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Ageing of Solid Rocket Propellants Investigated by Ultrasound Technique

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Abstract.
The goal of service life assessment of munitions is to provide the most reliable and most accurate prediction of service life possible in support of assuring safety, mission performance, and effective cost. Two parallel paths are generally followed for a continuing assessment of service life. Two paths is available – analytical and surveillance. The firs one assesses the rate of aging, the effect of aging on the system level (i.e., stability, performance, integrity, etc.) and the statistical probability of system failure during service life. The second path incorporates system observation and system trend analysis.
In striving to attain the goal of service life assessment of munitions the destructive methods is the best existing tool, characterized by partial or full destruction of these expensive products. Mostly, the received information from such a testing is not fully reliable and appropriate for accurate prognosis for age life.
The nondestructive methods are powerful tools in many industry areas, but not so popular for ammunition qualification. However several nondestructive methods exist – radiation, visual, microwave and other techniques. The ultrasound techniques are not so popular during qualification of ammunition for service use, except bond-line integrity of propellant and insulation.
The objective of this work is to develop ultrasound method as an auxiliary tool for estimation of life cycle period for solid propellants for missiles is proposed. Several artificial aged samples are investigated by 2 and 4 MHz sensors.
Good correlations between ultrasound velocity and age of solid propellants were found. These relations could be used as an additional information for prognosis for age life.

Keywords: Ultrasonic Pulse Echo; Rocket Propellants

Introduction

Solid propellant systems for rockets are designed to function within naпow performance boundaries, sometimes after several times extended shelf life. In order to guarantee these performances we must be abe to predict their performance during age, as well as determine their residual life span after the system has been subject to handling and storage under varying conditions which are not always fully recorded.
Service life assessment begins in the development phase and monitoring programs must be developed and implemented during the life span of the system.
The two interacting iteratively paths to produce current service life estimates are used [4]. One path is analytical which assesses the rate of material aging, the effect of material aging on the system (i.e., stability, performance, integrity, etc.) and the statistical probability of system failure during service life. The second path is one of system surveillance (monitoring) which includes system observation and system trend analysis. As a result, the service life estimate may predict a minimum service life (safe interval) that will likely be extended on testing at a later period. All aspects of service life issues for solid rocket motor will be addressed including chemical and physical aging mechanisms, methodology and techniques for determining service life, application of the service life methodology and techniques to systems and non-destructive test methods. For these paths NATO is developing system of standards [5]. Unfortunately,

nevertheless of the approach used most of the tools provided information for these paths are destructive ones.
Generally, NDT methods are powerful tool for many industry areas, but due to their inherent limitations and complementary nature of different types, many of them need to be applied depending on their suitability as a service life estimation tool [2].
For inspection at various stages of its production and service life of the rocket motors for instance:

- NDT methods such as radiography, ultrasonic testing and dye-penetrant testing are being employed for the inspection of hardware,
- ultrasonic testing is applied for checking the bond-line integrity of case and insulation layer and
- X-ray radiography is employed for evaluating both the integrity of propellant mass and the bond-line integrity of propellant and insulation.

Proposed ultrasound technique

In this article ultrasound technique, based on different propagation velocities for different aged samples, is proposed. The velocity difference for similar other conditions is due to different absorbtion and dissipation of ultrasound waves.
In every case ultrasound waves attenuation (due to impedance, absorption, etc.) is hardly to express precisely [4]. For the absorbtion α on the macro-level is valid the following [3]:

$$\alpha = \frac{\omega^2}{2\rho_0 V_i^2}\left[\eta + \left(\frac{\Delta\lambda}{\lambda + 2\mu}\right)\frac{K}{C_V}\right] \tag{1}$$

where:
$\Delta\lambda$ – the difference between isothermal and adiabatic Lame coefficients;
C_V – specific heat;
V_i – velocity of ultrasound wave;
ω – frequency.
For thermoelastic losses, similarly to (1) we can write:

$$\alpha = \frac{1}{2V}.\frac{\Delta c}{c_0}.\frac{\omega^2.\tau_{th}}{1+\omega^2.\tau_{th}^2} \tag{2}$$

where:
$\tau_{mx} = \frac{K}{C_P V^2}$
C_P – thermal capacity for constant pressure in volume.
Therefore:

$$\alpha = \frac{\gamma_G^2 C_V T}{2\rho V^3}.\frac{\omega^2.\tau_{th}}{1+\omega^2.\tau_{th}^2} \tag{3}$$

where:
$\gamma_G = \frac{3\beta K}{C_V}$ – Gruneisen constant;
β – linear extension constant.
The viscosity corresponds to the so-called loss of Akhieser and is the result of a detailed calculation of the "phonon-phonon". The detailed calculations were performed in [14].

Here, the final equation is presented:

$$\frac{\alpha}{f^2} = R\overline{\gamma}_G^{-2} \tag{4}$$

where:

$\overline{\gamma}_G$ – modified Gruneisen constant;

$$R \infty \frac{K_{\Theta_D}}{M\Theta_D^4 V_0^{2/3}} \tag{4a}$$

where:

K_{Θ_D} – thermal conductivity coefficient for Debye temerature Θ_D;

M – molecular weight;

V_0 – molecular volume.

The dissipation of ultrasound is depend mainly from different defects and reliable theory exist for materials with crystal lattice.

In this work this is not a case – similarly like [3, 13], here we use absolute or relative velocity variations.

Experimentation and Results

For experimentation three groups of samples are used. All the samples are originated from 40-year rocket propellants, that are articially aged for 8 months, 3 years and 10 years (Table 1). The aging program used is according AOP-48 Ed. 2 [1]. Obviously, there are an infinite number of temperatures that can be used for accelerating the aging process. It would be nice to say that the temperature selected was based on some highly quantifiable and/or scientific basis. The reality is that the temperature used is based on two very non-scientific reasons:

- the time available to conduct the ageing and,
- available funding.

The samples are finished to provide paralelism and roughness R_a<6.3 μm.

The classic contact ultrasound technique is used based on time of transit of a longitudinal ultrasound wave through the testpiece from the entrance point at the transducer to the exit point at the transducer. The 2MHz and 4MHz transducers are used.

The results showed that dependence between ultrasound waves velocity and age of samples exist.

This dependence is more clear for 4 MHz, that could be expressed with the relation of the sensitivity of the method with the frequency [2].

Table 1 Description of the samples groups

Samples groups	Samples age	Expected life spans	Average sample height, mm	Velocity of ultrasound wave	
				2 MHz	4 MHz
Samples group 1	40,7 years	9,3 years	11,713	1949,9	2041,1
Samples group 2	43 years	7 years	11,72	1945,2	2032,9
Samples group 3	50 years	none	11,727	1912,5	2002,9

With Table Curve 2D the following dependencies have been obtained between the service life and the ultrasound wave propagation rates (Fig. 1.):

$$y^2 = a + bx^3, \quad (5)$$

$$y^2 = a + bx^{2,5}, \quad (6)$$

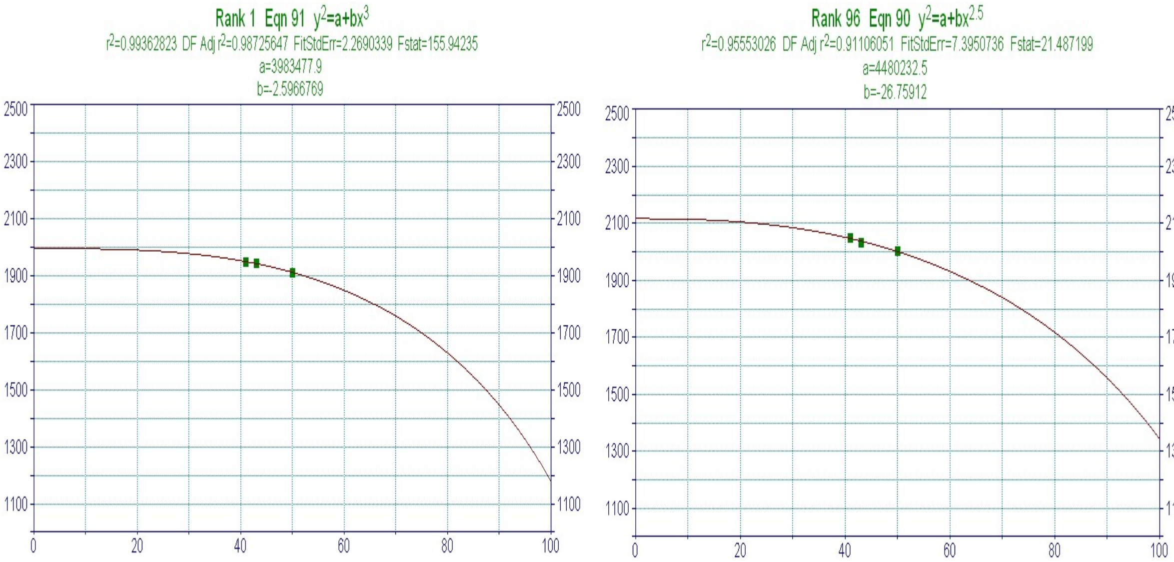

Fig. 1. Dependencies between the service life and the ultrasound wave propagation rates

The proposed these that the greater attenuation in samples with longer service life is proofed on the micro-level with the electronic scaning technique.
For longer serviced samples (43 and 50 years) the more structural changes are found – micro and macro cracks, rounding and sharpening due to stabilizer and binders depletion and mechanical and temperature stresses during service life.

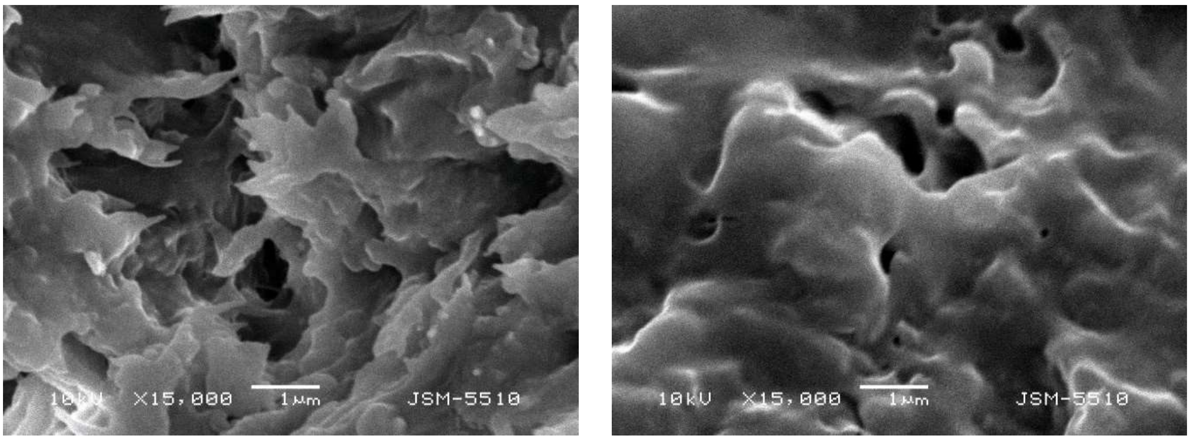

Fig. 2. "Sharpening" and "rounding"

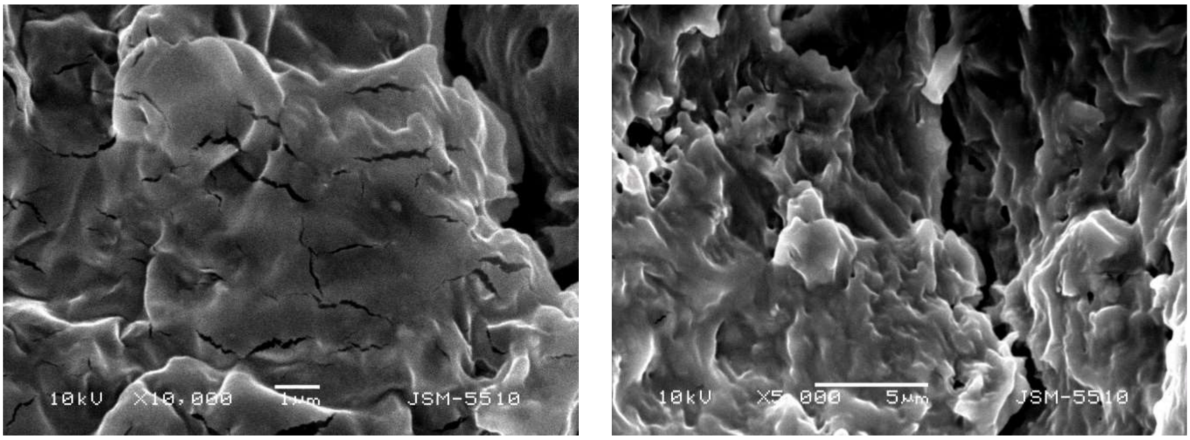

Fig. 3. Micro and macro cracks

Conclusion

The ultrasound technique is proposed as an additional tool in existing system of standards for service life qualification of rocket propellants. The method is partially proof for propellants include nitrate esters on micro level by electronic scaning microscopy. The future verification within the framework of more complex program is needed to develop the method to tool for prognosis of residual service life of explosives elements.

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