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U.S. Army Aberdeen Test Center (TEDT-AT-WFA)
6943 Colleran Rd, Bldg 400
Aberdeen Proving Ground, MD 21005

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6617 Aberdeen Boulevard
Aberdeen Proving Ground, MD 21005-5001

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14. ABSTRACT

The procedures in this Test Operations Procedure (TOP) describe how to test and separate batches of copper spheres, used in copper crusher gauges for pressure measurement, into lots which have a characteristic force/deflection relationship with minimal variability.

15. SUBJECT TERMS

copper spheres, crusher pressure gauge, sorting, proof testing, tarage

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 03-1-020 24 April 2019
DTIC AD No.

PROCEDURE FOR COMPARING BATCHES OF COPPER SPHERES FOR THE FORMATION OF COPPERS LOTS FOR TARAGE TABLE PURPOSES

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1. SCOPE.

This Test Operations Procedure (TOP) describes how to test and separate batches of copper spheres used in copper crusher gauges into lots which have a characteristic force/deflection relationship with minimal variability.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Material testing facility.	The facility shall have environmental controls that allow the room temperature to be maintained at 21 ± 2 °Celsius (°C) (69.8 ± 3.6 °Fahrenheit (°F))
Servo-hydraulic test machine.	The actuator of the machine shall be able to move at a constant rate (closed loop position control) up to 40 inches per second.
Compression fixturing for servo-hydraulic test machine.	Fixturing shall consist of upper and lower load bearing platens. Ideally, the lower platen will have a centering device similar to the spring in an M11 gauge. The material composition surface hardness, and surface roughness of the platens will be consistent with the bearing surface callouts for the crusher gauges: Material: 4140 Steel. Hardness: 43-47 Hardness Rockwell C scale (HRC). Surface Roughness: arithmetic average of the roughness profile (Ra) < 8 microinch (μin)).

2.2 Instrumentation.

The following instruments or their equivalents will be used.

Parameter	Device for Measuring	Permissible Measurement Uncertainty and/or Accuracy
Force Application Machine	A servo-hydraulic test machine with the appropriate pump, servo-valves, manifold, and accumulators to achieve actuator velocities up to 40 inches per second.	See force and displacement requirements below.
Force	Load cell mounted on servo-hydraulic load frame. Calibration shall comply with American Society for Testing and Materials (ASTM) E4-16[**1].	Repeatability < 0.3% when calibrated according to ASTM E4-16. Accuracy < 0.5% in compression when calibrated according to ASTM E4-16.
Displacement	Typically a linear variable differential transformer (LVDT) attached to the servo-hydraulic test machine. Other calibrated sensors mounted to the test frame may be used. Calibrations must be in accordance with ASTM E2309[2].	Linear gauge must be class A or equivalent (accuracy and repeatability) according to ASTM E2309.
Data Acquisition System (DAS)	Electronic data acquisition system that takes output of force and position sensors, conditions the data, samples it at a predetermined rate, and records it in a digital format.	Test results shall be recorded at a rate of at least 10 kilohertz (kHz). Higher is preferable.
Temperature	Temperature measurement device.	± 0.5 °F accuracy.
Length	Micrometer for the measurement of sphere diameter and final height.	± 0.0001 inch (in.) accuracy and 0.00005 in. resolution.

3. REQUIRED TEST CONDITIONS.

The test environment will be maintained at 21 ± 2 °C (69.8 ± 3.6 °F). Temperatures shall be recorded at the beginning and end of each test day. Prior to each test, the temperature measurement device shall be checked to ensure the temperature is within the ± 2 °C range. All spheres tested will be conditioned at the same temperature for a minimum of 24 hours prior to testing (lid off of container).

** Superscript numbers correspond to Appendix C, References.

4. TEST PROCEDURES.

a. The minimum batch size from a manufacturer should be as large as possible in order to minimize the number of potential lots that will be formed from them. Historically batches have contained anywhere from approximately 50,000 to 150,000 spheres. Spheres shall be manufactured and accepted according to Military Detail (MIL-DTL)-49514A[3], which contains all material requirements, heat treating (annealing) methods, physical characteristics, verification requirements, and testing and acceptance requirements.

b. Prior to testing.

(1) A random sample of 70 spheres will be selected from each batch for testing. An additional 100 samples will be randomly selected from each batch for storage for future reference.

(2) Each sphere will be visually inspected for defects that may affect test results (i.e., scratches, dents, etc.). A micrometer will be used to measure and record the initial diameter of each sphere to ensure it meets the requirement of the detail specification (0.1875 -0.0005 in.). If a sphere has a notable defect or fails to meet the diameter requirement, that sphere will be replaced (not used for testing), and will be properly discarded.

(3) The calibration date of all instrumentation shall be documented to show it is current and in compliance with error specifications (paragraph 2.2).

c. Testing.

(1) All test events will be identified with a unique test event number: (event #, batch #, production run date).

(2) Each individual sphere will be positioned in the center of the bottom compression platen using a positioning spring consistent with a M11 gauge or an equivalent device. Note: if the spring is not properly positioned in the groove it will be crushed by the loading head, and the test will become invalid.

(3) The servo-hydraulic machine will be set for the actuator to move at a rate of 30 inches per second during a test. The actuator will be positioned so that the space between the upper and lower compression surfaces (platens) equals the measured sphere diameter. This is the starting position of the compression test.

(4) The compression machine will be set to stop loading at a stroke (displacement) consistent with a nominal loading of 2100 pounds (lb). This stroke limit will be used for all testing (ensure the stroke value does not interfere with positioning spring). The machine will be set to automatically retract when this maximum condition is met. The DAS will output and record load, stroke, and time values at a rate of 10 kHz or more. Stroke values will be interpolated at 100 lb increments from 0 to 2000 lb.

(5) Each load/stroke curve will be visually inspected for proper machine function after each run. The crushed sphere will also be inspected for fracture or other anomalies. Testing personnel will exercise discretion over the need to acquire a new test specimen in the event of a malfunction or anomaly. Any such events will be documented. Sphere response anomalies with deformations that are uncharacteristic (as determined by an accepted outlier test) and/or that occur at an unacceptable frequency will be grounds for production lot rejection upon the judgement of the test organization.

(6) The platen loading surface will be inspected after each test. If degradation of the compression platen loading surface becomes visible in the course of testing, it shall be replaced with a new loading fixture.

(7) After each successful compression test, the test sphere's final crush height will be manually measured using a micrometer and recorded to the nearest 0.0001 in.

(8) Once the initial diameter, force, displacement, time, and final height measurements are electronically recorded for all 70 samples randomly selected from each batch, these data shall be downloaded to appropriate media, and transferred to an archive server at the overseeing test organization.

5. DATA COLLECTION AND ANALYSIS.

5.1 Data Acquisition.

a. The following data will be provided by the copper sphere manufacturer:

(1) Year of manufacture.

(2) Copper coil number.

(3) Production lot number.

(4) Production lot size.

(5) Batch number.

(6) Batch size.

(7) Annealing temperature and time for each batch.

(8) Any additional documentation from the manufacturer.

b. The following data will be recorded by the test organization:

(1) Test date.

(2) Test time.

(3) Test event number.

(4) Test facility temperature at the start and end of each test day.

(5) Calibration information of instrumentation.

(a) Load cell

(b) LVDT or equivalent.

(c) Micrometer.

(d) Temperature measurement device.

(6) Pre-test sphere diameter.

(7) Post-test crushed sphere height.

(8) Electronic digitized load/stroke/time files titled per paragraph 4.c(1). Both raw and tabulated at 100 lb increments.

5.2 Data Processing and Analysis.

a. The load stroke data will be processed to calculate load speed to confirm the load rate requirement was met. Also, the stroke values will be converted to crush height values by the relation: crush height equals the measured sphere diameter minus stroke.

b. Analysis Plan. The analytical plan for the separation of the batches into lots is as follows: M % is the one-sigma batch merge criteria for residuals in load versus height fits, targeted at <= 0.7 % (this value is determined achievable from available historic data).

(1) For all analysis, only data from the 1000 to 2000 lb range at 100 lb increments will be used. The load versus deformation height data will be fit for each batch using a third order polynomial. This order polynomial is consistent with North Atlantic Treaty Organization (NATO) practice (Allied Engineering Publication (AEP 23[4])) for characterizing copper crusher gauge performance, which is directly related to copper sphere response. A three-sigma outlier criteria for the residuals from the fits will be used, and only one outlier will be allowed to be eliminated per batch. If a batch has more than one outlier, the batch will be rejected unless it can be proven the outliers were test induced. Outliers will be noted in published reports. Curves will be refit after an outlier is removed.

(2) The standard deviation of the residuals (100 lb increment data) of the curve fit for each batch will be expressed in terms of percentages of the predicted load of the fit [(actual load – predicted load)*100 / predicted load]. The batch residuals will be considered homoscedastic

(independent of crush height) for the load range of 1000 to 2000 lb (historic data shows this to be true to within a few hundredths of a percent). Batches with one-sigma values > M % (M % is also the merge criteria), in the 1000 to 2000 lb range, will be rejected. Table 1 shows how the results will be tabulated for the curve fits and the residuals.

TABLE 1. CURVE FITS AND RESIDUALS

Batch#	Fit coefficients (a*x^3 + b*x^2 + c*x + d)				Residuals
	a	b	c	d	%
1					
2					
3					
4					
5					
6					
7					

(3) In order to form lots, batches will be evaluated at two standard crush heights simultaneously (because interaction with height changes from batch to batch as manifest by different slopes, therefore the residuals from combined batches will not necessarily be homoscedastic). These heights are at loads of ~1000 and ~2000 lb and are standardized at crush height values of 0.095 in. and 0.125 in. respectively. The load at each standard crush height will be calculated using the curve fit for each batch. Then the ± three-sigma (from residuals) load values will be calculated at each standard height in order to estimate the maximum and minimum bounds of response at each height. The mean load will also be calculated using the predicted loads at each standard crush height. The end result will be Table 2, indicating batch number, min and max load at 0.095 in., min and max load at 0.125 in., and the mean load. The formulas used for each calculation are shown in Table 2.

TABLE 2. DEFORMATION HEIGHT FORMULAS

Batch#	Curve Fit Residuals, R%	Values at 0.125 in. Deformation Height				Values at 0.095 in. Deformation Height				Mean Load =(L1+L2)/2
		Curve Fit, Predicted Load, L1	Standard Deviation SD1 = R% * L1/100	3 Sigma Max, = L1+3*SD1	3 Sigma Min, =L1- 3*SD1	Curve Fit, Predicted Load, L2	Standard Deviation SD2 = R% * L2/100	3 Sigma Max, = L2+3*SD2	3 Sigma Min, =L2- 3*SD2	
	SD%	lb	lbs	lbs	lbs	lb	lbs	lbs	lbs	lbs
1										
2										
3										
4										
5										
6										
7										

(4) A sorting routine will be used, which orders the batch datasets in ascending order of mean load (average of the predicted load at 0.095 and 0.125 in.). Starting with the first batch (lowest mean), inclusion of the successive batch into a lot will be determined by whether or not the estimated percent sigma (combined batches) at the two crush height values is less than M %. Sigma will be estimated at each standard height value by dividing the span of the load values ($max_{combined}$ - $min_{combined}$) by 6 [SD approximation based on normal distribution per the National Institute of Standards and Technology (NIST)], as shown in Figure 1. The sigma estimate may be multiplied by the Bessel correction (N/(N-1)) for further conservatism. The estimates are converted to percentages by dividing sigma by the average value of the span (see Figure 1) and multiplying by 100. The first batch not included in the lot (because combined sigma > M%) becomes first in the next lot forming sequence, the 2nd not included becomes the second in the sequence, etc. (maintains ascending load order). Once all batches are assessed, the process is repeated, stepping through the remaining batches to look for inclusive sets to form the next lot and so on. A single batch can become its own lot if no other batches will combine with it to meet the sigma criteria. When no batches remain the process is complete.

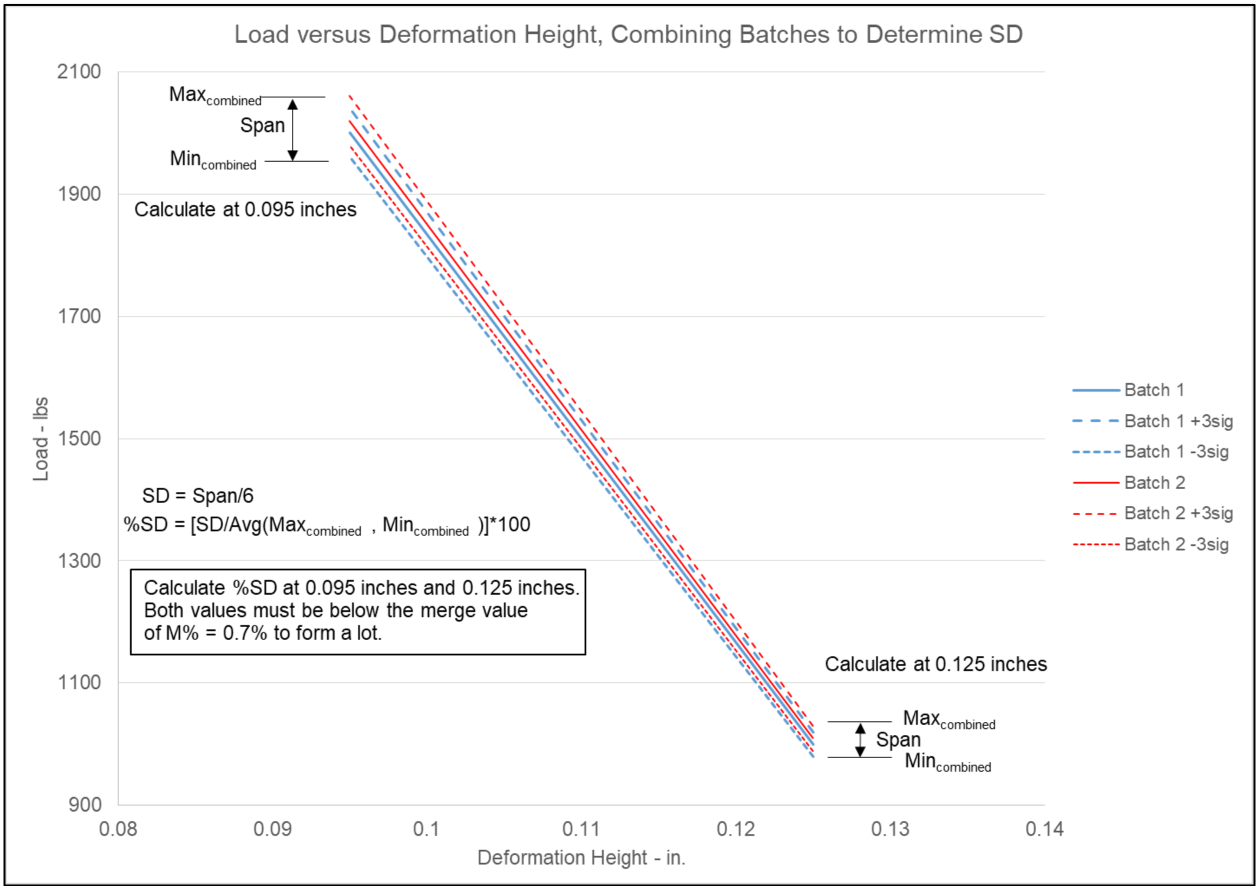

Figure 1. Determination of the standard deviation at each end of the ranges evaluated.

(5) Once lots have been formed, a third order fit will be performed of the individual data points (100 lb increment data) comprising the lots. The fit coefficients of individual and combined batches and SD % (residuals) will be included in tabulated output as shown in Table 3. The SD of the lot residuals will be compared against the SD of constituent batches. The analyst may further tighten the M % value if it is seen that one or more batches are driving the variation in the lot.

(6) Batches that are combined into a lot will be physically mixed in a thorough manner that limits abrasion. This will help reduce biasing effects, that is, reduce the likelihood of two spheres from the same batch being used in the same operational test.

6. PRESENTATION OF DATA.

The summary result data will be shown as in Table 1 and Figure 1.

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APPENDIX A. GLOSSARY.

Term	Definition
Batch	A batch consists of all copper crushers annealed in the same furnace charge and made from one lot.
Lot	A lot consists of all spheres made from wire coil of one billet.

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APPENDIX B. ABBREVIATIONS.

AEP	Allied Engineering Publication
ASTM	American Society for Testing and Materials
°C	degrees Celsius
DAS	data acquisition system
°F	degrees Fahrenheit
HRC	Hardness Rockwell scale C
in.	inch
ITOP	International Test Operations Procedure
kHz	kilohertz
LVDT	Linear Variable Differential Transistor
μin	microinch
MIL-DTL	Military Detail
NATO	North Atlantic Treaty Organization
NIST	National Institute of Standards and Technology
lb	pound
Ra	arithmetic average of the roughness profile
SD	standard deviation
STANAG	Standardization Agreement
TOP	Test Operations Procedure

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APPENDIX C. REFERENCES.

1. ASTM Standard E4-16, Standard Practices for Force Verification of Testing Machines, 2016.

2. ASTM Standard E2309/E2309M-16, Standard Practices for Verification of Displacement Measuring Systems and Devices Used in Material Testing Machines, 2016.

3. MIL-DTL-49514A, Copper Crusher Spheres for Cannon and Mortar Pressure Gauges, General Specification For, December 14, 2016.

4. AEP 23 Edition 2, Pressure Measurements by Crusher Gauges-NATO Approved Tests for Crusher Gauges, June 2004.

For information only (related publications).

a. Standardization Agreement (STANAG) 4113 (Edition 3), Pressure Measurement by Crusher Gauges, 4 June 1993.

b. International Test Operations Procedure (ITOP) 03-2-810(2), Copper Crusher Measurement of Weapon Chamber Pressure, March 2005.

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APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 24 April 2019

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure 03-1-020 Procedure for Comparing Batches of Copper Spheres for the Formation of Coppers Lots for Tarage Table Purposes, Approved for Publication

1. Test Operations Procedure (TOP) 03-1-020 Procedure for Comparing Batches of Copper Spheres for the Formation of Coppers Lots for Tarage Table Purposes, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

a. The procedures in this TOP describe how to test and separate batches of copper spheres, used in copper crusher gauges for pressure measurement, into lots which have a characteristic force/deflection relationship with minimal variability.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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RAYMOND G. FONTAINE
Associate Director, Test Management Directorate

FOR

MICHAEL J. ZWIEBEL
Director, Test Management Directorate

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: U.S. Army Aberdeen Test Center (TEDT-AT-WFA), 6943 Colleran Road, Aberdeen Proving Ground, Maryland 21005. Additional copies can be requested through the following website: https://www.atec.army.mil/publications/documents.html, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.