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Enhanced Efficiency of Fundamental Plate Impact Research Through Preparation of Multispecimen Targets

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NOTICES

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14. ABSTRACT
Plate impact experiments require that targets and flyers be carefully prepared to meet tolerances in flatness and parallelism to achieve one-dimensional shock loading. Typical target preparations consist of lapping a single target specimen flat and parallel, and then potting it centered on the target using high-strength epoxy. Here, we describe new tooling and techniques to improve the potting process. The adoption of these techniques has led to decreased time needed for preparing and potting specimens and allows for precise mounting of multiple specimens in a single target. The potting of multiple specimens in a single target not only reduces the total number of shots required to build a dataset but also improves data quality for material comparisons.

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1. Introduction and Problem Statement

Plate impact experiments are inherently resource intensive. Each shot requires approximately 20 man-hours in setup, preparation, and cleanup at a cost in excess of $13,000 per experiment—not including expendable material costs. To develop an equation of state (EOS) over a limited range of shock stresses for a single material requires at least five such costly experiments. A more complete dataset would require a minimum of 15–20 experiments resulting in a total experimental program cost in excess of $260,000 and a time cost of several months for a single material EOS. This approach produces too little benefit to justify such a high cost for most programs. However, the concern is not solely relegated to time and resource efficiency. In certain experiments, such as precursor decay measurements, variables like material and specimen thickness need to be changed without changing the initial loading conditions. In these instances, a single experiment with multiple specimens simultaneously loaded would save time and resources; but, more importantly, from a scientific perspective, would also remove ambiguity related to slight deviations in impact conditions. The modifications to the potting process described below have been made with the aim of improving data quality and—by reducing the total number of shots needed for a program—reducing setup time and program cost. We begin by describing the conventional approach and then detailing the advancements we have made to the procedure.

2. Conventional Specimen Preparation Procedure

Great care is taken in the preparation of a plate impact target to ensure that impact generates a one-dimensional stress wave without imparting transverse velocities, which would perturb the shock wave measurement. To this end, tight tolerances for flatness and parallelism are called during initial specimen manufacturing. Across a 30-mm-diameter plate, impact and back surfaces must be parallel to within 0.075 mm and flatness must remain within 0.05 mm. To achieve this, the final machining step is lapping the plate on each side for flatness, followed by careful cleaning prior to the potting process. Each specimen undergoes at a minimum a five-point thickness measurement via micrometer, followed by a measurement of the specimen diameter prior to potting. Additional measurements may include density as well as elastic longitudinal and shear wave speeds depending on the needs of the experiment.

After static value measurements have been recorded, the potting process can begin. A potting plate is sprayed with a silicone mold release agent to prevent the epoxy from adhering to it during the curing process. A target potting ring is then placed on the plate, and the specimen is placed impact face down in the center of the potting ring. When a flyer diameter is significantly larger than the specimen diameter, approximating a centered target and flyer by eye may suffice, but a spacer can provide greater precision of target and flyer concentricity. A 3D-printed spacer is typically used to position the specimen in the center of the potting ring and then the specimen and potting ring are locked into position using the potting clamp shown in Figure 1.

Figure 1.   A traditional potting clamp with specimen in position ready for potting.

The 3D-printed spacers can then be removed. With the specimen and potting ring secured, a two-part epoxy is thoroughly mixed and poured in the potting ring around the specimen. The epoxy used has a high-strength, low viscosity, and long working time, allowing it to flow into gaps and adhere strongly to the target ring and specimen. The epoxy is then left overnight to cure. After the epoxy is cured, the potting clamps are released, and the potted target is removed from the potting plate. The impact surface of the target is cleaned using isopropyl alcohol to remove residue from the mold release.

The target is then prepared for instrumentation. Holes for the ionization pins used to measure impact tilt and a Photon Doppler Velocimetry (PDV) probe are drilled into the epoxy surrounding the specimen. The target is then placed on a clean potting plate, and the ionization pins are inserted flush to the plate and secured using a 5-min epoxy. When the epoxy has cured, the entire impact surface of the potted specimen is lightly lapped until uniform marks appear on both the ionization pins and specimen, indicating a flush surface. The distance between the pins is then measured and later used to calculate the alignment of the flyer and target at time of impact. Cantilever mounts for PDV probes provide flexibility to accommodate small alignment errors accrued during potting. The mounts are glued to the outer edge of the potting ring to position the probes over the specimen center, and the target is ready for mounting in the target chamber.

3. Improvements to the Conventional Process

The conventional method for potting specimens works well for single specimens under normal plate impact and produces ready specimens in a short time. However, multiplate targets and oblique impacts require greater care to avoid misalignment, resulting in increased specimen preparation time along with increased possibility of significant error. Recently, several changes have been made to the potting process to improve processing speed and precise target and diagnostic placement. The first of the major changes to the classical process is the inclusion of a potting guide. This 3D-printed part is placed inside the potting ring to position a specimen similarly to the old spacers, but rather than being removed, these expendable guides are left in place when the epoxy is poured, eliminating the risk of the specimen shifting during tightening of the potting clamps. The guides are also printed with predrilled holes to guide consistent spacing and positioning of the ionization pins and PDV as shown in Figure 2.

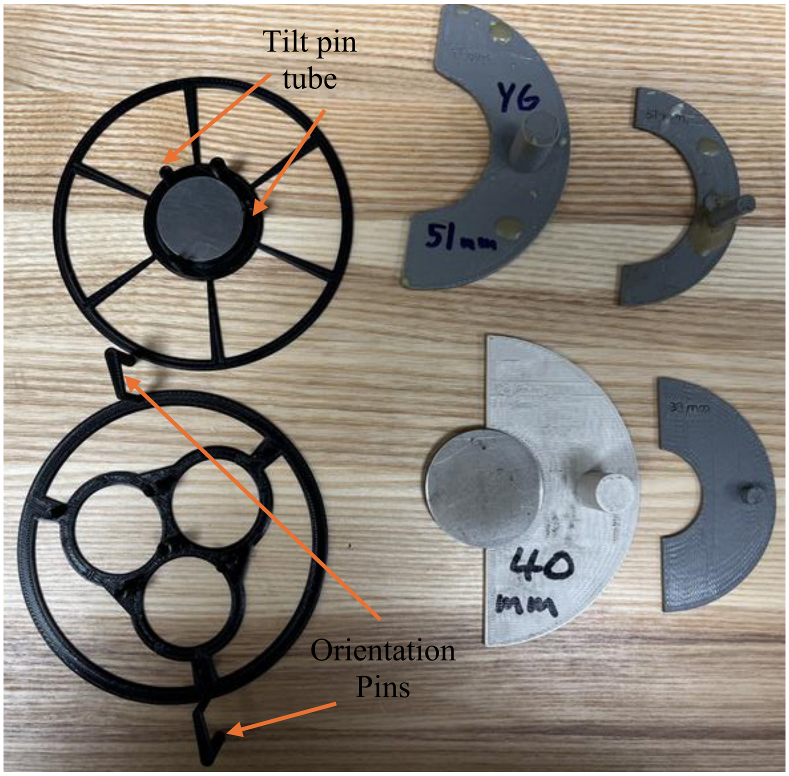

Figure 2. **New potting guides (left) compared with the potting spacers (right). The potting guides have prepositioned tubes for tilt pins and PDV, and the guide on the bottom left features posts to control orientation of the samples relative to the mounting holes on the target potting ring.**

The guides can be printed quickly, inexpensively, and modified as needed for a variety of specimen types. A well-designed guide can also aid consistent specimen orientation when necessary and fix the positions of multiple specimens in a single target as described in Section 4.

The second major change to the target preparation is the use of bridge-type PDV mounts. Since the potting guides reliably position target specimens, these bridge-type mounts shown in Figure 3 allow for positioning probes over the center of a specimen with a position error of less than 0.5 mm. The mounts use features of the target potting ring shown in Figure 2 to lock position and orientation of the probes. This control over orientation and positioning becomes critical for certain experiments, such as oblique impacts or low diameter-to-thickness ratio specimens.

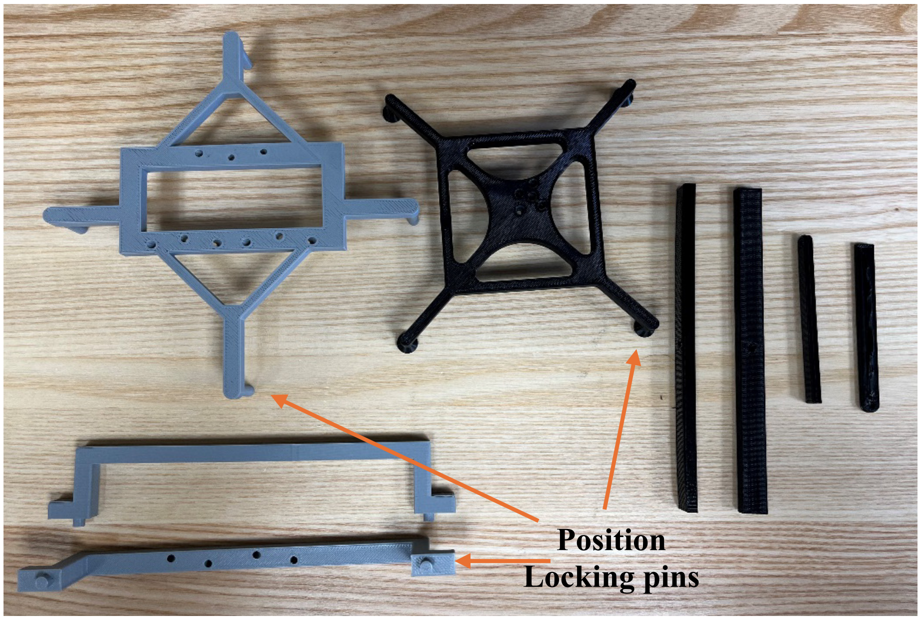

Figure 3. A variety of bridge-type PDV mounts (left), which lock position and orientation to the target potting ring via posts compared with the older free positioned cantilever mounts (right).

Several other minor changes have been made to improve target quality. One such change is the replacement of the old 0.25-inch-thick potting plates with 1-inch-thick plates. The thicker plates are more rigid and more easily lapped flat, which is important given that the flatness of the potting plate determines the flatness of the potted target. The original, thinner plates could develop slight deformations if debris were trapped beneath them when clamping pressure was applied, which results in uneven wear when refinishing as shown in Figure 4.

Figure 4. New potting plate (left) next to older plate (right). The circled regions on the old plate are low spots on the surface caused by plate bending and appear darker due to not making contact with the lapping plate during refinishing.

A second minor change to the process was made to the insertion of the ionization pins. It was found that using the conventional method, pins could sometimes be slightly recessed, and the pins themselves often had impact faces that were not flat. Thus, pins were often not properly flush with the specimen surface, introducing error to the tilt measurements. To correct for this, the ionization pins are now epoxied slightly protruding from the target surface intentionally and then carefully lapped until flush with the impact face. This helps to confirm the tilt measurements from the ionization pins accurately represent the timing of impact with the specimen surface. A third change is the reimplementation of an optical flat to confirm flatness across the entirety of a specimen surface. While optical flats have been used previously, this technique has not been used for standard normal plate impact experiments where high tolerance alignment requirements of less than 5 mrad make the additional surface preparation excessive. For oblique impact experiments, however, where the alignment is required to be less than 0.5 mrad, ensuring surface flatness is critical as surface curvature outside alignment tolerance may not be detected by a normal five-point measurement.

4. Preparation of Multispecimen Targets

One of the most impactful developments resulting from the improved target preparation has been the ability to produce targets containing multiple specimens. The most apparent benefit of testing multiple specimens in a single shot is the increase in experimental throughput via the reduction in the total number of shots needed for a given test series. Current improvements in instrumentation and tooling allow for potting up to four specimens at a time.

Potting for multiple specimens follows mostly the same process as potting a single specimen, with some slight further modifications to the tooling. A potting plate is treated with silicone mold release, a target ring is placed on the plate, and the specimens are positioned using a potting guide. Rather than using a normal potting clamp, however, a custom-made potting fixture is used to secure the specimens and potting ring. The fixture, shown in Figure 5, consists of eight toggle clamps that can be adjusted and locked independently.

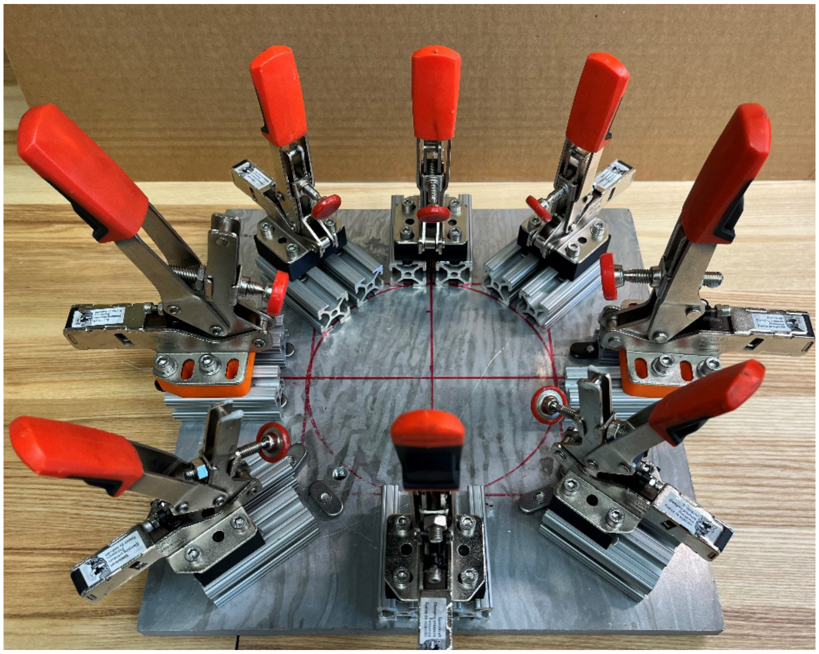

Figure 5. Adjustable potting fixture for multiple specimen targets.

Threaded rods control the depth of the clamp, allowing the fixture to accommodate specimens of different thicknesses. Both the design of the clamps and the mounting of them on t-slot extruded aluminum allow for large adjustments in positioning radially. Any clamps not used in securing the specimens to the potting plate can be used to lock down the target ring. With each of the specimens individually secured and the ring locked in place, epoxy can be poured as normal.

5. Applicability of Multiplate Experiments

Potting multispecimen targets is not always a viable solution and is limited to experimental programs that allow testing multiple materials or specimen dimensions under the same impact conditions. The simplest method is to use a large single-piece flyer designed to impact all specimens simultaneously. This method has the added benefit of comparing specimens under the exact same impact conditions, which could benefit experiments such as precursor decay measurements or direct comparison with the shock response of multiple materials with minor compositional differences. However, when a Hugoniot needs to be measured, the pressure state needs to be changed in the specimen. A single flyer material can only provide one shock pressure for a given impact velocity.

One solution to address the problem of the high financial and time cost of a Hugoniot measurement is the use of a multiplate flyer. Theoretically, with a keyed barrel, multiple flyers could be aligned with a multispecimen target to simultaneously generate multiple stress states in an array of similar specimens.

However, this adds further complications related to preparation and careful alignment of the flyer. Size constraints are the primary limiting factor for multiplate flyers and targets. Flyers should have larger diameter than the specimens to compensate for any rotational misalignment, which severely limits the maximum diameter of specimens. Furthermore, for normal plate impact experiments, specimens should maintain at most a 1:5 thickness-to-diameter ratio to avoid complications caused by release waves at the edge of the specimen; thus, setting a maximum bound on flyer thickness. Furthermore, the minimum combined thickness of a specimen and window should be approximately 3 mm as thin layers of epoxy do not maintain the necessary rigidity to hold the specimens and diagnostics such as tilt pins and PDV probes without covering the rear surface of the specimen in epoxy. This sets the lower limit of a specimen diameter to 15 mm. For near-homogeneous materials such as most alloys, monolithic polymers, and ceramics, smaller sizes can be reasonably achieved, enabling practical application of multiplate techniques for Hugoniot measurement. However, for heterogeneous materials such as composites, specimen sizes may be further limited by their largest significant structural feature (e.g., ply thickness). For a measurement of the bulk properties of the composite, the minimum dimension of a specimen—thickness in this case—cannot be less than 10 times the size of the largest microstructural feature. A material with significant feature size greater than 0.3 mm would require a thicker, and therefore larger diameter, specimen. While multiplate flyers are feasible and multispecimen targets have been shown to be practical, care must be taken in experimental design to ensure proper measurements result.

6. Conclusion

The new tooling and techniques described above represent a first step in an ongoing process to improve the reliability and efficiency of plate impact experiments. The use of potting guides has reduced the time needed for target and flyer preparation while improving the accuracy of specimen placement. The potting guides and redesigned PDV probe mounts allow for greater control over position and orientation of the experiment instrumentation, reducing measurement uncertainty. Multiple specimen targets, when testing conditions allow for them, can greatly reduce the time and expense required to execute a program while simultaneously improving data quality.

List of Symbols, Abbreviations, and Acronyms

3D	Three-Dimensional
EOS	Equation of State
PDV	Photon Doppler Velocimetry

1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA
1 (PDF)	DEVCOM ARL FCDD RLB CB TECH LIB