



Impact Testing of Inconel 718 for Material Impact Model Development

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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, cowlings 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 (NGFBBF). 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 NGFBBF 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

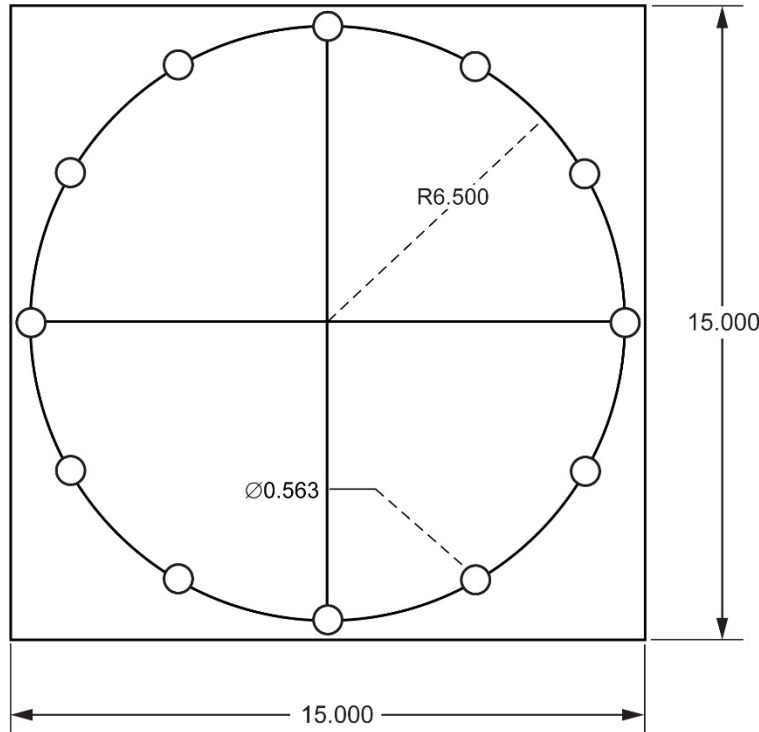


Figure 1.—Small panel test specimen. Dimensions in inches.

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.

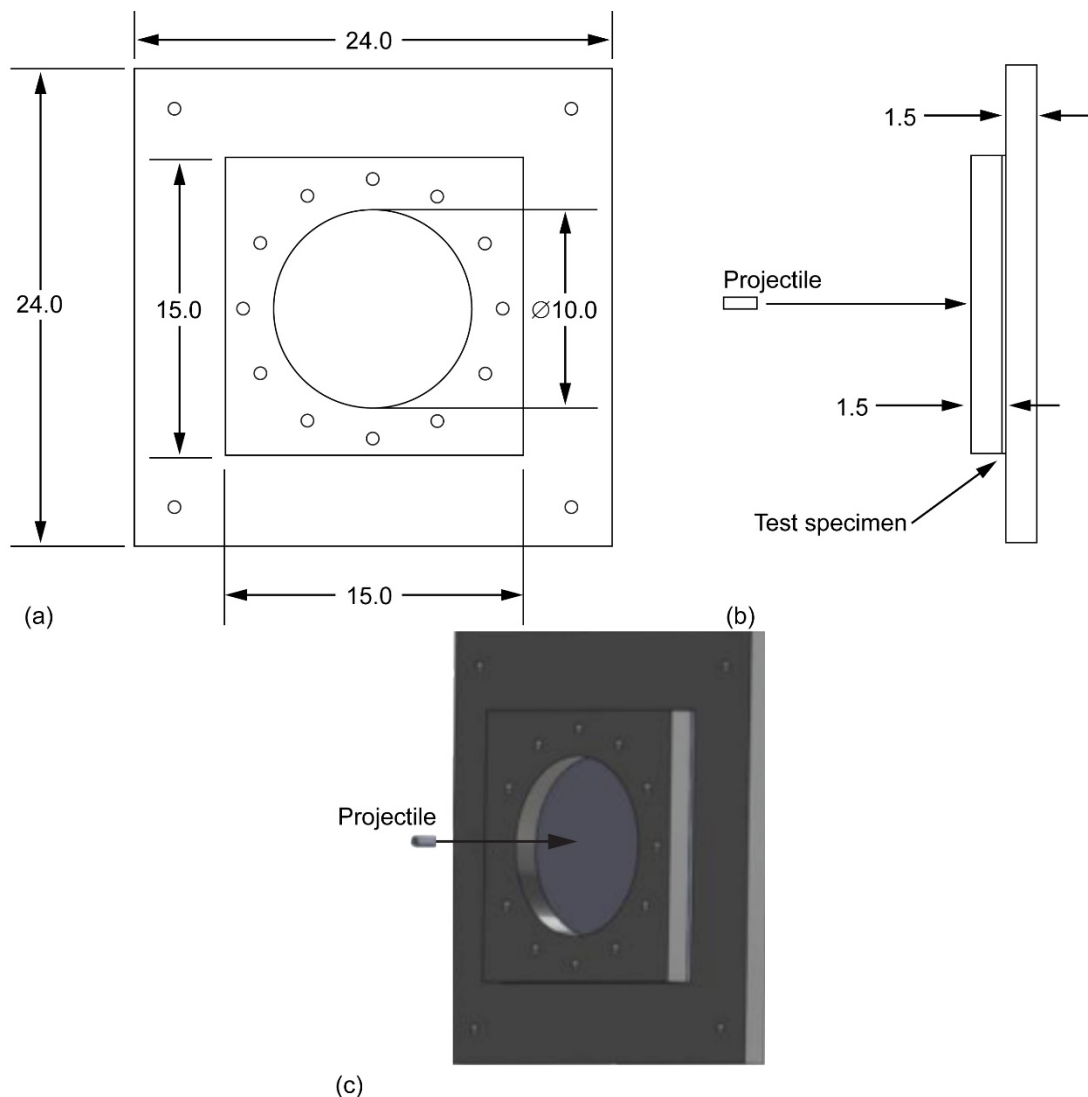


Figure 2.—Test fixture assembly. Dimensions in inches. (a) Front view. (b) Side view. (c) Clamp fixture assembly.

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

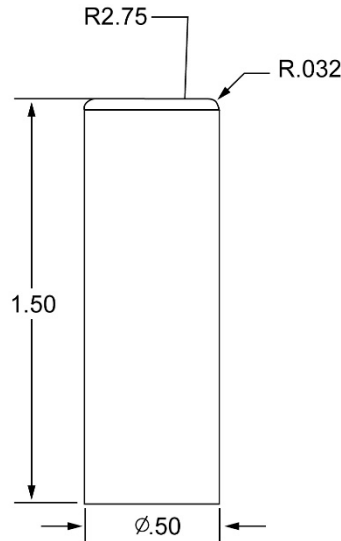


Figure 3.—Sample small panel projectile. Length and diameter vary depending on test specimen thickness and material. Dimensions in inches.

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 in³. 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.

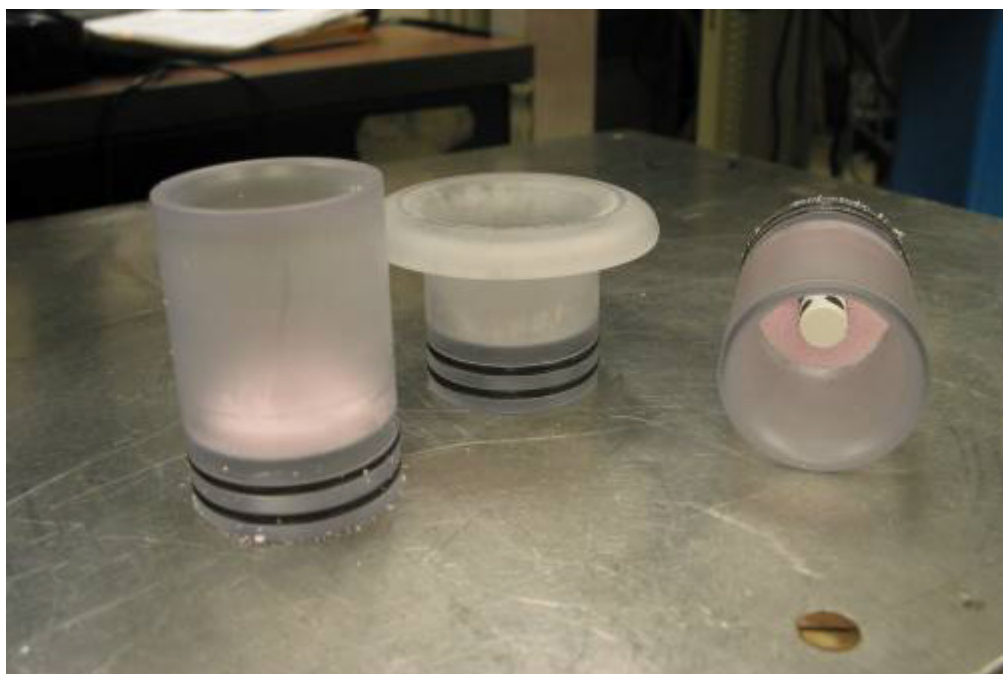


Figure 6.—Sabots used to transport projectile down gun barrel. Posttest sabot shown in center.

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.

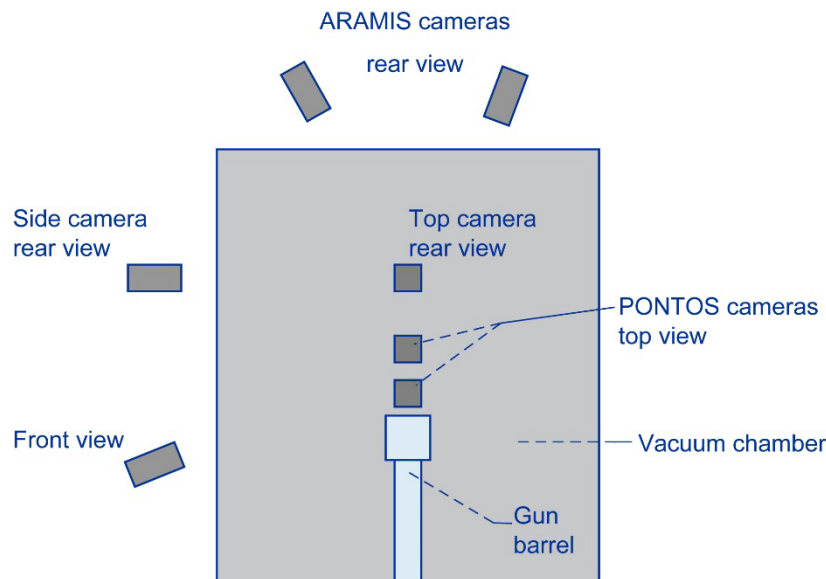


Figure 7.—Top view of vacuum chamber showing high-speed camera locations. PONTOS and ARAMIS made by GOM.

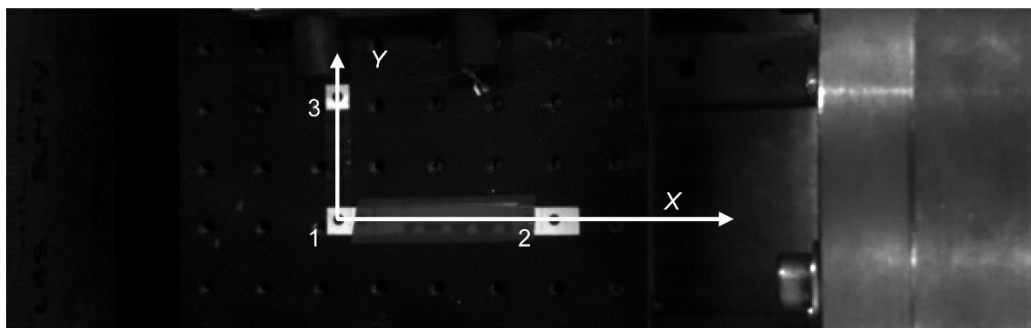


Figure 8.—Points used to define laboratory coordinate system.

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 $5 \mu\text{s}$ 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.

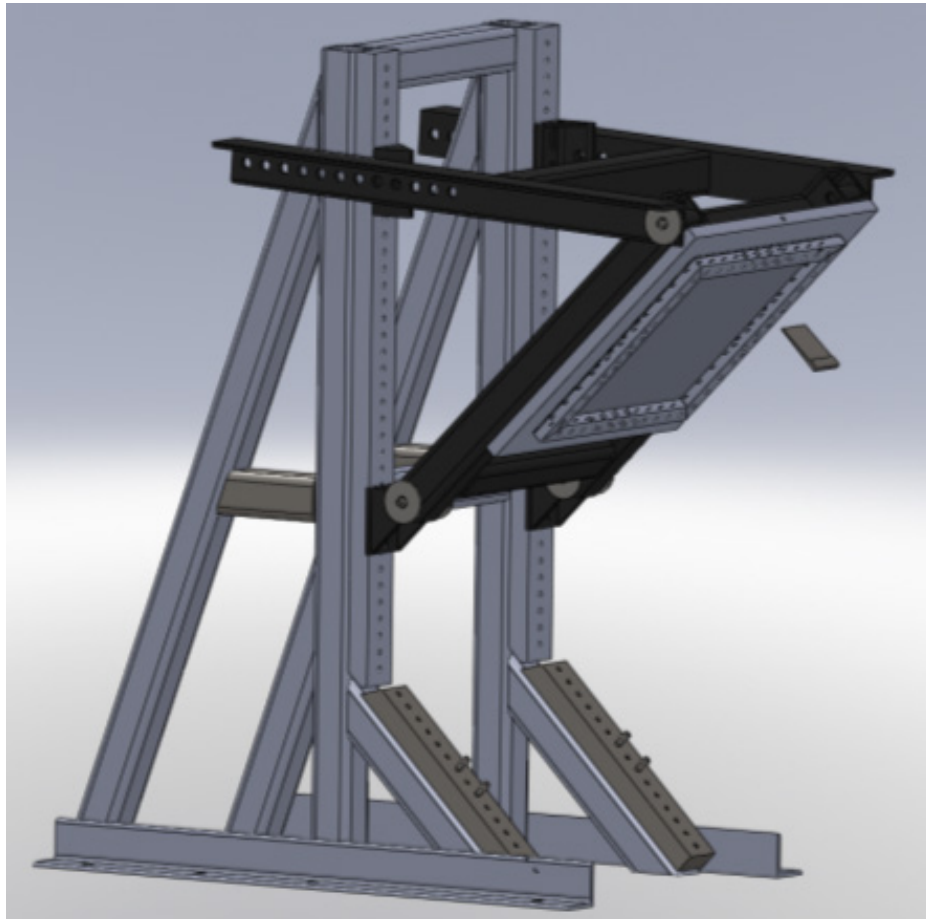


Figure 9.—Large panel test setup showing orientation of projectile and test specimen.

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.

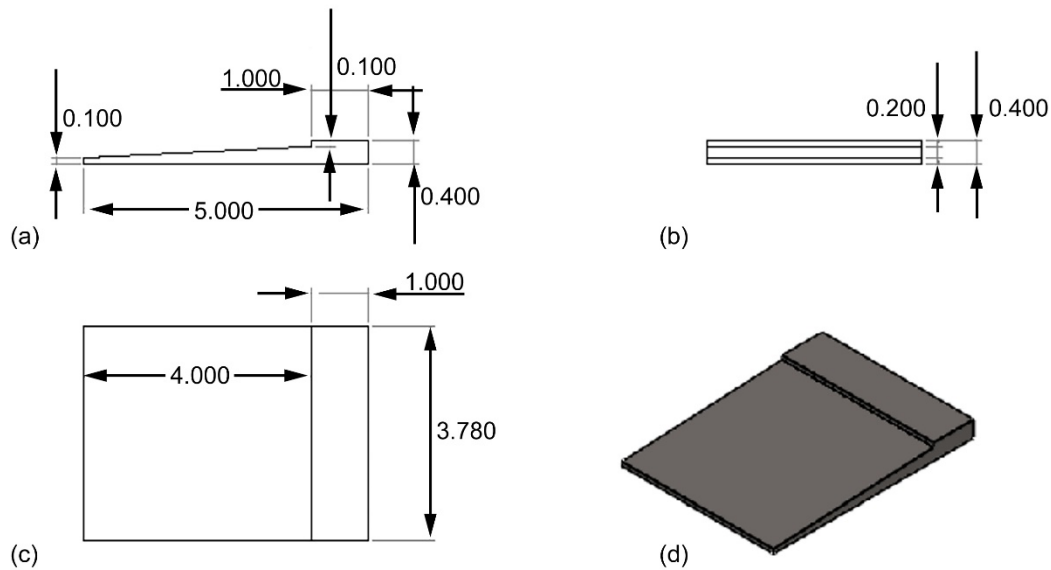


Figure 10.—Thin generic fan blade fragment. Dimensions in inches. (a) Side view. (b) Front view. (c) Top view. (d) View of model.

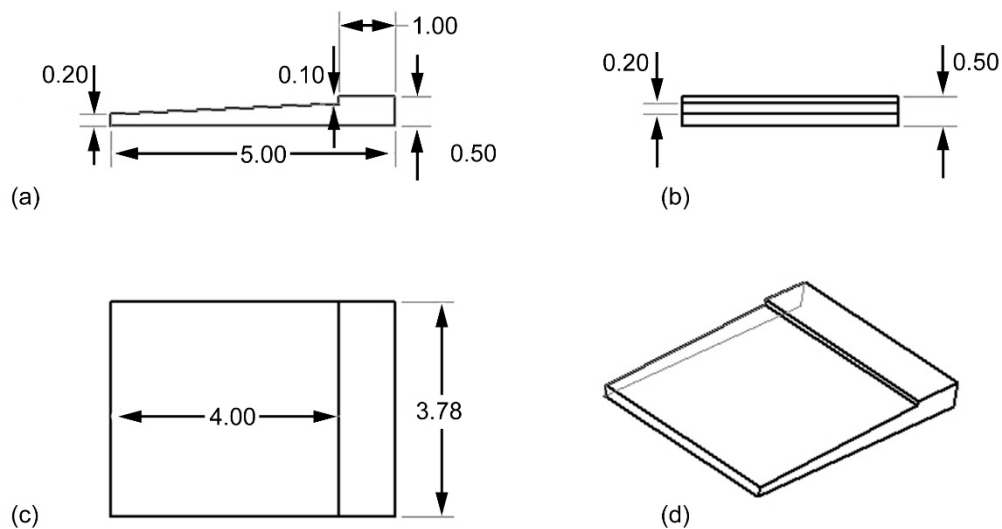


Figure 11.—Thick generic fan blade fragment. Dimensions in inches. (a) Side view. (b) Front view. (c) Top view. (d) View of model.

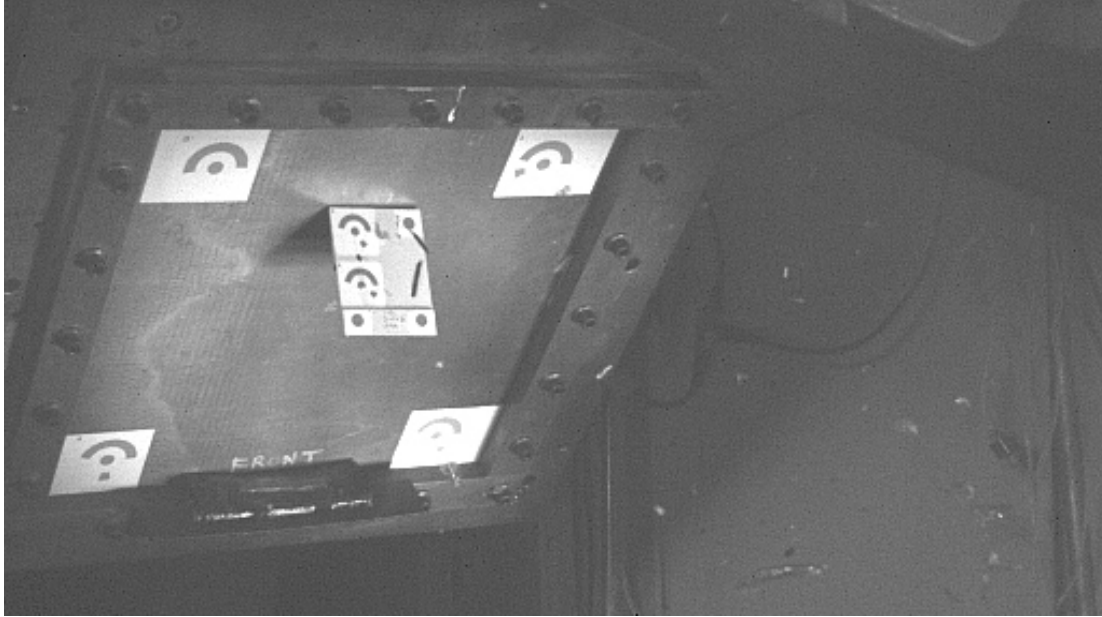


Figure 12.—Still image from high-speed movie of impact test taken directly before impact.

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.

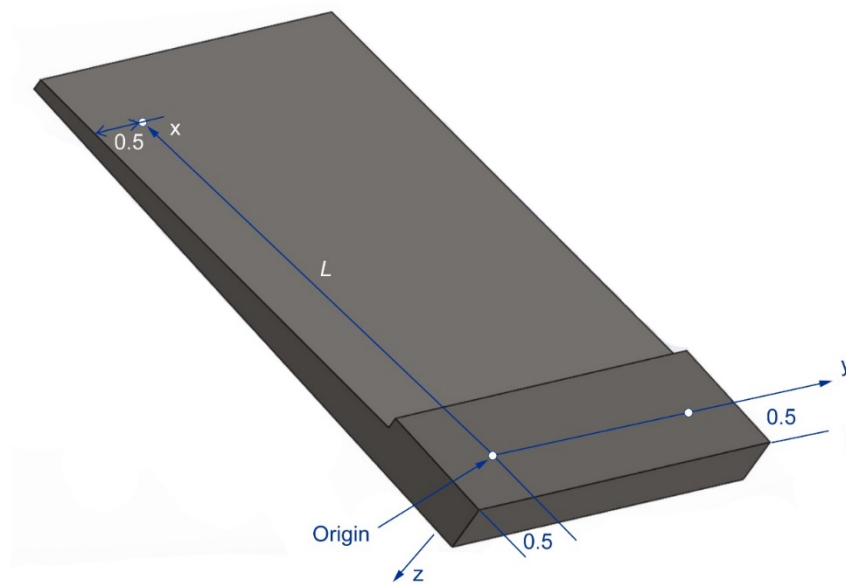


Figure 13.—Projectile local coordinate system. Dimensions are in inches.

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 $4\ \mu\text{s}$, and a resolution of 352×368 pixels. The front-side photogrammetry cameras were operating at 60,000 frames per second with an exposure of $2.5\ \mu\text{s}$ 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 $4\ \mu\text{s}$ and a resolution of 384×344 pixels. The front-side photogrammetry cameras were operating at 40,000 frames per second with an exposure of $2.5\ \mu\text{s}$ 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 $10\ \mu\text{s}$, and a resolution of 608×96 pixels. The top camera was operating at a rate of 10,000 frames per second, an exposure of $25\ \mu\text{s}$ 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

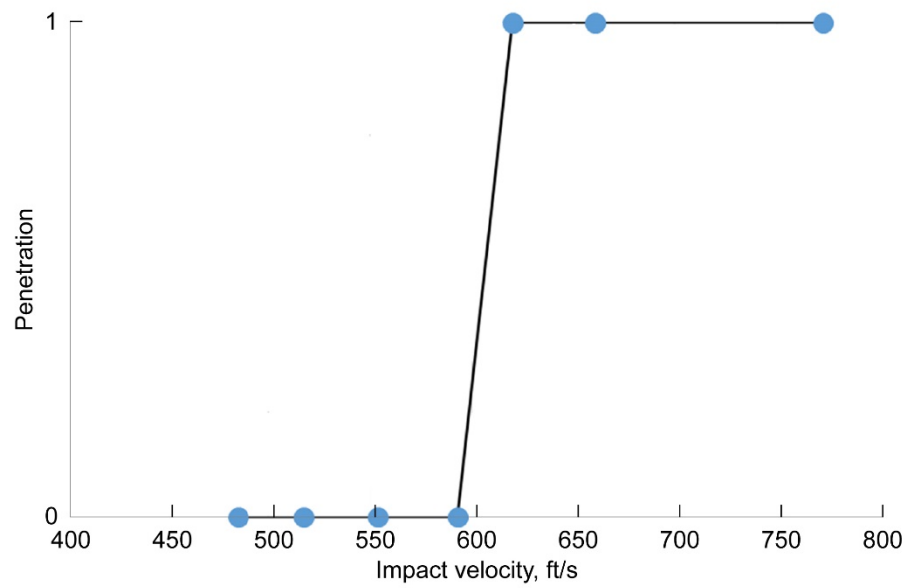
Test	Panel thickness, in.	Projectile			Impact velocity		Kinetic energy (KE), J	Exit velocity		Exit KE, J	Penetrate	Comments
		Dimensions, length × diameter, in.	Material	Mass, g	ft/s	m/s		ft/s	m/s			
DB232	0.0495	1.00×0.375	S7	14.94	806.0	245.7	450.8	660.1	201.2	302.4	1	Penetrate
DB234	0.0495	0.75×0.375	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.

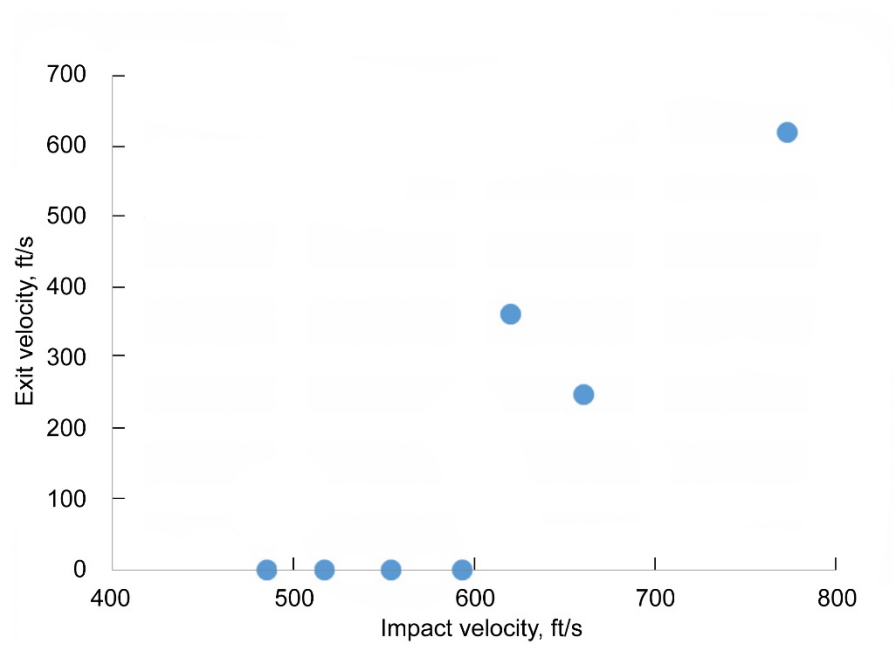
Test	Panel thickness, in.	Projectile			Impact velocity		Kinetic energy (KE), J	Exit velocity		Exit KE, J	Penetrate	Comments
		Dimensions, length × diameter, in.	Material	Mass, g	ft/s	m/s		ft/s	m/s			
DB245	0.0800	0.86×0.50	S2	21.23	683.0	208.2	460.0	259.0	78.9	66.2	1	Penetrated; and flap separated from 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

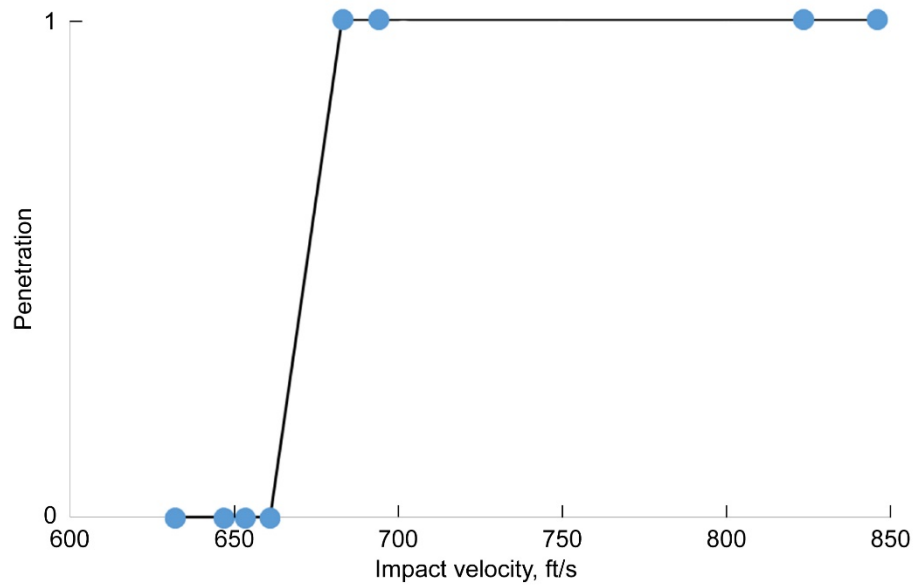


(a)

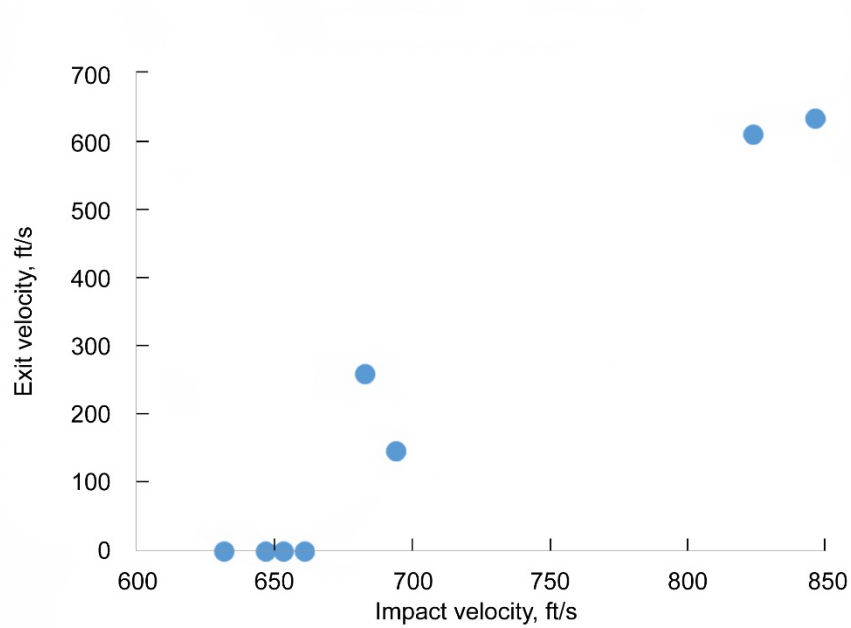


(b)

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.

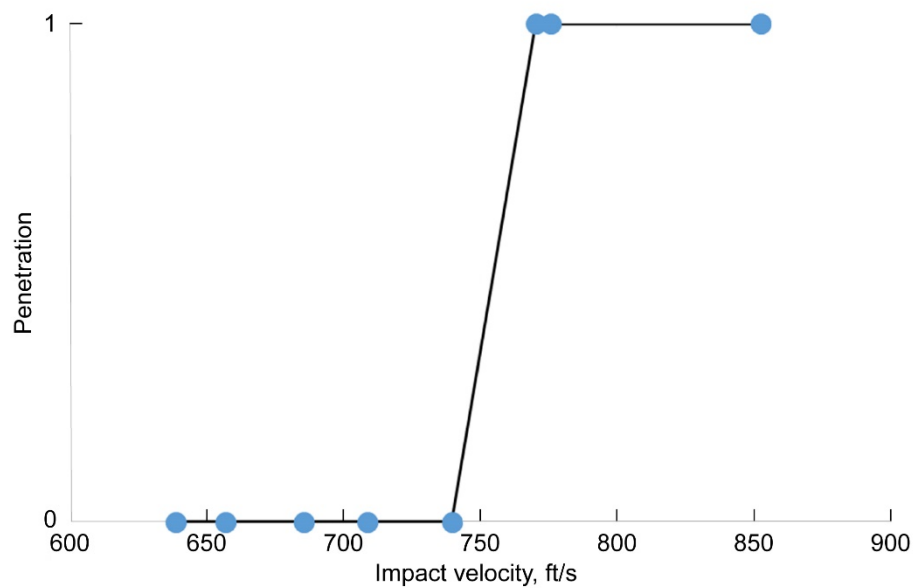


(a)

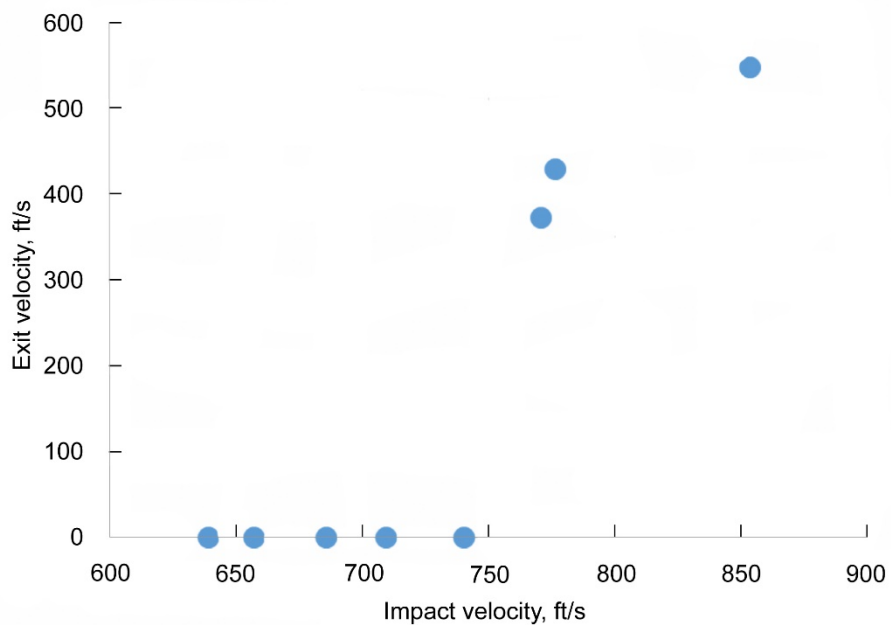


(b)

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.

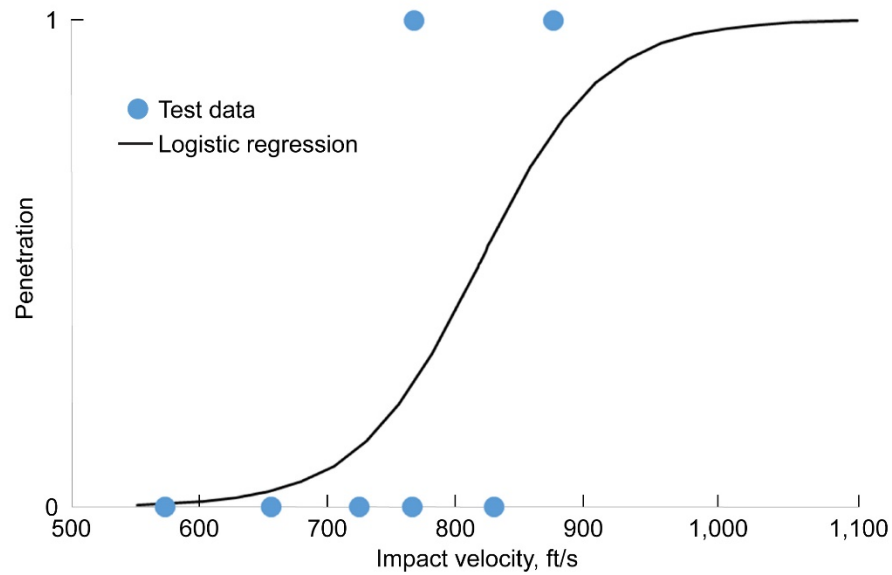


(a)

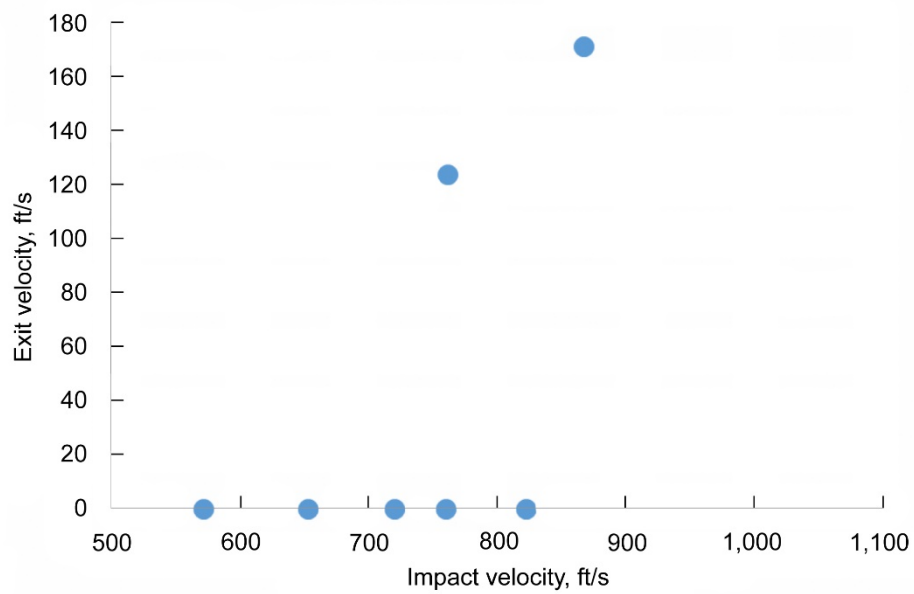


(b)

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.

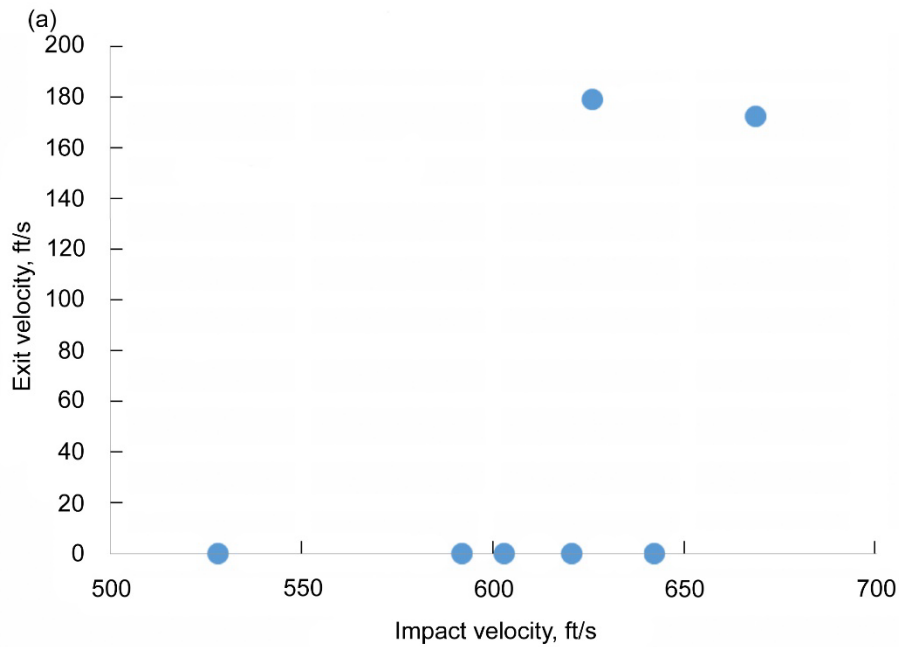
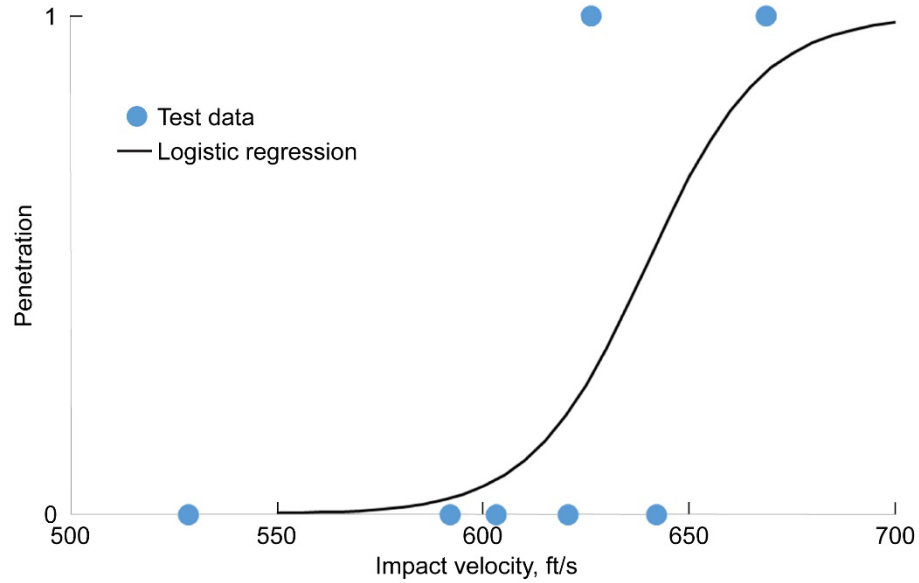


(a)



(b)

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.



(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.

BLM 43

NOTICE OF SHIPMENT/ PACKING LIST				 ATI Allegheny Ludlum Allegheny Technologies		CERTIFICATE OF TEST				AL 6168-3 308
CUST. ORD. NO. & DATE		CUST. CODE		ACCEPTING MTL	SUPPLIER NO.	PRODUCT CODE		MTL ORDER NUMBER	DATE SHIPPED	
01015776		02/04/10 110977		BRACKENRIDGE, PA	459793	13020103060000		32-020-043	06/16/10	
FORMS DISTRIBUTION SOLID ☐ 1 ☒ REPT ☐ 104 ☐ SPEC ☐ 1		REPEAT ORDER ☐ 1 B1639-5		RATE ☐ 26 DSO	PR-ORNTY ☐ 1 SEC. DSO	GOVT CONTRACT ☐ 1 MATL.	SHIPPING LOCATION 2245	INVOICE BRACKENRIDGE PA	030667	
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 "ALTEMP" 718 ALLOY SHEET C K 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-QMS-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)

ITEM PCS DIMENSIONS W/G/L HEAT # COIL # TEST # GROSS TARE NET THEO TAG # / CD SKID

001A 1 36.7.050/886. 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-- --AL-- --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

--T1-- --CO-- --B--- --FE--
 HEAT 068449-01 1.02 .16 .001 19.13
 TEST LOCATION BN BN BN BN

YIELD TENSILE & ELONG
 PSI * PSI 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

MELT INTER-GRAN MICROSTRUC MICROSTRUC OCCASIONAL AVERAGE
 SOURCE ATTACK P&W E-44 AMS 5596 GRAIN SIZE GRAIN SIZE MACROETCH
 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

[illegible]

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

NOTICE OF SHIPMENT/ PACKING LIST				ATI Allegheny Ludlum		CERTIFICATE OF TEST			
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01015776		02/04/10	110977	BRACKENRIDGE, PA	459793	13020103060000	32-020-043	06/16/10	
FORMS DISTRIBUTION		REPEAT ORDER	DO I TO	GOVT CONTRACT	MATL	SHIPPING LOCATION		INVOICE	
SOLD TO		81639-5	26		2245	BRACKENRIDGE PA		030667	
UNITED PERFORMANCE METALS		PRIME	SEC.		SHIP TO				
3475 SYMMES ROAD		DSO	DSO		UNITED PERFORMANCE METALS				
HAMILTON OH 45015		584			3475 SYMMES ROAD				
					HAMILTON OH 45015				

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 (ASTM-E-112-96 REAPPROVED 2004 E2) (B50TF133-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)

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

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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 specifications as set forth in Allegheny Ludlum's data book.

Tony McFarland
 Director, Customer Quality Assurance

American Special Metals
 Quality Assurance

Approved
 Date 6-2-2010

Figure A.1.—Continued.

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CUST. ORD. NO. & DATE		CUST. CODE	ACCEPTING MILL	SHIPPER NO.	PRODUCT CODE	BILL OF LADING NUMBER	DATE SHIPPED		
01015776		02/04/10 110977	BRACKENRIDGE, PA	459793	13020103060000	32-020-043	06/16/10		
FORMS DISTRIBUTION		REPEAT ORDER	DO I FILE	GOVT CONTRACT	MATL	SHIPPING LOCATION	INVOICE		
1 100 275		81639-5	26		2245	BRACKENRIDGE PA	030667		
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 (ASTM-E-112-96 REAPPROVED 2004 E2) (B50TF133-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)

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

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

MATERIAL TESTED AT ALLEGHENY LUDLUM GEAE 5400 (DATED 10/31/07) APPROVED FACILITIES (T1225): NATRONA HEIGHTS TECHNICAL CENTER AND BRACKENRIDGE, PA.

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Figure A.1.—Continued.

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01015776		02/04/10	110977	BRACKENRIDGE, PA	459793	13020103060000	32-020-043	06/16/10	
FORMING DISTRIBUTION		REPEAT ORDER	GOVT. CONTRACT	MATL.	SHIPPING LOCATION	INVOICE			
1		81639-5	26	2245	BRACKENRIDGE	PA 030667			
SOLD TO				SHIP TO					
UNITED PERFORMANCE METALS				UNITED PERFORMANCE METALS					
3475 SYMMES ROAD				3475 SYMMES ROAD					
HAMILTON OH 45015				HAMILTON OH 45015					

GRADE AND SPECIFICATIONS CARRIER - GROSS, RONALD, INC.
 "ALTEMP" 718 ALLOY SHEET C R COILS ANNEALED 2D FIN 3 EDGE (UTM 718) (10/30/08 EXCEPTIONS TO UPM 718)
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 (ASTM-E-112-96 REAPPROVED 2004 E2) (B50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17, F-22, F-23, F-MASTER) (FWA 300 REV 1J) (CONTROLLED TO FWA LCS REQUIREMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

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 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

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 We certify that this material conforms to the applicable specifications as shown on this purchase order.
 Customer FAA
 Customer PO# DTFACT-10-P-00290
 ASM Work Order# 2010-H-12311
 Qty 6 Pieces
LE 4-2-2010
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NOTICE OF SHIPMENT/ PACKING LIST				ATI Allegheny Ludlum		CERTIFICATE OF TEST							
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 I FIN ONLY		GOVT CONTRACT		MATERIAL		SHIPPING LOCATION		INVOICE	
1 SHIP		81639-9		26				2245 VANDERGRIFT		PA		650416	
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 - 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) (B50TF133-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)													
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													
HEAT 068623-02 --C--- --MN-- --P--- --S--- --SI--- --CR-- --NI-- --AL-- --MO-- --CU-- --CB-- --TA-- TEST LOCATION .05 .12 .008 .0001 .07 18.21 52.54 .55 2.90 .06 5.00 .01 TC BN BN BN TC BN BN BN BN BN BN TC HEAT 068623-02 --TI-- --CO-- --R--- --FE-- TEST LOCATION 1.00 .30 .002 19.05 BN BN BN BN													
ITEM TEST NO YIELD TENSILE % ELONG GRAIN 001A G210041 PSI * PSI IN 2" % R/A HARDNESS BEND SIZE T 62000. 128000 53. 93.HRBW T PASS 9. TEST LOCATION TC TC TC TC TC TC * Y.S. BY 0.2% OFFSET METHOD													
ITEM TEST NO MELT INTER-GRAN MICROSTRUC MICROSTRUC OCCASIONAL AVERAGE 001A G210041 SOURCE ATTACK P&W E-44 AMS 5596 GRAIN SIZE GRAIN SIZE MACROETCH 1. .0000 IN FIG 1 PASS 9. 9. PASS TEST LOCATION .0000 OUT FIG 1 PASS 9. 9. PASS TC TC TC TC TC TC PAGE 01 - CONTINUED ON PAGE 02 07/29/10 11:54:35													
DISCLAIMER: Please Note: This certification was turned over to the customer in full compliance with the terms of the contract. The customer and user assume all responsibility for loss or damage to the product. For your protection, please examine the product as it arrives. If any shortage or damage is discovered, please advise the supplier immediately. For your protection, please advise the supplier immediately. For your protection, please advise the supplier immediately. Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy, please call 724-226-8577. CAUTION: Processing this product may cause you to become a user of hazardous materials. For your protection, please advise the supplier immediately. For your protection, please advise the supplier immediately. WARNING: Les fiches d'information-sécurité de ce produit ont été fournies à votre département chargé des achats. Pour obtenir des renseignements supplémentaires, veuillez téléphoner au numéro suivant: 724-226-8577. Attention: les traitements entraînent la production de vapeurs, poussières, ou solutions pouvant être cause de maladies professionnelles. 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 data entered on this certification. It is not to be used for any other purpose without the written consent of Allegheny Ludlum. Tony M. Hall Director, Corporate Quality Assurance American Special Metals Quality Assurance Approved AS Date 8-2-2010													

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

NOTICE OF SHIPMENT/ PACKING LIST				CERTIFICATE OF TEST		AL 6160-3 9/08
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	TEST ORDER	DO ITA	GOVT CONTRACT	MATL	SHIP TO LOCATION	INVOICE
1 10 10 10	81639-9 26	PRIME SEC.	2245 VANDERGRIFF	PA	650416	
SOLD TO		SHIP TO				
UNITED PERFORMANCE METALS		UNITED PERFORMANCE METALS				
3475 SYMMES ROAD		3475 SYMMES ROAD				
HAMILTON OH 45015		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 REQUIREMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

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

CAUTION - Precautions - This material was found to contain a first class carcinogen, being directly loaded, as when used in accordance with the label or otherwise. For your protection please examine shipment as it arrives. If any shortage or damage is discovered, stop it for inspection - make the transportation agent on verbal before signing.

Maintain Safety Data Sheets for this product. Have been supplied to your Purchasing Department. For an authorized copy phone 724-226-6577. CAUTION: Precautions for material. Labels must be followed. May cause lung disease. See Material Safety Data Sheets for further information.

WARNING: 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 précautions entourant la production de produits, produits, ne doivent pas être cause de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

This document is a work order or data card. The material has not been tested to the above contract and specifications (as set forth in Allegheny Ludlum's Order Acknowledgment).

Tracy McFarland
 Director, Corporate Quality Assurance
 American Special Metals
 Quality Assurance
 Approved *[Signature]*
 Date 9-2-2010

Figure A.2.—Continued.

NOTICE OF SHIPMENT/ PACKING LIST				ATI Allegheny Ludlum		CERTIFICATE OF TEST							
CUST. ORD. NO & DATE		CUST. CODE		ACCEPTING MTL		SHIPPER NO.		PRODUCT CODE		BILL ORDER NUMBER		DATE SHIPPED	
01016216		04/19/10		110977		BRACKENRIDGE, PA		13020103060000		32-040-092		07/29/10	
FORMS DISTRIBUTION				REPEAT		UD		MATERIAL		SHIPPING LOCATION		INVOICE	
SOLD TO				PRIME		SEC.		2245		VANDERGRIFT		PA 650416	
UNITED PERFORMANCE METALS				DSO		DSO		UNITED PERFORMANCE METALS					
3475 SYMMES ROAD				584				3475 SYMMES ROAD					
HAMILTON OH 45015								HAMILTON OH 45015					

GRADE AND SPECIFICATIONS

"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) (P-14, F-17,
 F-22, F-23, F-MASTER) (PWA 300 REV BJ) (CONTROLLED TO PWA LCS REQUIREMENTS) (04/30/04 EXCEPTIONS TO B50TF14)

CARRIER - CLAY TRANSPORT, INC.

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

- MATERIAL MELTED, ROLLED AND TESTED IN THE UNITED STATES.
- 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 CERTIFICATIONS 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

CONSUMER-Please Note: This certificate was limited over to carrier in first class condition, being carefully packed, at which time our responsibility for loss or damage (if shipment) ceases. For information please advise shipment at 1 minute. If any shortage or damage is discovered, file a full description with the transportation agent on arrival before signing.

WARNING: Handle Safety Data Sheets for this product have been applied to your Purchasing Department. For an electronic copy contact the Supplier at 724-226-6577. CAUTION: Handling this material in any way, such as loading, may cause lung disease. See Material Safety Data Sheets for further information.

WARNING: Les fiches d'information-sécurité de ce produit ont été fournies à votre département d'achat. Pour copie des renseignements supplémentaires contactez le fournisseur au numéro 724-226-6577. Attention: les dangers liés à la manipulation de ce produit peuvent causer des maladies pulmonaires. Pour plus de renseignements consultez les fiches d'information-sécurité.

This sheet is a true copy of data on file. The material and test results conform to the order contract and specifications as set forth in Allegheny Ludlum Order Agreement.

Tracy McFarland
Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved *[Signature]*
Date 07-29-2010

Figure A.2.—Continued.

NOTICE OF SHIPMENT/ PACKING LIST				ATI Allegheny Ludlum		CERTIFICATE OF TEST					
CUST. ORD. NO. & DATE		CUST. CODE		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		GOVT CONTRACT		MATERIAL		SHIPPING LOCATION		INVOICE	
SOLD TO 1 SHIP TO 4 SPEC TO 4		81639-9 26				2245 VANDERGRIFT		PA		650416	
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 - 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 REQUIREMENTS) (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 R 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 <u>FAB</u> Customer PO# <u>DIFACT-10-P-00240</u> ASM Work Order# <u>2010-H-12311</u> Qty <u>6 Pieces</u> <u>16</u> <u>9-2-2010</u> Q.C. Certification Clerk Date					
PAGE 04 - CONTINUED ON PAGE 05											
CONSIGNEE: Please have this consignment was turned over to carrier in first class condition, being correctly loaded at which time our responsibility for loss or damage is terminated. For your protection please require shipment as a bill of lading. If any damage or change is indicated, take a full possession note by transportation agent on receipt before signing. WARNING: Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy, please call 724-226-5577. CAUTION: Placarding this material is required. For information on placarding, please call 724-226-5577. Attention: This material is extremely flammable and may cause serious injury. See Material Safety Data Sheets for further information. This sheet is a true copy of data on file. The material and test results conform to the above contract and specification(s) as set forth in Allegheny Ludlum's order Acknowledgment. Tracy McFarland Director, Corporate Quality Assurance											

Figure A.2.—Continued.

NOTICE OF SHIPMENT/ PACKING LIST				AL 0100 3 B1*	
TEST NO 6210041				CERTIFICATE OF TEST INVOICE NO 650416 SHIP DATE 7/29/2010	

SPECIFICATION		YIELD (PSI)	TENSILE (PSI)	ELONGATION IN 2"	HARDNESS	STRESS RUPTURE
B50TF14-S22 *						
HEAT TREAT (1)		159000	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.

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

PAGE 05 - FINAL PAGE.

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

Figure A.2.—Concluded.

BL-43

NOTICE OF SHIPMENT/ PACKING LIST				CERTIFICATE OF TEST		AL 6168-3 001	
CUST. ORD. NO. & DATE 01016426		CUST. CODE 110977		ACCEPTING MILL BRACKENRIDGE, PA		SHIPPER NO. 465610	
FORMS DISTRIBUTION SOLD TO UNITED PERFORMANCE METALS 3475 SYMMES ROAD HAMILTON OH 45015		REPEAT ORDER 87110-0		DO I Pkg- DATE CONTY 261		PRODUCT CODE 13010103060000	
		PRIME SEC. DSO DSO 584		SHIP TO UNITED PERFORMANCE METALS 3475 SYMMES ROAD HAMILTON OH 45015		MILL ORDER NUMBER 32-050-144	
						DATE SHIPPED 08/12/10	

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) (B50TF133-S9 CLASS C) (S-1000 DATED 1/2/08) (UPM-QRS-001) (F-14, F-17,
 F-22, F-23, F-MASTER) (FWA 300 REV BJ) (CONTROLLED TO FWA LCS REQUIREMENTS) (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	BN	TC
HEAT	068645-02	--TI--	--CO--	--B--	--FE--								
HEAT	068645-02	1.02	.16	.002	19.62								
TEST LOCATION	TC	BN	BN	BN	BN								

ITEM	TEST NO	YIELD	TENSILE	% ELONG	% R/A	HARDNESS	BEND	GRAIN
001A	3723828	PSI * PSI	IN 2"	% R/A				SIZE
		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 T

PAGE 01 - CONTINUED ON PAGE 02

08/12/10 14:34:27

CONSENT: Please Note: This agreement was formed only to certify in test cases condition, being correctly labeled, in which time our responsibility for test or damage is not intended. For your assurance please examine shipment as it arrives. If any shortage or damage is discovered, please a full description must be transposition signed on receipt before aging.

WARNING: Material Safety Data Sheets for this product have been supplied to your Purchasing Department. For an additional copy please call 724-225-6577. CAUTION: Processing this material involves dust or solvents may cause lung disease. See Material Safety Data Sheets for further information.

WARNING: 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 724-225-6577. Attention: les résidus, entraînant la production de vapeur, poussières, ou résidus peuvent être source de maladies pulmonaires. Pour plus de renseignements se référer aux fiches d'information-sécurité.

The above is a true copy of that on file. The material and test results conform to the same, content, and specifications as set forth in Allegheny Ludlum's Order Acknowledgment.

American Special Metals
 Quality Assurance
 Approved *[Signature]*
 Date 9-2-2010

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

AL 6168-3 903

Tracy McFarland,
Director, Concrete Quality Assurance

34

AL 61628-3 F028

[illegible]

Tracy McInland -
Director, Corporate Quality Assurance

American Special Metals
Quality Assurance
Approved LC
Date 9.2.2019

35

NOTICE OF SHIPMENT/ PACKING LIST				ATI Allegheny Ludlum		CERTIFICATE OF TEST			
CUST. ORD. NO. & DATE		CUST. CODE		ACCEPTING MFG.		SHIPPER NO.		PRODUCT CODE	
01016426		05/21/10 110977		BRACKENRIDGE, PA 465610		13010103060000		132-050-144	
FORMS DISTRIBUTION		REPEAT ORDER		DO NOT CONTRACT		MATERIAL		DATE SHIPPED	
1 10 1		87110-0 126				2245 BRACKENRIDGE		08/12/10	
SOLD TO		PRIME SEC.		SHIP TO		PA 030899		INVOICE	
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 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									
AMERICAN SPECIAL METALS CORP. CERTIFICATION OF COMPLIANCE We certify that this material conforms to the applicable specifications as shown on this purchase order. Customer <u>FAA</u> Customer PO# <u>DT FACT-10-B-00240</u> ASM Work Order# <u>2010-H-12311</u> Qty <u>6 Pieces</u> <u>AC</u> Certification Clerk <u>9-2-2010</u> Date									
FOR ACCESS TO ONLINE CERTIFICATES OF TEST REGISTER AT WWW.ALCEXTRA.COM									

Figure A.3.—Continued.

At 415.5 °C

INVOICE NO 30899
SHIP DATE 8/12/2010

SPECIFICATION	YIELD (PST)	TENSILE (PSI)	ELONGATION IN 2"	HARDNESS	STRESS RUPTURE
B50T14-S22 *					
HEAT TREAT (1)	168000	201000	20	46.HRC	
ELEVATED TEMP (3)	144000	163000	17		20.5 HOURS DISCONTINUED
STRESS RUPTURE (2)					
AMS 5596K *					
HEAT TREAT (4)	179000	206000	18	47.HRC	
ELEVATED TEMP (3)	144000	163000	16		
STRESS RUPTURE (2)			12		109.5 HOURS BROKE

* 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 COTI 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 9-7-76

PAGE 05 - FINAL PAGE.

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

CONSIGNEE: Please Note-This consignment was turned over to consignee in best possible condition, being correctly labeled, at which time carrier responsibility for loss or damage is assumed. Claimed for your protection please examine shipment at all arrival. If any shortage or damage is discovered, advise a full description made by consignee immediately on receipt before signing.

National Safety Data Sheets for this product have been
submitted to your Purchasing Department. For an additional copy,
phone 724-228-8577. CAUTION: Processing this material
burns, dusts, or solutions may cause lung disease. See National
Safety Data Sheets for further information.

WARNING Les données d'information données en ce prospectus ont été fournies à titre informatif seulement. Elles ne constituent ni une recommandation ni une sollicitation d'achat ou de vente de titres. Les investisseurs doivent effectuer leur propre analyse et prendre leur propre décision. Les données d'information données en ce prospectus ne constituent pas une offre de vente de titres. Les données d'information données en ce prospectus ne constituent pas une offre de vente de titres. Les données d'information données en ce prospectus ne constituent pas une offre de vente de titres.

[illegible]

37



500 Green Street
Washington, PA 15301

CERTIFIED MATERIAL
TEST REPORT
CERTIFICATE OF CONFORMANCE

OUR ORDER NO. PW03B6770
YOUR ORDER NO. T74040
MEMO NO. 361748-01
DATE 05/26/2010
SALESMAN NO. 424

BLM
43

48182

32

ALTEMP 718 HRAF
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)
06B516L03	03	15012	AAA	234006	.5000 x 48.0000 x 260.0000	1	1909 <i>IN 209304</i>
06B516L03	03	15012	AAB	234007	.5000 x 48.0000 x 258.0000	1	1895 <i>IN 209365</i>

Heat	C	MN	P	S	SI	NI	CR	MO	CO	CU	AL	TI	CB	B	FE
06B516L03	.048	.083	.008	.0001	.072	52.60	18.32	2.87	.20	.034	.54	1.02	4.94	.0029	19.25

06B516L03
TA
.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
			(A)	167.7 KSI	204.5 KSI	25.0		C044			
			(A&C)	140.2 KSI	166.1 KSI	28.0					
			(B)	160.8 KSI	200.2 KSI	27.0		C044			
			(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
			(A)	163.9 KSI	202.2 KSI	26.0		C043			
			(A&C)	139.8 KSI	164.9 KSI	29.0					
			(B)	172.5 KSI	204.6 KSI	24.0		C043			

PAGE 1 CONTINUE ON PAGE 2

REVIEWED BY Q.C.
Date 8/30/12 By *[Signature]*

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 W01TR0 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.



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. Test	Yield Strength	Tensile Strength	Elong %	Red. of Area %	Hardness	Bend	Corrosion	Grain Size
Lot No: 234006	(D)	STRESS RUPTURE - HRS BROKE	145.0 KSI	167.8 KSI	22.0					
Lot No: 234006	(E)	STRESS RUPTURE - HRS BROKE	145.0 KSI	167.8 KSI	22.0					
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	145.0 KSI	167.8 KSI	22.0					
Lot No: 234007	(E)	STRESS RUPTURE - HRS BROKE	145.0 KSI	167.8 KSI	22.0					
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, UPLDAD 5 KSI/8-10 HRS AFTER 23 HRS

(E) STRESS RUPTURE PER AMS 5596 & ASTM B670; UPLDAD 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: 9-7-2010

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 W00TRD 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, CO, V, BY WDXRF; B BY OES; AL AND TI (1-10 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.

CERTIFICATION OF TESTS • RAPPORT D'ESSAIS CERTIFIÉ • WERKSZEUGNIS												CUSTOMER COPY																	
Sales Order No. Reference Commande Bestellungs Nr.		Date Entered Date De Commande Bestelldatum		Customer Reference Reference Client Kundenbestell-Nr.		Report No. Rapport No. Zusammen Nr.		Pages of Pages Page de Page Anzahl der Seiten		HAYNES International		Haynes International 1020 West Park Avenue PO Box 9013 Kokomo, Indiana, 46902																	
580571001-0		03/18/10		T74082		20100821006		2 Of 3																					
Tensile Test at Room Temperature • Essai De Traction A Temp. Ambiante • Zugversuch Bei Raum Temp.						Tensile Test at Elevated Temperature • Essai De Traction A Hot Temp. Warm Zugversuch						Stress Rupture Temperature • Essai A Charge De Rupture Zélatendversuch																	
Ultimate Zugfestigkeit	1% Yield Lim. Elast. A 1% 1% Streckgrenze	0.2% Yield Lim. Elast. A 0.2% 0.2% Streckgrenze	% Elong In N. Elong EN % Dehnung	N/A	N/A	Temp.	Yield Zugfestigkeit	1% Yield Lim. Elast. A 1% 1% Streckgrenze	0.2% Yield Lim. Elast. A 0.2% 0.2% Streckgrenze	% Elong In N. Elong EN % Dehnung	N/A	Temp.	Yield Zugfestigkeit	1% Yield Lim. Elast. A 1% 1% Streckgrenze	0.2% Yield Lim. Elast. A 0.2% 0.2% Streckgrenze	% Elong In N. Elong EN % Dehnung	N/A												
131000 PSI 208500 PSI 206000 PSI		53500 PSI 179000 PSI 167000 PSI	50 % 21 % 21 %		1(A) 1(B) 1(C)	1200 °F 1200 °F	170000 PSI 166000 PSI		149000 PSI 138000 PSI	23 % 22 %	1(B) 1(C)	1200 °F 1200 °F	105000 PSI 105000 PSI	206.7 HRS 118.7 HRS	17 % 30 %		1(B)* 1(C)*												
Asme Hardness Dureté Rockwell Gefühlte Härte						Grain Size Grosser De Grain Korngrösse						IGA		Uniformity		Corrosion Rate		Oxidation Rate		Charpy Impact Test				Creep Rupture					
Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse	Rockwell Dureté Rockwell Gefühlte Härte	Grain Size Grosser De Grain Korngrösse
95 HRBW 45 HRC 43 HRC	1(A) 1(B) 1(C)	6.5 6.5 100	0 0 6	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1

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

8/21/2010 1) 2758057101

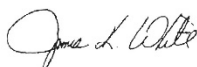
American Special Metals
Quality Assurance
Approved: AC
Date: 9-2-2010

Figure A.4.—Continued.

CERTIFICATION OF TESTS • RAPPORT D'ESSAIS CERTIFIÉ • WERKSZEGNYIS					HAYNES International	CUSTOMER COPY Haynes International 1020 West Park Avenue PO Box 9013 Kokomo, Indiana, 46902
Sub Order No. Référence Commande Bestellungs Nr.	Date Entered Date de Commande Bestellungsdatum	Customer Reference Référence Client Kundenbestellnummer	Report No. Rapport No. Zugangs Nr.	Page of Pages Page de Pages Anzahl der Seiten		
580571001-0	03/18/10	T74082	20100821006	3 Of 3		

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 furnished to PWA 900 and PWA 465 as per MCT-F-177- (5536)
 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 C1 F condition and material supplied to C1E condition.
 Samples tested to B50TF14 C1B condition and material supplied to C1A condition.
 All aged test specimens are aged after final machining.
 Mill Orders Used: 2258057101 (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. (A1B,Cr,P,Si); LECO (C,S); XARL DIRECT RATIO (Ch,Fe); XARL LINFIT (CBTA,Cu,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 Hrs Total Time: 18 Hrs
 C) 1725 °F to 1825 °F; Step 1: 1750 °F, 1 Hr; Step 2: 1325 °F, 8 Hrs; Step 3: 1150 °F, 8 Hrs Total Time: 18 Hrs

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



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

Customer: F A A
 Customer PO# DT FACT-10-P-00240
 ASM Work Order# 2010-H-12311
 Qty. 6 Pieces
 Date 9-2-2010
 Q.C. Certification Clerk

THE DATA CONTAINED HEREIN WAS OBTAINED FROM SAMPLES THAT ARE REPRESENTATIVE OF THE PRODUCTS IN THIS SUBJECT PURCHASE. THIS MATERIAL WITH THE SIGNATURE OF THE LETTERS SPECIFICALLY IDENTIFIED BY ANY EXCEPTION OR PURCHASE UNDER THIS IDENTIFYING NUMBER. THE DATA CONTAINED HEREIN IS NOT TO BE USED FOR ANY OTHER PURPOSES. THE DATA CONTAINED HEREIN IS NOT TO BE USED FOR ANY OTHER PURPOSES. THE DATA CONTAINED HEREIN IS NOT TO BE USED FOR ANY OTHER PURPOSES.

Figure A.4.—Continued.



500 Green Street
Washington, PA 15301

CERTIFIED MATERIAL
TEST REPORT
CERTIFICATE OF CONFORMANCE

OUR ORDER NO. FW03B6770 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-12311

Qty 1 Piece

JS 9-2-2010
Q.C. Certification Clerk 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 LEECHSBURG, PA FACILITIES OR A NADCAP AND ISO/IEC 17025 ACCREDITED LABORATORY. EN 10204 - 3.1 ALLEGHENY LUDLUM IS APPROVED AS MANUFACTURER ACCORDING TO AC-MERKBLATT W02TRD 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, BI, CR, NI, MO, CU, CB, CO, V, BY WDXRF; B BY OES; AL AND TI ($\leq 0.10\%$) BY WDXRF, OTHERWISE BY OES. PB, SI, AG BY GPAA.

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

Material: other

We are pleased to provide you with the following certification.

Quantity	Part Number / Part Name / Part Description	Pounds
1	Inconel 718 Inconel 718 Mat'l Plates 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.

HTI 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 TREATING, 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 CONSIDERED 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.
Notions for storage in weight or count will be maintained unless presented in writing within five (5) business days after receipt of materials by the Buyer. No claims will be allowed for shrinkage, expansion, deformation, or rupture of material in handling or transportation, 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 customer 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 its 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 the 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 (excluding 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 acknowledgment 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.
Copyright 2011 © Metal Treating Institute. All Rights Reserved.

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.

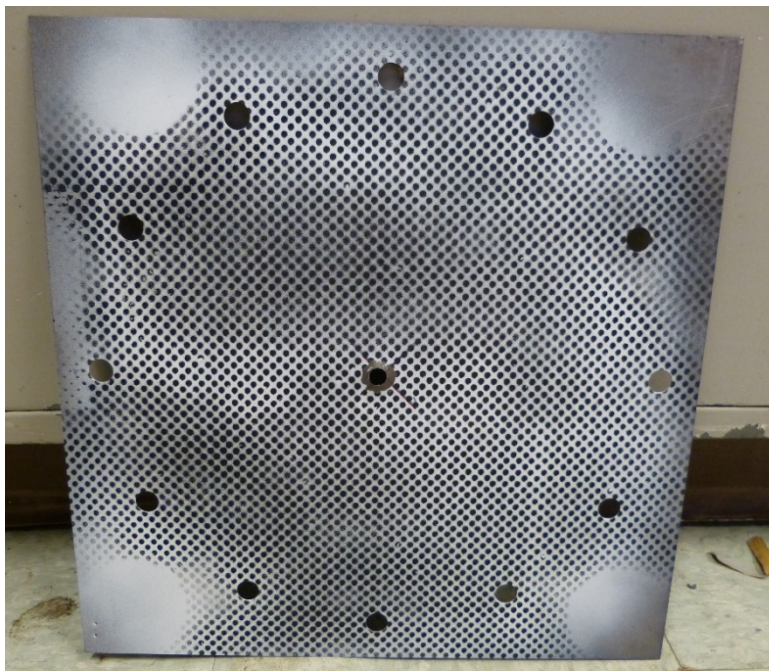


Figure C.2.—DB232 posttest rear view.

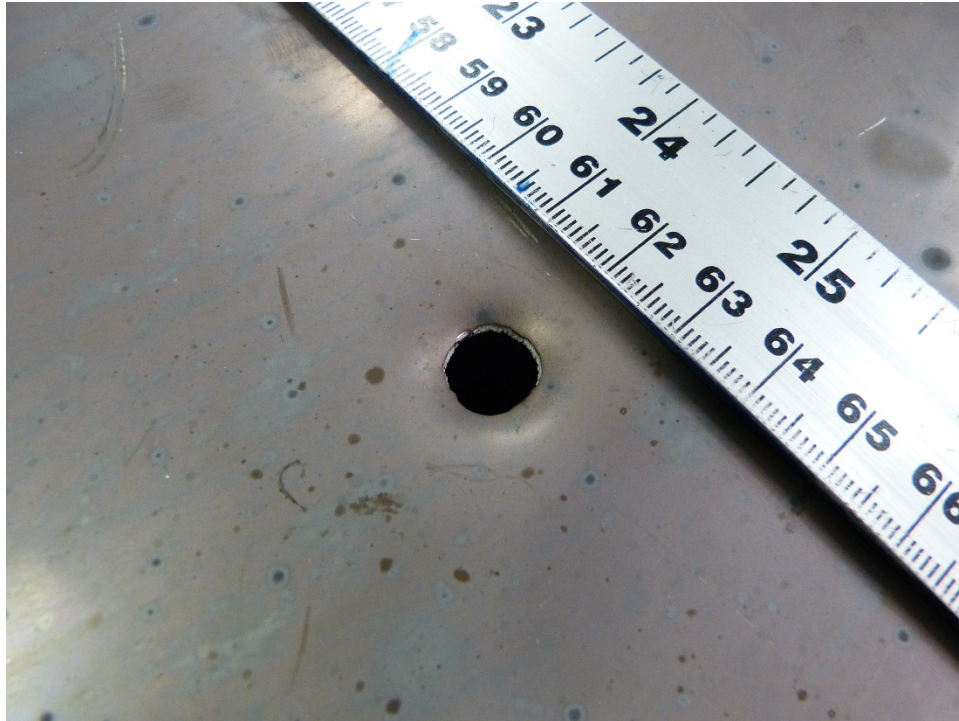


Figure C.3.—DB232 posttest front view closeup.

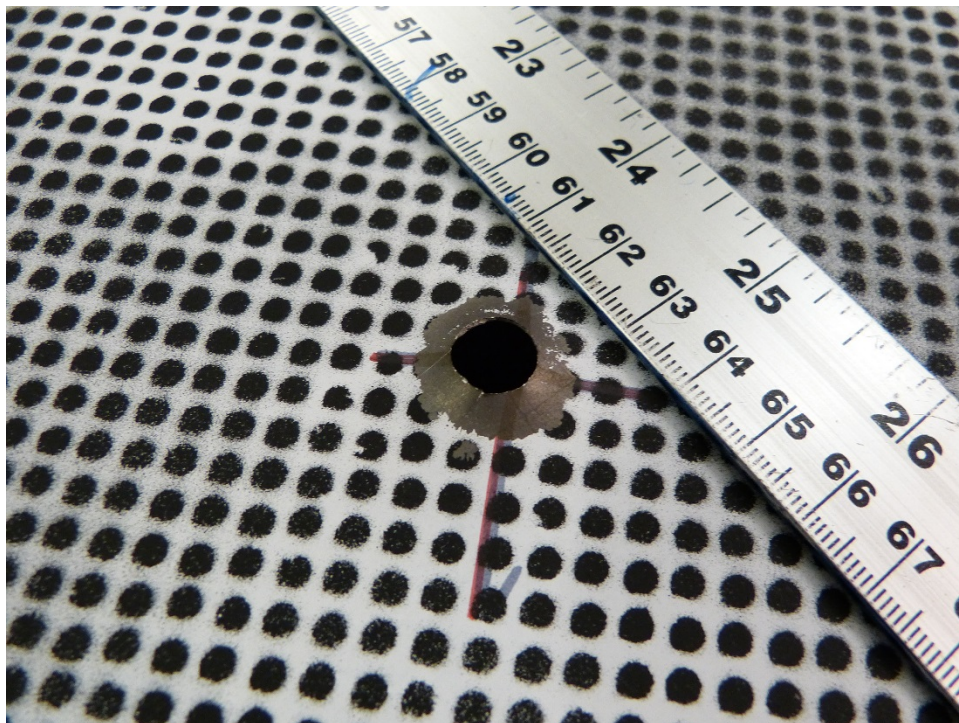


Figure C.4.—DB232 posttest rear view closeup.

Test DB234

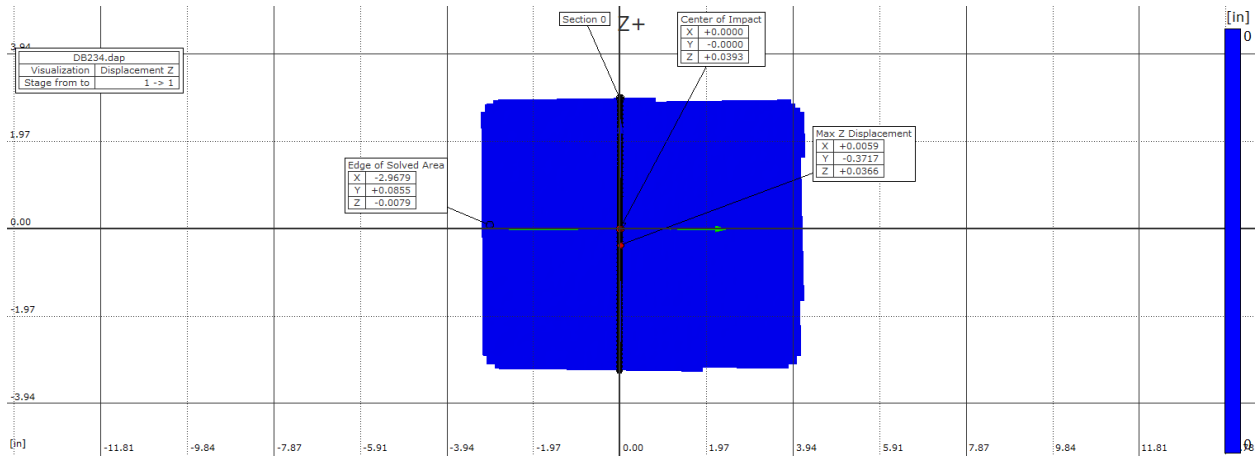


Figure C.5.—DB234 locations of digital image correlation (DIC) measurements.

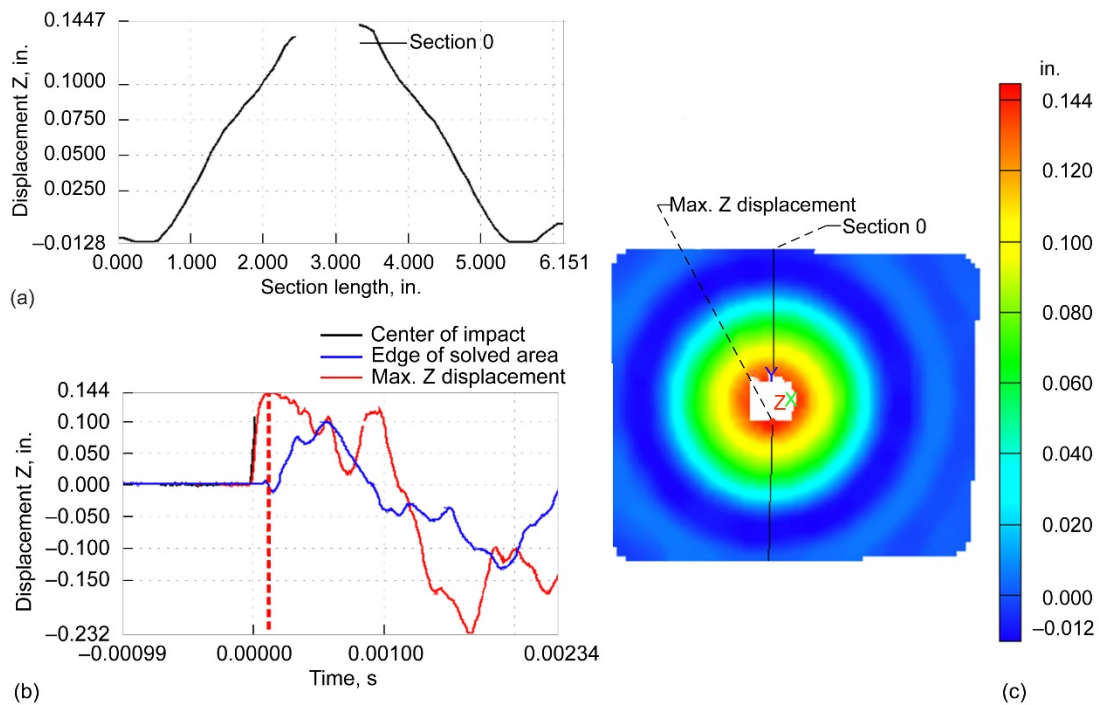


Figure C.6.—DB234 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



Figure C.7.—DB234 pretest front view.

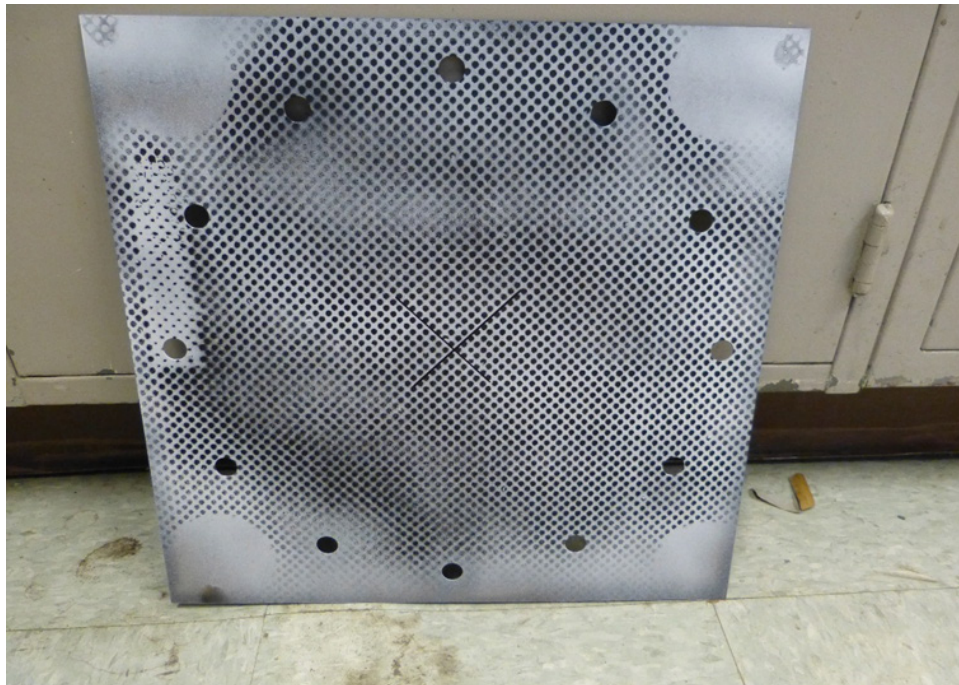


Figure C.8.—DB234 pretest rear view.

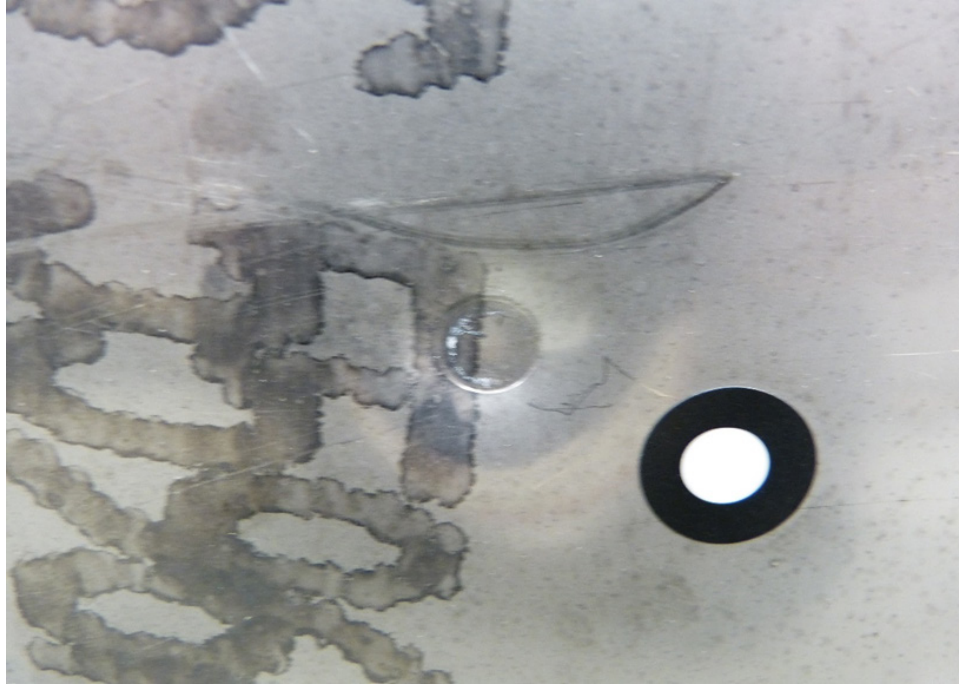


Figure C.9.—DB234 posttest front view closeup.

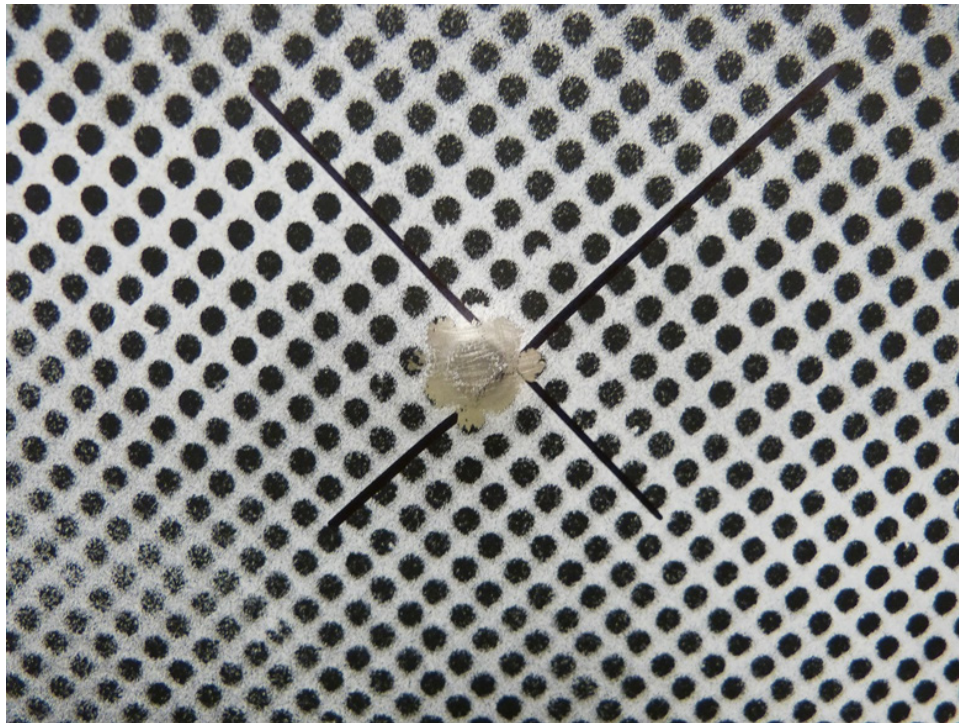


Figure C.10.—DB234 posttest rear view closeup.

Test DB235

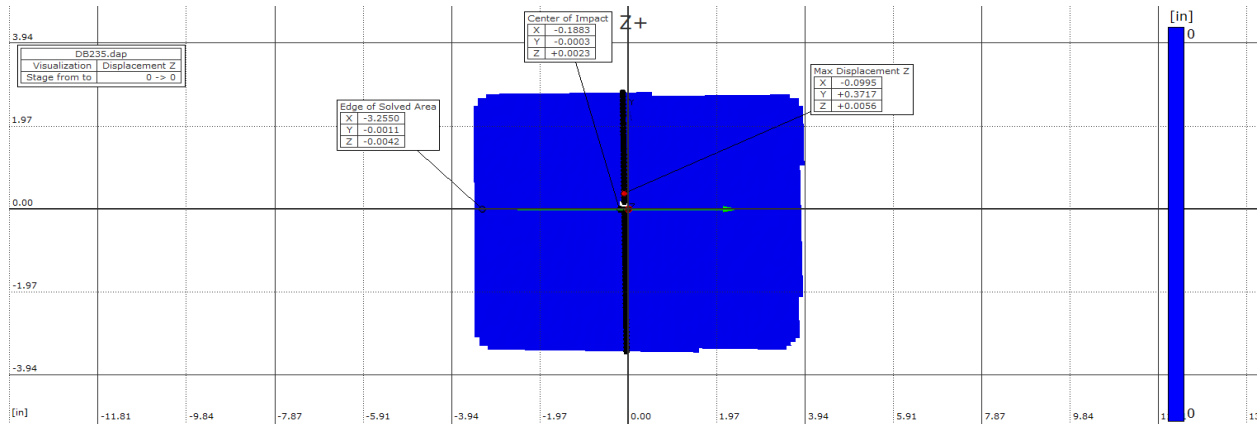


Figure C.11.—DB235 locations of digital image correlation (DIC) measurements.

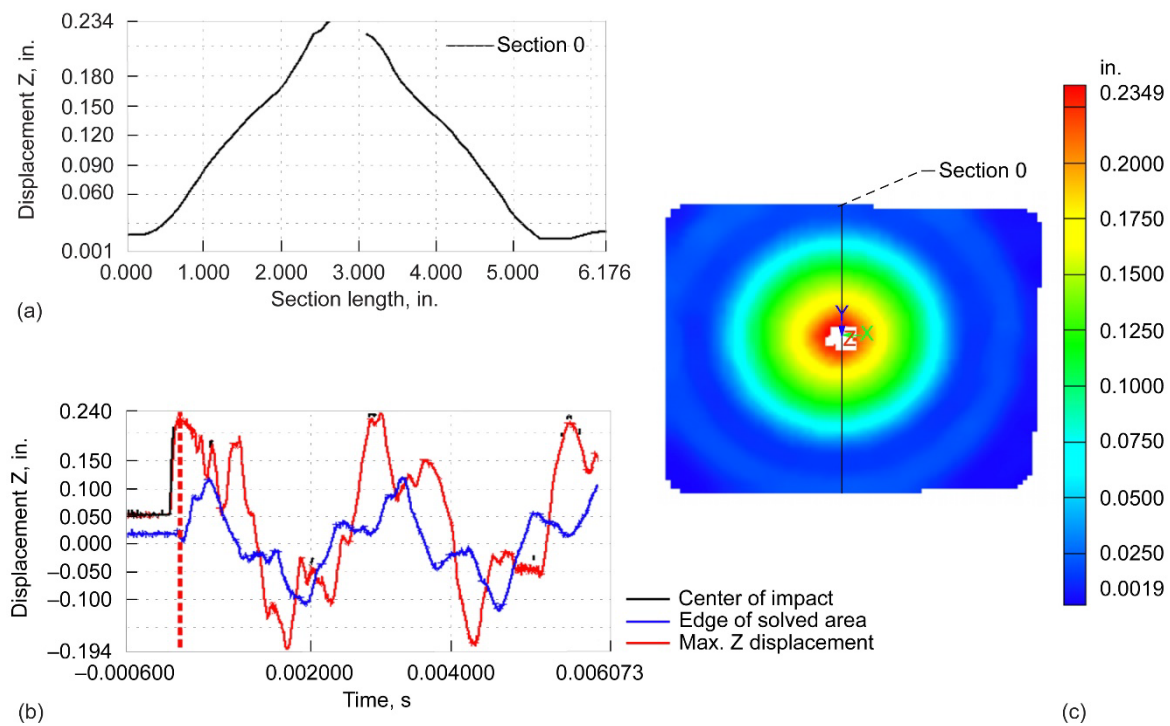


Figure C.12.—DB235 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

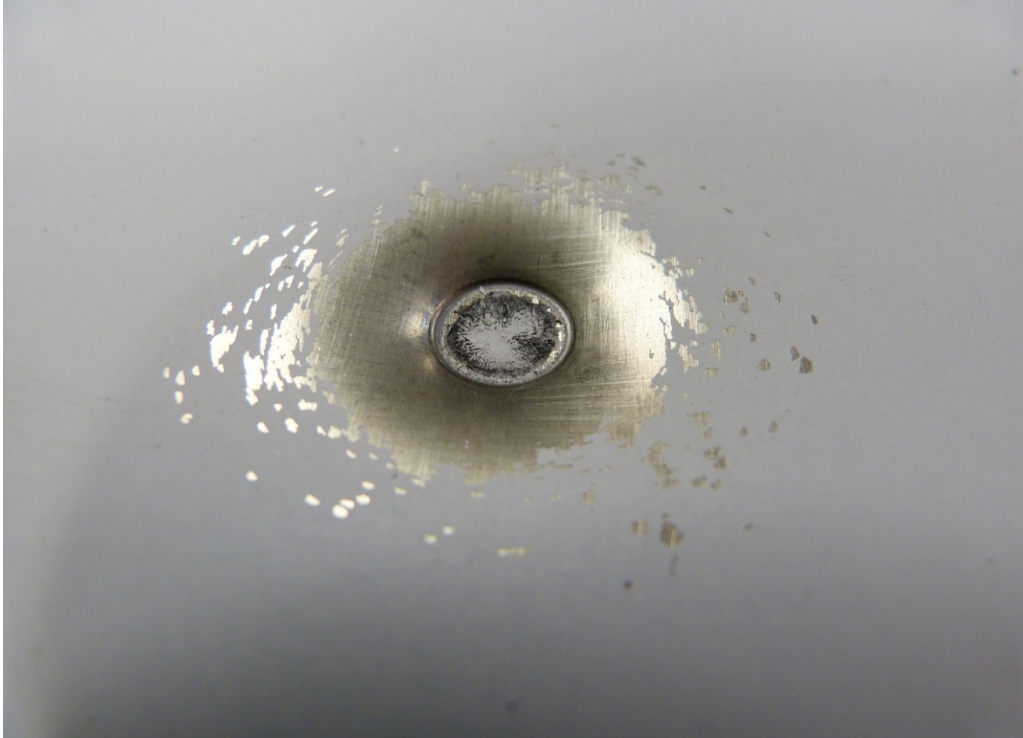


Figure C.13.—DB235 posttest front view closeup.

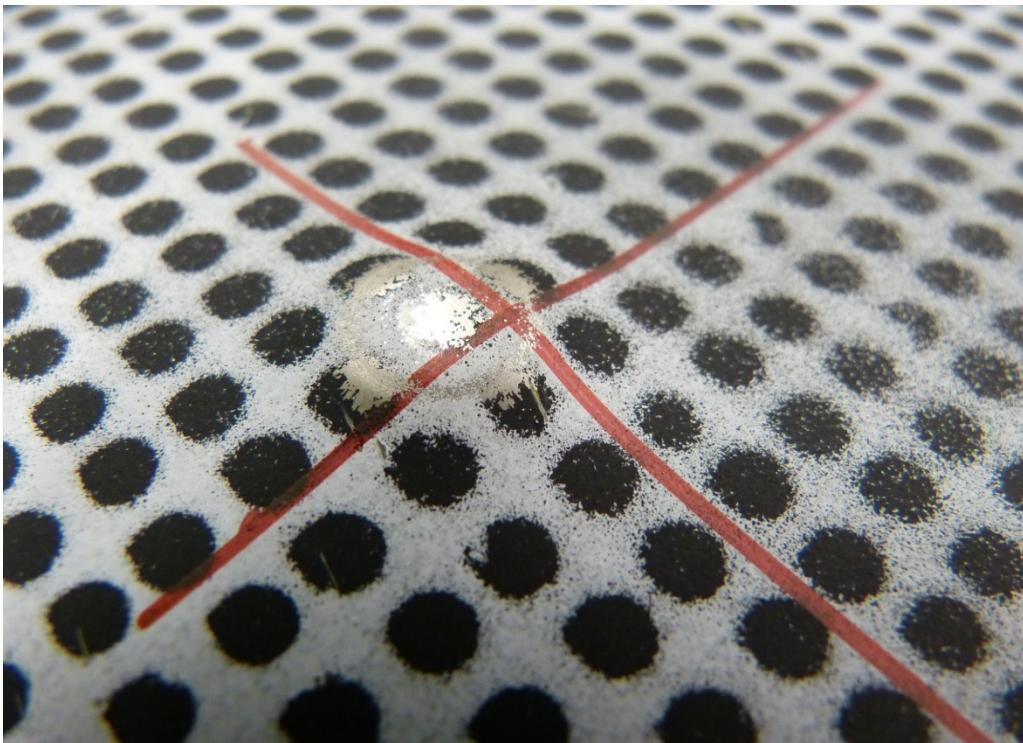


Figure C.14.—DB235 posttest rear view closeup.

Test DB236

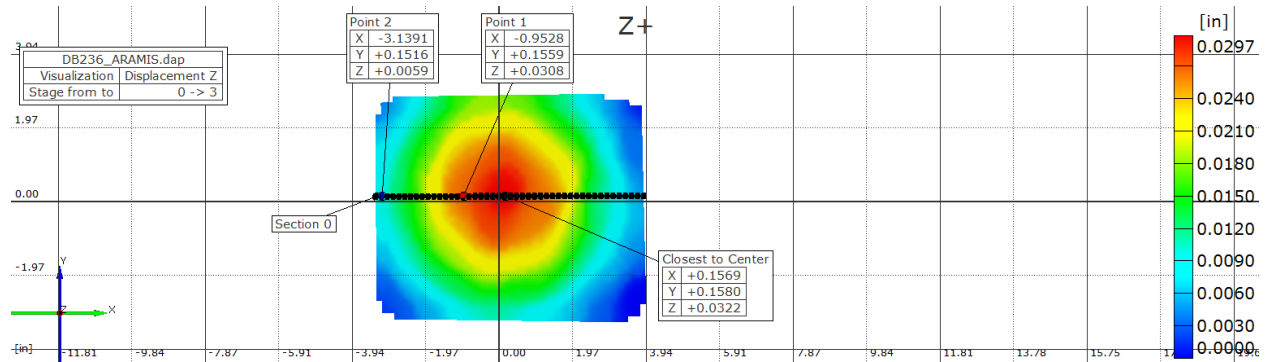


Figure C.15.—DB236 locations of digital image correlation (DIC) measurements.

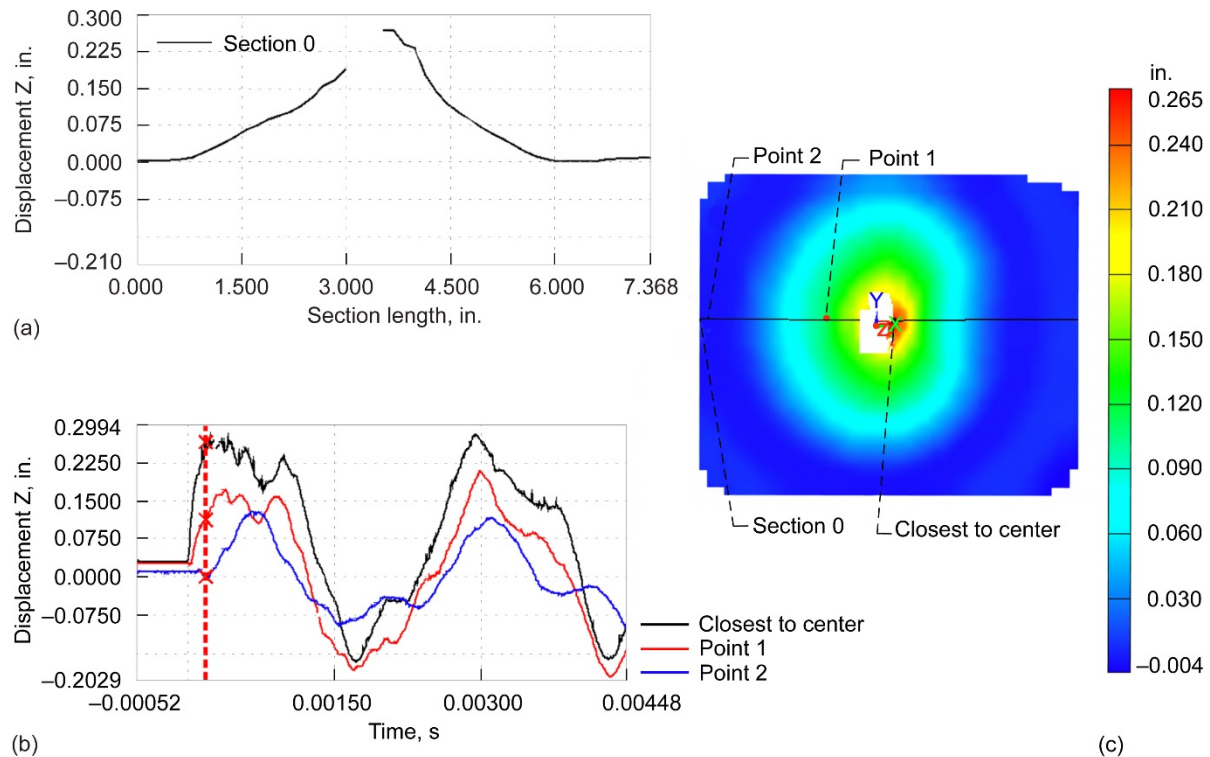


Figure C.16.—DB236 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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



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

Test DB237

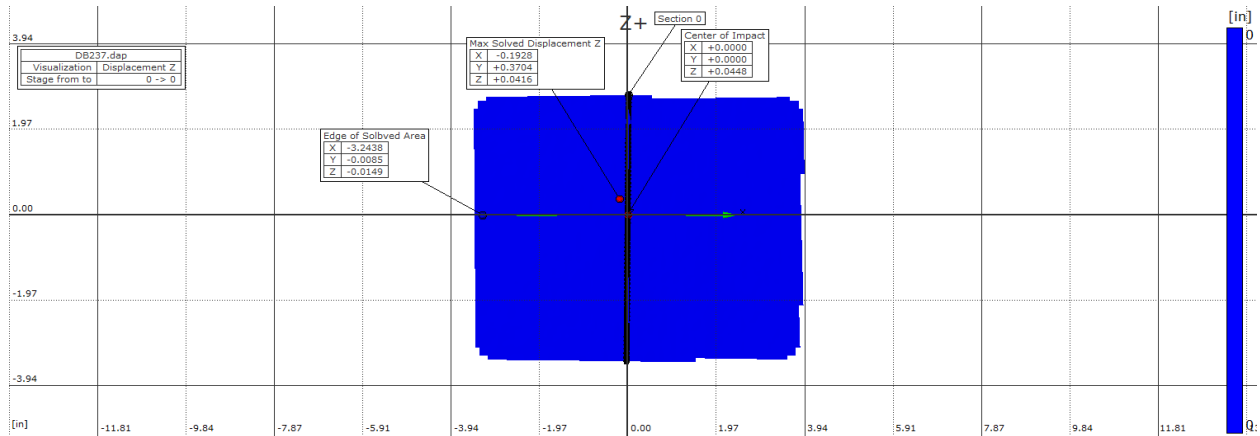


Figure C.19.—DB237 locations of digital image correlation (DIC) measurements.

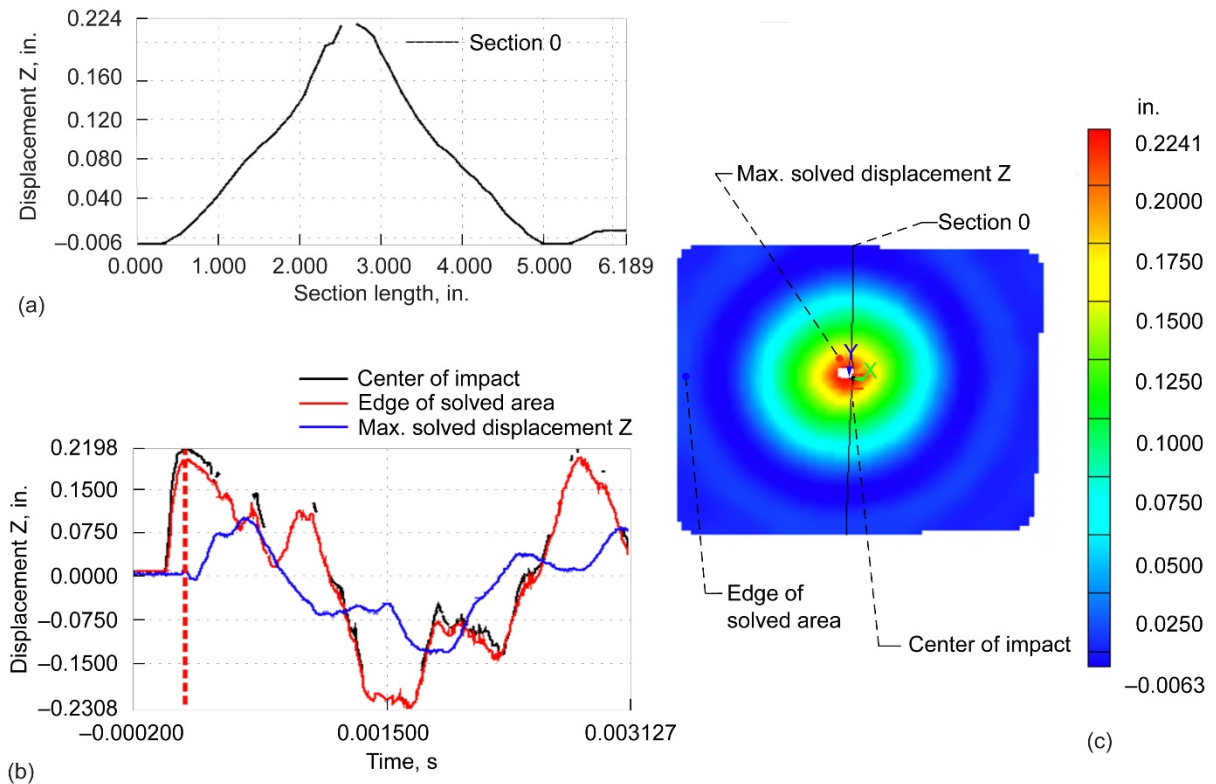


Figure C.20.—DB237 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

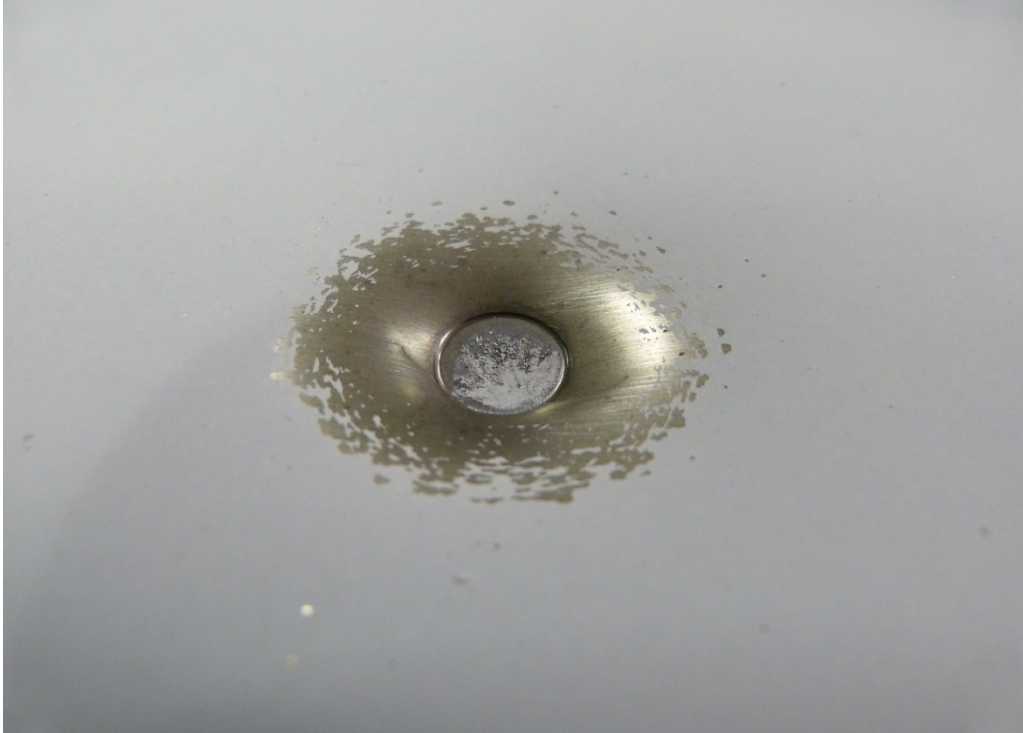


Figure C.21.—DB237 posttest front view closeup.

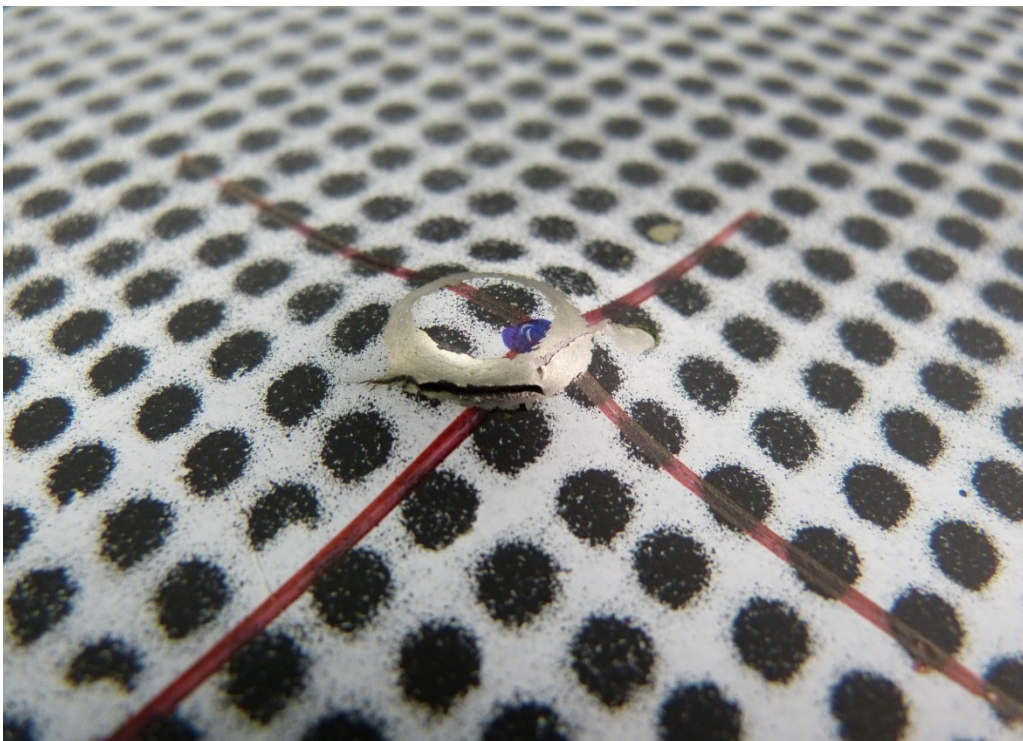


Figure C.22.—DB237 posttest rear view closeup.

Test DB238

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

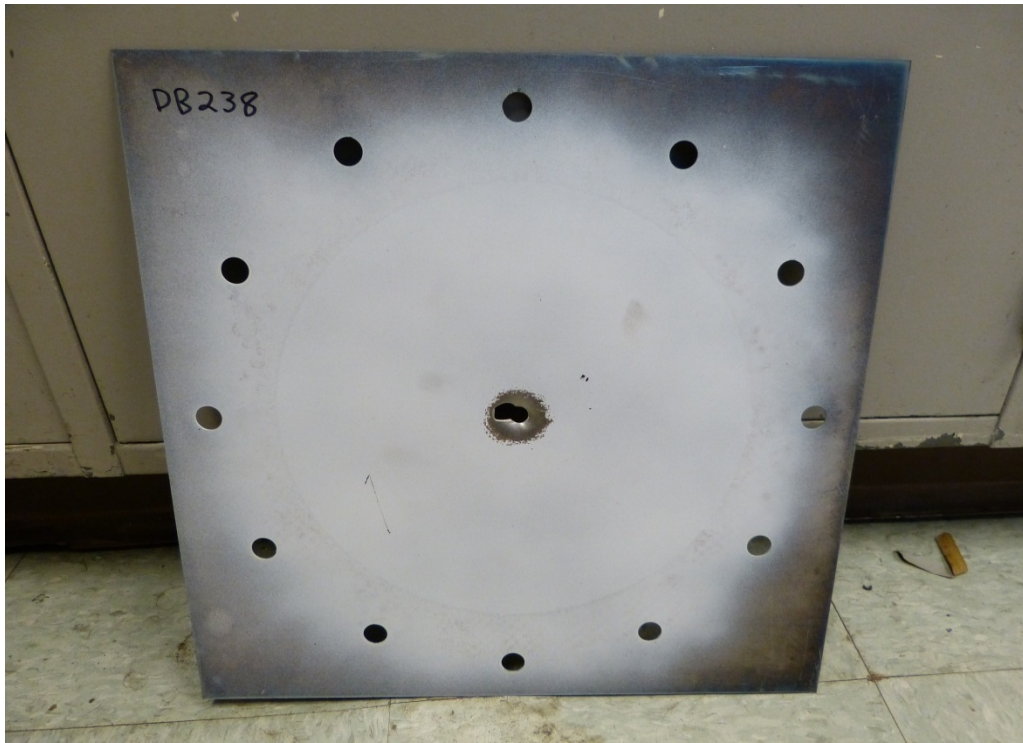


Figure C.23.—DB238 posttest front view.

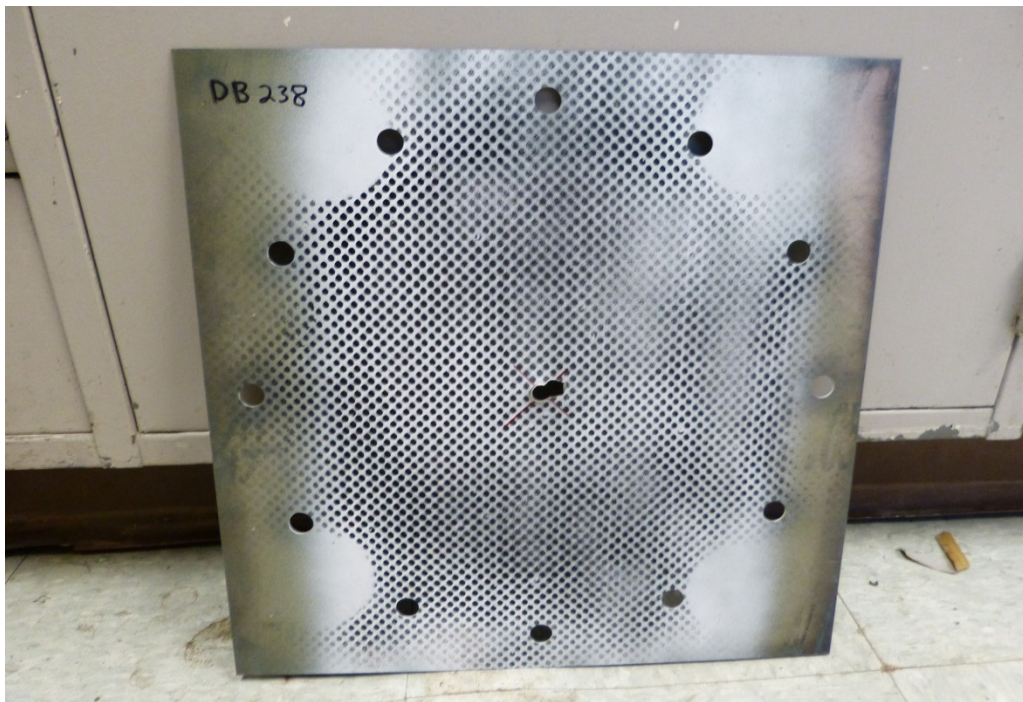


Figure C.24.—DB238 posttest rear view.



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

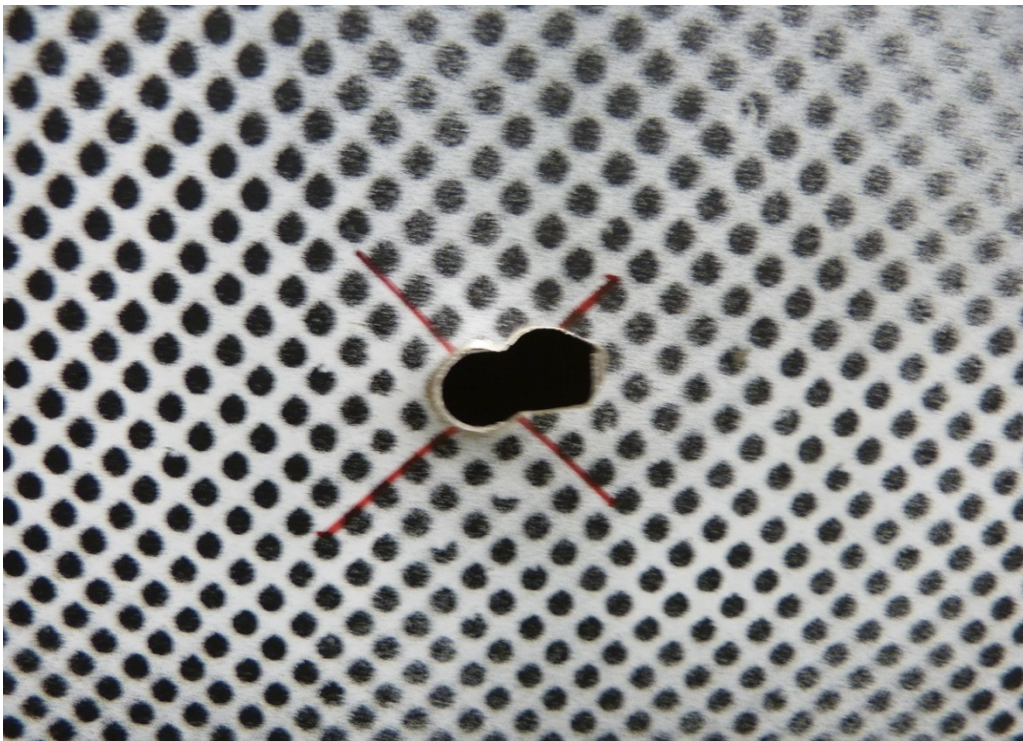


Figure C.26.—DB238 posttest rear view closeup.

Test DB239

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

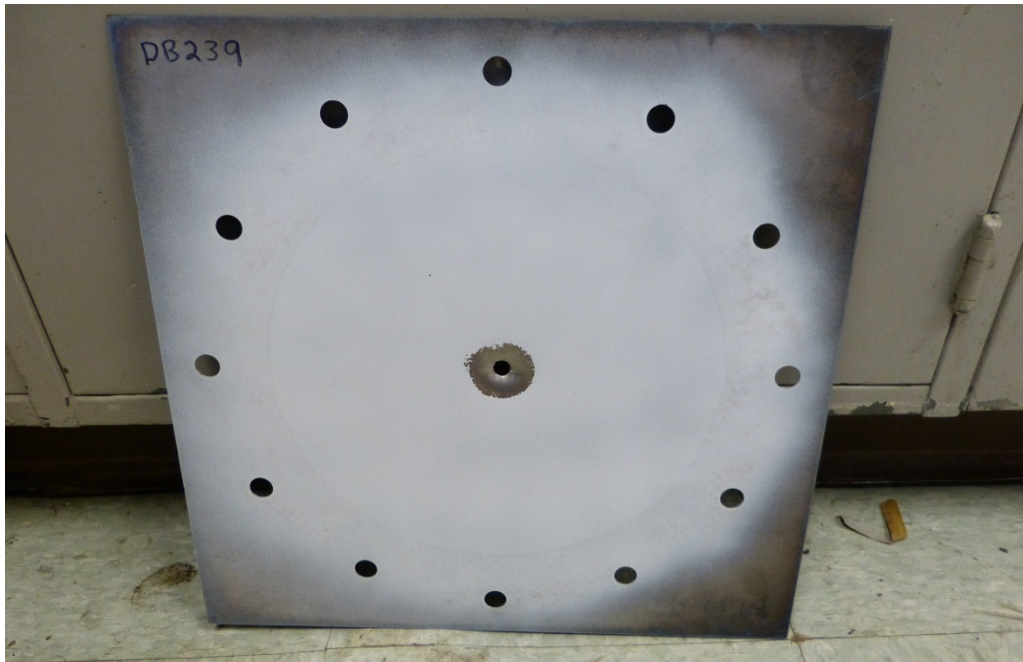


Figure C.27.—DB239 posttest front view.

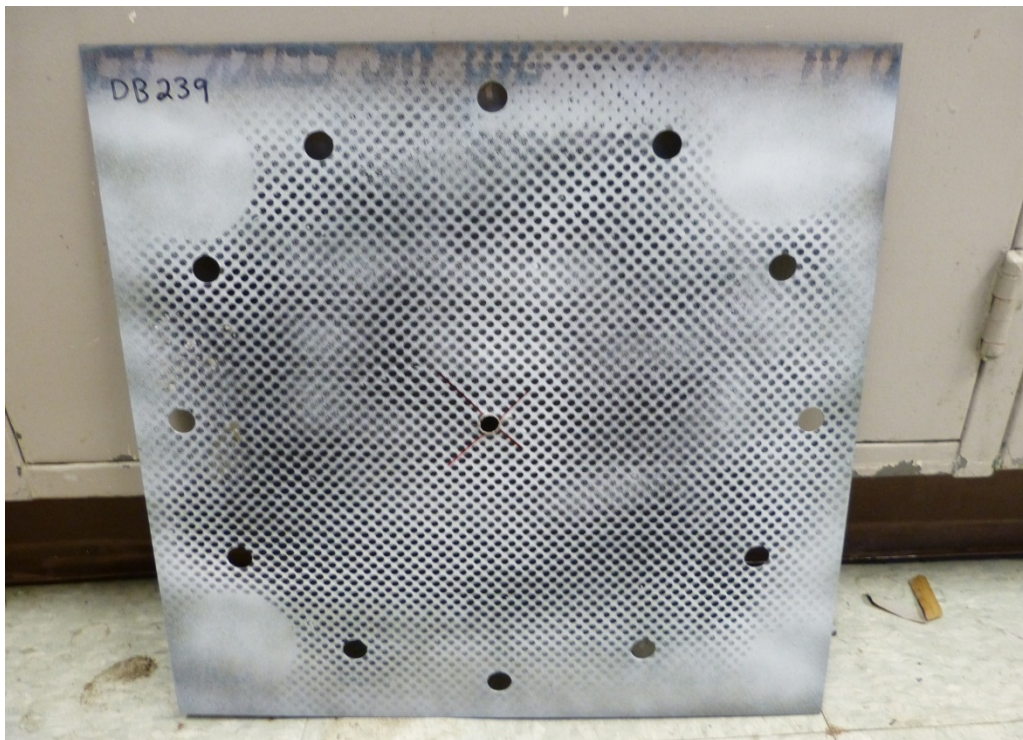


Figure C.28.—DB239 posttest rear view.

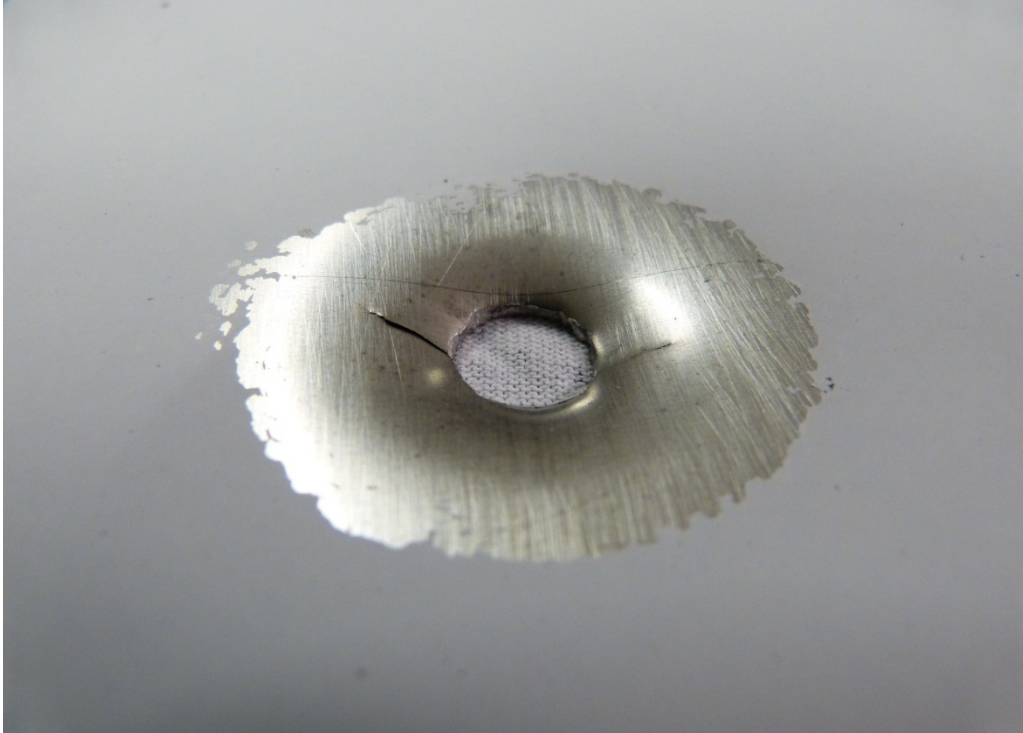


Figure C.29.—DB239 posttest front view closeup.

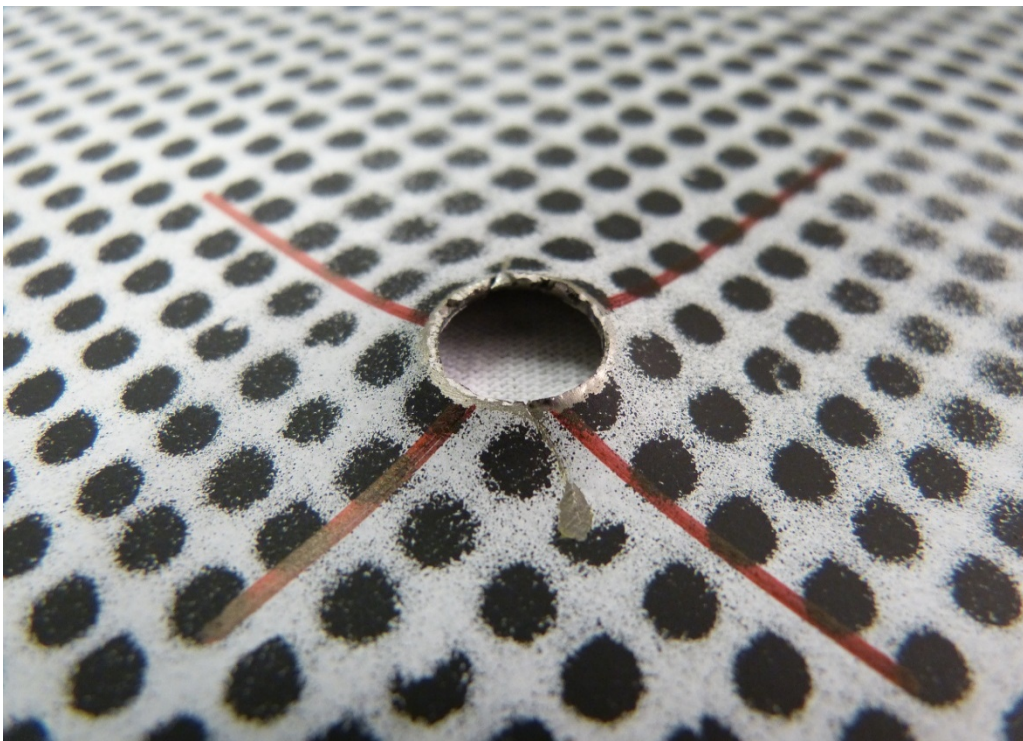


Figure C.30.—DB239 posttest rear view closeup.

Test DB240

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

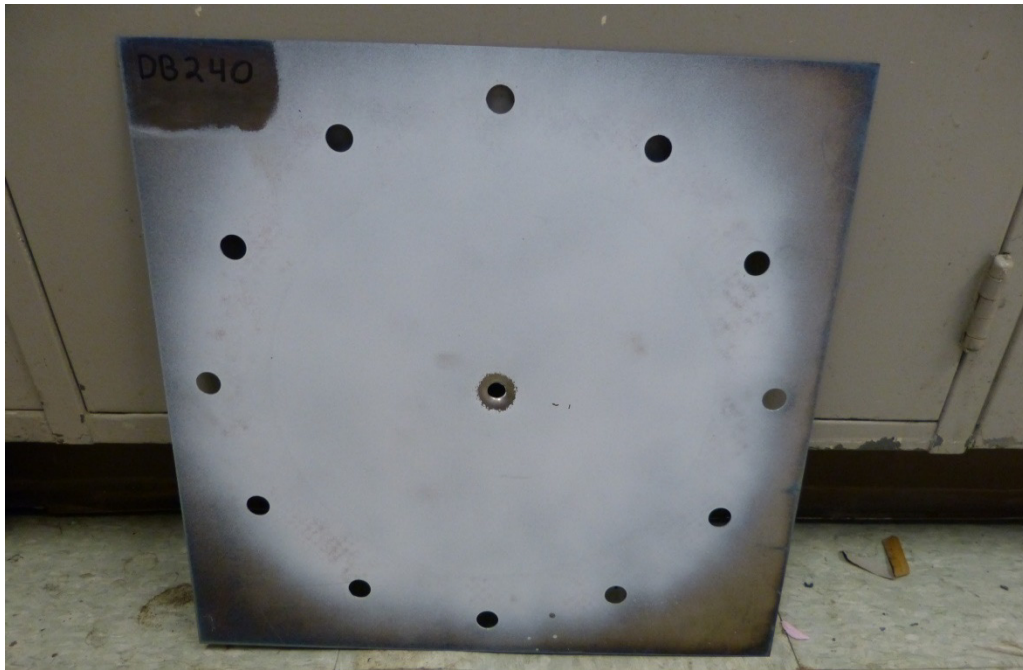


Figure C.31.—DB240 posttest front view.

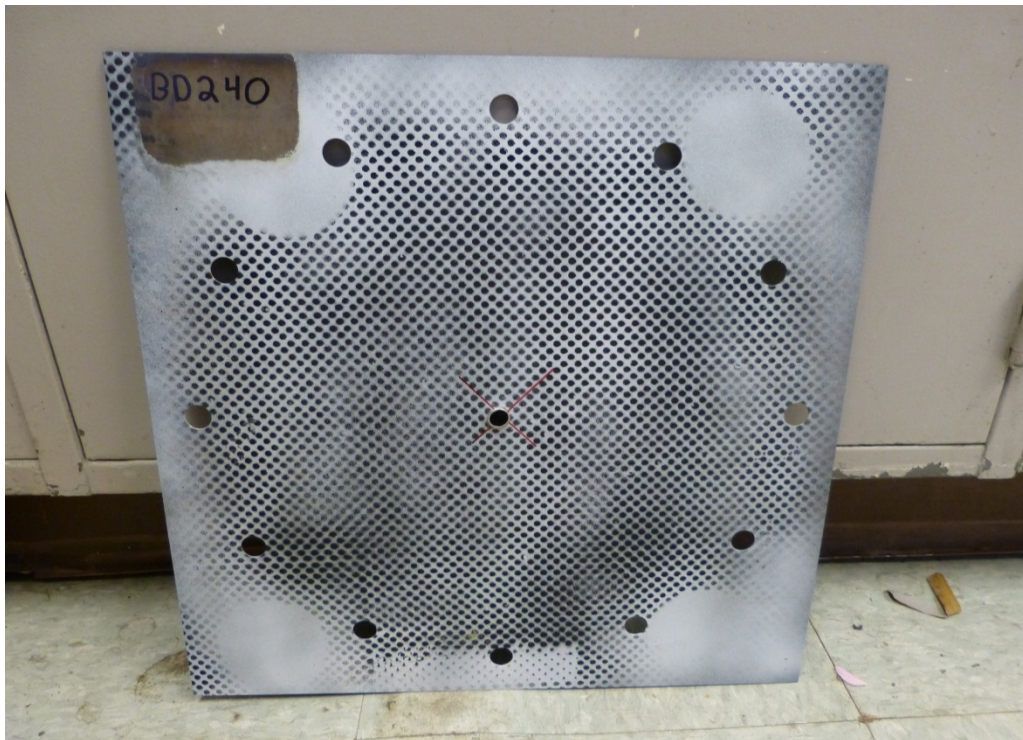


Figure C.32.—DB240 posttest rear view.



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

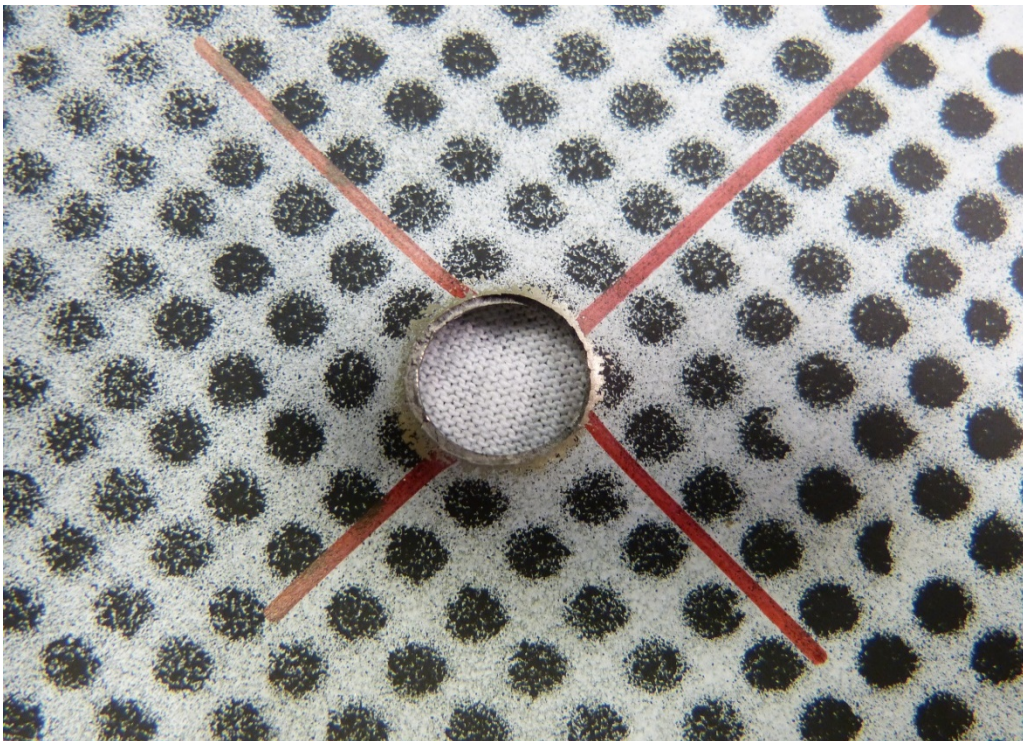


Figure C.34.—DB240 posttest rear view closeup.

Test DB241

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



Figure C.35.—DB241 posttest front view.

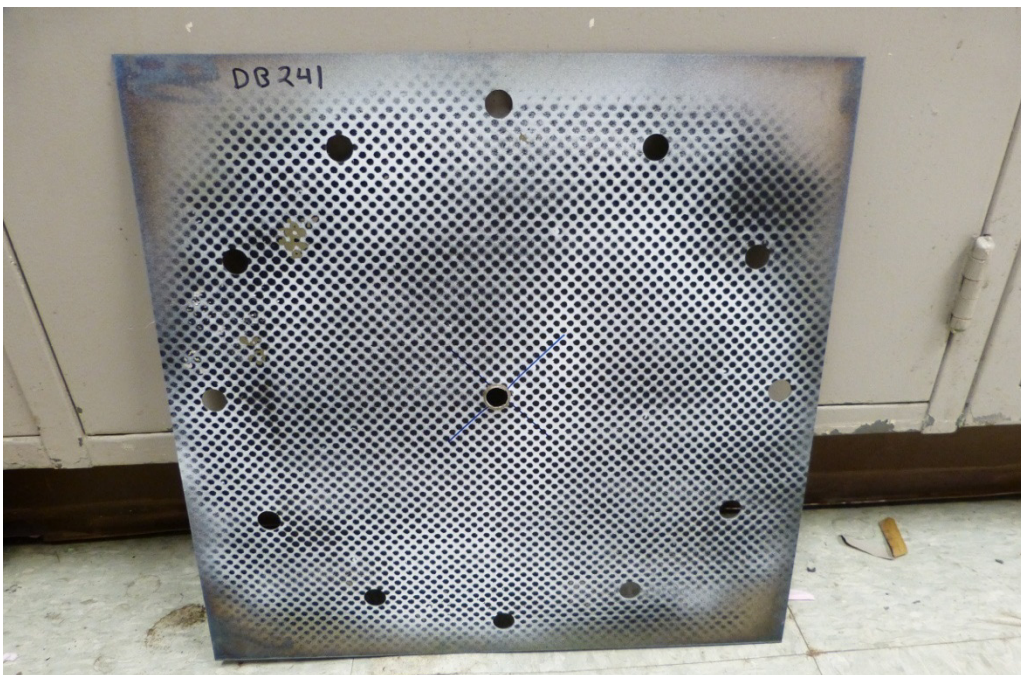


Figure C.36.—DB241 posttest rear view.

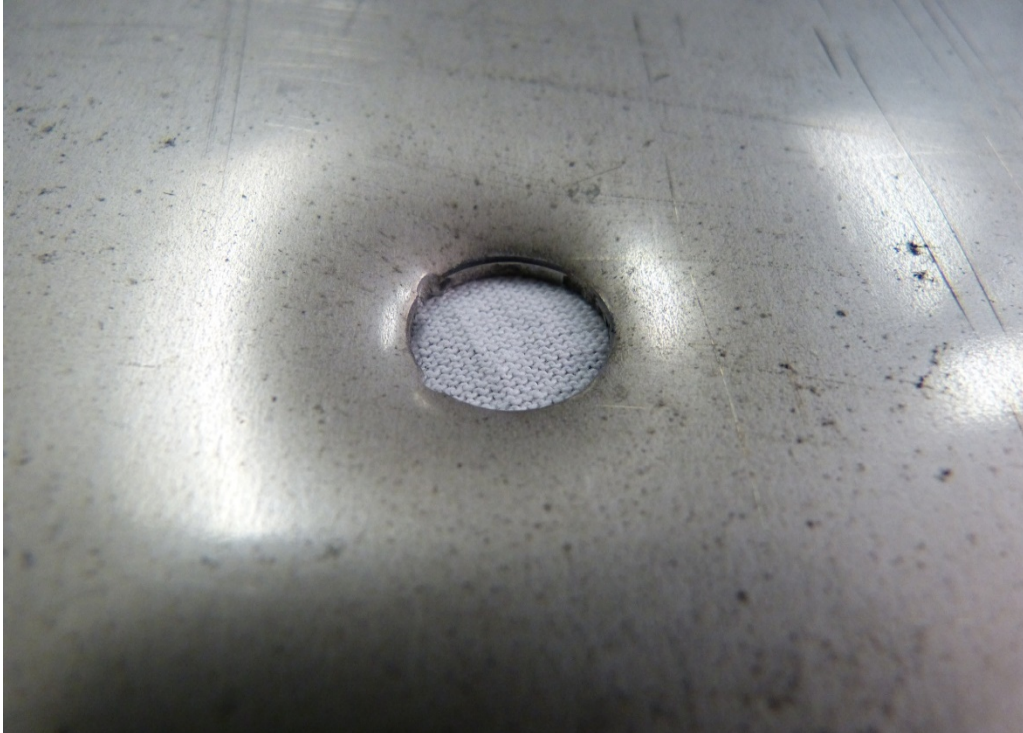


Figure C.37.—DB241 posttest front view closeup.

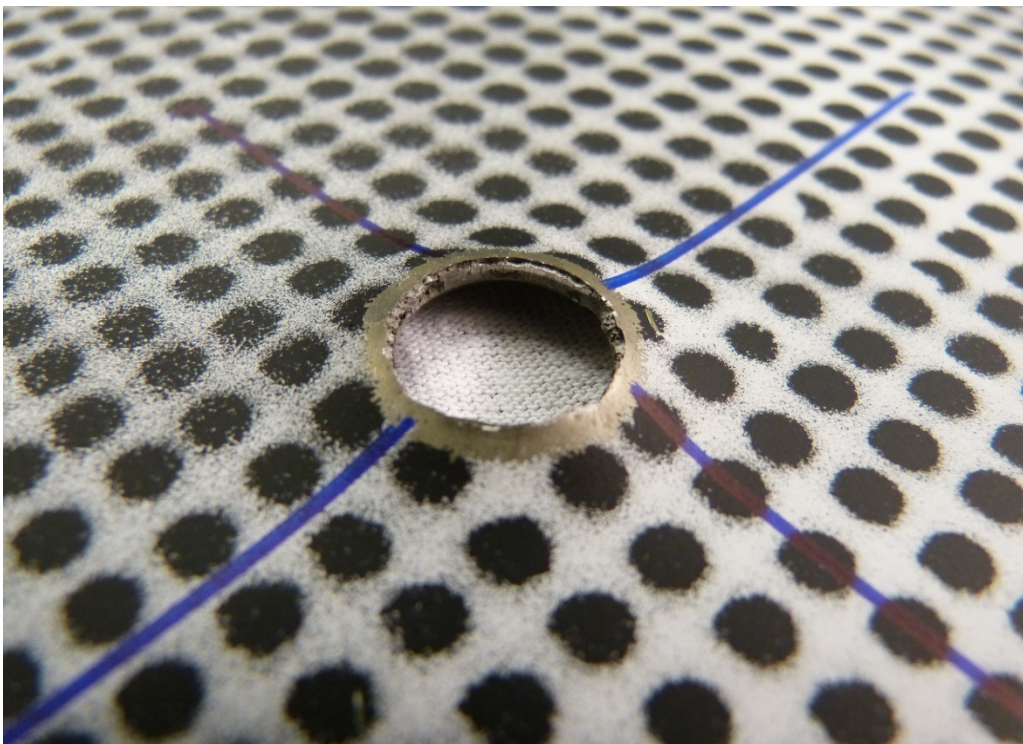


Figure C.38.—DB241 posttest rear view closeup.

Test DB242

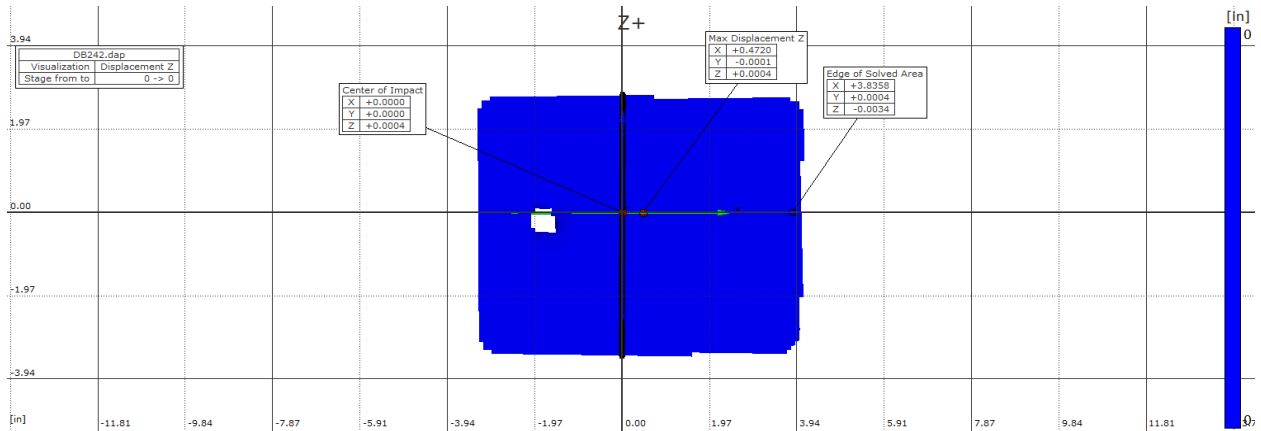


Figure C.39.—DB242 locations of digital image correlation (DIC) measurements.

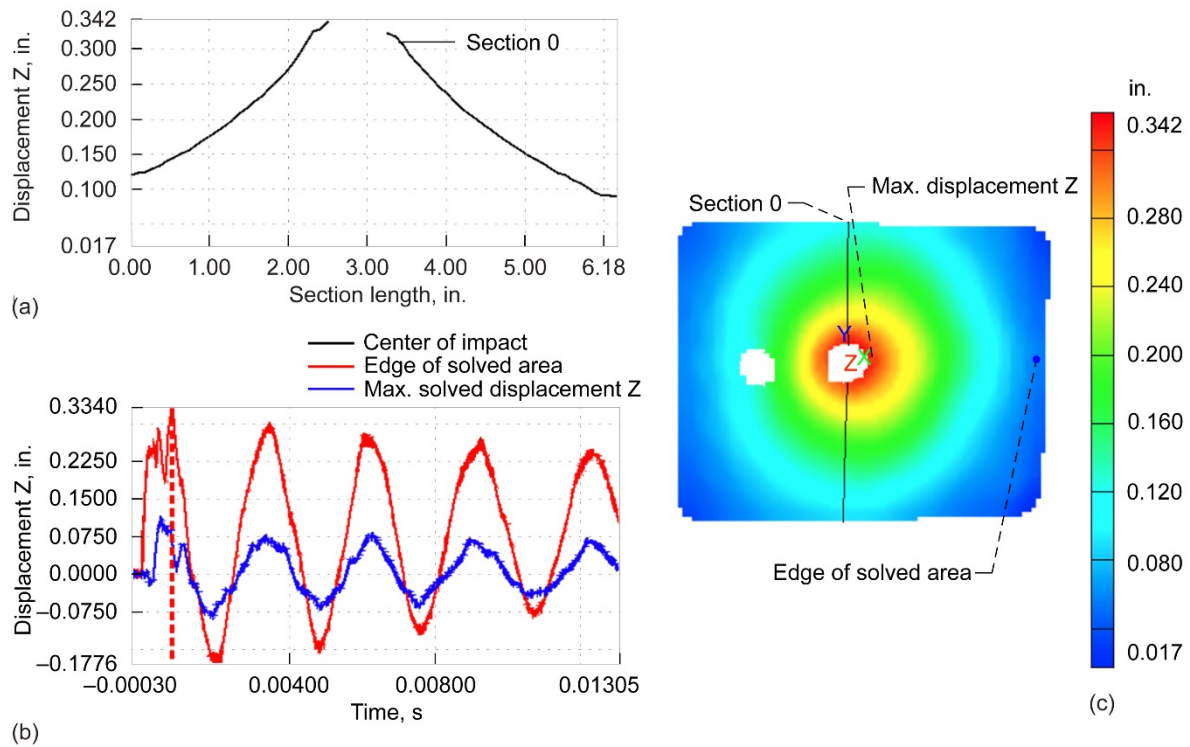


Figure C.40.—DB242 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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



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

Test DB243

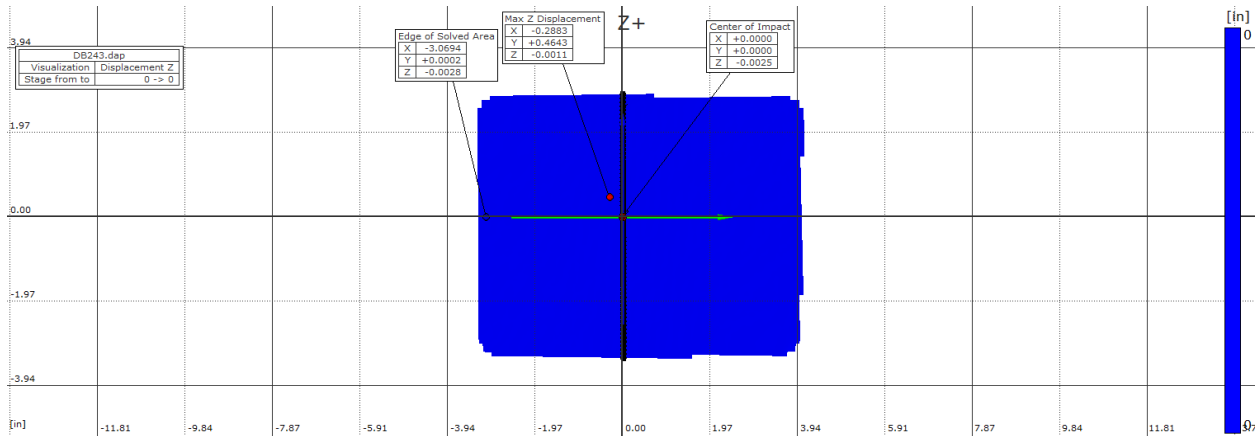


Figure C.43.—DB243 locations of digital image correlation (DIC) measurements

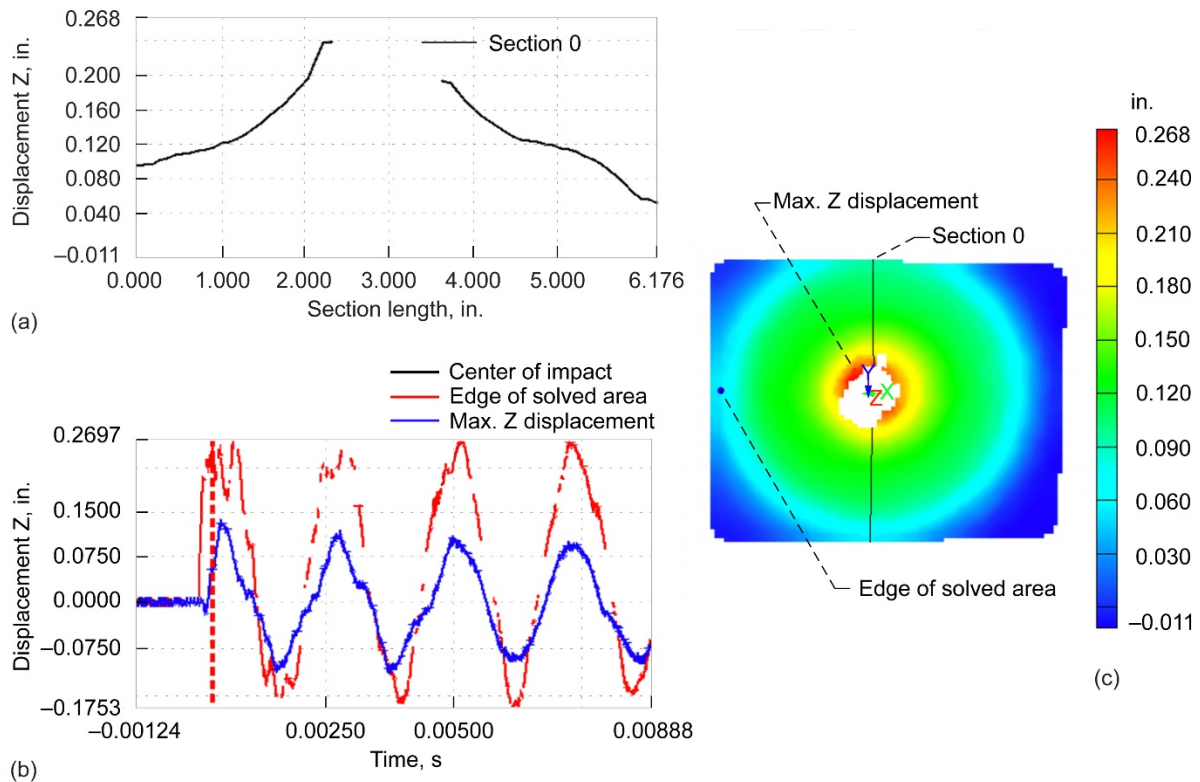


Figure C.44.—DB243 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

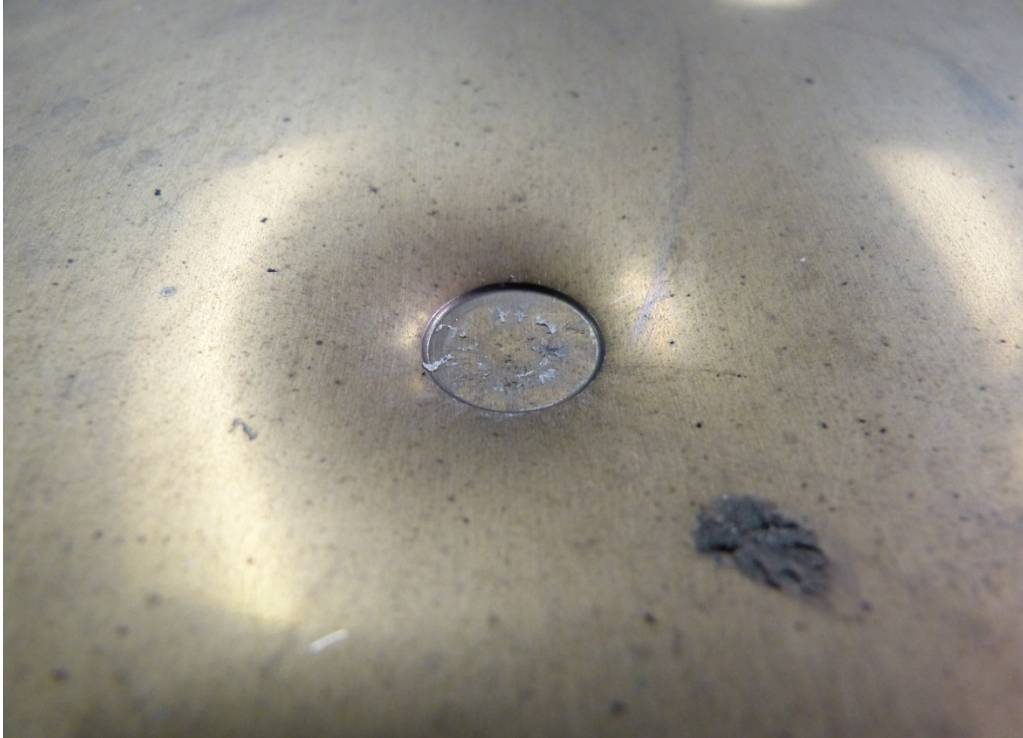


Figure C.45.—DB243 posttest front view closeup.

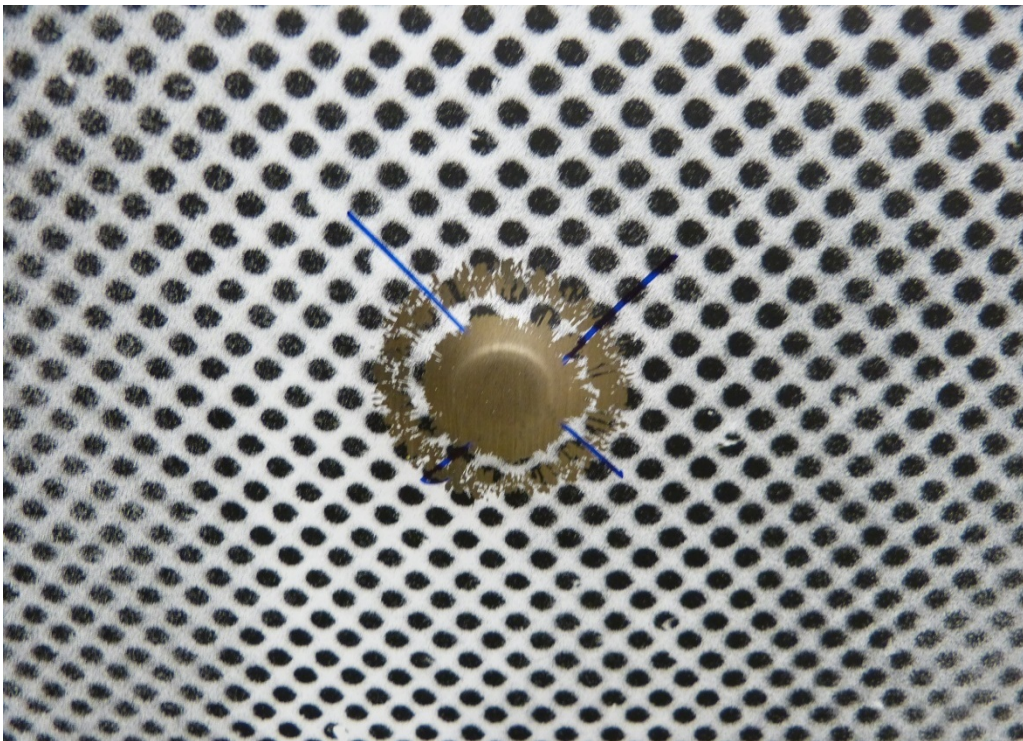


Figure C.46.—DB243 posttest rear view closeup.

Test DB244

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



Figure C.47.—DB244 posttest front view.

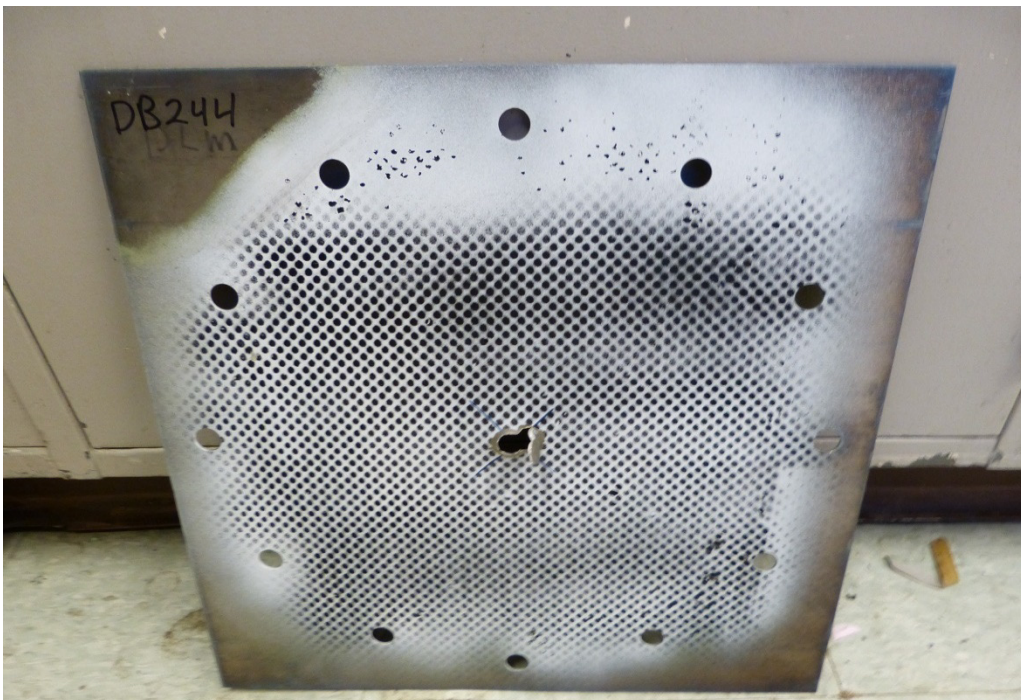


Figure C.48.—DB244 posttest rear view.



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

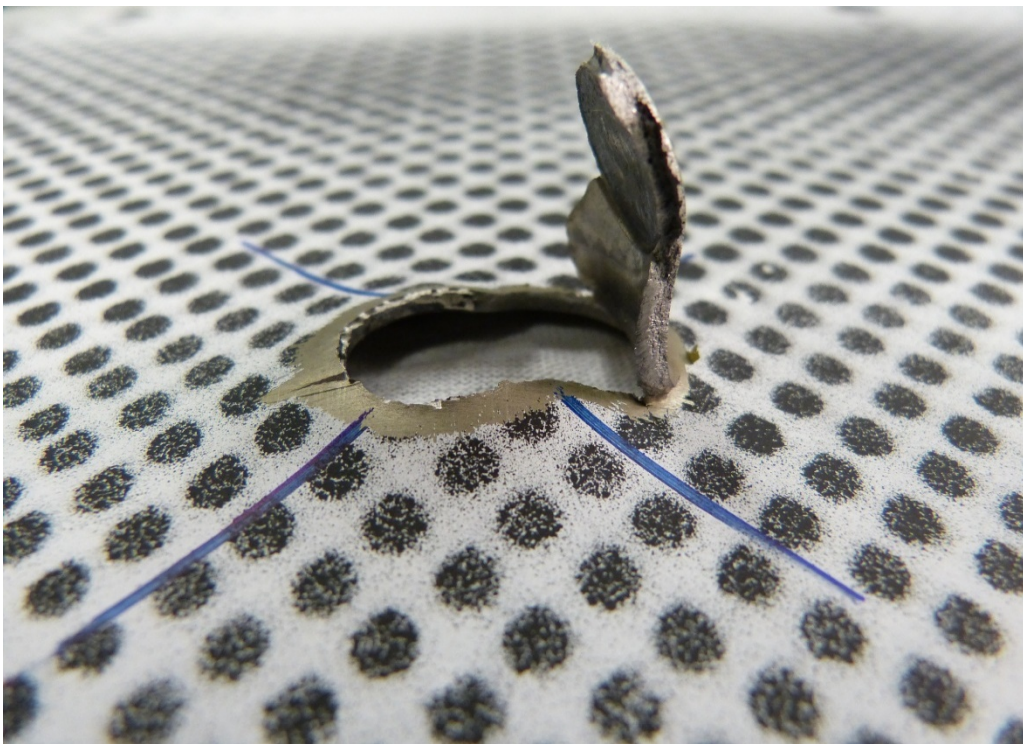


Figure C.50.—DB244 posttest rear view closeup.

Test DB245

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



Figure C.51.—DB245 posttest front view.

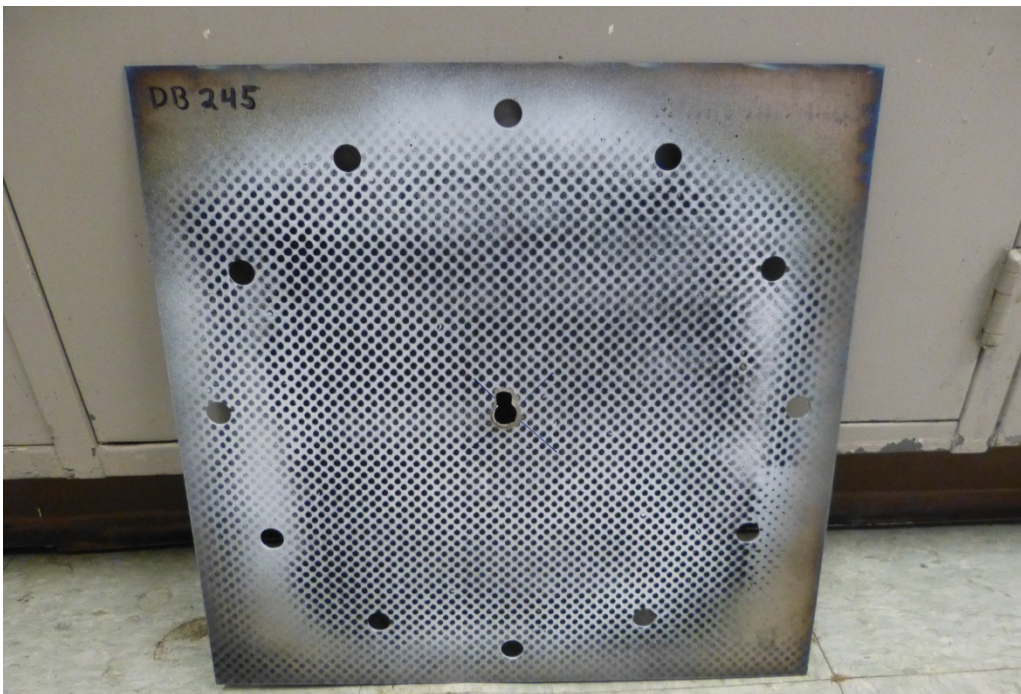


Figure C.52.—DB245 posttest rear view.

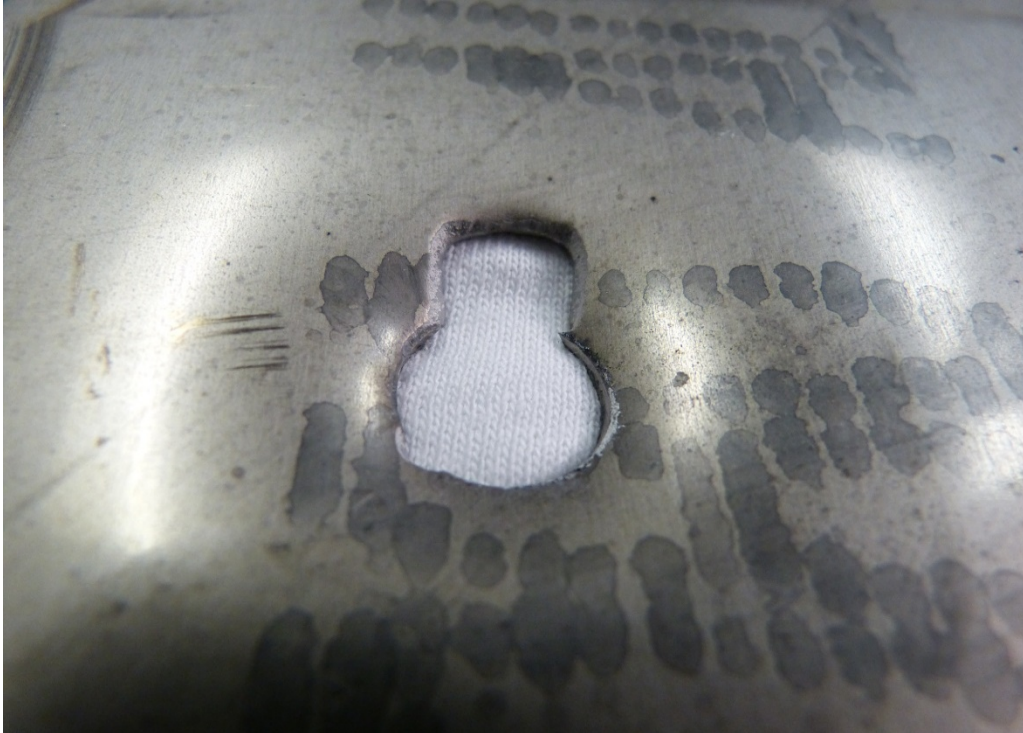


Figure C.53.—DB245 posttest front view closeup.

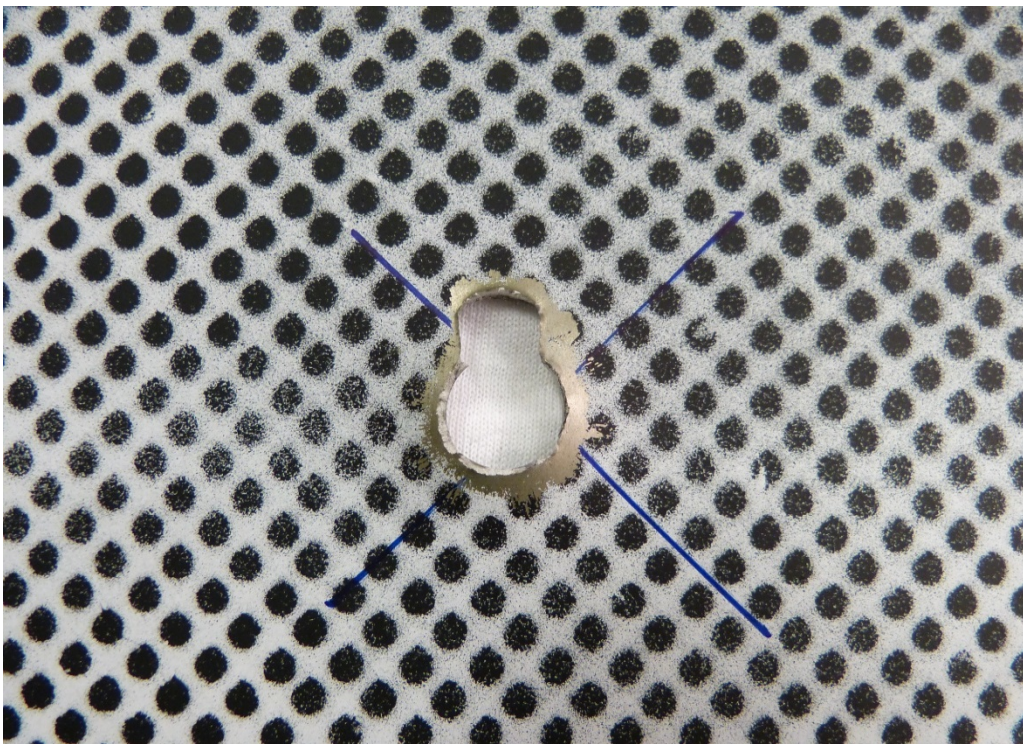


Figure C.54.—DB245 posttest rear view closeup.

Test DB246



Figure C.55.—DB246 posttest front view.

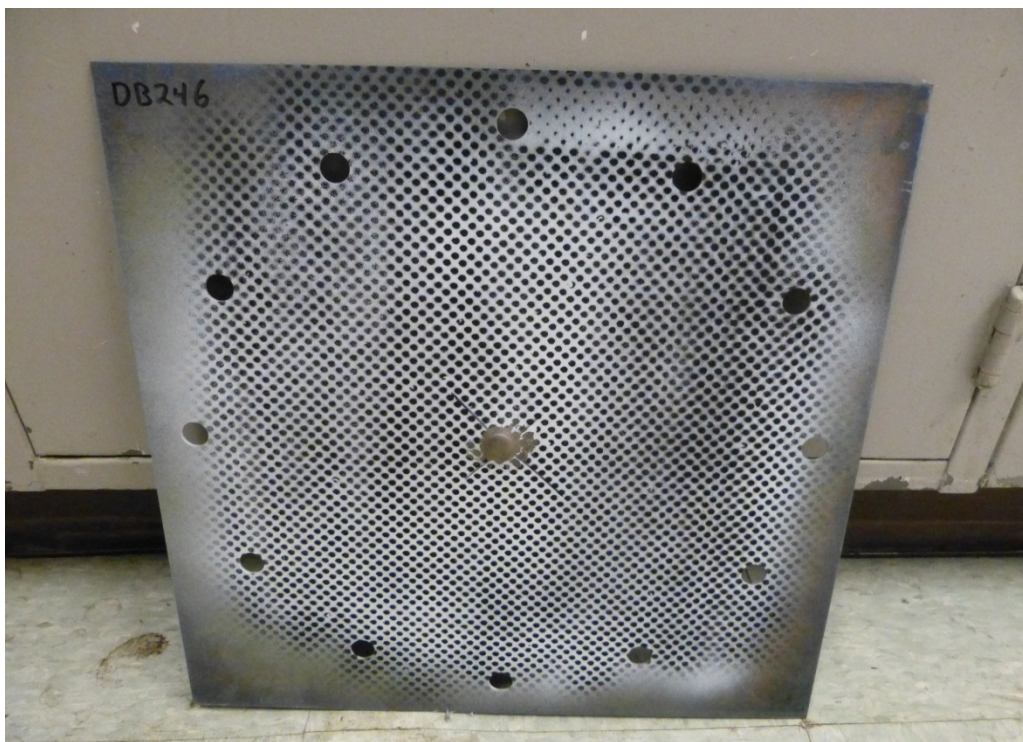


Figure C.56.—DB246 posttest rear view.

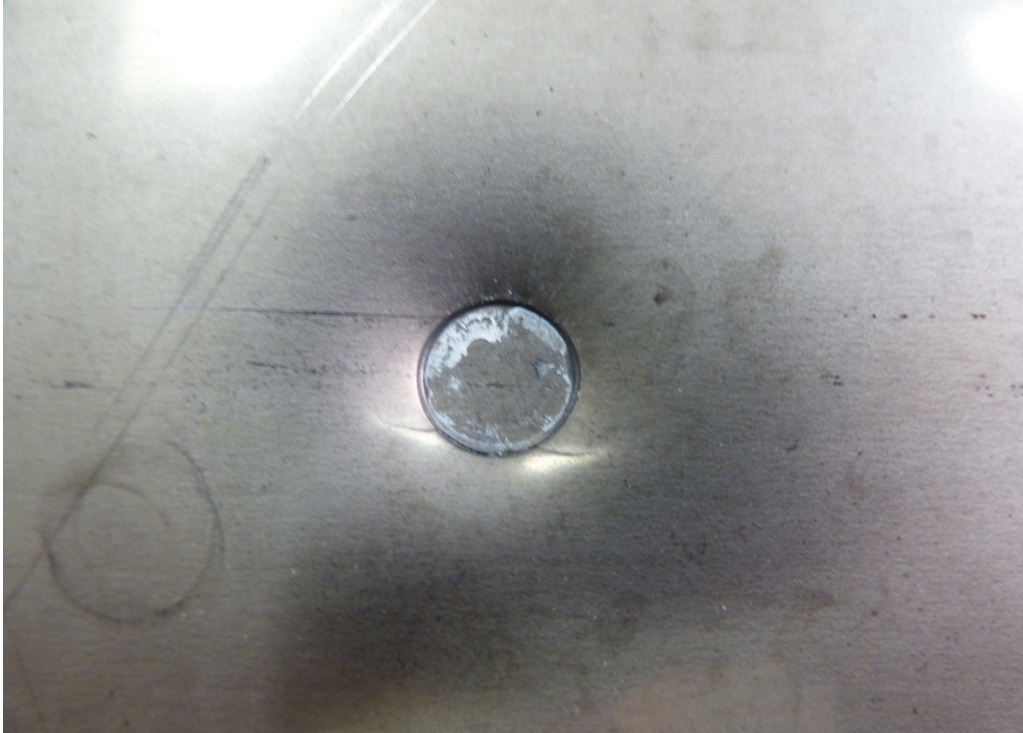


Figure C.57.—DB246 posttest front view closeup.



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

Test DB247

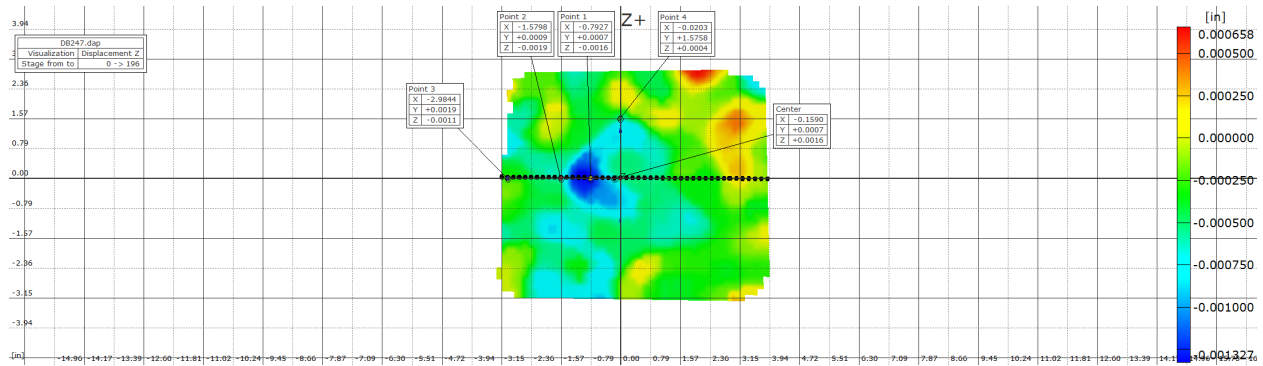


Figure C.59.—DB247 locations of digital image correlation (DIC) measurements.

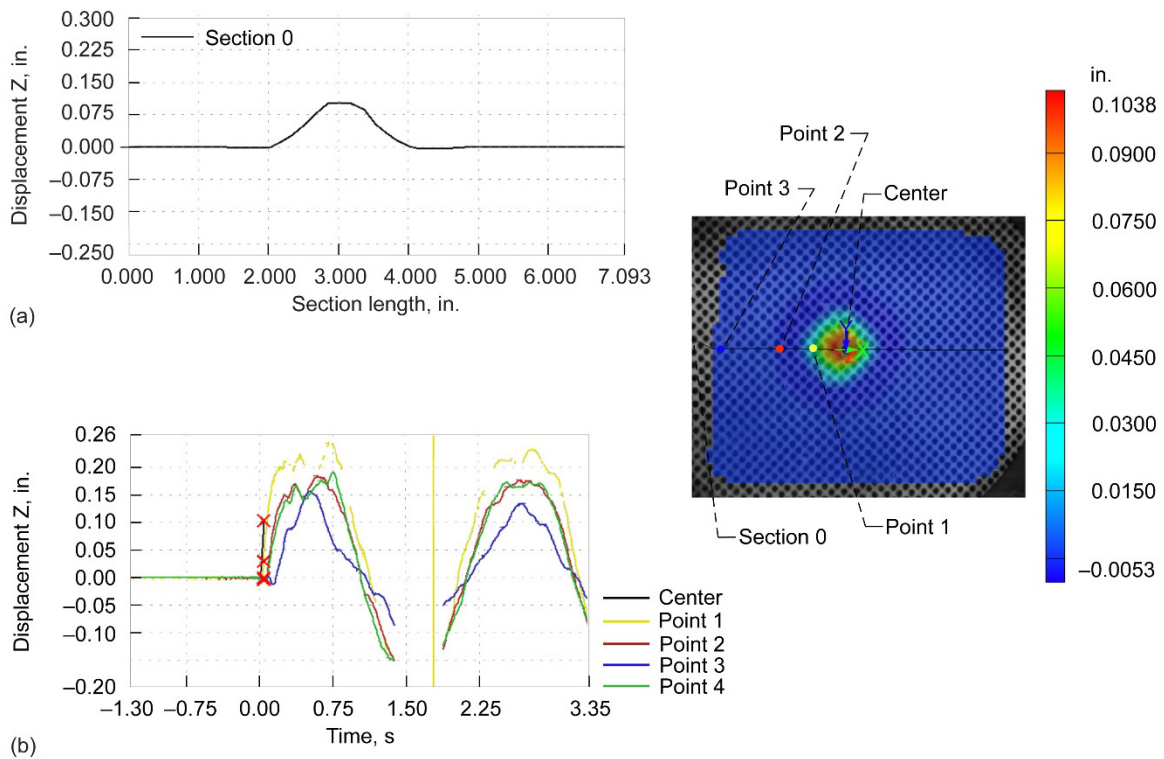


Figure C.60.—DB247 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

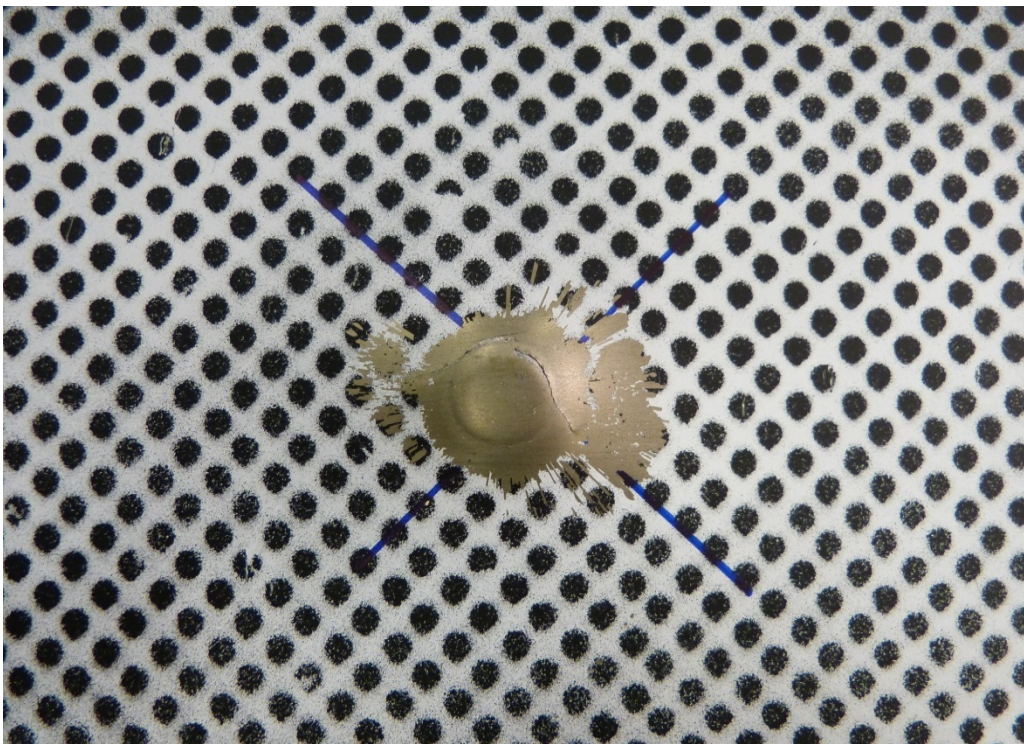


Figure C.62.—DB247 posttest rear view closeup.

Test DB248

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



Figure C.63.—DB248 posttest front view.

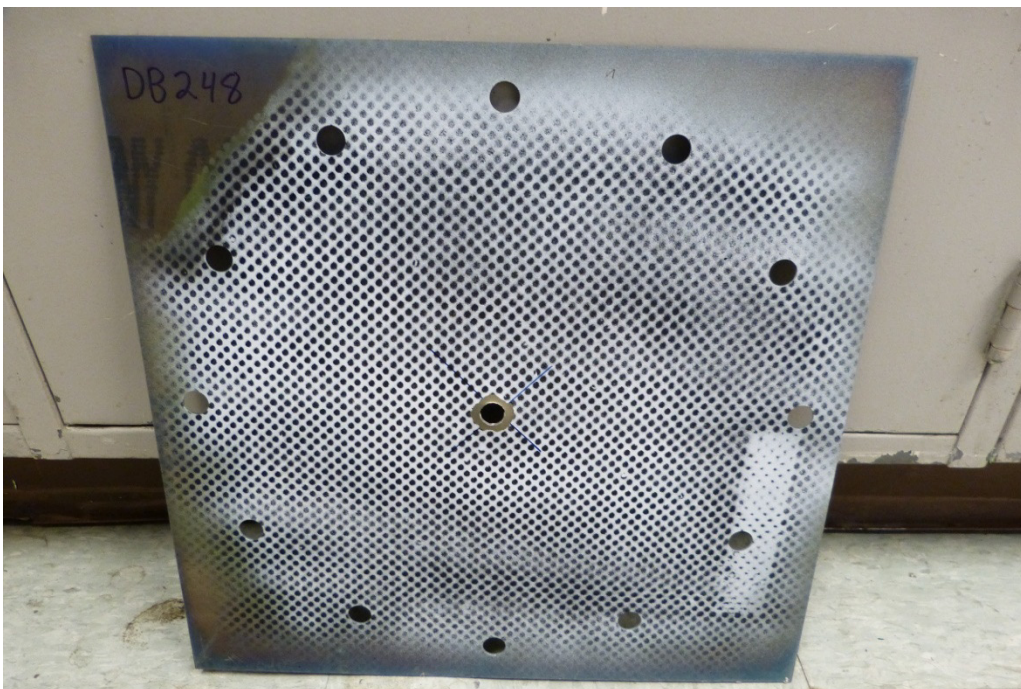


Figure C.64.—DB248 posttest rear view.

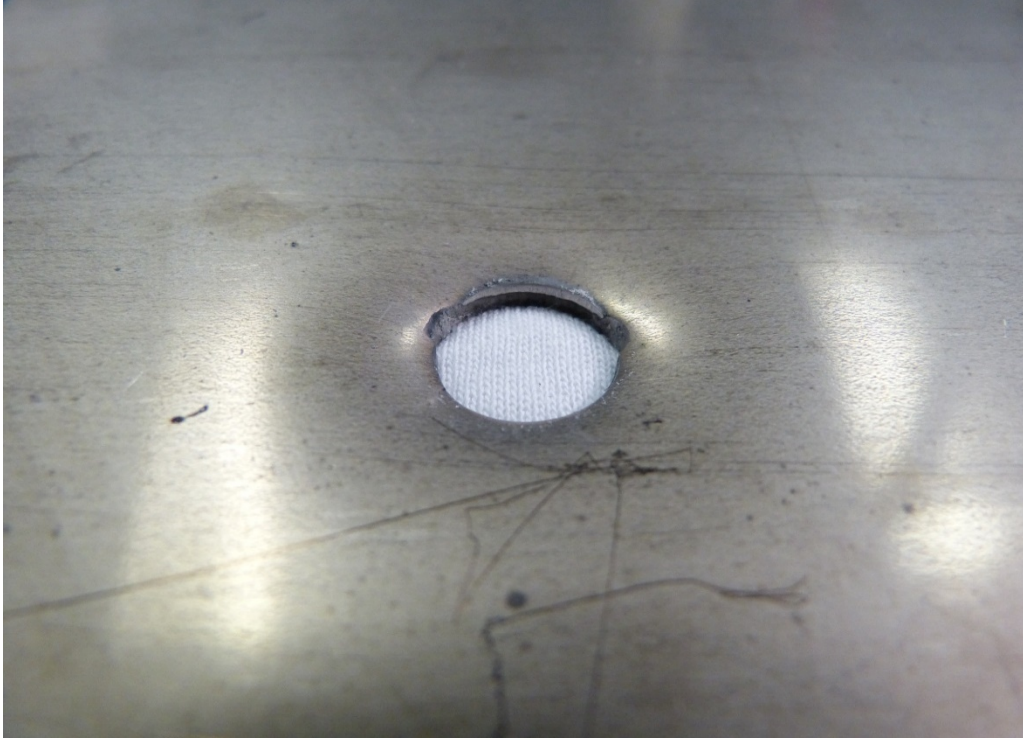


Figure C.65.—DB248 posttest front view closeup.

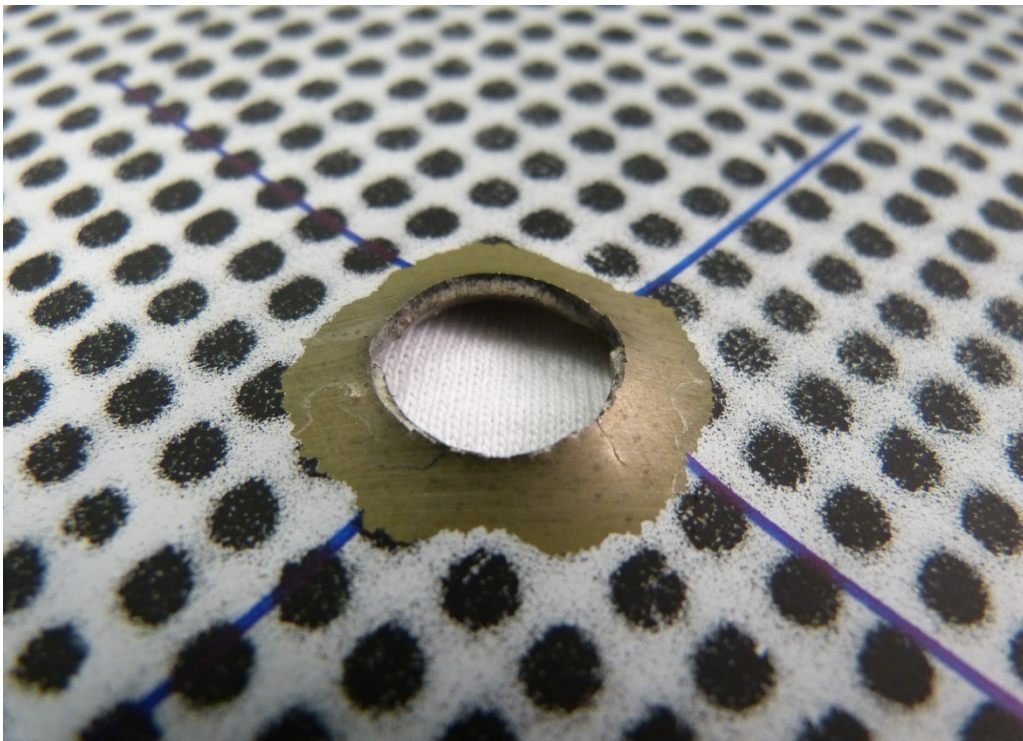


Figure C.66.—DB248 posttest rear view closeup.

Test DB249

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



Figure C.67.—DB249 posttest front view.

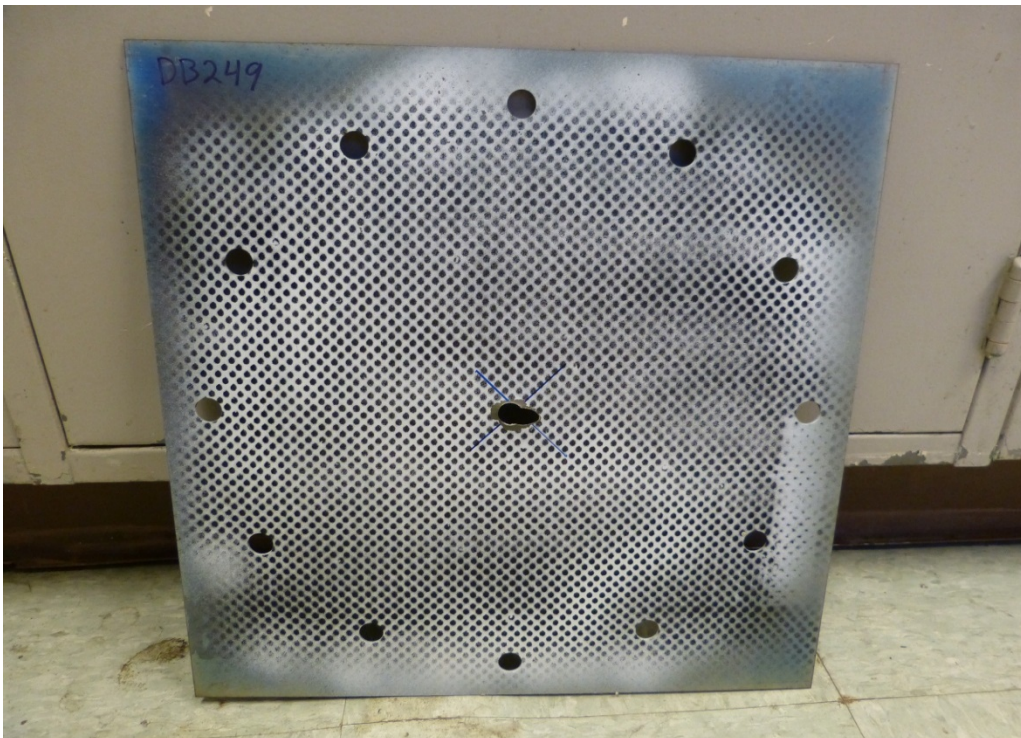


Figure C.68.—DB249 posttest rear view.



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

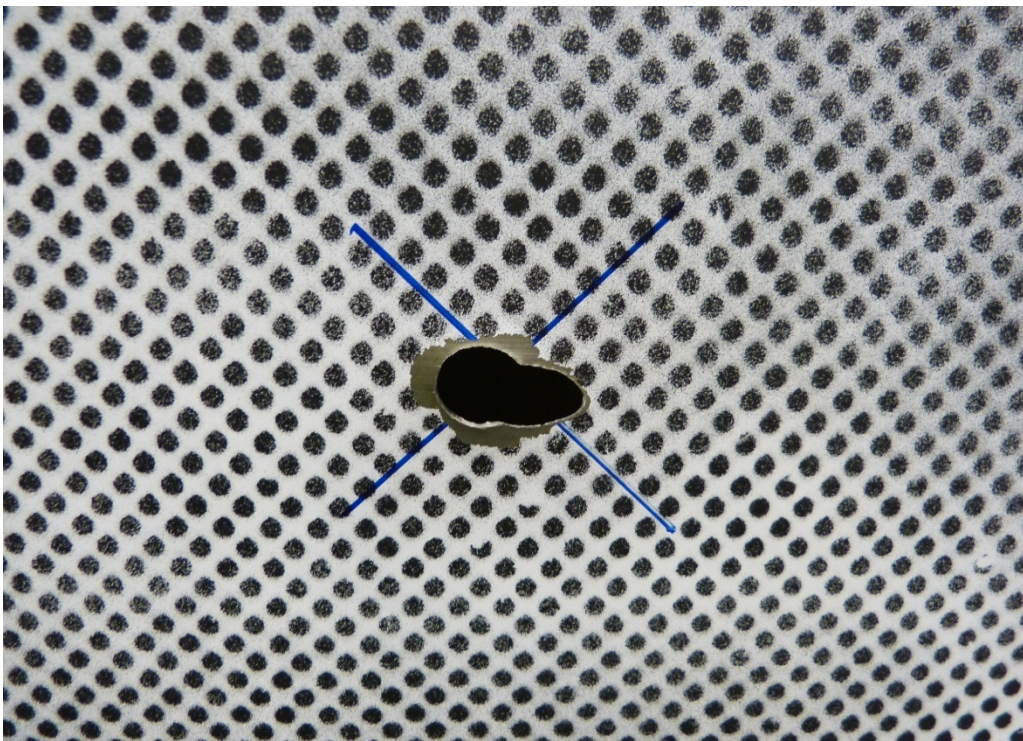


Figure C.70.—DB249 posttest rear view closeup.

Test DB250

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

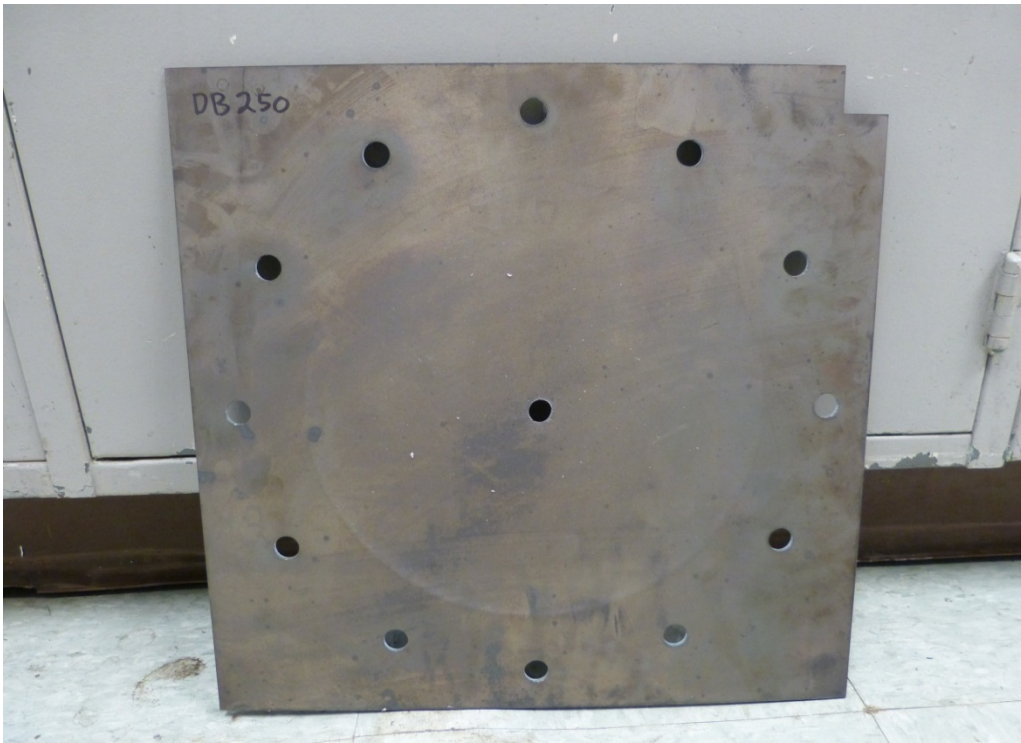


Figure C.71.—DB250 posttest front view.

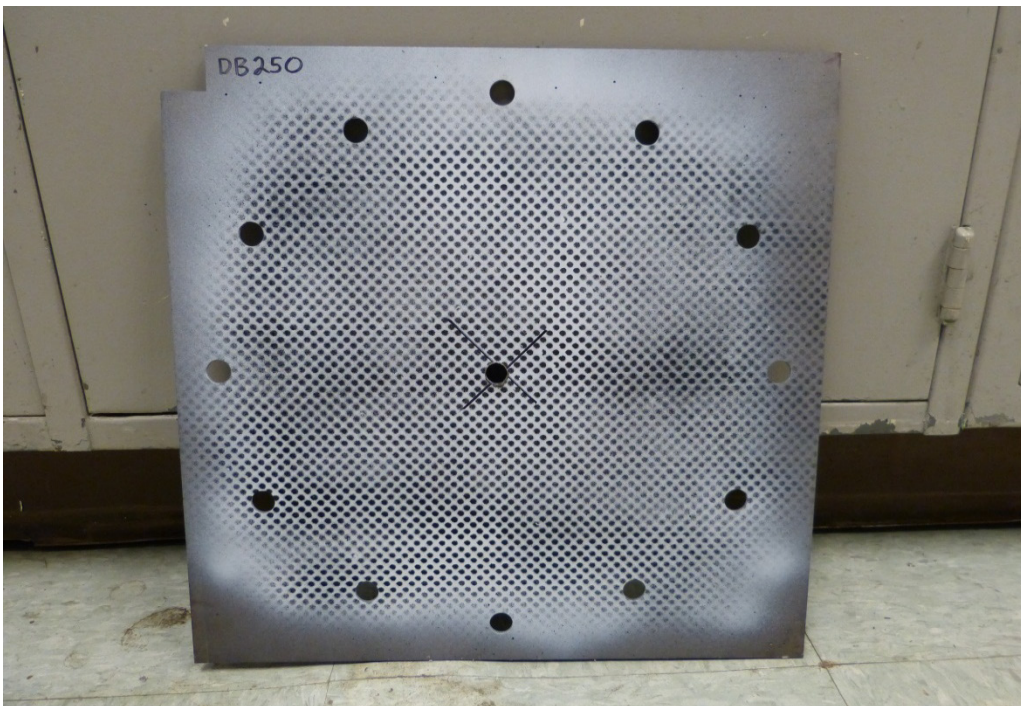


Figure C.72.—DB250 posttest rear view.



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

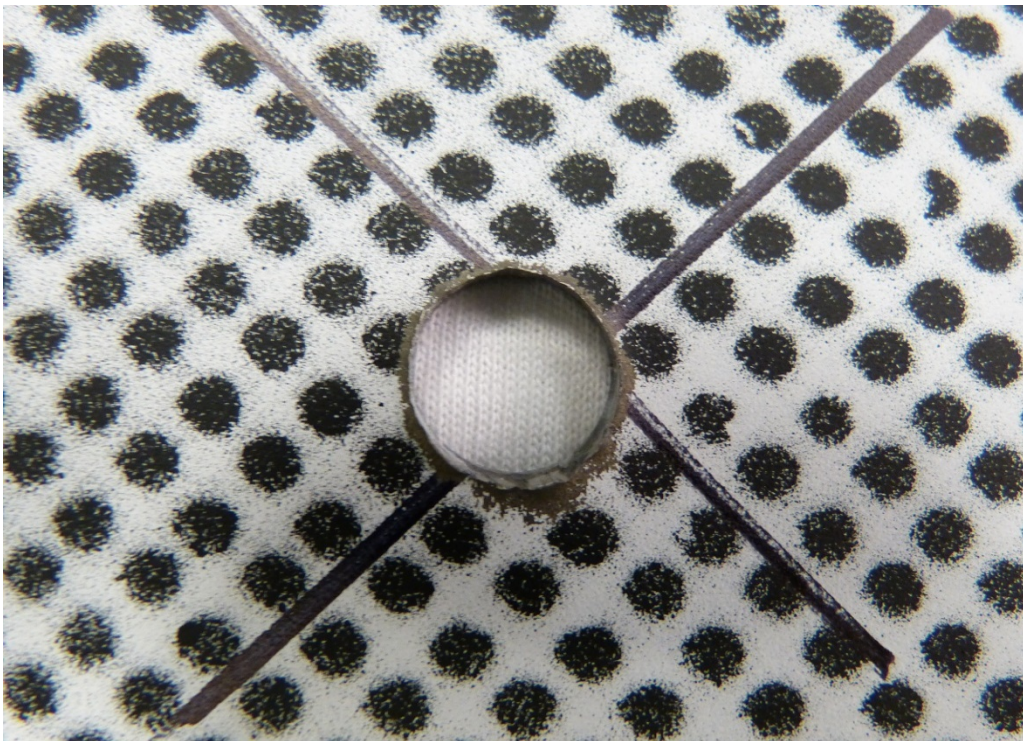


Figure C.74.—DB250 posttest rear view closeup.

Test DB251

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



Figure C.75.—DB251 posttest front view.

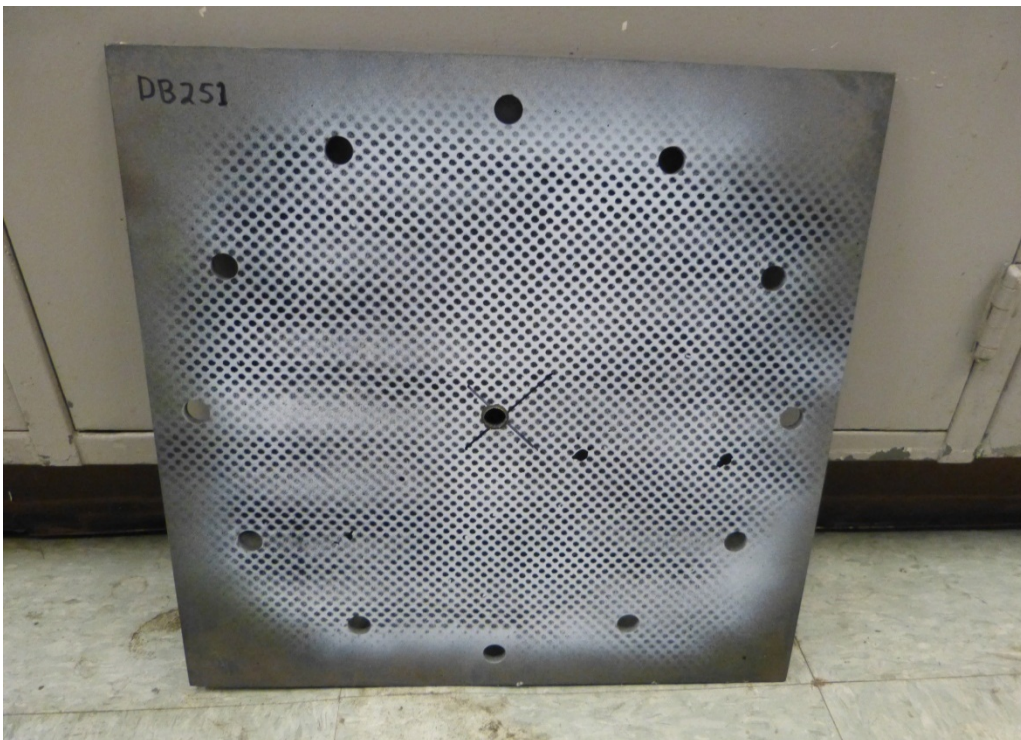


Figure C.76.—DB251 posttest rear view.



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

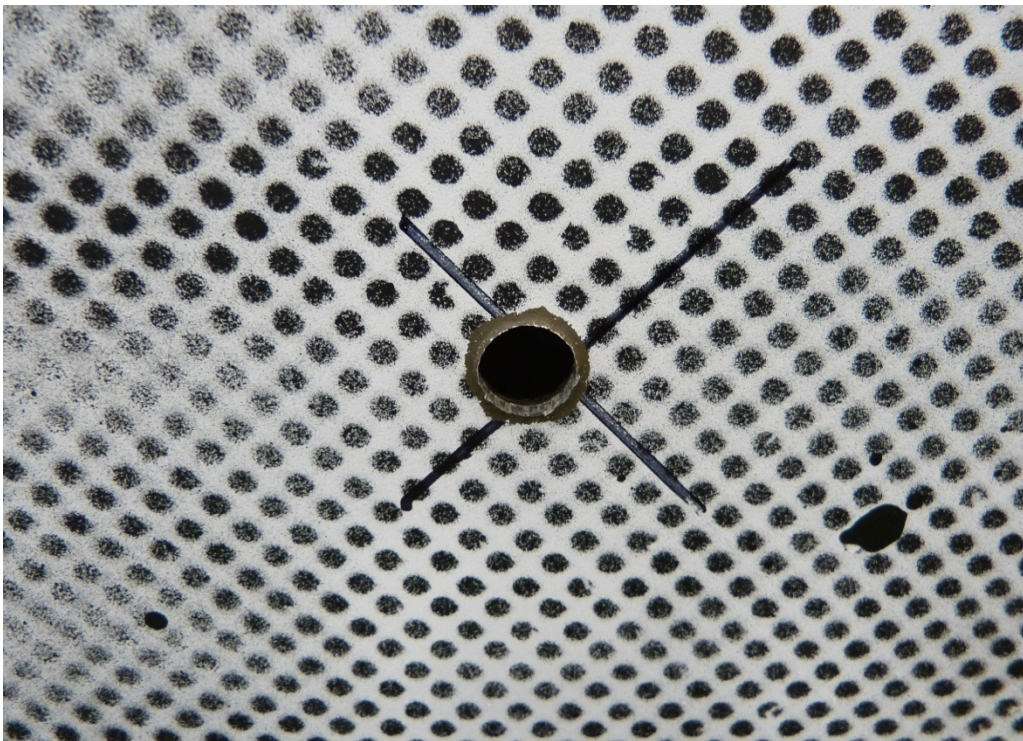


Figure C.78.—DB251 posttest rear view closeup.

Test DB252

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



Figure C.79.—DB252 pretest front view.

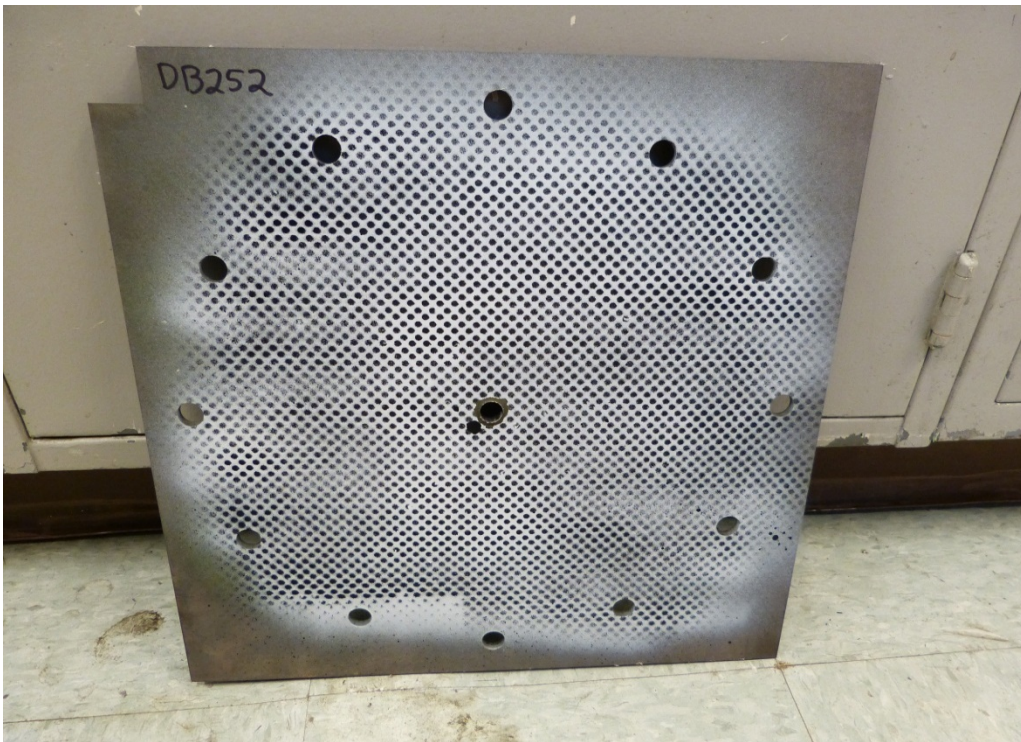


Figure C.80.—DB252 posttest rear view.



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

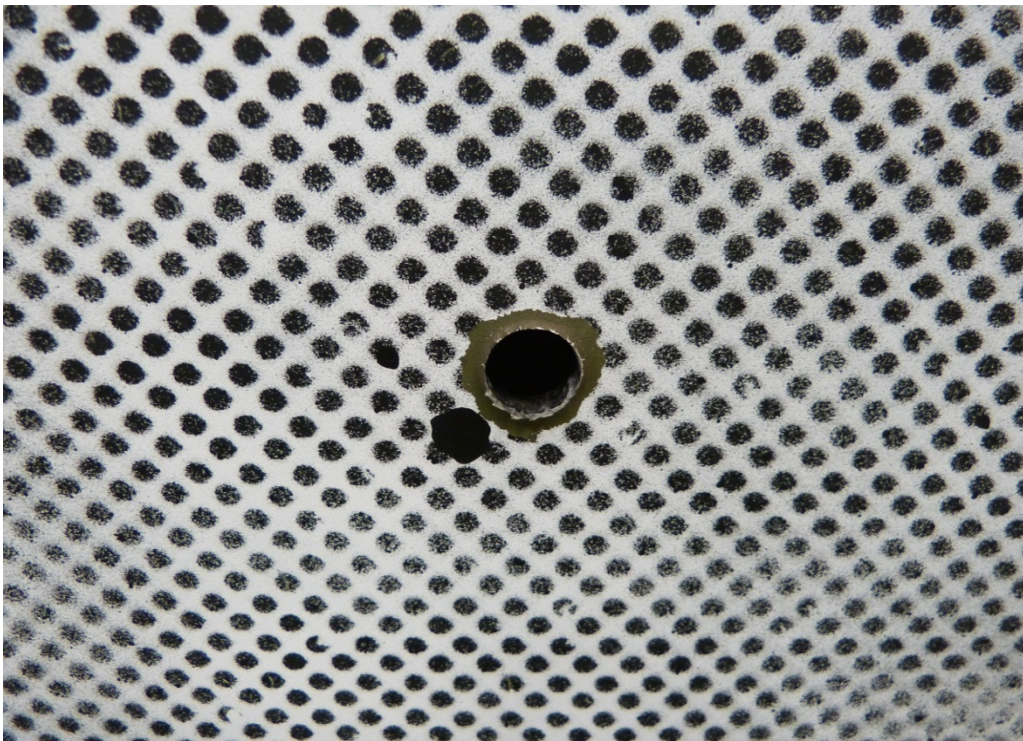


Figure C.82.—DB252 posttest rear view closeup.

Test DB253

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



Figure C.83.—DB253 posttest front view.

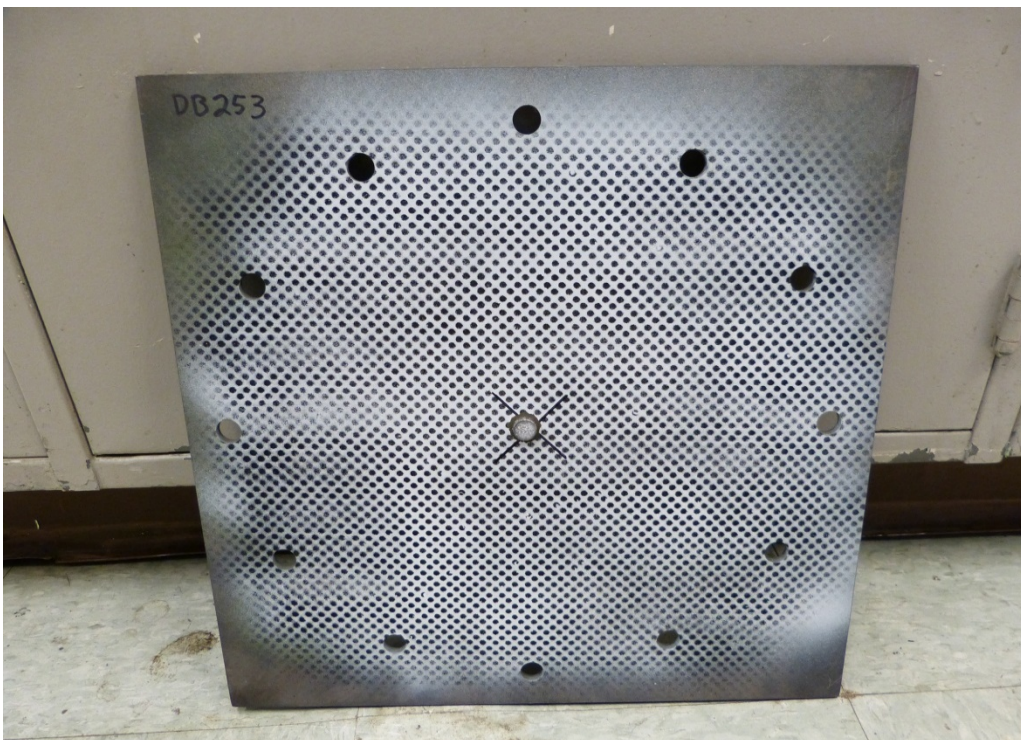


Figure C.84.—DB253 posttest rear view.



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

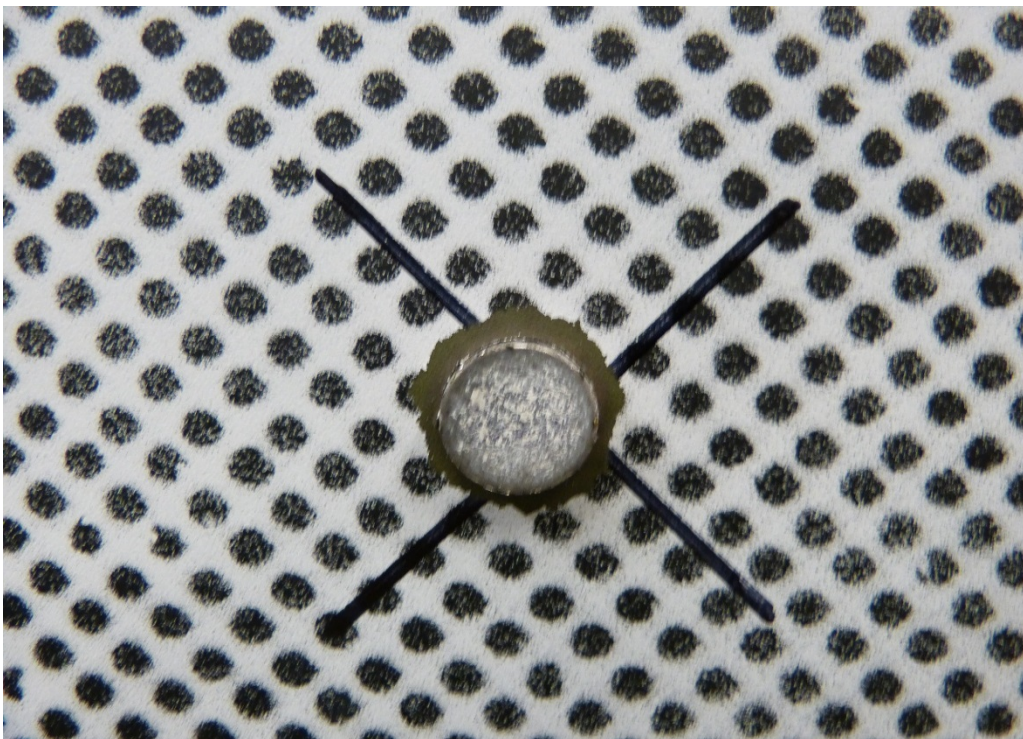


Figure C.86.—DB253 posttest rear view closeup.

Test DB254

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



Figure C.87.—DB254 posttest front view.

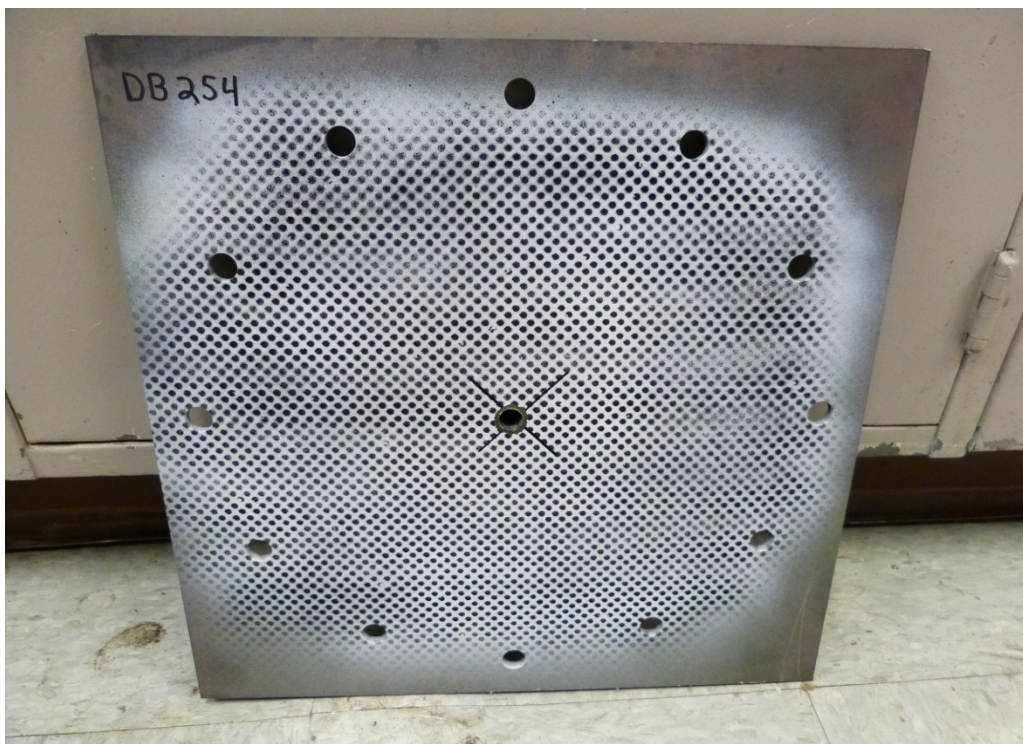


Figure C.88.—DB254 posttest rear view.

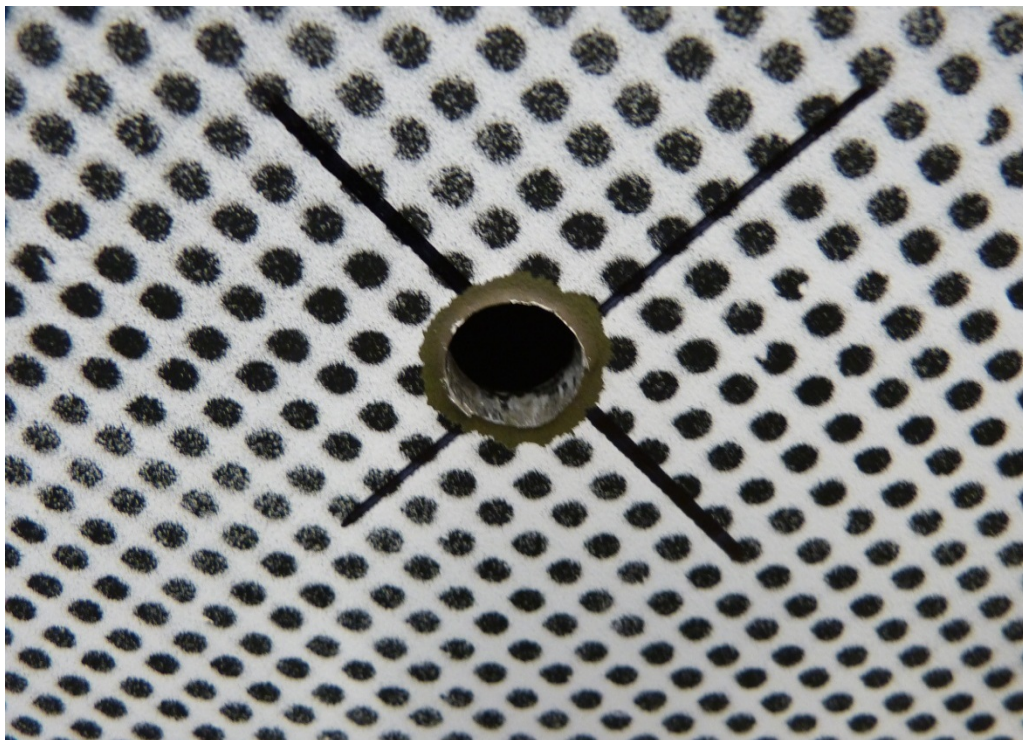


Figure C.89.—DB254 posttest rear view closeup.

Test DB255

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



Figure C.90.—DB255 posttest front view.

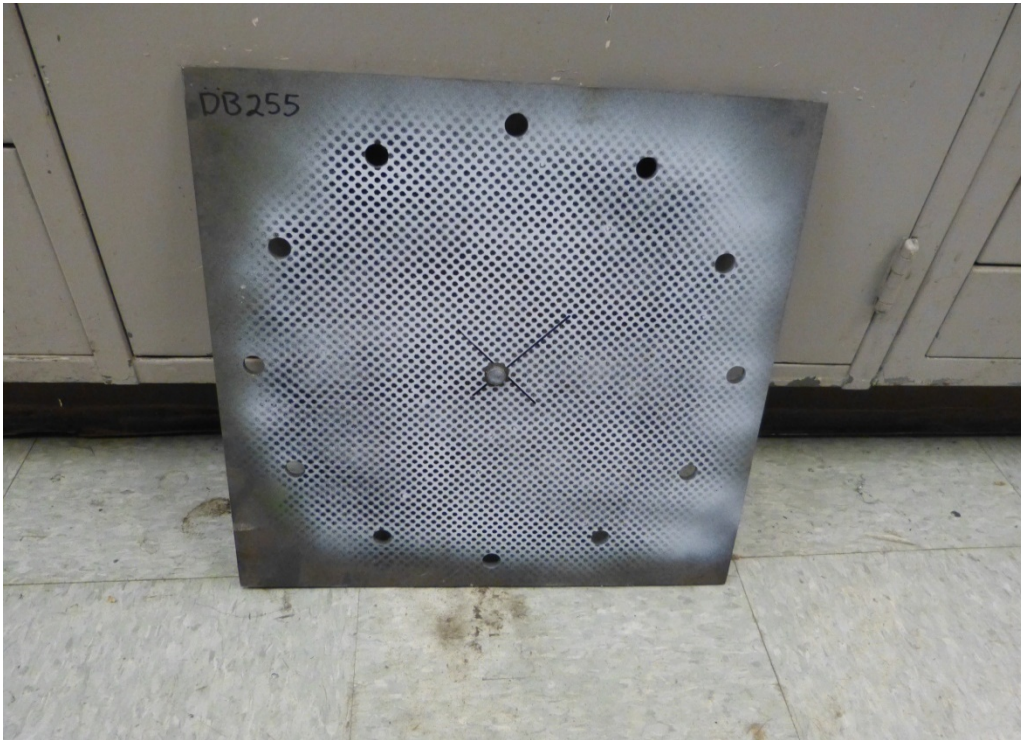


Figure C.91.—DB255 posttest rear view.



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

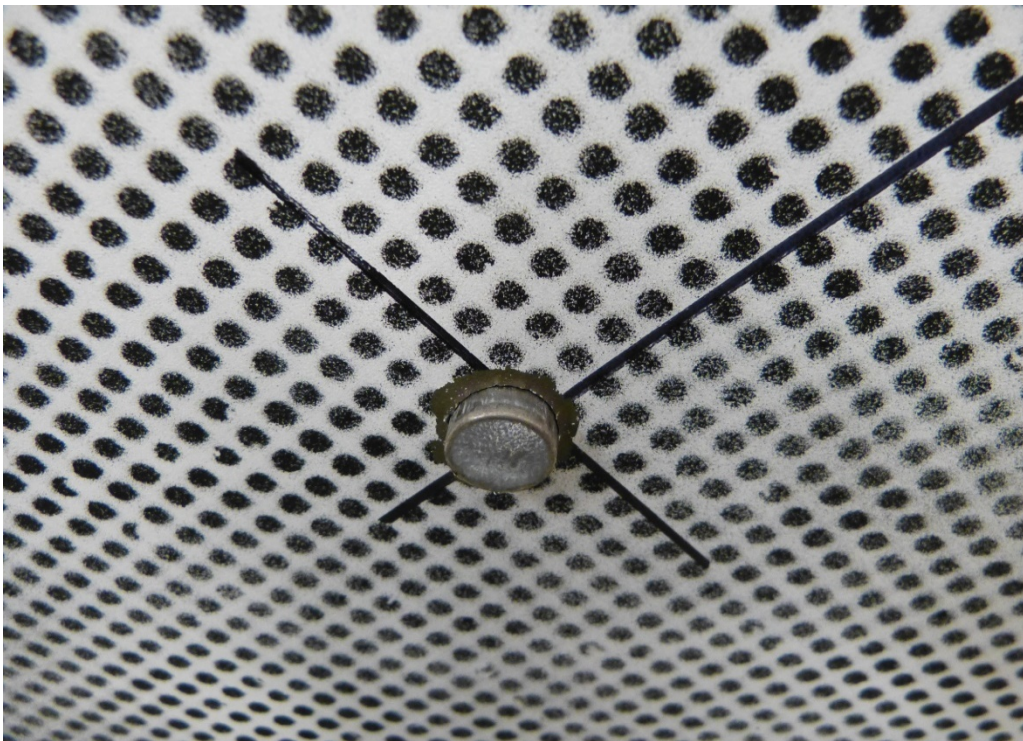


Figure C.93.—DB255 posttest rear view closeup.

Test DB256

No pretest or posttest pictures were taken of sample DB256.

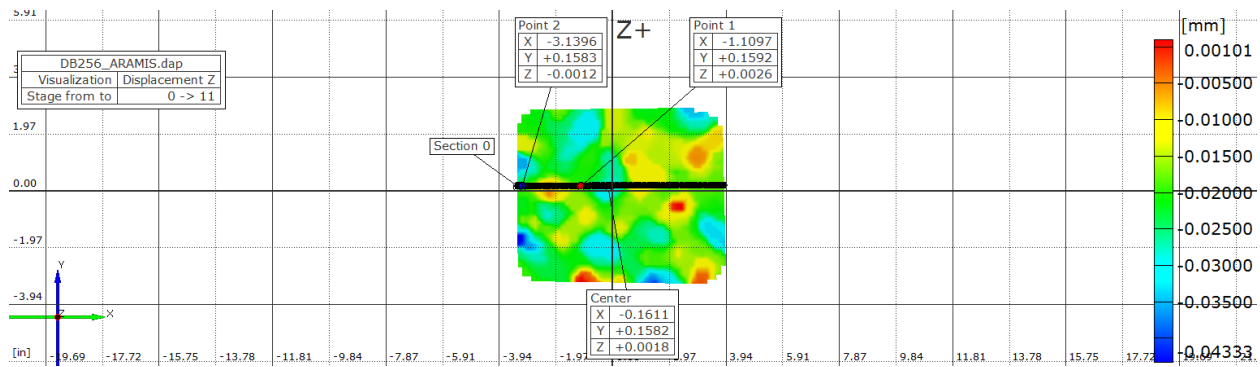


Figure C.94.—DB256 locations of digital image correlation (DIC) measurements.

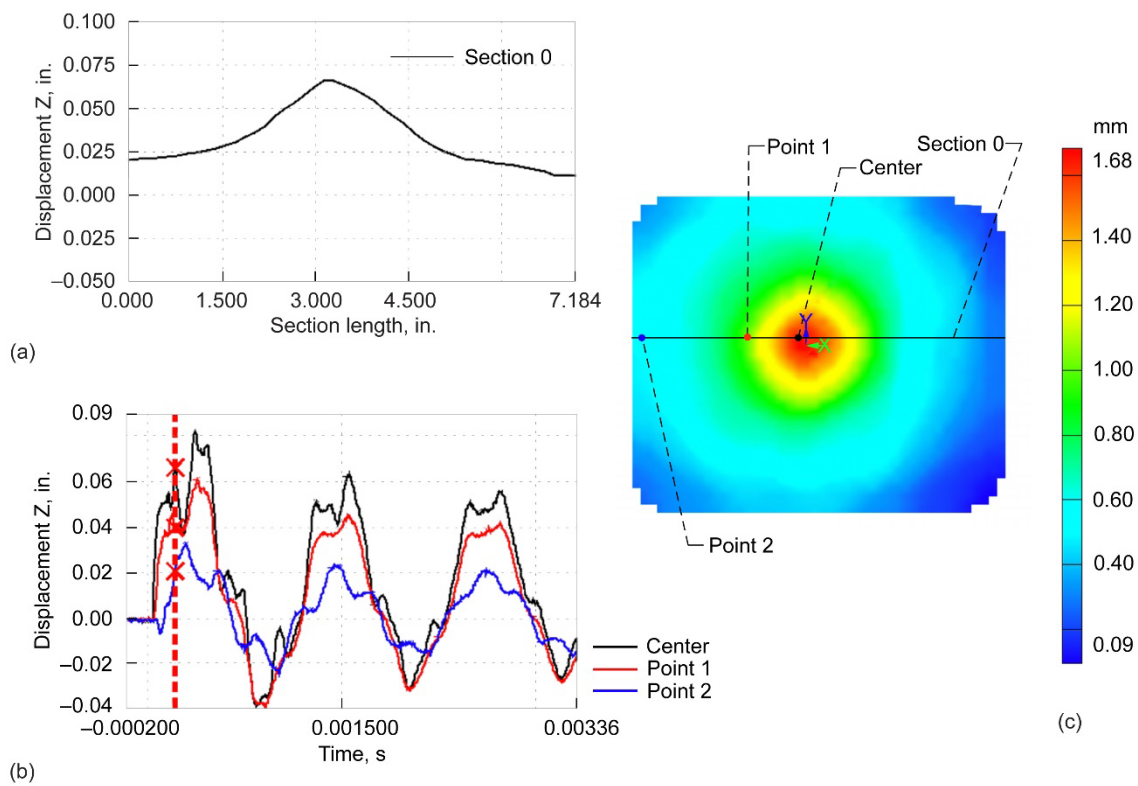


Figure C.95.—DB256 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

Test DB257

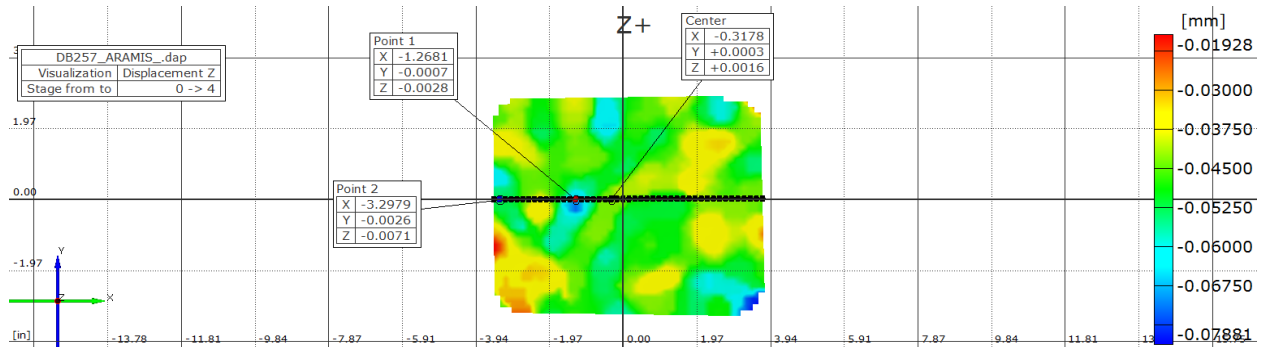


Figure C.96.—DB257 locations of digital image correlation (DIC) measurements.

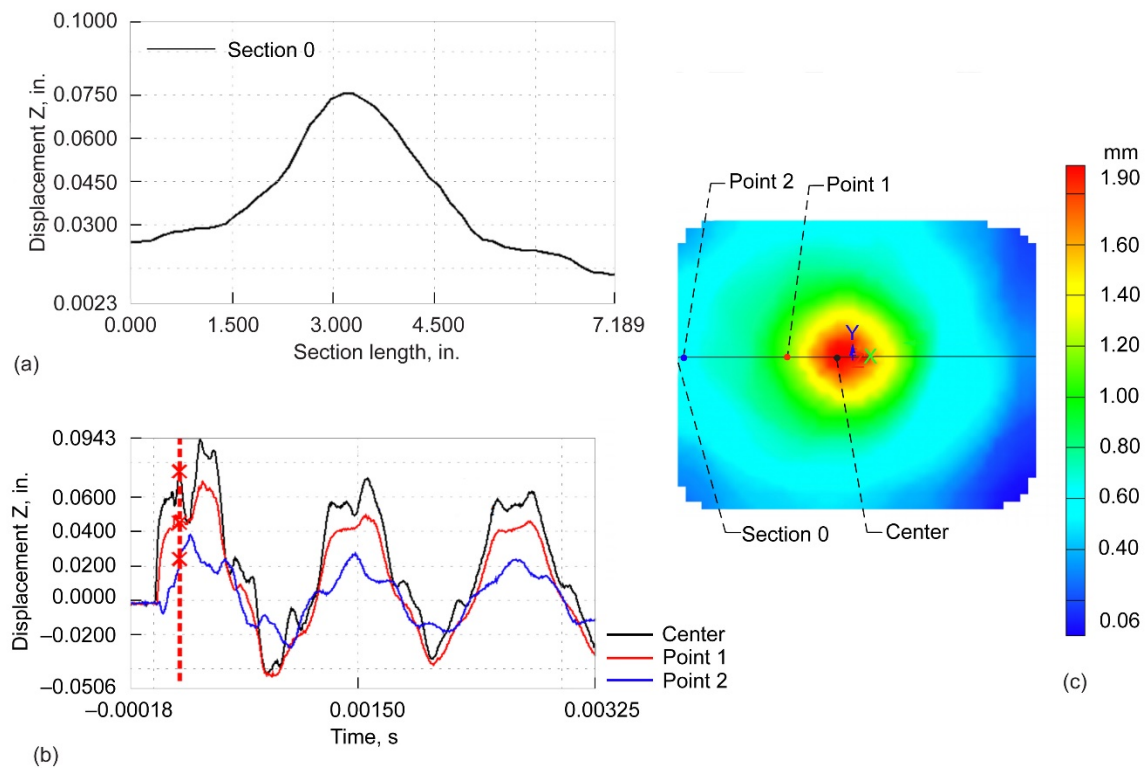


Figure C.97.—DB257 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

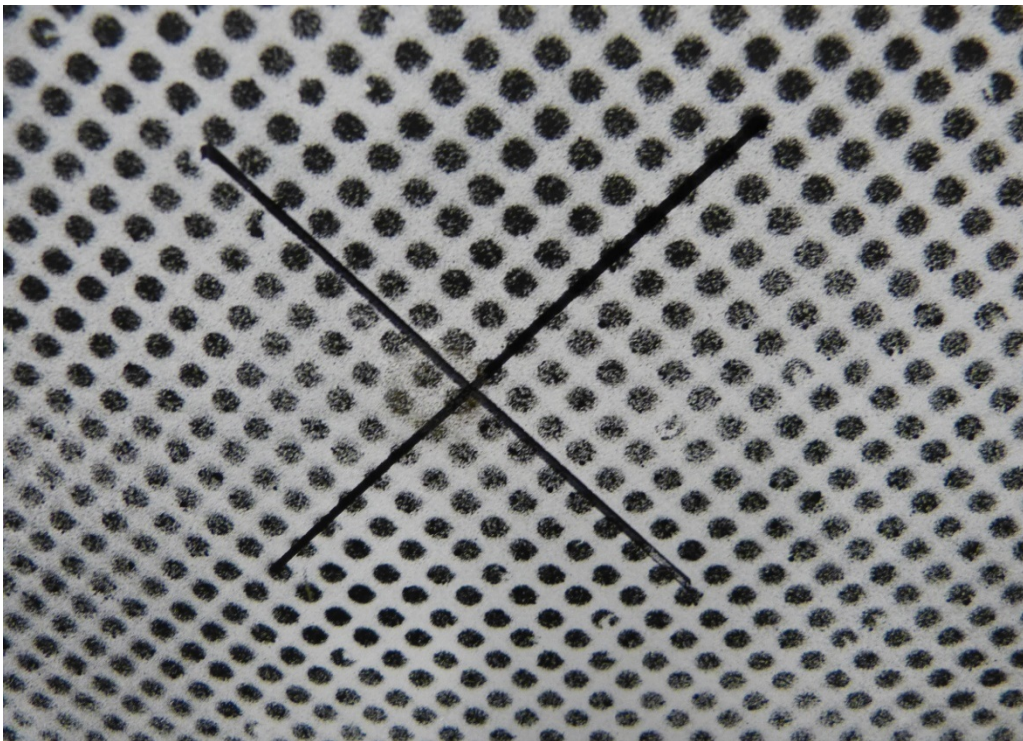


Figure C.99.—DB257 posttest rear view closeup.

Test DB258

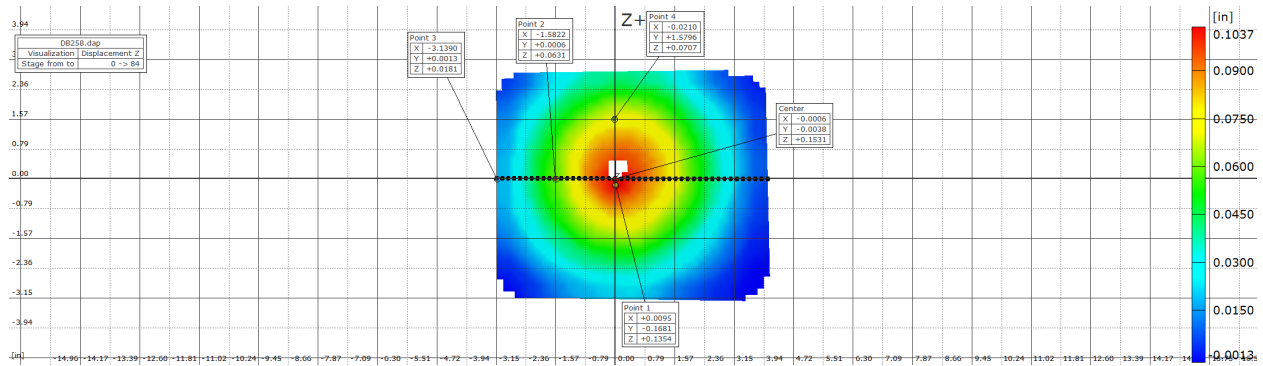


Figure C.100.—DB258 locations of digital image correlation (DIC) measurements.

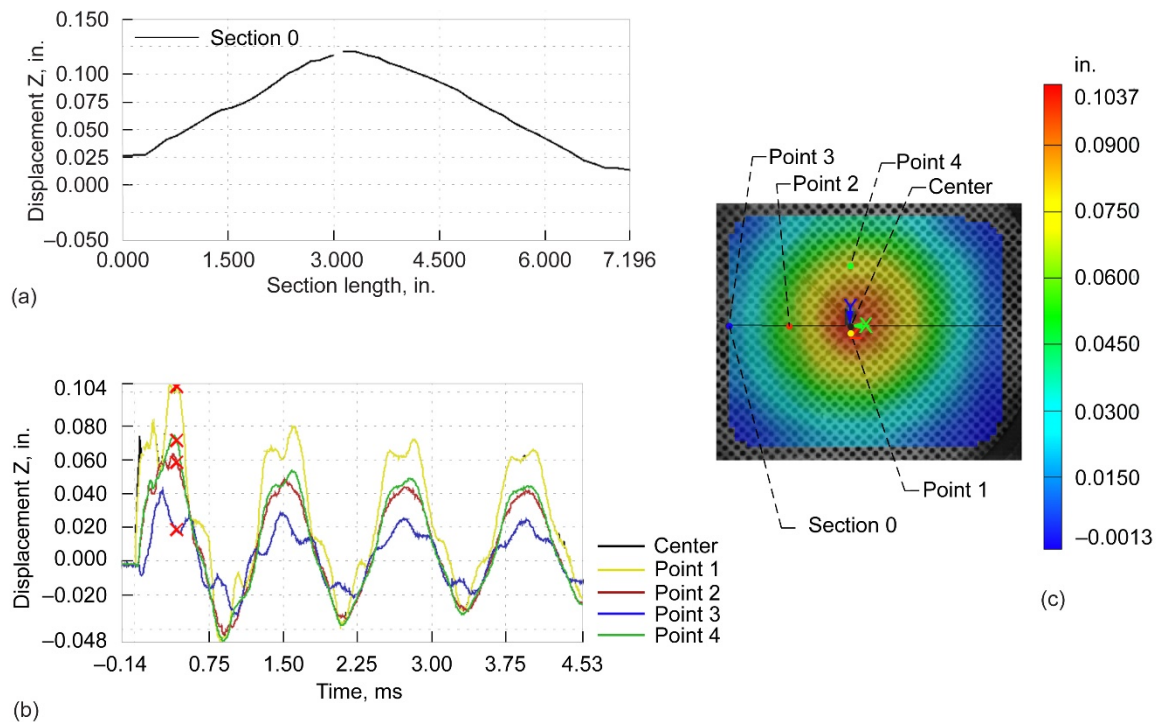


Figure C.101.—DB258 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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



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

Test DB259

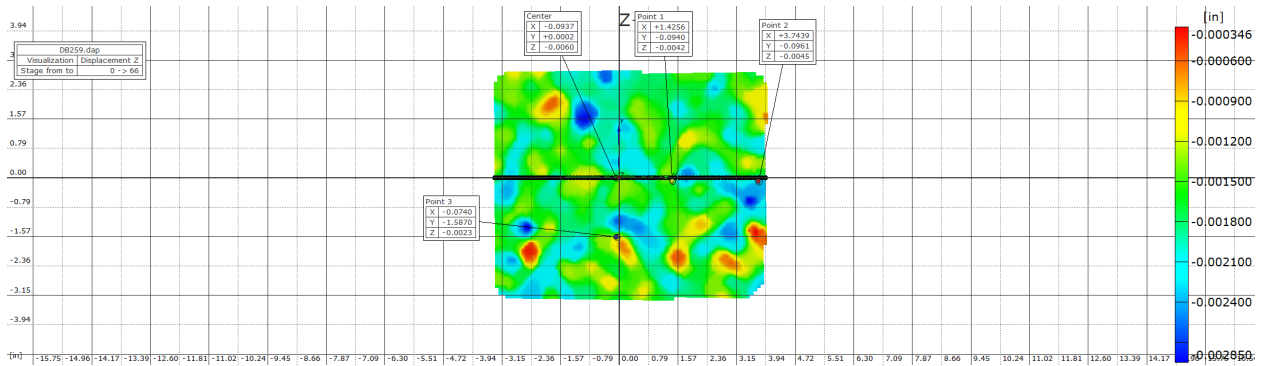


Figure C.104.—DB259 locations of digital image correlation (DIC) measurements.

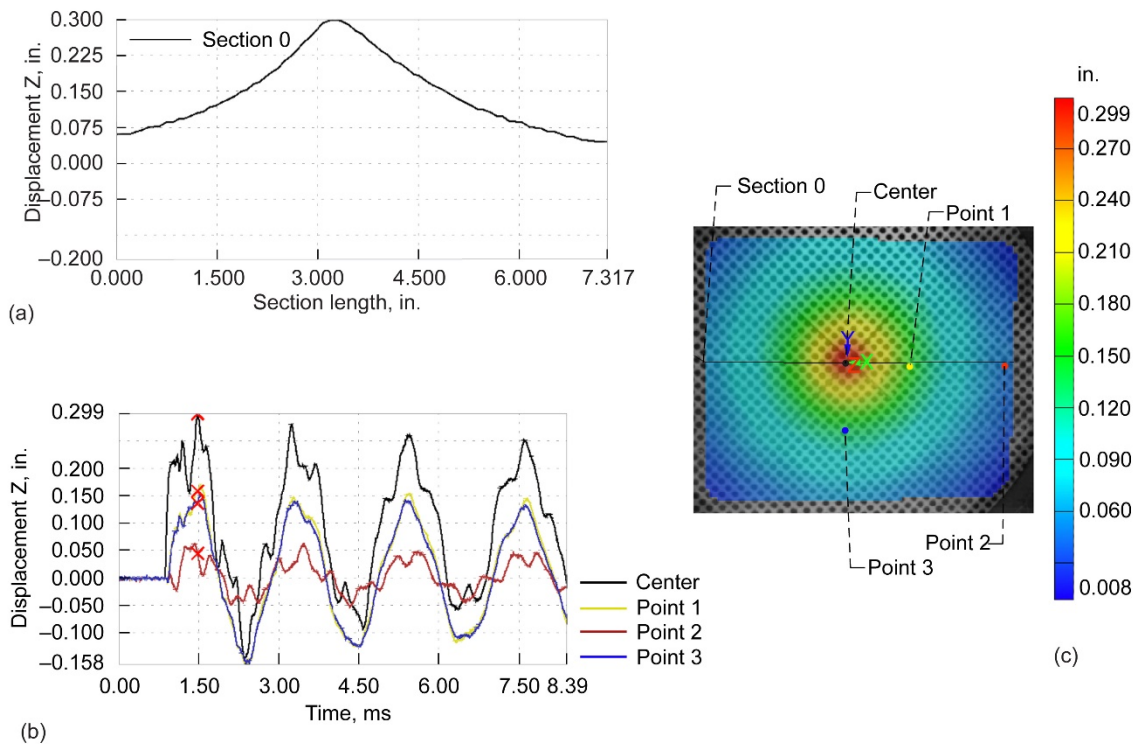


Figure C.105.—DB259 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

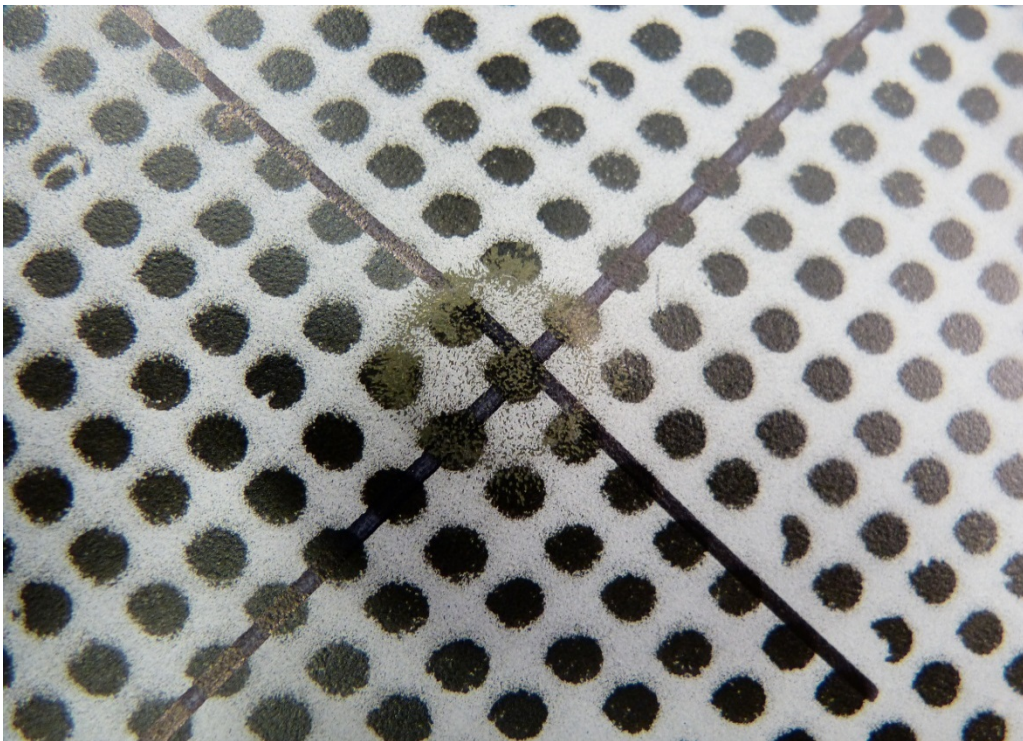


Figure C.107.—DB259 posttest rear view closeup.

Test DB260

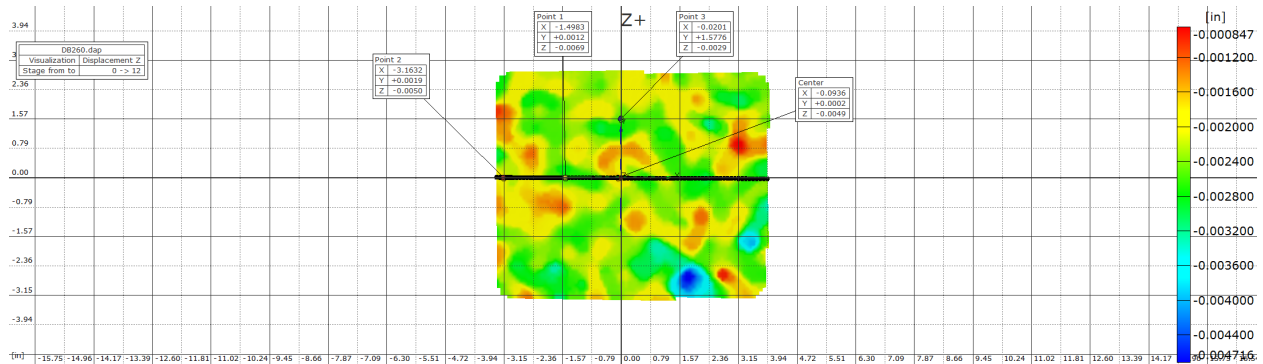


Figure C.108.—DB260 locations of digital image correlation (DIC) measurements.

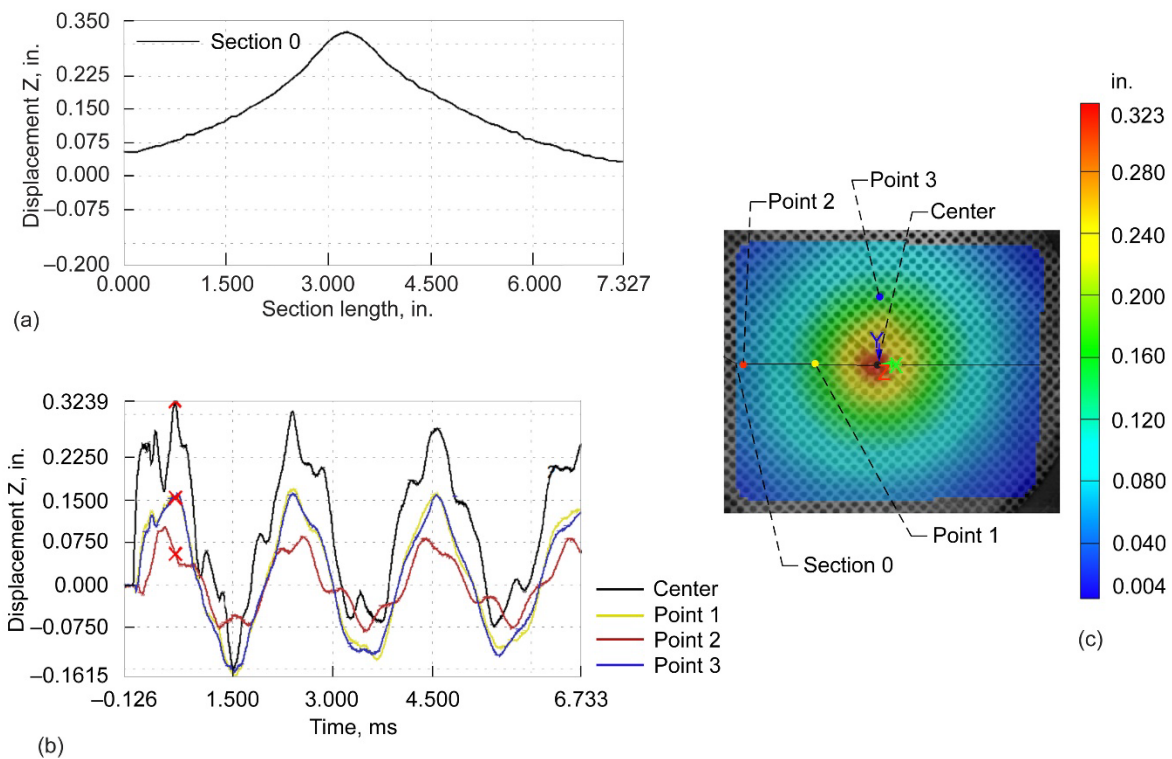


Figure C.109.—DB260 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

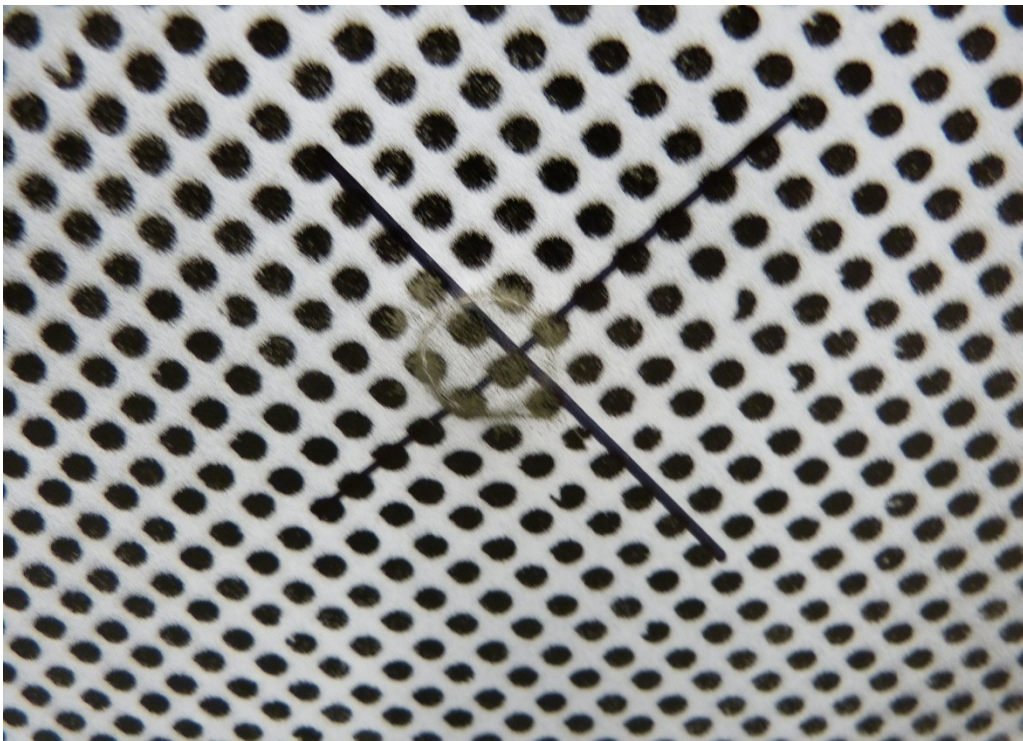


Figure C.111.—DB260 posttest rear view closeup.

Test DB261

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

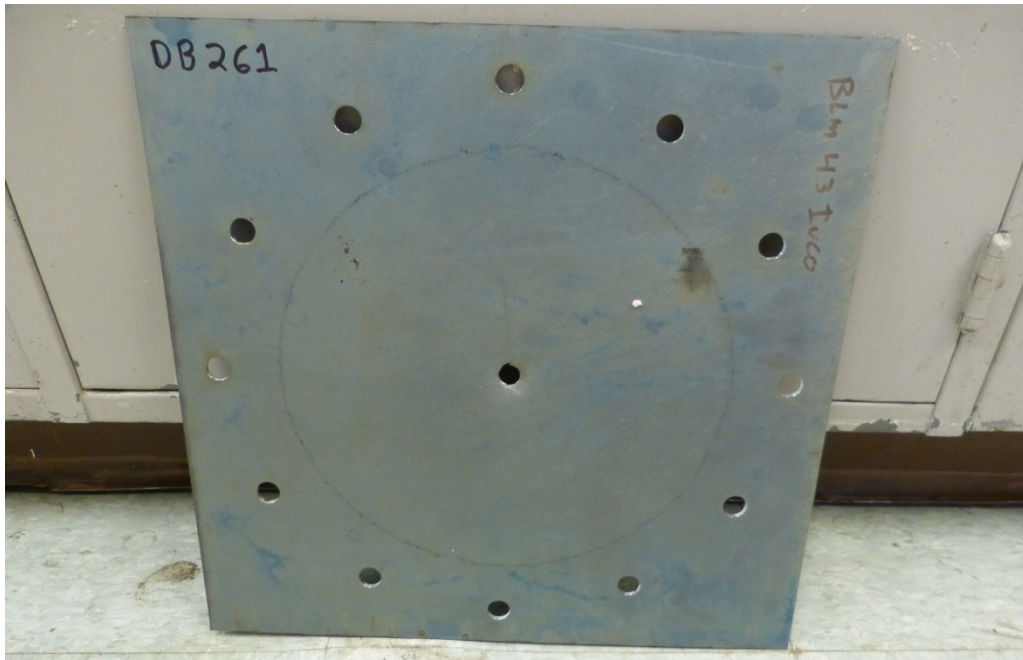


Figure C.112.—DB261 posttest front view.



Figure C.113.—DB261 posttest rear view.



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

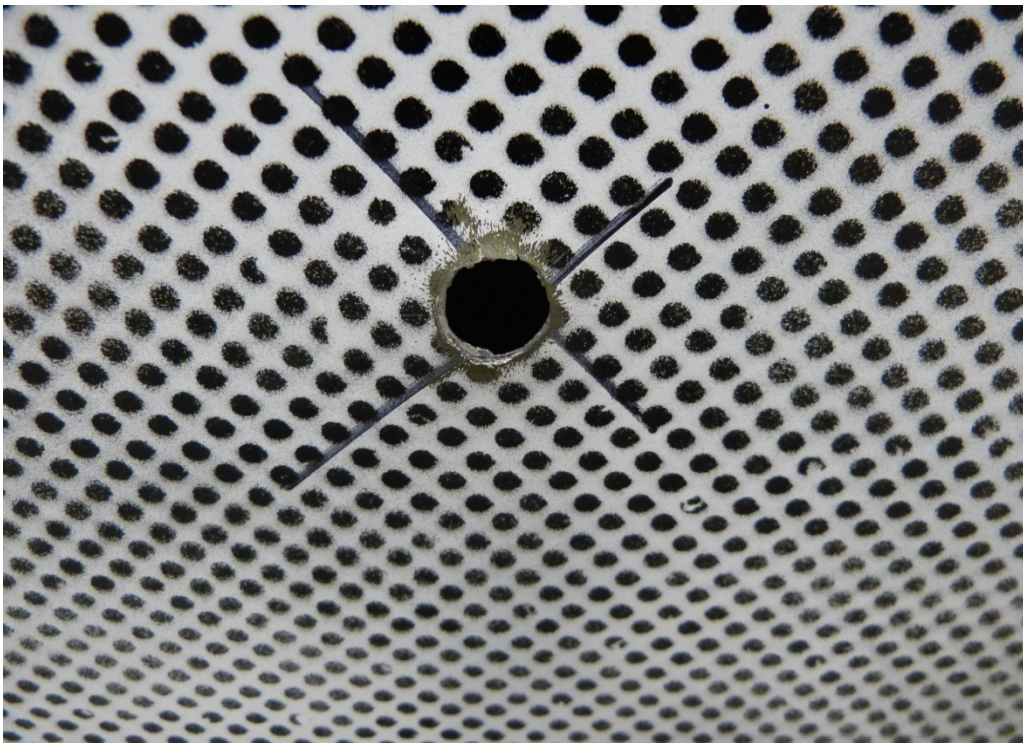


Figure C.115.—DB261 posttest rear view closeup.

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.

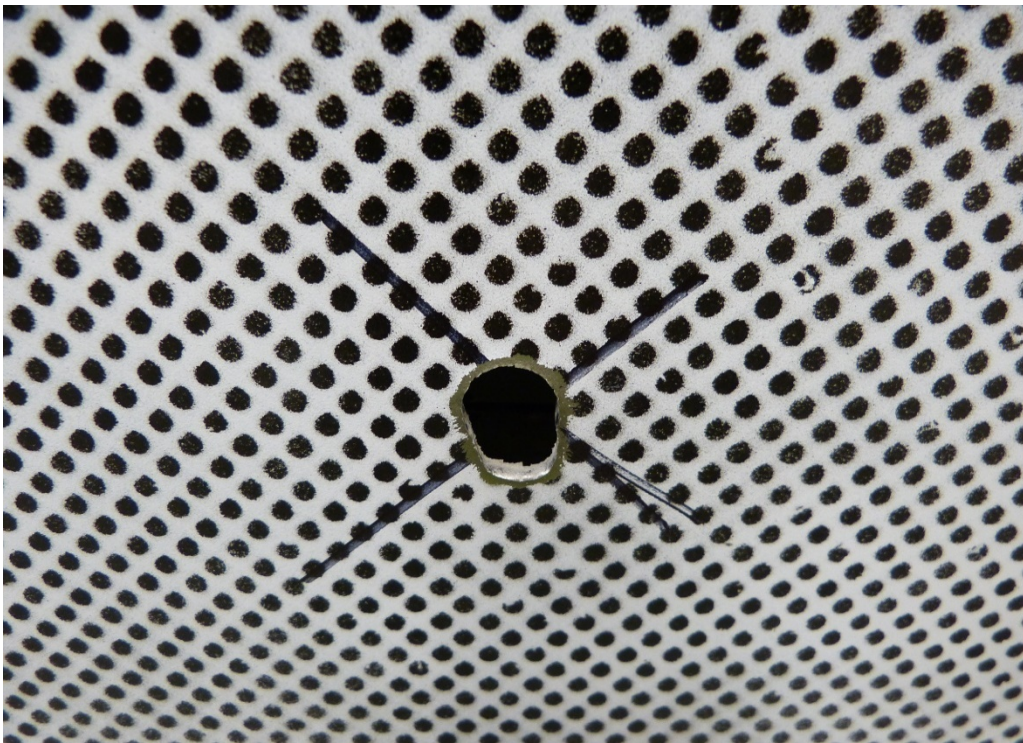


Figure C.119.—DB262 posttest rear view closeup.

Test DB263

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



Figure C.120.—DB263 posttest front view.

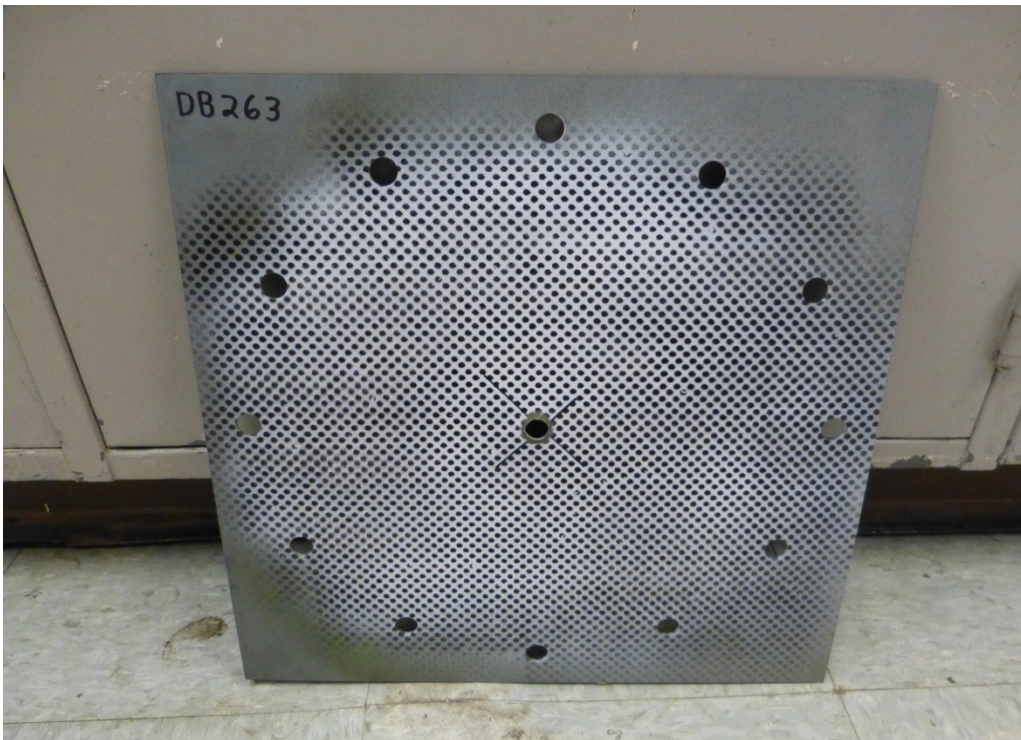


Figure C.121.—DB263 posttest rear view.

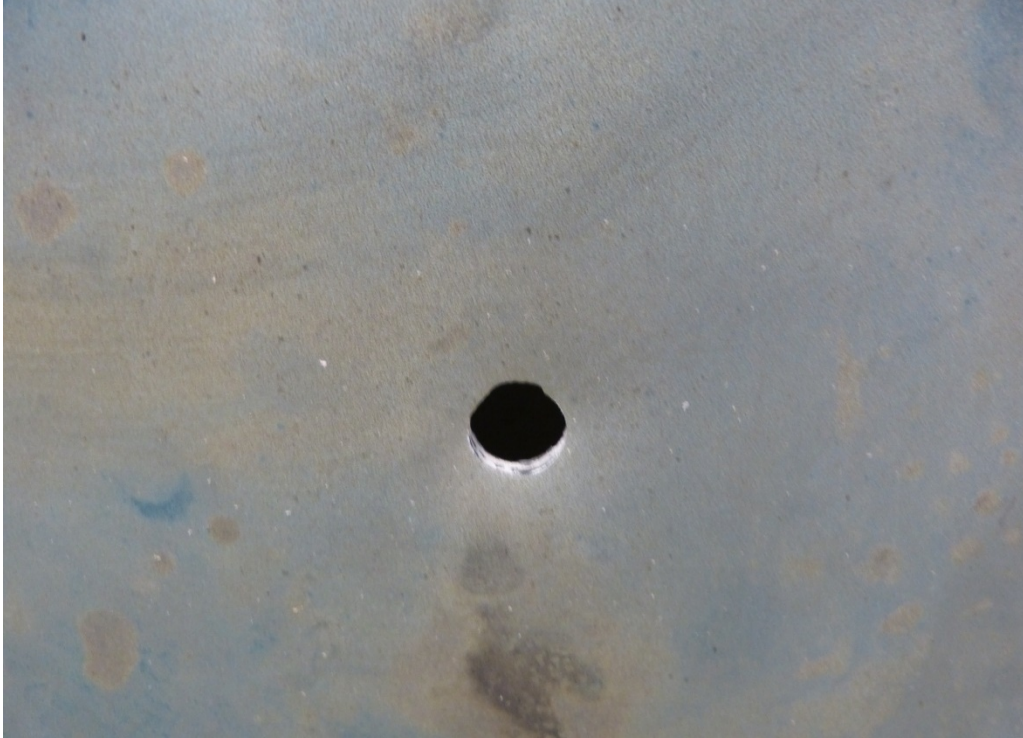


Figure C.122.—DB263 posttest front view closeup.

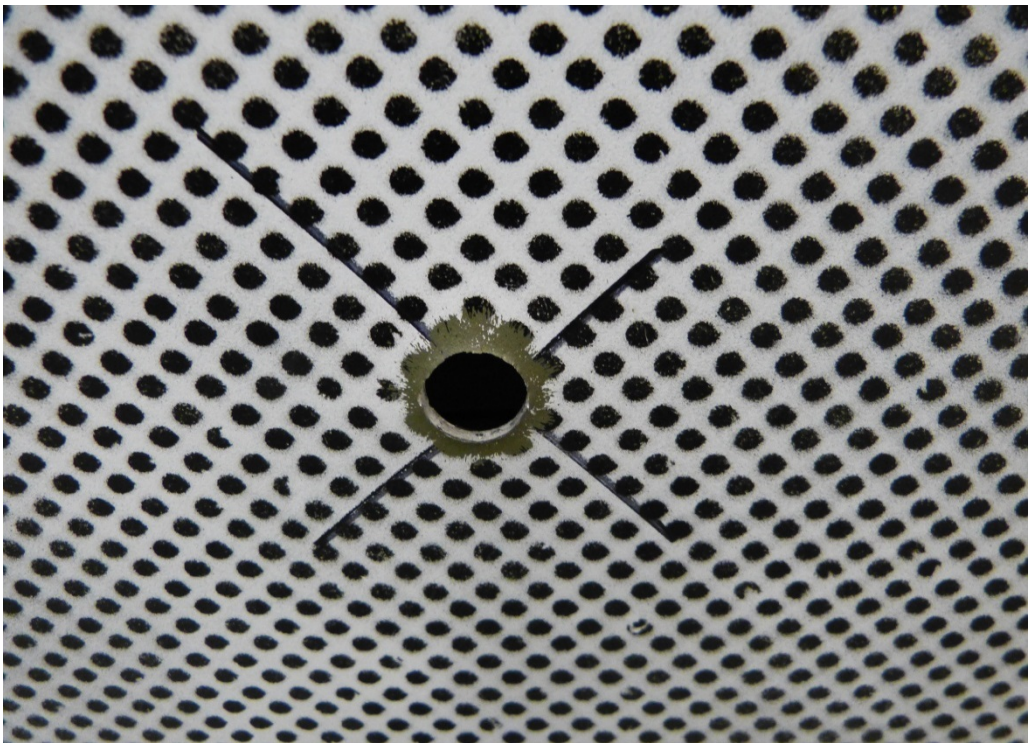


Figure C.123.—DB263 posttest rear view closeup.

Test DB264

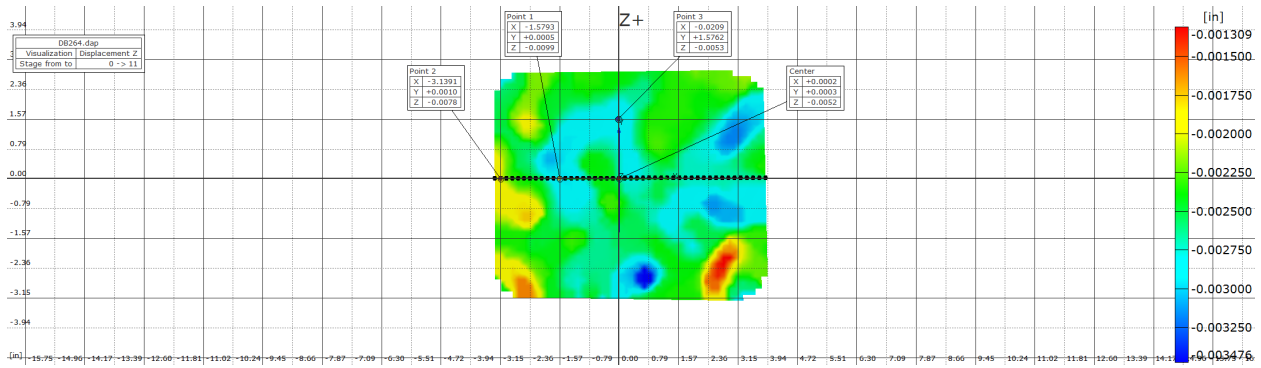


Figure C.124.—DB264 locations of digital image correlation (DIC) measurements.

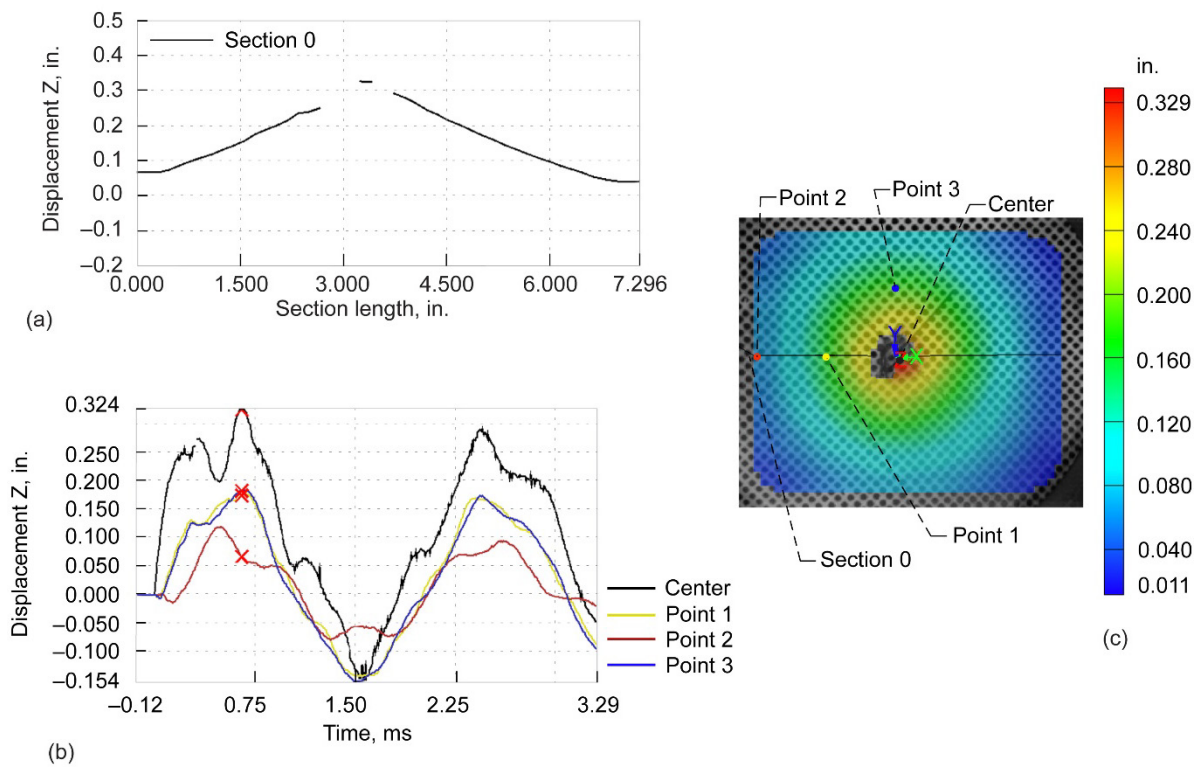


Figure C.125.—DB264 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

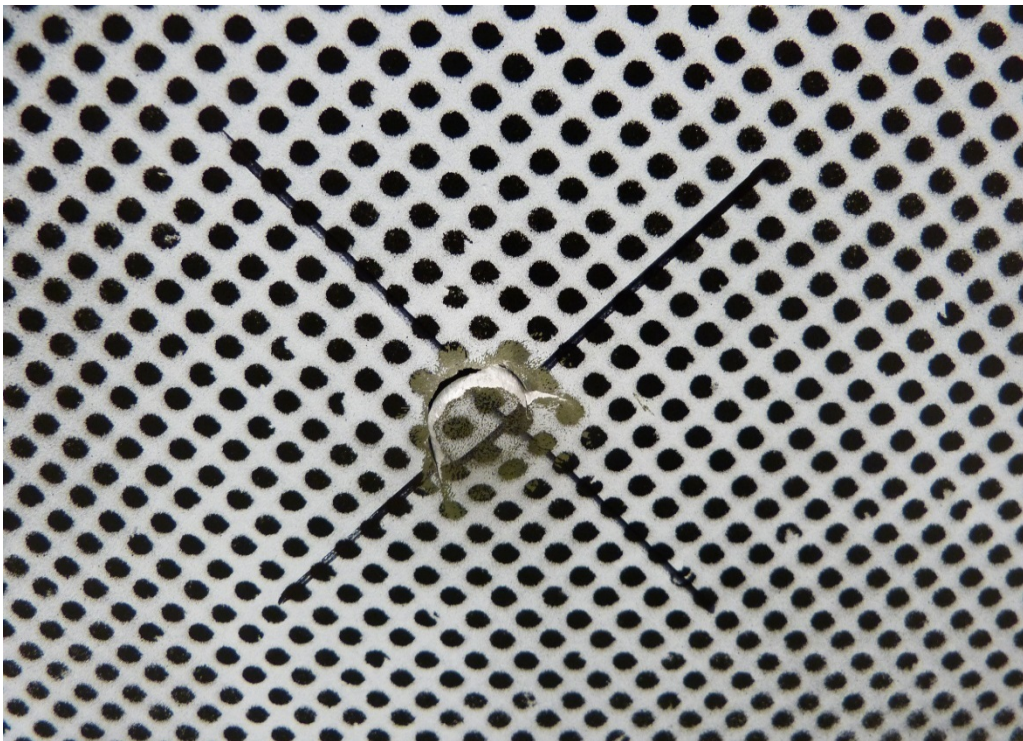


Figure C.127.—DB264 posttest rear view closeup.

Test DB265

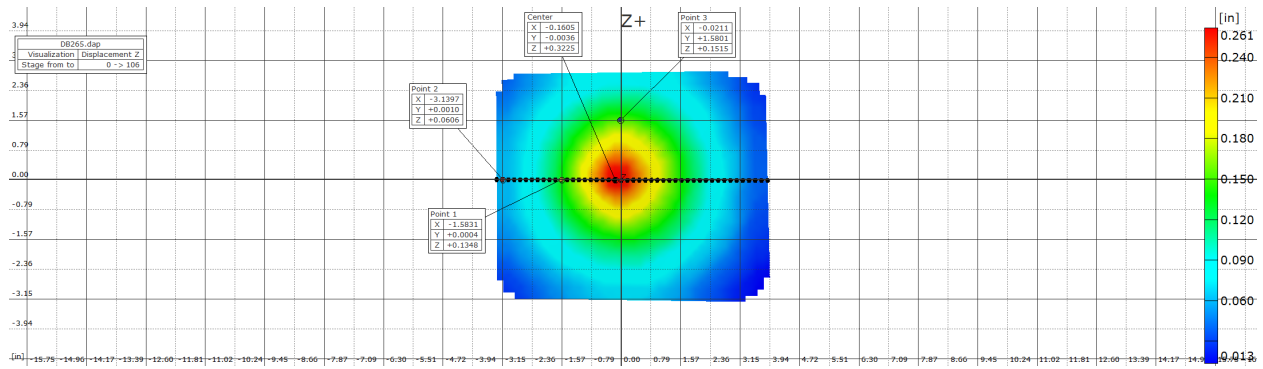


Figure C.128.—DB265 locations of digital image correlation (DIC) measurements.

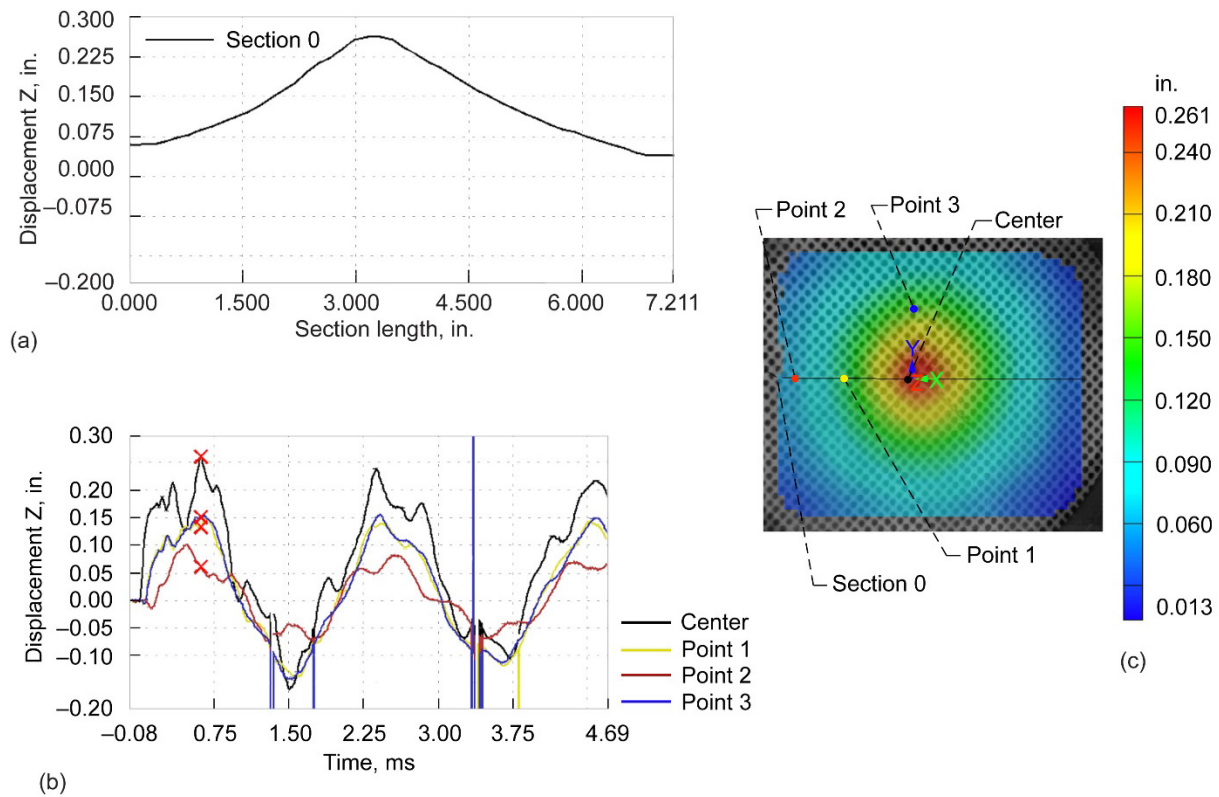


Figure C.129.—DB265 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

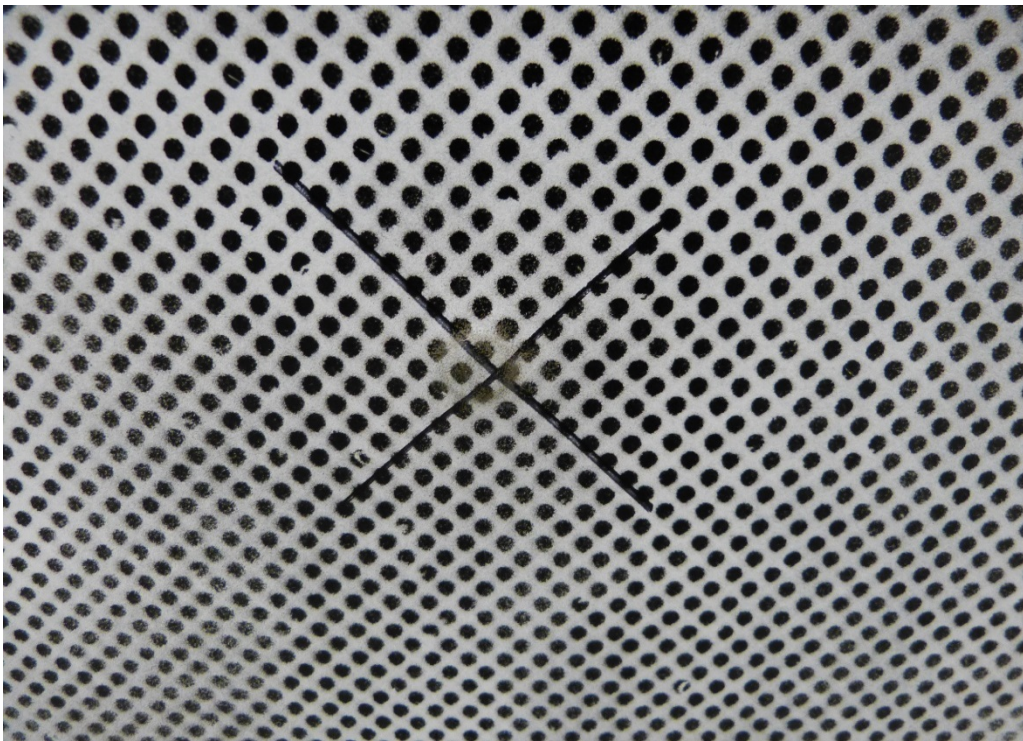


Figure C.131.—DB265 posttest rear view closeup.

Test DB266

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

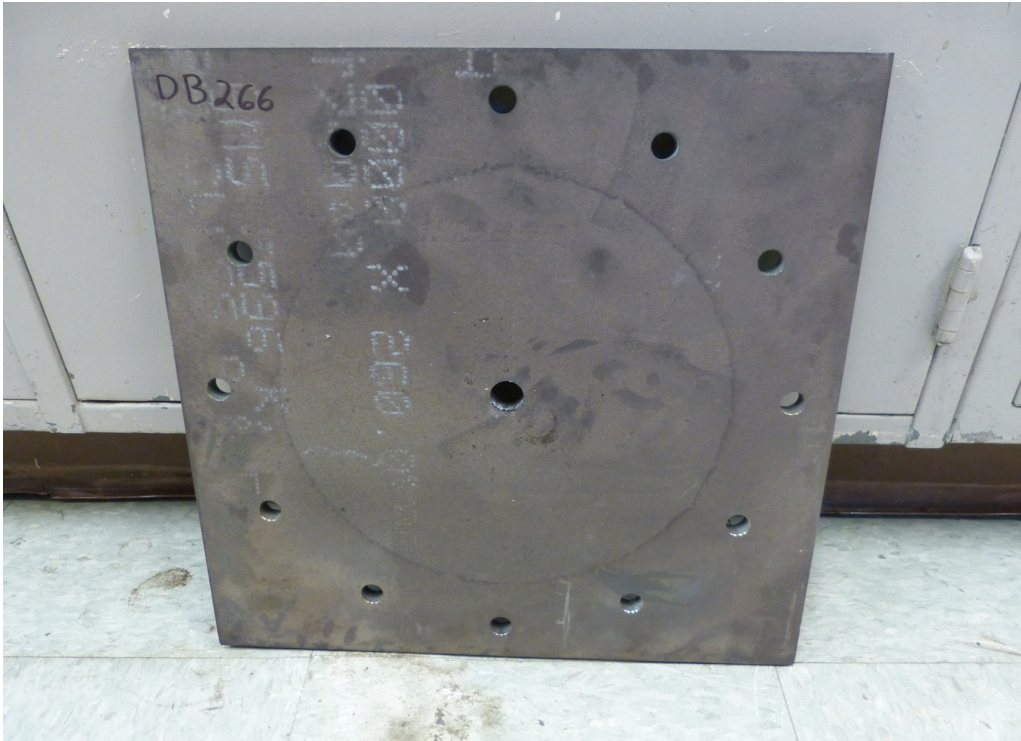


Figure C.132.—DB266 posttest front view.

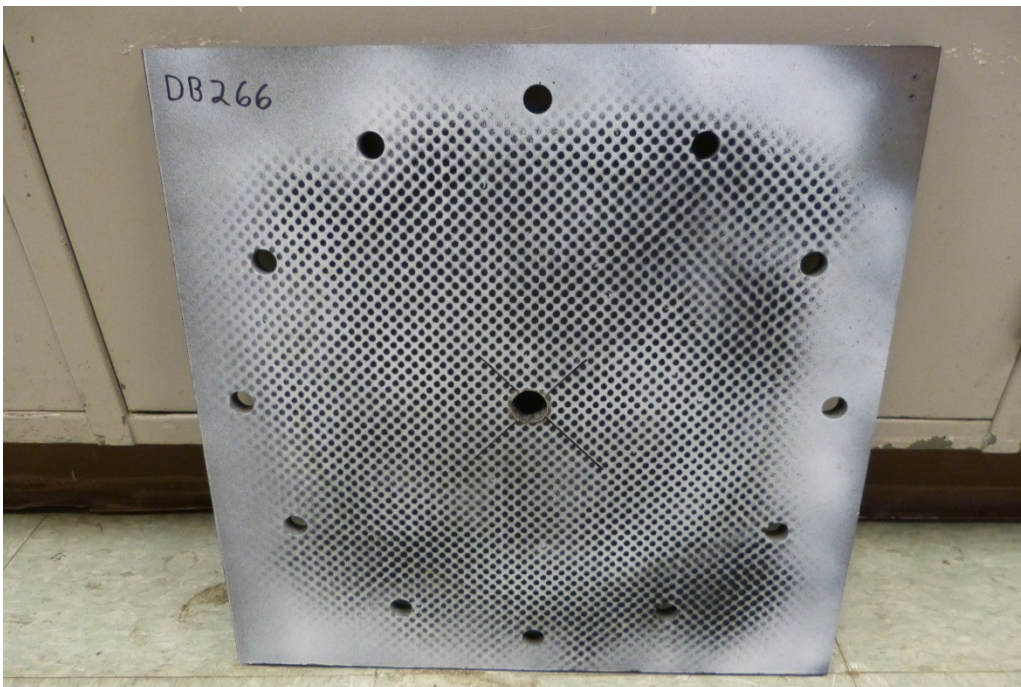


Figure C.133.—DB266 posttest rear view.



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

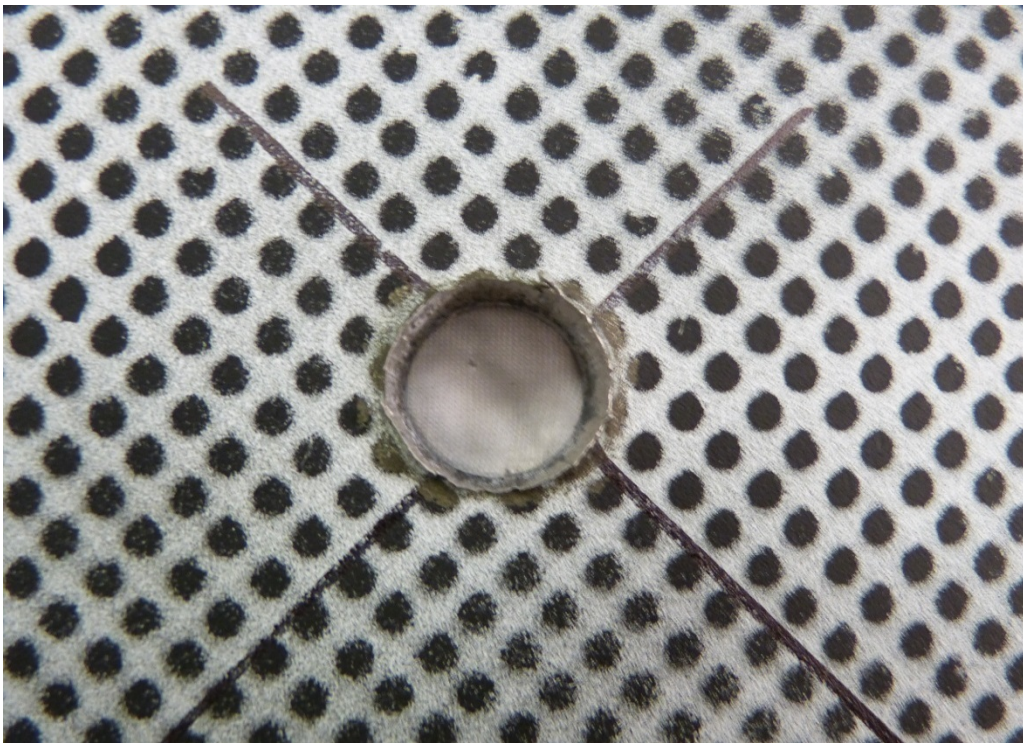


Figure C.135.—DB266 posttest rear view closeup.

Test DB267

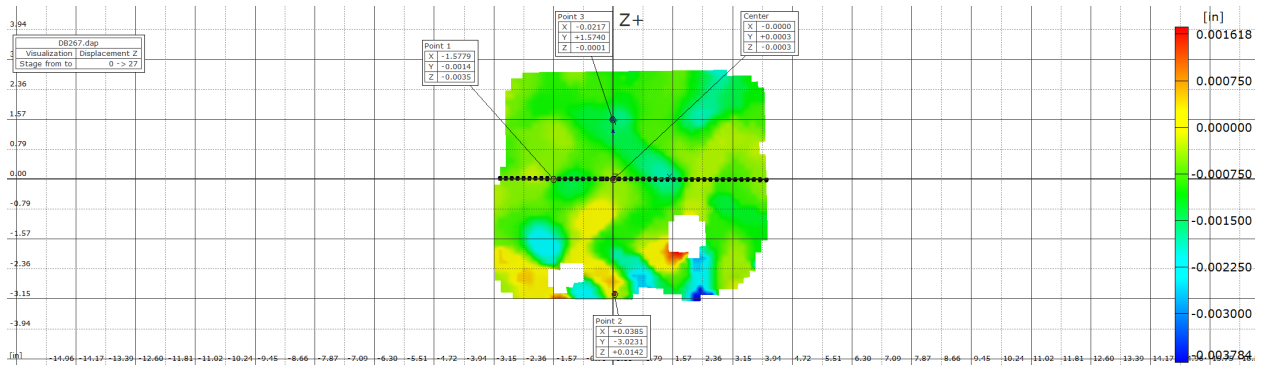


Figure C.136.—DB267 locations of digital image correlation (DIC) measurements.

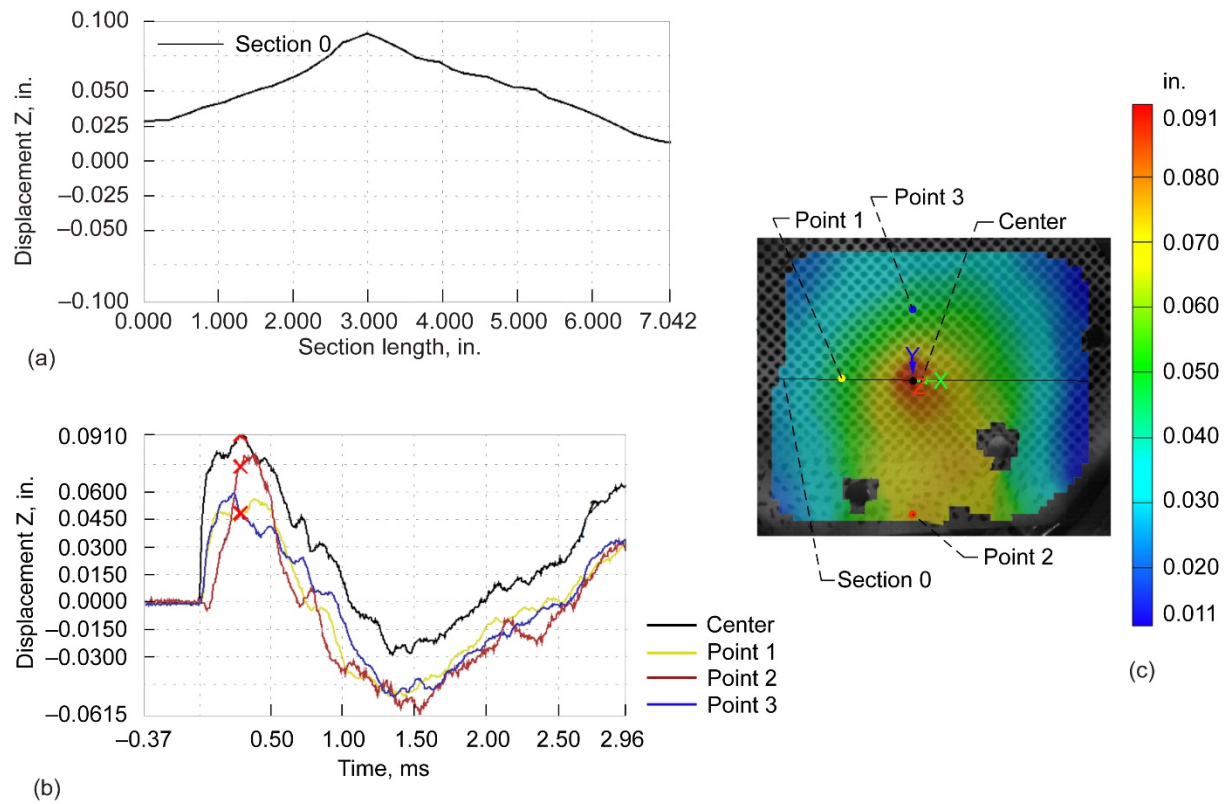


Figure C.137.—DB267 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

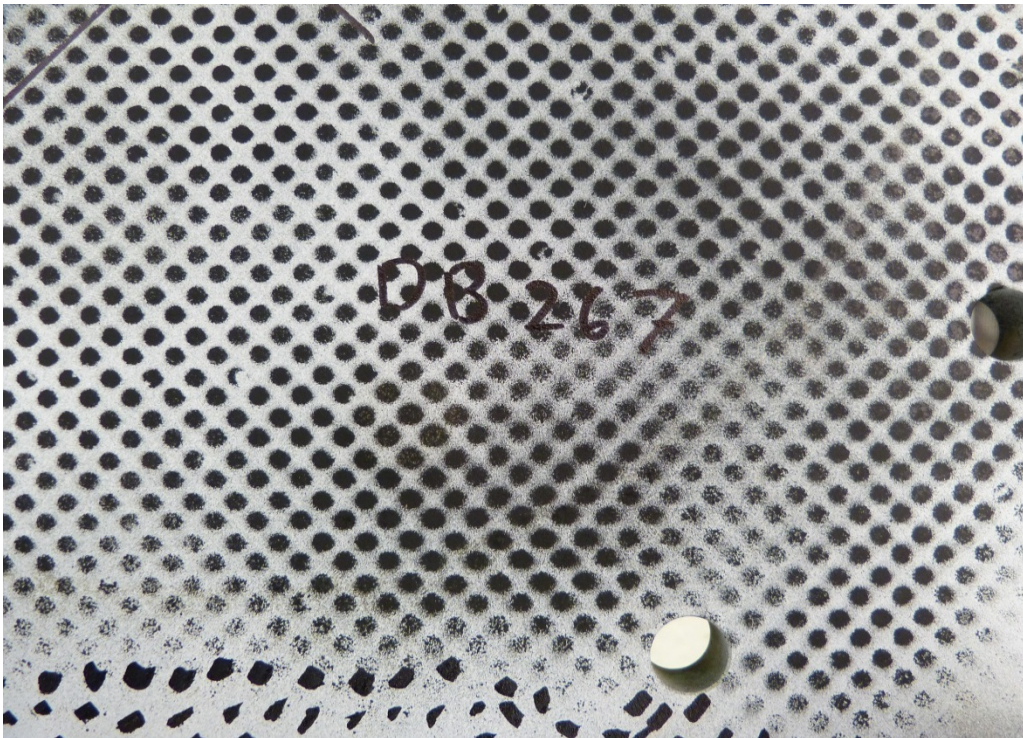


Figure C.139.—DB267 posttest rear view closeup.

Test DB268

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

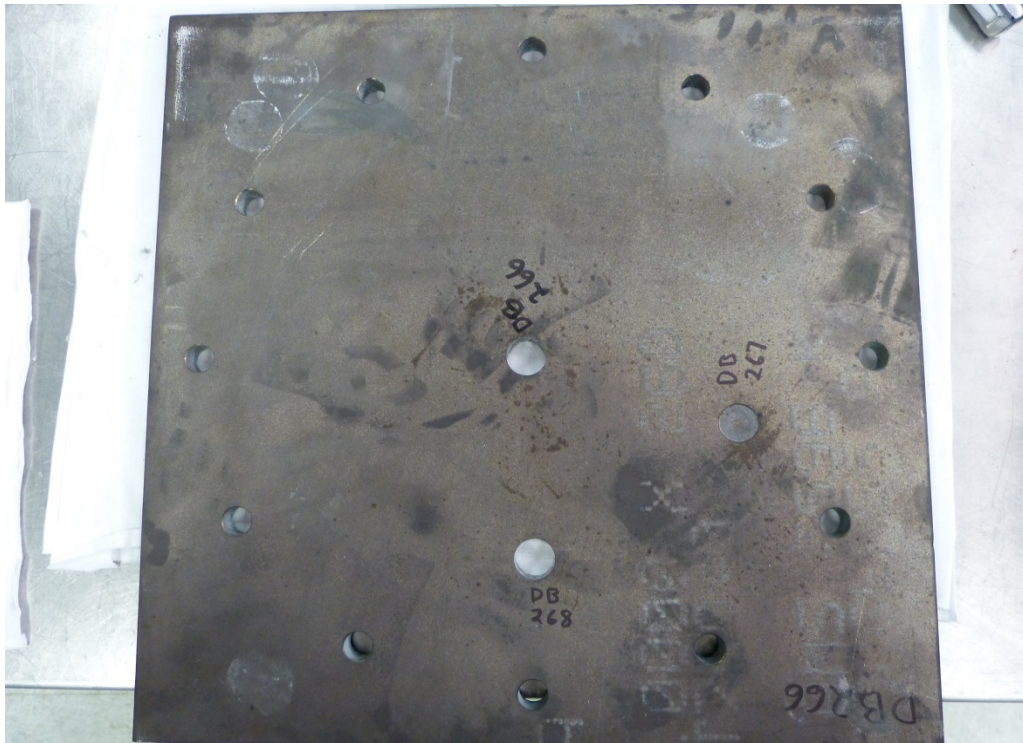


Figure C.140.—DB268 posttest front view.

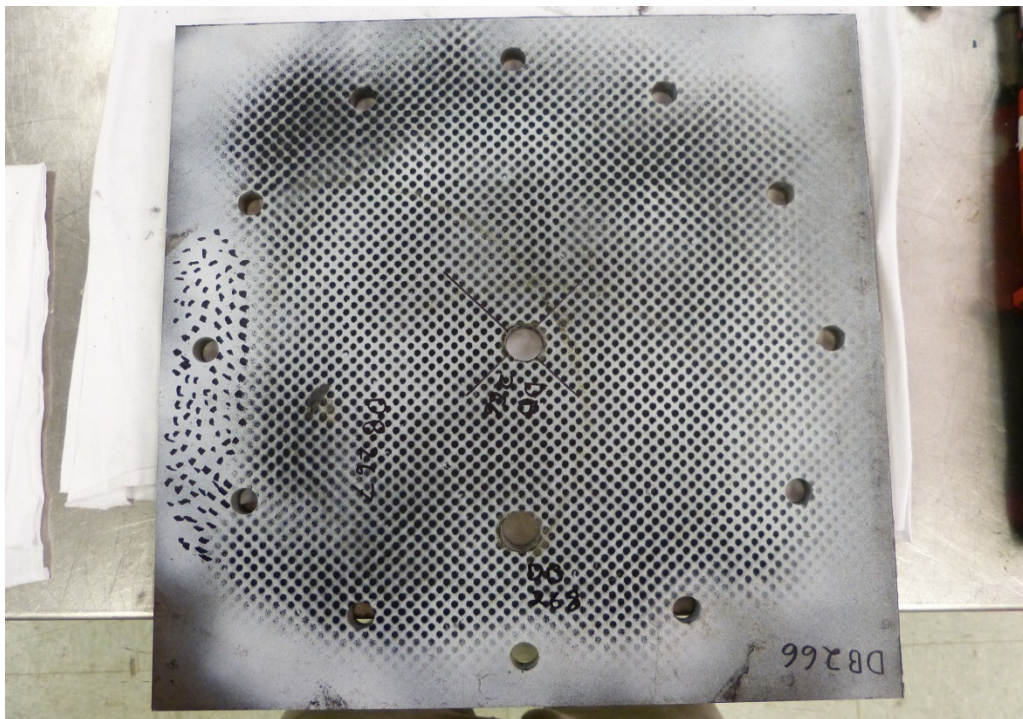


Figure C.141.—DB268 posttest rear view.



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



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

Test DB269

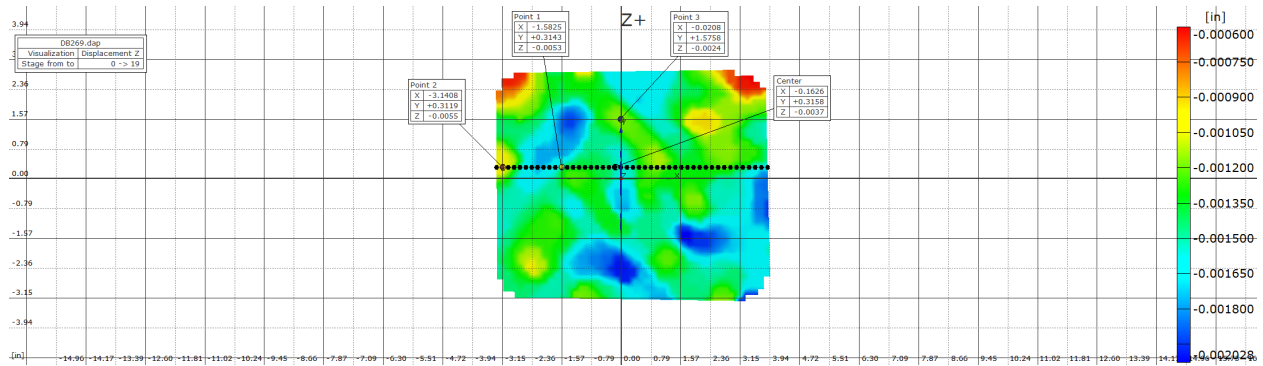


Figure C.144.—DB269 locations of digital image correlation (DIC) measurements.

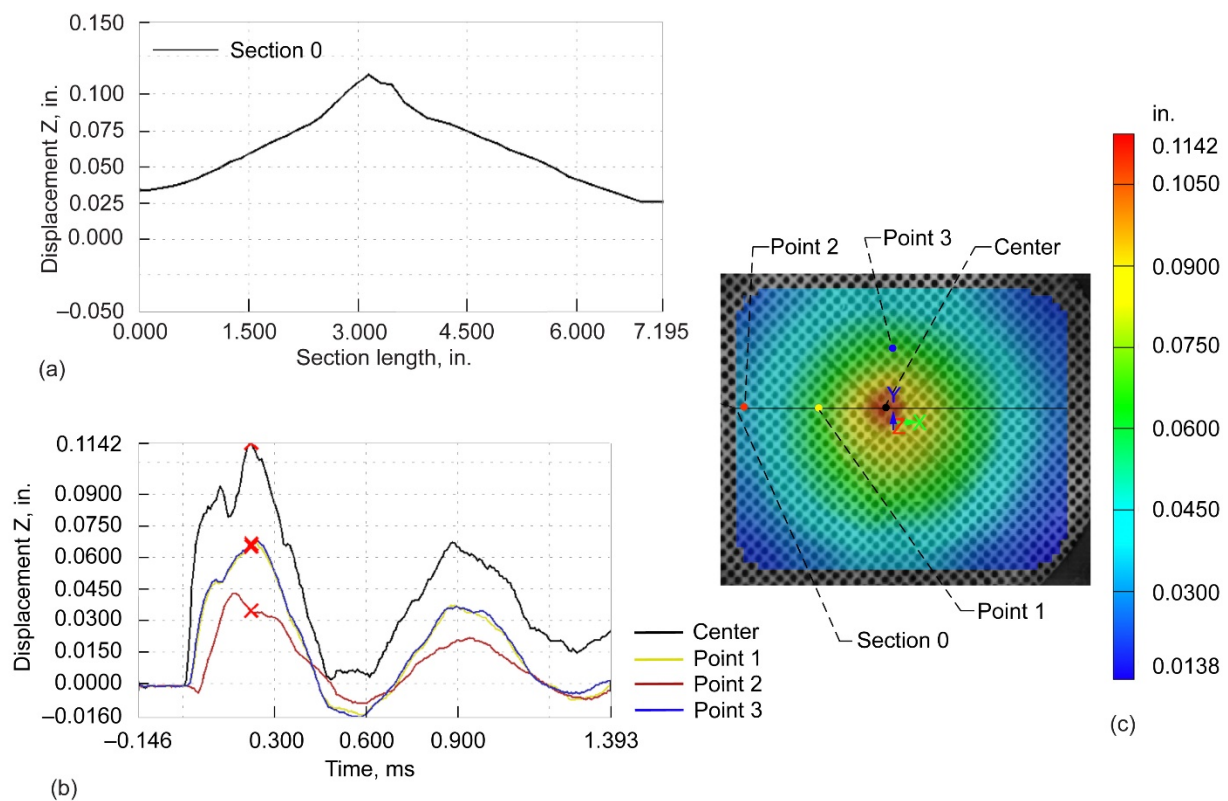


Figure C.145.—DB269 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

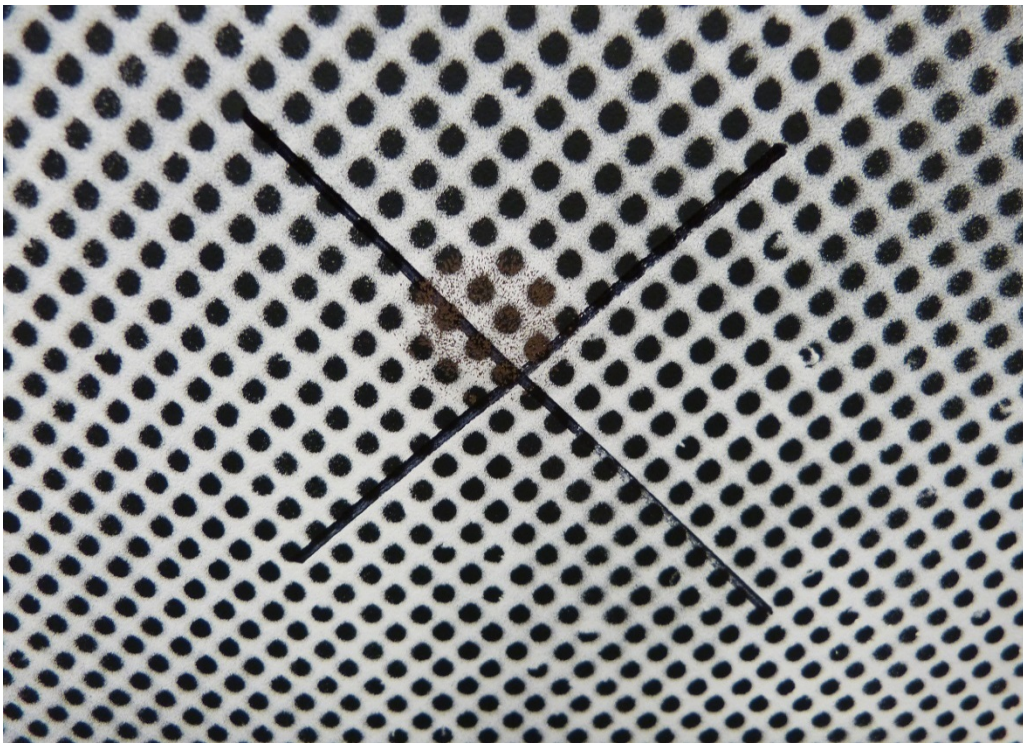


Figure C.147.—DB269 posttest rear view closeup.

Test DB270

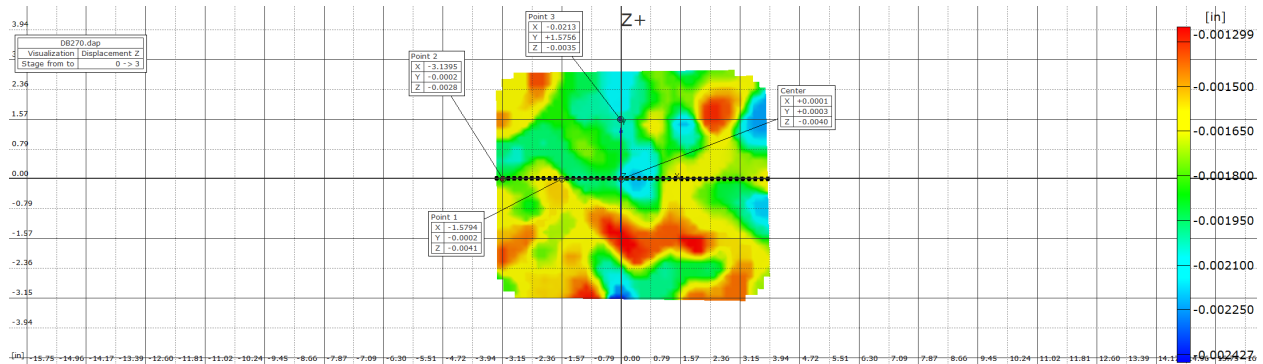


Figure C.148.—DB270 locations of digital image correlation (DIC) measurements.

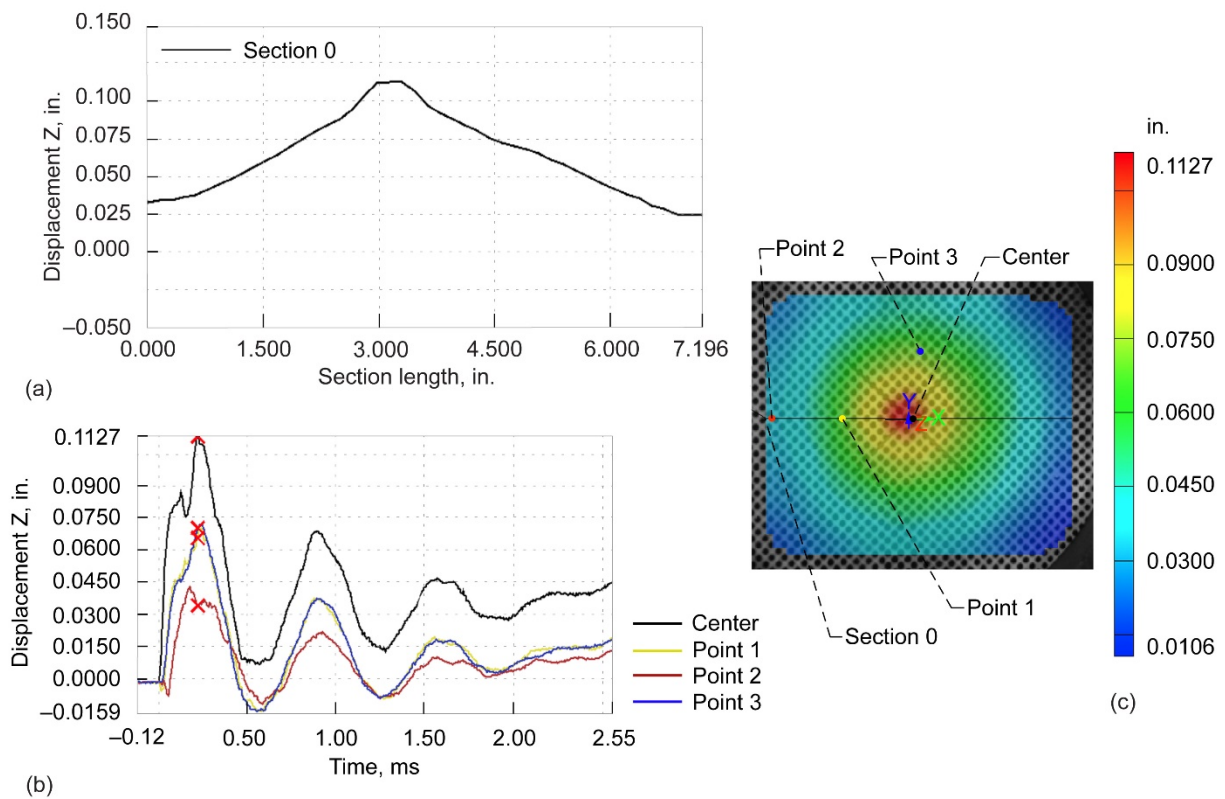


Figure C.149.—DB270 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

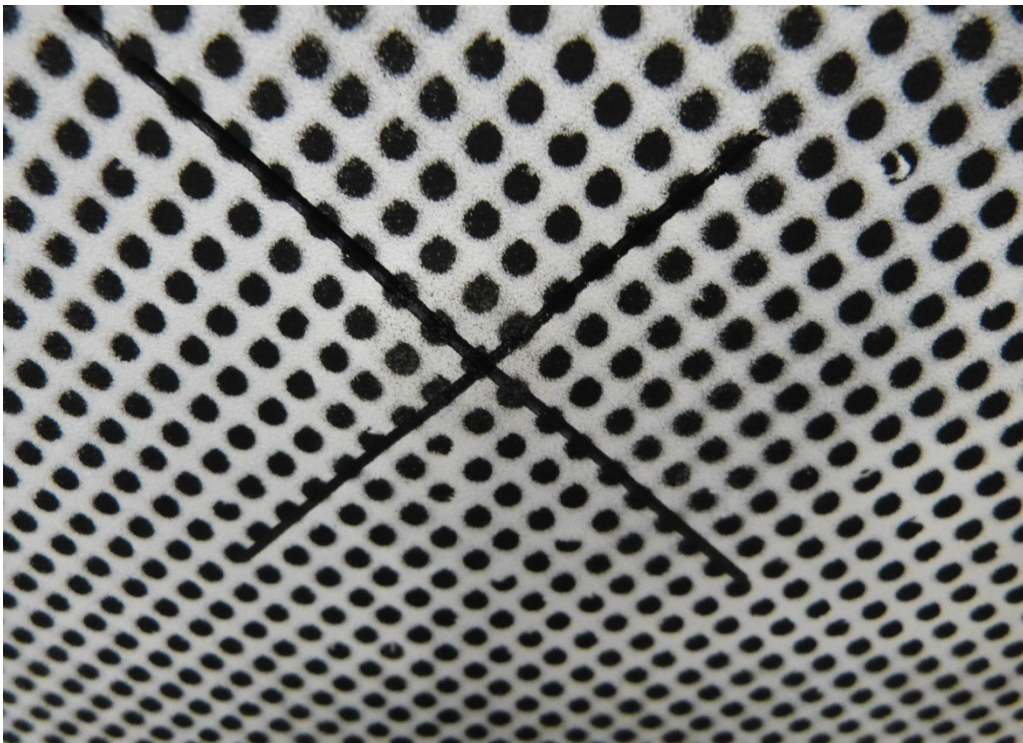


Figure C.151.—DB270 posttest rear view closeup.

Test DB271

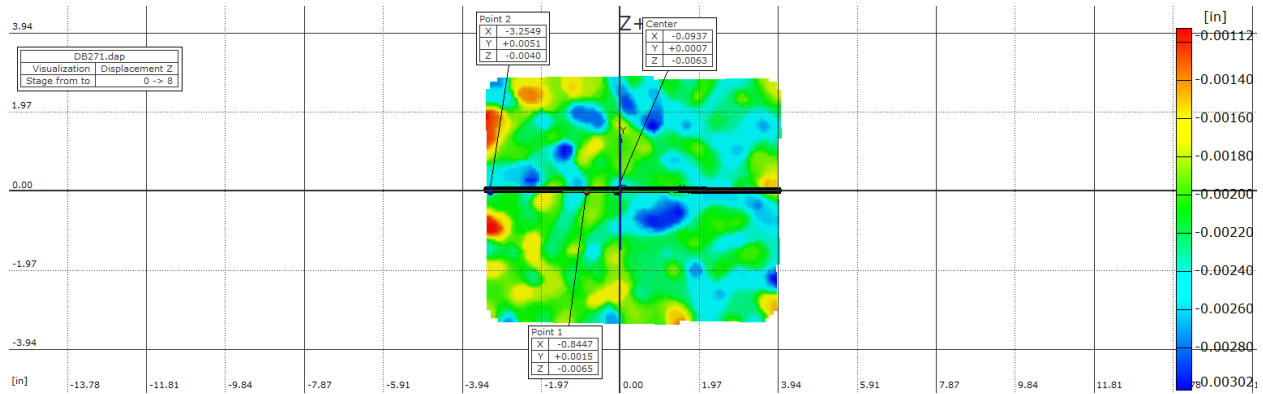


Figure C.152.—DB271 locations of digital image correlation (DIC) measurements.

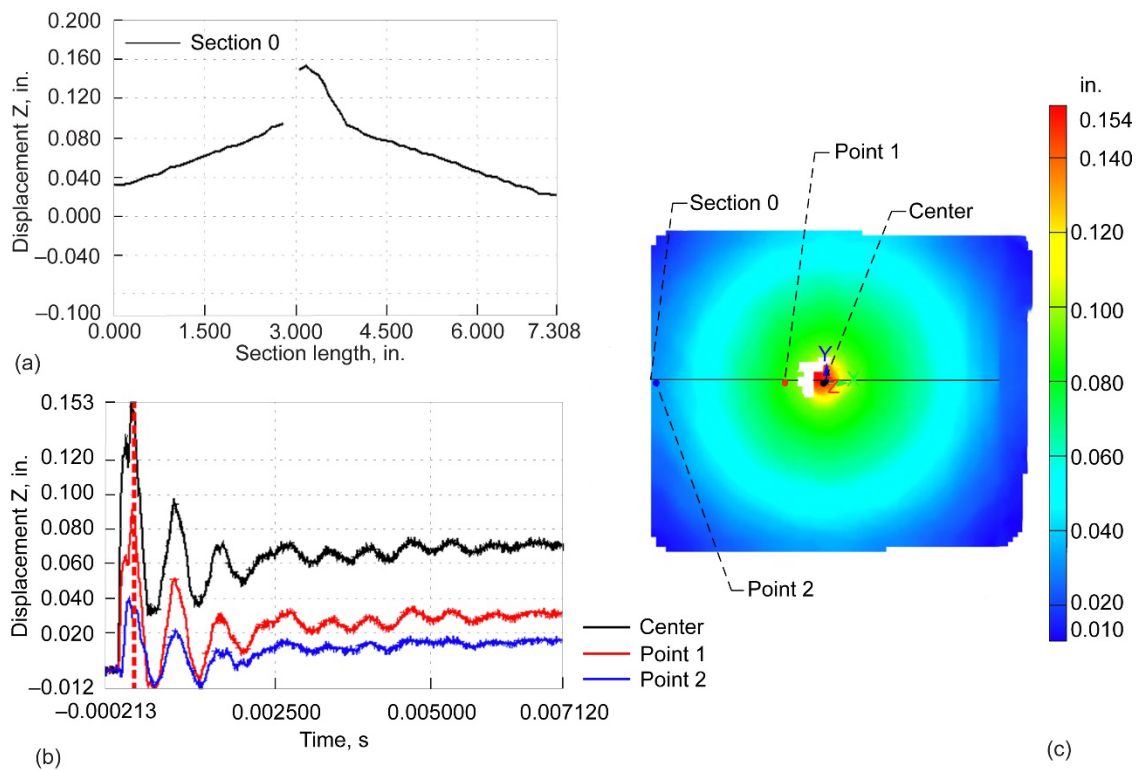


Figure C.153.—DB271 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

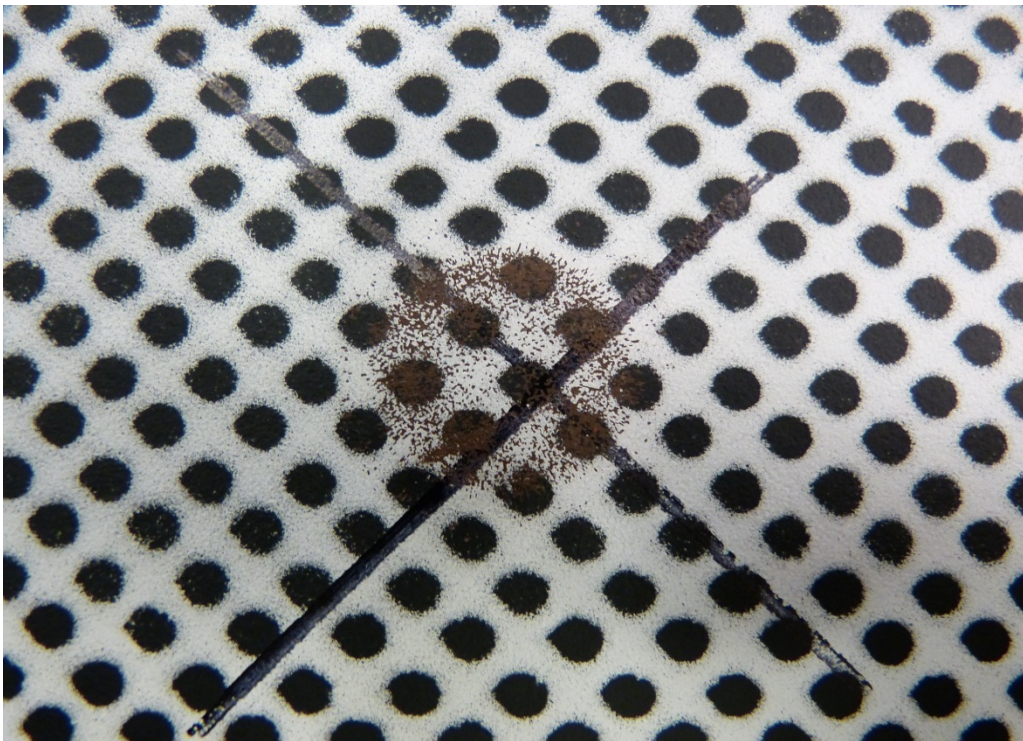


Figure C.155.—DB271 posttest rear view closeup.

Test DB272

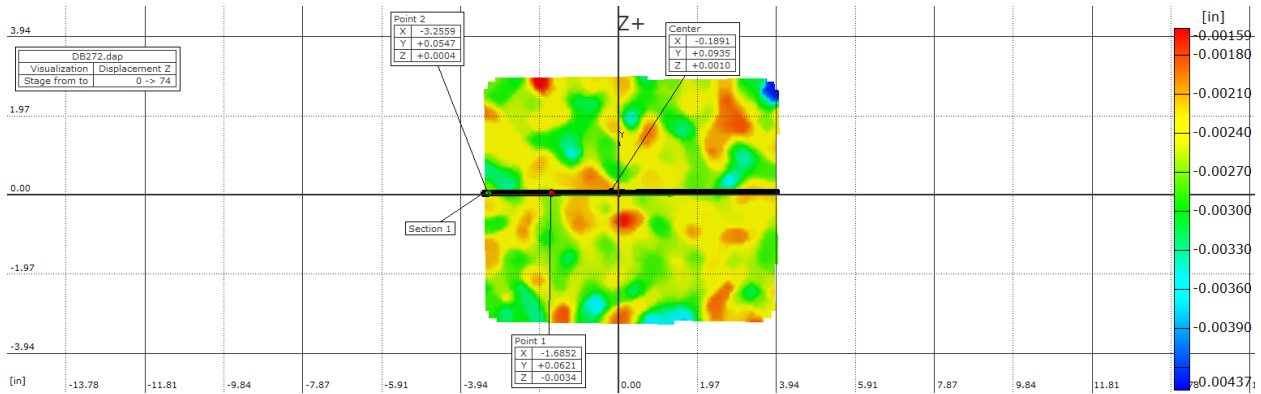


Figure C.156.—DB272 locations of digital image correlation (DIC) measurements.

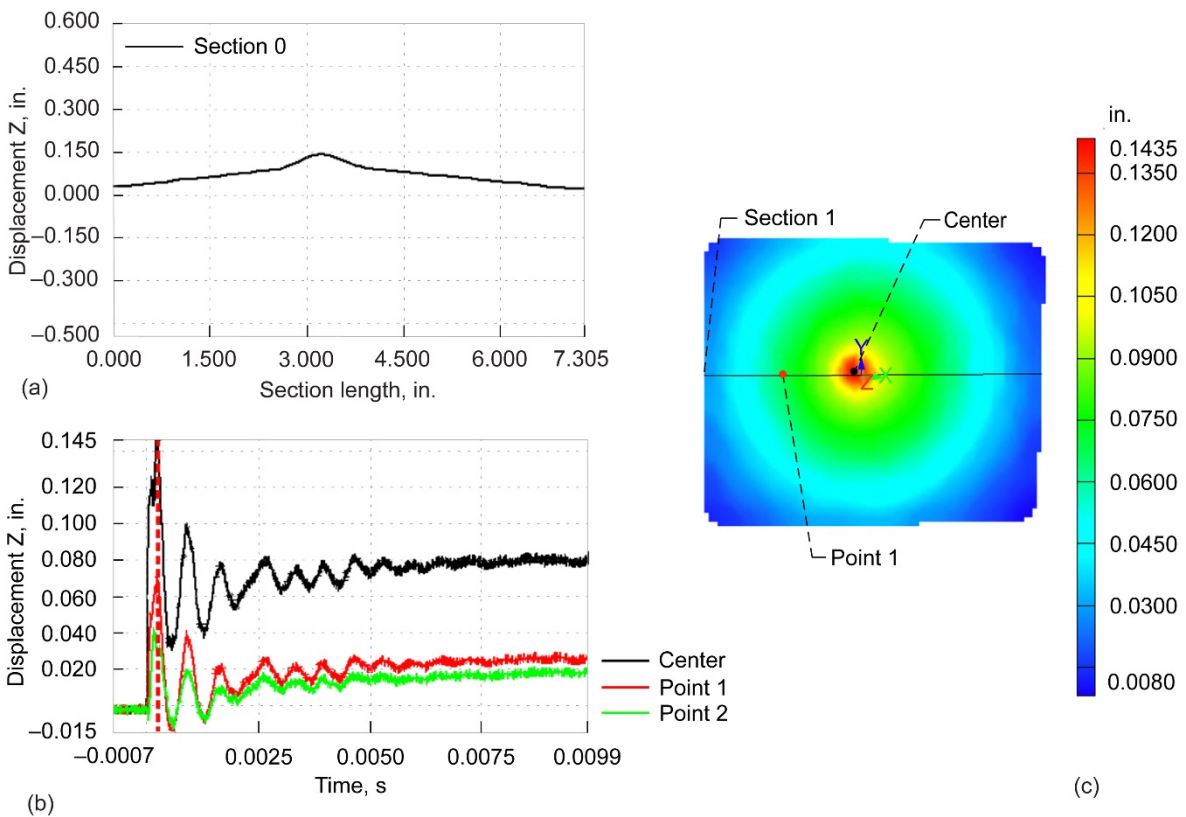


Figure C.157.—DB272 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.



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

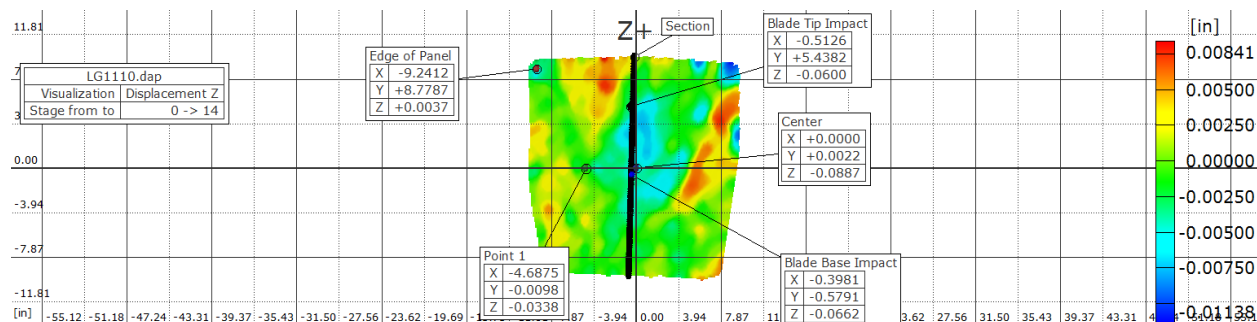


Figure D.1.—LG1110 locations of digital image correlation (DIC) measurements.

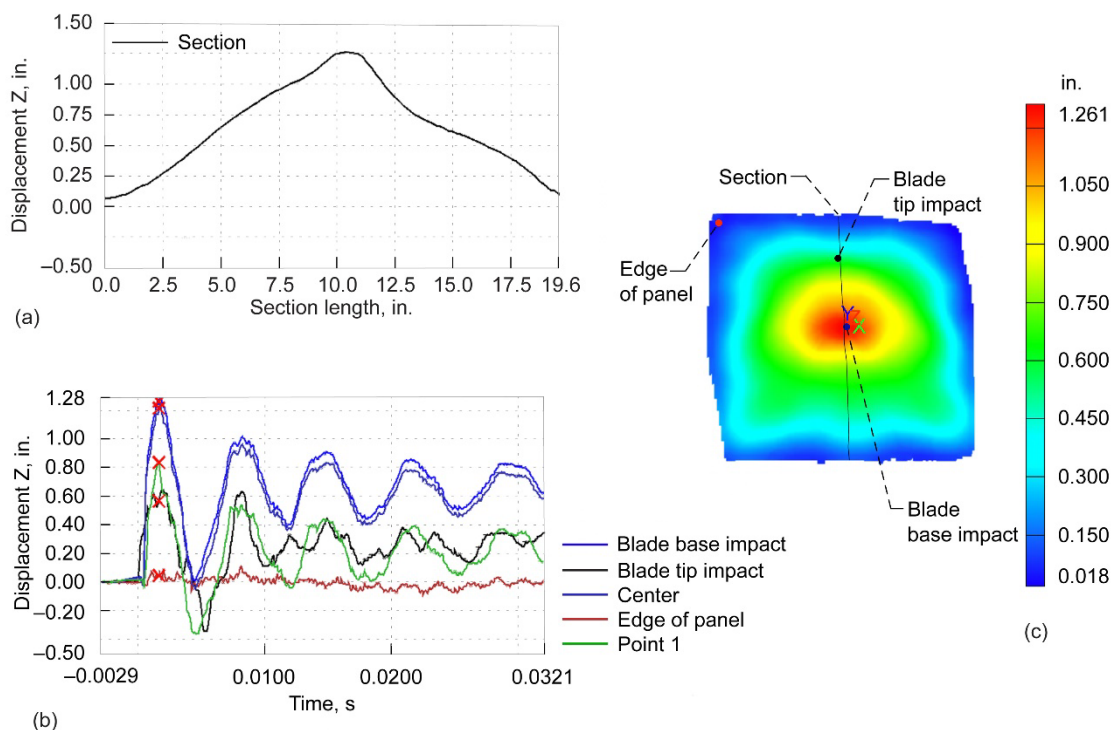


Figure D.2.—LG1110 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z .



Figure D.3.—LG1110 posttest front view.

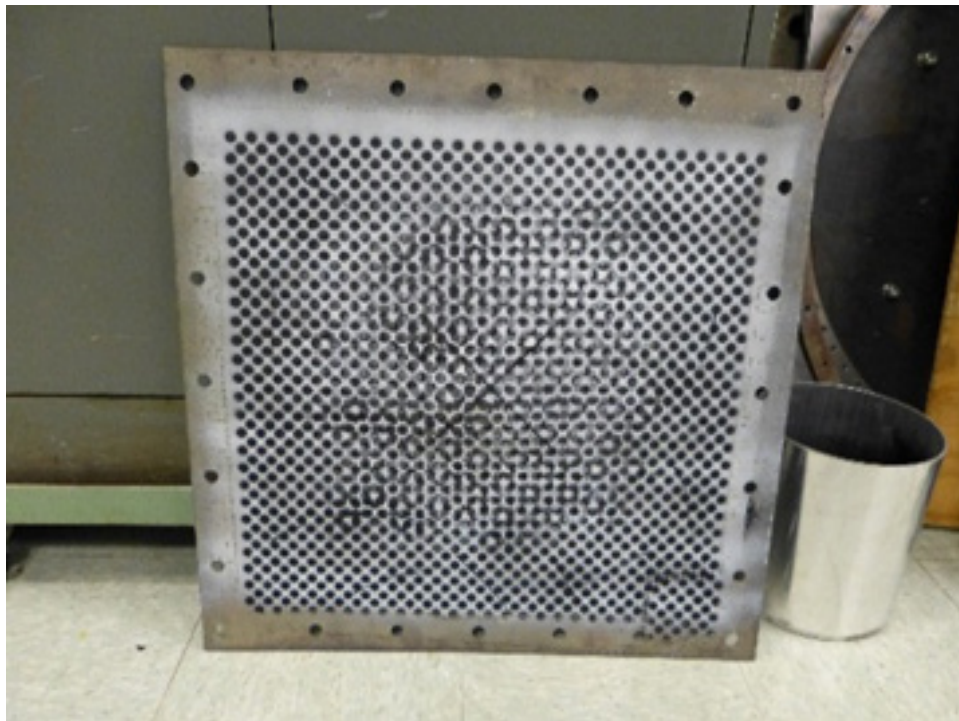


Figure D.4.—LG1110 posttest rear view.



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



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

Test LG1111

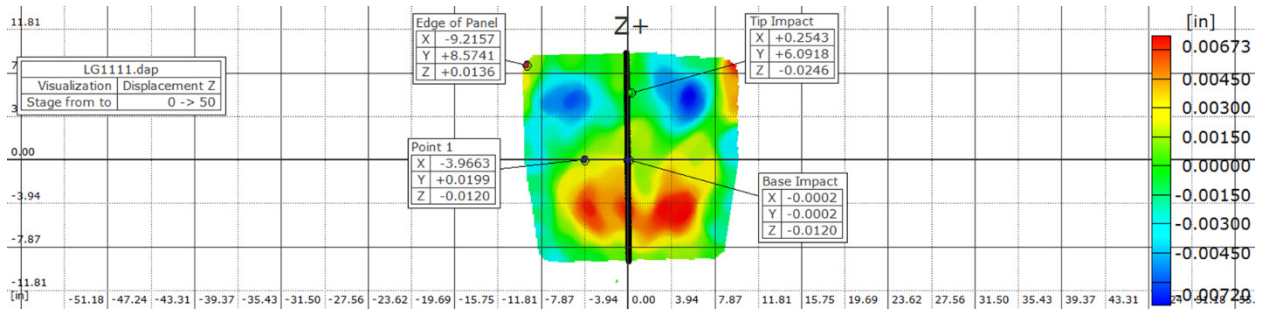


Figure D.7.—LG1111 locations of digital image correlation (DIC) measurements.

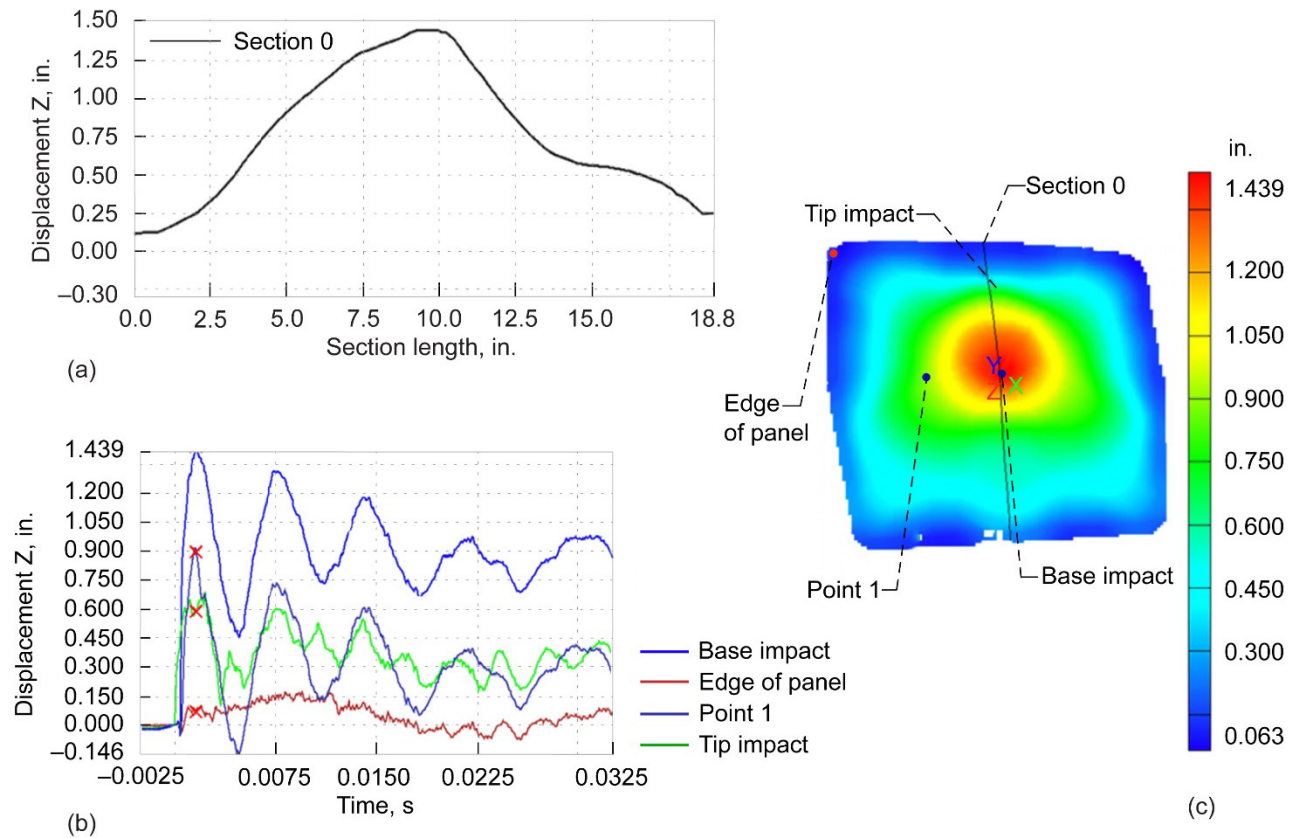


Figure D.8.—LG1111 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

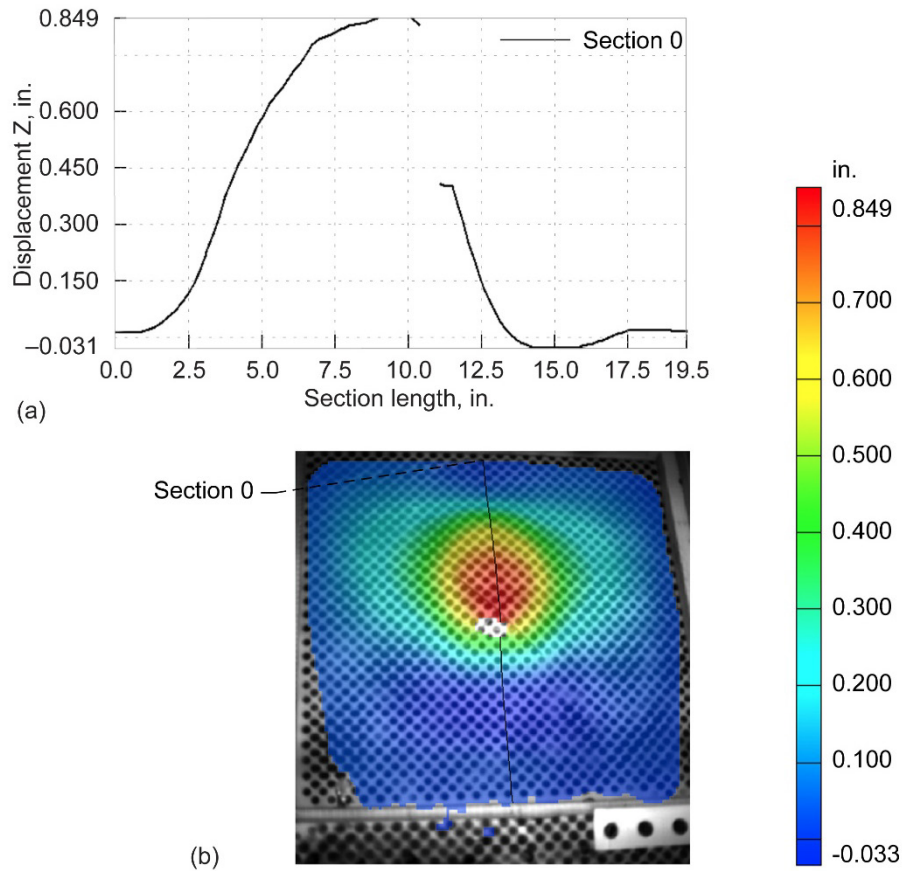


Figure D.9.—LG1111 posttest displacements (a) Displacement versus length. (b) Displacement Z.



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.

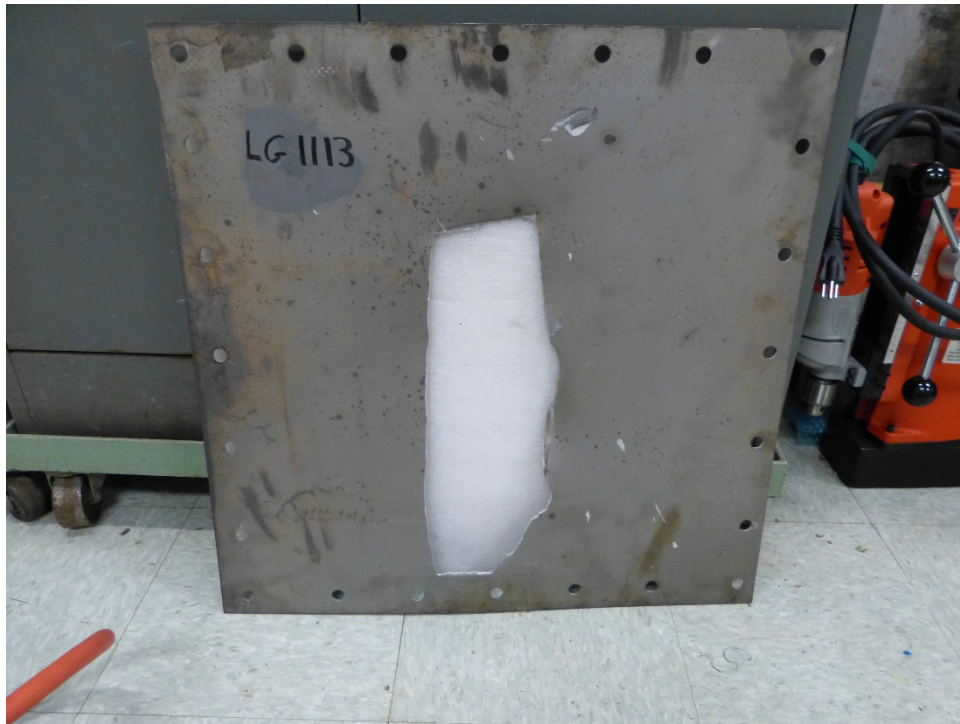


Figure D.13.—LG1113 posttest front view.

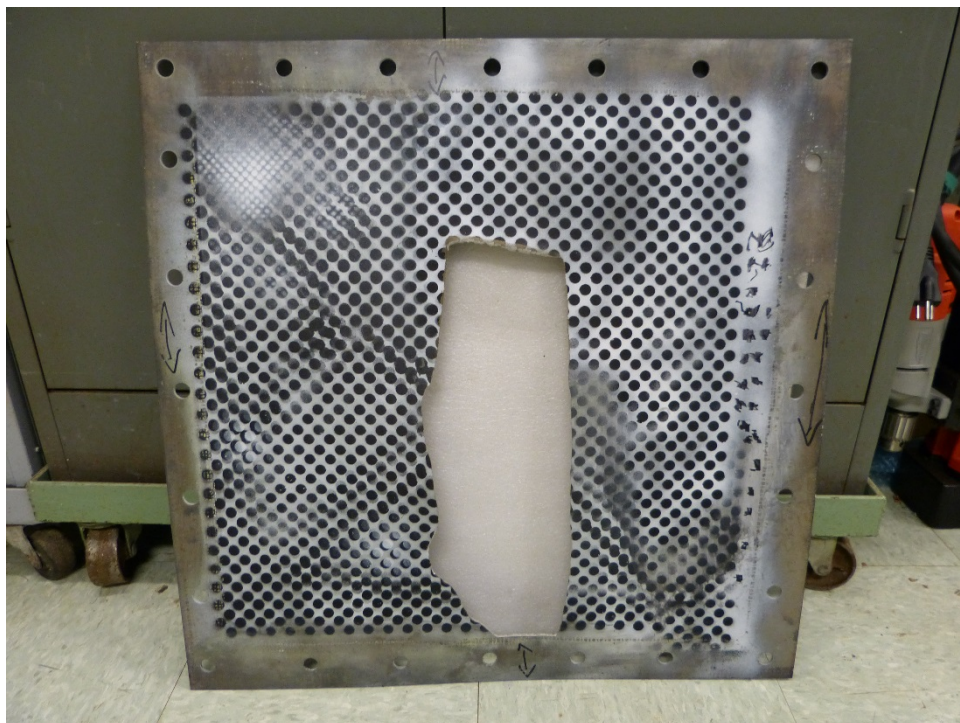


Figure D.14.—LG1113 posttest rear view.



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.

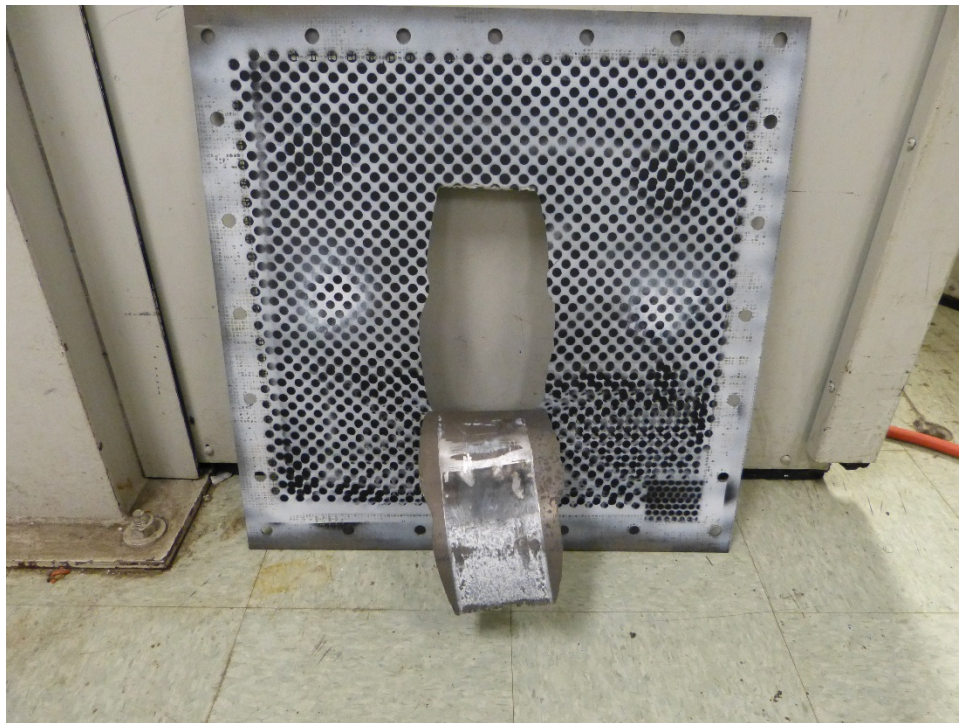


Figure D.18.—LG1114 posttest rear view.



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

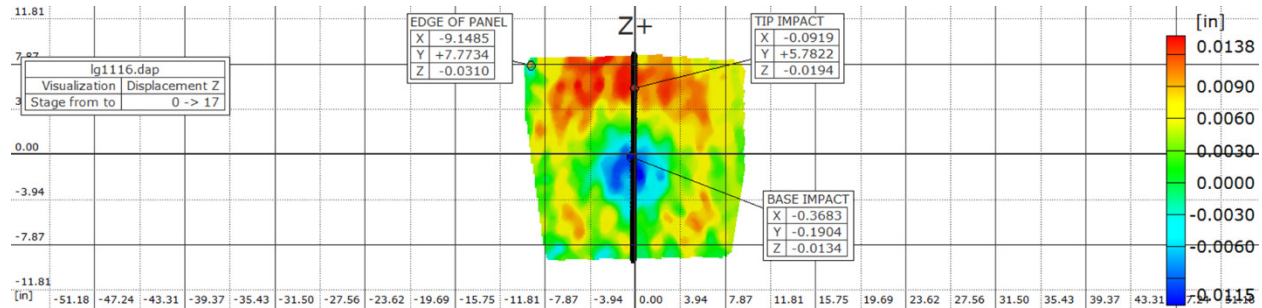


Figure D.23.—LG1116 locations of digital image correlation (DIC) measurements.

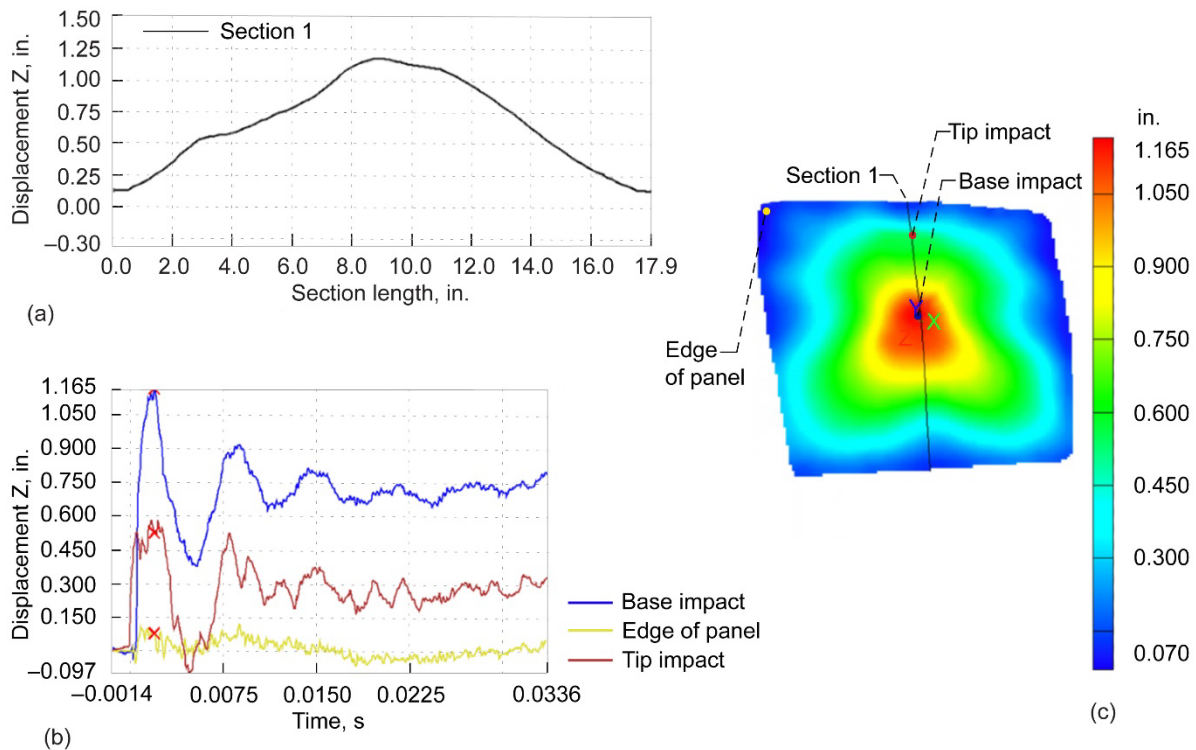


Figure D.24.—LG1116 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

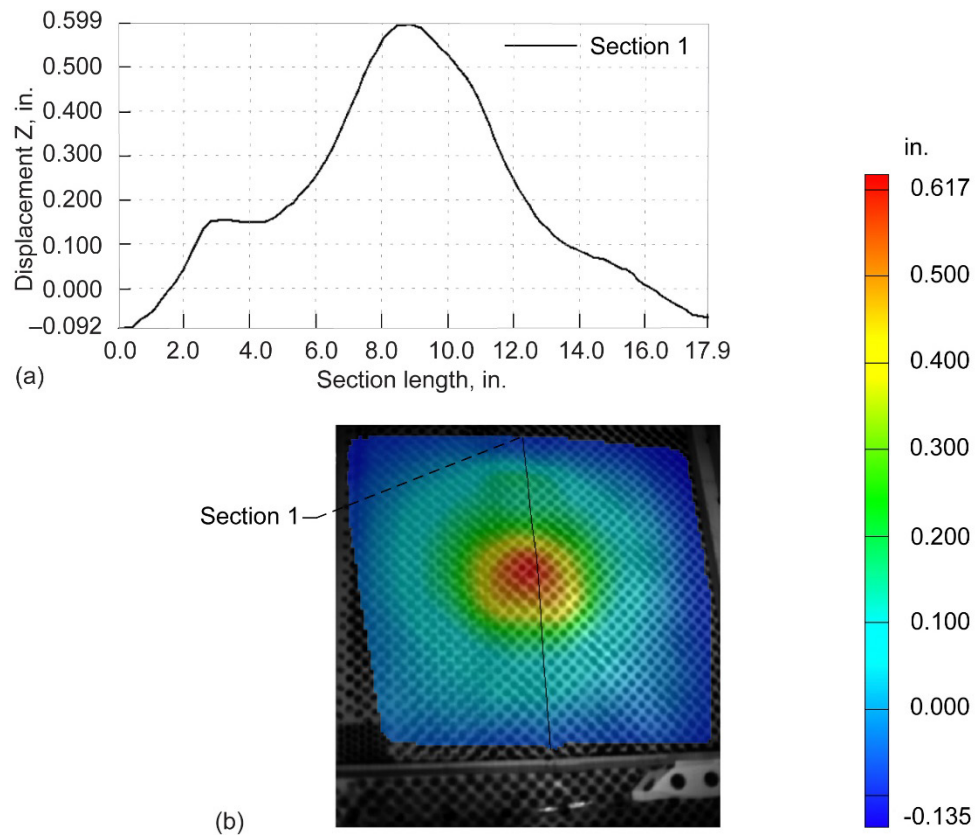


Figure D.25.—LG1116 posttest displacements. (a) Displacement versus length. (b) Displacement Z.



Figure D.26.—LG1116 posttest front view.



Figure D.27.—LG1116 posttest top view.

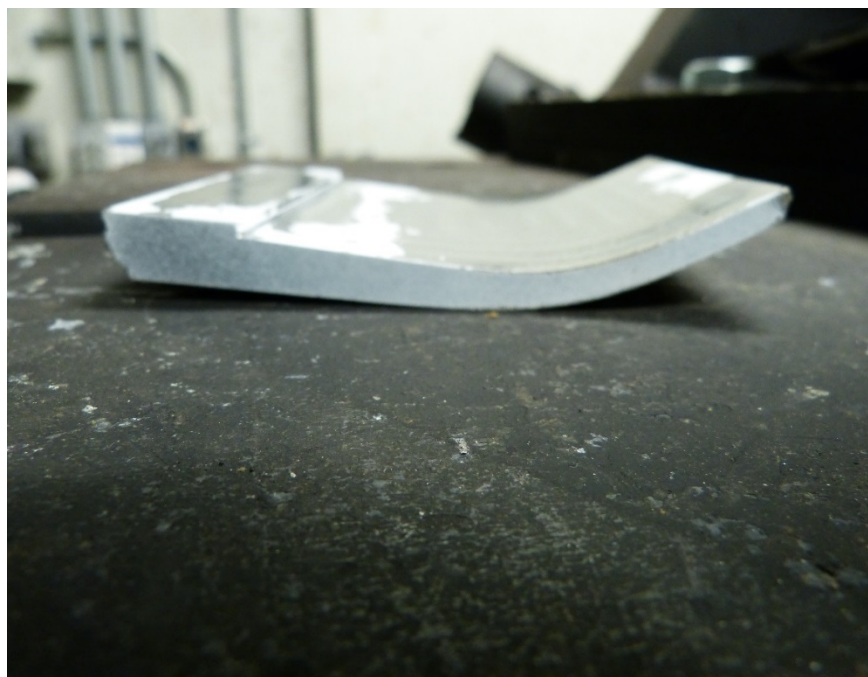


Figure D.28.—LG1116 posttest projectile side view.



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.

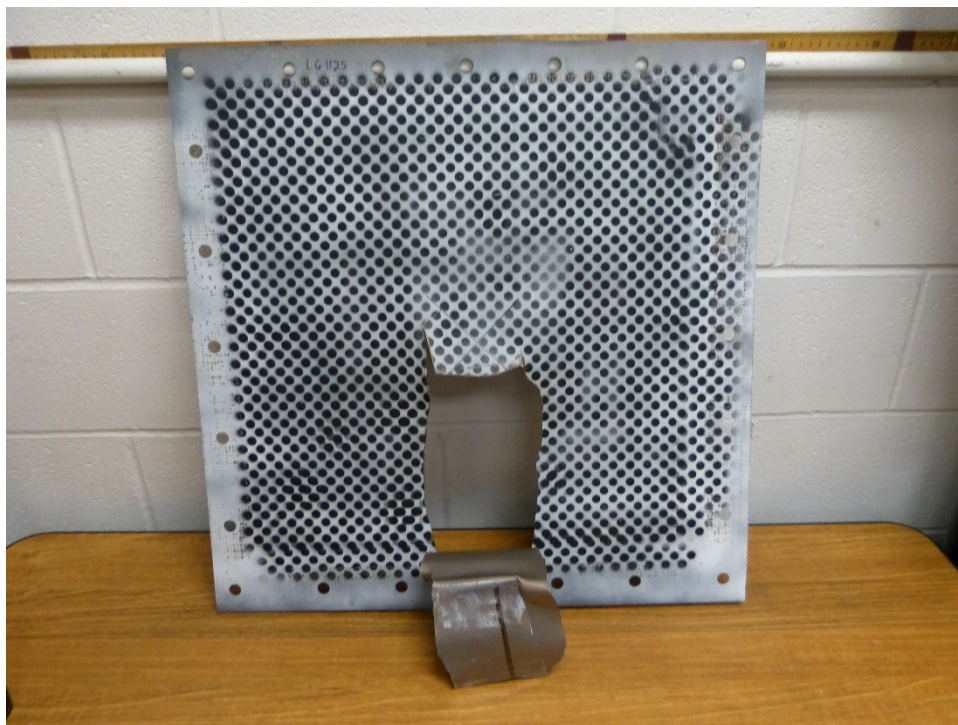


Figure D.31.—LG1125 posttest rear view.



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.

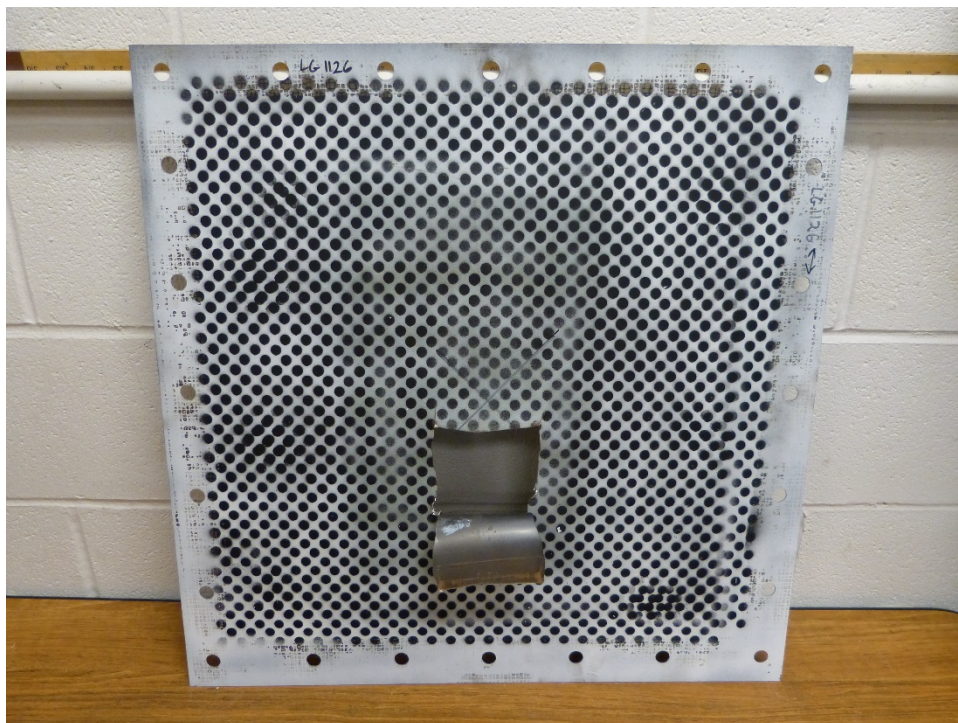


Figure D.34.—LG1126 posttest rear view.



Figure D.35.—LG1126 posttest projectile.

Test LG1127

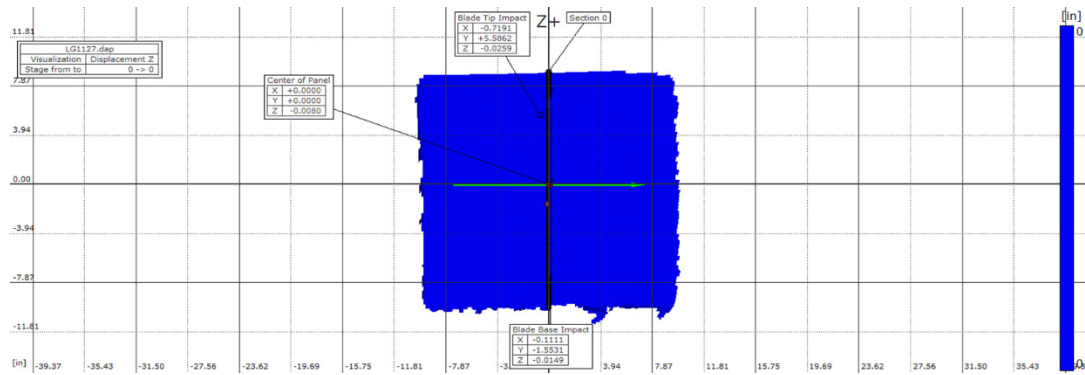


Figure D.36.—LG1127 locations of digital image correlation (DIC) measurements.

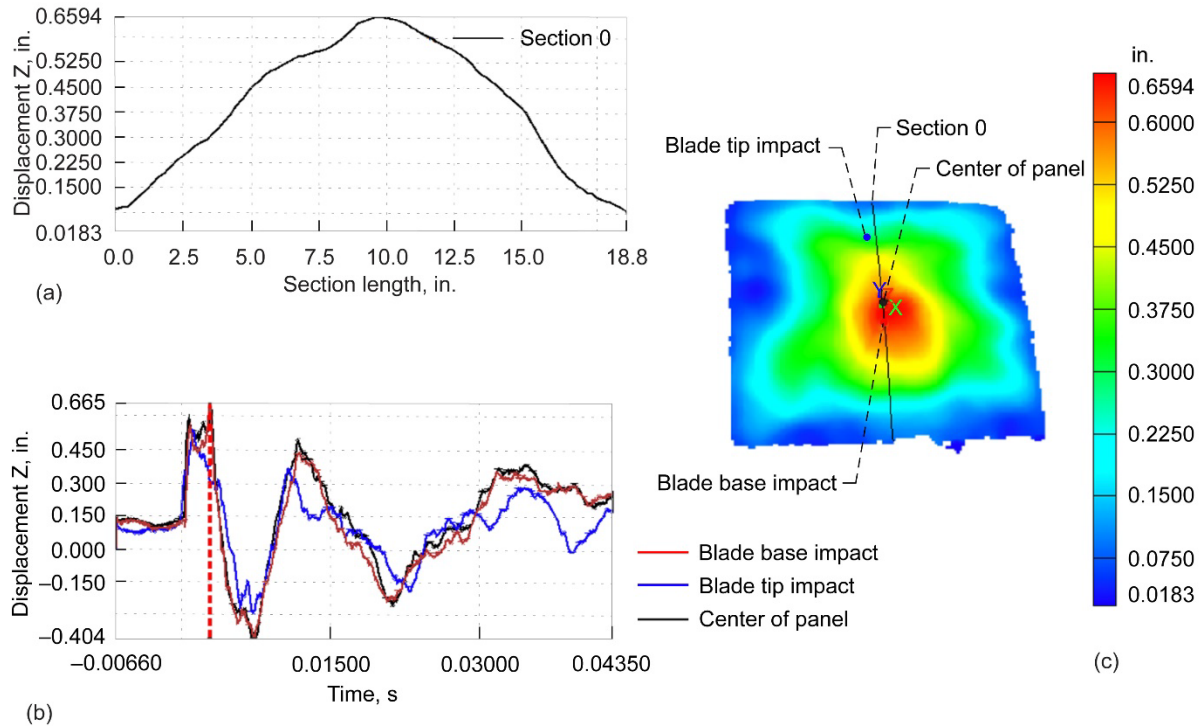


Figure D.37.—LG1127 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

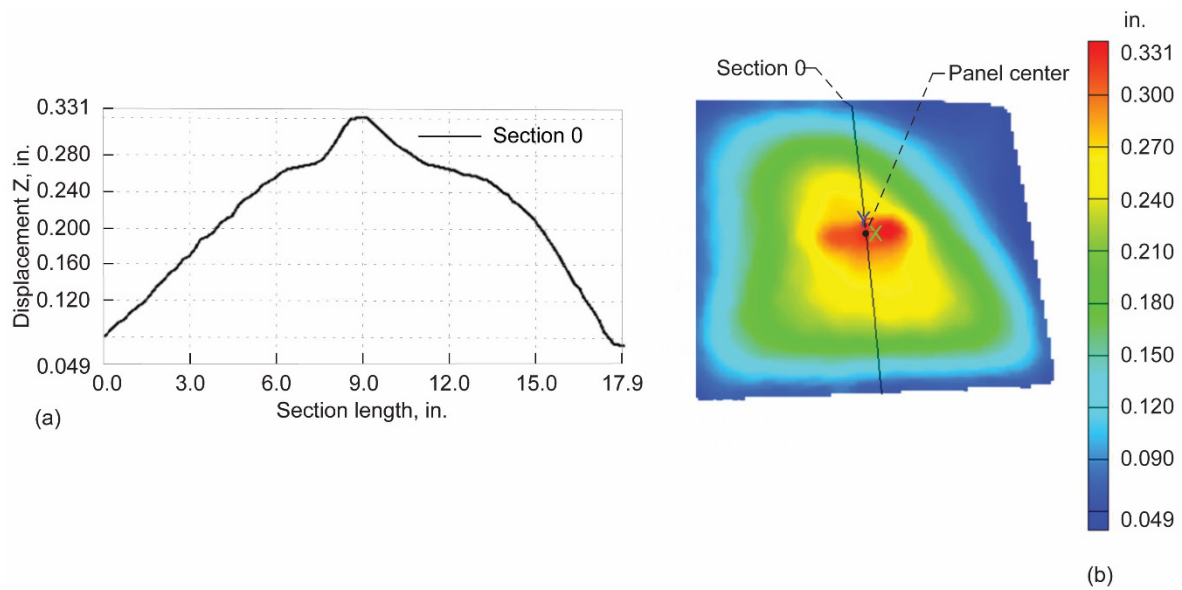


Figure D.38.—LG1127 posttest displacements. (a) Displacement versus length. (b) Displacement Z.



Figure D.39.—LG1127 posttest front view.

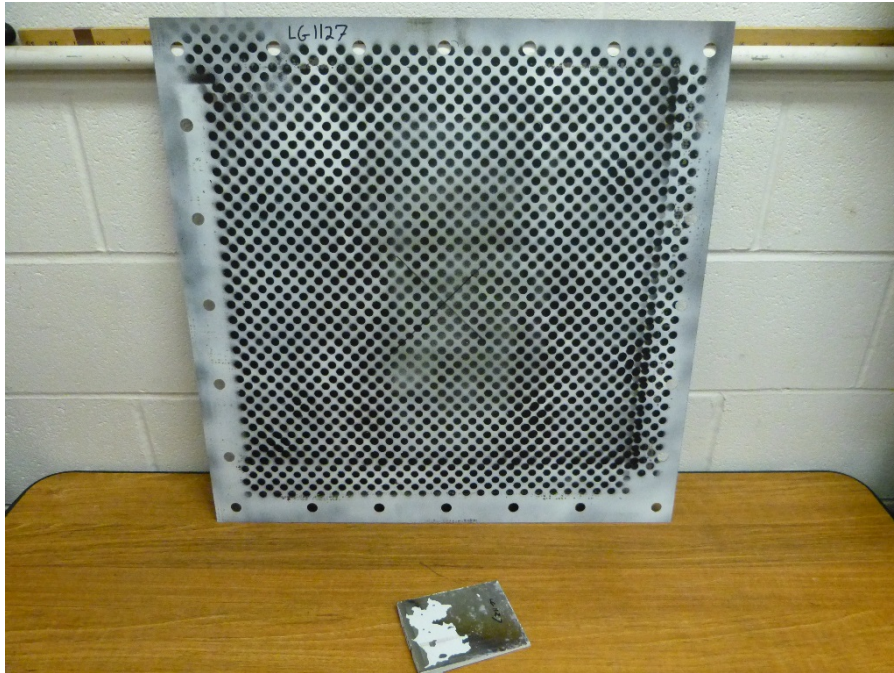


Figure D.40.—LG1127 posttest rear view.



Figure D.41.—LG1127 posttest projectile.

Test LG1128

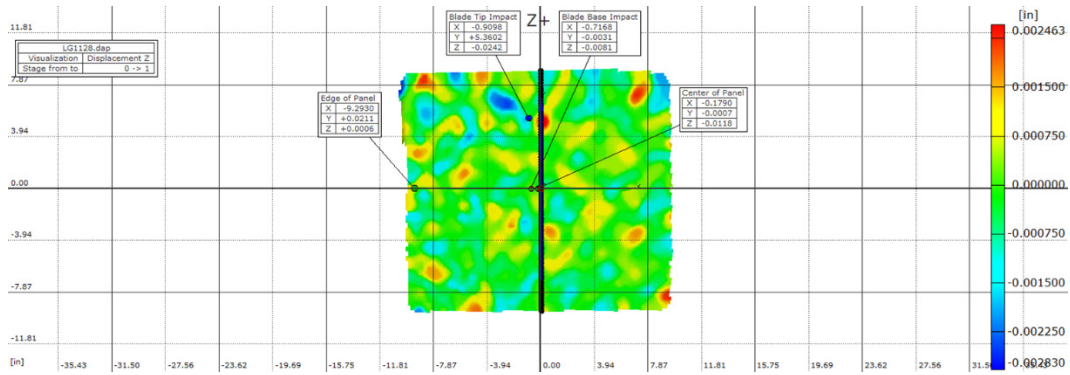


Figure D.42.—LG1128 locations of digital image correlation (DIC) measurements.

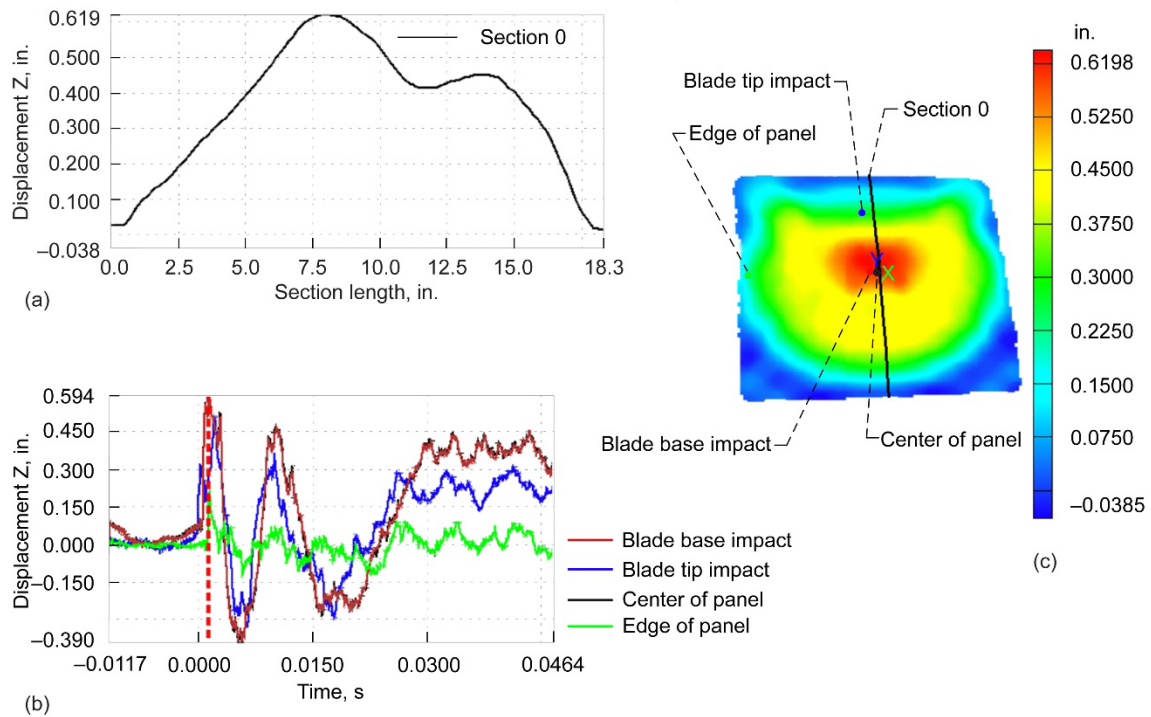


Figure D.43.—LG1128 out-of-plane displacement at time of maximum displacement. (a) Displacement versus length. (b) Displacement versus time. (c) Displacement Z.

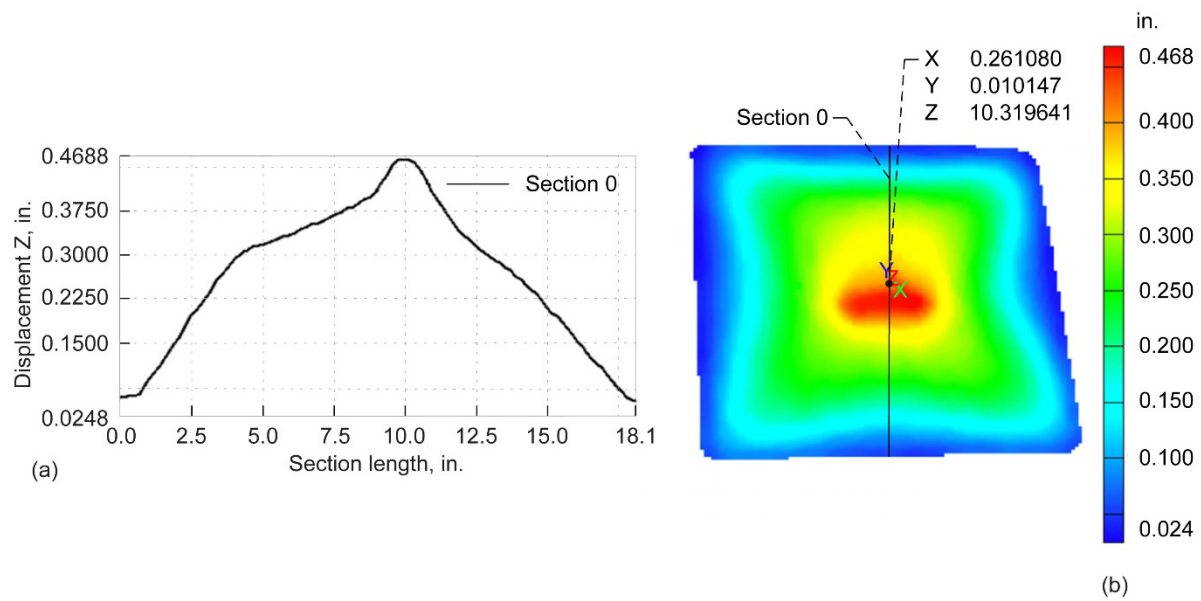


Figure D.44.—LG1128 posttest displacements. (a) Displacement versus length. (b) Displacement Z.

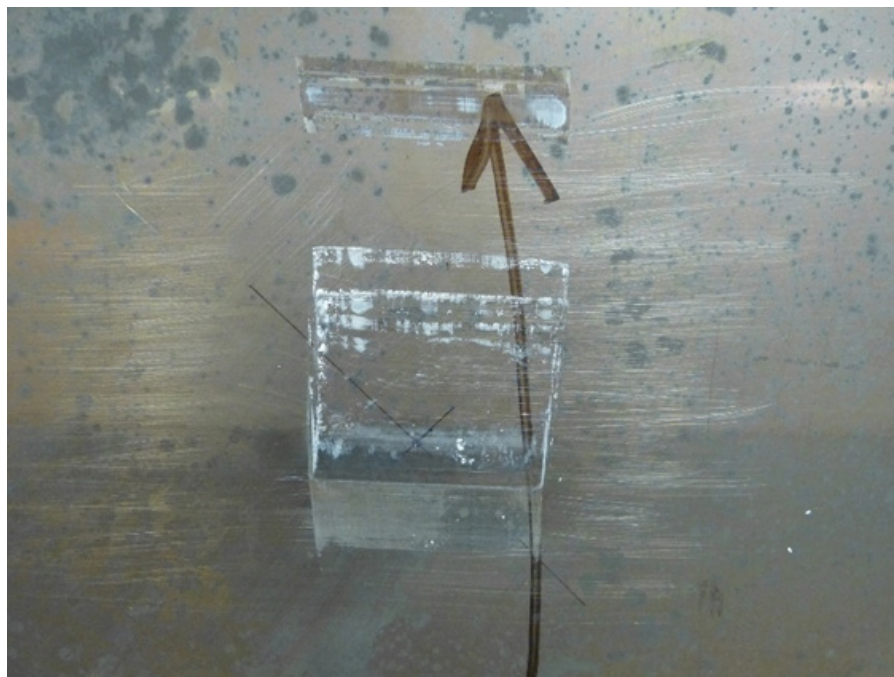


Figure D.45.—LG1128 posttest front view.



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>

