 | | | BUTT END *02 |
| | [illegible] | Ta | Zr | Bi | Se | La | [illegible] | Pb | Mg | Y | Ag | N | Ca | Al+Ti | Ni+Co | Ni+Mo | | |
| 2180 0 9812 | 5.160 | <0.05 | | | | | | | | | | | | | | | BUTT END *02 | |

Certified By • Certifie Par • Bescheinigt Durch: Jim White
Certification Supervisor

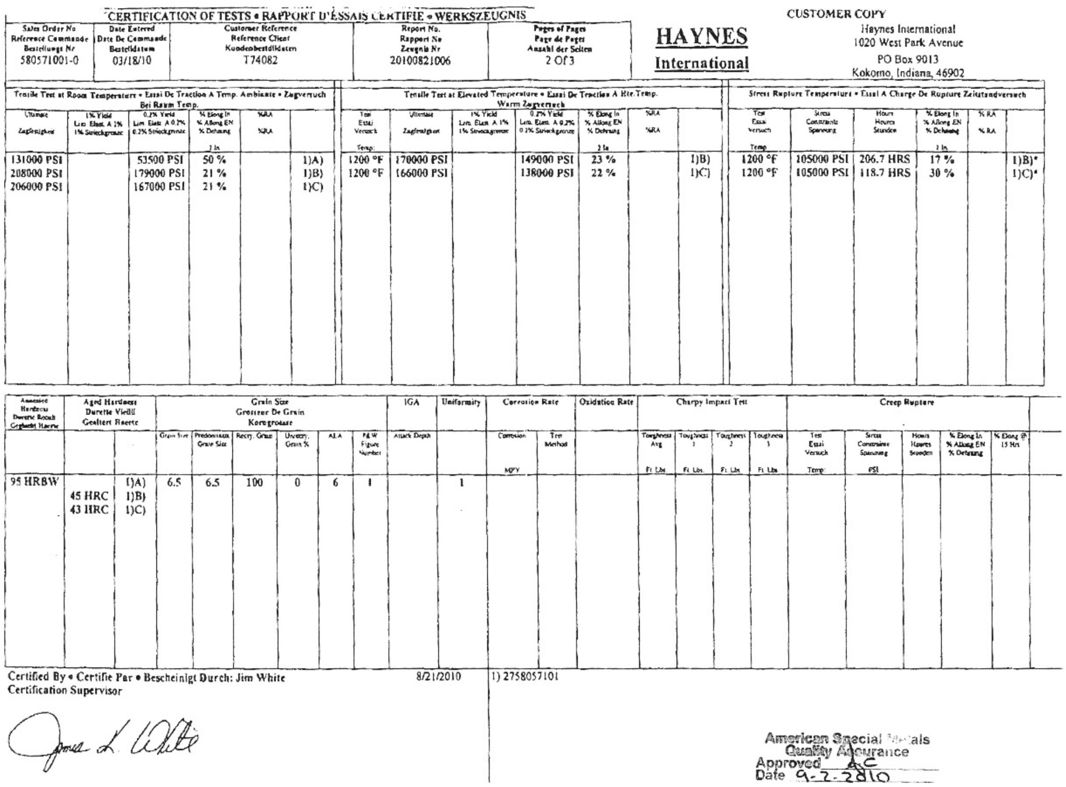
8/21/2010

James L. White

REVIEWED BY Q.C.
Date 8/30/10 By TS

American Special Metals
Quality Assurance
Approved J.C
Date 9-2-2010

Figure A.4.—Continued.


CERTIFICATION OF TESTS • RAPPORT D'ESSAIS CERTIFIE • WERKSZEUGNIS

| Sales Order No / Reference Commande / Bestellungs Nr | Date Entered / Date De Commande / Bestelldatum | Customer Reference / Reference Client / Kundenbestdlldatem | Report No. / Rapport No / Zeugnis Nr | Pages of Pages / Page de Pages / Anzahl der Seiten |
|---|---|---|---|---|
| 580571001-0 | 03/18/10 | T74082 | 20100821006 | 2 Of 3 |

**HAYNES International**

CUSTOMER COPY
Haynes International
1020 West Park Avenue
PO Box 9013
Kokomo, Indiana, 46902

Tensile Test at Room Temperature • Essai De Traction A Temp. Ambiante • Zugversuch Bei Raum Temp.

| Ultimate / Zugfestigkeit | 1% Yield / Lim. Elast. A 1% / 1% Streckgrenze | 0.2% Yield / Lim. Elast. A 0.2% / 0.2% Streckgrenze | % Elong In / % Allong EN / % Dehnung 2 In | %RA / %RA | |
|---|---|---|---|---|---|
| 131000 PSI | | 53500 PSI | 50 % | | 1)A) |
| 208000 PSI | | 179000 PSI | 21 % | | 1)B) |
| 206000 PSI | | 167000 PSI | 21 % | | 1)C) |

Tensile Test at Elevated Temperature • Essai De Traction A Hte.Temp. Warm Zugversuch

| Test / Essai / Versuch Temp. | Ultimate / Zugfestigkeit | 1% Yield / Lim. Elast. A 1% / 1% Streckgrenze | 0.2% Yield / Lim. Elast. A 0.2% / 0.2% Streckgrenze | % Elong In / % Allong EN / % Dehnung 2 In | %RA / %RA | |
|---|---|---|---|---|---|---|
| 1200 °F | 170000 PSI | | 149000 PSI | 23 % | | 1)B) |
| 1200 °F | 166000 PSI | | 138000 PSI | 22 % | | 1)C) |

Stress Rupture Temperature • Essai A Charge De Rupture Zeitstandversuch

| Test / Essai / Versuch Temp | Stress / Contrainte / Spannung | Hours / Heures / Stunden | % Elong In / % Allong EN / % Dehnung 2 In | % RA / % RA | |
|---|---|---|---|---|---|
| 1200 °F | 105000 PSI | 206.7 HRS | 17 % | | 1)B)* |
| 1200 °F | 105000 PSI | 118.7 HRS | 30 % | | 1)C)* |

| Annealed Hardness / Durete Recuit / Geglueht Haerte | Aged Hardness / Durete Vieilli / Gealtert Haerte | | Grain Size / Grosseur De Grain / Korngroesse: Grain Size | Predominant Grain Size | Recry. Grain | Unrecry. Grain % | ALA | P&W Figure Number | IGA: Attack Depth | Uniformity | Corrosion Rate: Corrosion MPY | Test Method | Oxidation Rate | Charpy Impact Test: Toughness Avg Ft Lbs | Toughness 1 Ft Lbs | Toughness 2 Ft Lbs | Toughness 3 Ft Lbs | Creep Rupture: Test / Essai / Versuch Temp | Stress / Contrainte / Spannung PSI | Hours / Heures / Stunden | % Elong In / % Allong EN / % Dehnung | % Elong @ 15 Hrs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95 HRBW | | 1)A) | 6.5 | 6.5 | 100 | 0 | 6 | 1 | | 1 | | | | | | | | | | | | |
| | 45 HRC | 1)B) | | | | | | | | | | | | | | | | | | | | |
| | 43 HRC | 1)C) | | | | | | | | | | | | | | | | | | | | |

Certified By • Certifie Par • Bescheinigt Durch: Jim White
Certification Supervisor

8/21/2010

1) 2758057101

Jim L. White

American Special Metals
Quality Assurance
Approved A.C
Date 9-2-2010

Figure A.4.—Continued.

CERTIFICATION OF TESTS • RAPPORT D'ESSAIS CERTIFIE • WERKSZEUGNIS

| Sales Order No<br>Reference Commande<br>Bestellungs Nr | Date Entered<br>Date De Commande<br>Bestelldatum | Customer Reference<br>Reference Client<br>Kundenbestelldaten | Report No.<br>Rapport No<br>Zeugnis Nr | Pages of Pages<br>Page de Pages<br>Anzahl der Seiten |
|---|---|---|---|---|
| 580571001-0 | 03/18/10 | T74082 | 20100821006 | 3 Of 3 |

**HAYNES**
**International**

CUSTOMER COPY
Haynes International
1020 West Park Avenue
PO Box 9013
Kokomo, Indiana, 46902

Heat Codes: AMS 5596/9812: YBXCF
All tests and inspections have been performed and results meet specification requirements.
THIS MATERIAL IS FREE FROM MERCURY, CADMIUM, RADIUM, AND ALPHA SOURCE CONTAMINATION.
THIS MATERIAL WAS MELTED AND MANUFACTURED IN THE UNITED STATES
~~Material controlled to PWA 300 and PWA LCS as per MCL F-17.~~ SD
Microstructure: Acceptable
Surface microstructural evaluation was performed at 500X magnification.
Tested at Haynes International, Inc. Kokomo, In.
Microstructure complies with E50TF133 Class C.
Samples tested to B50TF14 Cl. F condition and material supplied to Cl.E condition.
Samples tested to B50TF14 Cl.B condition and material supplied to Cl.A condition.
All aged test specimens are aged after final machining.
Mill Orders Used: 2758057101 (4 PC)
* This test was performed at Connecticut Metallurgical, Inc., 100 Prestige Park, East Hartford, CT, Phone # (860)289-7481 Fax # (860)528-1516
Method of Chemistry Analysis for Heat# 09812 BUTT END *02: O.E. (Al,B,Cr,P,Si); LECO (C,S); XARL DIRECT RATIO (Cb,Fe); XARL LINFIT (CBTA,Co,Cu,Mn,Mo,Ni,Ta,Ti),
A) 1725 °F to 1825 °F
B) 1725 °F to 1825 °F; Step 1:1325 °F, 8 Hrs; Step 2:1150 °F, 8 HrsTotal Time. 18 Hrs)
C) 1725 °F to 1825 °F; Step 1:1750 °F, 1 Hrs; Step 2:1325 °F, 8 Hrs; Step 3:1150 °F, 8 HrsTotal Time: 18 Hrs)

**Certified By • Certifie Par • Bescheinigt Durch: Jim White** 8/21/2010
**Certification Supervisor**

James L. White

AMERICAN SPECIAL METALS, CORP.
CERTIFICATION OF COMPLIANCE
We certify that this material conforms to the applicable specifications as shown on this purchase order.
Customer FAA
Customer PO# DTFACT-10-P-00240
ASM Work Order# 2010-H-12711
Qty. 6 Pieces
LC 9-2-2010
Q.C. Certification Clerk Date

Figure A.4.—Continued.

JS0281A-1 200

ATI Allegheny Ludlum

500 Green Street
Washington, PA 15301

CERTIFIED MATERIAL TEST REPORT
CERTIFICATE OF CONFORMANCE

| | |
|---|---|
| OUR ORDER NO. | FW0386770 Page 3 |
| YOUR ORDER NO. | T74040 |
| MEMO NO. | 361748-01 |
| DATE | 05/26/2010 |
| SALESMAN NO. | 424 |

Tracy McFarland

Tracy McFarland - Director, Corporate Quality Assurance

48182 1182

NADCAP CERT #122335 WESTMORELAND MECHANICAL TESTING (WMTR) YOUNGSTOWN, PA EXPIRES 4/30/2010

AMERICAN SPECIAL METALS, CORP.
CERTIFICATION OF COMPLIANCE
We certify that this material conforms to the applicable specifications as shown on this purchase order.

Customer FAA
Customer PO# DTFACT-10-P-00240
ASM Work Order# 2010-H-12711
Qty 1 Piece
Q.C. Certification Clerk 9-2-2010 Date

PAGE 3 FINAL PAGE

THIS CERTIFICATE OF TEST SHALL NOT BE REPRODUCED IN FULL WITHOUT THE WRITTEN APPROVAL OF THE COMPANY. THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THE CERTIFICATE MAY BE PUNISHED AS A FELONY UNDER FEDERAL LAW. TESTING WAS PERFORMED AT ALC NADCAP AND ISO/IEC 17025 APPROVED LABORATORIES LOCATED AT NATRONA HEIGHTS, BRACKENRIDGE, LATROBE, MIDLAND, AND LEECHBURG, PA FACILITIES OR A NADCAP AND ISO/IEC 17025 ACCREDITED LABORATORY. EN 10204 - 3.1 ALLEGHENY LUDLUM IS APPROVED AS MANUFACTURER ACCORDING TO AD-MERKBLATT WO/TRD 100 AND THE PRESSURE EQUIPMENT DIRECTIVE PED 97/23/EC.

ALLEGHENY LUDLUM PERFORMS CHEMICAL ANALYSIS BY THE FOLLOWING TECHNIQUES: C, S BY COMBUSTION/INFRARED. N, O, H BY INERT FUSION/THERMAL CONDUCTIVITY. MN, P, SI, CR, NI, MO, CU, CB, CO, V, BY WDXRF. B BY OES. AL AND TI (>=0.10%) BY WDXRF, OTHERWISE BY OES. PB, BI, AG BY GFAA

CERTIFICATE OF TEST STATEMENT & CHEMISTRY STATEMENT EXCEPT AS OTHERWISE NOTED, THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH THE LISTED SPECIFICATIONS AND RESULTS CONFORM TO THE SPECIFICATION AND ORDER REQUIREMENTS.

Figure A.4.—Concluded.

# Appendix B.—Heat Treatment Certification

The following sheet certifies the material hardness after heat treatment.

**The Euclid Heat Treating Company**

**Certification**

**Order No.:** 337371
**Date:** 03/14/2013
**Entry Date:** 03/12/2013
**Page:** 1 of 1

To:
NASA Glenn Research Center
Cleveland OH

**Purchase Order No.:** 13-1114
**Packing List No.:** AERX2013D
1 **Material:** other

We are pleased to provide you with the following certification.

| Quantity | Part Number / Part Name / Part Description | Pounds |
|---|---|---|
| 1 | Inconel 718<br>Inconel 718 Mat'l Plates<br>Age harden per Instructions (42 RC min) | 1584 |

Serial Numbers / Other Numbers: 1 Qty- 1 Lot.

Subject material was age hardened per customer instructions. Samples show a resultant hardness of 44 Rc.

MTI STATEMENT OF LIMITED LIABILITY (Please Read Carefully)
ALL WORK IS PERFORMED SUBJECT TO THE FOLLOWING TERMS: THE BUYER OF METAL TREATING SERVICES FROM THE SELLER, UNDERSTANDS THAT EVEN AFTER EMPLOYING ALL THE SCIENTIFIC METHODS KNOWN TO THE SELLER, HAZARDS STILL REMAIN IN METAL TREATING. THE BUYER THEREFORE AGREES THAT SELLER'S LIABILITY SHALL NOT EXCEED TWICE THE AMOUNT OF THE CHARGES FOR THE WORK DONE ON ANY MATERIAL. THE BUYER AGREES AND UNDERSTANDS THAT THIS LIMITATION OF LIABILITY IS NOT AN EXCULPATORY CLAUSE. THE REIMBURSEMENT AND FULL LIABILITY OF THE SELLER SHALL NOT EXCEED TWICE THE AMOUNT OF THE CHARGES FOR THE WORK DONE BY THE SELLER ON ANY MATERIAL. THIS IS INTENDED TO REIMBURSE THE BUYER FOR THE CHARGES AND TO FULLY COMPENSATE THE BUYER IN THE AMOUNT OF THE CHARGES. THIS TERM APPLIES TO ALL WORK DONE BY THE SELLER EXCEPT WHERE OTHERWISE AGREED TO IN A WRITTEN AGREEMENT SIGNED BY AN AUTHORIZED REPRESENTATIVE OF THE SELLER. THE BUYER, BY CONTRACTING FOR METAL TREATMENT, AGREES TO ACCEPT THE LIMITS OF LIABILITY AS EXPRESSED IN THIS STATEMENT TO THE EXCLUSION OF ANY AND ALL OTHER PROVISIONS AS TO LIABILITY THAT MAY BE SET FORTH IN THE BUYER'S OWN INVOICES, PURCHASE ORDERS OR OTHER DOCUMENTS. IF THE BUYER PROPOSES A DIFFERENT OR ADDITIONAL LIABILITY PROVISION, THE SAME MUST BE AGREED TO IN WRITING AND SIGNED BY AN OFFICER OF THE SELLER BEFORE WORK IS STARTED OR SERVICES ARE PROVIDED. IN SUCH EVENT, THE BUYER UNDERSTANDS THAT A DIFFERENT CHARGE FOR SERVICES MUST BE AGREED ON, REFLECTING THE HIGHER RISK TO THE SELLER AND THAT NO WORK WILL BE STARTED UNTIL BOTH THE SELLER AND THE BUYER HAVE SIGNED AN AGREEMENT SETTING FORTH THE NEW CHARGES AND TERMS OF LIABILITY. OTHERWISE, THE TERMS SET FORTH HEREIN ARE BINDING ON THE BUYER. IT IS AGREED BY THE BUYER AND THE SELLER THAT THE INABILITY TO DISCOVER A DEFECT WITHIN A REASONABLE PERIOD OF TIME AFTER THE RECEIPT OF A SHIPMENT OF HEAT TREATED MATERIAL, NOT TO EXCEED FIVE (5) BUSINESS DAYS, WILL NOT VOID THE LIMITATION OF LIABILITY CONTAINED IN THIS AGREEMENT. IT IS THE BUYER'S OBLIGATION TO NOTIFY THE SELLER IF IT DOES NOT AGREE TO THE LIMITATION OF LIABILITY CONTAINED HEREIN AND A FAILURE ON THE PART OF THE BUYER TO DO SO IN WRITING BEFORE WORK STARTS WILL BE DEEMED ACCEPTANCE OF THIS LIMITATION OF LIABILITY. THE SELLER MAKES NO EXPRESS OR IMPLIED WARRANTIES AND SPECIFICALLY DISCLAIMS ANY IMPLIED WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE OR MERCHANTABILITY, AS TO THE PERFORMANCE OR CAPABILITIES OF THE MATERIAL AS HEAT TREATED, OR THE HEAT TREATMENT. THE AFOREMENTIONED LIMITATION OF LIABILITY STATED ABOVE IS SPECIFICALLY IN LIEU OF ANY EXPRESS OR IMPLIED WARRANTY, INCLUDING ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS, AND ANY OTHER SUCH OBLIGATION ON THE PART OF THE SELLER. THE SELLER'S LIABILITY TO THE BUYER SHALL CEASE ONCE ANY FURTHER PROCESSING, ASSEMBLING OR ANY OTHER WORK HAS BEEN UNDERTAKEN BY THE BUYER OR ANY THIRD PARTY.
No claims for shortage in weight or count will be entertained unless presented in writing within five (5) business days after receipt of materials by the Buyer. No claims will be allowed for shrinkage, expansion, deformity, or rupture of material in heating or straightening, except by prior written agreement, as above, nor in any case for rupture caused by or occurring during subsequent grinding. Whenever the Seller is given material with detailed instructions as to treatment, the Seller's responsibility shall end with the execution and completion of those instructions. Failure by the Buyer to indicate plainly and correctly the kind of material (i.e., proper alloy designation) to be treated, shall cause an extra charge to be made to cover any additional expense incurred as a result thereof, but shall not change the LIMITATION OF LIABILITY stated above. When the Buyer provides specifications for the heat treating service to be provided, makes changes in the kind of materials (i.e. proper alloy designation) to be treated, or changes the process to be used, the Buyer specifically understands and agrees that this LIMITATION OF LIABILITY shall remain in effect, but that additional charges for services will be due and owing to cover the additional expense incurred as a result of changes made by the Buyer. The Buyer agrees there will be no liability on the Seller in contract or tort (including negligence and strict liability) for any special, indirect or consequential damages arising from any reason whatsoever, including but not limited to personal injury, property damages, loss of profits, loss of production, recall or any other losses, expenses or liabilities allegedly occasioned by the work performed on the part of the Seller. No agent or representative is authorized to alter the conditions, except in writing duly signed by an officer of the Seller. The Seller's services and work are expressly limited to the terms and conditions contained on the face and back of the Seller's quotation, purchase order, sale acknowledgement or other forms. Any different or additional terms contained in any of the Buyer's forms are hereby deemed to be a material alteration and notice of objection to them is hereby given.
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We hereby certify that these samples have been heat treated to the above specifications.

Bruce Baker
Quality Control Manager
The Euclid Heat Treating Company

1408 East 222 Street Cleveland OH 44117 **Phone:** (216) 481-8444 **Fax:** (216) 481-3473

Figure B.1.—Heat treatment certification.

# Appendix C.—Small Panel Test Results

This section shows photographs of test specimens and digital image correlation (DIC) results for each of the small panel tests conducted. In certain tests, where there was full penetration, no DIC results are shown.

### *Test DB232*

The DIC data was not obtained due to full penetration of projectile.


Figure C.1.—DB232 posttest front view.

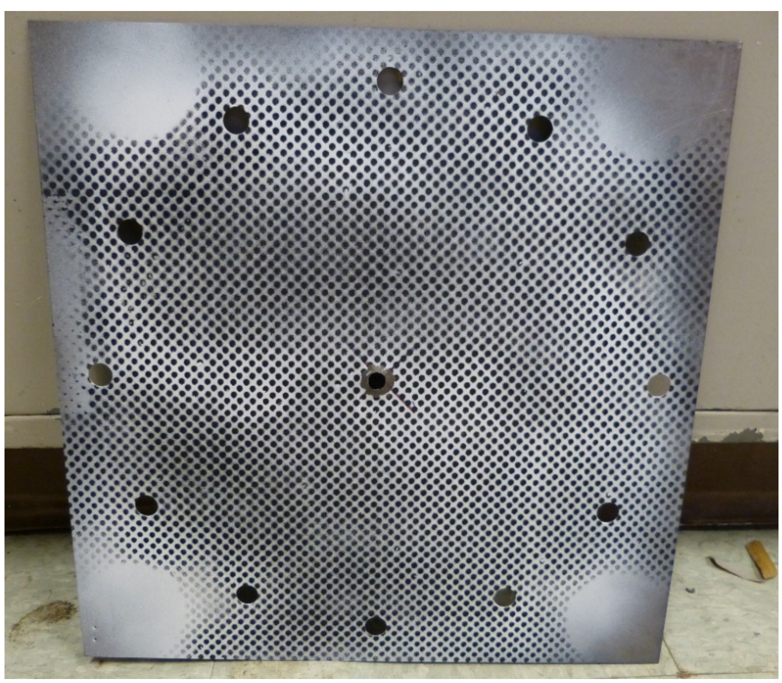


Figure C.2.—DB232 posttest rear view.

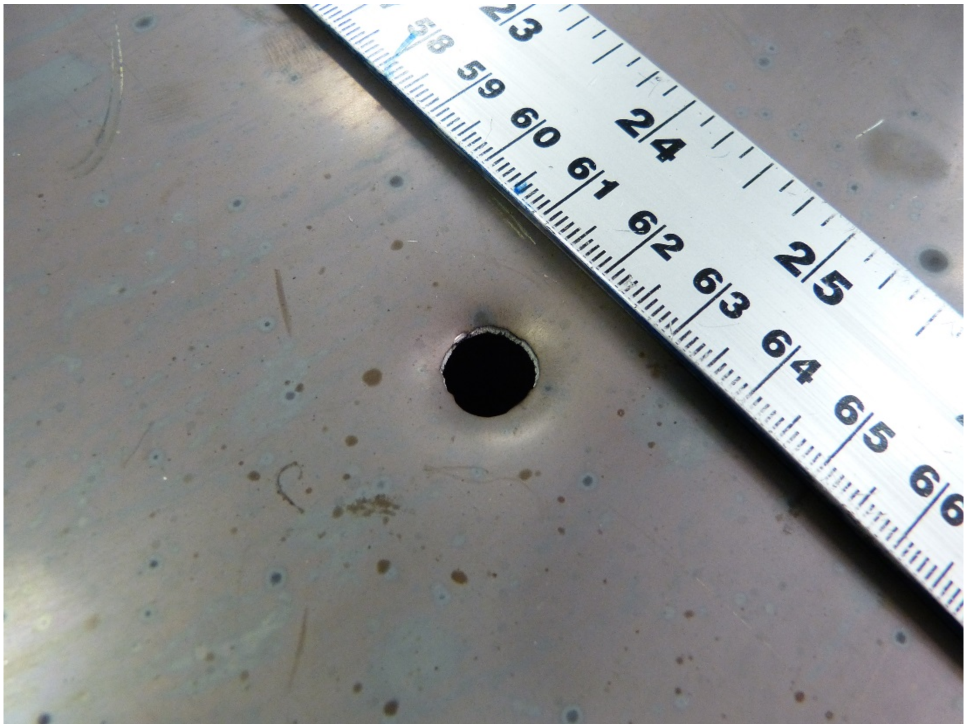


Figure C.3.—DB232 posttest front view closeup.

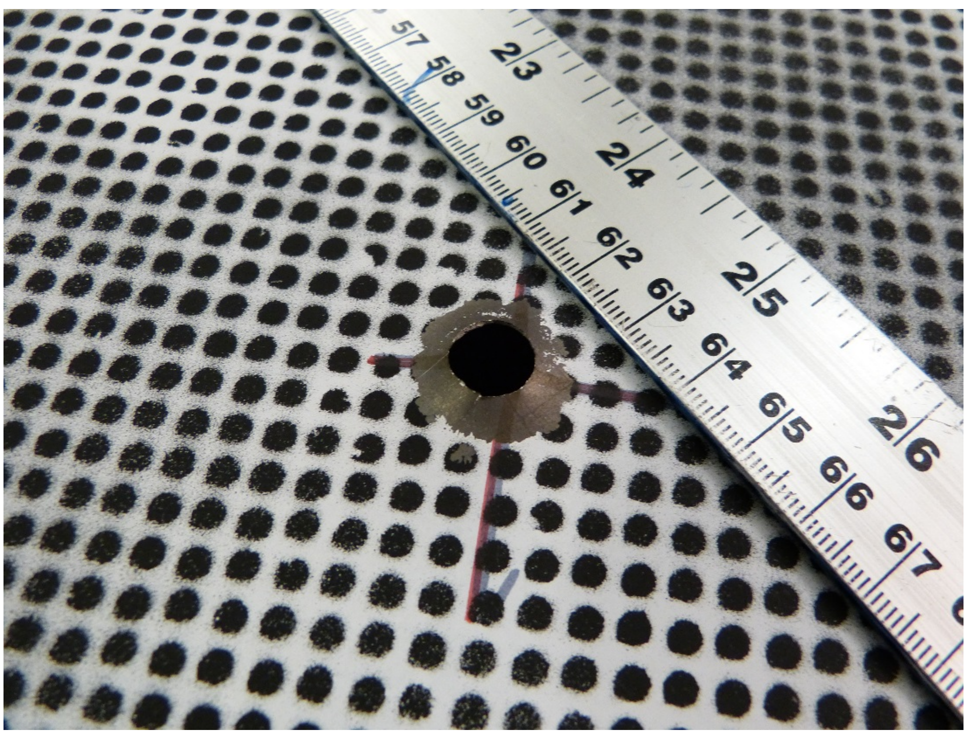


Figure C.4.—DB232 posttest rear view closeup.

### *Test DB234*

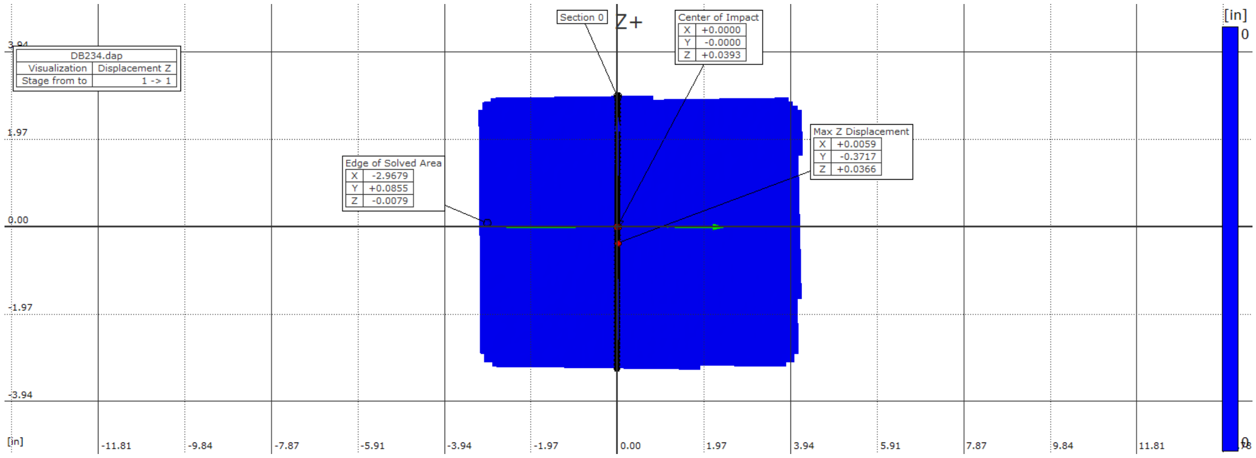



Figure C.5.—DB234 locations of digital image correlation (DIC) measurements.

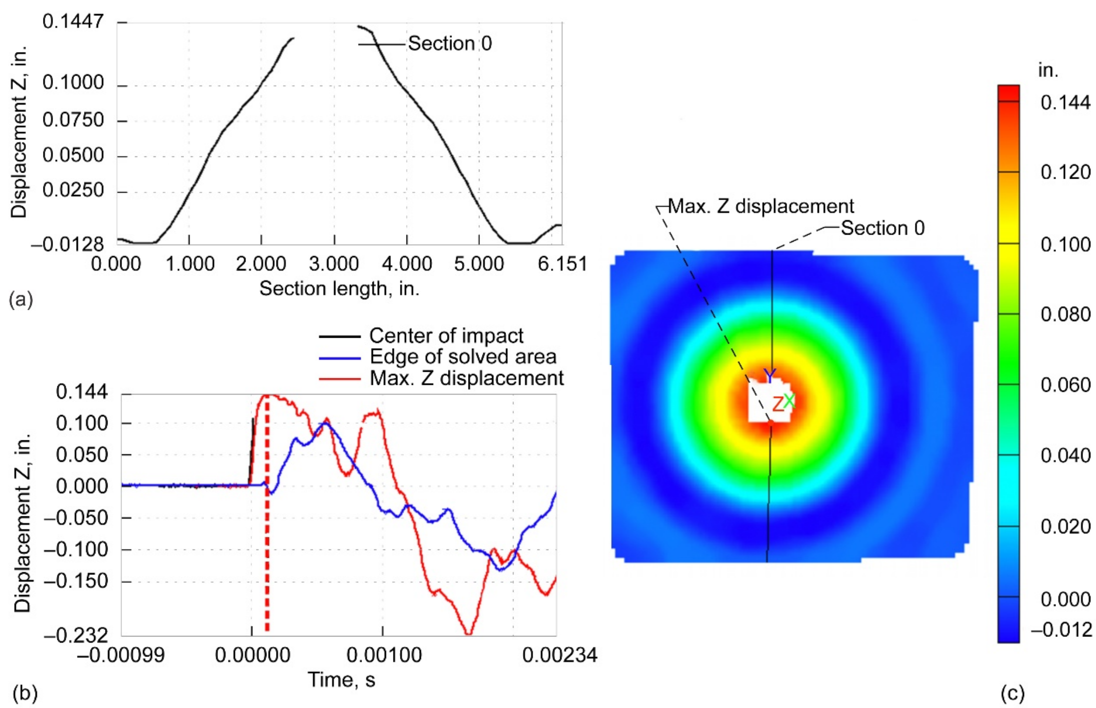



Figure C.6.—DB234 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.


Figure C.7.—DB234 pretest front view.

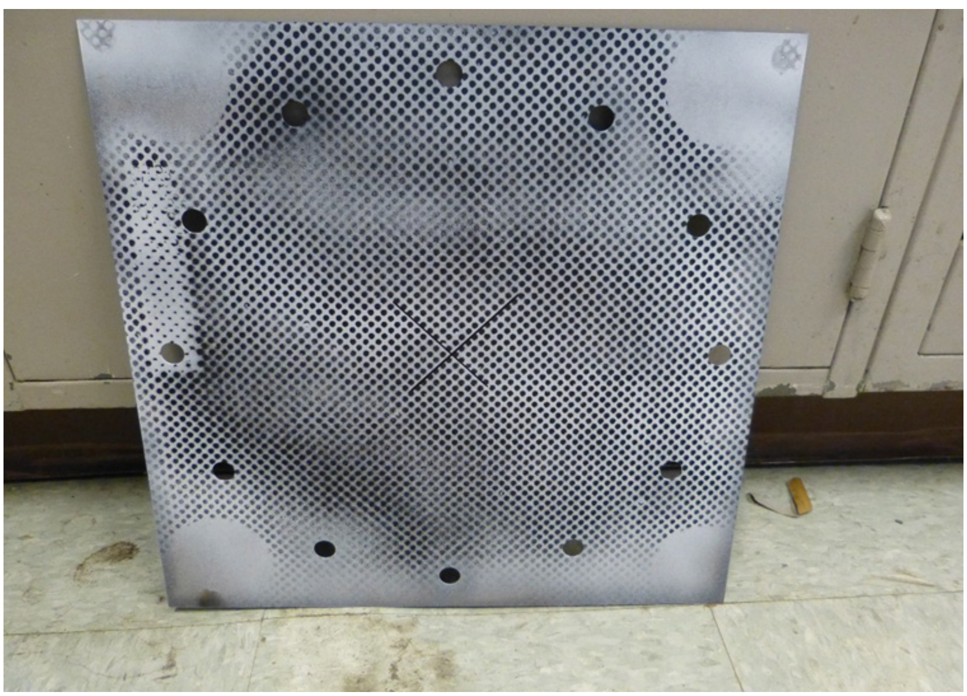


Figure C.8.—DB234 pretest rear view.

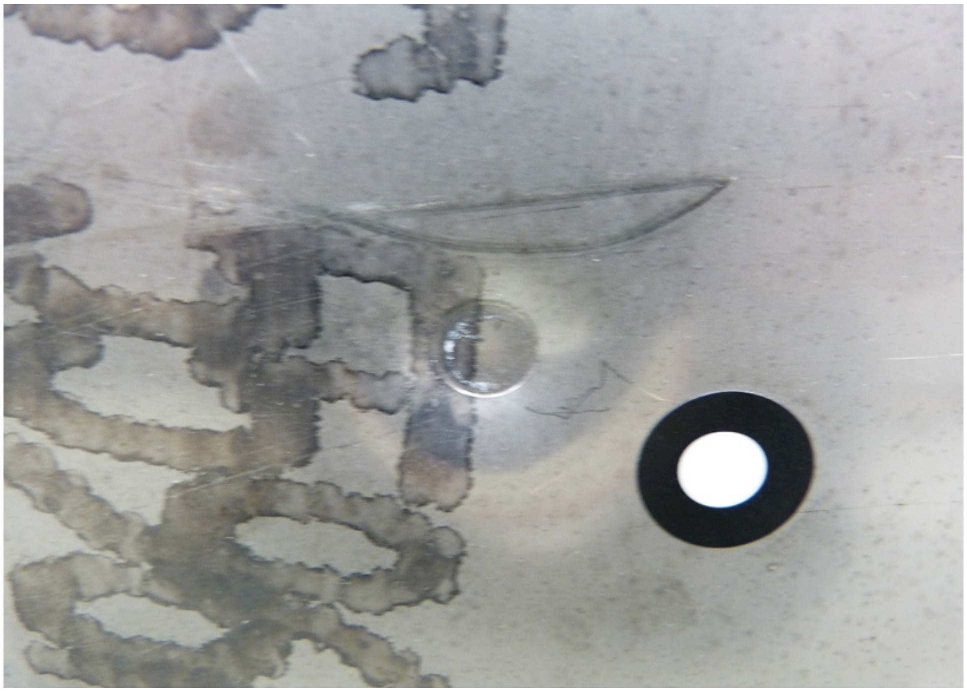


Figure C.9.—DB234 posttest front view closeup.

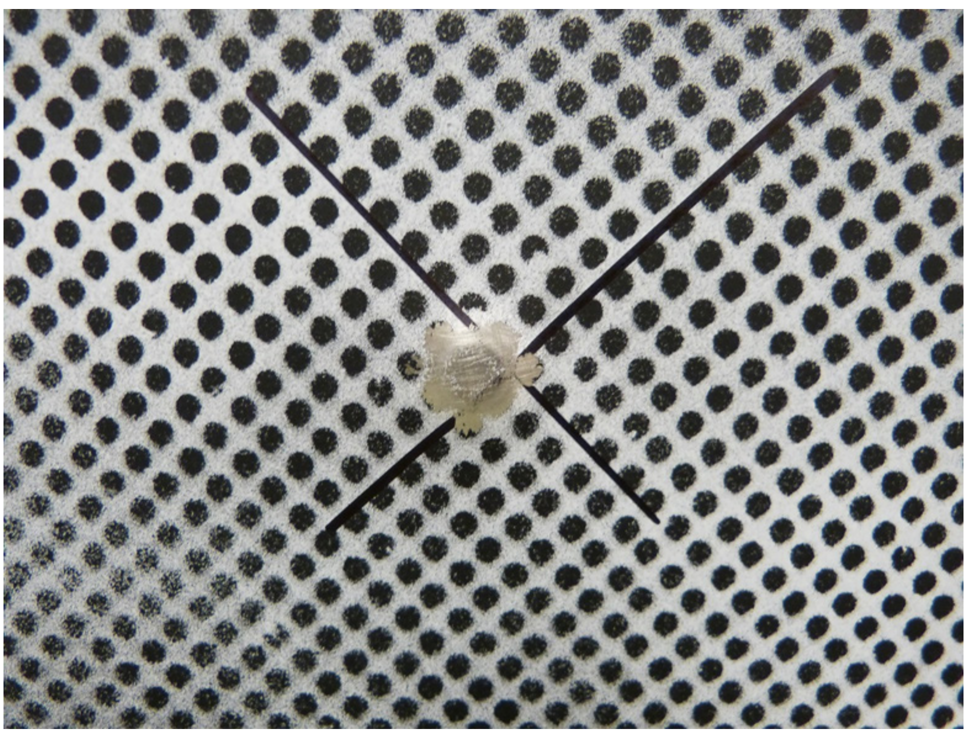


Figure C.10.—DB234 posttest rear view closeup.

### *Test DB235*

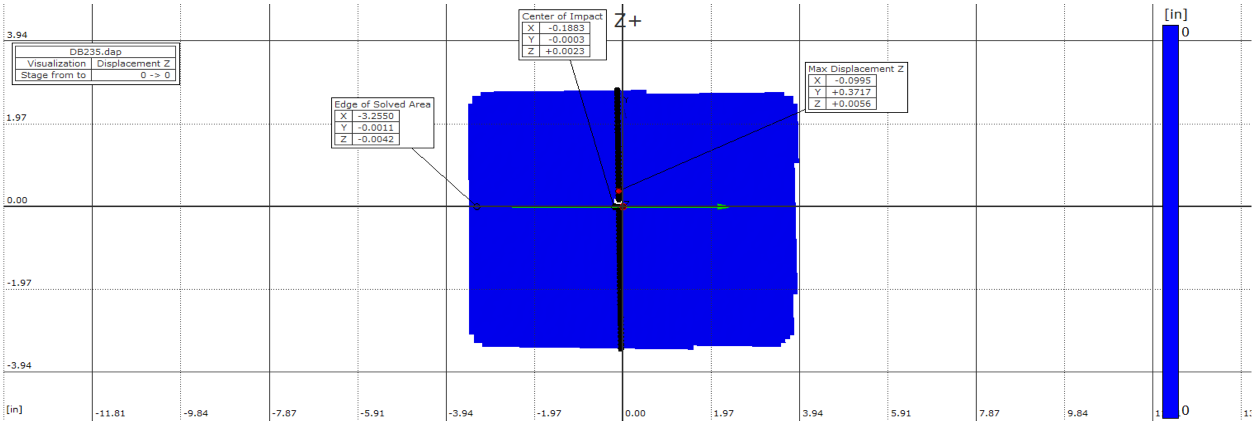



Figure C.11.—DB235 locations of digital image correlation (DIC) measurements.

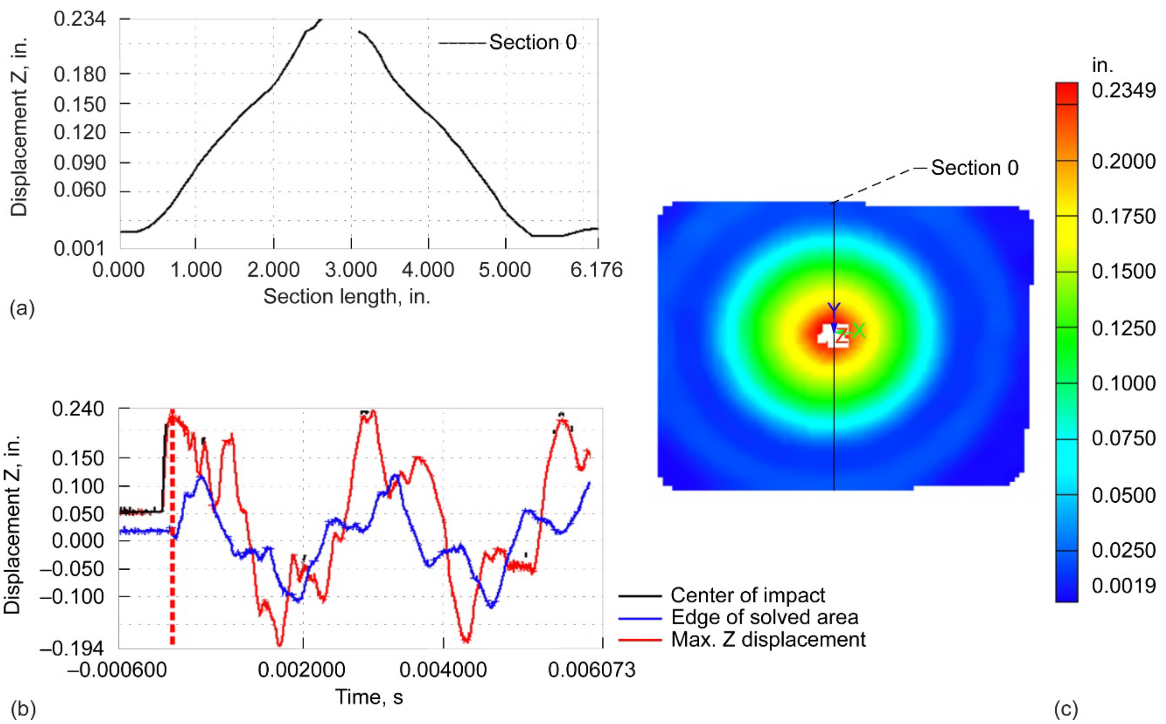



Figure C.12.—DB235 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

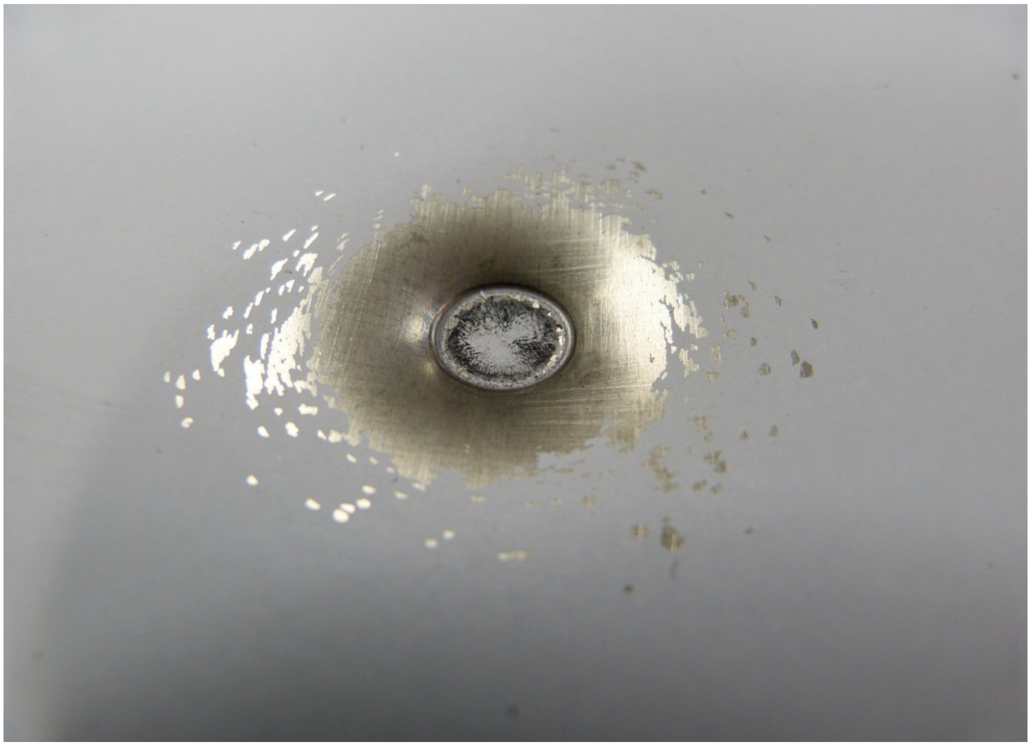


Figure C.13.—DB235 posttest front view closeup.

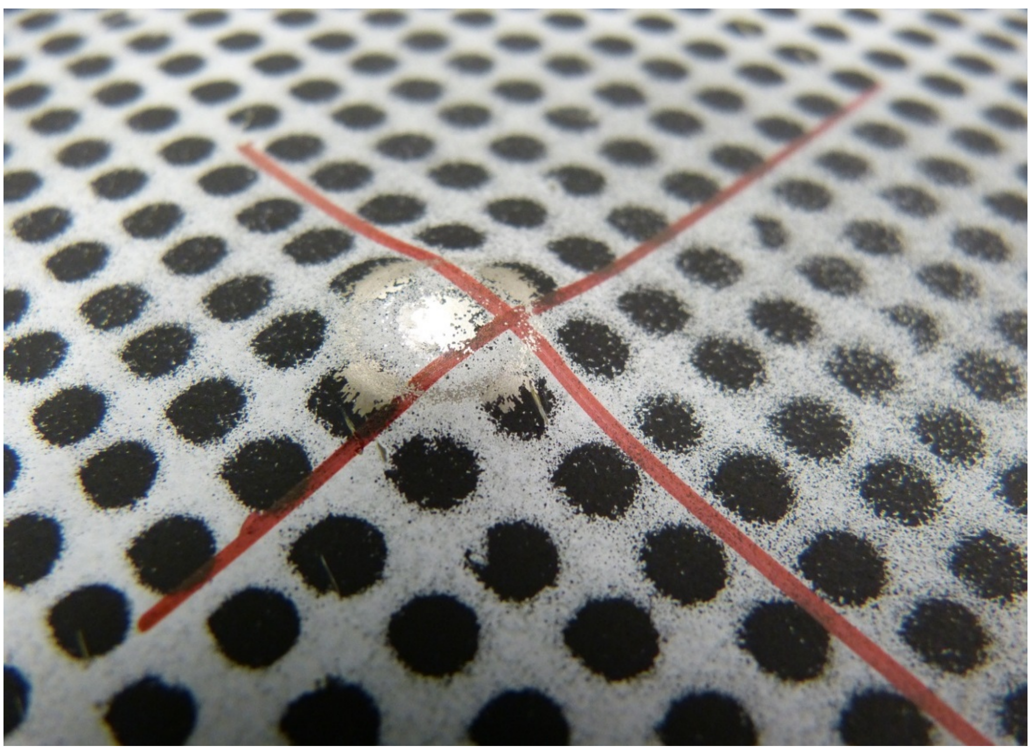


Figure C.14.—DB235 posttest rear view closeup.

### *Test DB236*

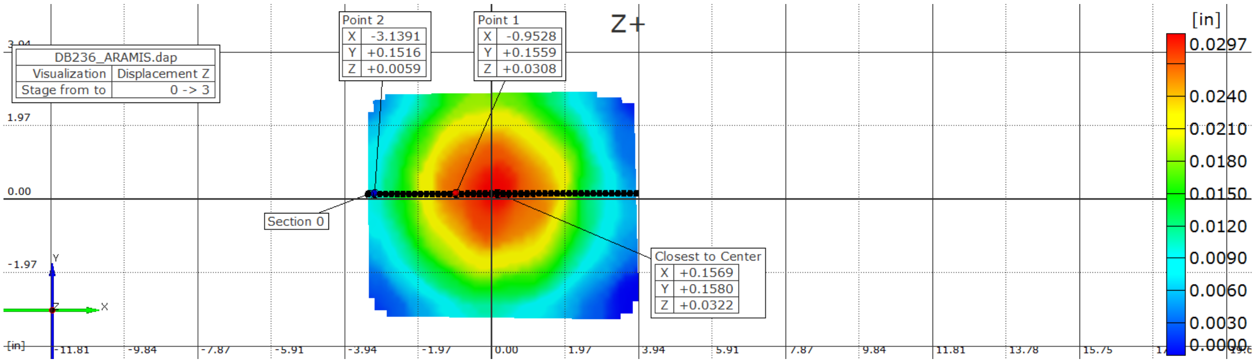



Figure C.15.—DB236 locations of digital image correlation (DIC) measurements.

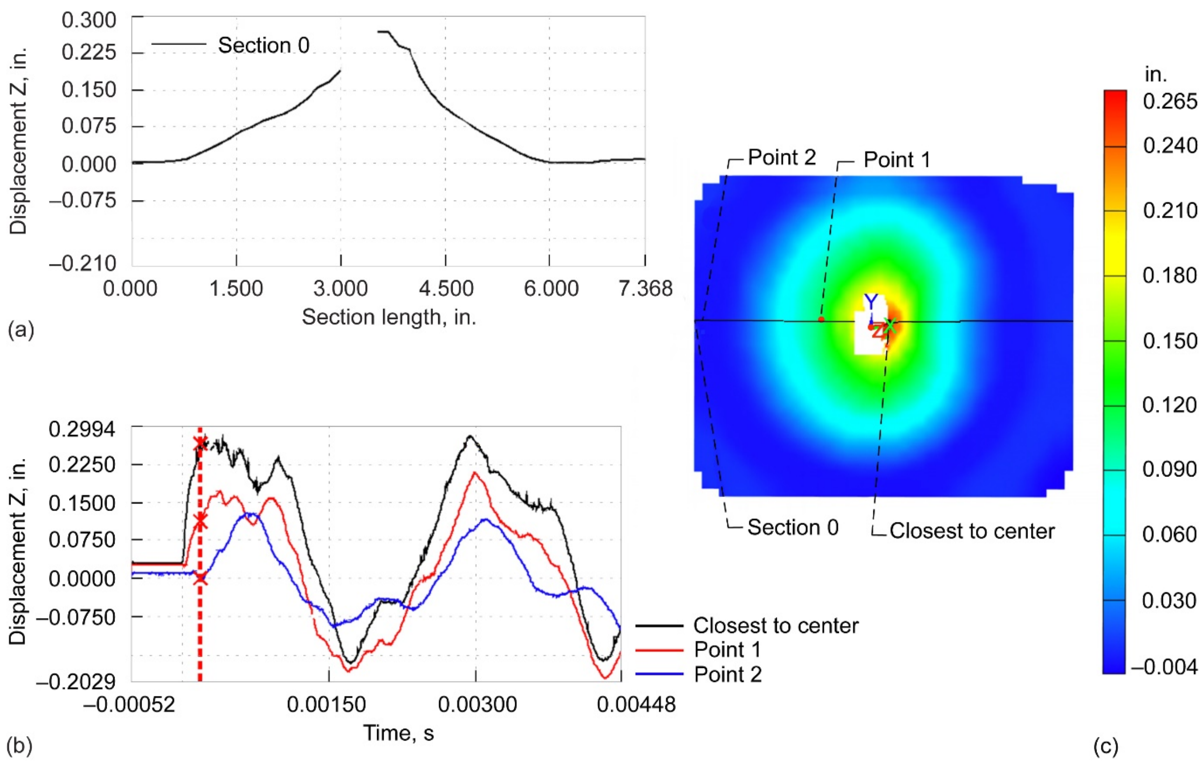



Figure C.16.—DB236 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.17.—DB236 posttest front view closeup.

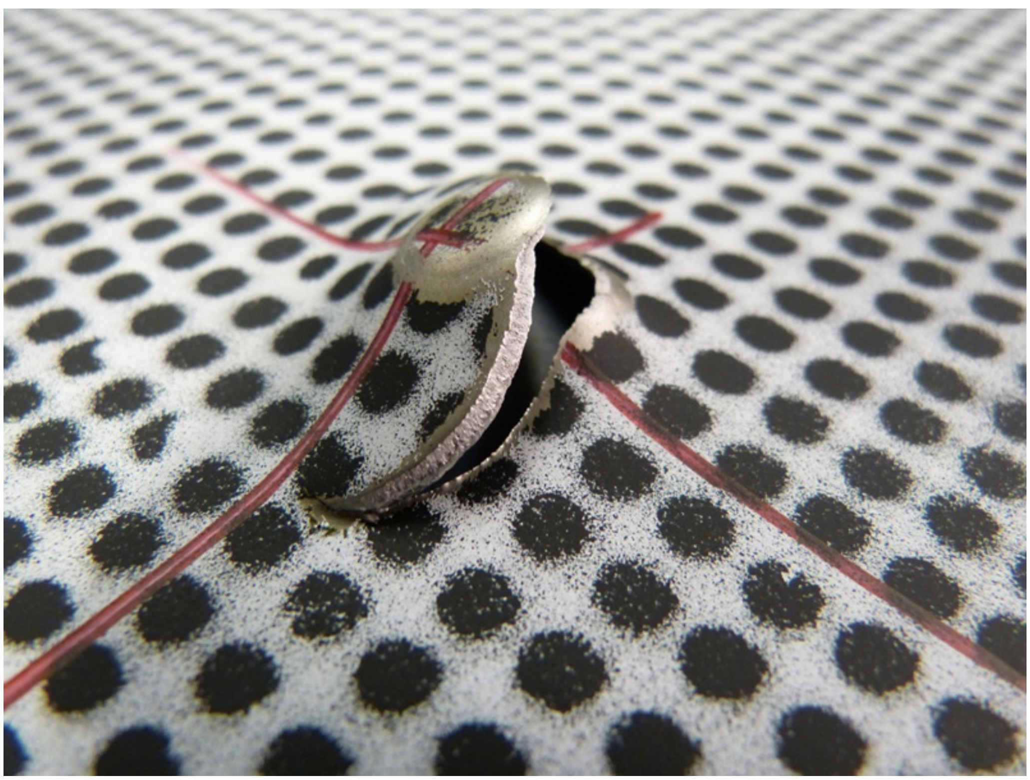


Figure C.18.—DB236 posttest rear view closeup.

### *Test DB237*

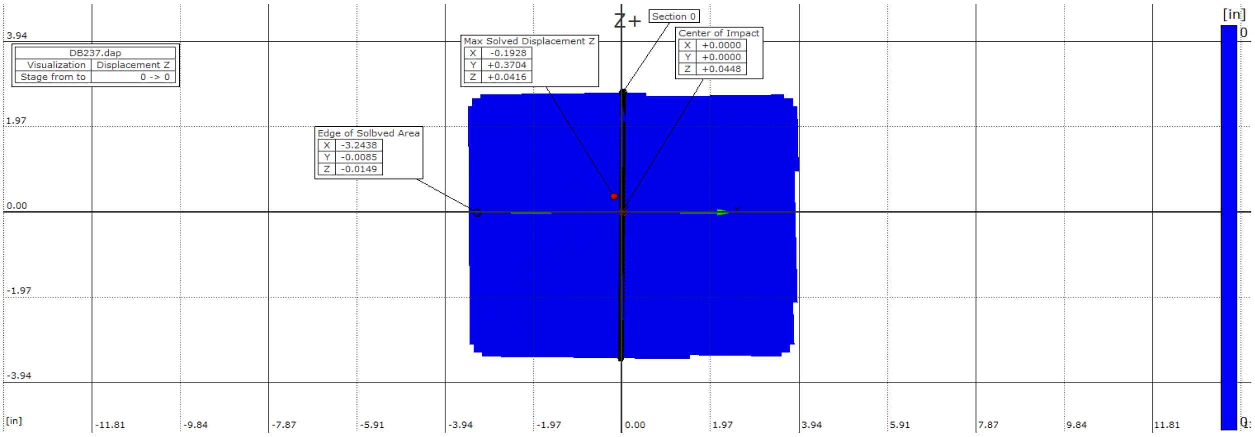



Figure C.19.—DB237 locations of digitial image correlation (DIC) measurements.

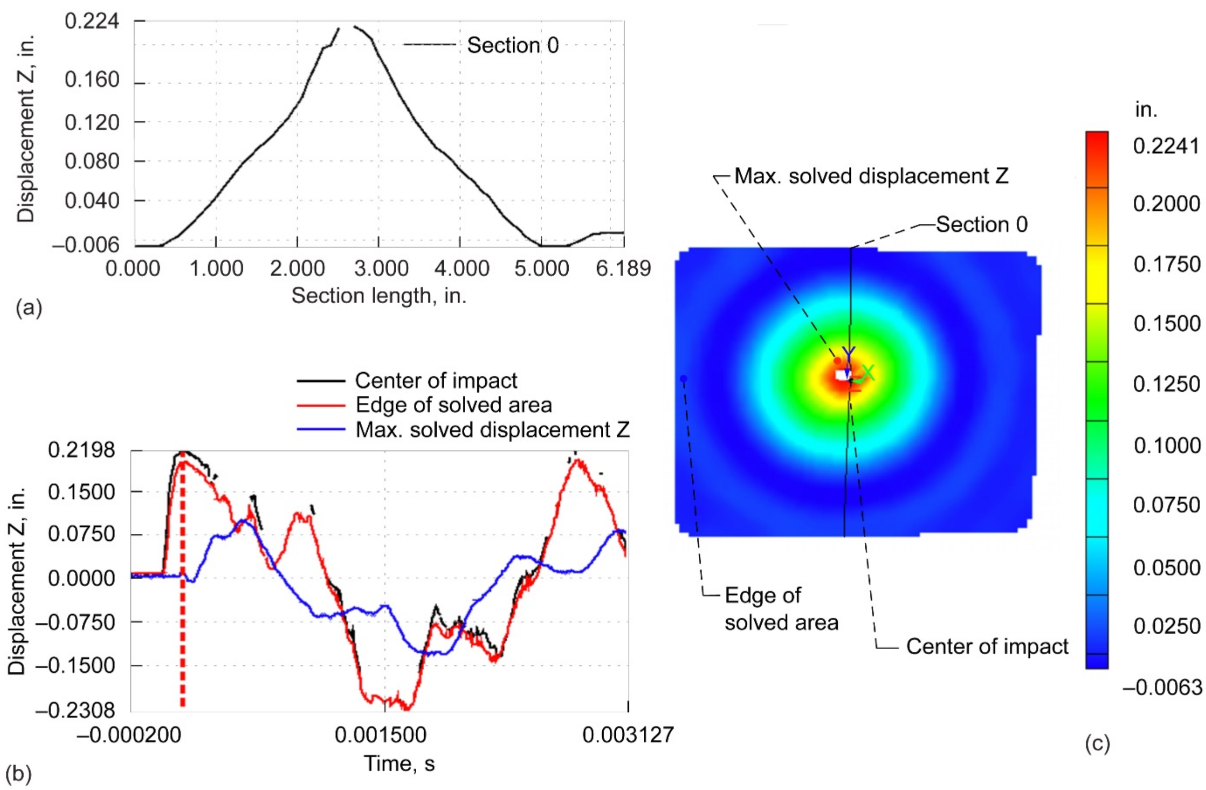



Figure C.20.—DB237 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

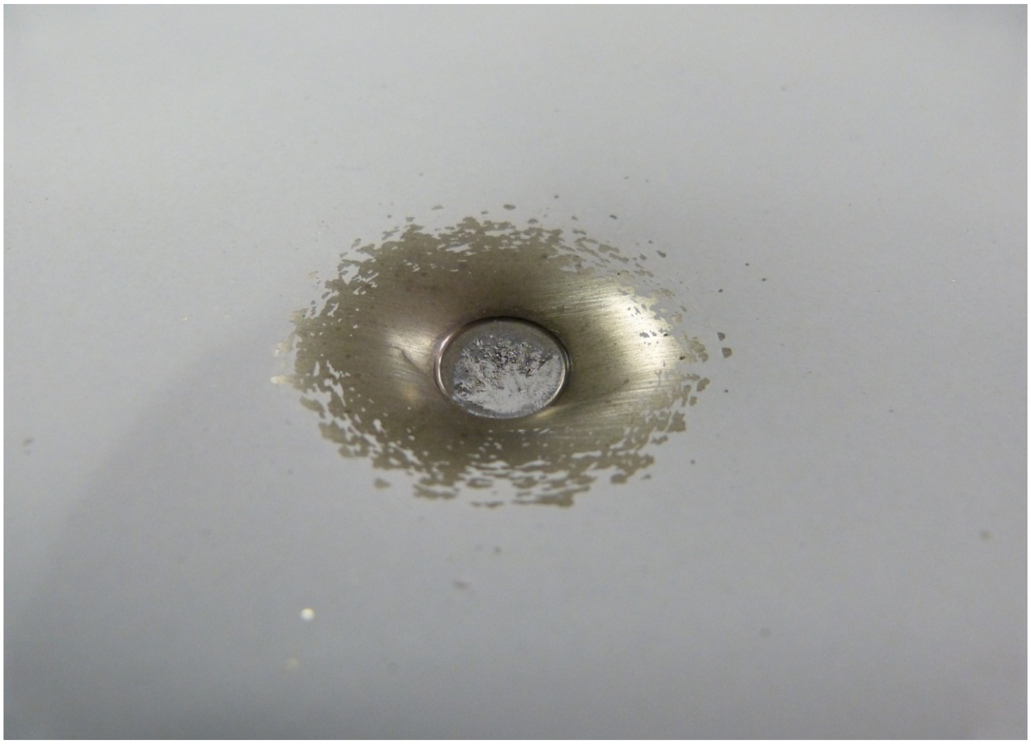


Figure C.21.—DB237 posttest front view closeup.

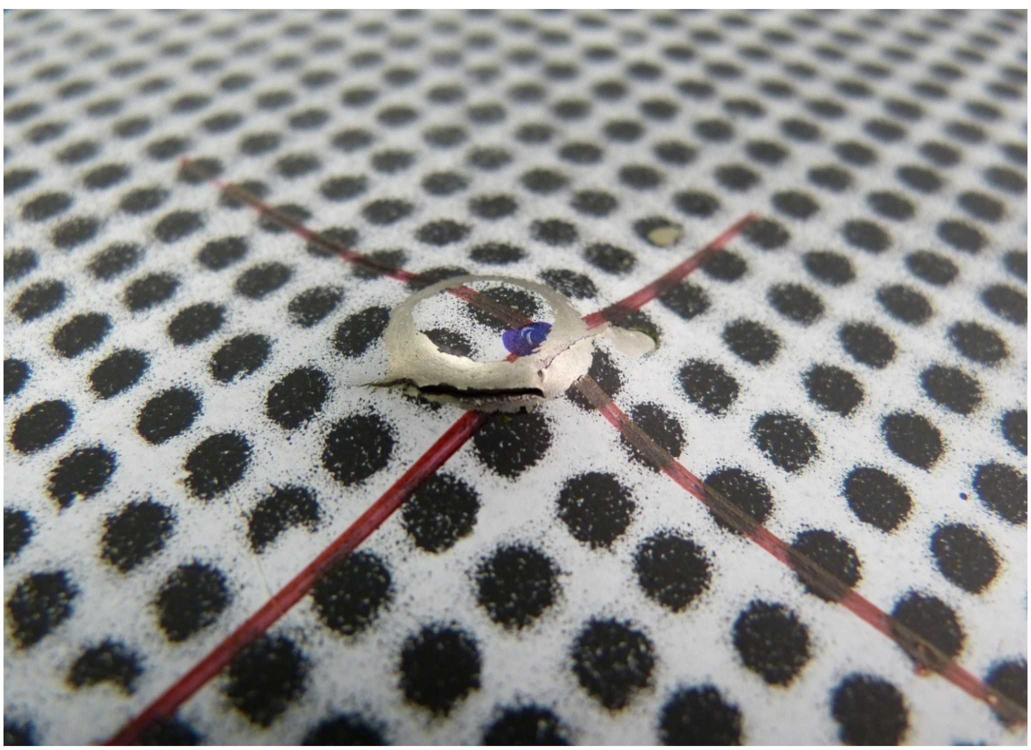


Figure C.22.—DB237 posttest rear view closeup.

### *Test DB238*

The DIC data was not obtained due to full penetration of projectile.

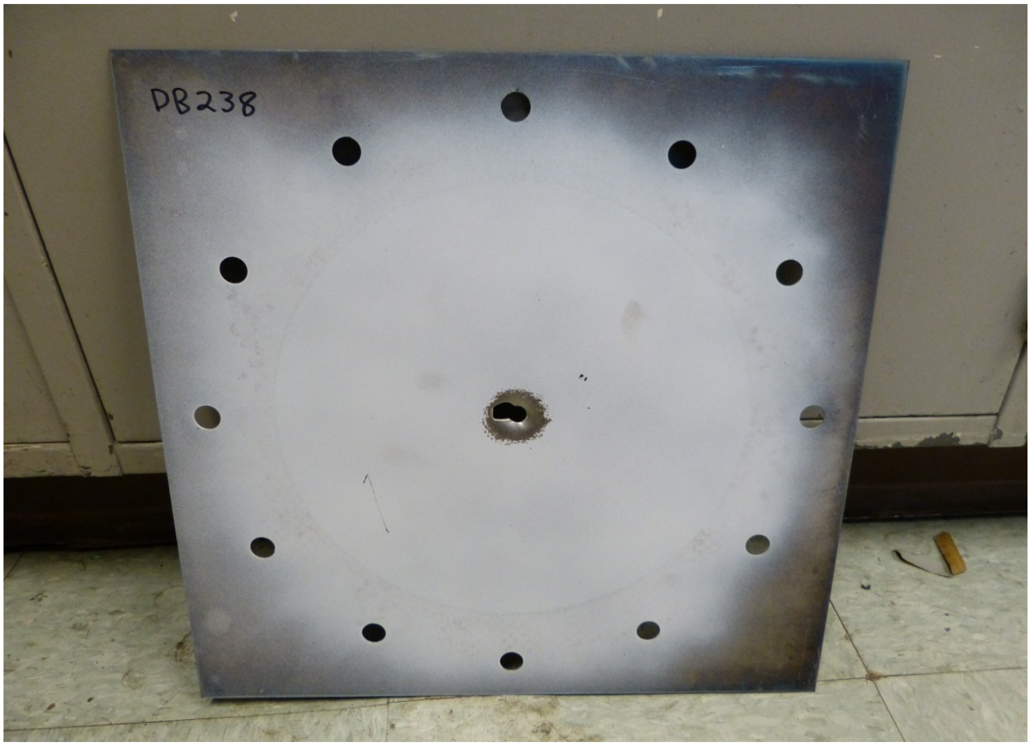



Figure C.23.—DB238 posttest front view.

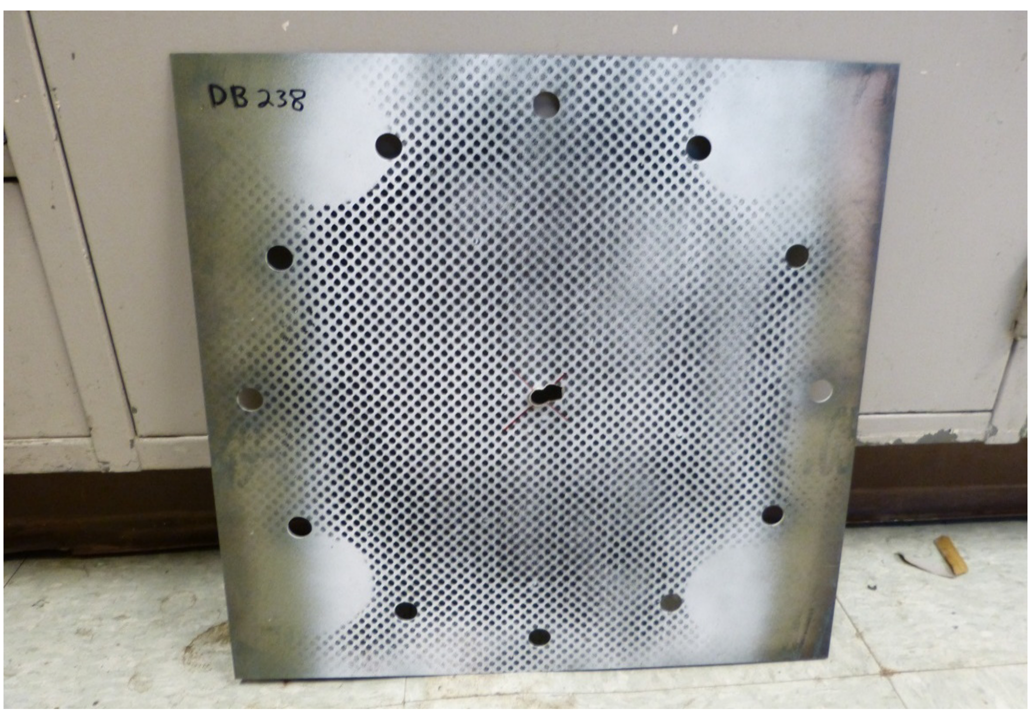



Figure C.24.—DB238 posttest rear view.

Figure C.25.—DB238 posttest front view closeup.

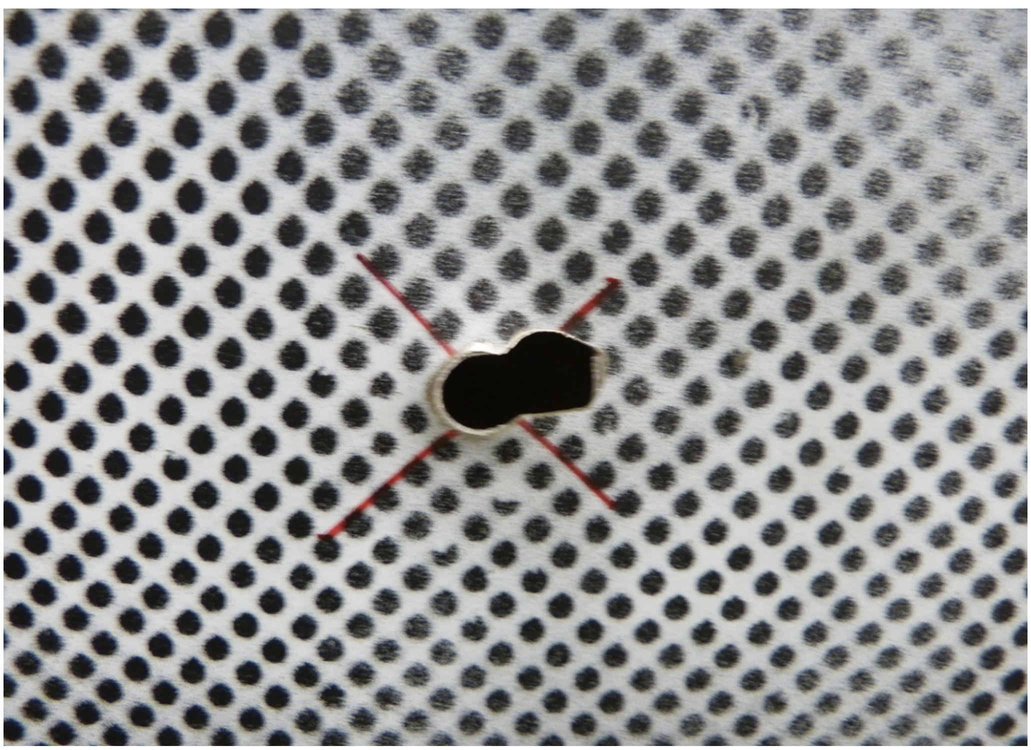


Figure C.26.—DB238 posttest rear view closeup.

### *Test DB239*

The DIC data was not obtained due to full penetration of projectile.

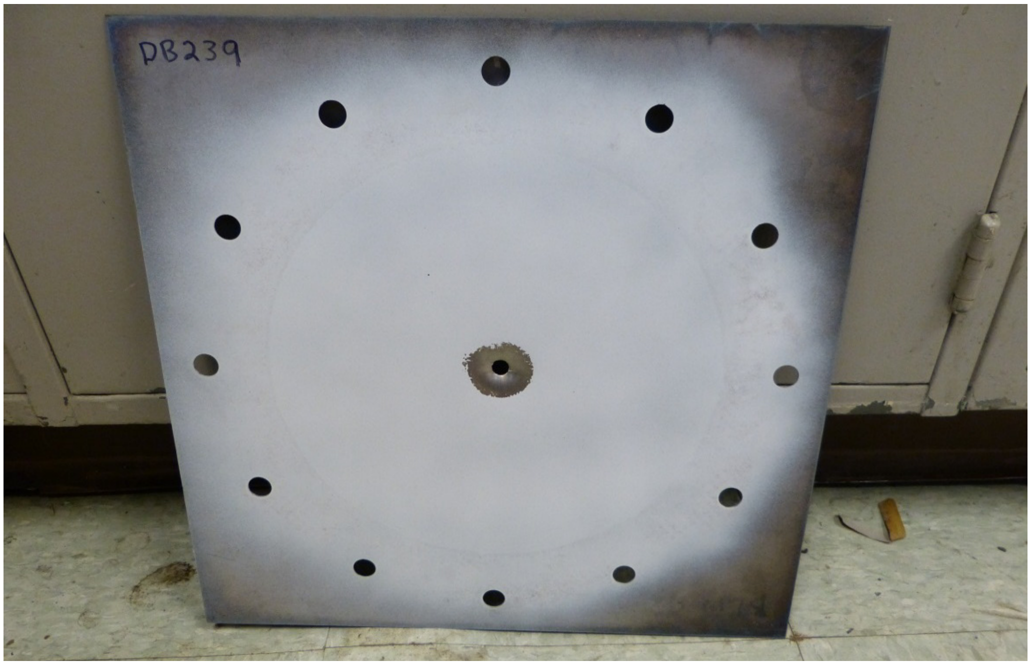



Figure C.27.—DB239 posttest front view.

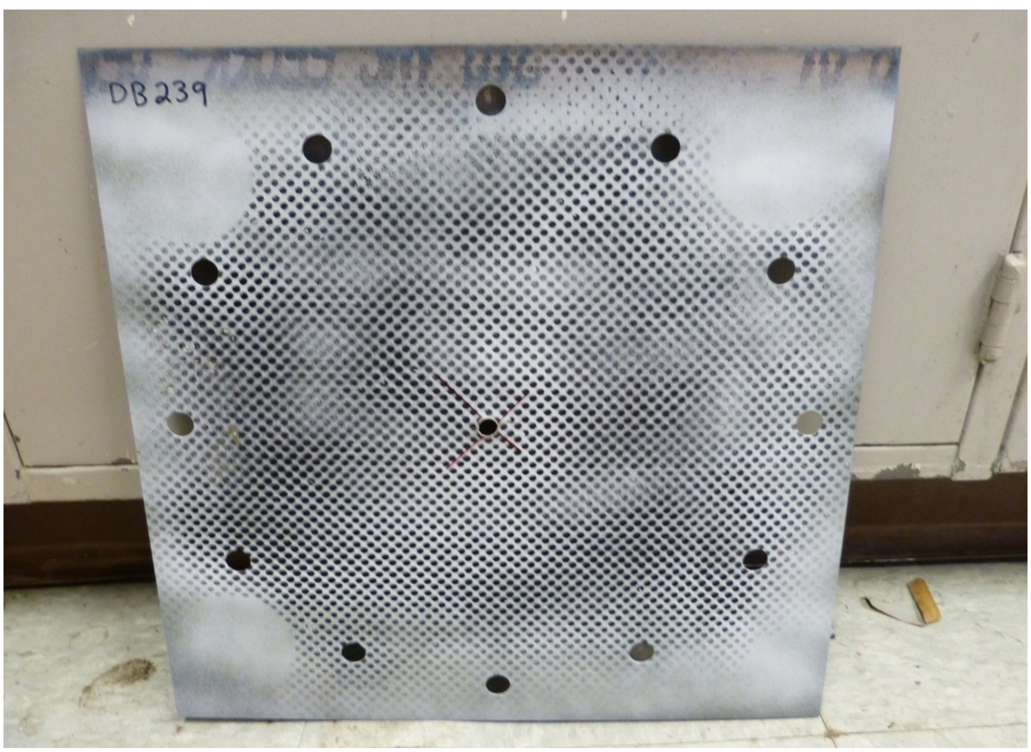



Figure C.28.—DB239 posttest rear view.

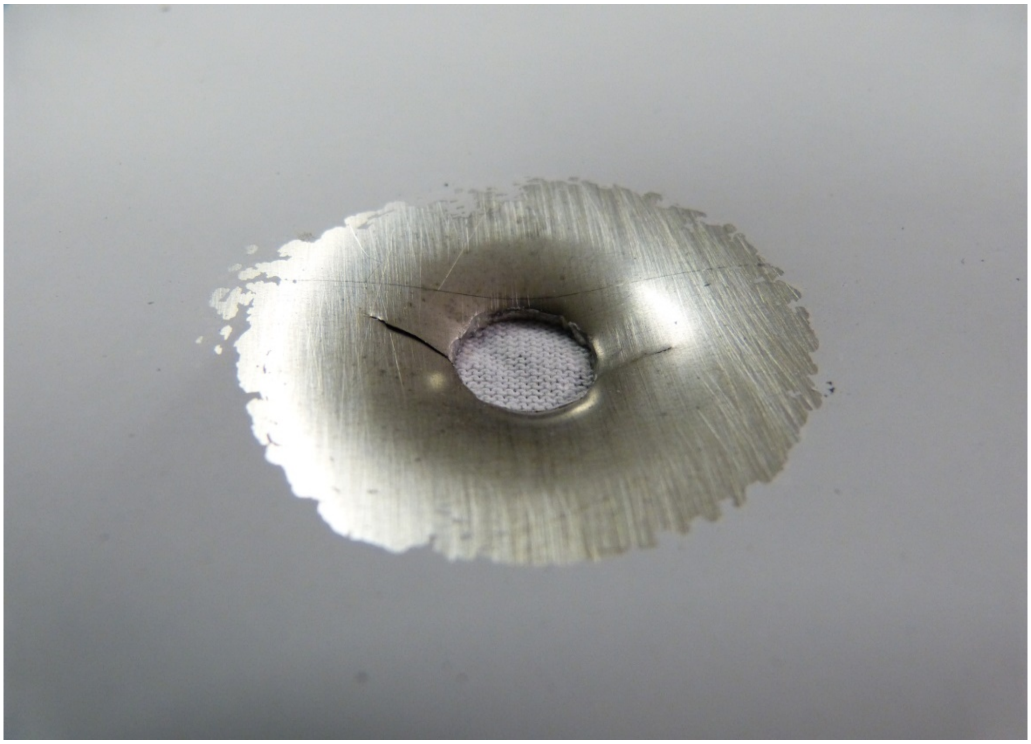


Figure C.29.—DB239 posttest front view closeup.

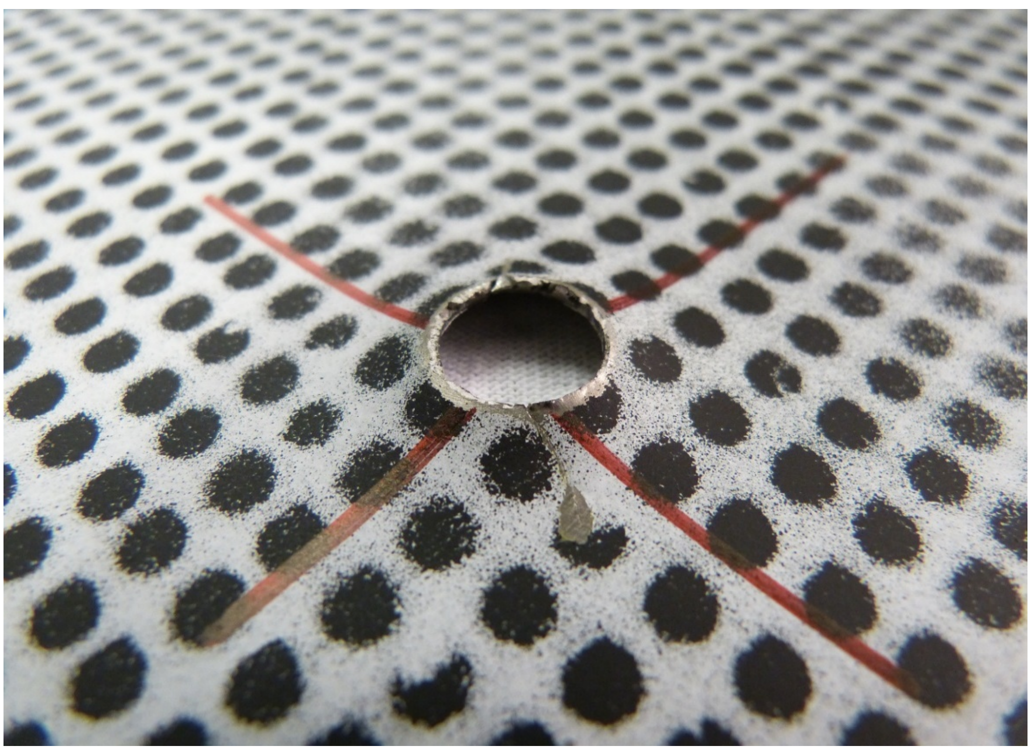


Figure C.30.—DB239 posttest rear view closeup.

### *Test DB240*

The DIC data was not obtained due to full penetration of projectile.

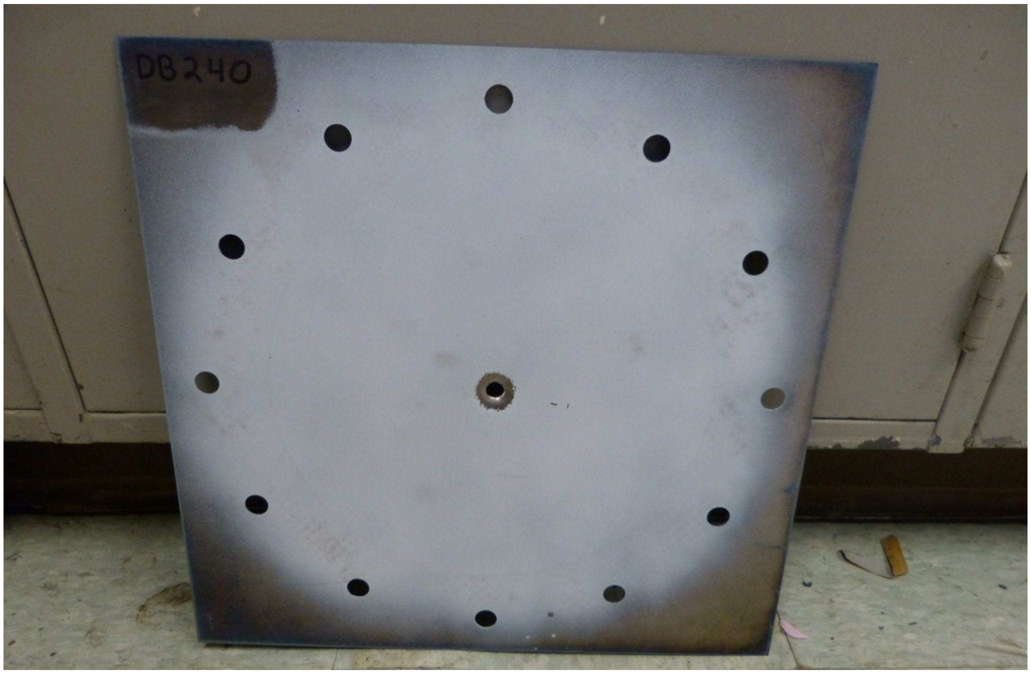



Figure C.31.—DB240 posttest front view.

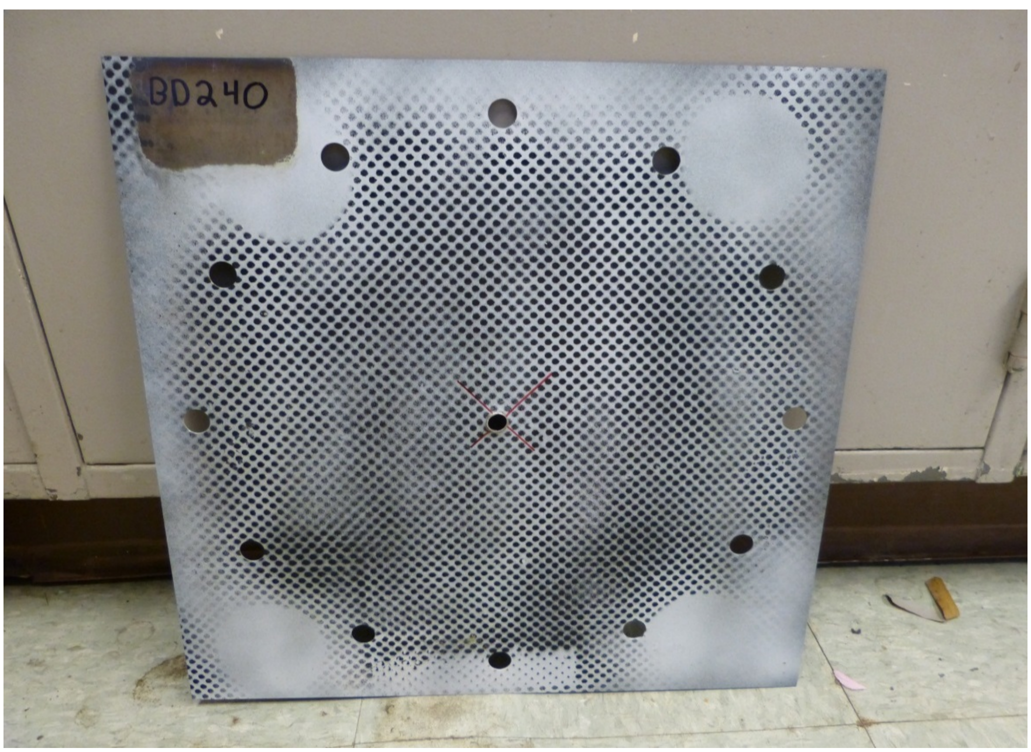



Figure C.32.—DB240 posttest rear view.

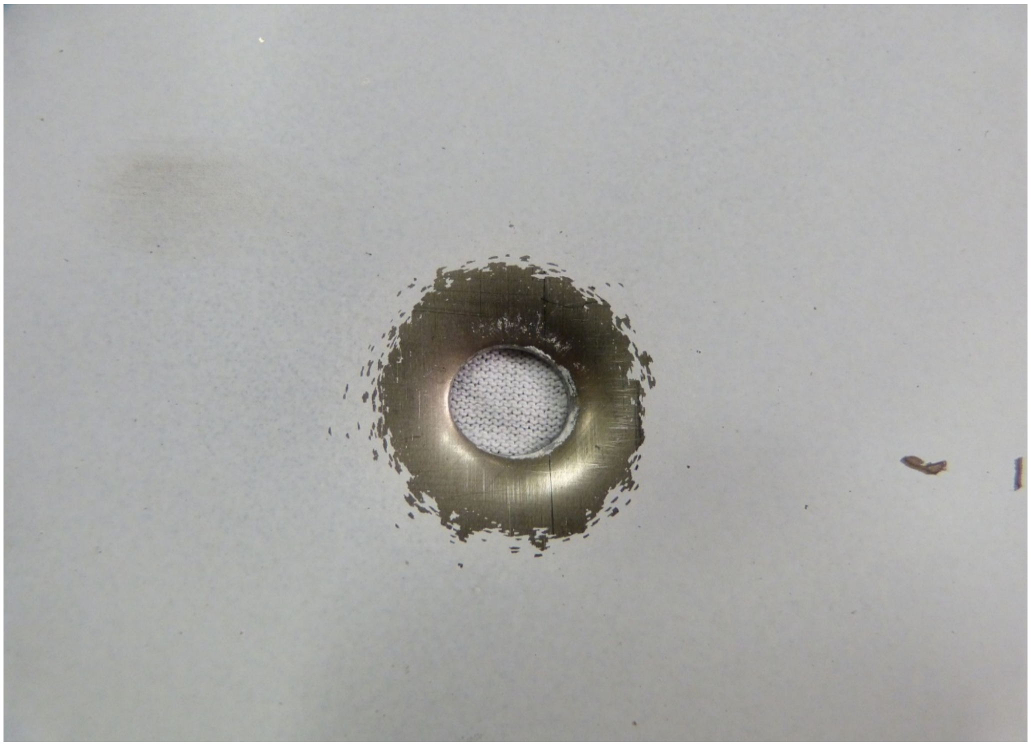


Figure C.33.—DB240 posttest front view closeup.

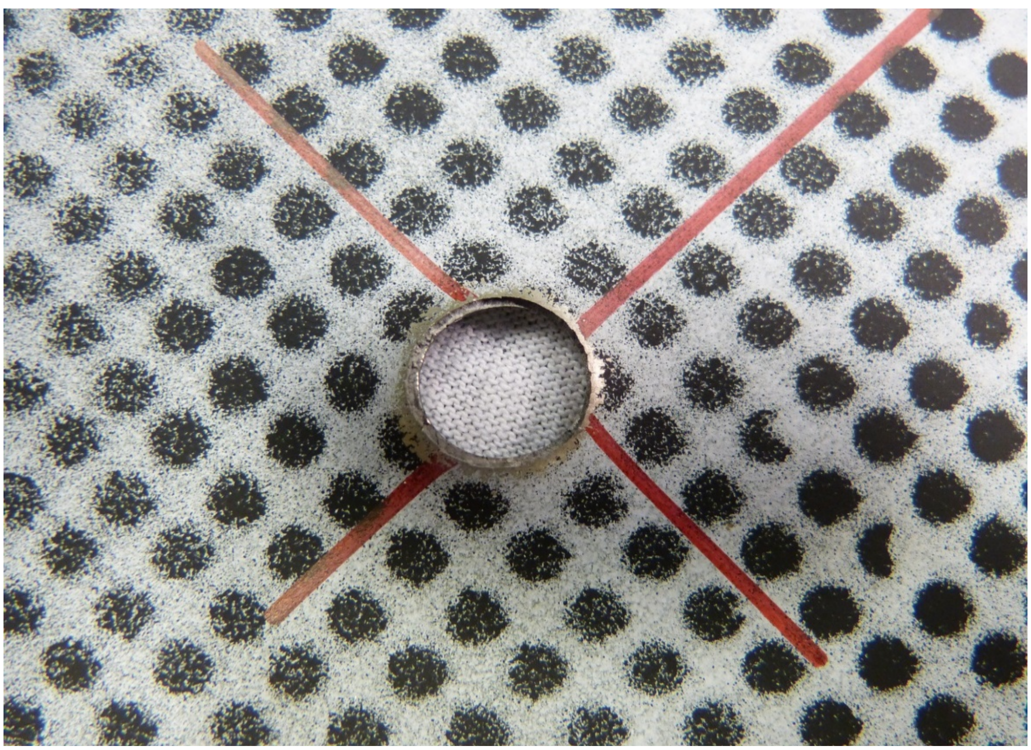


Figure C.34.—DB240 posttest rear view closeup.

### *Test DB241*

The DIC data was not obtained due to full penetration of projectile.


Figure C.35.—DB241 posttest front view.

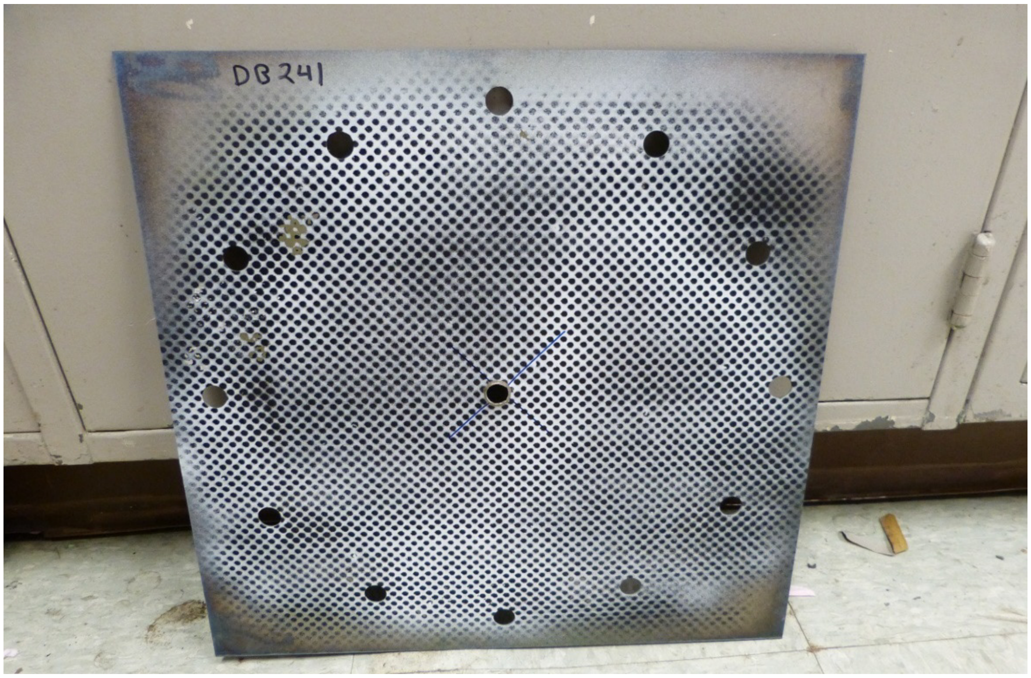



Figure C.36.—DB241 posttest rear view.

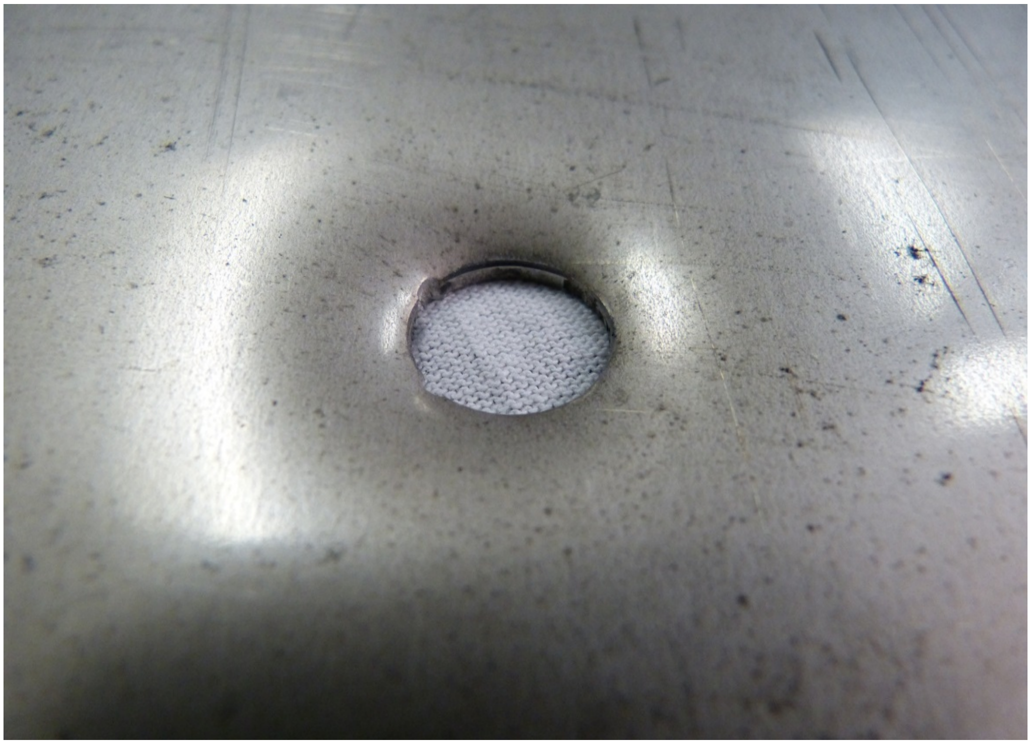


Figure C.37.—DB241 posttest front view closeup.

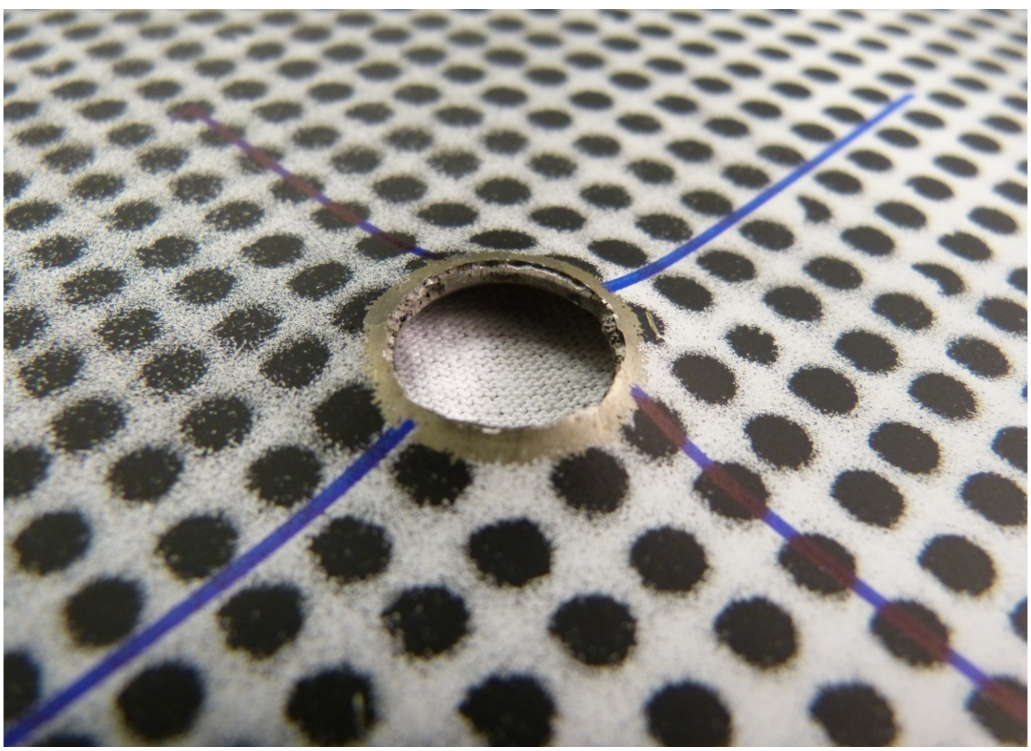


Figure C.38.—DB241 posttest rear view closeup.

***Test DB242***

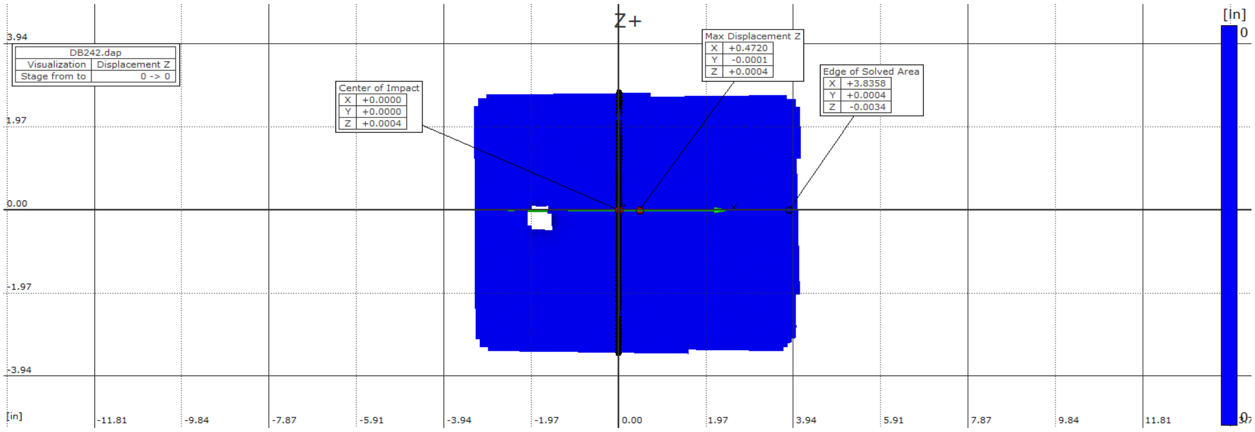



Figure C.39.—DB242 locations of digital image correlation (DIC) measurements.

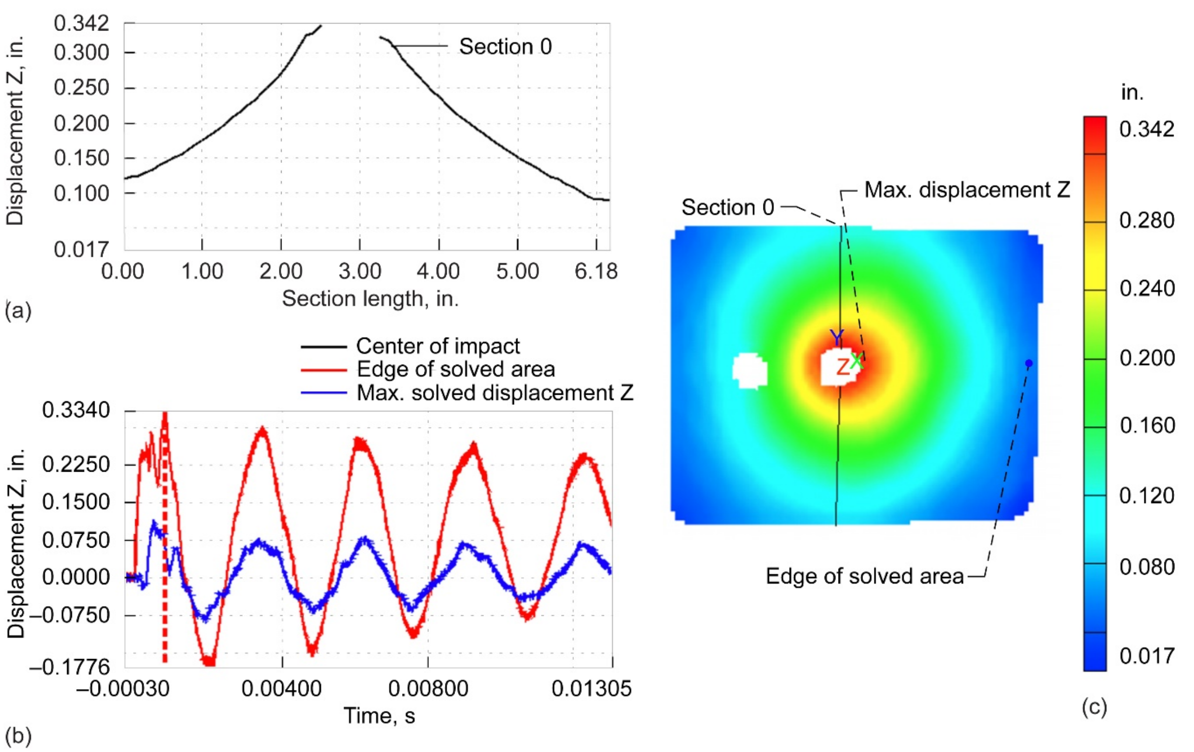



Figure C.40.—DB242 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

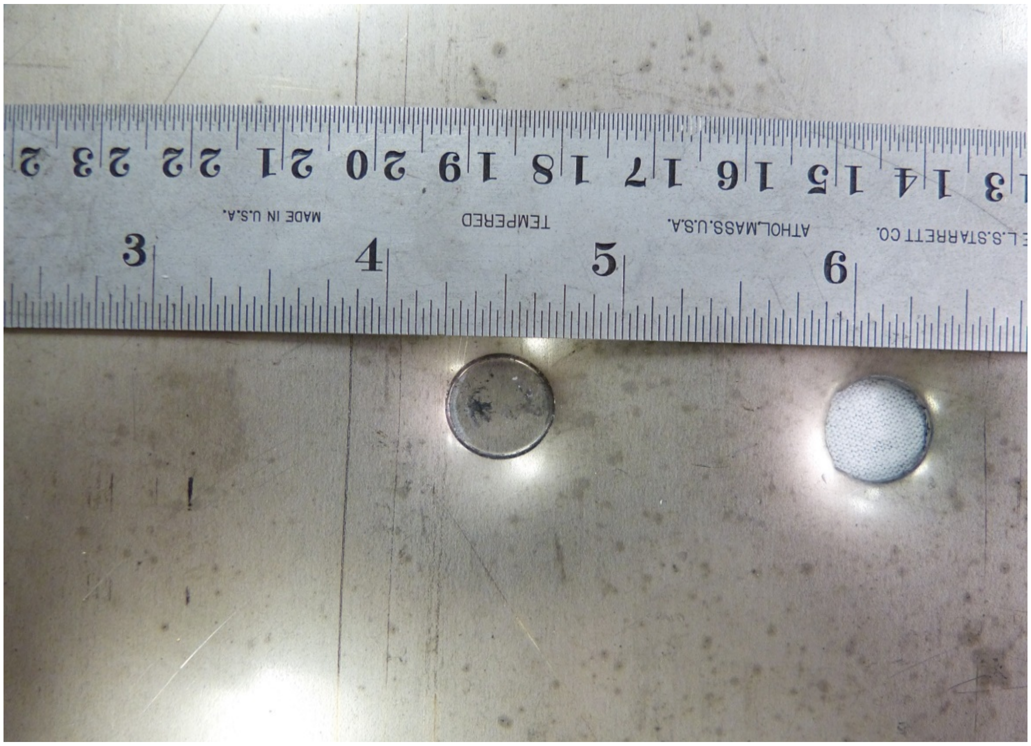


Figure C.41.—DB242 posttest front view closeup.

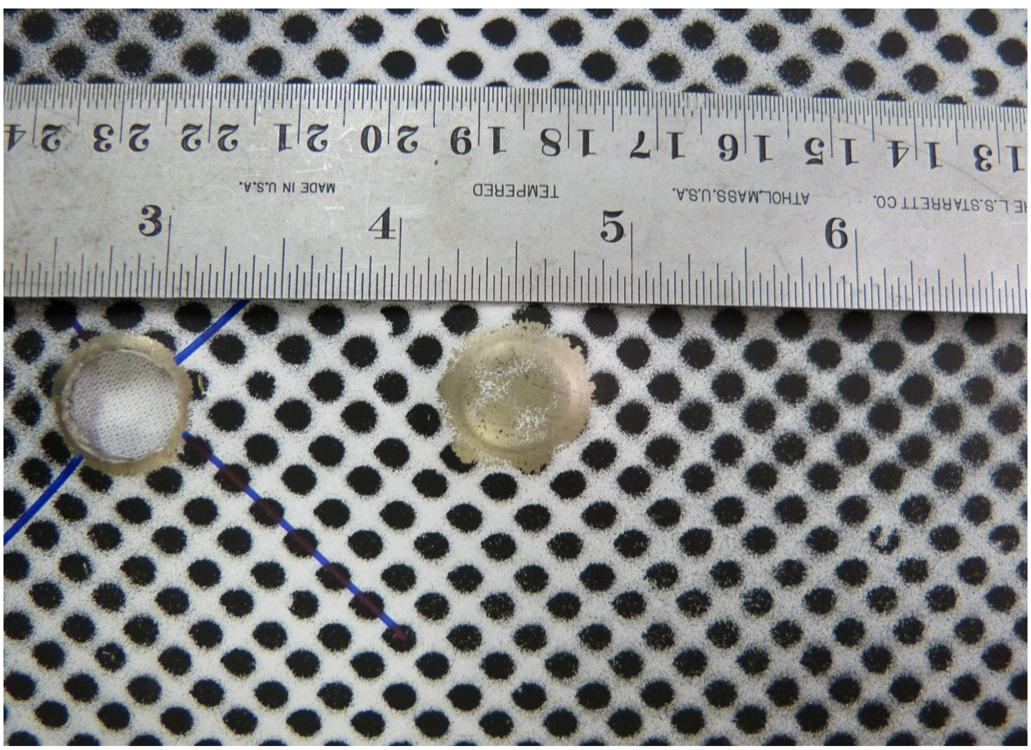


Figure C.42.—DB242 posttest rear view closeup.

### *Test DB243*

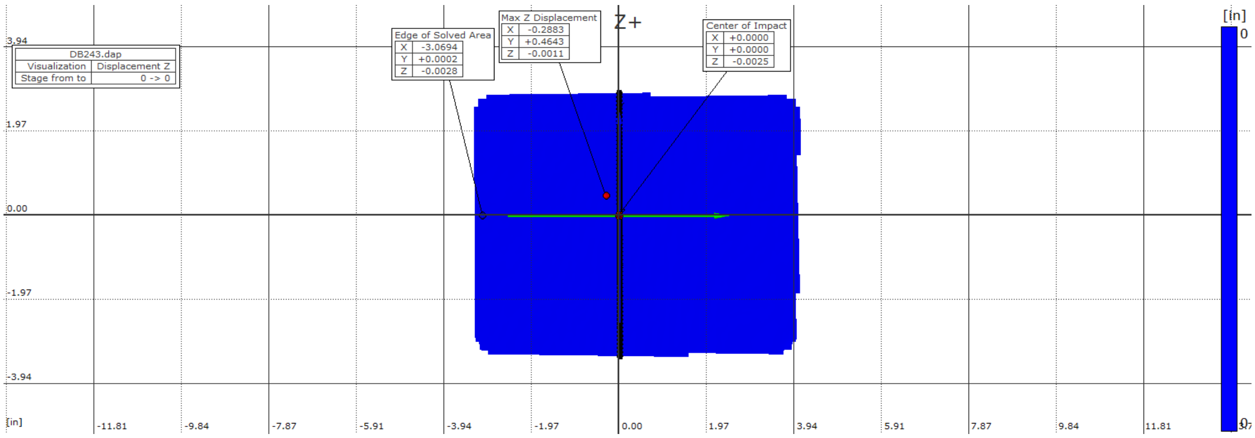


Figure C.43.—DB243 locations of digital image correlation (DIC) measurements

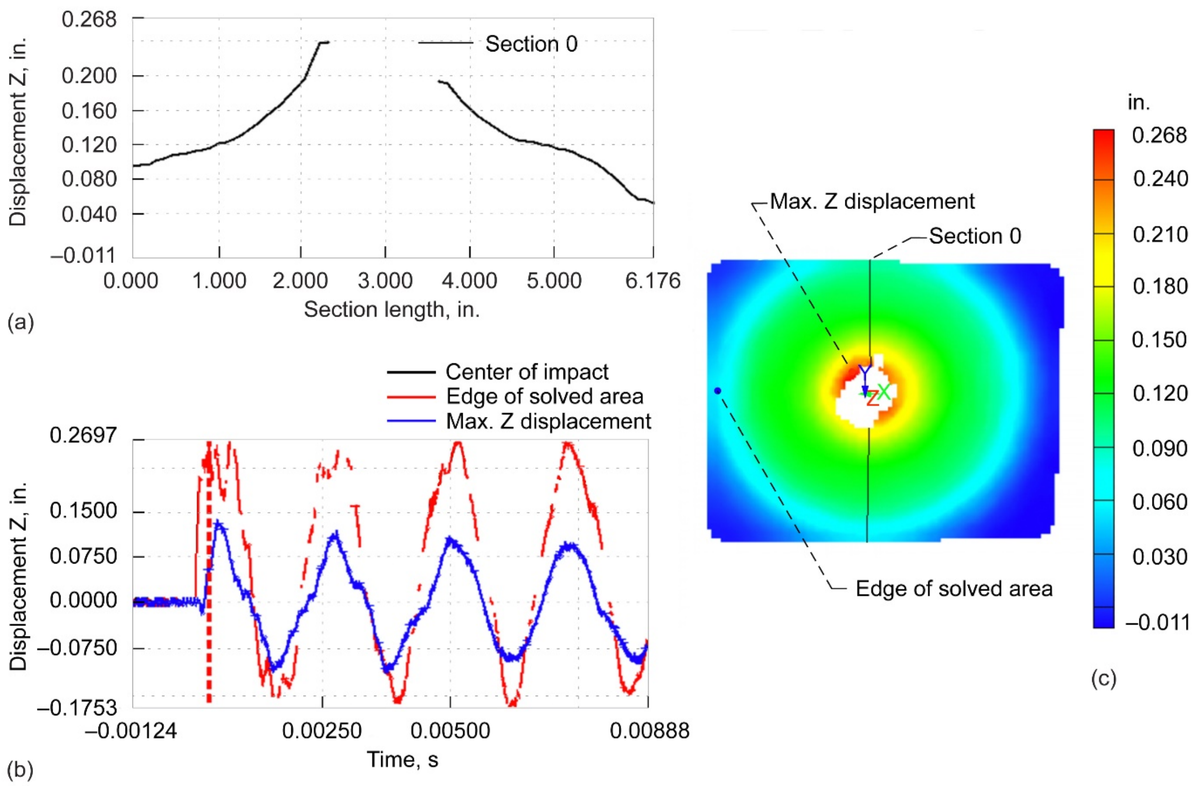



Figure C.44.—DB243 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

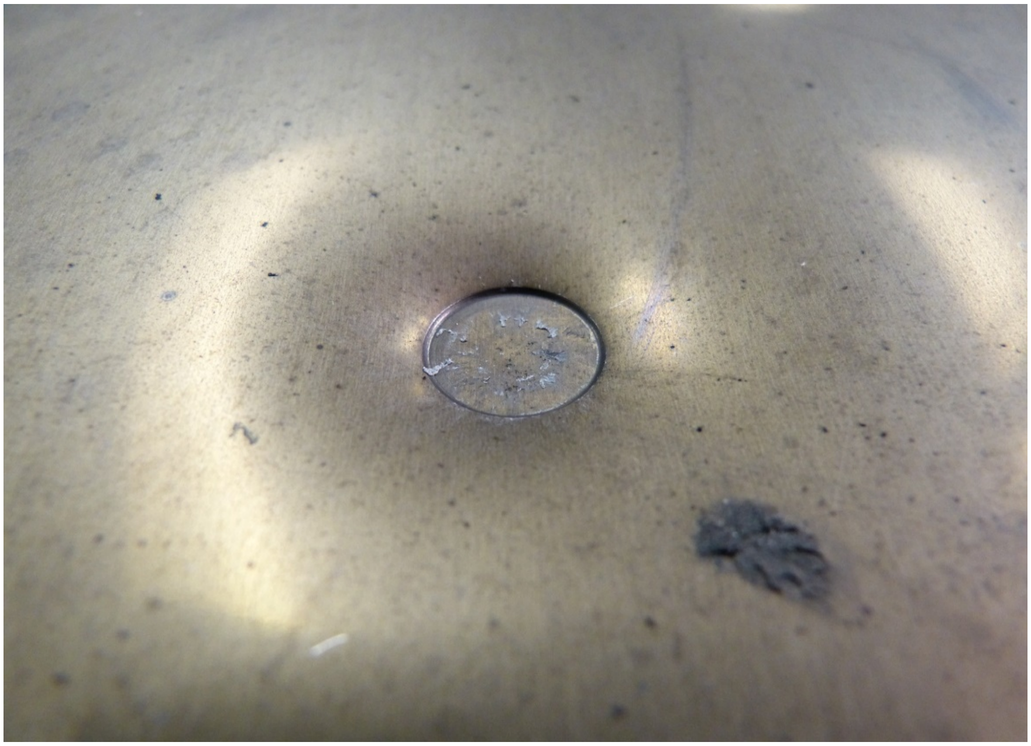


Figure C.45.—DB243 posttest front view closeup.

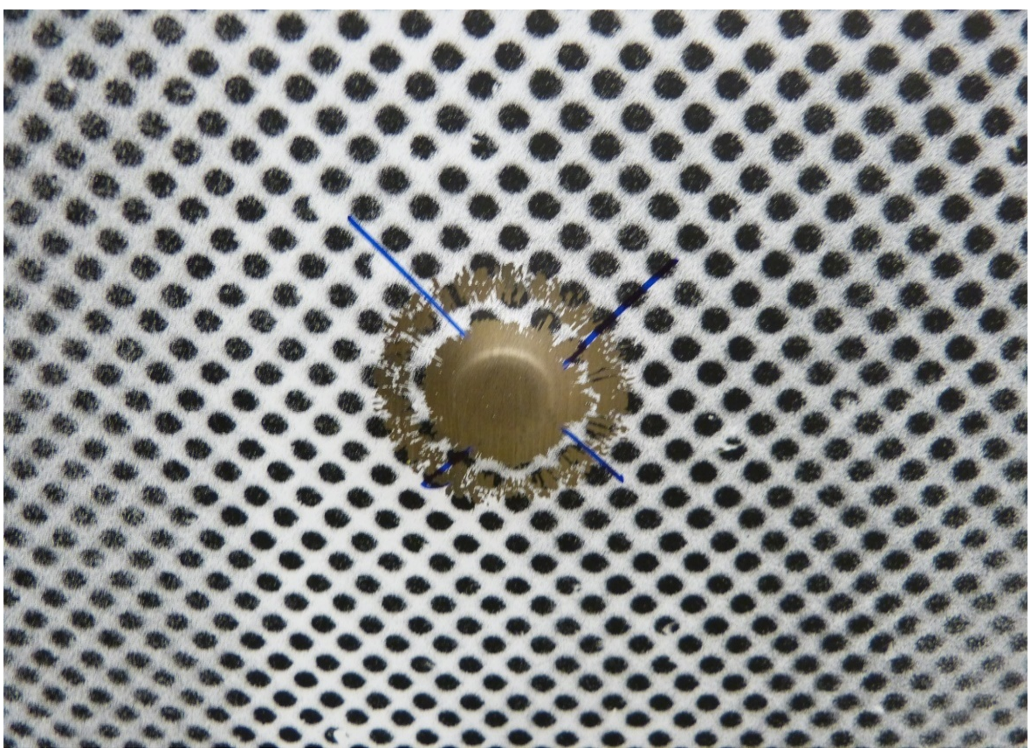


Figure C.46.—DB243 posttest rear view closeup.

### *Test DB244*

The DIC data was not obtained due to full penetration of projectile.


Figure C.47.—DB244 posttest front view.

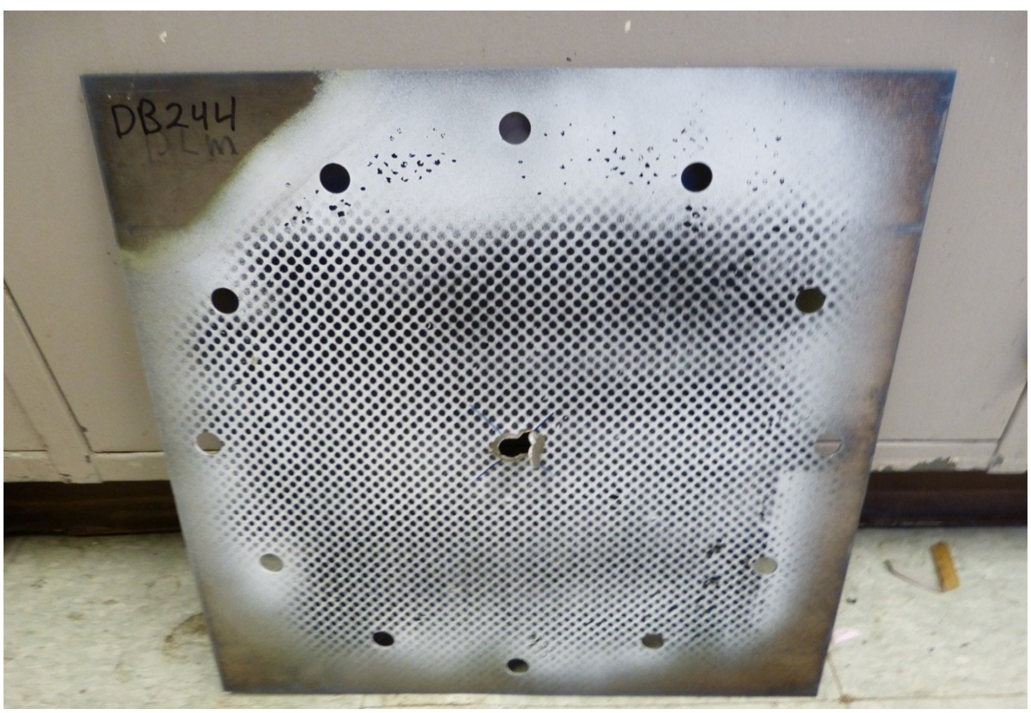



Figure C.48.—DB244 posttest rear view.

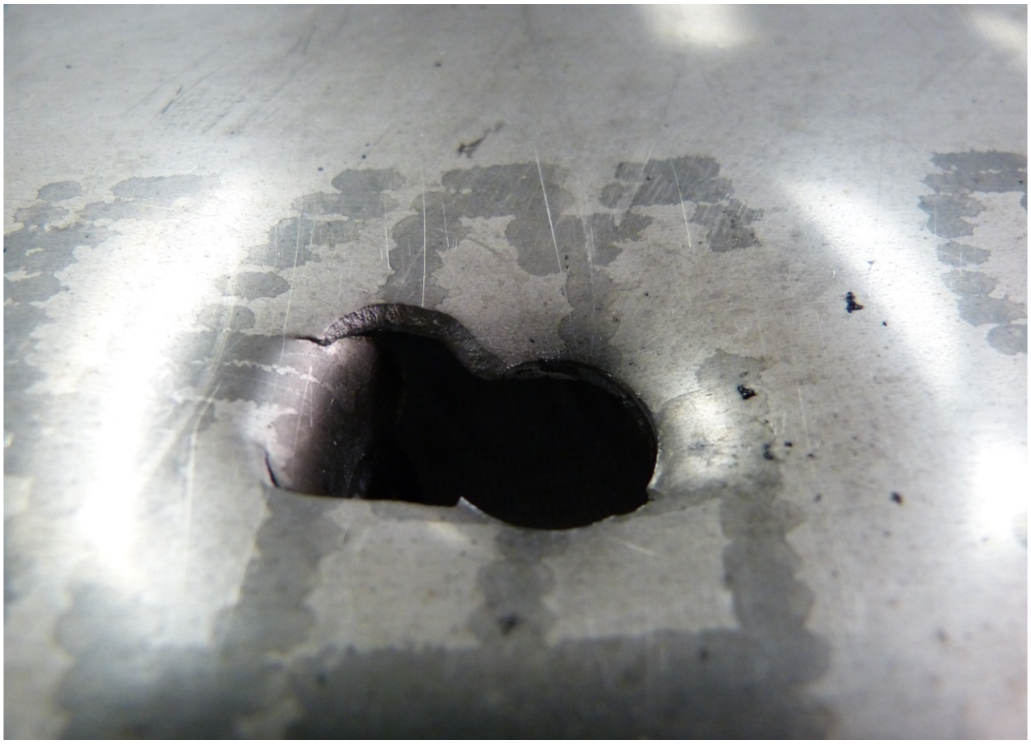


Figure C.49.—DB244 posttest front view closeup.

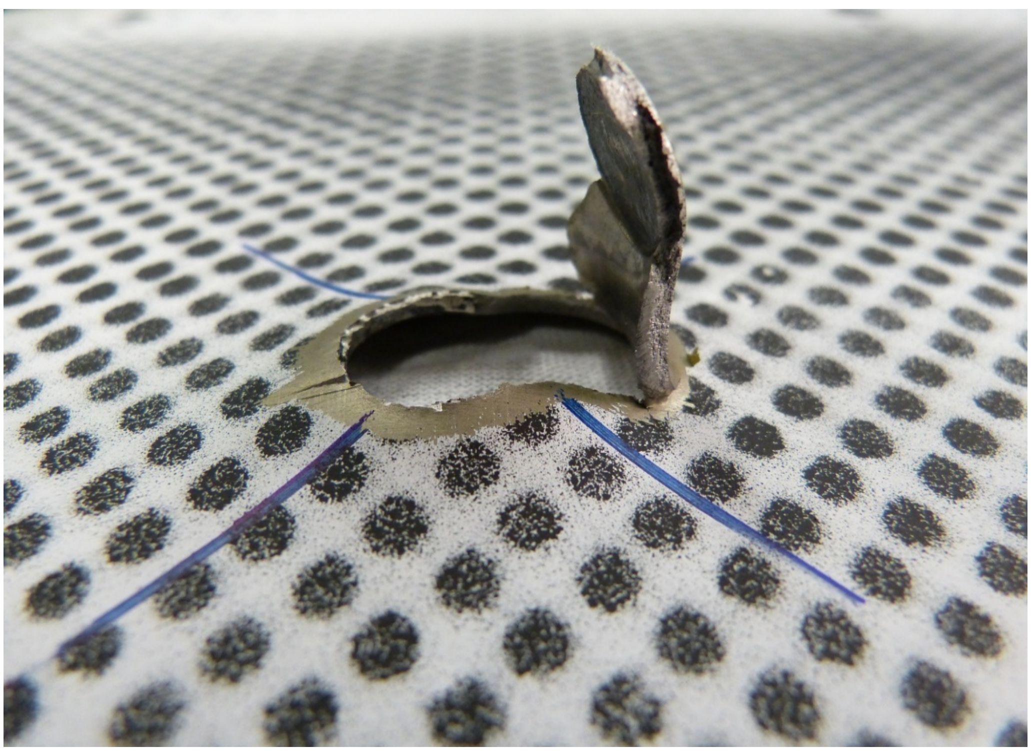


Figure C.50.—DB244 posttest rear view closeup.

*Test DB245*

The DIC data was not obtained due to full penetration of projectile.


Figure C.51.—DB245 posttest front view.

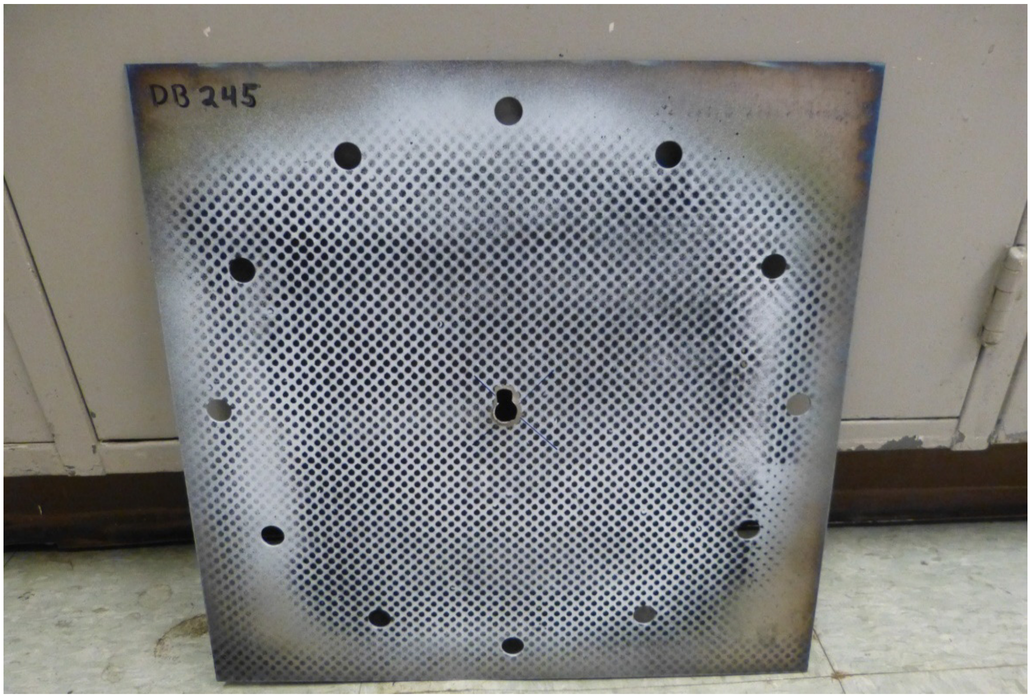



Figure C.52.—DB245 posttest rear view.

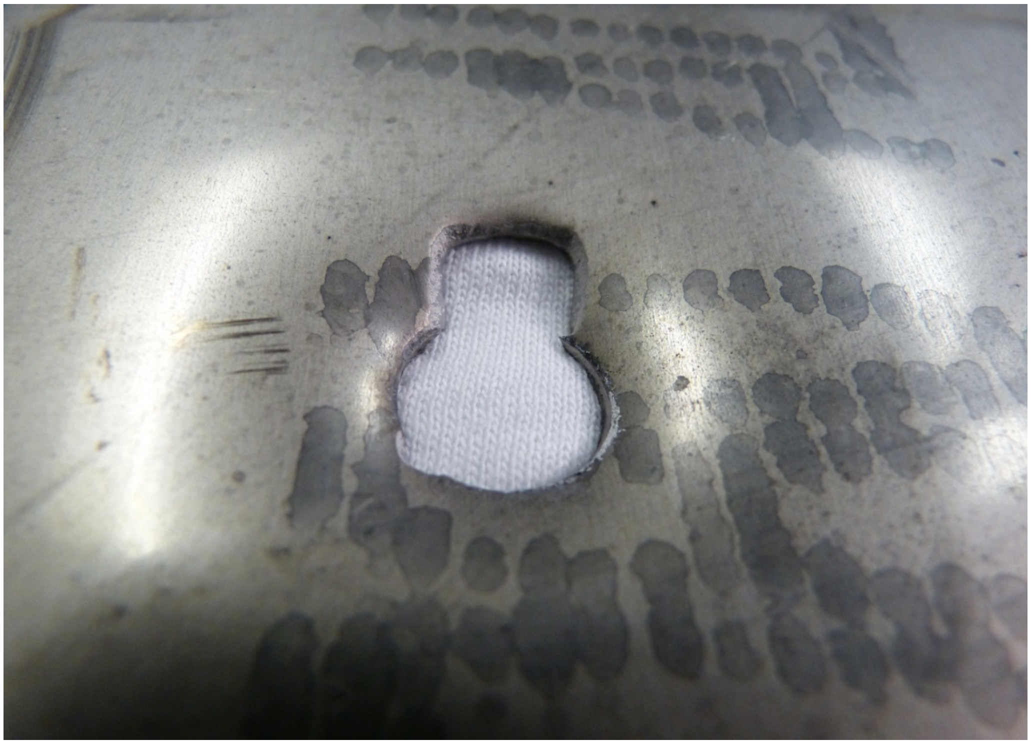


Figure C.53.—DB245 posttest front view closeup.

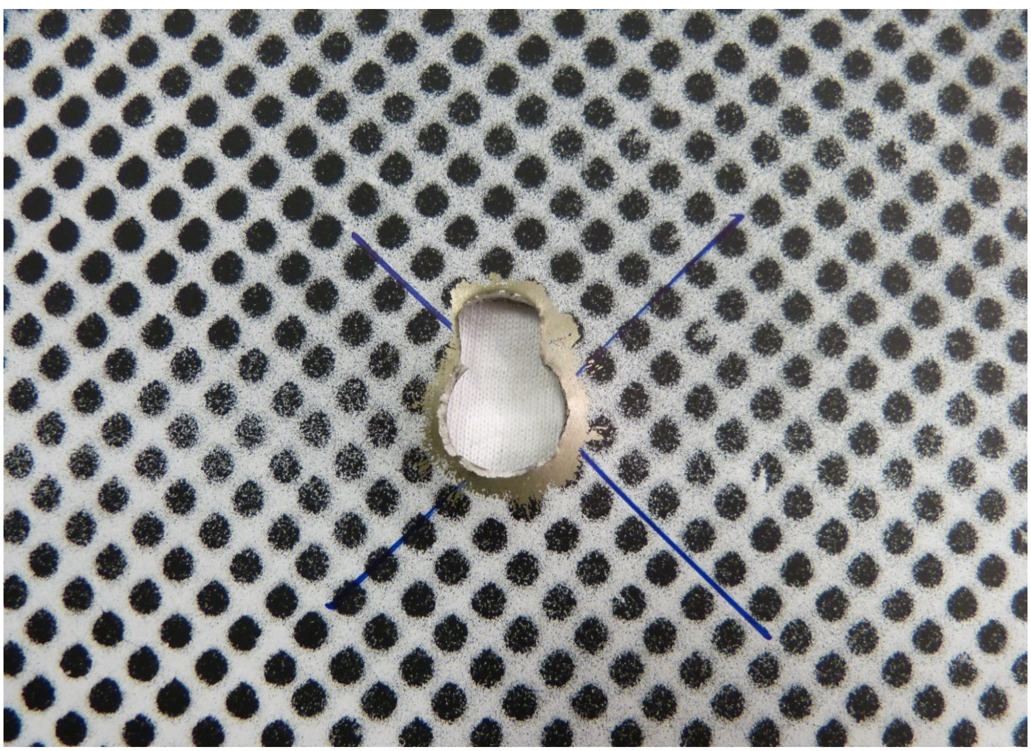


Figure C.54.—DB245 posttest rear view closeup.

*Test DB246*


Figure C.55.—DB246 posttest front view.

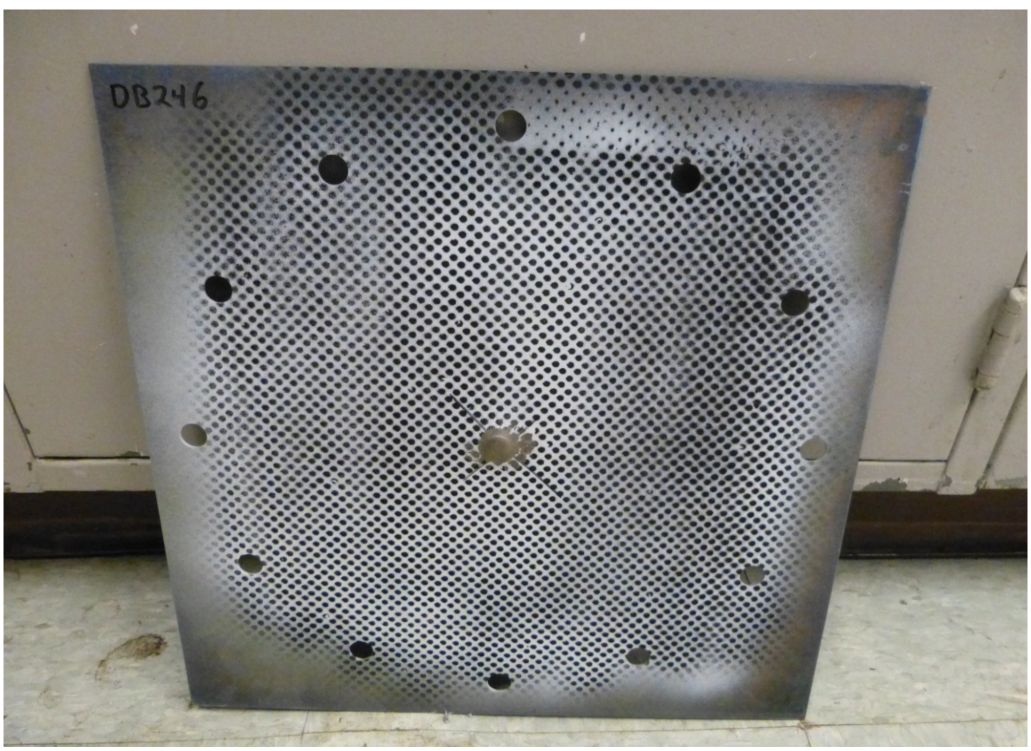



Figure C.56.—DB246 posttest rear view.

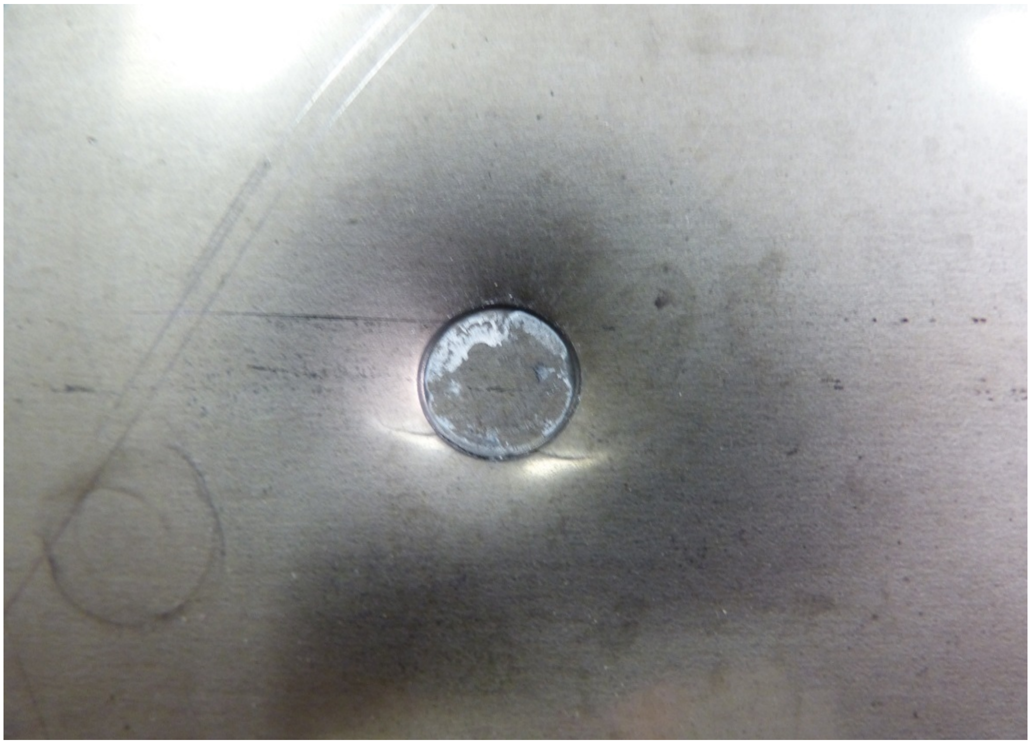


Figure C.57.—DB246 posttest front view closeup.

Figure C.58.—DB246 posttest rear view closeup.

## *Test DB247*

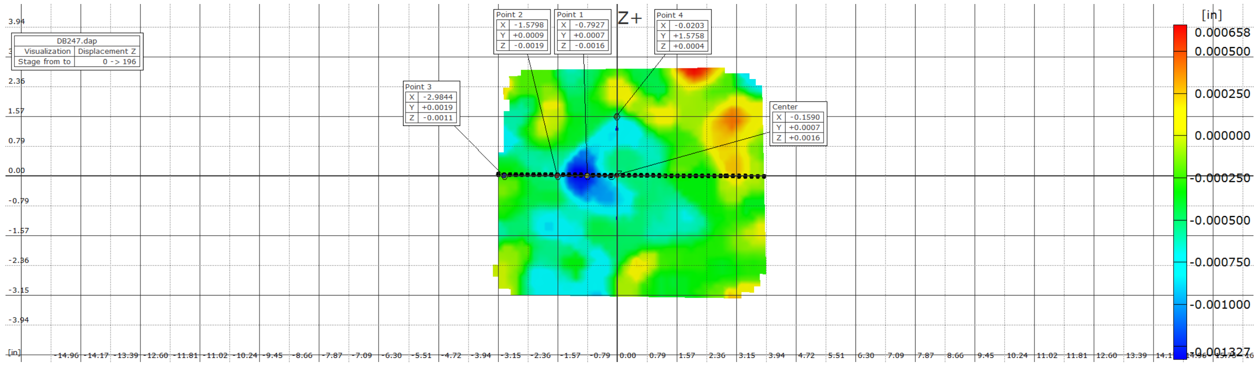



Figure C.59.—DB247 locations of digital image correclation (DIC) measurements.

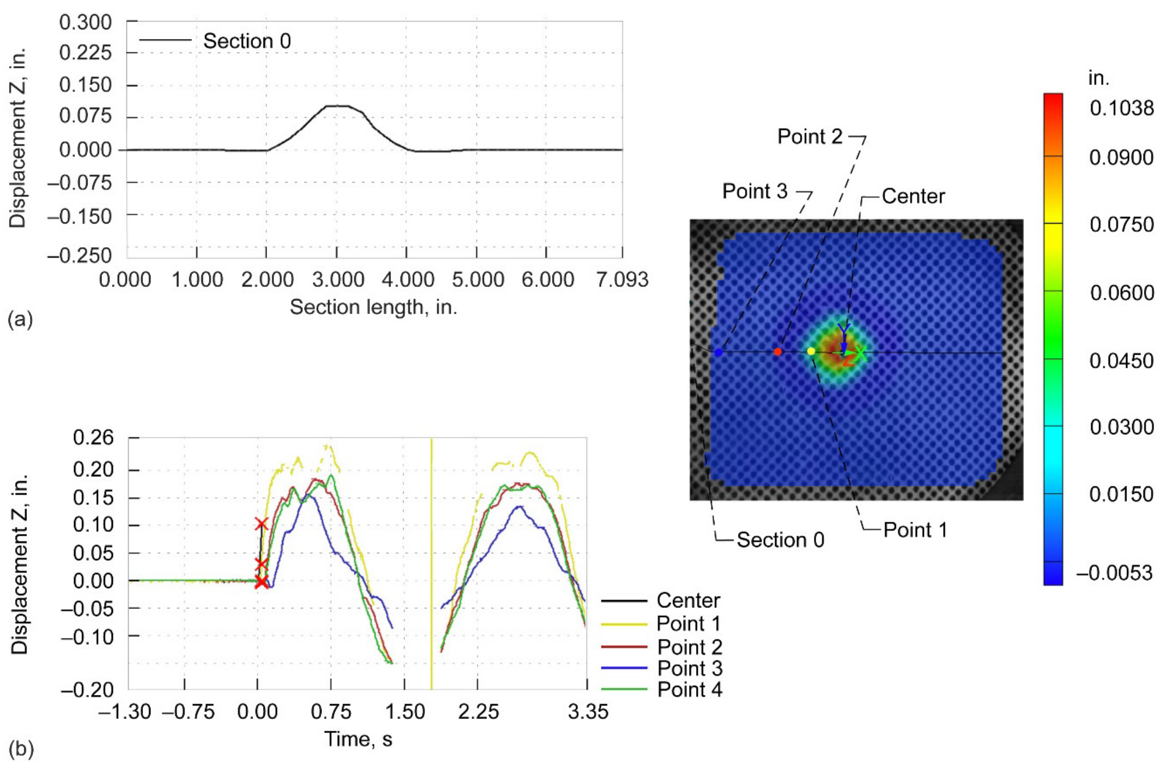



Figure C.60.—DB247 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

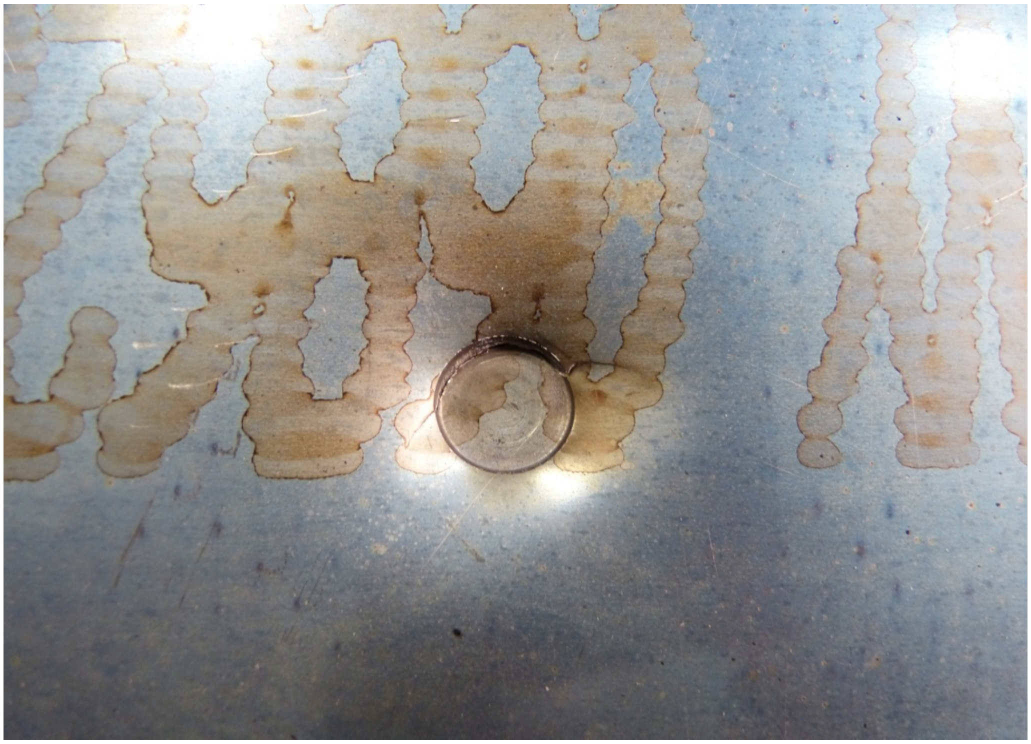


Figure C.61.—DB247 posttest front view closeup.

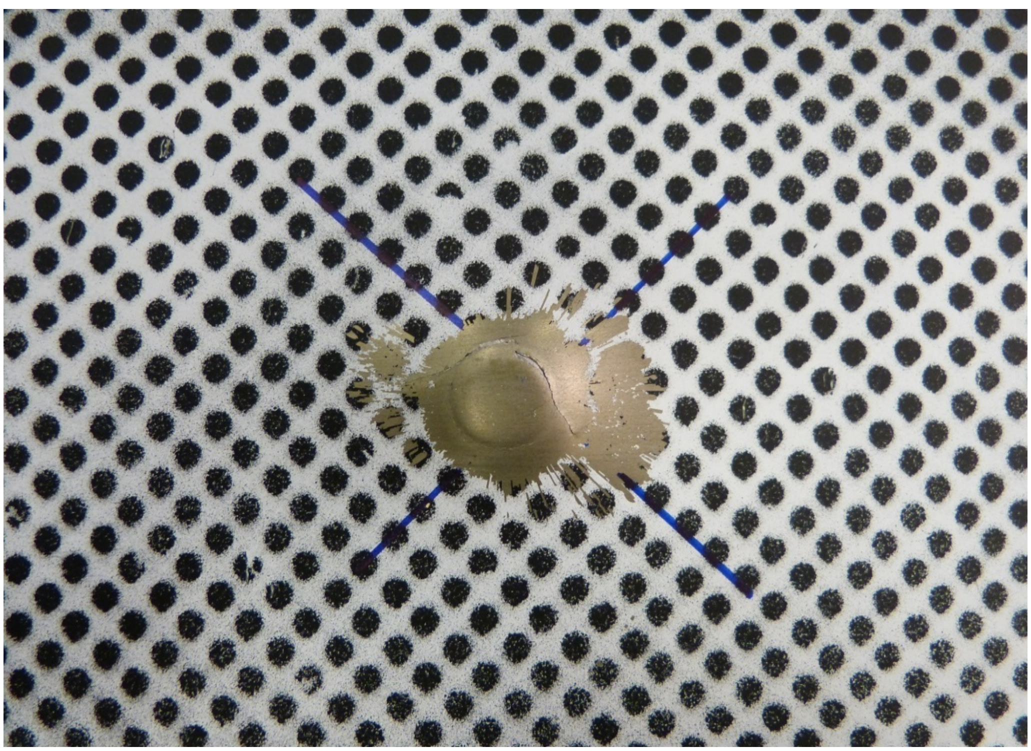


Figure C.62.—DB247 posttest rear view closeup.

### *Test DB248*

The DIC data was not obtained due to full penetration of projectile.


Figure C.63.—DB248 posttest front view.

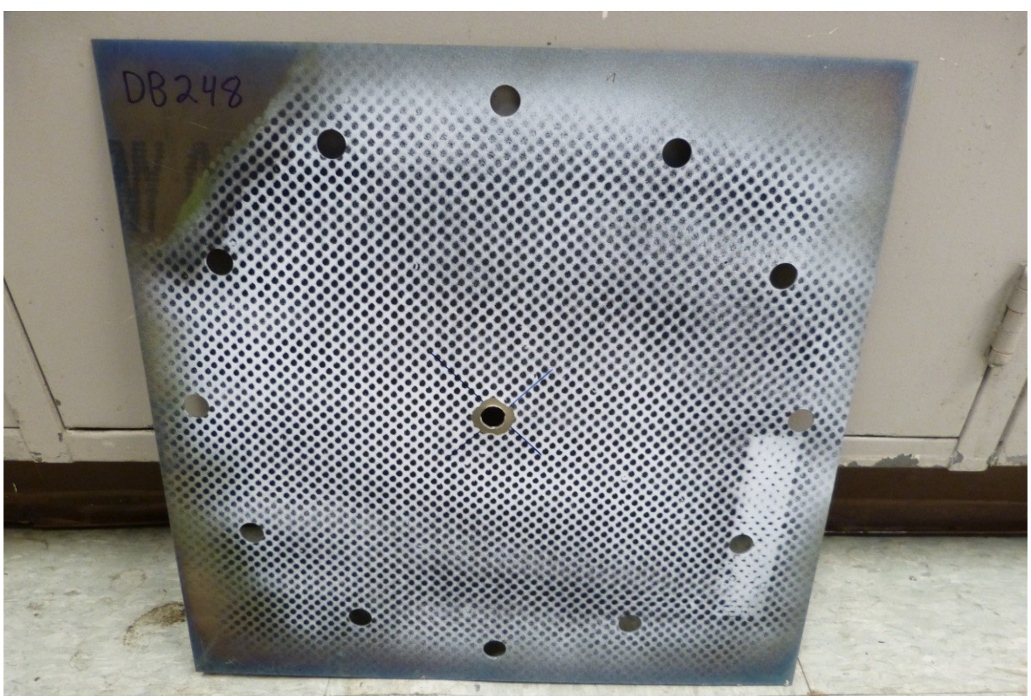



Figure C.64.—DB248 posttest rear view.

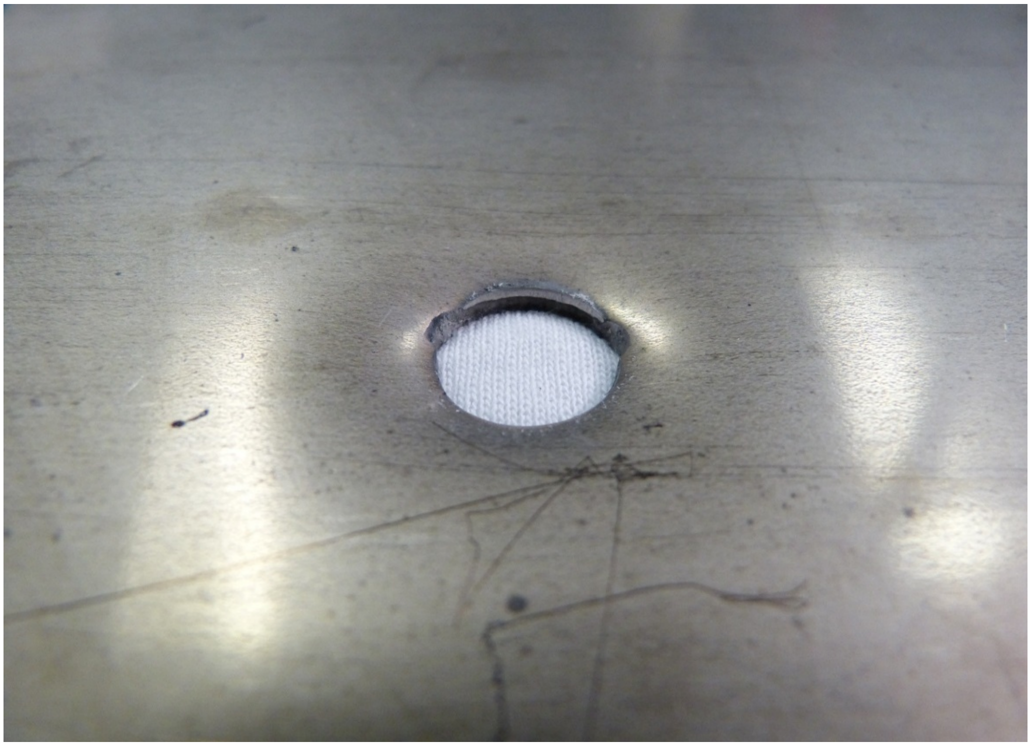


Figure C.65.—DB248 posttest front view closeup.

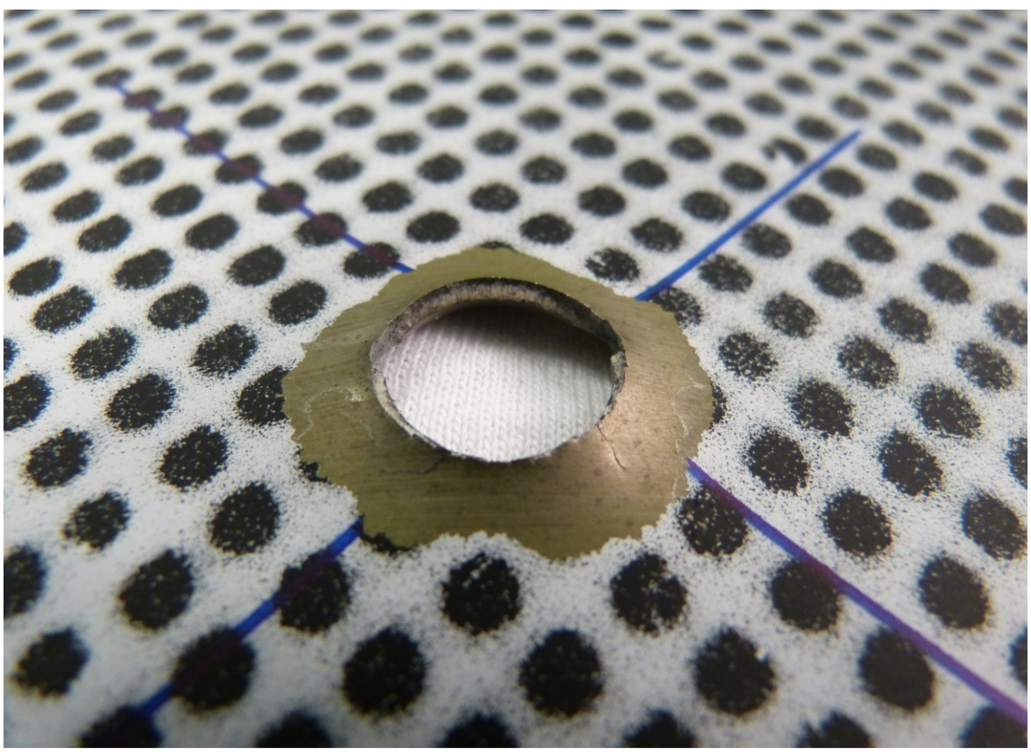


Figure C.66.—DB248 posttest rear view closeup.

*Test DB249*

The DIC data was not obtained due to full penetration of projectile.


Figure C.67.—DB249 posttest front view.

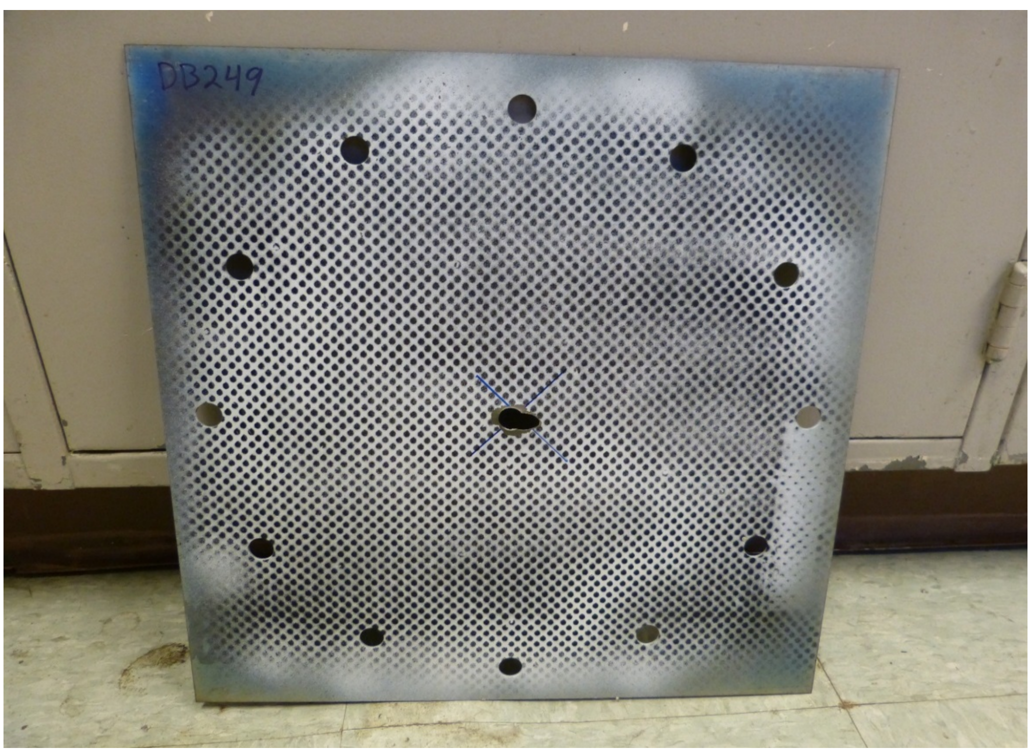



Figure C.68.—DB249 posttest rear view.


Figure C.69.—DB249 posttest front view closeup.

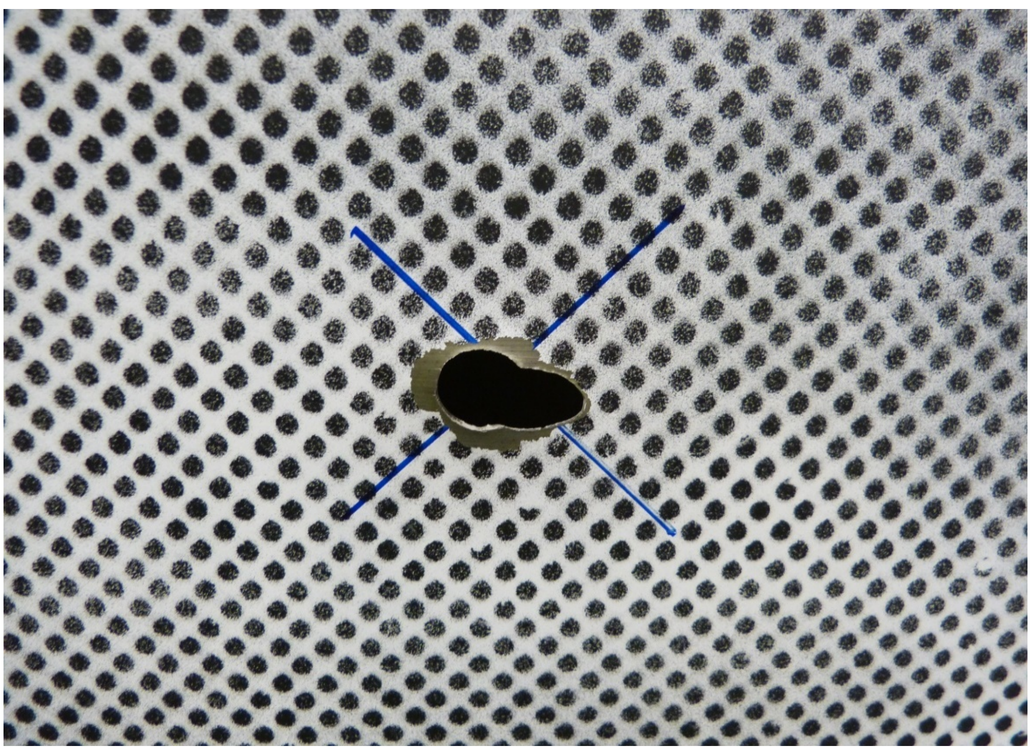


Figure C.70.—DB249 posttest rear view closeup.

### *Test DB250*

The DIC data was not obtained due to full penetration of projectile.

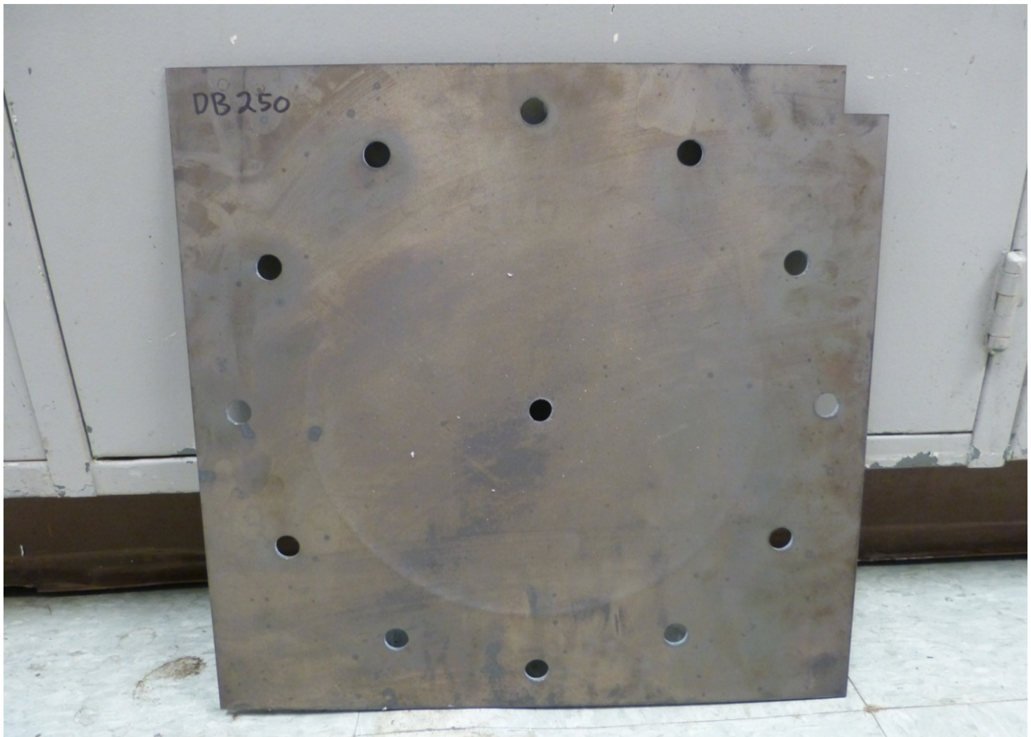



Figure C.71.—DB250 posttest front view.

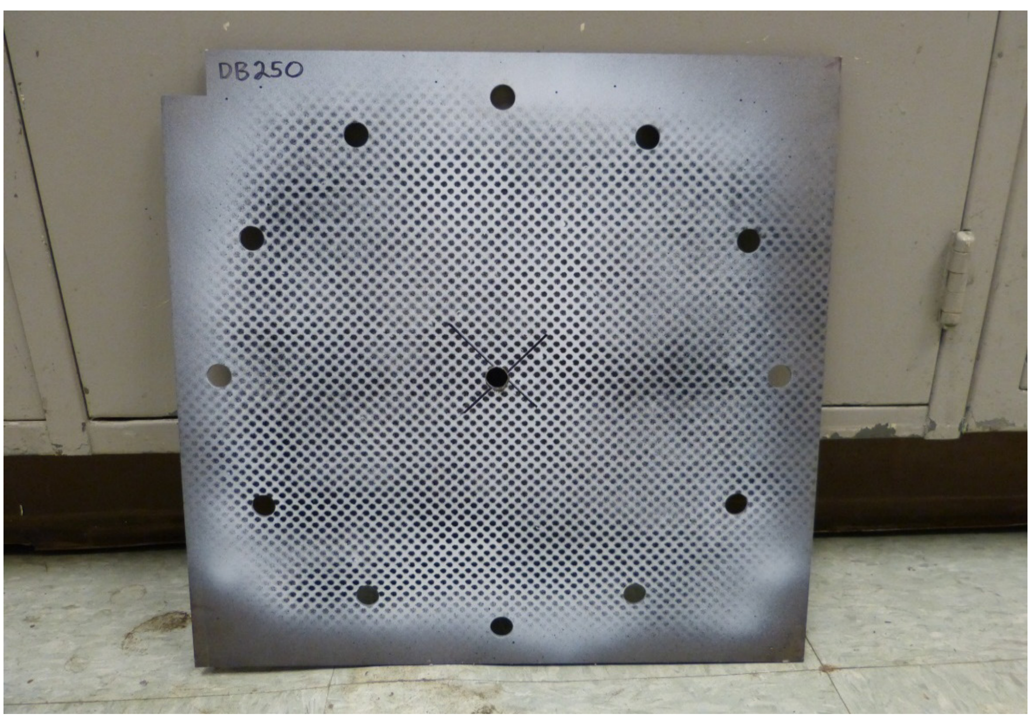



Figure C.72.—DB250 posttest rear view.

Figure C.73.—DB250 posttest front view closeup.

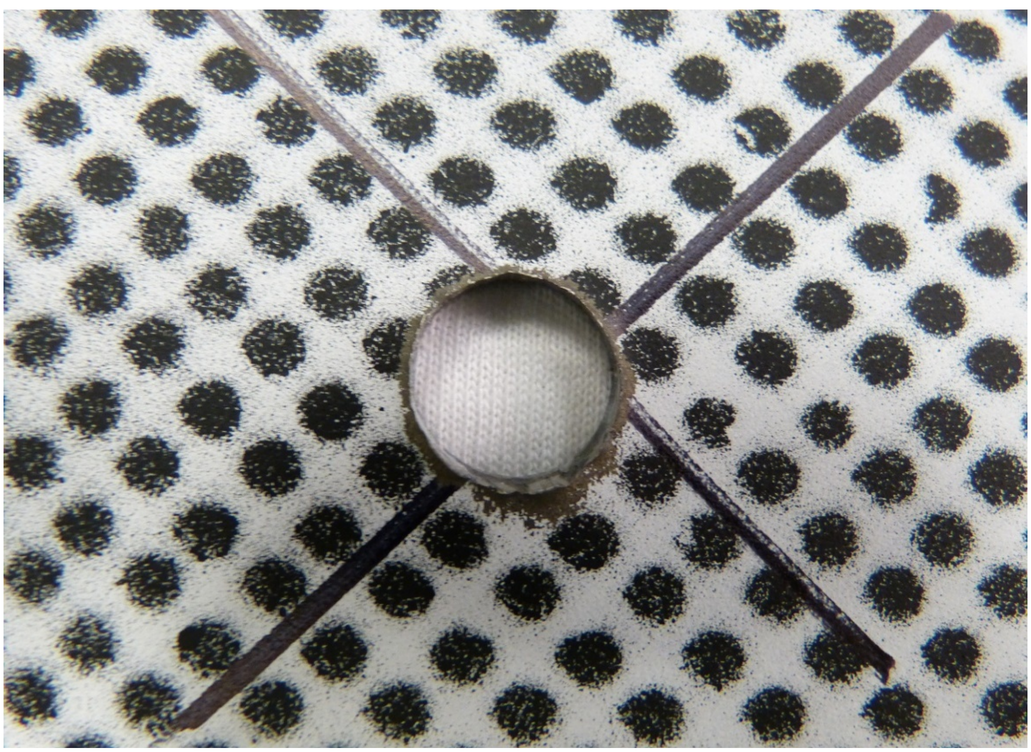


Figure C.74.—DB250 posttest rear view closeup.

*Test DB251*

The DIC data was not obtained due to full penetration of projectile.


Figure C.75.—DB251 posttest front view.

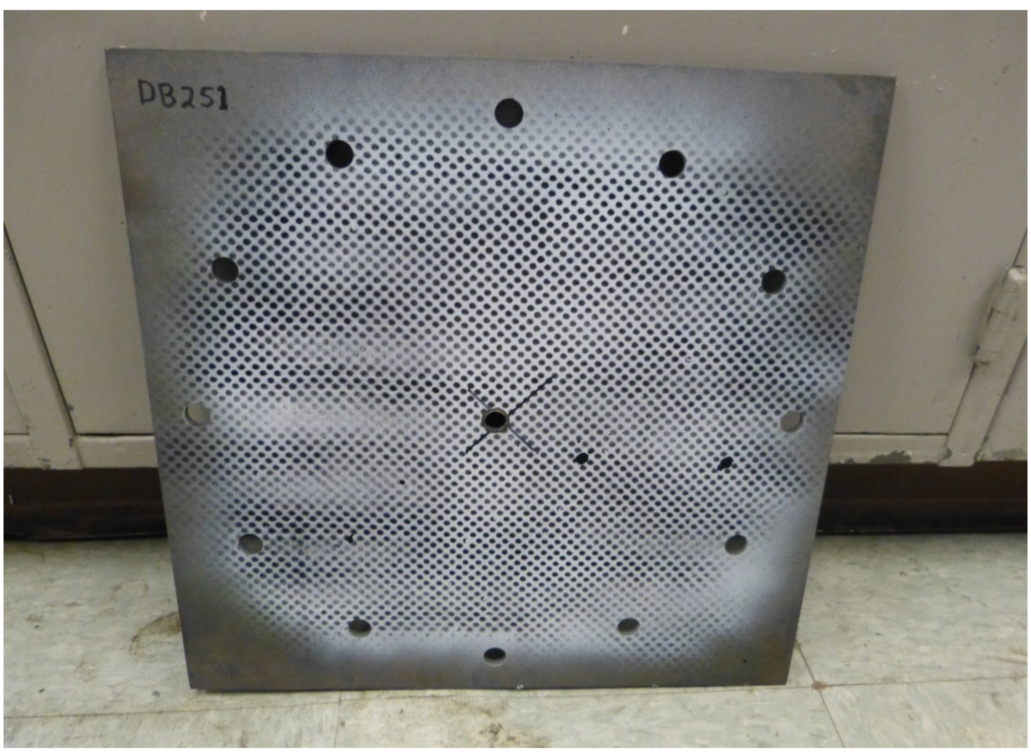



Figure C.76.—DB251 posttest rear view.

Figure C.77.—DB251 posttest front view closeup.

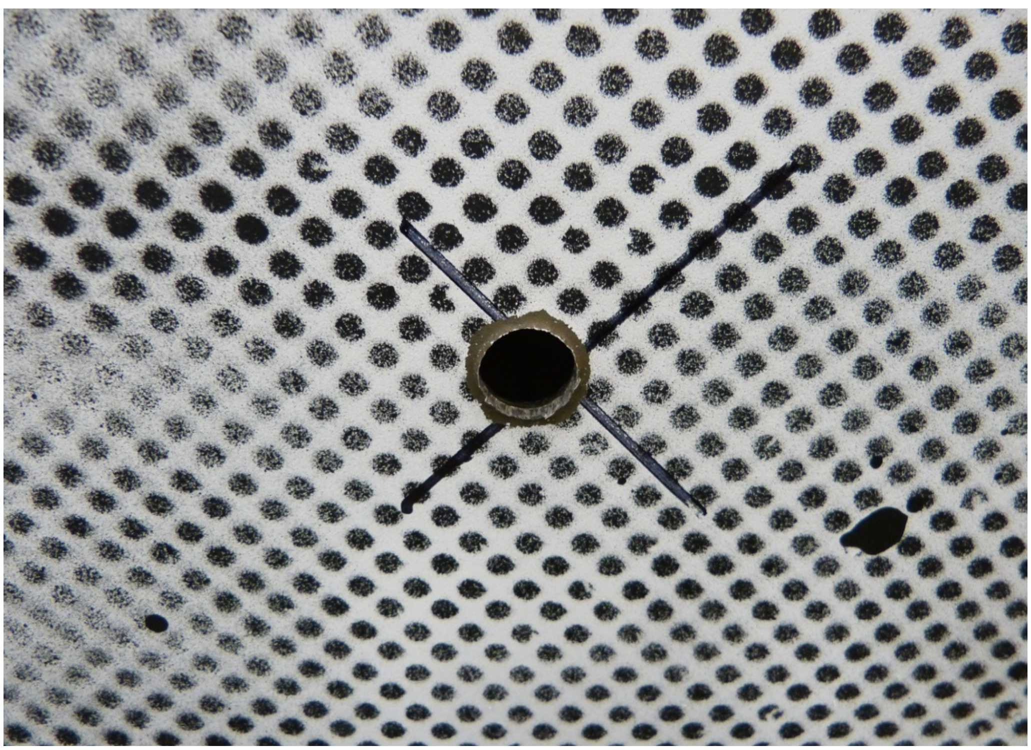


Figure C.78.—DB251 posttest rear view closeup.

### *Test DB252*

The DIC data was not obtained due to full penetration of projectile.


Figure C.79.—DB252 pretest front view.

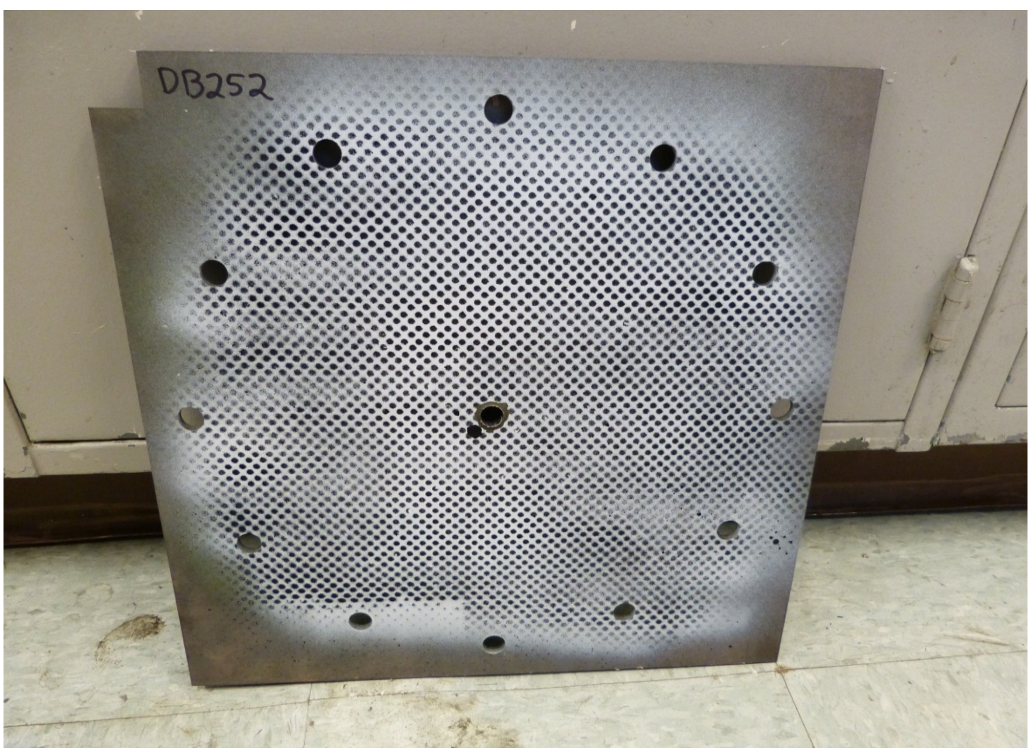



Figure C.80.—DB252 posttest rear view.

Figure C.81.—DB252 posttest front view closeup.

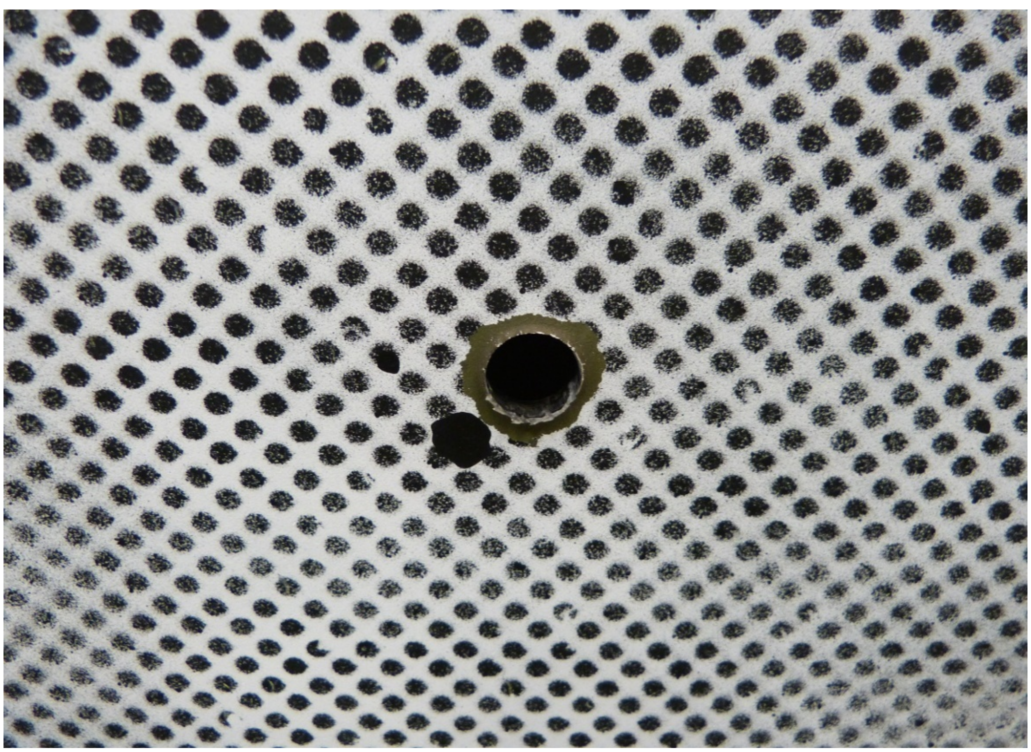


Figure C.82.—DB252 posttest rear view closeup.

*Test DB253*

The DIC data was not obtained due to projectile being captured.


Figure C.83.—DB253 posttest front view.

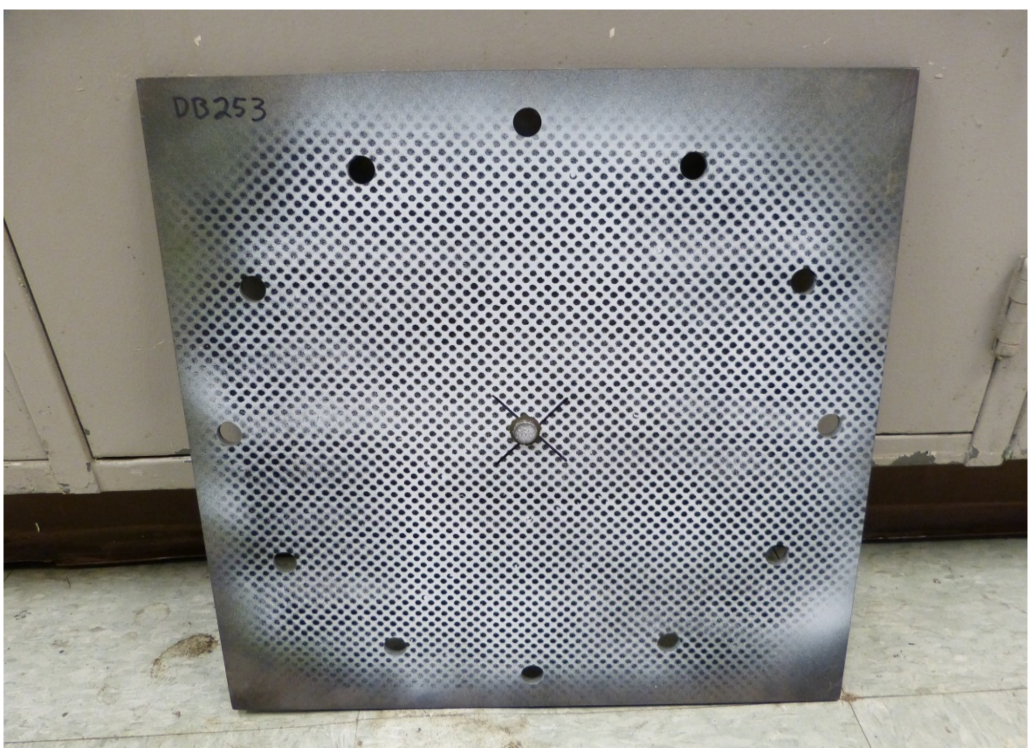



Figure C.84.—DB253 posttest rear view.

Figure C.85.—DB253 posttest front view closeup.

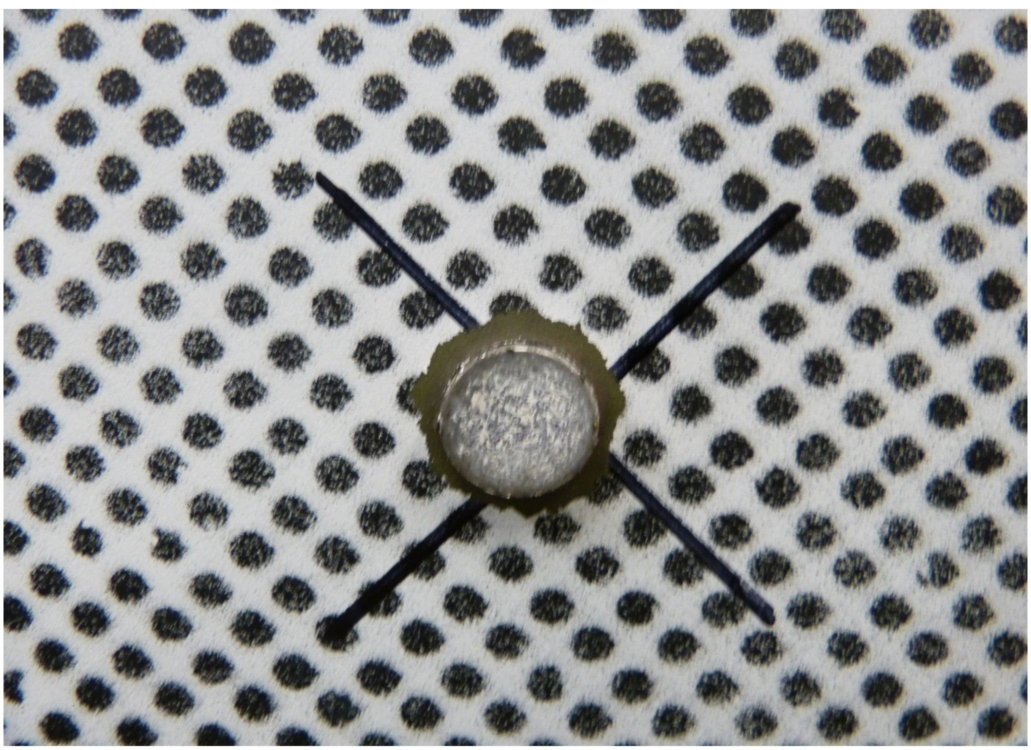


Figure C.86.—DB253 posttest rear view closeup.

### *Test DB254*

The DIC data was not obtained due to full penetration of projectile.


Figure C.87.—DB254 posttest front view.

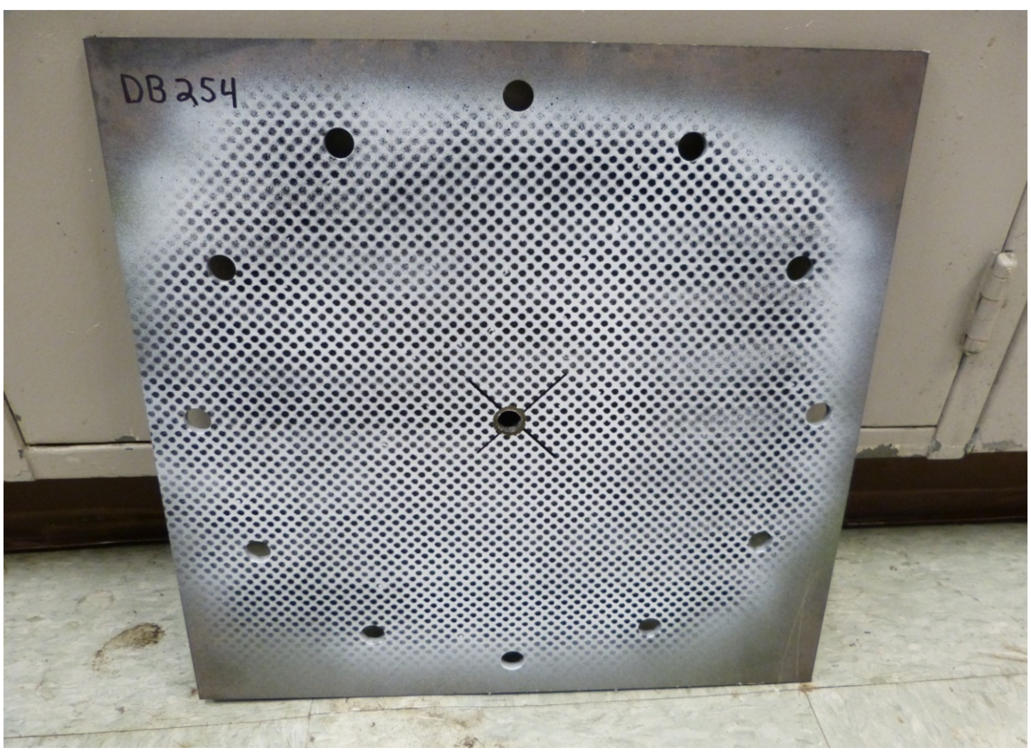



Figure C.88.—DB254 posttest rear view.

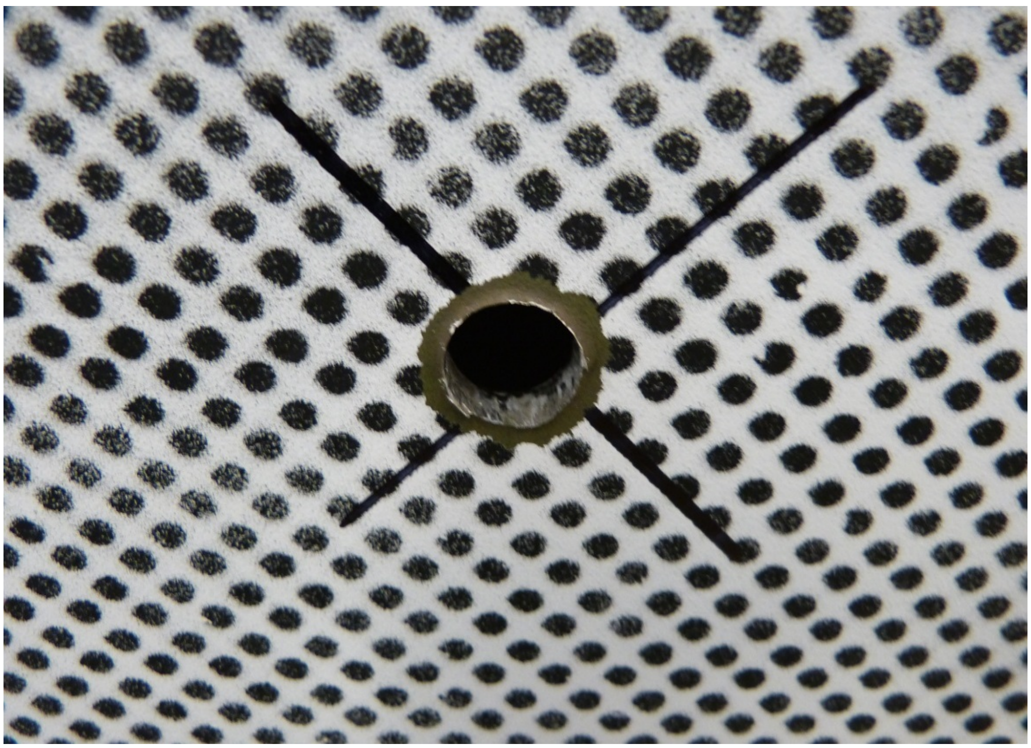


Figure C.89.—DB254 posttest rear view closeup.

### *Test DB255*

The DIC data was not obtained due to projectile being captured.

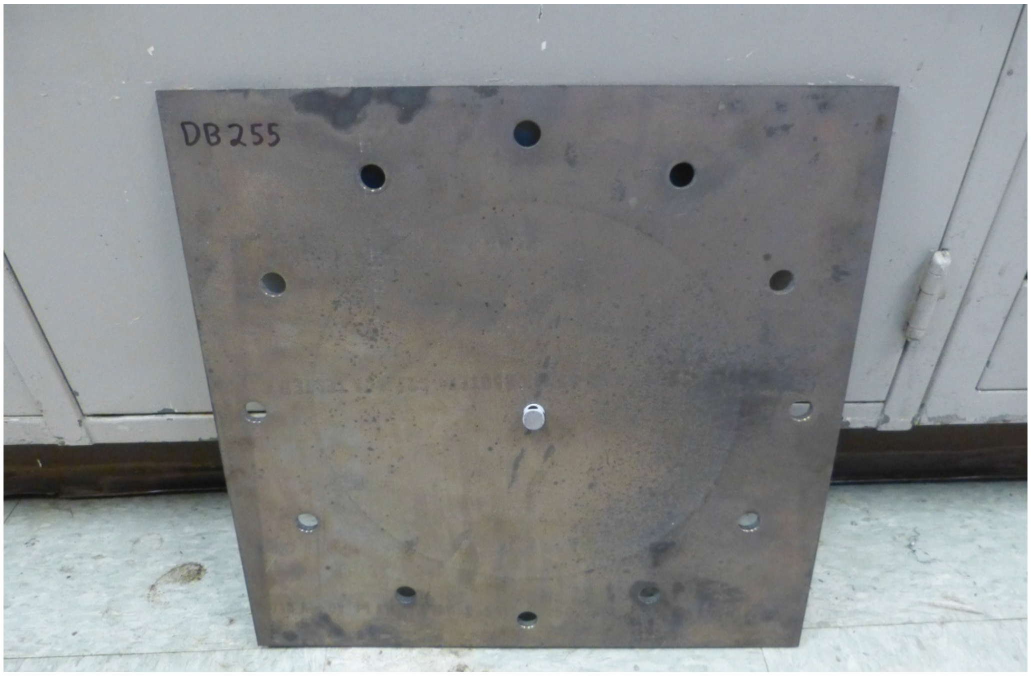


Figure C.90.—DB255 posttest front view.

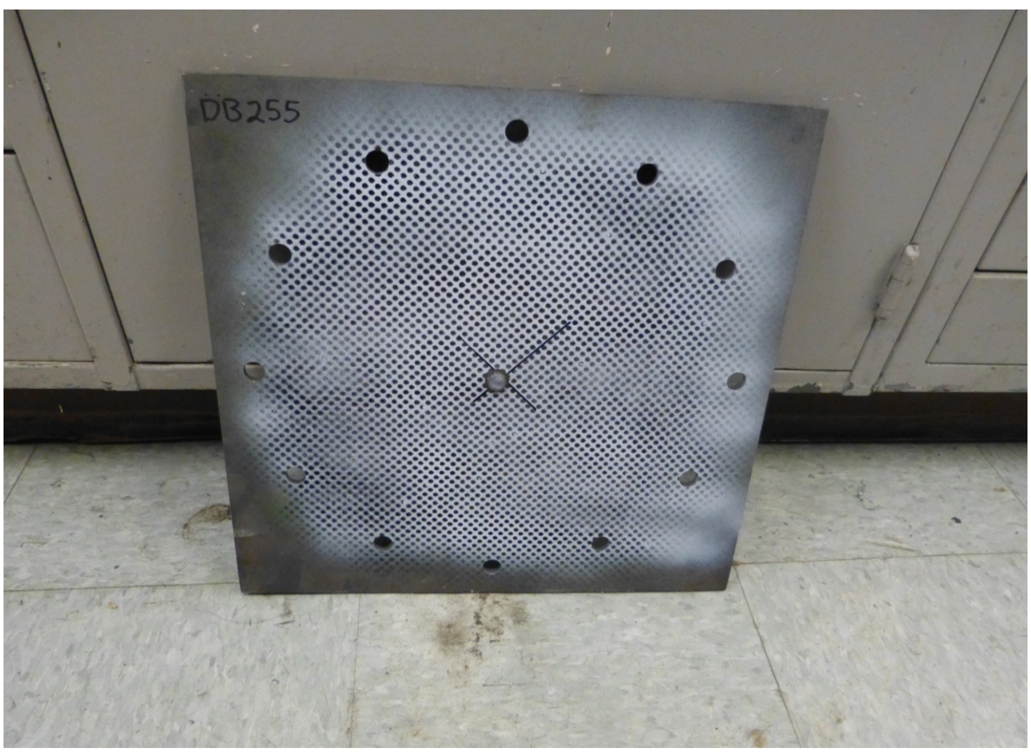


Figure C.91.—DB255 posttest rear view.

Figure C.92.—DB255 posttest front view closeup.

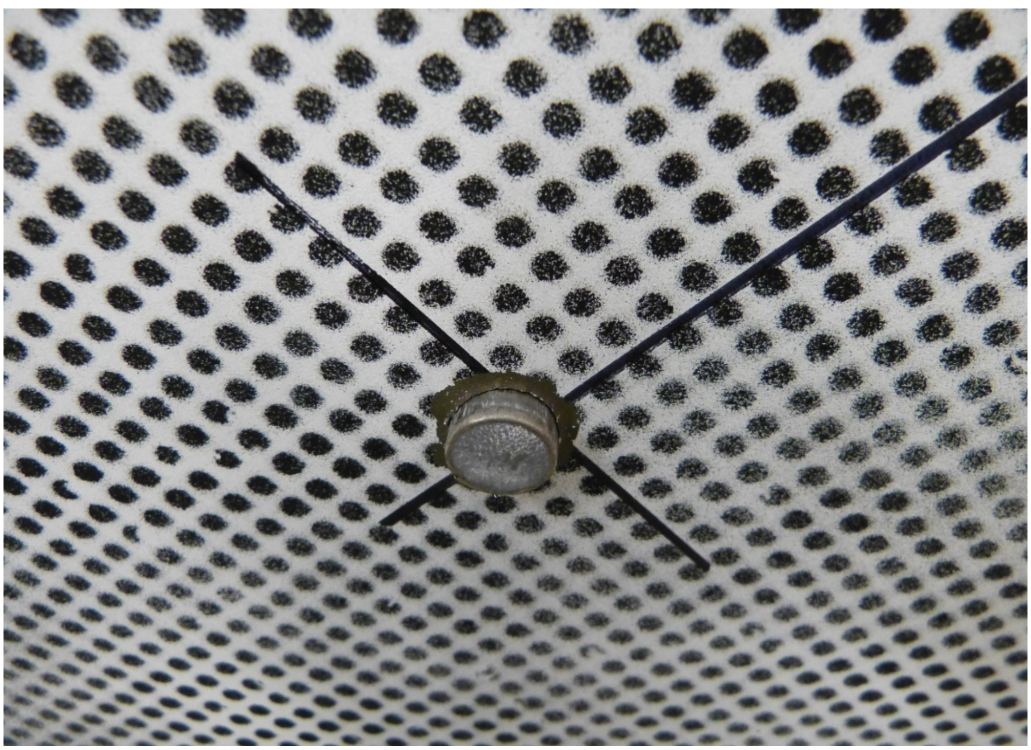


Figure C.93.—DB255 posttest rear view closeup.

### *Test DB256*

No pretest or posttest pictures were taken of sample DB256.

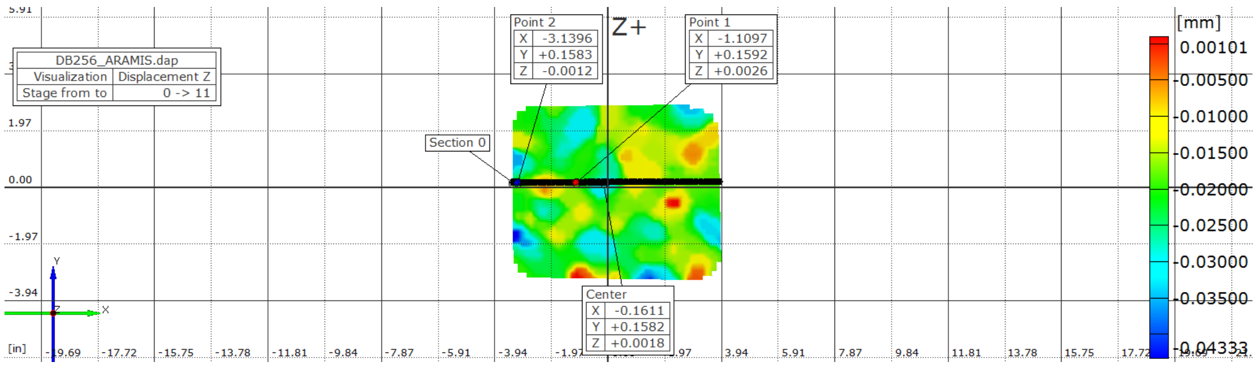



Figure C.94.—DB256 locations of digital image correlation (DIC) measurements.

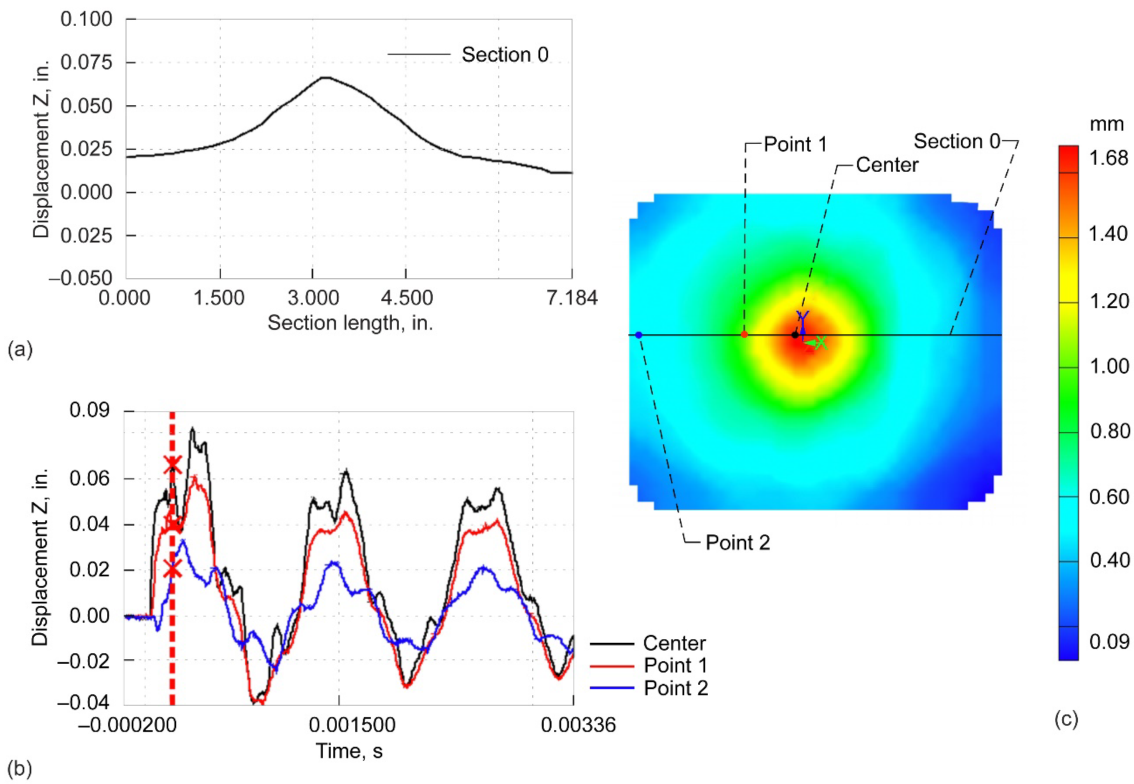



Figure C.95.—DB256 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

*Test DB257*

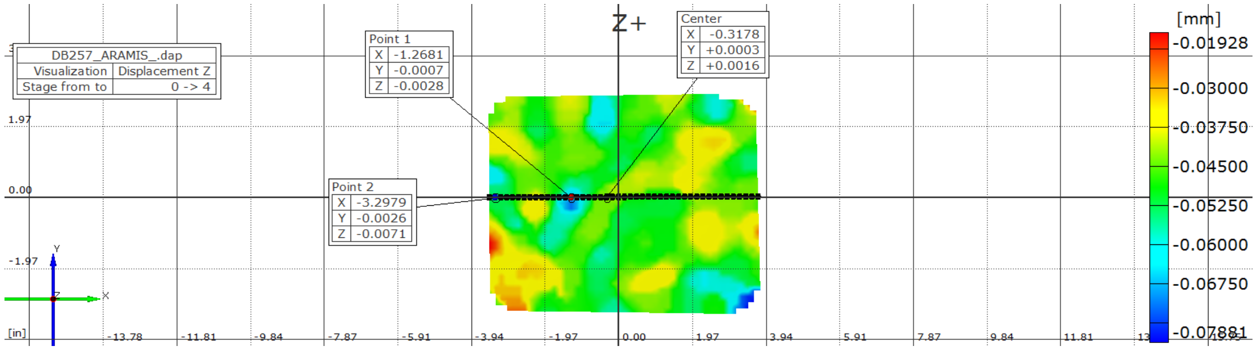



Figure C.96.—DB257 locations of digital image correlation (DIC) measurements.

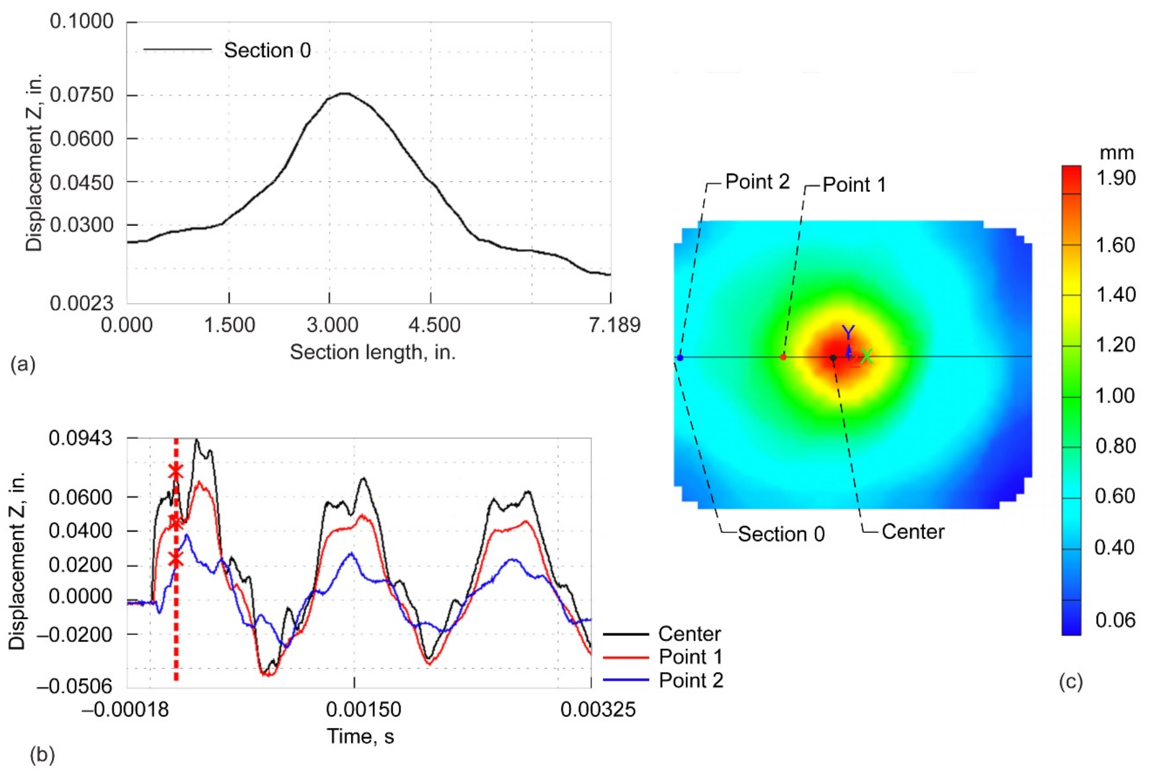



Figure C.97.—DB257 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.98.—DB257 posttest front view closeup.

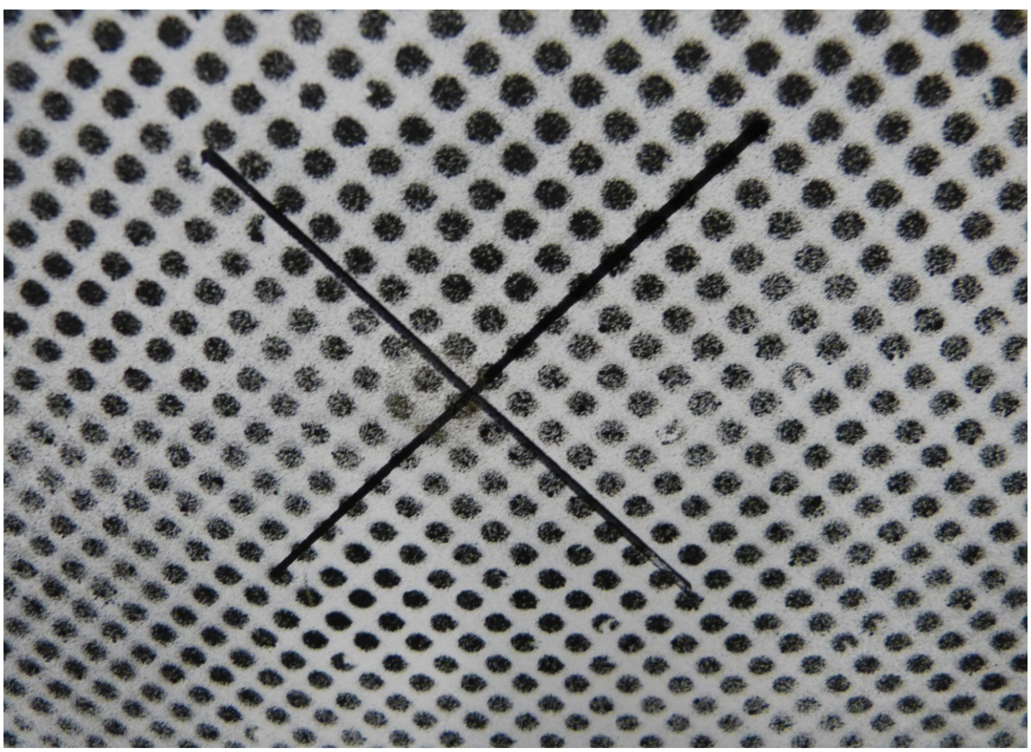


Figure C.99.—DB257 posttest rear view closeup.

### *Test DB258*

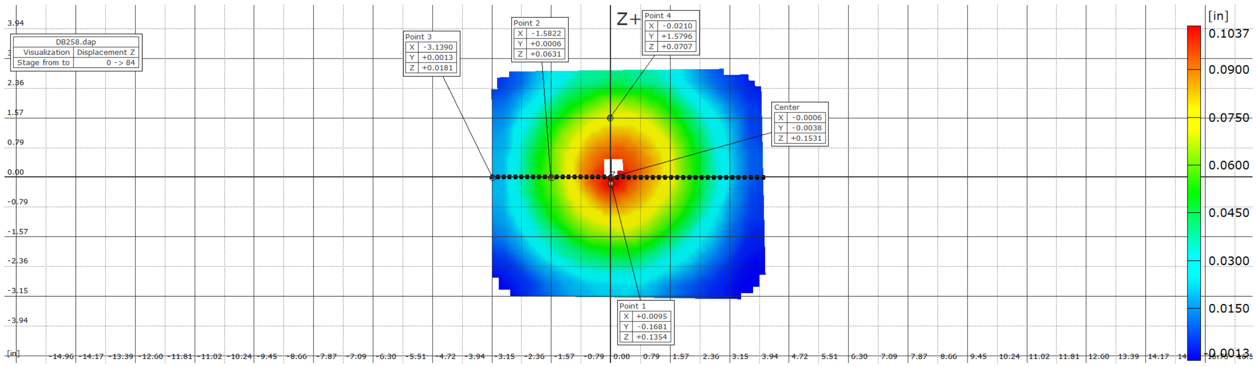


Figure C.100.—DB258 locations of digital image correlation (DIC) measurements.

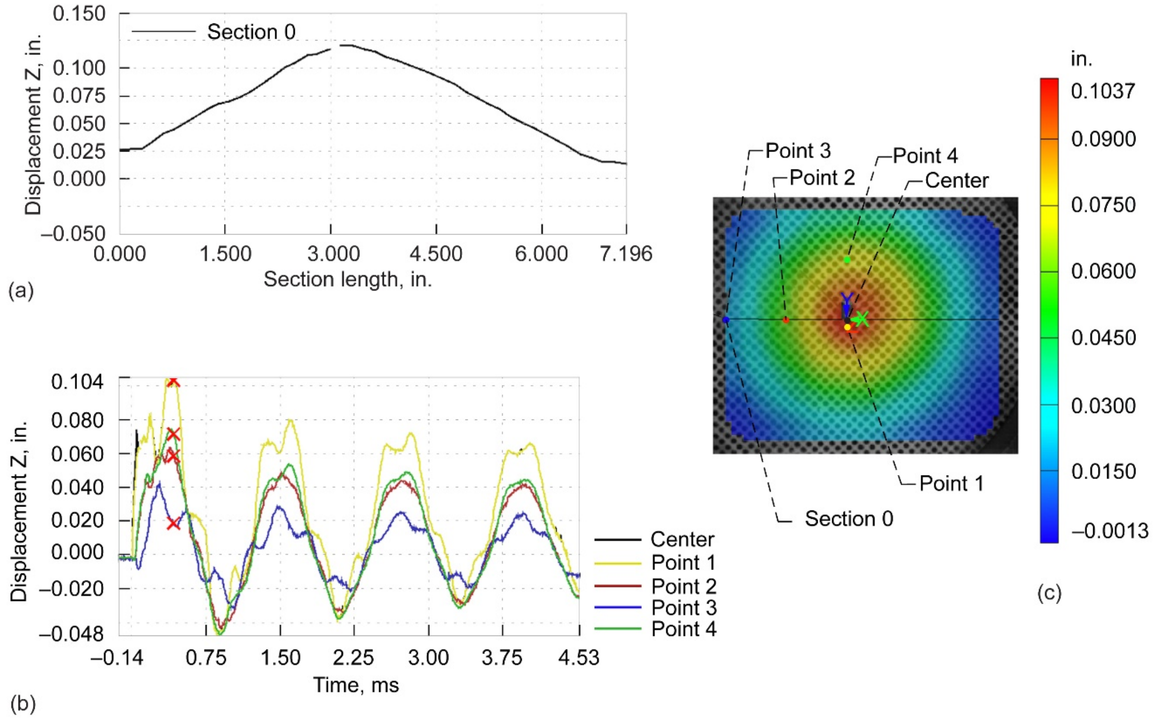



Figure C.101.—DB258 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.102.—DB258 posttest front view closeup.

Figure C.103.—DB258 posttest rear view closeup.

### *Test DB259*

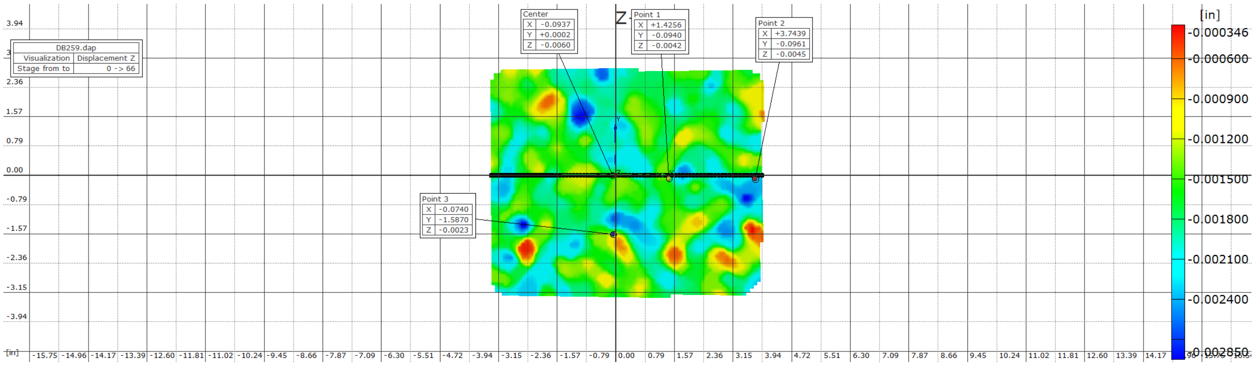



Figure C.104.—DB259 locations of digital image correlation (DIC) measurements.

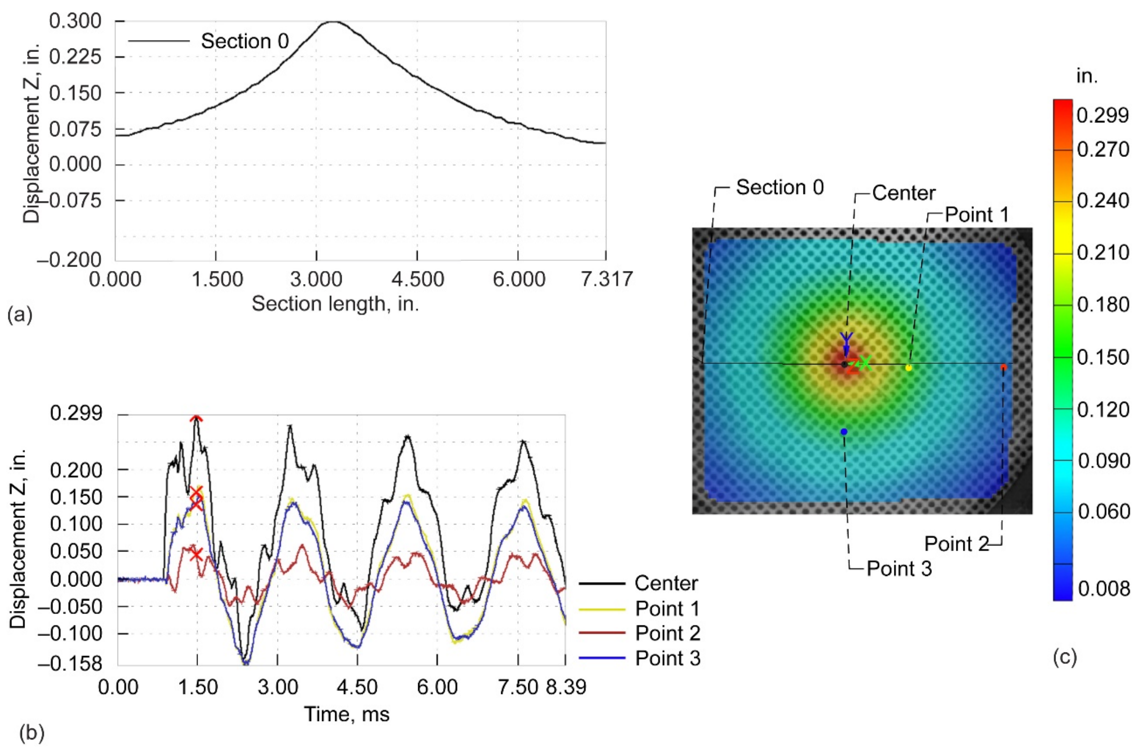



Figure C.105.—DB259 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.106.—DB259 posttest front view closeup.

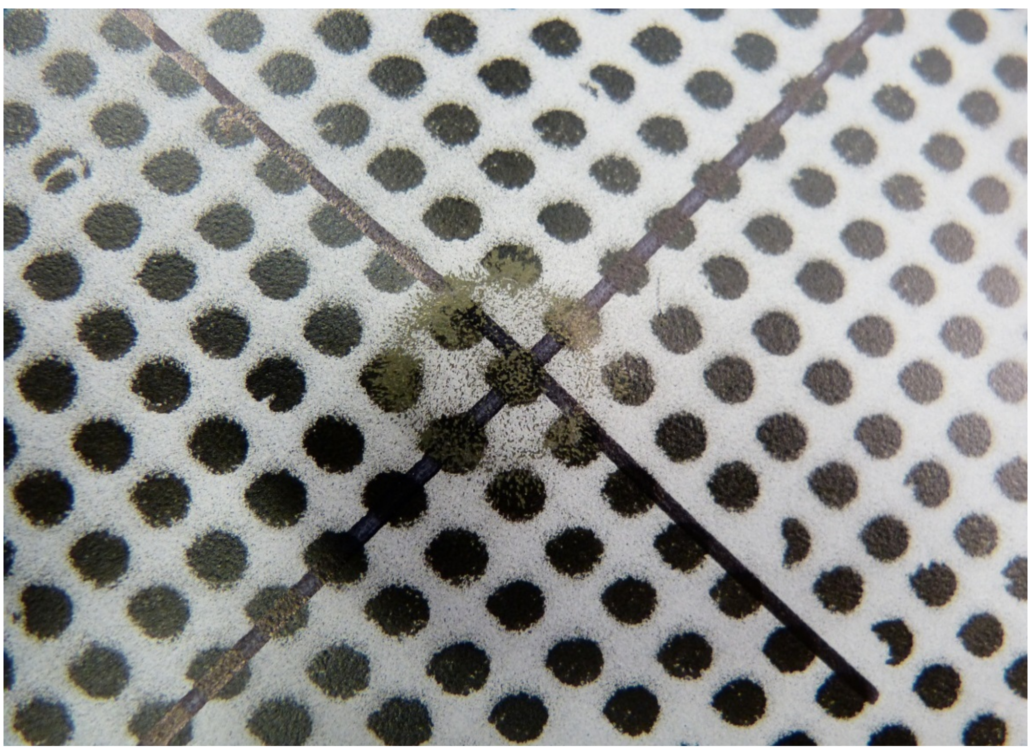


Figure C.107.—DB259 posttest rear view closeup.

### *Test DB260*

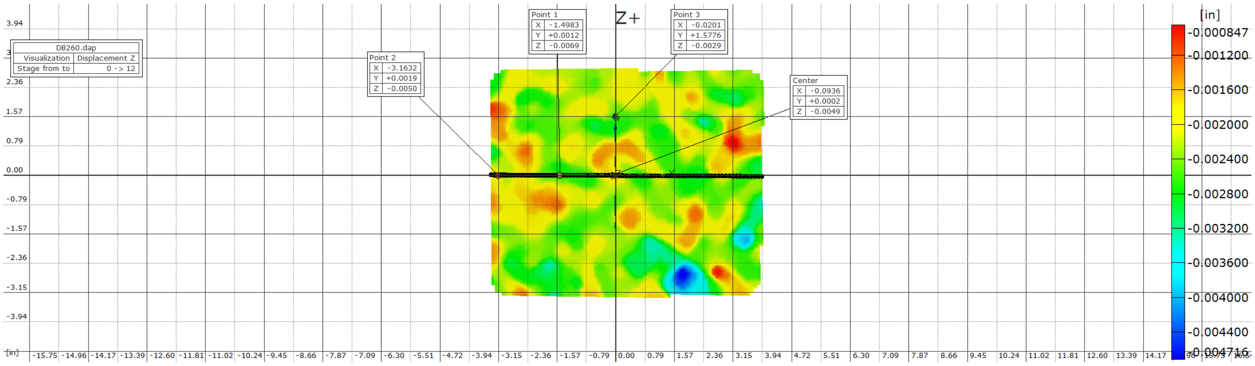


Figure C.108.—DB260 locations of digital image correlation (DIC) measurements.

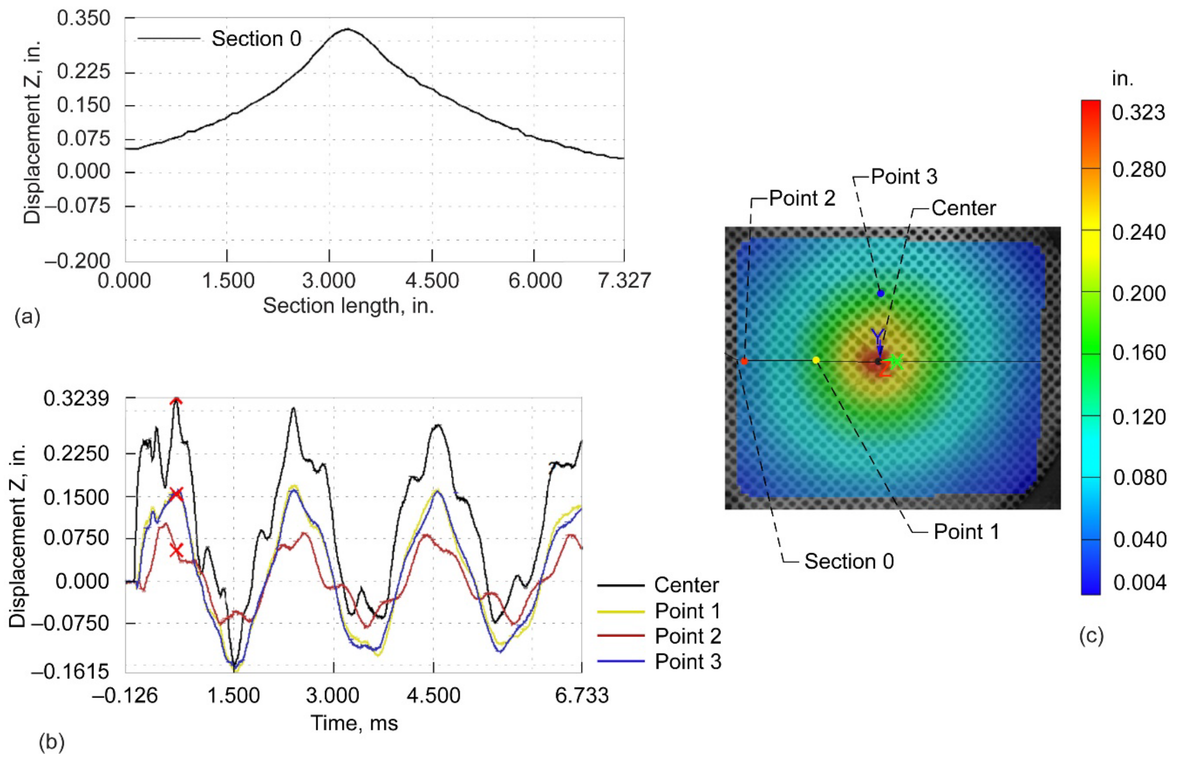


Figure C.109.—DB260 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.110.—DB260 posttest front view closeup.

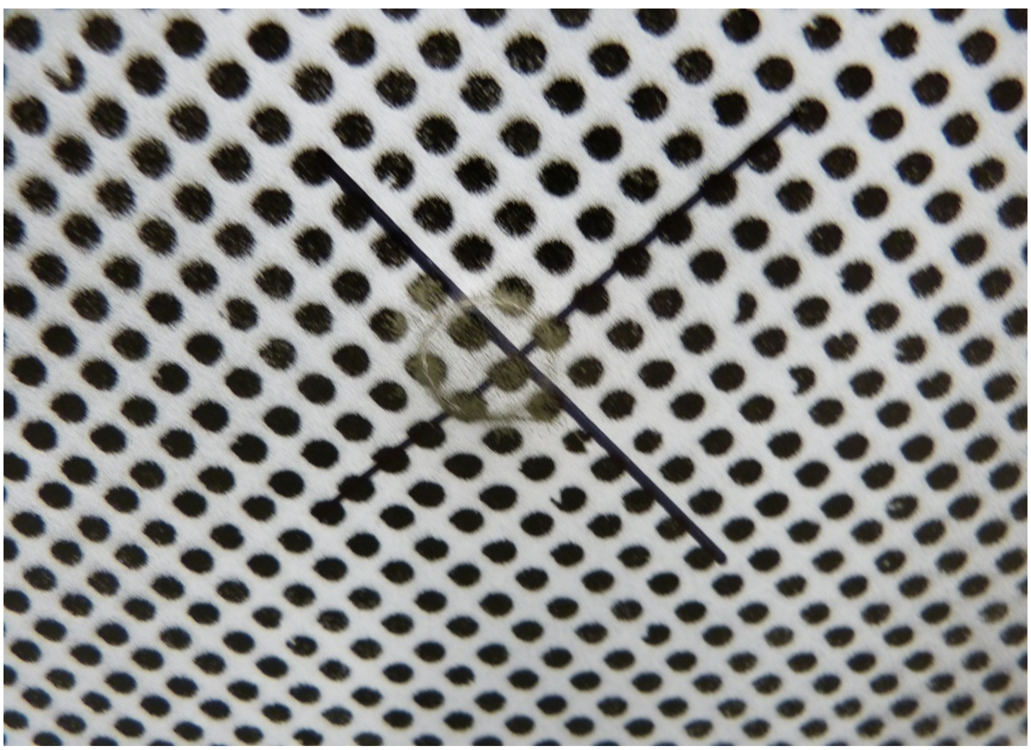


Figure C.111.—DB260 posttest rear view closeup.

### *Test DB261*

The DIC data was not obtained due to perferation of specimen.

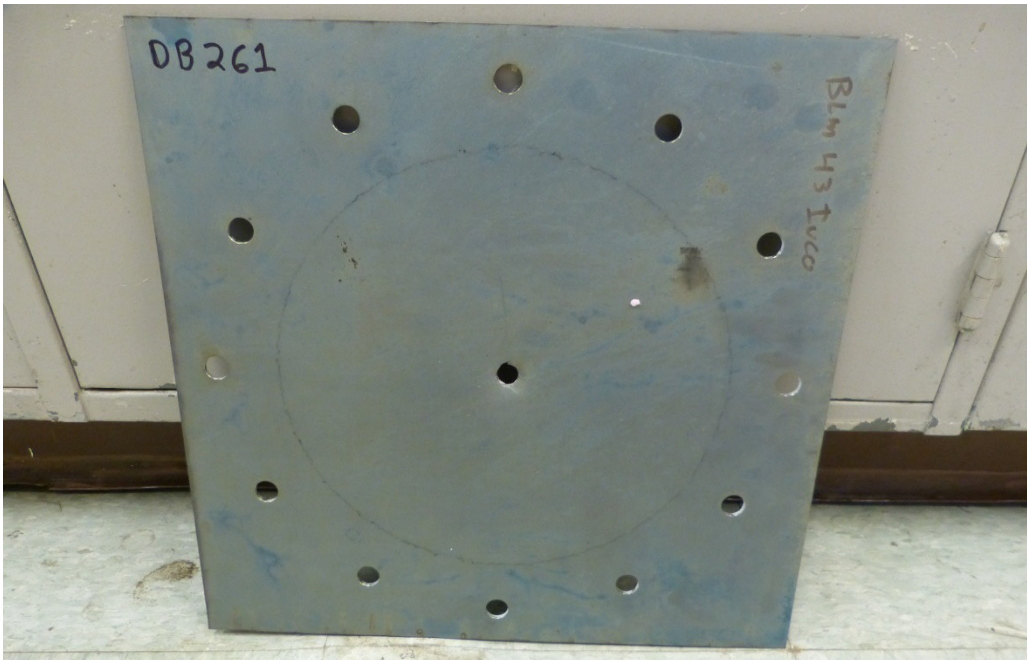



Figure C.112.—DB261 posttest front view.

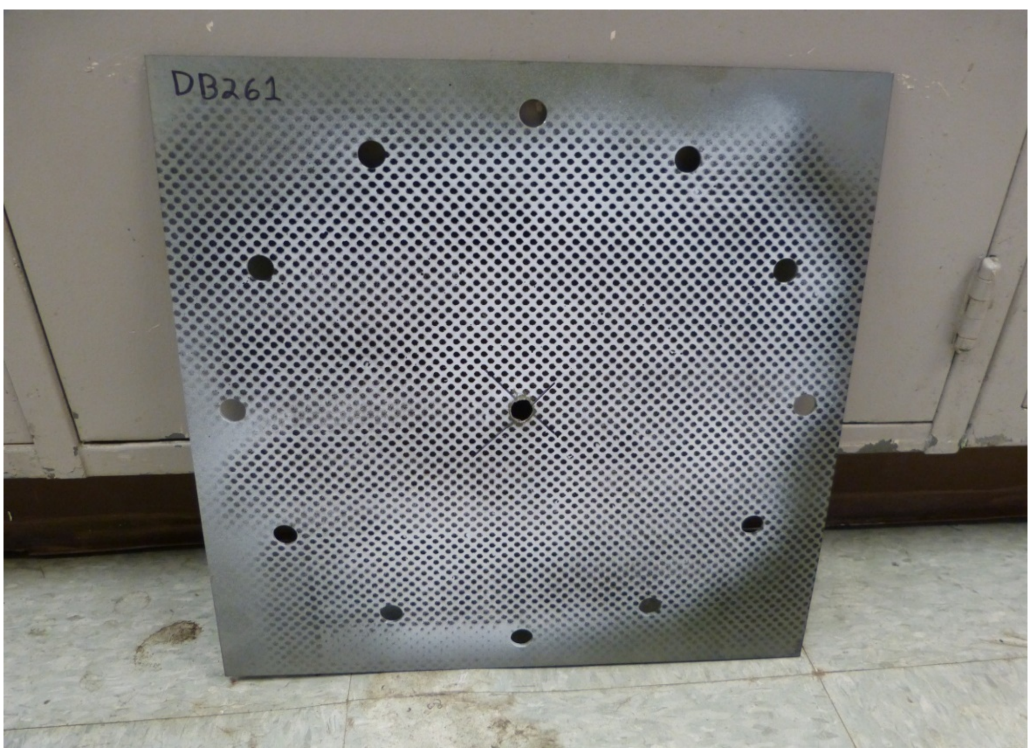



Figure C.113.—DB261 posttest rear view.

Figure C.114.—DB261 posttest front view closeup.

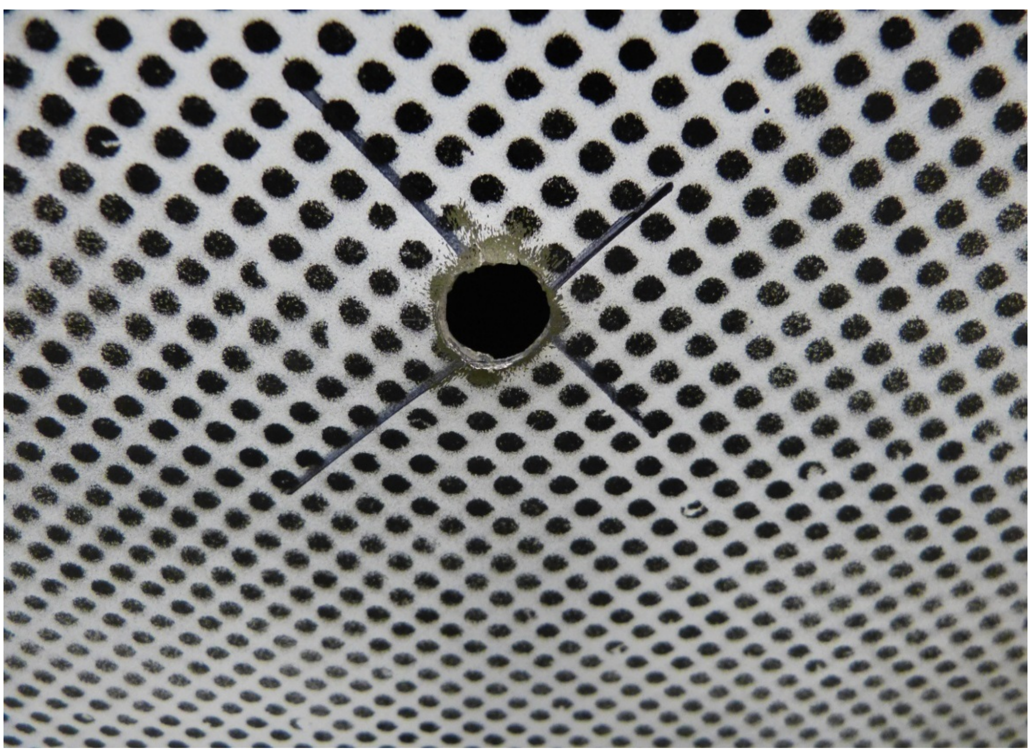


Figure C.115.—DB261 posttest rear view closeup.

### *Test DB262*

The DIC data was not obtained due to full penetration of projectile.


Figure C.116.—DB262 posttest front view.

Figure C.117.—DB262 posttest rear view.

Figure C.118.—DB262 posttest front view closeup.

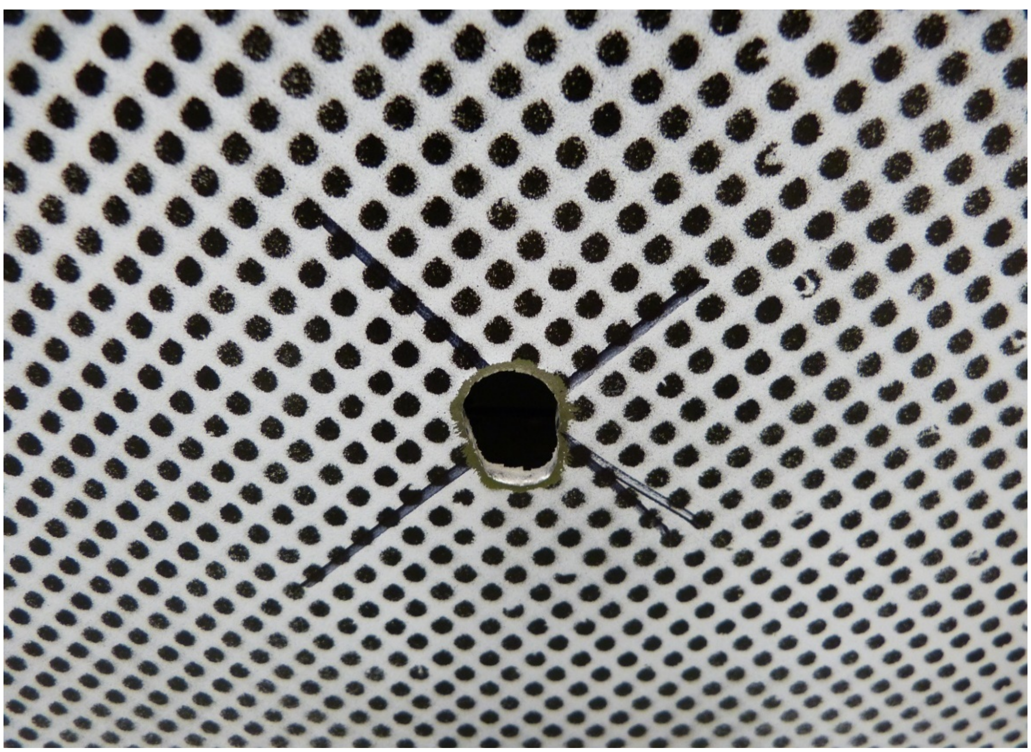


Figure C.119.—DB262 posttest rear view closeup.

### *Test DB263*

The DIC data was not obtained due to full penetration of projectile.


Figure C.120.—DB263 posttest front view.

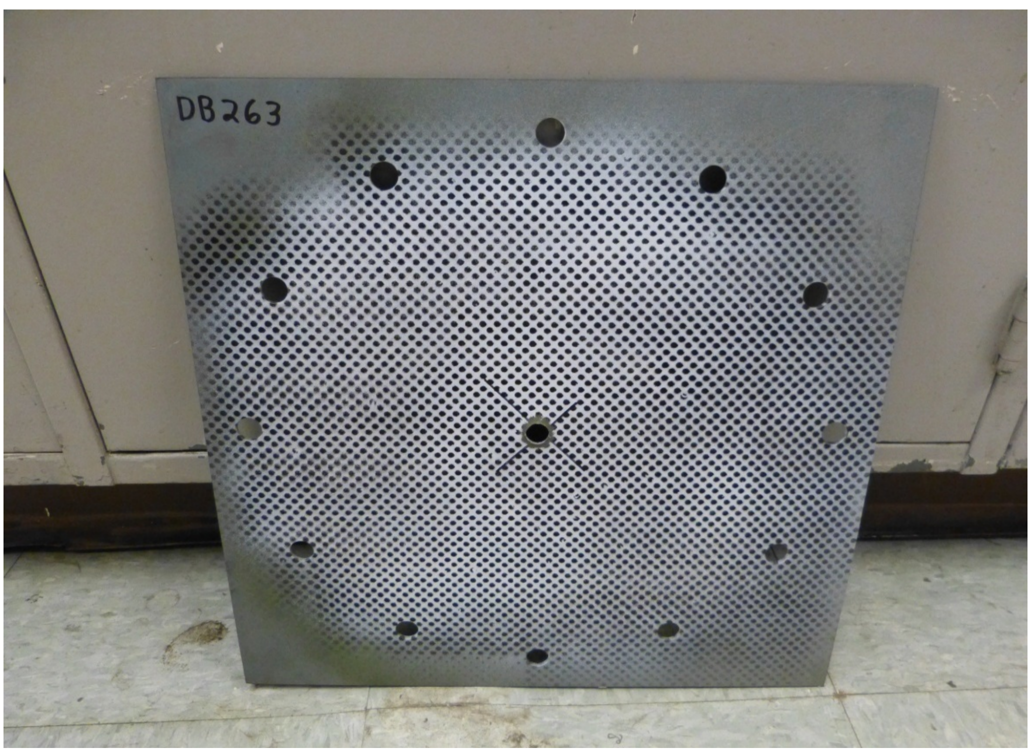



Figure C.121.—DB263 posttest rear view.

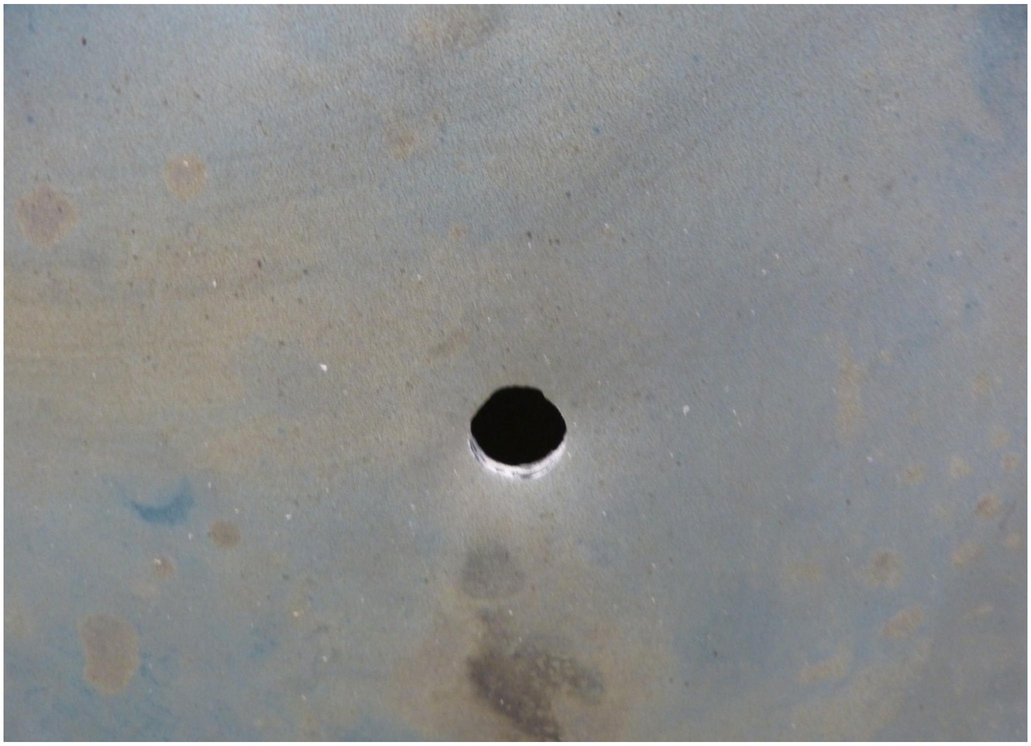


Figure C.122.—DB263 posttest front view closeup.

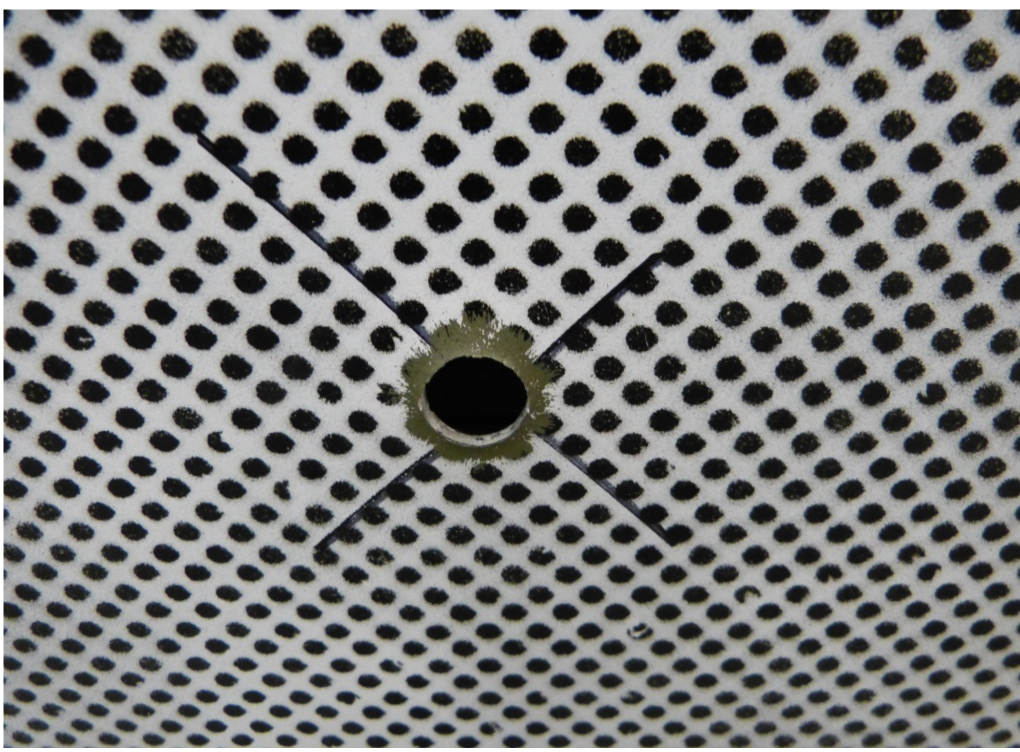


Figure C.123.—DB263 posttest rear view closeup.

### *Test DB264*

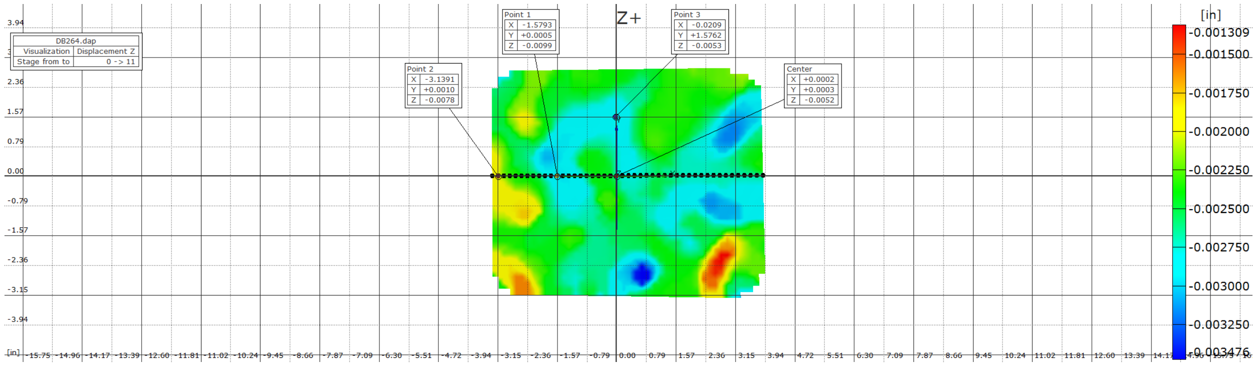


Figure C.124.—DB264 locations of digital image correlation (DIC) measurements.

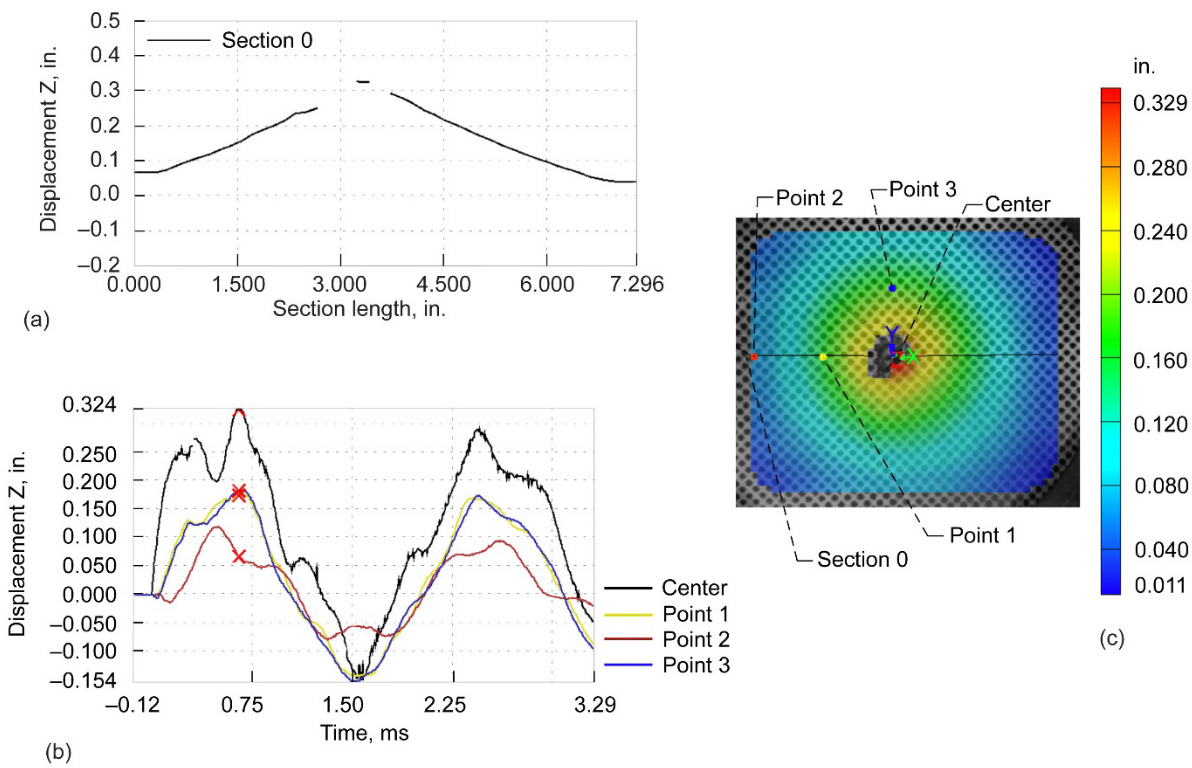



Figure C.125.—DB264 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.126.—DB264 posttest front view closeup.

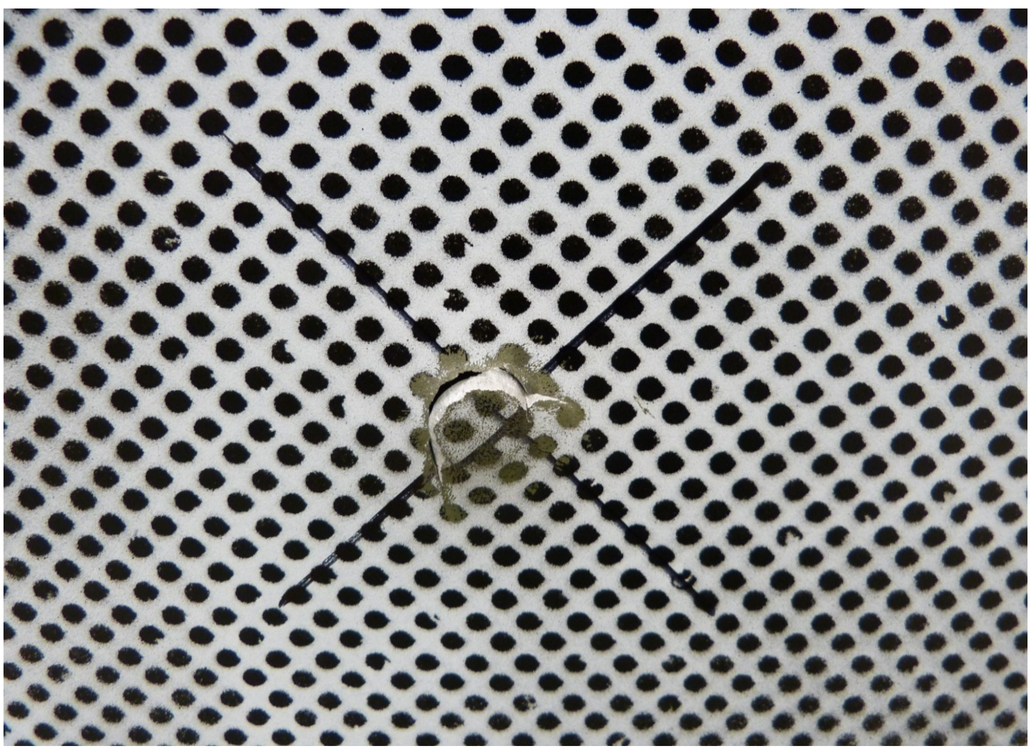


Figure C.127.—DB264 posttest rear view closeup.

### *Test DB265*

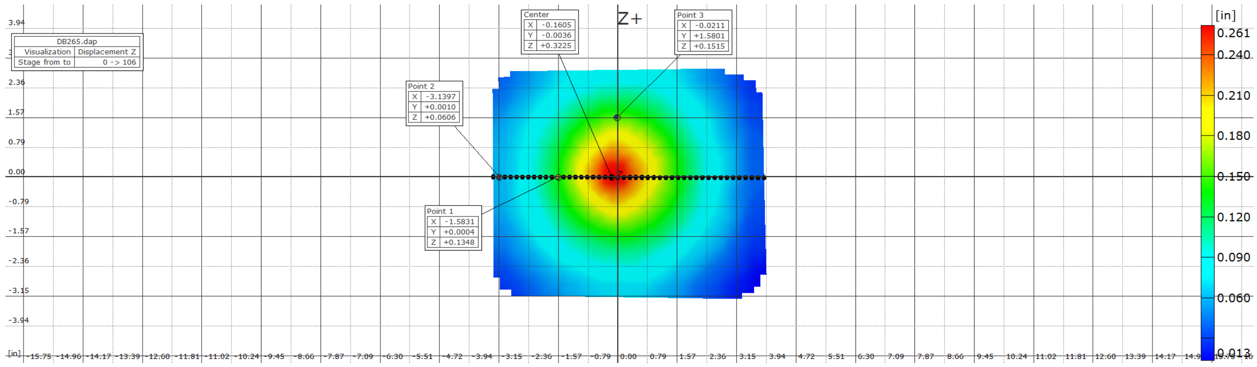


Figure C.128.—DB265 locations of digital image correlation (DIC) measurements.

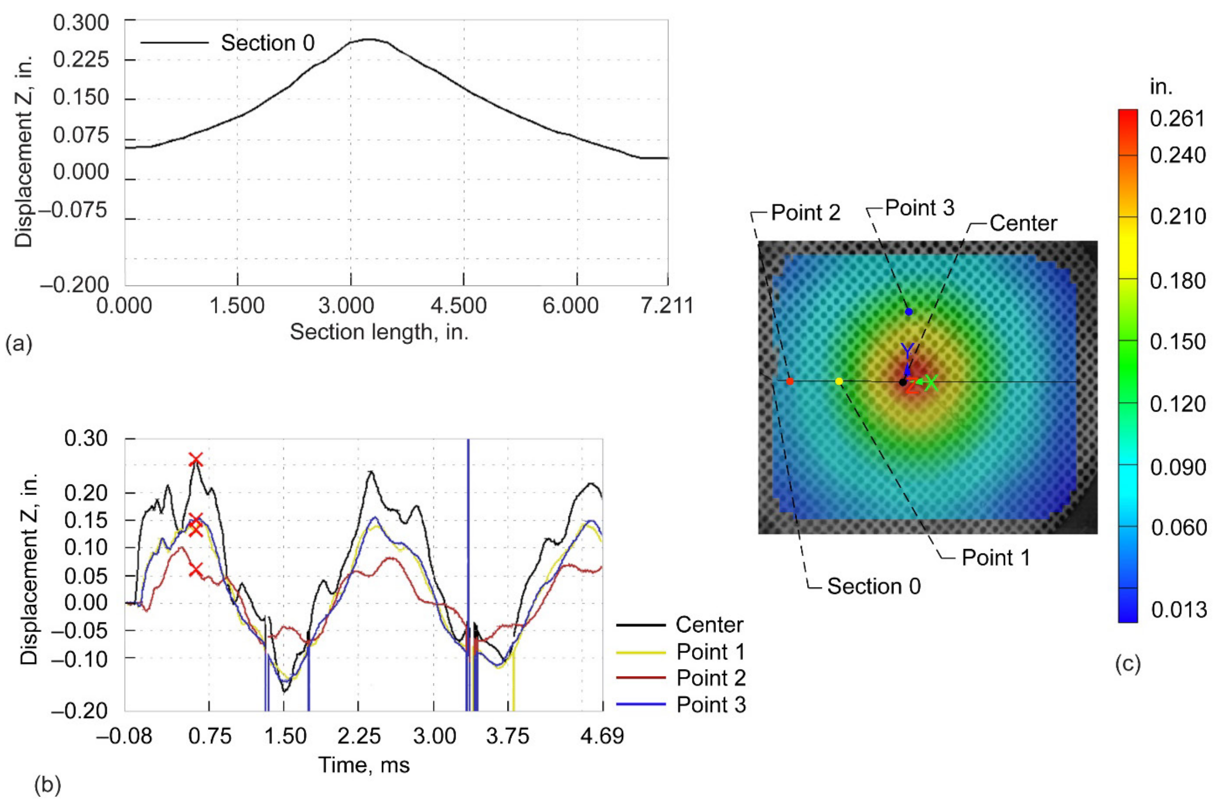



Figure C.129.—DB265 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.130.—DB265 posttest front view closeup.

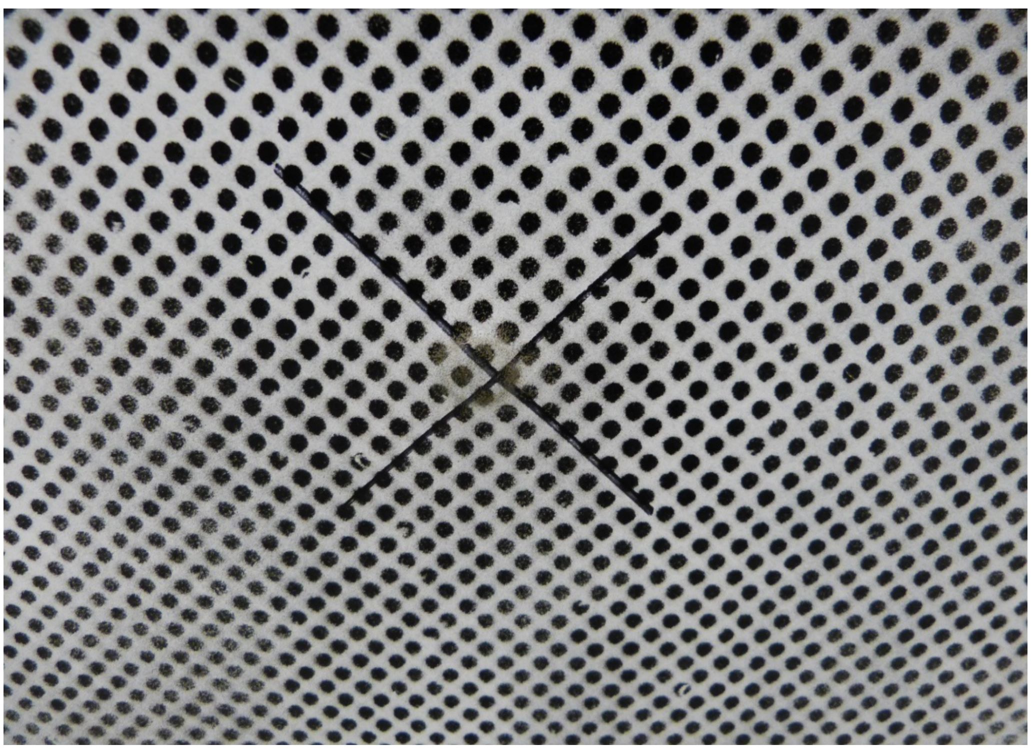


Figure C.131.—DB265 posttest rear view closeup.

*Test DB266*

The DIC data was not obtained due to full penetration of projectile.

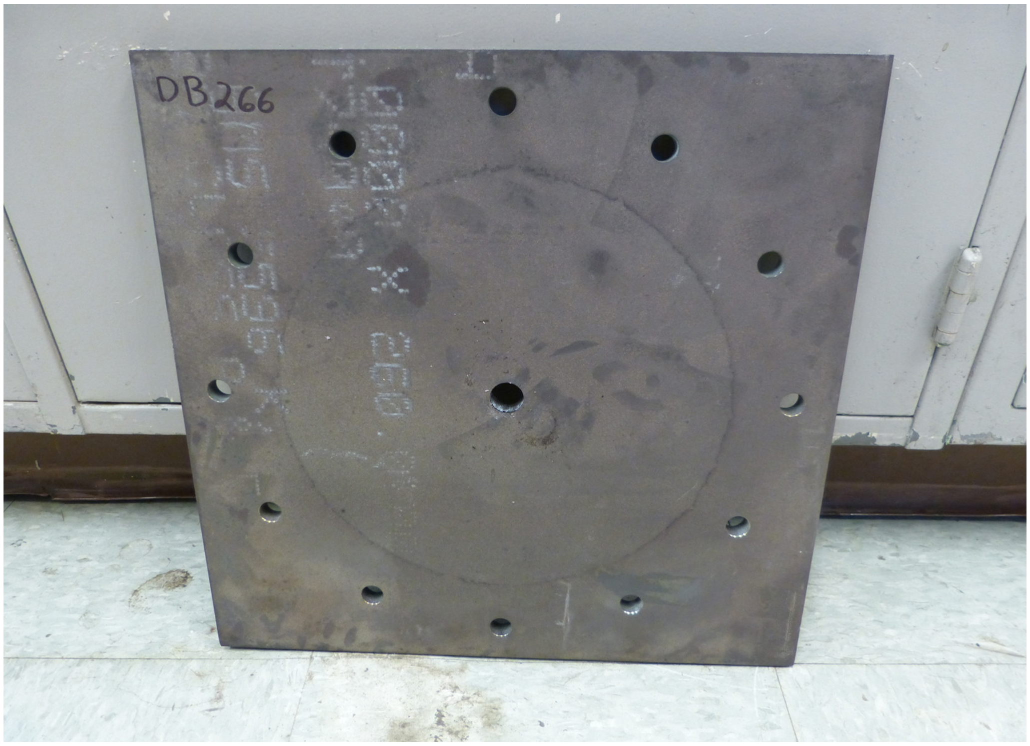



Figure C.132.—DB266 posttest front view.

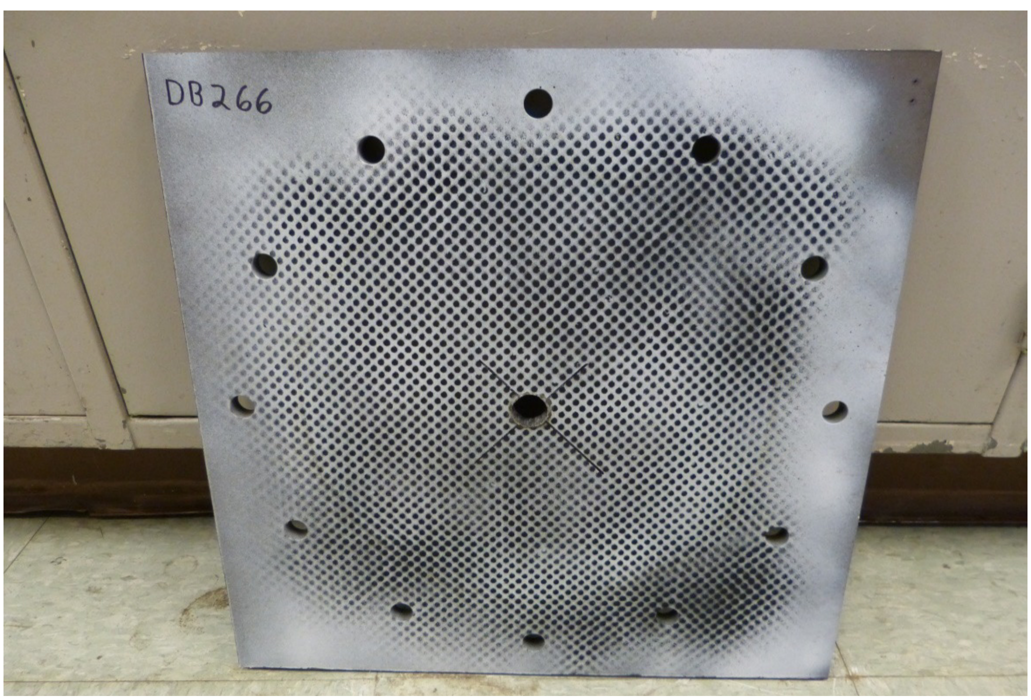



Figure C.133.—DB266 posttest rear view.

Figure C.134.—DB266 posttest front view closeup.

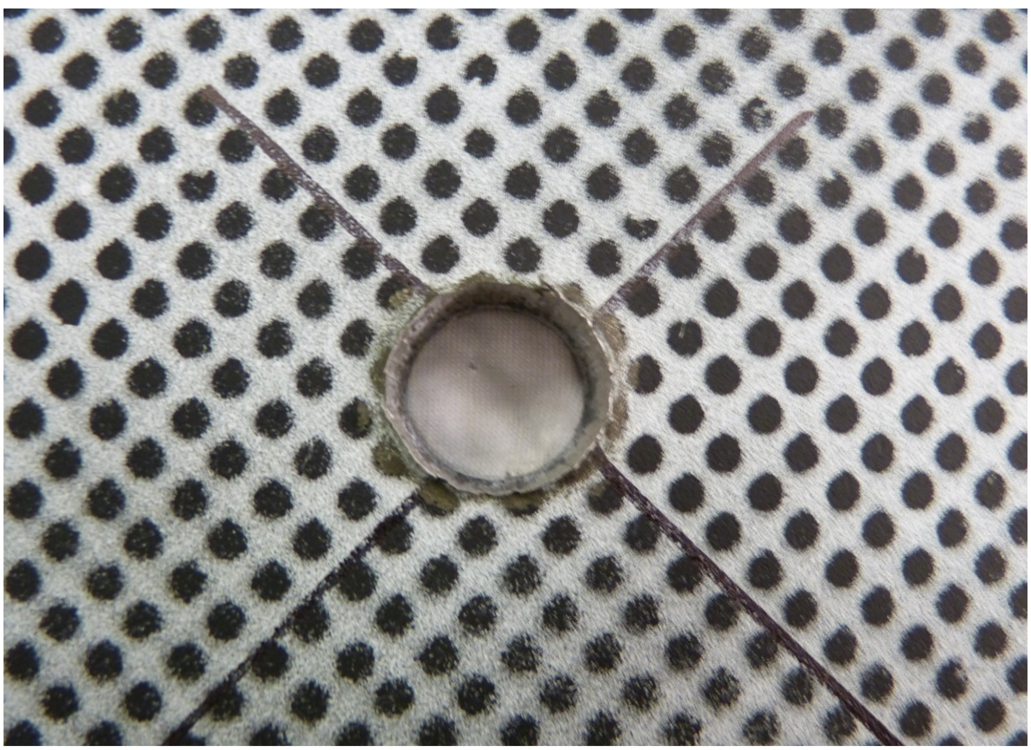


Figure C.135.—DB266 posttest rear view closeup.

*Test DB267*

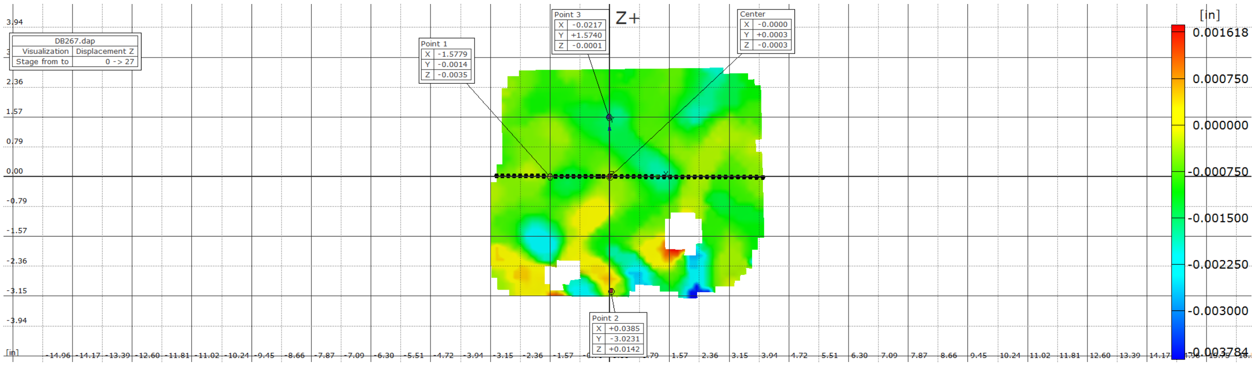


Figure C.136.—DB267 locations of digital image correlation (DIC) measurements.

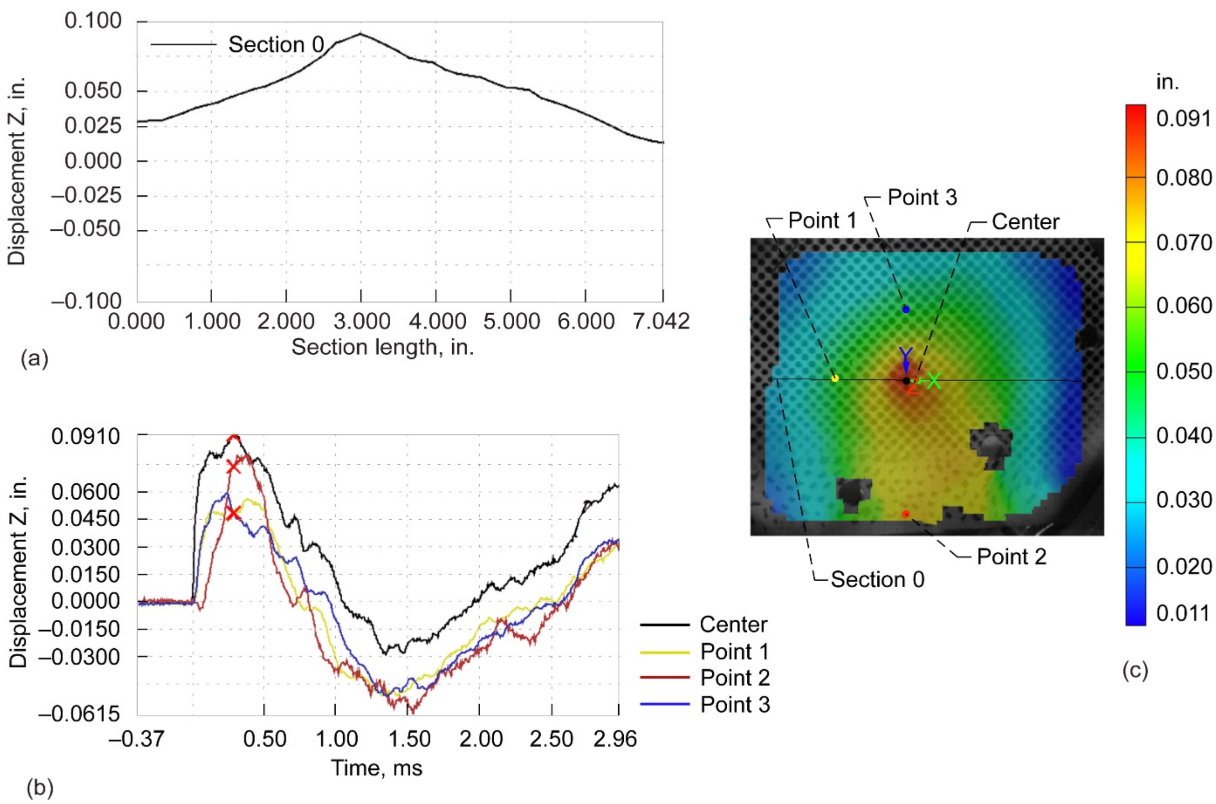



Figure C.137.—DB267 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.138.—DB267 posttest front view closeup.

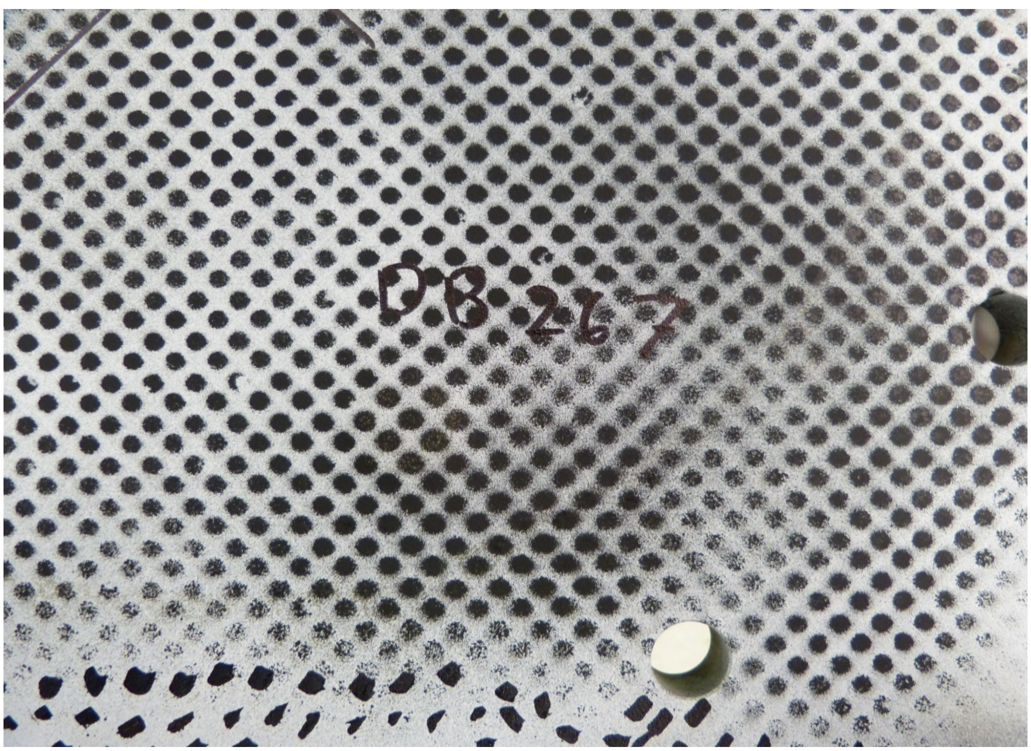


Figure C.139.—DB267 posttest rear view closeup.

## *Test DB268*

The DIC data was not obtained due to full penetration of projectile.

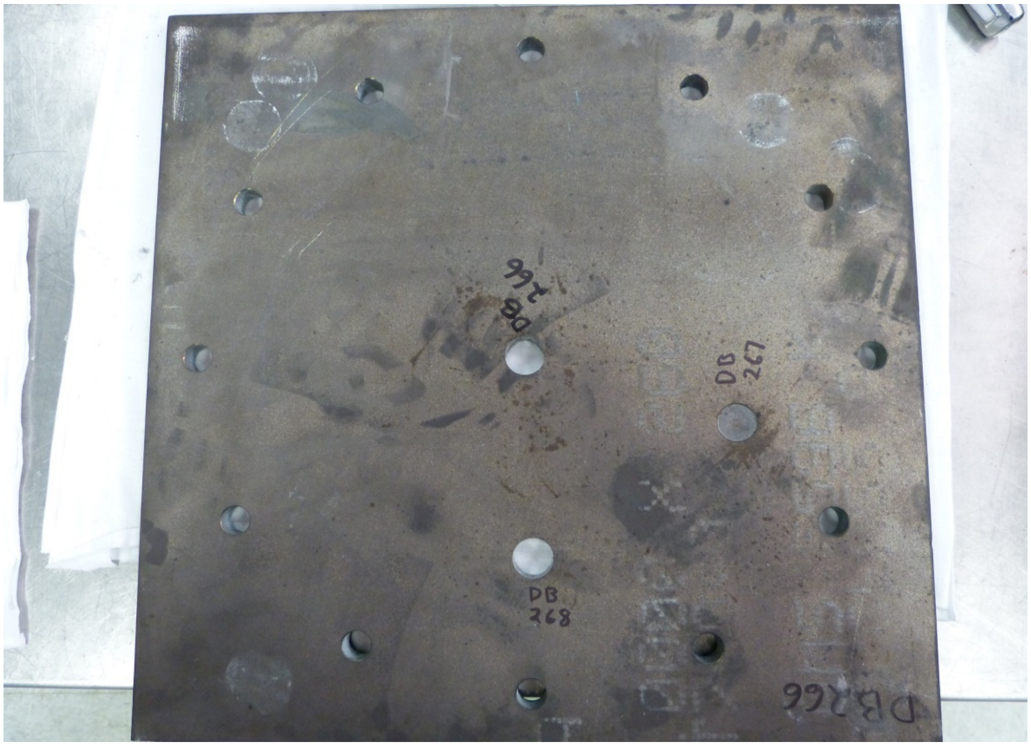



Figure C.140.—DB268 posttest front view.

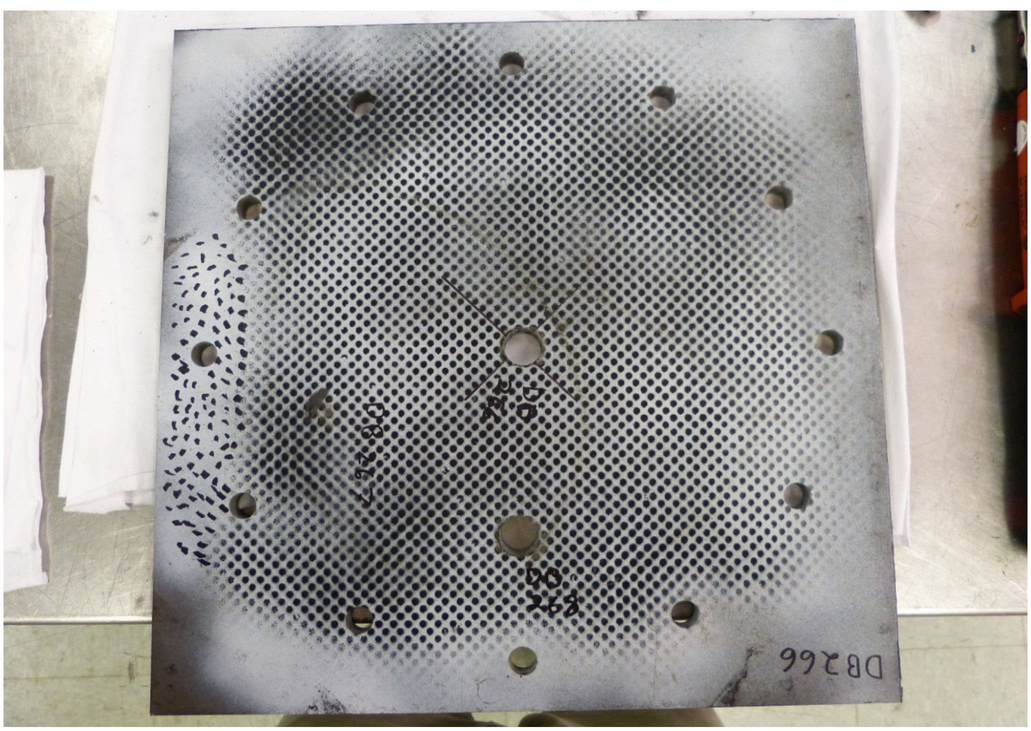


Figure C.141.—DB268 posttest rear view.

Figure C.142.—DB268 posttest front view closeup.


Figure C.143.—DB268 posttest rear view closeup.

### *Test DB269*

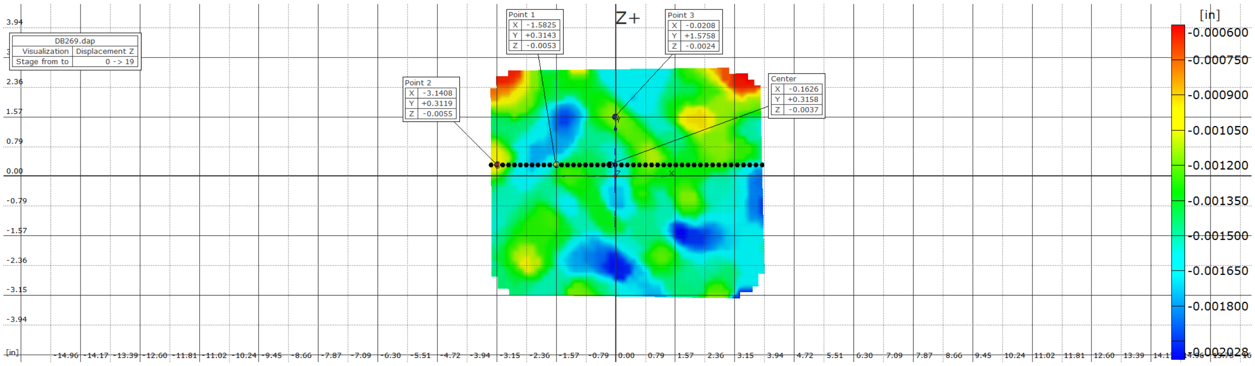


Figure C.144.—DB269 locations of digital image correlation (DIC) measurements.

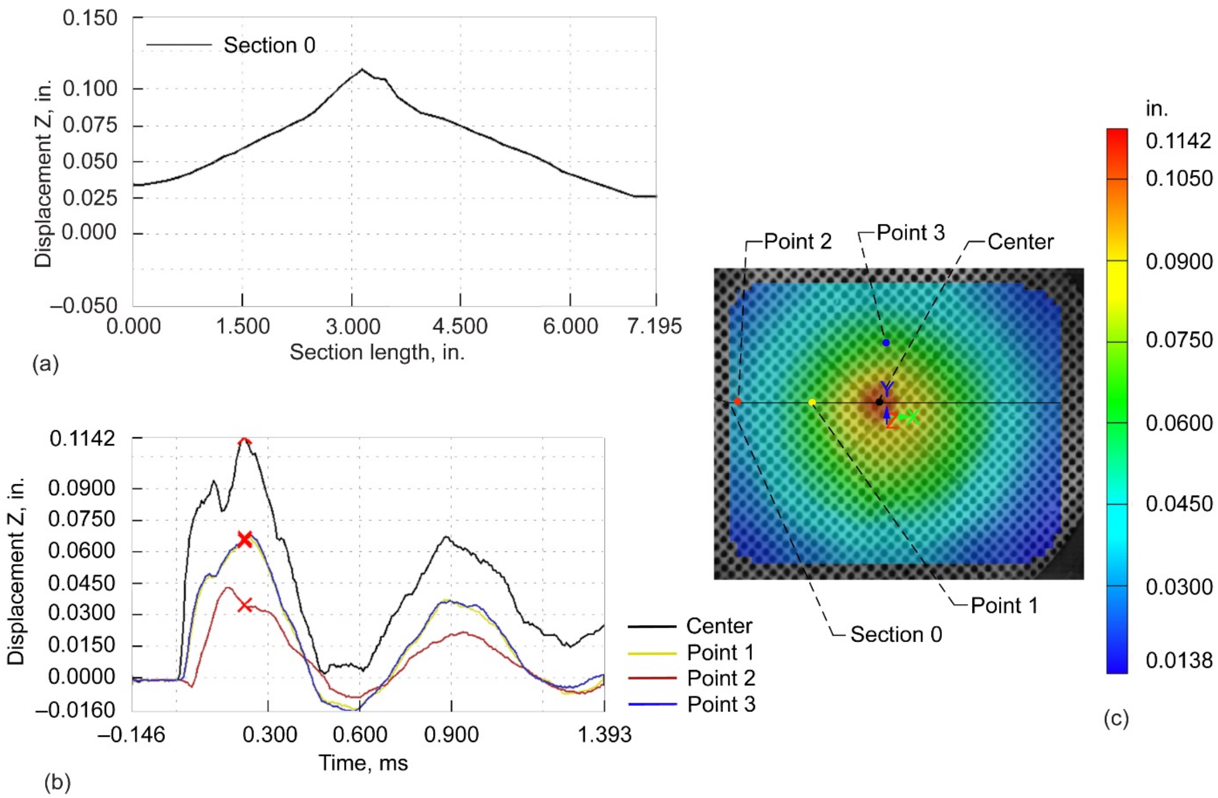



Figure C.145.—DB269 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.146.—DB269 posttest front view closeup.

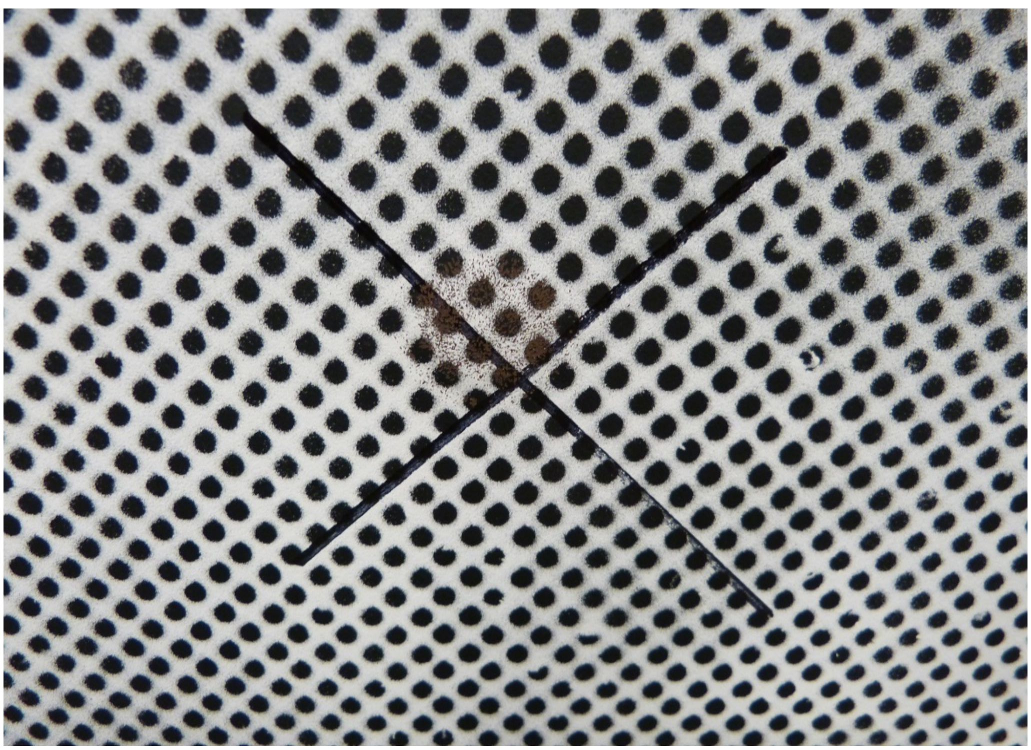


Figure C.147.—DB269 posttest rear view closeup.

## *Test DB270*

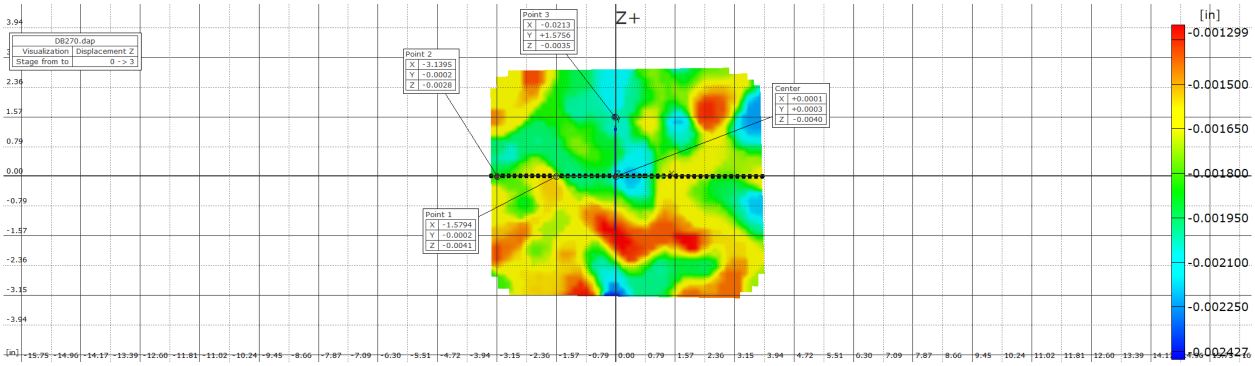


Figure C.148.—DB270 locations of digital image correlation (DIC) measurements.

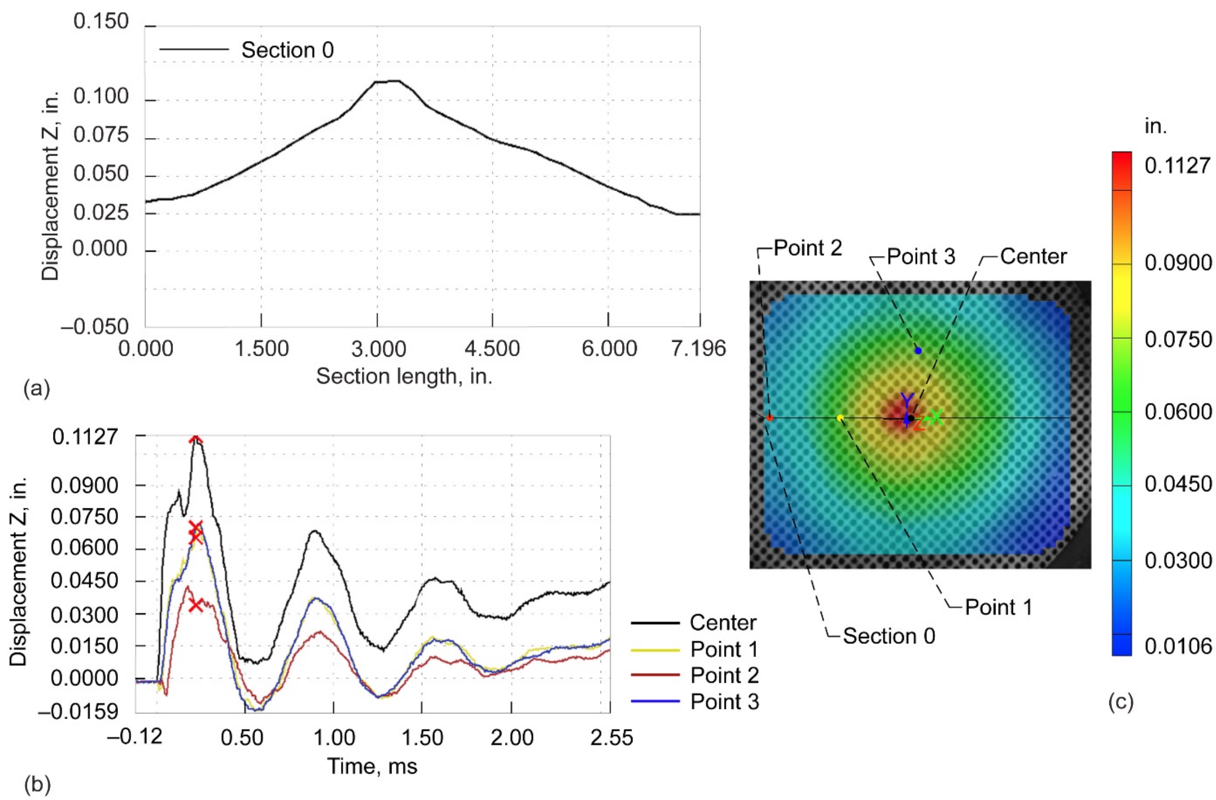



Figure C.149.—DB270 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.150.—DB270 posttest front view closeup.

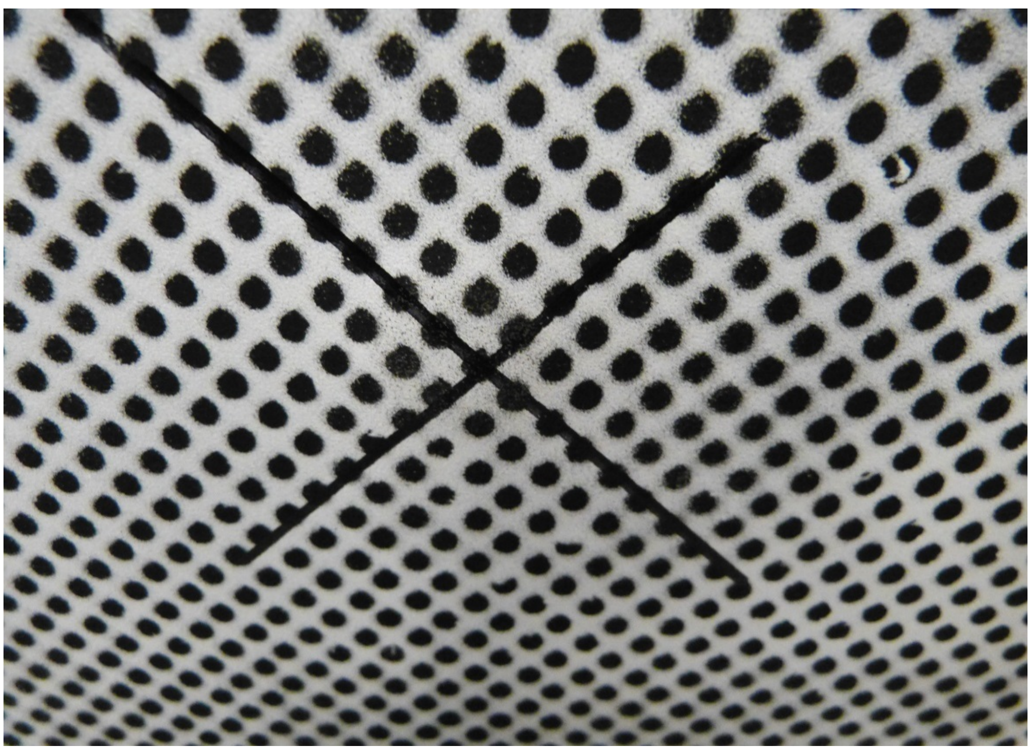


Figure C.151.—DB270 posttest rear view closeup.

### *Test DB271*

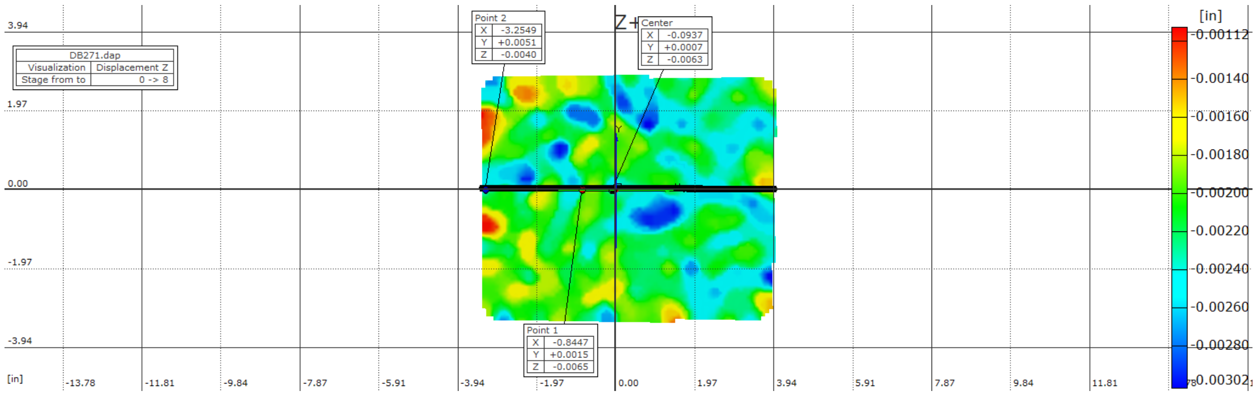



Figure C.152.—DB271 locations of digital image correlation (DIC) measurements.

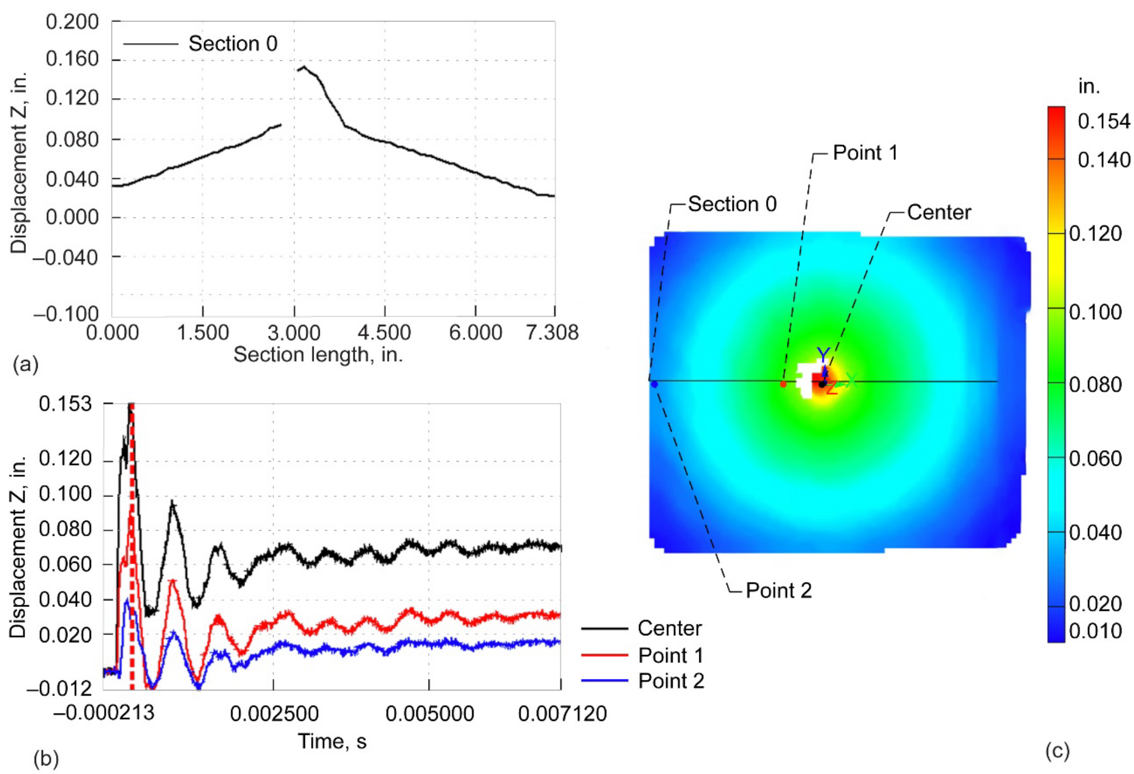



Figure C.153.—DB271 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.154.—DB271 posttest front view closeup.

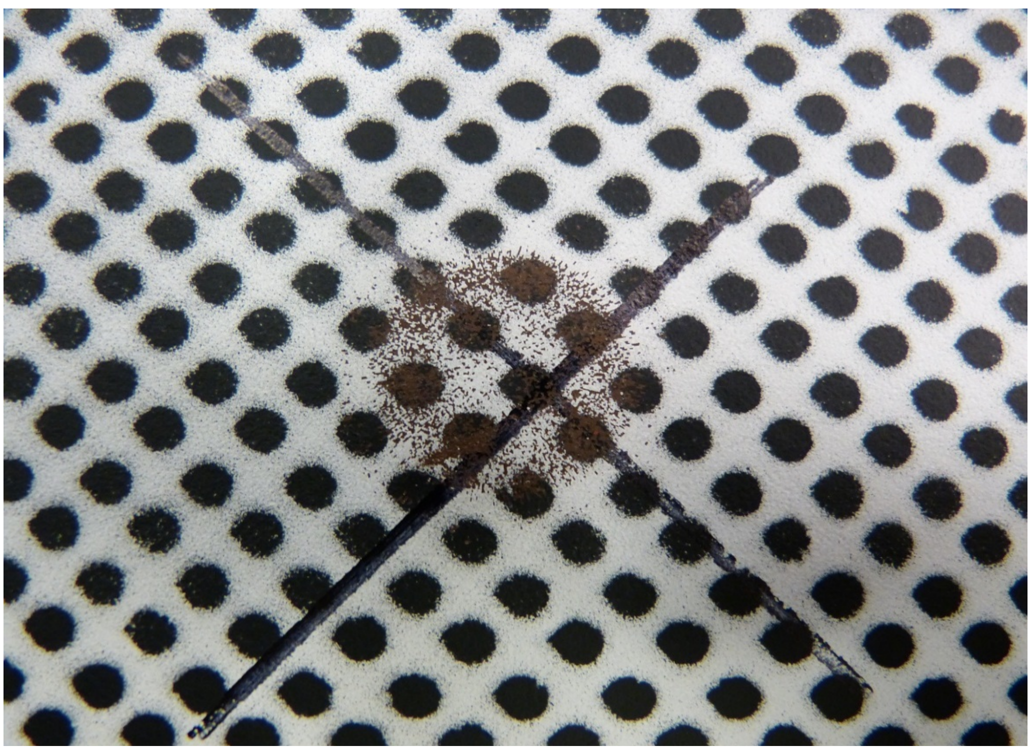


Figure C.155.—DB271 posttest rear view closeup.

### *Test DB272*

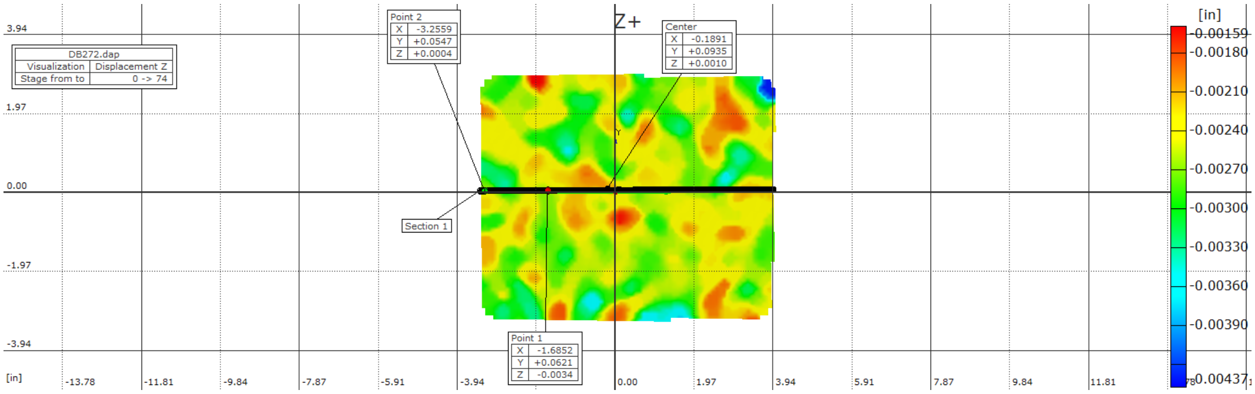


Figure C.156.—DB272 locations of digital image correlation (DIC) measurements.

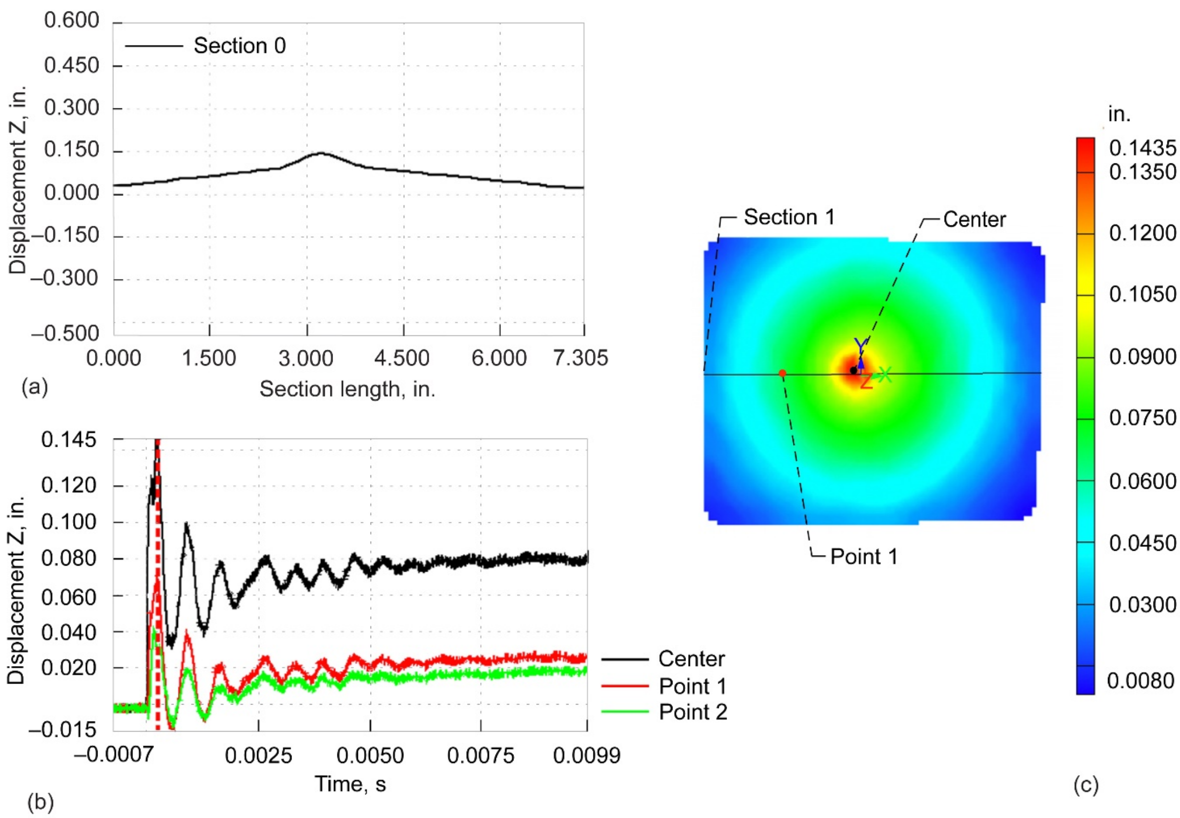


Figure C.157.—DB272 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Figure C.158.—DB272 posttest front view closeup.

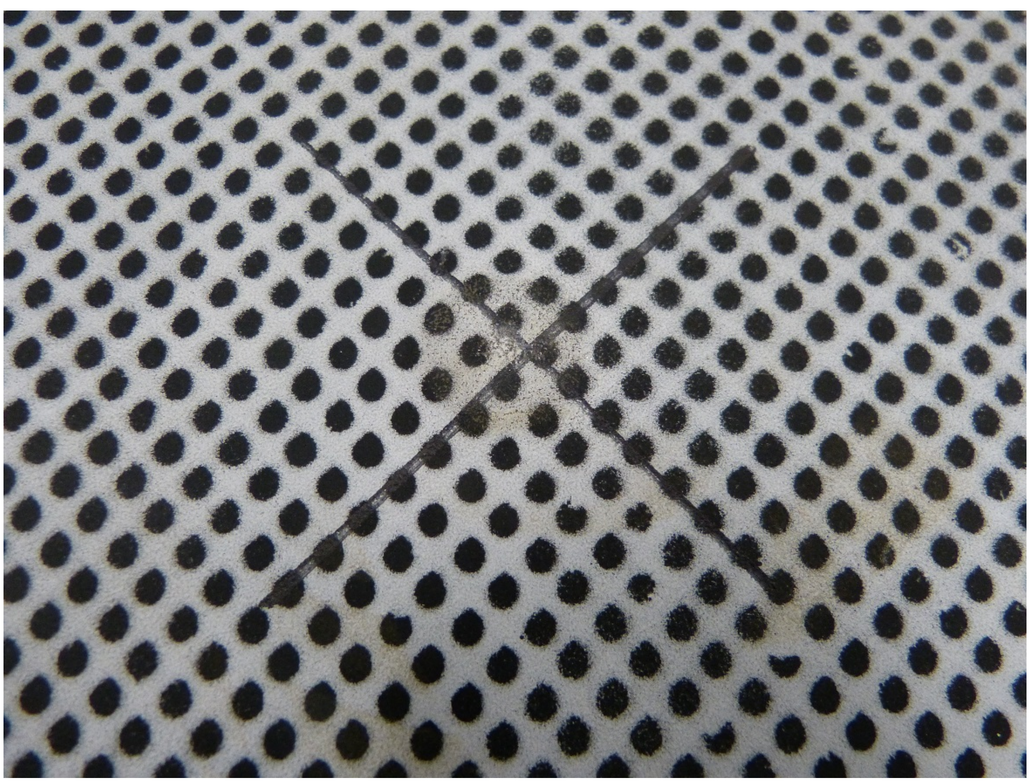


Figure C.159.—DB272 posttest rear view closeup.

# Appendix D.—Large Panel Test Results

This section shows photographs of test specimens and digital image correlation (DIC) results for each of the large panel tests conducted. In certain tests, where there was full penetration, no DIC results are shown.

### *Test LG1110*

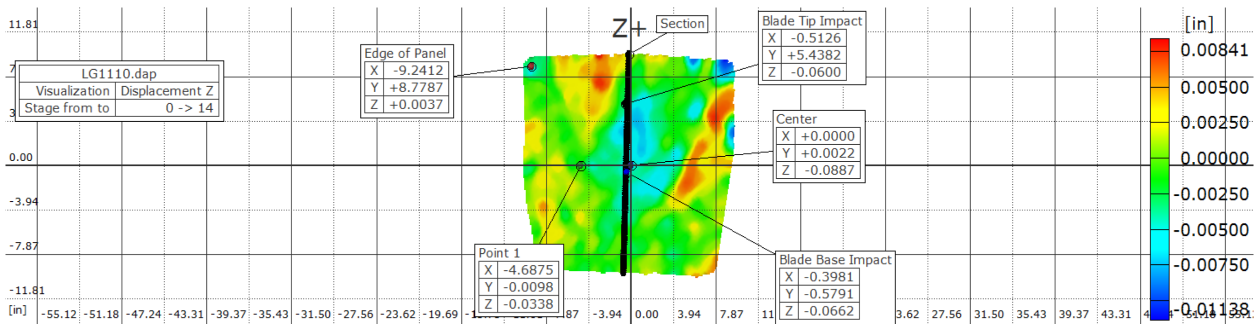



Figure D.1.—LG1110 locations of digital image correlation (DIC) measurements.

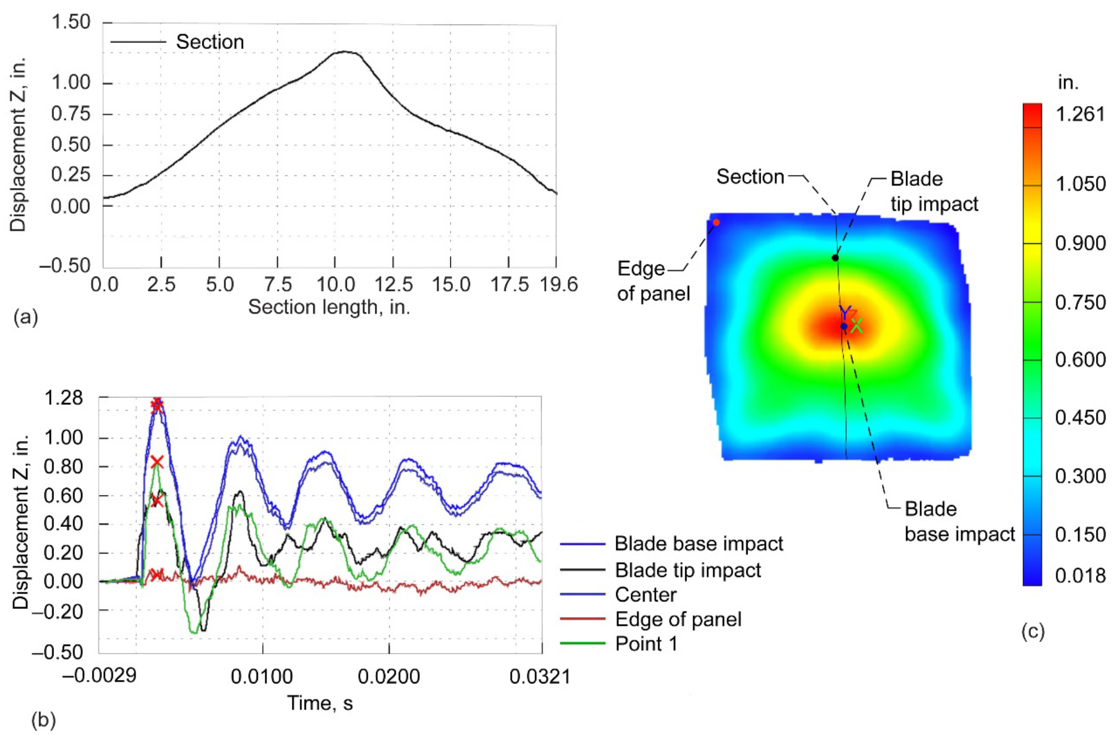



Figure D.2.—LG1110 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.


Figure D.3.—LG1110 posttest front view.

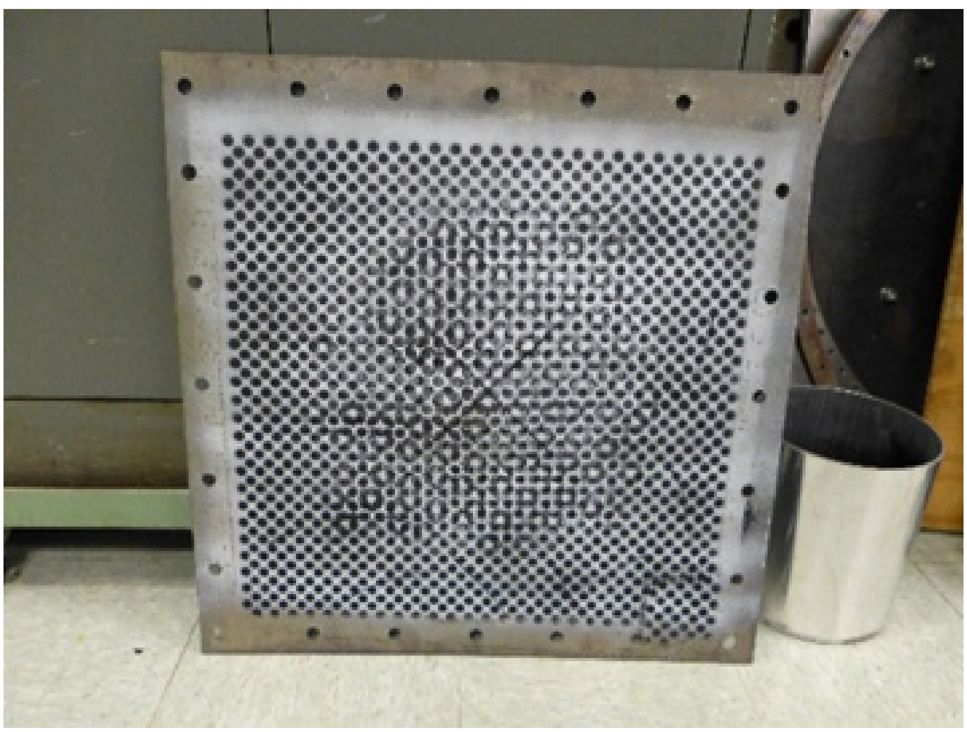


Figure D.4.—LG1110 posttest rear view.

Figure D.5.—LG1110 posttest projectile top view.



Figure D.6.—LG1110 posttest projectile bottom view.

### *Test LG1111*

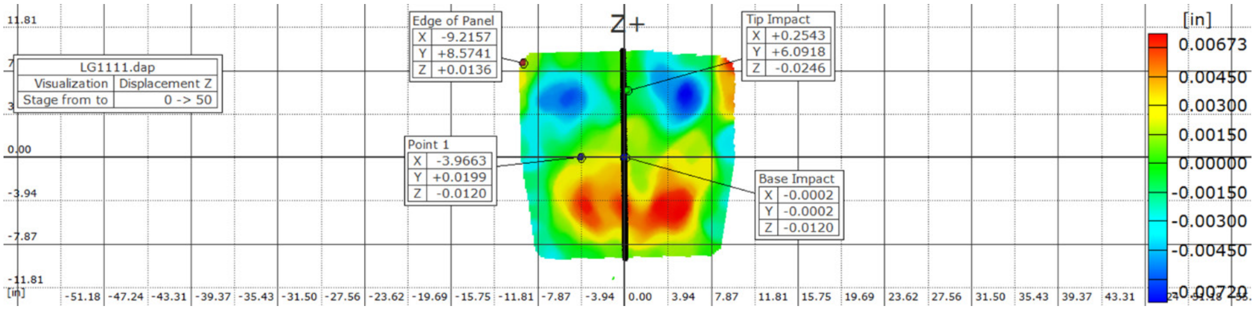



Figure D.7.—LG1111 locations of digital image correlation (DIC) measurements.

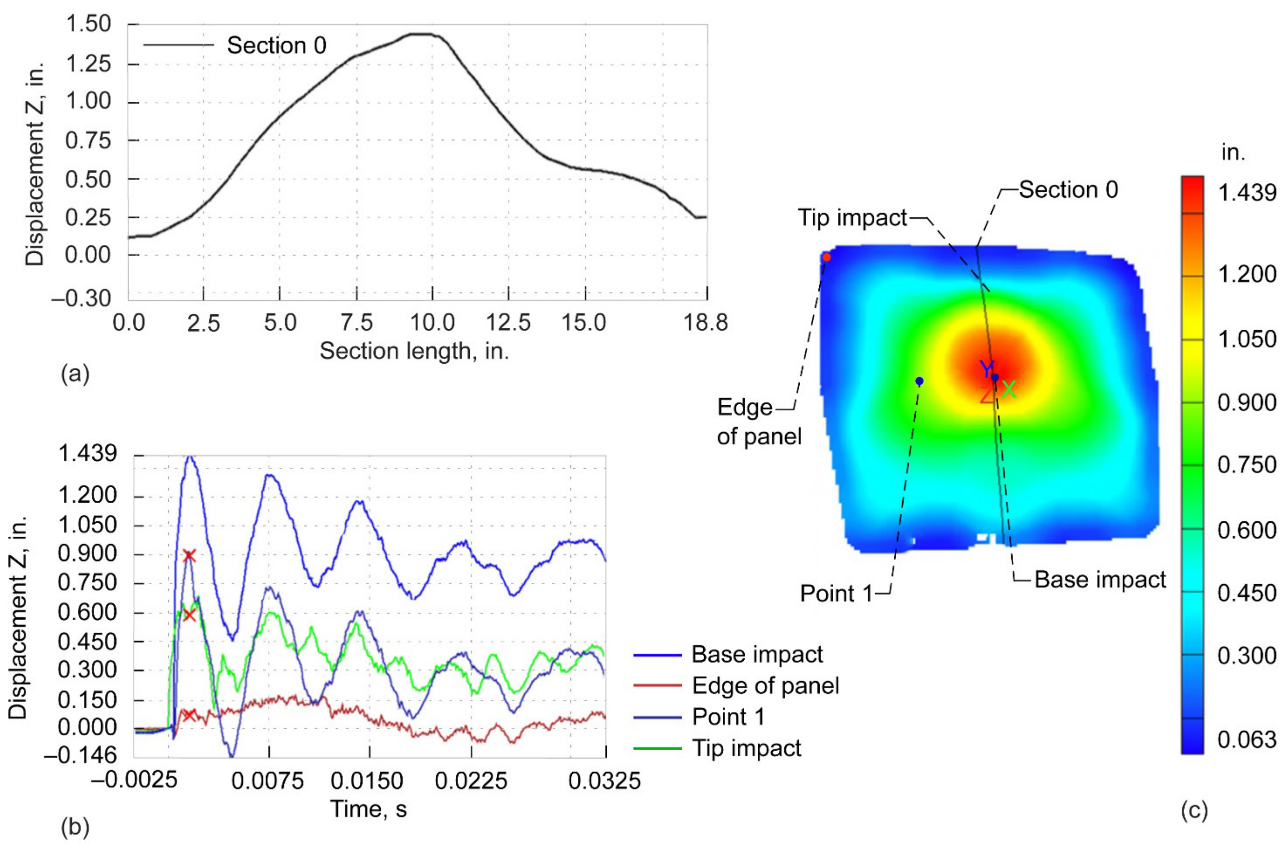



Figure D.8.—LG1111 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

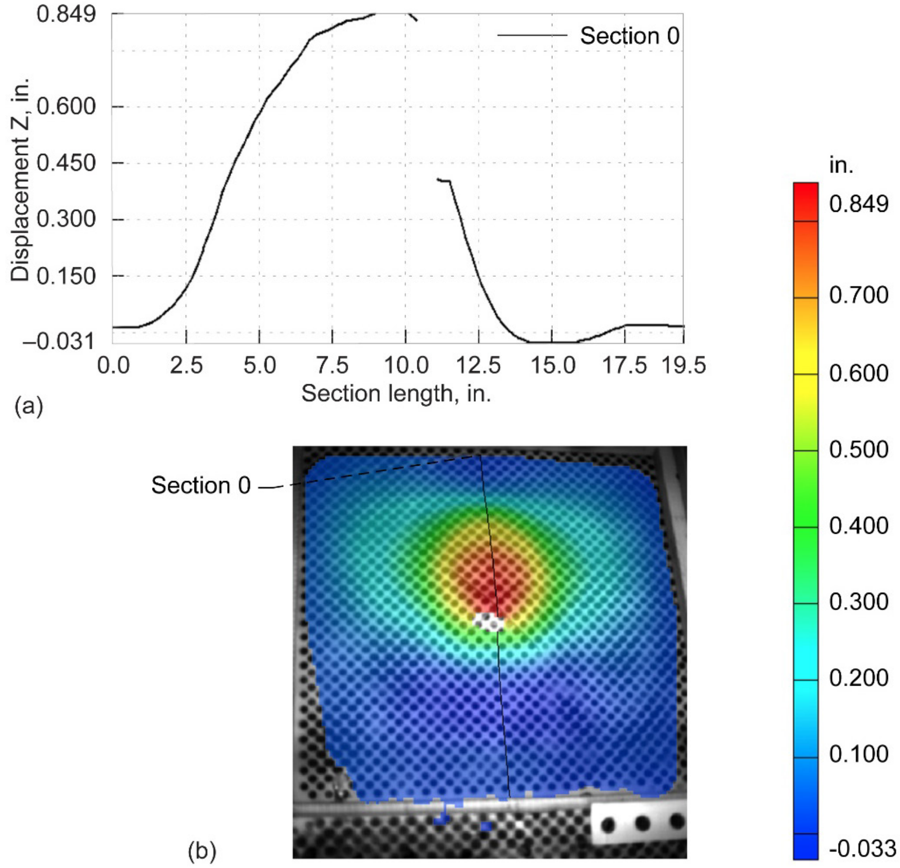



Figure D.9.—LG1111 posttest displacements (a) Diplacement versus length. (b) Displacement Z.

Figure D.10.—LG1111 posttest front view.

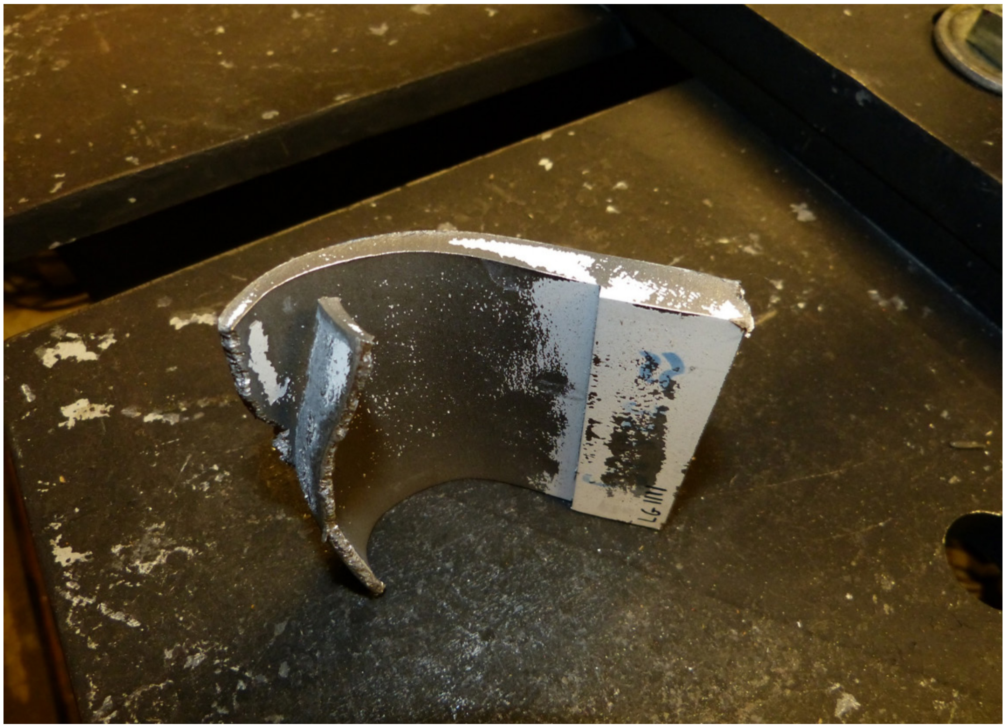


Figure D.11.—LG1111 posttest projectile bottom view.

Figure D.12.—LG1111 posttest projectile side view.

### *Test LG1113*

The DIC data was not obtained due to full penetration of projectile.

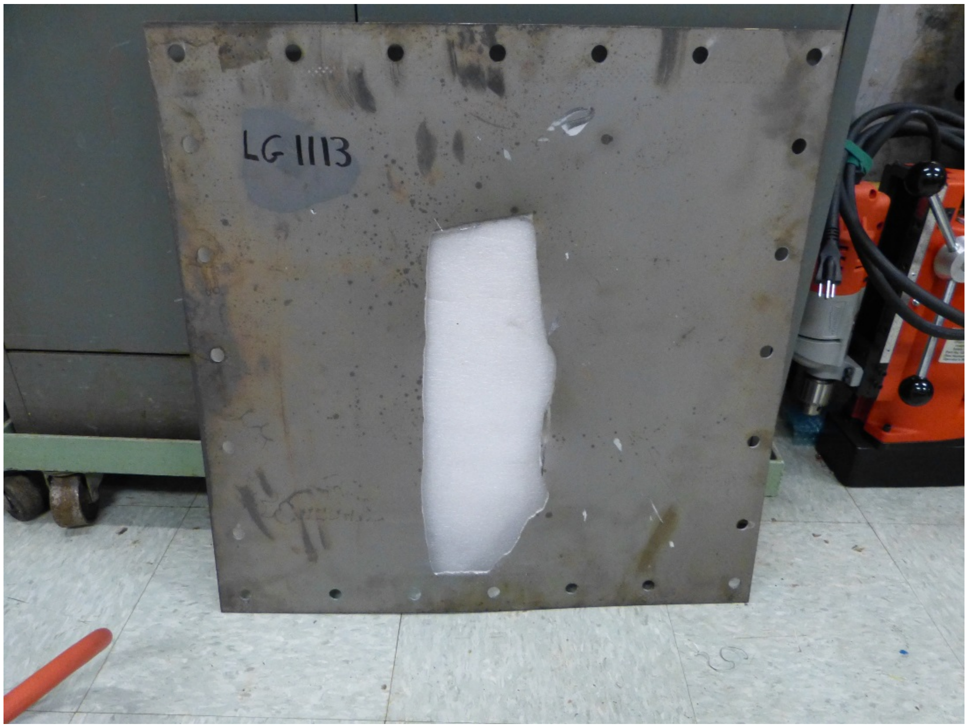



Figure D.13.—LG1113 posttest front view.

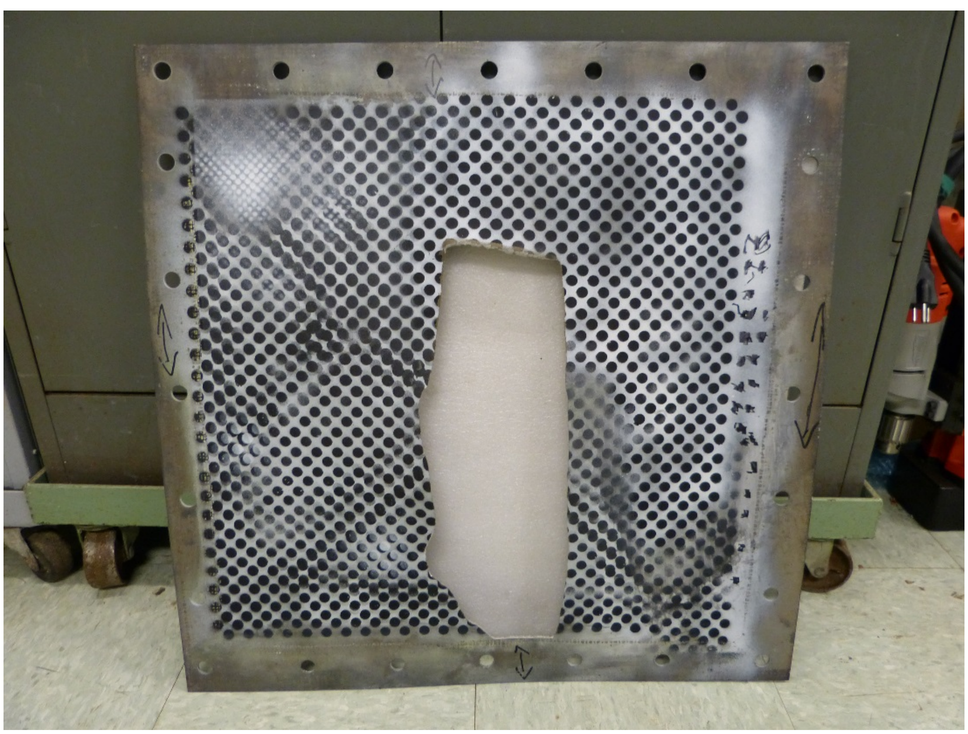


Figure D.14.—LG1113 posttest rear view.

Figure D.15.—LG1113 ejected material from panel.

Figure D.16.—LG1113 posttest projectile.

### *Test LG1114*

The DIC data was not obtained due to full penetration of projectile.


Figure D.17.—LG1114 posttest front view.

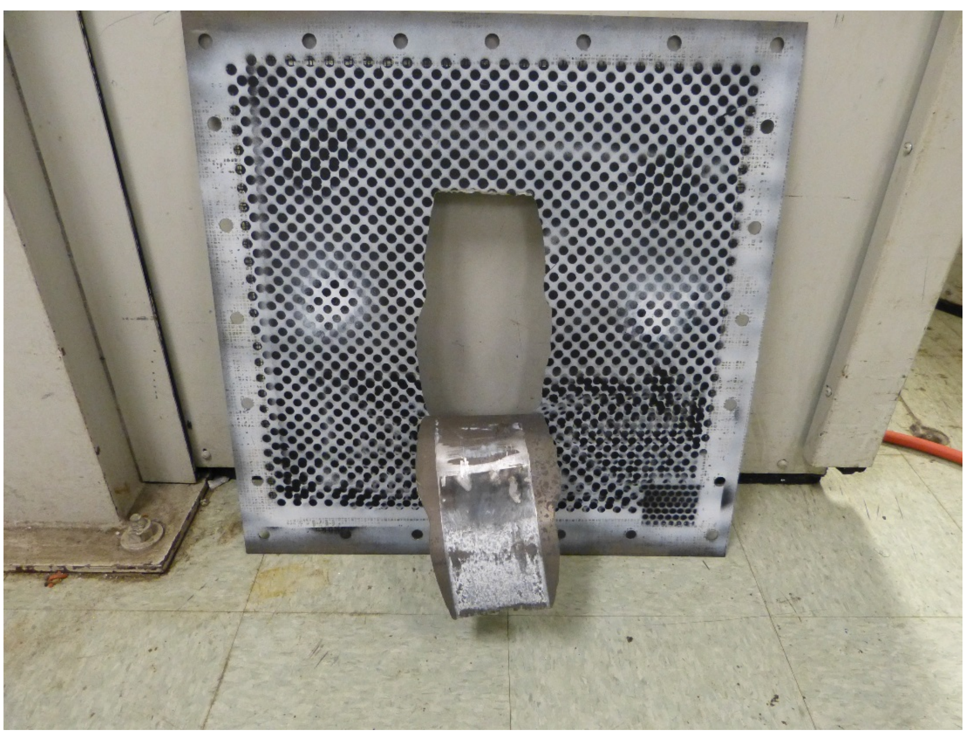


Figure D.18.—LG1114 posttest rear view.

Figure D.19.—LG1114 posttest projectile.

### *Test LG1115*

No DIC data available due to improper impact location.


Figure D.20.—LG1115 posttest front view.

Figure D.21.—LG1115 posttest rear view.

Figure D.22.—LG1115 posttest projectile.

## *Test LG1116*

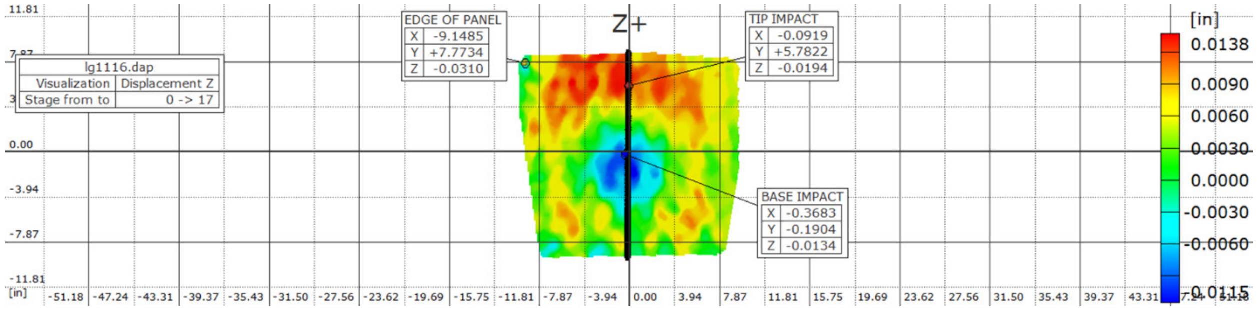


Figure D.23.—LG1116 locations of digital image correlation (DIC) measurements.

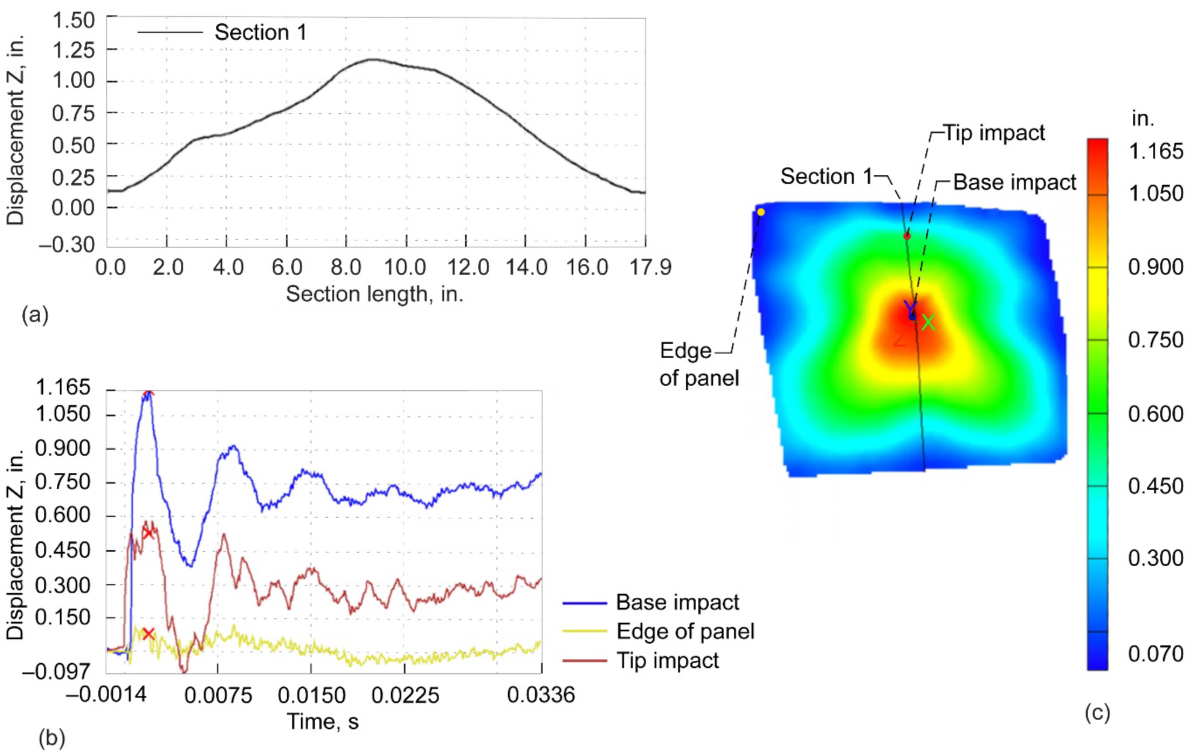



Figure D.24.—LG1116 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

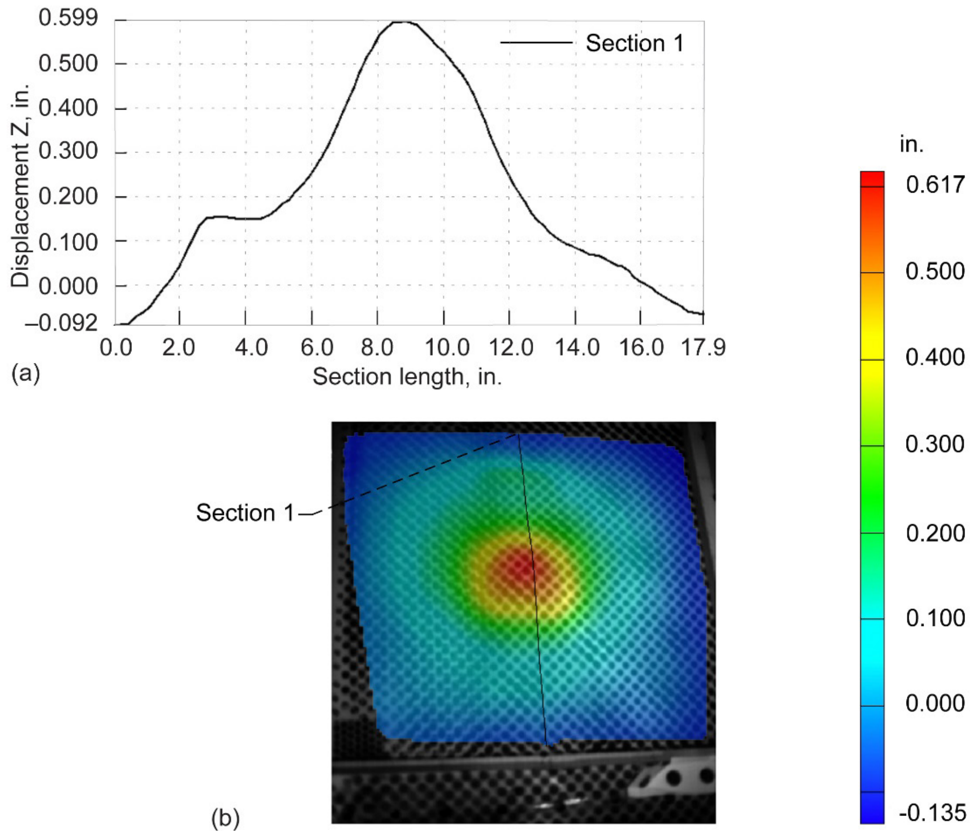


Figure D.25.—LG1116 posttest displacements. (a) Displacement versus length. (b) Displacement Z.

Figure D.26.—LG1116 posttest front view.

Figure D.27.—LG1116 posttest top view.

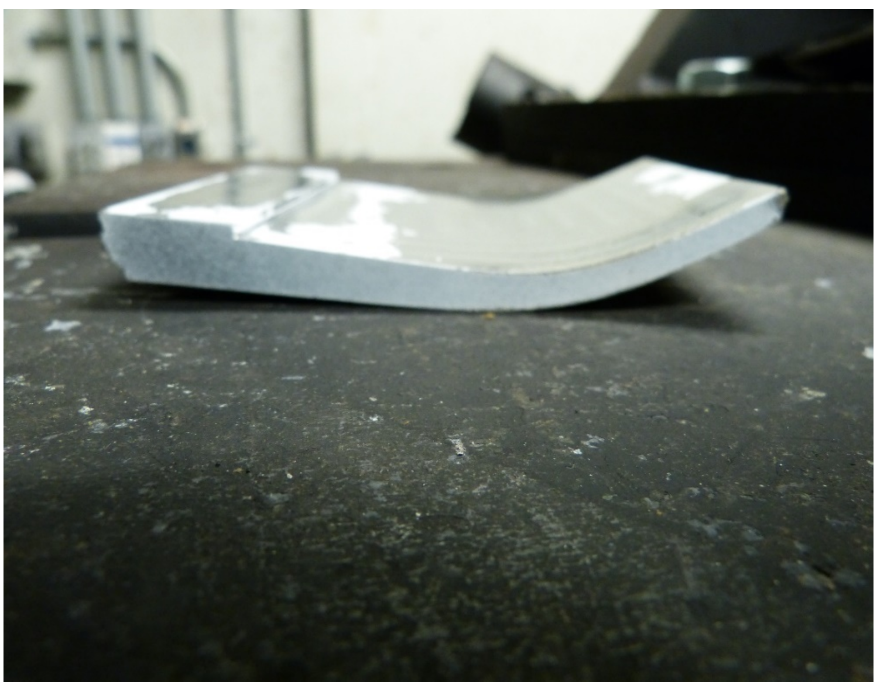


Figure D.28.—LG1116 posttest projectile side view.

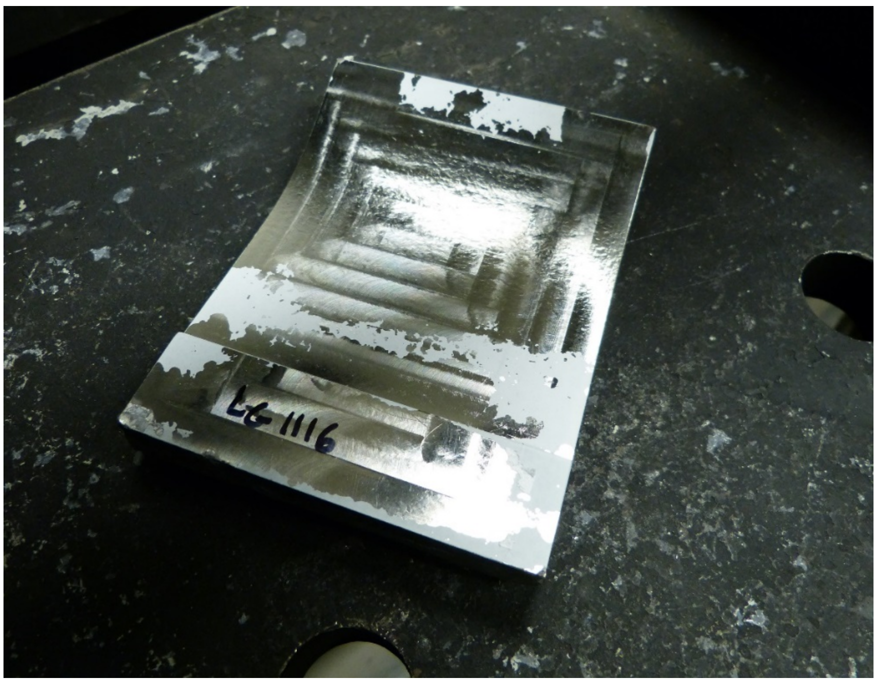


Figure D.29.—LG1116 posttest projectile bottom view.

### *Test LG1125*

The DIC data was not obtained due to full penetration of projectile.


Figure D.30.—LG1125 posttest front view.

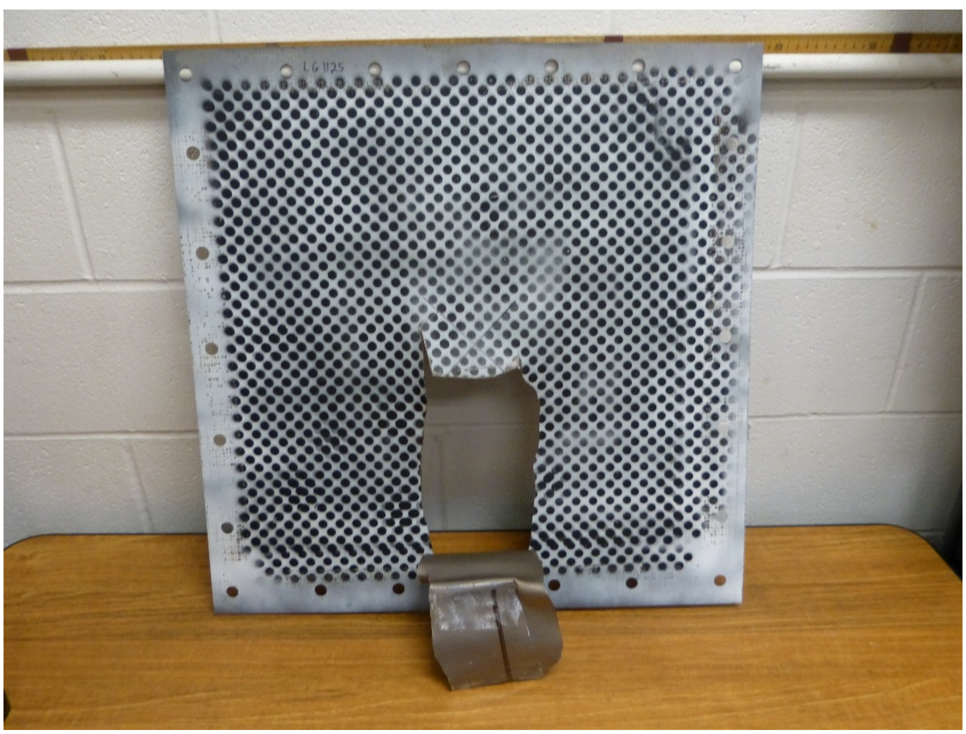


Figure D.31.—LG1125 posttest rear view.


Figure D.32.—LG1125 posttest projectile.

### *Test LG1126*

The DIC data was not obtained due to full penetration of projectile.


Figure D.33.—LG1126 posttest front view.

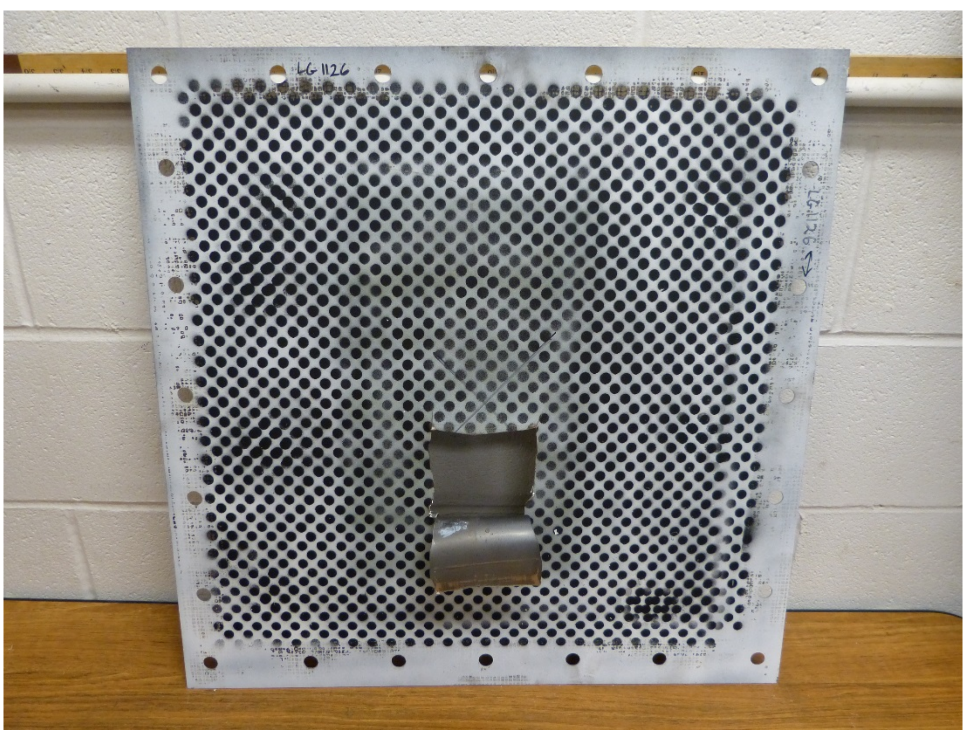



Figure D.34.—LG1126 posttest rear view.


Figure D.35.—LG1126 posttest projectile.

## *Test LG1127*

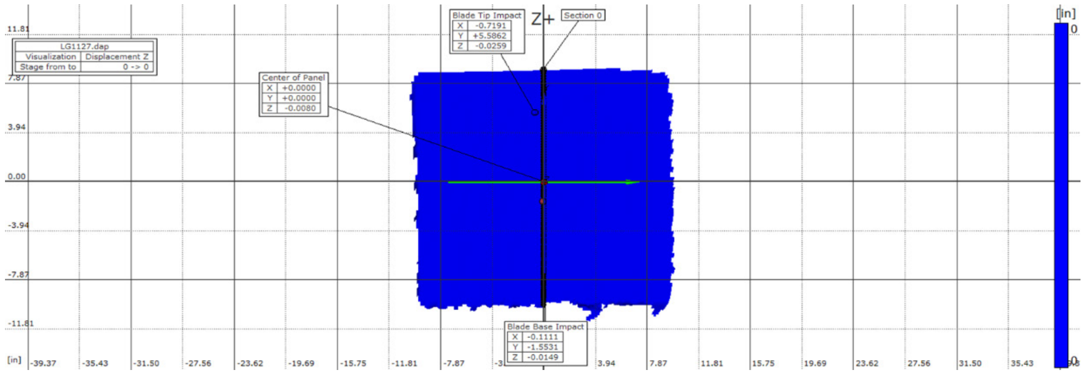



Figure D.36.—LG1127 locations of digital image correlation (DIC) measurements.

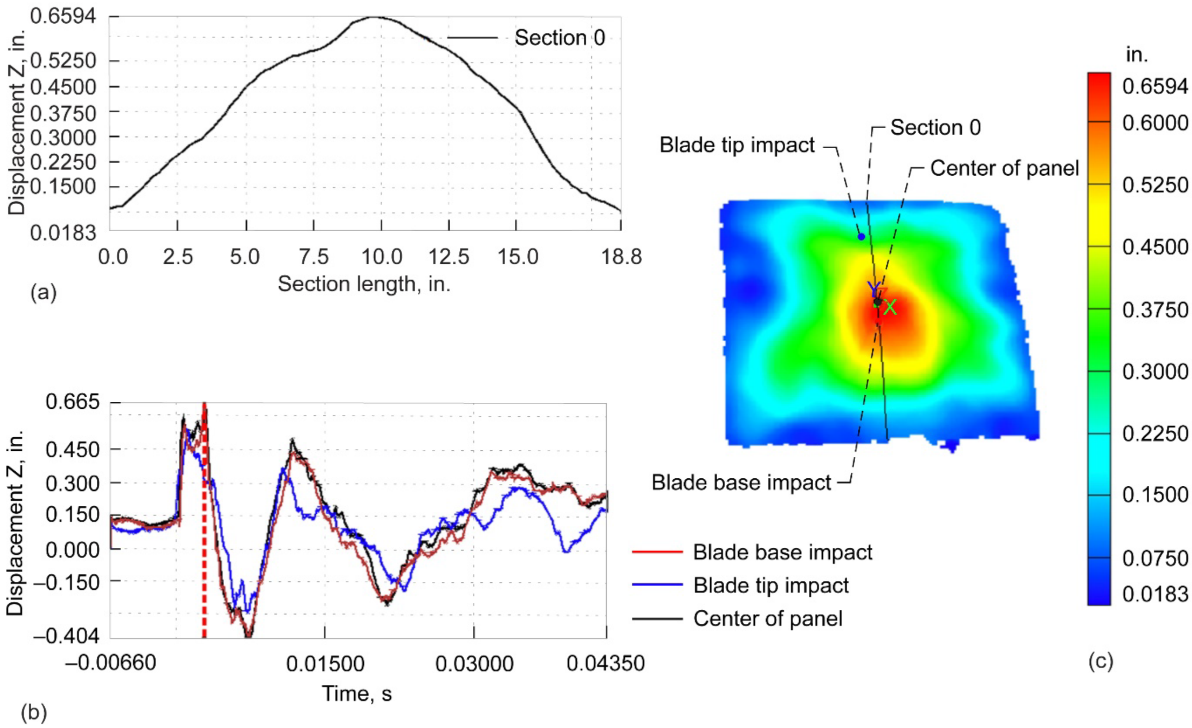



Figure D.37.—LG1127 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

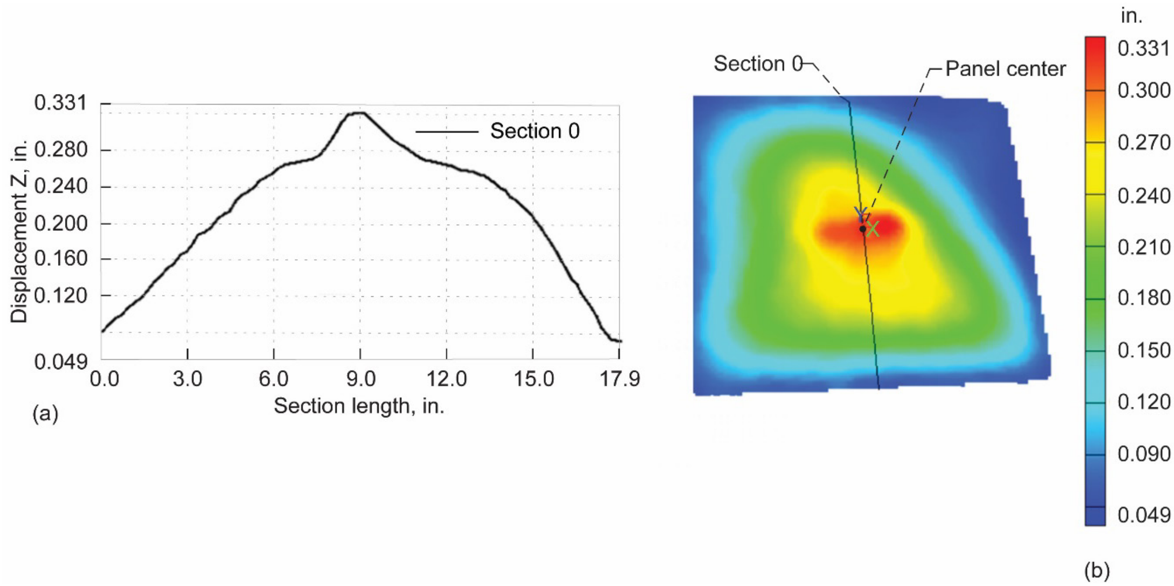



Figure D.38.—LG1127 posttest displacements. (a) Displacement versus length. (b) Displacement Z.

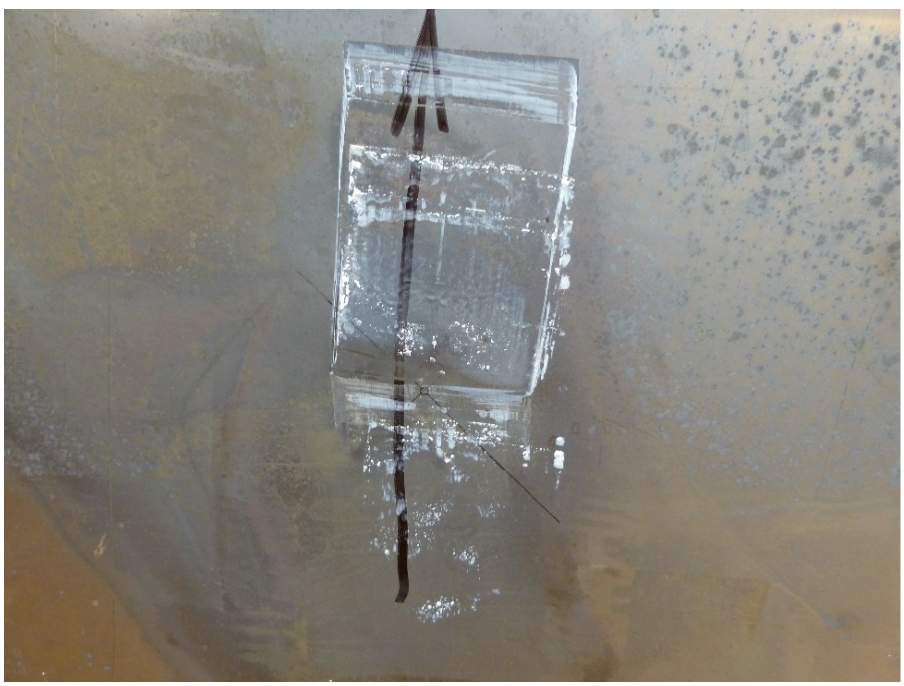


Figure D.39.—LG1127 posttest front view.

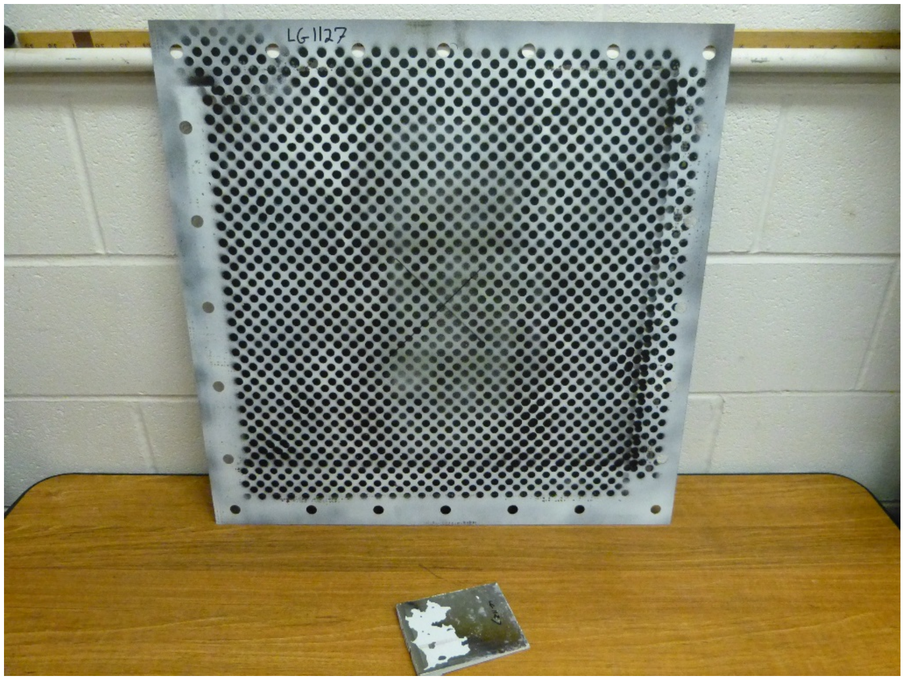



Figure D.40.—LG1127 posttest rear view.


Figure D.41.—LG1127 posttest projectile.

### *Test LG1128*

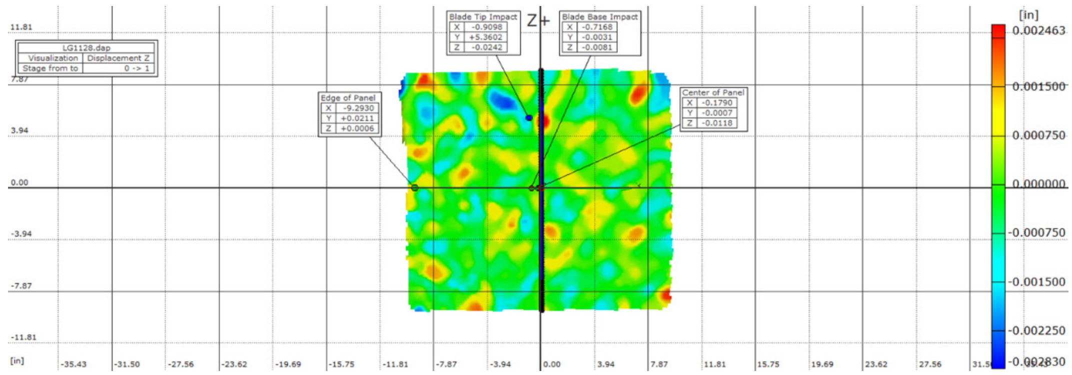


Figure D.42.—LG1128 locations of digital image correlation (DIC) measurements.

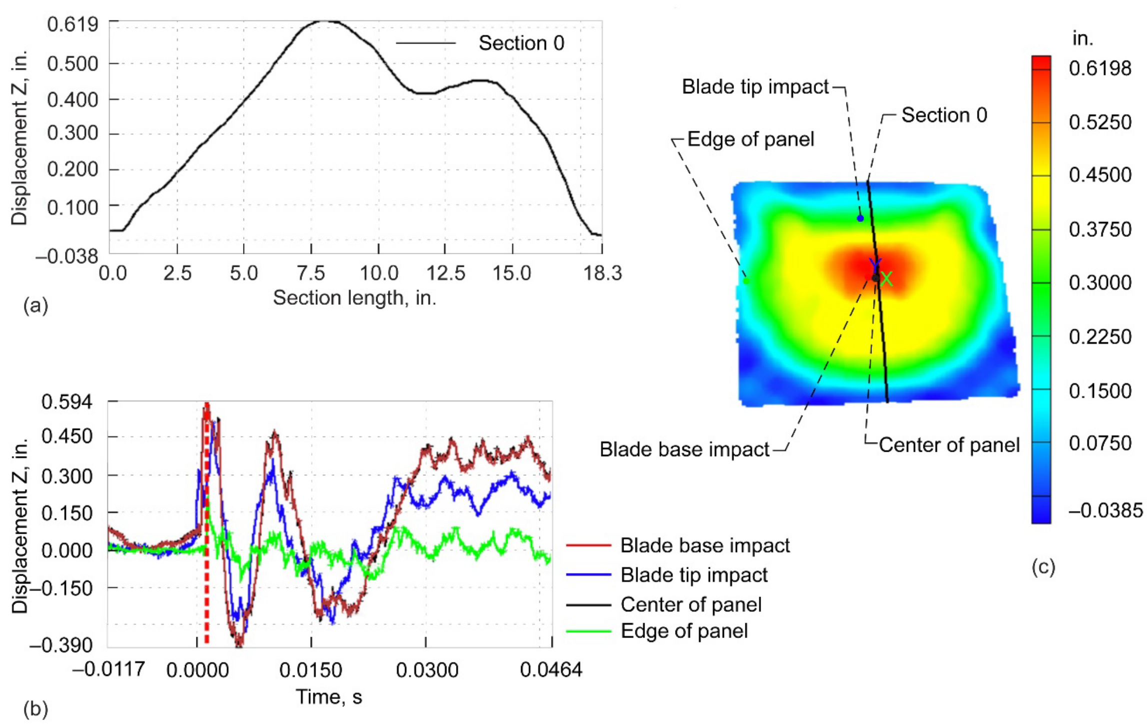
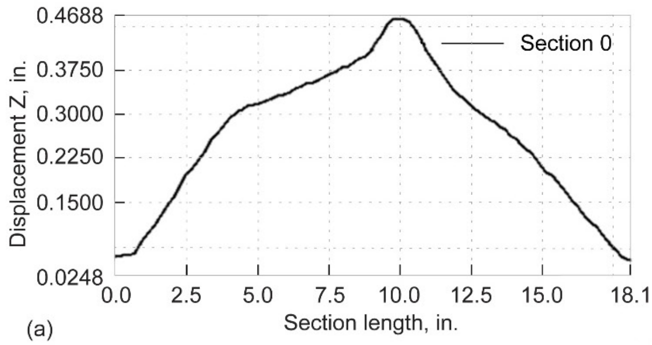



Figure D.43.—LG1128 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



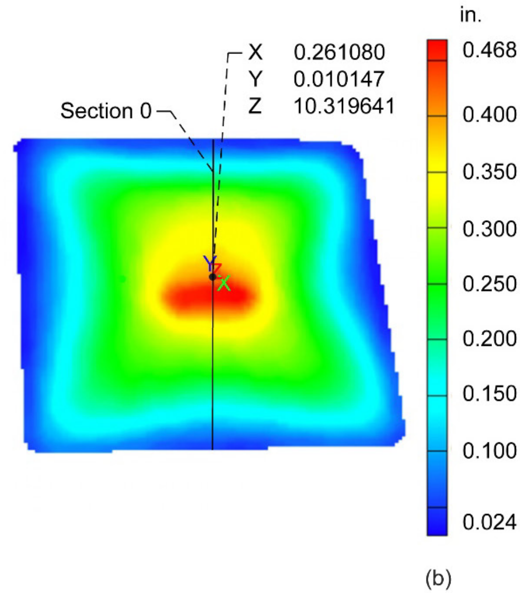




Figure D.44.—LG1128 posttest displacements. (a) Displacement versus length. (b) Displacement Z.

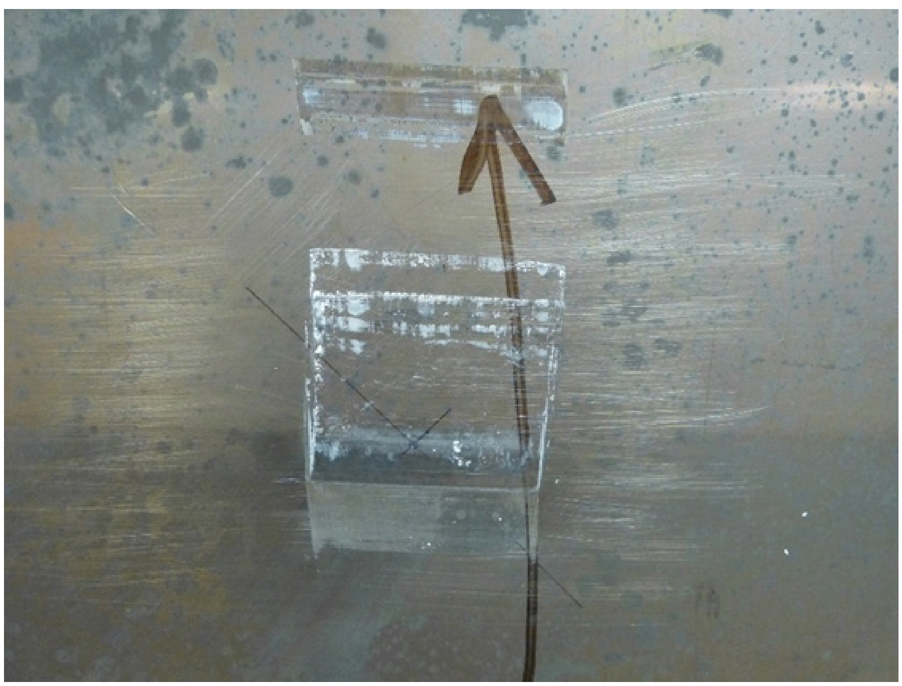


Figure D.45.—LG1128 posttest front view.

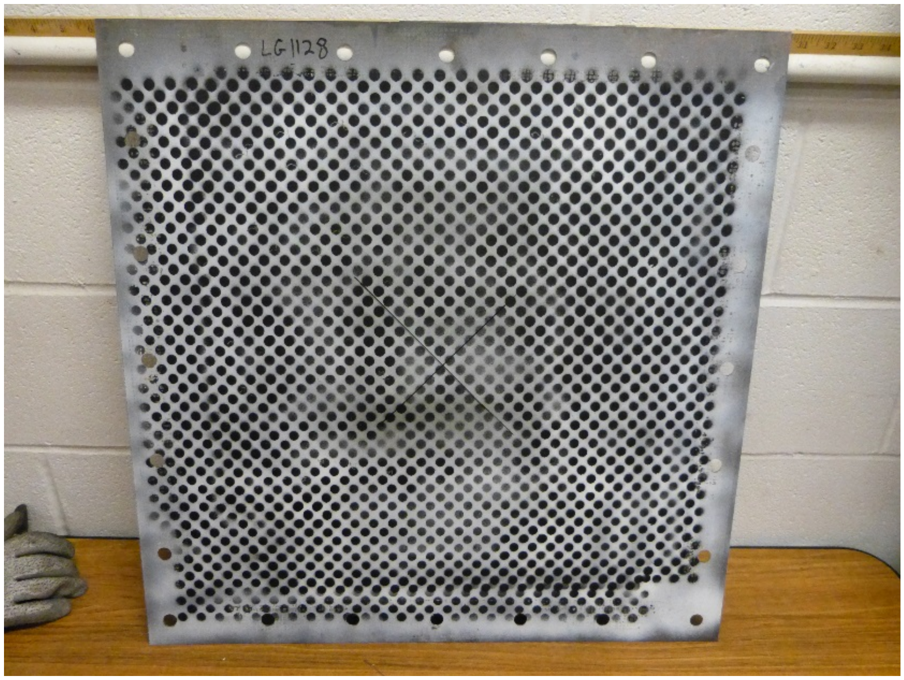



Figure D.46.—LG1128 posttest rear view.


Figure D.47.—LG1128 posttest projectile.

# Reference

1. Pereira, J.M., et al.: Impact Testing of Aluminum 2024 and Titanium 6Al-4V for Material Model Development. NASA/TM—2013-217869 (DOT/FAA/TC–12/58), 2014. http://ntrs.nasa.gov