Ballistic Assessments of the ARL Reusable Temperature Insensitive Clay (ARTIC) as a Ballistic Backing Material

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Abstract. Backing materials play an important role in evaluating the performance of body armour materials. In 1977 Russel N. Prather et al. investigated the use of Roma Plastilina No.1 (RP1) artistic modeling clay as a surrogate for human tissue to define the penetration and deformation characteristics of soft body armour as worn. In that study, Prather nominally compared backface signature, the behind armour deformation of the clay, against a 20% ballistic gelatin formula which previous researchers correlated with the penetration resistance of human tissue. As noted by Prather then and as is still true today, clay has some notable drawbacks for simulating human tissue response, but it provides advantages over gelatin for cost-effective high-volume testing. First, is the relative preservation of the backface signature which allows for fast, direct measurement of behind armour deformation. Additional practical advantages of clay include ease of use in its handling and storage, ready commercial availability, and lower cost. Overall, Prather's studies effectively demonstrated the suitability of clay as a backface material, and the subsequent use of RP1 led to the creation of new body armour test methods which were broadly adopted by government, academic, and industrial institutions for the research, development, and testing of body armour materials and systems. Although RP1 proved the best choice at the time and has served an integral role in the testing and evaluation of body armour over nearly a half century of use, it is not the ideal ballistic clay material. Thus, the United States Army has found reason to reevaluate the continued use of RP1. The primary impetus for this reevaluation is the result of periodic changes in RP1's material constituents (due to market availability, artistic improvements, or both). Some of these changes have influenced the ballistic response of RP1. One clear indication of the changes in ballistic response over time is the noteworthy fact that RP1 must be heated to near 38°C (100°F) to achieve similar impact responses observed at ambient room temperatures nearly a half century ago. To address the issues related to the change in RP1's properties, the United States Army Research Laboratory (ARL) developed a substitute backing material called the ARL Reusable Temperature Insensitive Clay (ARTIC). Following ARL's development of ARTIC, the United States Army Aberdeen Test Center (ATC) conducted ballistic assessments of ARTIC's performance, and this paper presents the results of ATC's testing. ATC focused this ballistic evaluation of ARTIC on: (1) body armour commodities including soft armour, hard armour, and helmets; and (2) characterizing the effects of mechanical work, aging, temperature, and changes in material formulation. Where practicable, ATC completed side-by-side comparisons between ARTIC and RP1 during testing. This paper finds that in general ARTIC behaves very similarly to RP1 with some noted advantages and a few noted differences that do not likely interfere with or preclude the use of ARTIC as a snap in replacement for RP1. ATC is also supporting the future implementation of ARTIC through the development of new test protocols and material handling procedures.

1. INTRODUCTION

The United States Army, in conjunction with many partners within and outside of the body armour community, conducted a review of the clay backing material used for the ballistic testing of body armour. This review produced a recommendation for the development of a material replacement for Roma Plastilina No.1 (RP1) ballistic clay. In following up on the Army's recommendation, Army collaboration partners sought a replacement material for RP1. After review of several candidate materials, the United States Army Research Laboratory's (ARL) ARL Reusable Temperature Insensitive Clay (ARTIC) was selected as the most promising candidate for further development. Following the selection of ARTIC, these same partners began a thorough evaluation of ARTIC as a replacement for RP1 with the United States Army Aberdeen Test Center (ATC) performing most of the ballistic assessments and the primary development of material handling and test procedures. This paper discusses portions of this testing done by ATC and provides an overview of the results obtained. Through these discussions and data overview, this paper examines ARTIC's ballistic performance in testing and the suitability of ARTIC's use as a direct replacement for RP1.

RP1 is part of a commercial line of artistic modeling clays. Although not an intentional use by product design, the ballistic testing community found that RP1 was a highly practical medium to test body armour, dating to 1977 with the publication of Russell N. Prather et al.'s study "Backface Signatures of Soft Body Armors and the Associated Trauma Effects [1]." Prather's work focused mostly on the

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identification of a material for use in production scale testing of soft body armour. Since Prather's report, the ballistic testing community has employed RP1 as a backing material for resistance to penetration and ballistic limit testing of all the major body armour commodities i.e., soft and hard amour constructions for torso and extremity protection as well as helmet systems for head protection.

Despite its suitability as an initial choice and prevalence of use by the ballistic testing community since 1977, the use of RP1 as a primary backface material for the ballistic testing of body armour has had a significantly negative effect on reproducibility in testing. One of the flaws of RP1 stems from RP1's intended use – as a modeling clay. RP1 has "about 10 constituents … include[ing] pigments or colorants, antioxidants, and other minor materials as well as an intentional blending of multiple sources of, for example, the microcrystalline wax to dampen out lot-to-lot variations from individual suppliers" [1]. Formulation changes in RP1 due to commercial constraints (e.g., constituent availability or price) or due to purposeful product improvement (e.g., in response to artistic modeler feedback) have downstream effects on the consistency and repeatability of ballistic testing using RP1 as the backface material. These changes are unannounced, can occur frequently or infrequently, are noticed by a change in clay "feel" or statistical trending data, or are not noticed at all. Out of all possible concerns, the primary concerns associated with the continued use of RP1, and that form the justification for this work, relate to how changes made in RP1's constituents have led to an increase in material hardness. RP1 must now be heated to near 38°C (100°F) to match its historical ballistic performance. This creates numerous logistical and technical challenges in testing that could be removed using a material replacement with a set, controlled formulation, and a calibrated response optimized at room temperature conditions.

Finding a replacement for RP1 that meets the required criteria is no trivial task. Finding a true surrogate for human tissue response or suitability for injury evaluation is even harder. Testing materials intended for the evaluation of protective systems for the human body must achieve an optimum balance of suitability in mechanical response, repeatability, range flexibility, and affordability despite complex, difficult, and counterproductive material performance interrelationships in the desired zone of testing. During his 1977 study, Prather also examined a secondary correlation with behind armor blunt trauma (BHBT) by comparing RP1 to 20% ballistic gelatin formula [2]; however, he did not and no one since has completed a comprehensive study on the current use of ballistic clays for assessment of human injury [3]. Body armour testing using RP1 (or other clays) as the backface material thus relies primarily on comparative metrics, historical comparisons, and operational benchmarks to evaluate performance. Like Prather's own efforts, this study assesses ARTIC as a ballistic backing material using the following approach but without attempting to address the medical questions associated with the use of ballistic clay in the testing of body armour, such as whether ballistic clay replicates an anthropomorphic response.

2. APPROACH

Ballistic performance assessments of ARTIC were made by taking backface deformation (BFD) measurements using a laser arm scanner during testing of the three major body armour commodity types including soft armour, hard armour, and head protection (helmets). Testing was also conducted to evaluate ARTIC for changes in ballistic response based on mechanical work, aging, temperature effects, and changes in material formulation. When practicable, ballistic results for ARTIC were compared with RP1 (heated to near 38°C (100°F)) by means of side-by-side i.e., concurrent testing. This study focuses on making material performance assessments of the clay under relevant ballistic strain conditions and not on the performance of the body armour test items themselves. Each body armour commodity type provides a unique assessment of ballistic clay performance based on the BFD shape it produces and the resultant strain conditions in the clay. By seeking out unique test cases and strain conditions, the tester can explore the entire breadth of the representative mechanical response tradespace without the need to make or use associations between test article response and performance specifications. Therefore, ATC did not make, use, or note associations between test article response and performance specifications during this study. This approach has several advantages including increased flexibility in test sample selection and allowance of the use of non-standard projectile types, velocities, and obliquities. This approach also enables sharing of the results of this study with the broader body armour community.

During all testing for this study, only test personnel who possess extensive work experience with RP1 were employed. No such extensive experience yet exists for the handling of ARTIC. Research personnel possessing comparatively limited (but still the highest level attained by anyone anywhere) experience working with ARTIC provided the test personnel with recommendations on the handling of ARTIC for preparation and repair of clay blocks, molds, and headforms. The research personnel's recommendations pertained primarily to handling procedures such as spreading and cutting and the researcher's experience with the effects of mechanical work on the overall workability of ARTIC. In

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most cases no further guidance was provided to the testers unless explicitly requested. This limitation was directed purposefully to conduct the ARTIC evaluation in a test environment that mirrors the RP1 operating conditions as closely as possible and to minimize bias in the feedback solicited from the testers. The values for “n” of each test design in tables 1-6 represent the number of shots conducted in each test.

2.1 Soft Armour

Four subtests were designed to evaluate clay performance by resistance to penetration testing (RTP) of soft armour and to characterize ballistic responses of the clay types due to periodic mechanical work (and rest), aging, the effect of changes in temperature and material formulation. For this, soft armor ballistic panels, consisting of stacked uniformly sized plies of soft armor fabric enclosed in a fabric sleeve were mounted to the face of a clay block using strapping. A unique five-shot pattern (Figure 1) was developed and adopted specifically for the soft armour testing in this study to provide the data consistency and reproducibility necessary for direct comparisons between data sets. The design of the five-shot pattern considers the boundary conditions provided by the clay block, shot obliquities, expected BFD volumes, and resultant shot order effects to maximize the data collected from the available test articles and clay blocks. Shot locations on the ballistic panel correspond with the shot locations on the clay block, and test personnel executed all shots by location in numerical order. The distance between shot locations is larger on the clay block than on the ballistic panel. Therefore, for the shot locations to align, test personnel moved the ballistic panel and remounted it to the clay block between shots. Except for the aging study (see below) which purposefully aged the clay for one year, this study used only ARTIC and RP1 that was less than one year old, and the typical material used for this study was within three to nine months of the manufacturing date.

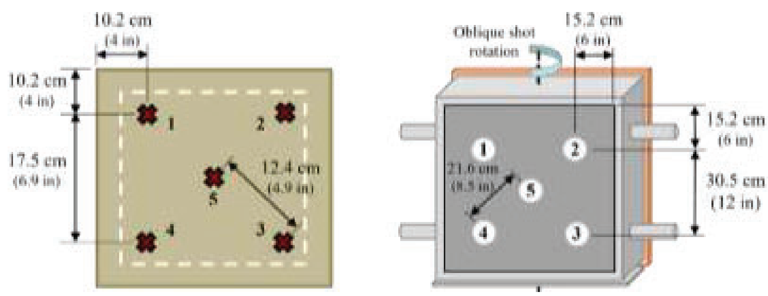

Figure 1. Five-shot pattern shot locations on a soft armor ballistic panel (left) and clay block (right).

The first soft armor subtest compared BFD results over a one-year period of material aging (1-Year Aging subtest) to evaluate the effect of shelf-life on material response. This subtest conducted shots at two distinct obliquity angles using three dedicated, initially untested blocks of ARTIC. The 1-Year Aging subtest interrogated each block of material three times per obliquity at approximately 30-day intervals between each test series. Only soft armor ballistic panels from the same design and manufacturing lot were used during this subtest and all tests were conducted using a single set of test conditions i.e., projectile type, velocity window, and shot obliquities. An evaluation of ARTIC’s performance between months two to twelve was then made versus data from month 1 (test series from the first month) as a baseline comparison to assess ARTIC’s ballistic aging response over a 1-year period. To compare ARTIC’s ballistic aging response versus RP1, a baseline for RP1 was generated by selecting BFD data that had been collected intermittently during the 1-year lifetime of select RP1 clay blocks from subtests using a matching shot pattern, ballistic panel type, and shot conditions. Table 1 summarizes the design of the 1-Year aging subtest.

Table 1. Ballistic test design for the 1-Year Aging subtest.

Subtest Name	Time between tests (days)	Obliquity 1 n (Clay Type)	Obliquity 2 n (Clay Type)
1-Year Aging	Approximately 30	530 (ARTIC) 185 (RP1)	530 (ARTIC) 187 (RP1)

The second soft armor subtest (Temperature Effects subtest) evaluated the effect of temperatures below and above ambient (from 13.9 ºC to 29.9 ºC) on BFD response. ATC assessed that the selected temperature range of the evaluation is relevant to the body armour test community, although some of the

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range evaluated (both below and above) is outside of typical ambient test requirements. This subtest used two blocks of initially untested ARTIC for each temperature condition and each block was tested twice per shot obliquity. Soft armor ballistic panel type and test conditions matched those used in the 1-Year Aging subtest, including shot obliquities. An evaluation of ARTIC's performance at temperatures below and above ambient was then made versus BFD data from the month 1 (first month tested at 21.1 ºC) test series within the 1-Year Aging subtest as a baseline for ARTIC's ambient temperature performance. Table 2 summarizes the Temperature Effects subtest design.

Table 2. Ballistic test design for the Temperature Effects subtest.

Subtest Name	Temperature (ºC)	Obliquity 1 n	Obliquity 2 n
Temperature Effects	Cold (13.9 ºC)	20	20
	Hot (29.9 ºC)	19	20

The third soft armor subtest (Formulation Changes subtest) evaluated formulation changes to the fumed silica ingredient in ARTIC for constituent percentages below and above the standard formulation. ARL produced batches of ARTIC with these two formulation changes for ATC to investigate the effects of potential alterations in ARTIC's material recipe on BFD response. This subtest used one block of initially untested ARTIC for each formulation type and tested each block nine times per shot obliquity. As in the Temperature Effects subtest, soft armor ballistic panel type and test conditions matched those used in the 1-Year Aging subtest, including shot obliquities. A performance evaluation of the two variations in ARTIC's formulation was then made versus BFD data from the month 1 (first month) test series within the 1-Year Aging subtest as a baseline comparison for the performance of ARTIC's standard formulation. Table 3 summarizes the Formulation Changes subtest design.

Table 3. Ballistic test design for the Formulation Changes subtest.

Subtest Name	Material Formulation	Obliquity 1 n	Obliquity 2 n
Formulation Changes	Soft (lower % fumed silica)	44	45
	Hard (higher % fumed silica)	45	45

The fourth soft armor subtest (Mechanical Work and Rest Time subtest) evaluated the effects of mechanical work and rest times on BFD response: (1) by varying the procedures used for block repair between hand kneading and pneumatic air hammer methods and (2) by varying block resting times between 1 hour, 1.5 hours, 3 hours, and 24 hours. This subtest used a single shot obliquity and required eight clay blocks. The clay blocks were selected and labeled to identify their use for each preparation method and associated rest time in the subtest. Two blocks (those used for the 24-hour condition) contained initially untested ARTIC, and six blocks (those used for the 1-, 1.5-, and 3-hour conditions) contained material that had been used lightly for earlier non-ballistic testing. Testers allowed all blocks to rest for a minimum of two weeks after being filled, or after previous use, prior to testing. This subtest used a different design of soft armor ballistic panels with a similar construction to those used in the aging, temperature, and formulation studies. The same projectile type was used as the previous subtests but with a slightly modified velocity window. ARTIC's performance for the various rest times and work methods was evaluated by comparing against a pooled BFD data set from the first test series of the 1-, 1.5-, and 3-hour conditions for both work methods representing ARTIC's performance in a rested condition. Table 4 summarizes the design of the Mechanical Work and Rest Time subtest.

Table 4. Ballistic test design for the Mechanical Work and Rest Time subtest.

Subtest Name	Rest Time (hr.)	Hand kneaded n	Air hammer n
Mechanical Work and Rest Time	1	23	25
	1.5	75	78
	3	24	23
	24	5	5

2.2 Hard Armour

Two subtests were conducted to assess clay performance for testing of hard armour plates. Deformation witnessed in hard armour can exceed those of soft armour and helmets due to the increased energy of rifle-fired projectiles. Therefore, the first subtest was designed to assess a range of strain and deformation conditions in the clay during hard armour RTP testing by targeting three BFD depths of approximately 30mm, 40mm, and 50mm. Multiple projectile types and velocities were used to achieve the various BFD target depths. The second subtest simulated the conditions of a hard armour V_{50} Ballistic Limit (BL) test. All hard armor test articles used were of a non-standard design. All impacts were placed in the crown region of the plates, the location on the front of the plate where the peak curvature of a curved hard armor plate is located and produced highly repeatable test results in both RTP and V_{50} BL testing. These subtests used three blocks of initially untested ARTIC, and RP1 testing was conducted concurrently with ARTIC using matching test designs. Table 5 summarizes the hard armor subtest designs.

Table 5. Hard armour ballistic subtest designs.

Subtest Name	Shot Location	Target BFD (mm)	n
RTP	Crown	30	15
		40	15
		50	15
V_{50} BL	Crown	-	36

2.3 Helmets

Two helmet RTP subtests were conducted to assess clay performance during helmet testing using the National Institute of Justice (NIJ) headform. Although there are several headforms used for helmet testing, the body armour test community uses the NIJ headform perhaps more widely than any other. The NIJ headform is constructed of solid aluminum and has channels of equal width machined symmetrically along the sagittal (front to back), and coronal (side to side) planes. When filled with ballistic clay, the NIJ headform can be used to test helmets from any of five principle shot orientations along these planes, i.e., the front, back, crown, left side, and right side. These subtests used previously untested ARTIC to fill and repair clay in the headforms. ATC also devised and used a hydraulic press molding method to ensure repeatability of the clay filling procedure. The first subtest (RTP 1) evaluated ARTIC for the crown and back shot locations using test conditions designed to produce minimally constrained BFDs, i.e., with as little contact between the deformation in the helmet and the channel posts of the NIJ headform as possible. The second subtest (RTP 2) evaluated clay BFD under comparatively higher strain and deformation conditions for the back shot location only. These subtests used two helmet types to generate the required BFD conditions and RP1 testing was conducted concurrently with ARTIC during both subtests using matching test designs. Table 6 summarizes the helmet test designs.

Table 6. Helmet ballistic subtest designs.

Subtest Name	Shot Pattern	n
RTP 1	1st Shot Crown 2nd Shot Back	22
RTP 2	Back	32

3. RESULTS

3.1 1-Year Aging (Soft Armour) Subtest

Figure 2 provides monthly ARTIC results of the 1-Year Aging subtest with a plot of average BFDs by shot location and obliquity combination (brightly colored "moving" lines) for each month (two through twelve) versus the ARTIC Month 1 BFD baseline for the same shot location and obliquity combination (light grey straight lines). This plot shows the relative (to scale) differences between the ARTIC subsequent monthly averages and the ARTIC first month BFD average values, and the listed standard deviations by shot location and obliquity combination provide a sense of the total magnitude of the observed variance for each shot series (see column noted as "σ" to the right of the plot). The plot marks with a small, open, red circle where the average ARTIC BFD by shot location and obliquity combination in that month is statistically significantly different (α=0.05) than the average ARTIC Month 1 BFD baseline for the same condition combination. The plot also marks months with a large, open, blue circle

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where the average ARTIC BFD by condition combination is statistically significantly different than the average RP1 BFD baseline for that same condition combination. Note that RP1 was not tested concurrently with ARTIC during this subtest. Although not depicted in Figure 2, ATC also observed statistically significant differences between the ARTIC Month 1 baseline and RP1 baseline for obliquity 1 at shot locations 1 and 4, and for obliquity 2 at shot location 5. The total (pooled) average BFD differences between ARTIC and RP1 in this dataset for obliquities 1 and 2 is 0.8mm and 0.1mm, respectively and is not statistically significant.

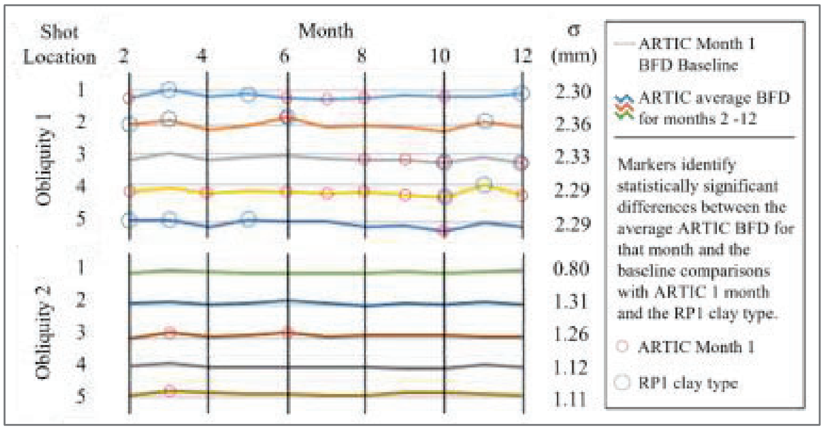

Figure 2. ARTIC monthly BFD averages by shot location and obliquity combination with significant difference notations versus the ARTIC month 1 baseline for the same shot location and obliquity combination. Statistical significance threshold for notation is α=0.05.

3.2 Temperature Effects (Soft Armour) Subtest

Figure 3 shows the results of the Temperature Effects subtest. For both obliquities, differences in the average ARTIC BFD for the cold (13.9 ºC) and hot (29.9 ºC) temperature conditions versus the baseline at ambient (21.1 ºC) temperature are not statistically significant. For obliquity 1 cold and hot temperature conditions, the difference is 0 and 1.7mm, respectively. For obliquity 2 cold and hot temperature conditions, the difference is 0.2mm and 2.0mm, respectively.

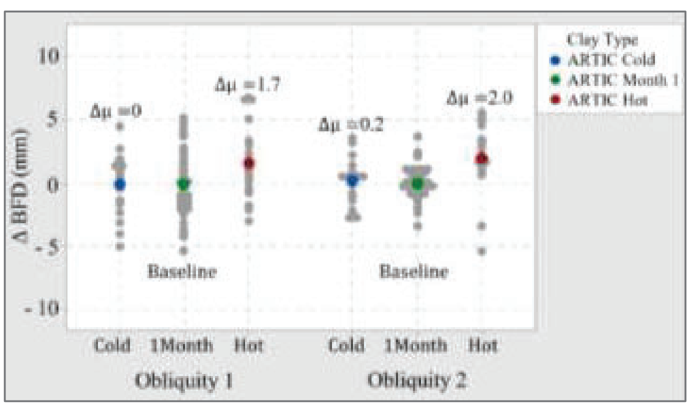

Figure 3. Sample average differences in ARTIC BFD for cold and hot temperature conditions at two shot obliquities versus the ARTIC Month 1 BFD baseline from the 1-Year Aging subtest.

3.3 Formulation Changes (Soft Armour) Subtest

Figure 4 shows results of the Formulation Changes subtest which evaluates the effects of changes in ARTIC's material formulation. Differences in the average BFD for the hard (higher percentage fumed silica) and soft (lower percentage fumed silica) formulations versus the baseline ARTIC standard formulation are not statistically significant. For obliquity 1, the average BFD differences for the hard and soft formulations versus the baseline are 0.5mm and 0.9mm respectively. For obliquity 2, the average BFD differences for the hard and soft formulations from the baseline are 0.5mm and 2.1mm respectively.

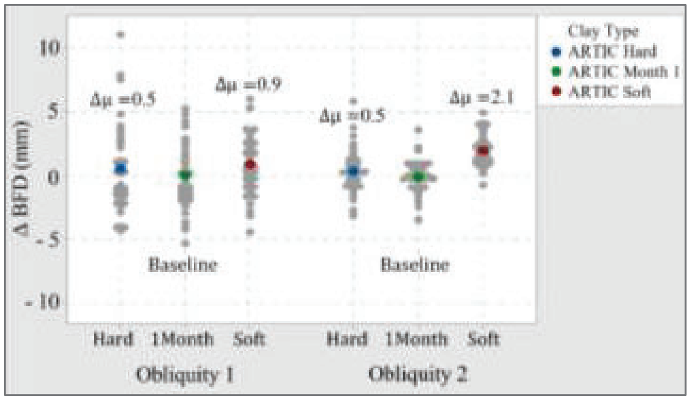

Figure 4. Sample average differences in BFD for hard and soft formulations of ARTIC at two shot obliquities versus the ARTIC Month 1 BFD baseline from the 1-Year Aging subtest.

3.4 Mechanical Work and Rest Time (Soft Armour) Subtest

Figure 5 shows the results of the Mechanical Work and Rest Time subtest. The figure plots sample averages for each rest time and work method versus a baseline of pooled data including the first test series from the 1-, 1.5-, and 3-hour conditions for both work methods. None of the observed differences in the average ARTIC BFD for each rest time interval and work method are statistically significant. However, additional testing is being planned to increase the confidence of the statistical model.

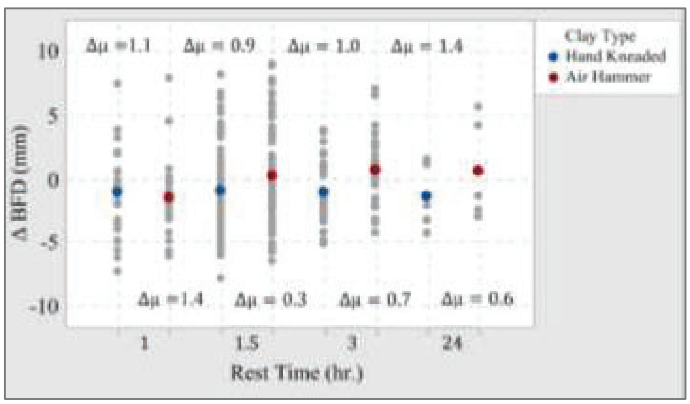

Figure 5. Sample average differences in BFD for four rest time intervals and two work methods versus the baseline of pooled data including the first test series from the 1-, 1.5-, and 3-hour conditions.

3.5 RTP and V_{50} BL (Hard Armour) Subtests

Figure 6 shows representative photos and laser surface scans from the hard armour RTP subtest in which testers evaluated ARTIC and RP1 concurrently. Color in the surface scan images indicates changes in crater depth. Testers observed highly comparable responses between ARTIC and RP1 clay types with respect to the BFD depth, shape, and overall behavior of the materials. The differences in average BFD between clay types for the target BFD depths of 30mm, 40mm, and 50mm are 1.0mm, 0.8mm, and 0.5mm, respectively. None of these differences are statistically significant. Testers noted differences between clay types in the extent of cracking on the clay surfaces after removal of test items. Table 7 shows the average BFD and standard deviations for each BFD depth and clay type from this subtest.

Table 7. BFD results from the hard armour RTP test.

Target BFD (mm)	ARTIC BFD (mm)		RP1 BFD (mm)	
	μ	σ	μ	σ
30	29.6	2.0	30.6	2.1
40	41.7	2.4	42.5	1.9
50	51.7	1.9	51.2	2.0

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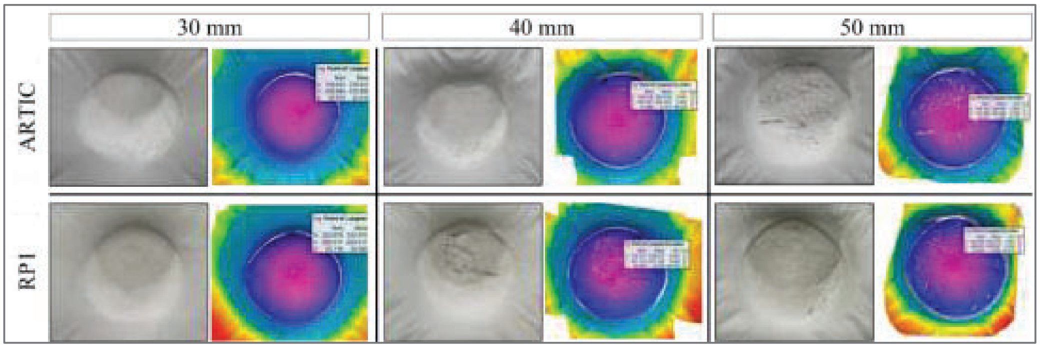

Figure 6. Post-test photos and laser arm scans from the hard armour RTP subtest showing BFD depths of approximately 30mm (left), 40mm (center), and 50mm (right) in ARTIC (top) and RP1 (bottom).

Hard armour V_{50} BL testing for ARTIC and RP1 produced a difference in V_{50} BL point estimates of 3 m/s that is not statistically significant. Figure 7 shows statistically modeled probability of penetration curves that ATC derived from this data. In addition to the test on the V50, a statistical test on the overall performance was conducted. Even though there is some difference in the tails observed in figure 7, the test indicates that the difference in overall performance is not statistically significant; however, additional study is needed prior to drawing firm conclusions.

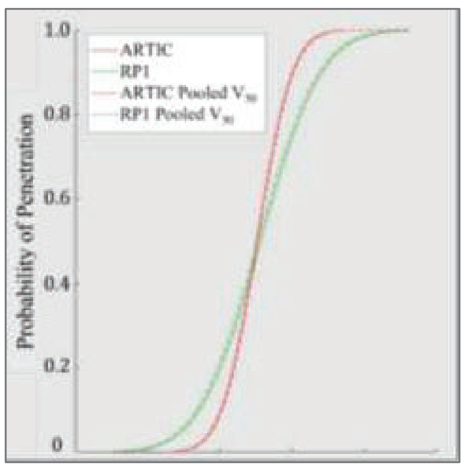

Figure 7. Probability of penetration versus projectile velocity from the hard armour V_{50} BL subtest.

3.6 RTP 1 and RTP 2 (Helmet) Subtests

Figure 8 shows representative photos from the helmet RTP 1 subtest in which ARTIC and RP1 were tested concurrently. In this subtest, testers observed highly comparable responses between ARTIC and RP1 clay types with respect to the BFD depth, shape, and overall behavior of the materials for the crown and back shot locations. The difference in average BFD between clay types for the crown and back shot locations is 0.6mm and 0.2mm respectively with standard deviations of 0.8mm and 0.32mm, as shown in Table 8.

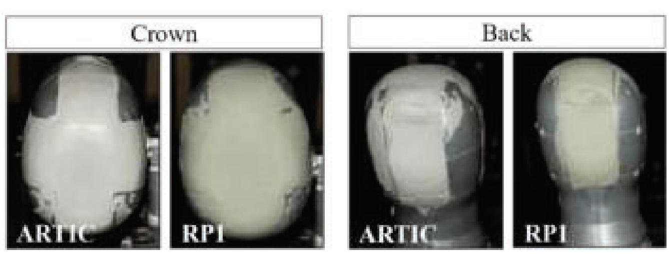

Figure 8. Post-test photos from the helmet RTP 1 subtest showing BFDs in ARTIC and RP1 for the crown (left) and back (right) shot locations.

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Table 8. Difference in BFD between ARTIC and RP1 from the helmet RTP 1 subtest.

Shot location	Δ BFD Difference (mm)	
	μ	σ
Crown	0.6	0.08
Back	0.2	0.32

Testers witnessed similar results in the helmet RTP 2 subtest for comparatively greater BFD depths, as shown in Figure 9. This subtest generated significant flow in both clay types because of high compressive and shear strain conditions. Test personnel observed a highly comparable response throughout testing between ARTIC and RP1 regarding the overall behavior of the materials for the back shot location. Figure 10 shows a plot of the full data set for ARTIC and RP1 and depicts the 1.3mm difference found in the average BFDs with a difference in standard deviations of 0.09mm.

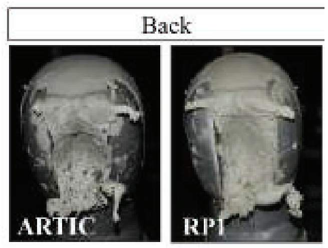

Figure 9. Post-test photos from the helmet RTP 2 subtest showing BFDs in ARTIC and RP1 for the back shot location.

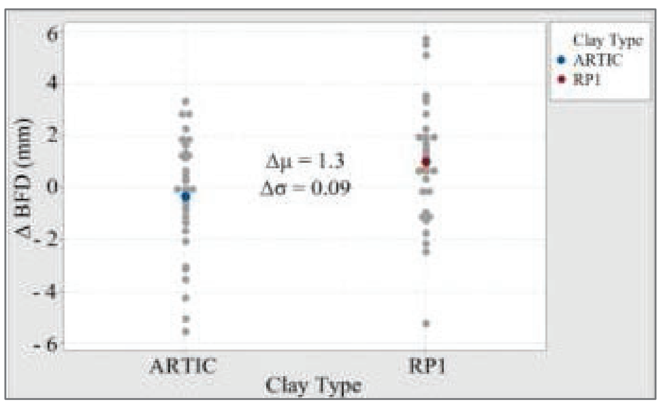

Figure 10. Differences in BFD sample average and standard deviation in ARTIC and RP1 for the back shot location from the helmet RTP 2 subtest.

4. DISCUSSION

This study uses ballistic performance assessments to evaluate the suitability of ARTIC as a material replacement for RP1 ballistic clay in the testing of body armour. To support this suitability assessment, ATC collected backface deformation (BFD) measurements using a laser scanning arm to compare clay performance during controlled conditions with soft armour, hard armour, and helmet testing. Testers also conducted four additional subtests to assess the effects of aging, temperature conditioning, changes in material formulation, mechanical work, and resting time. From a testing perspective, key considerations in the development of a material replacement for RP1 are repeatability, reproducibility, and a robust characterization of the differences in ballistic performance. Therefore, during the testing phase of ARTIC's development, the primary goals are to evaluate material performance for relevant ballistic strain conditions, reproduce those results, and characterize differences in ballistic performance with RP1.

Previously during the material development phase, ARL focused on the development of a robust manufacturing process and matching the material performance of ARTIC to RP1 (heated to near 38°C (100°F)) as closely as possible. ARTIC's performance is not an identical match for RP1 under every test condition examined; however, the results of this multi-year work demonstrate that these objectives have

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been achieved to a high degree. This study shows that by a significant margin most (although not all) of the differences observed through ballistic comparisons of ARTIC and RP1 are not statistically significant. On the other hand, shot order, obliquity, and location do affect the ballistic response of both ARTIC and RP1, usually similarly. There are some shot conditions (for example some obliquities) where the similarities between ARTIC and RP1 begin to deviate to a statistically significant level. The most marked example of such a deviation that this study shows is in the 1-Year Aging soft armour subtest where a statistically significantly different material response between the monthly ARTIC results and the RP1 baseline BFD for 14 out of 55 total possible pairwise comparisons for the obliquity 1 portion of the subtest was found. This is well above the 2.75 total expected by chance alone when using a significance threshold of 0.05 and is strongly indicative of a true underlying difference in that test condition. The probability of penetration model created during hard armour V_{50} BL testing also predicts that for certain test designs, projectile velocities above and below the V_{50} BL of the test article may produce different results for ARTIC and RP1, but this finding is very tenuous given the relatively large size of the uncertainly intervals in the tail regions of the ballistic limit curves compared to the strength of the effect this study demonstrated. Lastly, ATC has completed a very limited study that this paper does not discuss in detail that examined the two-year shelf-life of ARTIC. That newer, more limited study does show that there are statistical differences in performance between year one and two – differences that are worth further exploration and study.

In total, the findings of this study support the use of ARTIC as a snap-in replacement for RP1; albeit ARTIC is not nor ever will be an exact match to the highly variable, formulation changing RP1. Despite these positive findings, further testing and changes to handling procedures for ARTIC are necessary prior to full-scale implementation as the replacement for RP1. ATC and others are conducting additional studies and handing procedure trials currently, and this study's authors anticipate that the additional changes recommended by these ongoing studies and trials will be minor. Ongoing and future work in testing includes a large, somewhat comprehensive, ARL led interlaboratory study and continued ATC conducted ballistic testing to increase confidence in existing data. One other element of potential fruitful additional study is in focusing on the surface cracking differences observed by this study between ARTIC and RP1. ATC and the body armour testing community may benefit from verification of similar measurement accuracies for scans taken with these cracks using proven measurement techniques or methods to ensure accuracy and repeatability across the full range of cracking observed on RP1 and ARTIC. Lastly, ATC is also evaluating potential modifications and alternatives to the current drop test calibration method due to observed tactile differences in the current calibration methods across the two clay types.

The final stages of ARTIC's development are commercialization and a phased implementation into full-scale testing. ATC is continuing the development of test procedures for that purpose and for the eventual verification of a commercially produced ARTIC product. ATC in conjunction with U.S. Army material developer partners is planning for concurrent production testing with RP1, during full-scale implementation, for the purpose of collecting additional data in the operational environment and to increase confidence by testing over an extended and more intense period of use. This additional data will add greatly to the body of knowledge presented here and prove very useful to the broader body armor testing community.

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