Initial Studies on Roma Plastilina no. 1.2; Improvements to the Original Ballistic Testing Clay

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Abstract. Roma Plastilina no. 1 (RP1) was developed as a sculpting clay and adopted as a ballistics testing clay. Several changes have been made to improve performance as a ballistic clay without changing some key attributes of the original formula. This new version, Roma Plastilina no. 1.2 (RP1.2), yields similar results as RP1 in side-by-side live fire tests using 0.44 magnum handgun ammunition on soft armour. However, RP1.2 is in calibration at room temperature and shows less shot-to-shot variability than RP1. Small scale laboratory tests suggest that RP1.2 is less thixotropic than RP1 and changes less over time than RP1.

1. INTRODUCTION

Roma Plastilina no. 1 (RP1) was chosen as a ballistic witness material in 1977 [1,2] because it was the best option among commonly available materials at the time. Its use has been problematic [3] and the need to improve the clay has been cited [4]. The US Army had awarded a research grant to Chavant, Inc. to make an improved clay [5] and a new room temperature calibrated clay was developed that successfully mimicked the original RP1 in live fire tests on soft armour, hard armour, and helmets [6,7]. However, the improved clay was not adopted, for several reasons. One problem was that the clay still hardened with age, as does RP1. Unfortunately, a year or so after manufacture, the new clay hardened out of calibration at room temperature.

Using lessons learned from developing other clays in Chavant's product line, the aging of a new ballistics testing clay (RP1.2) has been minimized. Extrapolating the data collected, RP1.2 is expected to remain in calibration for more than 10 years after manufacture. This report describes the initial characterisation of RP1.2.

2. MATERIALS AND METHODS

RP1 and RP1.2 were made in the laboratory using a 2.8 L. Readco laboratory mixer. The ingredients of both clays are proprietary but include wax, oil, kaolin clay and sulphur. Larger scale samples to pack ballistics boxes were made in the factory with industrial scale equipment.

For laboratory hardness measurements, an Ametek-Brookfield CT3 Texture Analyzer was used with a TA39 2 x 20 mm steel cylindrical probe. Using software provided by the manufacturer, the test speed was set at 0.5 mm/sec with a target value (probe travel distance) of 4 mm.

For temperature-controlled experiments, samples were incubated in a Thermo-Fisher Scientific Heratherm Incubator.

For the thixotropy experiments, a Pasta Queen® pasta maker (Himark Enterprises, Inc.) was purchased from a local retail store.

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Live fire tests were conducted at Element US Space and Defense in Belcamp MD. All aspects of the test were in accordance with the National Institute of Justice (NIJ) standard 0101.06 [2] including drop tests, range setup, shot pattern, etc. Ballistic boxes with RP1 were incubated at 37.4 ºC prior to calibration and use.

Soft armour (Pathfinder shoot pack with and 8 layers of SP71) was strapped to test boxes and fired upon with 0.44 magnum ammunition at a velocity of 430-490 m/sec.

3. RESULTS

3.1 Correlation between NIJ cylinder drop results with measurements from a Brookfield Engineering CT3 Texture Analyzer

To predict whether experimental clays made on a small scale in the laboratory would be in calibration if made on a larger scale, hardness measured by a Brookfield CT3 Texture Analyzer were correlated with the cylinder drop calibration test data [7]. Clay was sent to Aberdeen Test Center (ATC) for cylinder drop test measurements and compared with CT3 measurements on the same clay. Figure 1 shows a linear correlation between the two methodologies.

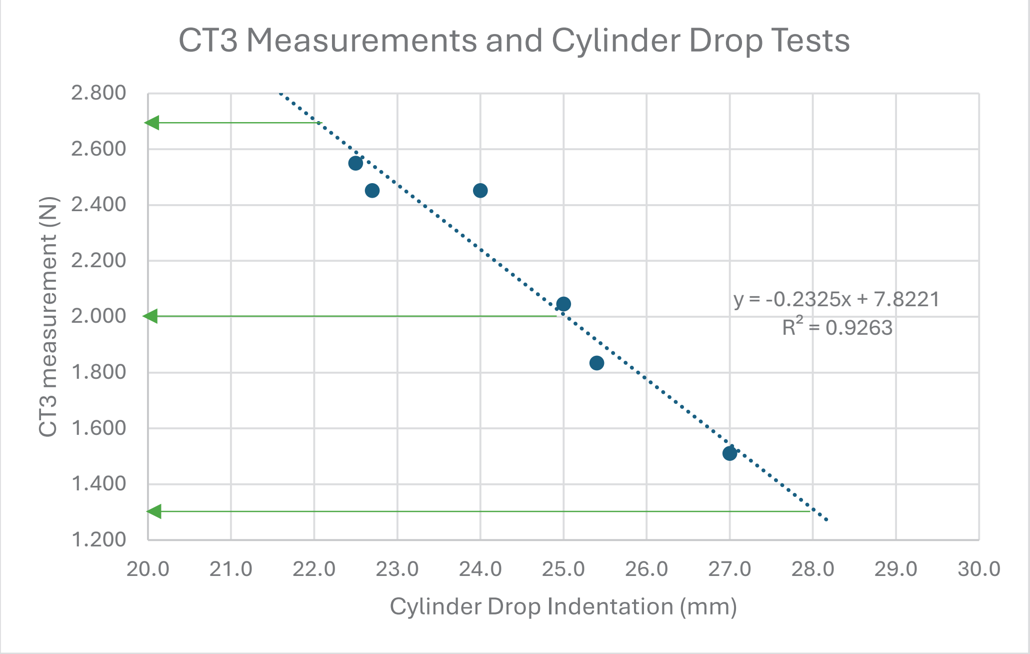

Figure 1. Correlation between CT3 measurements and cylinder drop tests done at ATC. The top arrow indicates the 22 mm drop "hard limit" (approximately 2.7N). The middle arrow indicates the 25 mm drop target hardness (approximately 2.0N). The bottom arrow indicates the 28 mm drop "soft limit" (approximately 1.3N).

The formula for the linear regression model was used to calculate pass/fail values for the CT3 that would predict pass/fail cylinder drop calibration values (Table 1). The 25 ± 3 mm cylinder drop correlates with predicted CT3 measurements of 2.707N for 22 mm lower limit, 2.010N for 25 mm, and 1.312N for 28 mm upper limit.

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Table 1 Extrapolating the data from figure 1, calibration limits are calculated for the CT3 Texture Analyzer.

	Drop Depth (mm)	Predicted CT3 (N)
Hard Limit	22	2.707
Pass	25	2.010
Soft Limit	28	1.312

3.2 Aging

RP1 was made side-by-side with RP1.2. The hardness of each clay was measured over a period of 70 days (Figure 2). RP1 was out of the calibration range (green shaded area) the day after it was made and continued to harden. In contrast, RP1.2 remained well in calibration during the entire course of the study. Using the formula from the non-linear regression model y = 0.0571 ln(x) + 1.601, the predicted hardness as measured by the CT3 would be 2.07 when x, or the age in days, is equal to 3650. In other words, RP1.2 can be predicted to remain in calibration 10 years after manufacture.

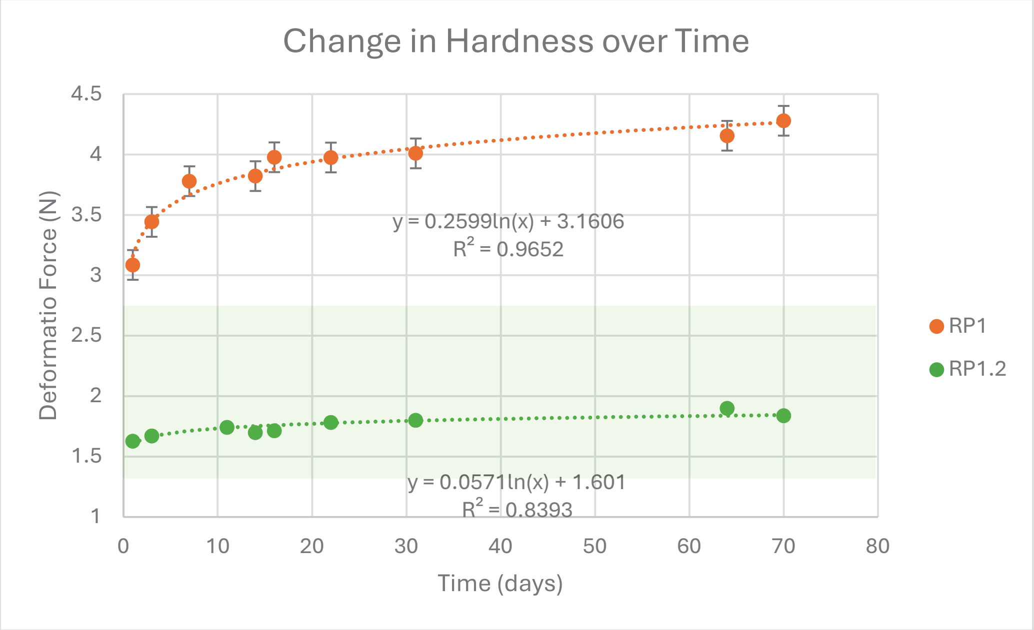

Figure 2. Time dependent changes in hardness comparison between RP1 and RP1.2. The area shaded in green represents the predicted calibration range.

3.3 Thermal Stability

Blocks of RP1 and RP1.2 were cut in blocks roughly 7 x 5 x 3 cm weighing approximately 175 gm. Between day 70 and day 72, CT3 measurements were made at temperatures between 17-27 ºC in two-degree increments. For changes of two degrees C, clay was incubated for about 7 hours. For changes of six degrees, clays were incubated overnight (Table 2).

Table 2 Schedule for temperature adjustments on clay for the thermal stability tests.

Temp (°C)	Age (d)
17	71
19	71
21	70
23	70
25	72
27	72

Within the time period tested, age related changes in hardness should have been minimal. As expected, RP1 is out of calibration in this temperature range (Figure 3). In contrast, RP1.2 is in calibration in the entire temperature range tested.

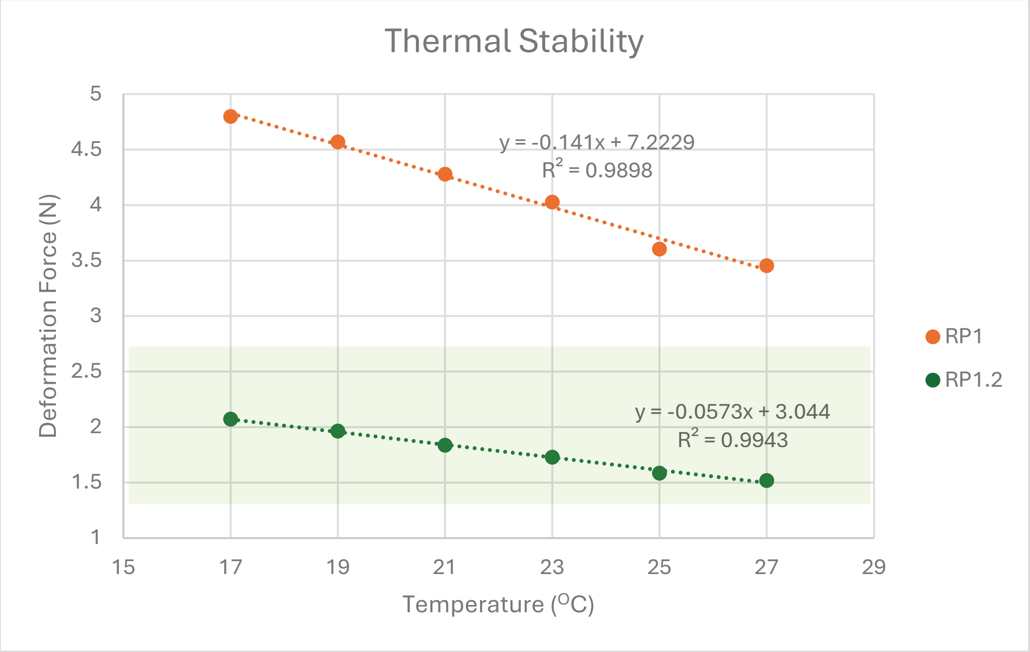

Figure 3. Temperature dependent hardness change comparison between RP1 and RP1.2. The area shaded in green represents the predicted calibration range.

Given the small number of data points, it is worth mentioning that, at the 95% confidence level, the slope for RP1 is -0.141 ± 0.020 and the slope for RP1.2 is -0.057 ± 0.006. These data indicate that RP1.2 is more thermal stable than RP1.

3.4 Thixotropic Recovery

A pasta maker was used to "cold work" the clay to varying degrees. The thixotropic impact and recovery over time were measured. Six 20-gram samples were prepared from the same 0.9 kg. block of RP1 or RP1.2. Five samples were passed through a Pasta Queen® pasta maker (Figure 4) at setting 6 according to the following schedule:

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Sample 1 - 0 passes
Sample 2 - 2 passes
Sample 3 - 4 passes
Sample 4 - 7 passes
Sample 5 - 10 passes

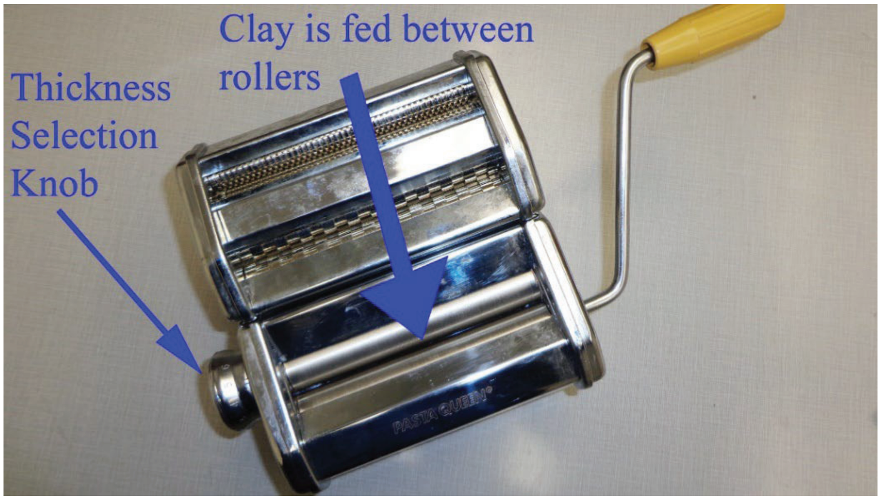

Figure 4. Pasta Queen pasta maker

Passing the clay through the pasta maker formed clay ribbons (Figure 5), which were folded and gently pressed into blocks approximating the original size and shape of the clay block (figure 6). These blocks were either passed through the pasta maker again or set aside for CT3 analysis.

Figure 5. Clay ribbon formed after passing through the pasta maker.

Figure 6. Folded ribbon of clay after gently pressing the layers together.

Figure 7 shows the softening of RP1 and RP1.2 from successive passes through the pasta maker. The change as a percent of the unaltered control is given in Table 3, clearly indicating that RP1.2 shows a smaller change in hardness as a result of the kinetic energy input from the pasta maker as compared to RP1.

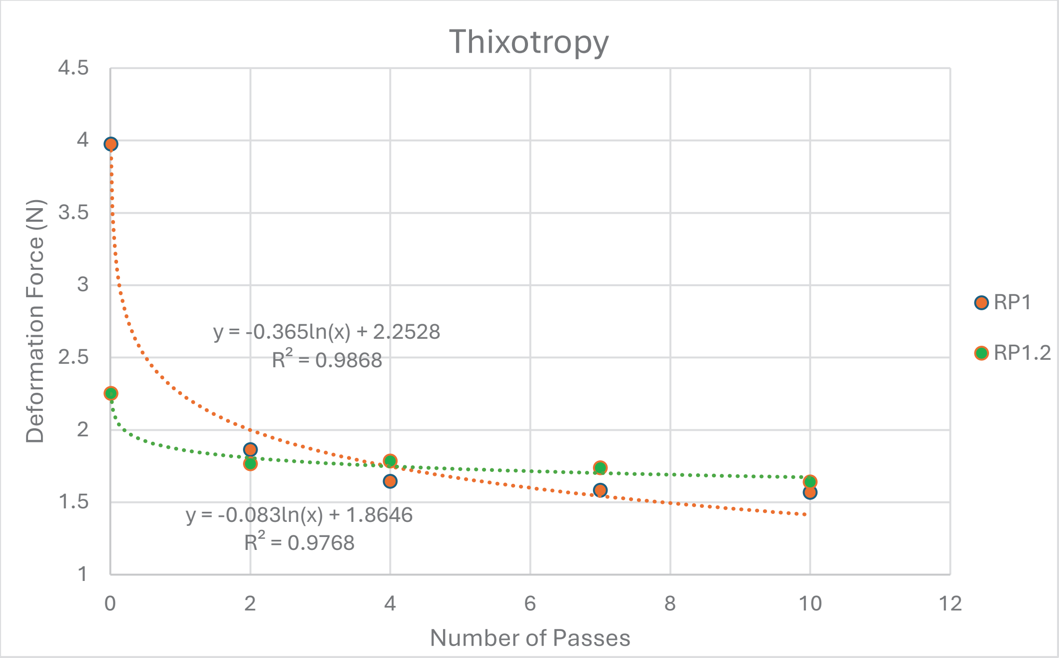

Figure 7. Thixotropic response of RP1 (green) and RP1.2 (orange) after successive passes through a pasta maker.

Table 3 Percent change in hardness after successive passes through the pasta maker.

	Percent Change from Control	
Passes	RP1	RP1.2
2	53.13	21.63
4	58.62	20.74
7	60.15	22.87
10	60.53	27.18

3.5 Live Fire Test

Soft armour vests were shot on two NIJ ballistic boxes of RP1 and one box of RP1.2. Heated RP1 (34.4-34.5 °C) and room temperature (21.4-21.5 °C) RP1.2 boxes passed calibration as per NJ 0101-06 immediately before live fire tests. Six shots were fired on each test article. Two boxes of RP1 were used to limit the thixotropic effect of the clay being "cold worked" by repeated firing on the same box. There was no evidence that previous shots softened the clay and increased the backface deformations (BFDs) of subsequent shots when only a single box of RP1.2 was used (Table 4).

Each of the shot locations on Roma 1.2 is similar in depth to the corresponding shot locations on Roma 1. Except for Shot 5, the standard deviation of shots on Roma 1.2 were smaller than shots on Roma 1 (Table 4).

Table 4 The backface deformations (BFDs) in mm for each shot on RP1 and RP1.2 and the mean and standard deviation of three shots at each location.

	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
Roma 1 Block 28	36.4	39.2	35.3	28.1	29.1	33.3
Roma 1 Block 28	34.3	33.9	36.7	26.5	27.6	35.5
Roma 1 Block 11	39.2	38.5	41.9	33.8	26.7	33.9
Mean	36.6	37.2	38.0	29.5	27.8	34.2
SD	2.46	2.88	3.48	3.84	1.21	1.14
Roma 1.2 Block 1	35.9	37.3	36.8	30.0	25.6	34.6
Roma 1.2 Block 1	36.9	35.6	36.7	28.7	29.7	34.2
Roma 1.2 Block 1	35.4	35.7	33.9	27.1	21.2	34.1
Mean	36.1	36.2	35.8	28.6	25.5	34.3
SD	0.76	0.95	1.65	1.45	4.25	0.26

4. DISCUSSION

This study is a revival of earlier work to improve RP1 as a ballistic backing material [6]. The earlier revised clay (prototype 8, also referred to as BT18c in other literature) was not adopted for a variety of reasons, including the desire

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for government ownership of the formula. As a result, Army Research Labs have developed ARTIC (ARL Temperature Insensitive Clay, ref. 8). While Chavant's parent company, Smooth-On, has been chosen to manufacture ARTIC under license, the problems with RP1 still need to be addressed.

RP1.2 has many advantages over the existing RP1. Being in calibration at room temperature, the clay can be used without pre-heating the clay to 35-37 ^{o}C provided that the clay is not stored at extreme temperatures. The clay will not cool down during use, extending the range time of each box. Also, a small standard deviation of mean BFD measurements can result in less shots needing to be fired for the same statistical level of confidence in an outcome. A lower level of thixotropy would allow more shots to be fired on the same block of clay, reducing the overall number of clay boxes that would be needed to pack, less clay to buy and less time needed to switch out boxes between tests.

5. Conclusions

The improved clay described in this report, RP1.2, has overcome the aging problem of both RP1 and the original prototype 8 clay. While RP1.2 has been shown to record similar BFDs as calibrated RP1 on soft armour, more live-fire testing needs to be done on soft armour, hard armour, and helmets.

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