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STANAG 4115 LAND (EDITION 2) - DEFINITION AND DETERMINATION OF BALLISTIC PROPERTIES OF GUN PROPELLANTS

References:
a. MAS(ARMY)(70)79 dated 31 March 1970 (Edition 1)
b. AC/225(LG/4-SG/2)D/43 dated 12 January 1995 (Edition 2)(1st Draft)

1. The enclosed NATO Standardization Agreement which has been ratified by nations as reflected in page iii is promulgated herewith.

2. The references listed above are to be destroyed in accordance with local document destruction procedures.

3. AAP-4 should be amended to reflect the latest status of the STANAG.

ACTION BY NATIONAL STAFFS

4. National staffs are requested to examine page iii of the STANAG and, if they have not already done so, advise the Defence Support Division, IS, through their national delegation as appropriate of their intention regarding its ratification and implementation.

A. GRØNHEIM
Major General, NOAF
Chairman MAS

Enclosure:
STANAG 4115 (Edition 2)

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STANAG No. 4115
(Edition 2)

NORTH ATLANTIC TREATY ORGANIZATION
(NATO)

MILITARY AGENCY FOR STANDARDIZATION
(MAS)

STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: DEFINITION AND DETERMINATION OF BALLISTIC PROPERTIES OF GUN PROPELLANTS

Promulgated on 30 June 1997

A. GRØNHEIM
Major General, NOAF
Chairman MAS

RECORD OF AMENDMENTS

No.	Reference/date of amendment	Date entered	Signature

EXPLANATORY NOTES

AGREEMENT

1. This NATO Standardization Agreement (STANAG) is promulgated by the Chairman MAS under the authority vested in him by the NATO Military Committee.

2. No departure may be made from the agreement without consultation with the tasking authority. Nations may propose changes at any time to the tasking authority where they will be processed in the same manner as the original agreement.

3. Ratifying nations have agreed that national orders, manuals and instructions implementing this STANAG will include a reference to the STANAG number for purposes of identification.

DEFINITIONS

4. Ratification is "The declaration by which a nation formally accepts the content of this Standardization Agreement".

5. Implementation is "The fulfilment by a nation of its obligations under this Standardization Agreement".

6. Reservation is "The stated qualification by a nation which describes that part of this Standardization Agreement which it cannot implement or can implement only with limitations".

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

7. Page iii gives the details of ratification and implementation of this agreement. If no details are shown it signifies that the nation has not yet notified the tasking authority of its intentions. Page iv (and subsequent) gives details of reservations and proprietary rights that have been stated.

Agreed English/French texts

NATO STANDARDIZATION AGREEMENT (STANAG)

DEFINITION AND DETERMINATION OF BALLISTIC PROPERTIES OF GUN PROPELLANTS

Annexes:
- A - Experimental Procedures
- B - Glossary of Terms
- C - Burning Rate Calculations
- D - List of Symbols
- E - Data Exchange Sheet
- F - Selected Bibliography

Related documents:

STANAG 4367 - Thermodynamic Interior Ballistic Model with Global Parameters

STANAG 4400 - Derivation of Thermochemical Values for Interior Ballistic Calculations

AIM

1. The aim of this agreement is to standardize the use of the closed vessel procedure for the determination of propellant burning properties for use in interior ballistic calculations (absolute measurements) and for comparative purposes (relative measurements).

AGREEMENT

2. Participating nations agree to use the definitions and procedures described in this STANAG for the determination of propellant burning properties for use in the interior ballistic simulation codes and for interchange of information.

DEFINITIONS

3. The definitions used for the purpose of this STANAG are given in Annex B.

GENERAL

4. The burning characteristics of propellants need to be definitively determined for assessment of gun performance. In order for nations to exchange these propellant properties, the data must be obtained in a manner that is common to all. One experimental procedure used to collect these data is the closed vessel technique.

It should be noted that from the closed vessel work, the pressurisation rate (quickness) and the vivacity are the only parameters that can be determined with certainty from the experimental results. The determined values of force and covolume contain errors arising from uncertainties of heat loss and vessel expansion. Although these experimentally obtained values of force and covolume are not acceptable as input data for ballistic modelling, they are valid for the intermediate calculations of the burning rate.

DETAILS OF AGREEMENT

5. The details of the agreement are given under Annex A, Experimental Procedures.

IMPLEMENTATION OF AGREEMENT

6. This STANAG is implemented when a nation has issued instructions to use the procedures described in this STANAG as a national procedure.

EXPERIMENTAL PROCEDURES

1. The experimental procedures involve:

A. Closed vessel and jacket
B. Pressure gauge and its calibration
C. Recorder
D. Propellant
E. Ignition System
F. Operation
G. Data reduction

A. Closed vessel: For artillery propellant, the recommended vessel volume is 700cm^3; the minimum volume should be 400cm^3. For other than artillery propellants, a smaller volume is acceptable. The vessel volume shall be determined within 0.25%

To prevent pressure oscillations, the following empirical relationship should be fulfilled:

$$l * p_{max} * L < c \qquad (1)$$

where

c = constant 100 m/s
l = length of combustion chamber
L = expected dynamic vivacity
p_{max} = expected maximum gas pressure

All quantities shall be in the respective SI units.

Also critical is the length/diameter (l/D) ratio which should be approximately 2.

B. Pressure gauge: Measurement of the pressure should be achieved using a piezo-electric pressure transducer mounted in an adapter or other stress free environment. The specification of the gauge is not important, but the minimum frequency response of the transducer will be 25 kHz.

A valid calibration is required prior to firing, and this should be carried out with the transducer mounted in the adapter in which it will be used in the closed vessel. Verification of the calibration will be carried out at a pressure close to the maximum expected in the closed vessel. The gauge will be recalibrated after 6 months or after 100 firings which ever occurs sooner. If the gauge is removed from its adapter for any purpose (such as exchange of heat shield), then it shall be reverified after re-assembly over the pressure range of interest.

Calibration of the gauge should be carried out using a polynomial fit of the observed electrical output to pressure input. The degree of the polynomial fit will depend on the linearity of the gauge. The criterion for the degree of the polynomial fit is that at pressures between 20% and 100% of the expected maximum pressure, the maximum error between the polynomial curve and the observed values shall not exceed 0.5%. For most commercially available gauges either quadratic (2nd order) or cubic (3rd order) fits will be required. The minimum number of equally spaced calibration points should be 8. At each pressure a minimum of three readings is required; these should be consistent with the values specified by the manufacturer, but in any case must not exceed 0.2%.

C. **Recorder**: The recorder, including an analog to digital converter, should be certified by a National Authority procedure and allow for a sampling frequency of at least 20 kHz and 4,000 points minimum. This device should have a minimum resolution of 12-bit. The time base accuracy shall be equal to or better than ± 0.1%. All recorder performance measurements should comply with IEEE Standard for Digitizing Waveform Recorders, or an equivalent standard.

D. **Propellant**: The propellant may be bagged or loaded loose if it is shown to be statistically similar. The procedure used shall be specified in the report. For firings at nominal load density, propellant sample massess should be within ± 0.1% of each other. If necessary one grain may be cut to trim mass.

For stick propellant, all sticks should be the same length to within ± 50% or 1mm, whichever is the greater of the web thickness. The value of the average length shall be used for reduction input.

Grain Measurement: As the grain dimensions have a most significant effect on the calculated burning rate values, measurement of the grain size must be precise and consistent. Where possible grains should be measured immediately before the test. Details of the procedure results and date of the measurement should be reported.

E. Ignition system: The ignition system shall consist of a power source and the igniter material. The power source should greatly exceed the minimum energy requirements for consistent ignition of the electric match, squib or the igniter material. The igniter material may be black powder, clean burning igniter, Benite or a similar substitute. The quality and type of igniter material shall be reported and shall be sufficient to ensure consistent ignition of the propellant during long-term storage.

F. Operation: The propellants must be conditioned at the test temperature ± 2 K for at least 8 hours. The humidity level and temperature of the reference propellant should be controlled and monitored.

The temperature at the inner surface of the vessel at the moment of loading must be controlled at 294 ± 2 K.

A test series should consist of 1 warmer shot, at least 3 reference or standard shots, and the same number of test shots. The reference and test shots should alternate. A test series shall be completed in one shift. If any test series is interrupted for more than two hours, another warmer may be required.

G. Data reduction: The pressure data has to be smoothed in a way that scattering and oscillations are eliminated without affecting the underlying trend of the dynamic vivacity curve. From the smoothing we get the smoothed experimental maximum pressure and pressure-time curve. The time differential of pressure (dp/dt) can be obtained analytically or arithmetically from the smoothed pressure-time data. The dynamic vivacity is calculated according to equation 2, page B-1. If the surface generation rate is appropriate for the form function of the propellant, then burning rate reduction calculations can continue as specified in Annex C.

GLOSSARY OF TERMS

1. Maximum Pressure: p_{max}

The maximum gas pressure of the smoothed pressure time curve.

2. Dynamic Vivacity: L

$$L = \frac{dp}{dt} \cdot \frac{1}{p * p_{max}} \qquad (2)$$

3. Relative Dynamic Vivacity: L_{rel}

$$L_{rel}(z) = \frac{\sum_{1}^{m} L_{test}(z)}{\sum_{1}^{m} L_{ref}(z)} \qquad (3)$$

Where "m" indicates the number of rounds and "z", approximated by the ratio p/p_{max}.

4. Characteristic Dynamic Vivacity: L_k

The mean value of the relative dynamic vivacity in the range from 0.3 to 0.7 p/p_{max} taken in steps of 0.1 p/p_{max}. If another range is used, it should be noted.

$$L_k = \frac{\sum_{z=0.3}^{0.7} L_{rel}(z)}{5} \qquad (4)$$

5. Loading density: Δ

Initial mass of propellant per unit of volume of the closed vessel.

6. Covolume: η

The covolume is defined in the Noble-Abel equation.

$$p\left(\frac{1}{\Delta} - \eta\right) = n R T \qquad (5)$$

where η is called the covolume.

7. Force: f_p

This is a quantity used by interior ballisticians. It represents the work capacity of the propellant and is proportional to the energy released by a unit mass of propellant at a specific temperature.

8. Form Function: $\phi(z)$

The form function is defined as the ratio of the burning surface area to the initial surface area as given by the equation S/S_0. This expression is designated by the letter ϕ.

BURNING RATE CALCULATIONS

The Noble-Abel equation of state can be notated as follows:

$$p = \frac{f_{ex}\, z}{\left(\frac{1}{\Delta} - \frac{1}{\rho}\right) - z\left(\eta_{ex} - \frac{1}{\rho}\right)} \qquad (6)$$

The burning rate is defined as:

$$r = \frac{de}{dt} \qquad (7)$$

Defining a term related to the form function

$$\frac{de}{dz} = \frac{V_{0,p}}{S_{0,p}} \cdot \frac{1}{\phi(z)} \qquad (8)$$

and a term for the differentiated equation of state

$$\frac{dz}{dp} = \frac{1}{p_{max,ex}} * \frac{1 + \left(\eta_{ex} - \frac{1}{\rho}\right)\frac{p_{max,ex}}{f_{ex}}}{\left[1 + \left(\eta_{ex} - \frac{1}{\rho}\right)\frac{p}{f_{ex}}\right]^2} \qquad (9)$$

and using the differentiated smoothed pressure time-curve (dp/dt), the burning rate can be calculated from the following expression:

$$r = \frac{de}{dt} = \frac{de}{dz} \cdot \frac{dz}{dp} \cdot \frac{dp}{dt} \qquad (10)$$

The experimental force and covolume to be used should be estimated by linear regression on basis of three loading densities, each separated by 30 kg/m³ and corresponding p_{max} by the following formula:

$$\frac{p_{max,ex}}{\Delta} = \eta_{ex}\, p_{max,ex} + f_{ex} \qquad (11)$$

The central value of the loading density should be commensurate with the weapon system pressure. If results are

$$f_{ex} = \left(\frac{1}{\Delta} - \eta_{th} \right) p_{\max, ex} \qquad (12)$$

available only for one loading density, the theoretical value of covolume should be used. In this case the force should be computed using:

Finally, in accordance with STANAG 4367(Ed.2), if both the force constant and the covolume are unavailable, they can be determined theoretically.

LIST OF SYMBOLS

Symbol	Definition	SI units
D	Chamber diameter	m
e	Thickness of layer of burnt propellant	m
f_{ex}	Experimental force of propellant	J/kg
f_p	Force of propellant	J/kg
l	Chamber length	m
L	Dynamic vivacity	1/(Pa-s)
L_k	Characteristic dynamic vivacity	1/(Pa-s)
L_{rel}	Relative dynamic vivacity	-
L_{test}	Dynamic vivacity of test propellant	1/(Pa-s)
L_{ref}	Dynamic vivacity of reference propellant	1/(Pa-s)
m	Number of rounds per series	-
m_p	Propellant mass	kg
n	Number of moles of gas per unit mass of propellant	mol/kg
p	Pressure	Pa
p_{max}	Maximum gas pressure	Pa
$p_{max,ex}$	Maximum gas pressure, experimental	Pa
r	Burning rate	m/s
R	Universal gas constant (= 8.3143)	J/(mol-K)
$S_{0,p}$	Initial propellant grain surface	m^2
t	Time	s
T	Temperature	K
V	Volume of vessel	m^3
$V_{0,p}$	Initial propellant grain volume	m^3
z	Fraction of burnt propellant mass	-
Δ	Loading density	kg/m^3
η	Propellant gas covolume	m^3/kg
$\eta_{ex,p}$	Experimental propellant gas covolume	m^3/kg
$\eta_{th,p}$	Theoretical propellant gas covolume	m^3/kg
ρ	Propellant density	kg/m^3
$\phi(z)$	Form function (as function of z)	-

DATA EXCHANGE SHEET

STANAG 4115 DATA EXCHANGE SHEET

Test Number: Page of Page(s)

TEST SITE INFORMATION	**TEST CONDITIONS**
Laboratory: Date: Date Tested: POC:	Loading Density: Closed Vessel Volume (cm^3): Serial number: Temperature (°C): Relative Humidity (%): Ignition: Pressure gauge: Serial number: Calibration:
TEST PROPELLANT INFORMATION	**REFERENCE PROPELLANT INFORMATION**
Identification: Lot Number: Manufacturer: Date of Manufacturing: Density Grain Dimensions: Composition:	Identification: Lot Number: Manufacturer: Date of Manufacturing: Density Grain Dimensions: Composition:

VIVACITY TEST PROPELLANT [1/MPa.s]										Pmax
Round P/Pm	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	MPa
1 2 3 4 5										
Mean										
S dev										

VIVACITY REFERENCE PROPELLANT [1/MPa.s]										Pmax
Round P/Pm	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	MPa
1 2 3 4 5										
Mean										
S dev										

Number:	NATO STANAG 4115 DATA EXCHANGE SHEET	Page of Page(s)

RELATIVE VIVACITY [%]

P/Pm	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	L_k

BURNING RATE

P [MPa]	Test [mm/s]	Reference [mm/s]
50 100 150 . . . Pm		

Burn Rate Law γ (Cm/Spc)= a.P(MPa).exp(b)
Coefficient a =
Coefficient b =
Valid Pressure Range =

VIVACITY PLOT

EXPERIMENTAL COVOLUME/FORCE

Loading Density	Δ1	Δ2	Δ3		Experimental Covolume: Experimental Force:
Average Pmax					

SELECTED BIBLIOGRAPHY

[1] J. Domen; Closed Bomb Analysis Program (CBA); US ARMY ARDEC; April 1994

[2] J.C. Post; TBI13 Closed Vessel Data Reduction Code, User's Manual, version 3.1; RNLA DMKL/AB; to be released

[3] Form Functions for the IBHVG code, US Army BRL Technical Report ARBRL-TR-02438, November 1982

[4] IC Schoeffert; Filtrage numérique des signaux de pression dans le dépouillement des tirs en enceinte manométrique; Note Technique CE/DMS/MMB/TDP N° 15/87; 7 octobre 1987.