Central European Journal of Energetic Materials, **2011**, *8*(4), 223-231
ISSN 1733-7178

Analysis of Uniaxial Tensile Tests for Homogeneous Solid Propellants under Various Loading Conditions

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Abstract: The main object of this paper is to reveal basic response of solid rocket fuels to different working conditions such as variable strain rates or temperature. Experimental data acquired during experimental tests is a base for development of a suitable constitutive model for homogeneous solid propellants. In the world literature there is still insufficient information about typical mechanical features for considered materials. Universal standards for carrying out typical strength experiments have not yet been fully elaborated for this type of materials. Such problems as quasi-static strain range for solid propellants or so called scale effect are still not standardized. Though, this paper is a next step in preliminary investigation devoted to modeling of nonlinear properties of solid propellants. In particular, the influence of temperature and strain rate on selected mechanical parameters variations is discussed.

Keywords: solid propellants, experimental results, temperature, strain rate

Introduction

Solid propellants are basically used to produce an appropriate pressure and temperature combustion products in a rocket motor. Rocket fuels are composed of special energetic materials. Their combustion process is generally complex, mainly due to physicochemical changes from solid state to gas and liquid, including exothermic rapid reactions.

This particular work concerns analysis of experimental results of uniaxial tensile tests carried out on homogeneous solid propellants. The main aim of this paper is to reveal a complex behaviour of a selected group of solid rocket fuels related to various loading conditions. In experimental part different strain rates were applied to prove the viscoplastic type behaviour of tested materials. Moreover, solid propellants behave differently to classic viscoplastic materials such as some metals or plastomers. This statement is confirmed in the section related to analysis of some mechanical properties variations in a temperature or strain rate functions.

In the world literature there is still insufficient information about particular properties or physico-mechanical parameters of solid rocket fuels. Standard experimental methodology related to solid propellants [1-3] is mainly devoted to a temporary analysis of the surface conditions of analyzed testing specimens. Moreover, it is quite expensive and does not provide a complex information about real condition of material structure. Such a situation is obvious according to lack of published experimental results. Evaluation of so called scale effect seems to be particularly interesting. Being able to evaluate global physical and mechanical properties basing only on relatively small testing samples is principally important according to economic aspect. The next challenge is to define clear relations between mechanical properties of solid propellants and their ballistic features.

In this paper the authors would like to present some experimental results of uniaxial loading of homogeneous solid propellants. Different temperatures, strictly related to real operational conditions, are taken into consideration. Additionally, various strain rates are examined. Acquired experimental results underline a very complex behaviour of tested materials.

Experiments

The solid propellants investigated in this paper, as it was previously mentioned, belong to the group of so called homogeneous solid rocket fuels. Their main compound is nitrocellulose (NC). NC is quite a rigid material, which makes it inconvenient for direct applications. To improve the exploitation properties of NC, different types of modifiers are admixed. They are mainly plasticizers, stabilizers or combustion modifying agents such as nitroglycerin, diphenylamine or dinitrotoluen.

Solid propellants investigated in this paper differ one from the other mainly by NC and nitroglycerin (NG) contents. Agat material consisted of 55% NC, 33% NG and 12% modifiers (Centralit and DNT). Bazalt 2a was made of 58% NC, 37% NG, Pb_3O_4, nickel oxide, vaseline and graphite. Szafir is a composition of NC (58%), NG (40%), Centralit + petroleum jelly.

Individual modifications of the microstructure of solid propellants influence on their global mechanical properties. Evidently, they also cause important differences in combustion processes. Throwing materials should guarantee a possibly long operational use period and reliability.

The scheme and picture of testing pieces taken into consideration in experimental probes are illustrated in Figures 1 and 2.

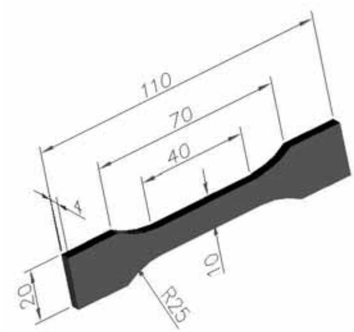


Figure 1. Main dimensions of the testing piece.

Figure 2. Illustration of the homogeneous solid propellant specimen.

Uniaxial tensile probes were conducted on a classical tensile testing machine *Instron 4500* (Figure 3). It was additionally equipped with a thermal chamber, enabling applying optional thermal loading conditions to the testing sample.

Figure 3. Instron 4500 – universal tensile testing machine with a thermal chamber.

The temperature influence on plastic behaviour of homogeneous solid propellants is quite a complex problem. Some remarks related to this problem can be found in papers [4-6], where authors focused only on the shape of experimentally obtained hardening curves for various temperatures. Concluding remarks in papers mentioned previously showed that temperature is a very important parameter, necessary to be taken into consideration during developing a suitable constitutive model for this group of materials. This paper is a next stage of investigation of temperature impact on the selected strength parameters.

Uniaxial tensile probes were conducted at temperatures: T_i = 238, 294 and 313 K. Selected range of temperatures is strictly related to the Polish military standards (for example NO-91-A523-1 or NO-91-A523-2). Additionally, various strain rates have been applied: $\dot{\varepsilon}_i$ = 0.00018; 0.00185; 0.0185 and 0.075 1/s. It corresponds to an elongation of the sample by 0.5; 5, 50 and 200 [mm] per minute. The impact of a strain rate on experimental hardening curves character is very significant.

Typical experimental results are depicted in Figures 4-6.

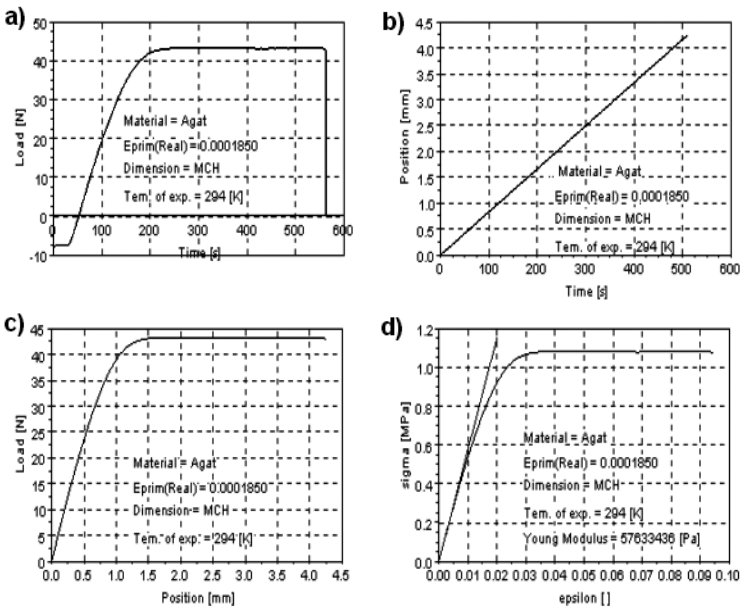


Figure 4. Experimental results for AGAT solid propellant, $\acute{\varepsilon}$ = 0.000185 [1/s], T = 294 [K] – the whole set of results (a - direct experimental data for loading force-displacement, b - displacement-time diagram, c - modified load vs. position diagram, d - total stress-strain characteristic).

It is worth mentioning that three experimental series of each experiment were conducted (Figure 5) to eliminate possible gross error.

In Figure 5 also the average value of Young modulus is depicted. It was calculated basing on three separate results of uniaxial loading.

It is worth emphasizing that scatter of typical experimental results is much more observable for higher values of temperatures and higher strain rates. This phenomenon is depicted in Figure 6.

Although mentioned problems are very important, they will be omitted in this paper, due to their complexity.

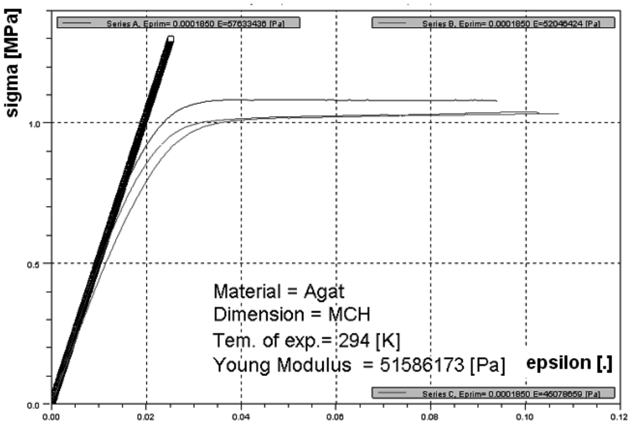


Figure 5. Experimental results for AGAT sample: three experimental series; έ = 0.000185 [1/s], T = 294 [K], E = 51586173 [Pa].

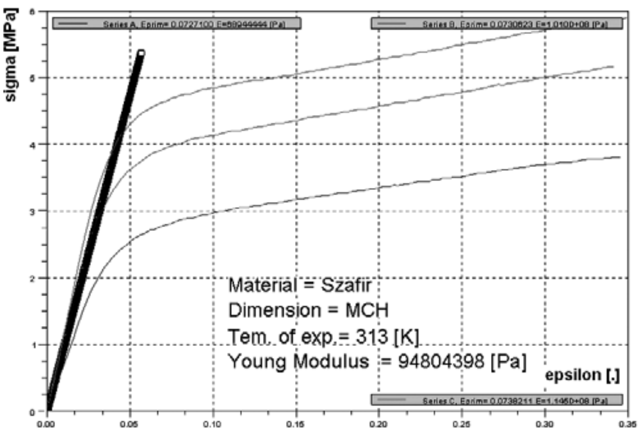


Figure 6. Experimental results for SZAFIR sample: three experimental series; έ = 0.075 [1/s], T = 313 [K], E = 94804398 [Pa].

Analysis of experimental results

Strain rate influence

To fully understand the influence of the strain rate value on the character of homogeneous solid propellant uniaxial loading curve, the comparison of exemplary experimental results is depicted in Figure 7.

It is clear that the strain rate influences a lot the global response of solid propellants samples. The higher strain rate generates higher position of related hardening curve. It is particularly interesting that for $\dot{\varepsilon}_1$ 0.075 1/s, stress values in a plastic part of stress-strain curves are more than two times higher than for the lowest value of applied strain rate ($\dot{\varepsilon}_2$ 0.00018 1/s). Such a behaviour of tested material exhibits typical features of viscoplastic bodies.

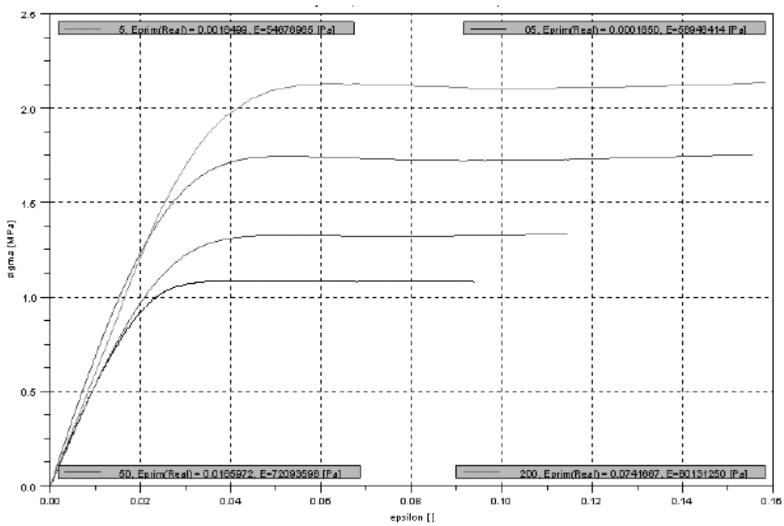


Figure 7. The impact of a strain rate on "Agat" homogeneous solid rocket fuel samples.

Analysis of the strain rate influence leads to the following open questions:

- is the Young modulus parameter a function of the strain rate?
- does the higher strain rate influences on the breaking stress and strain values?

To find answers to the questions formulated above, it is convenient to perform supplementary diagrams (Figure 8).

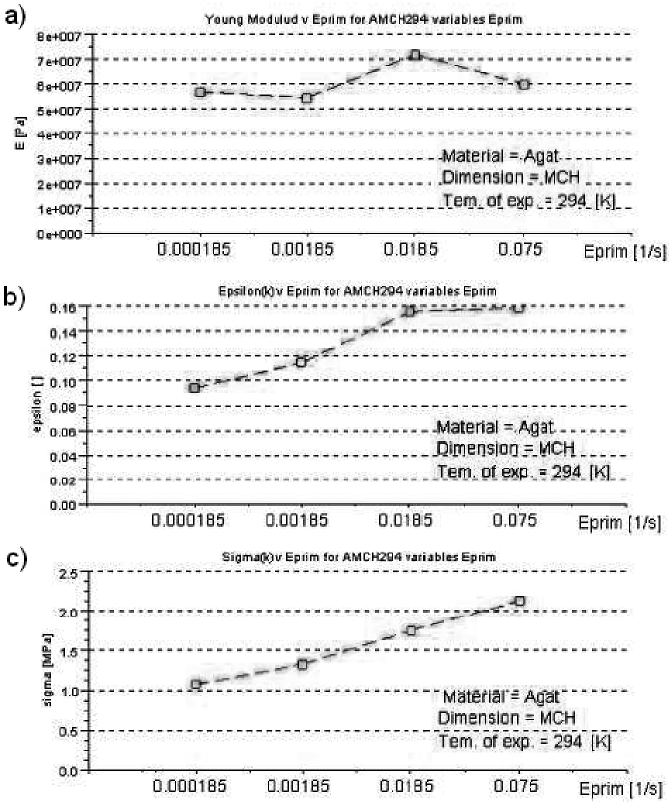


Figure 8. The influence of a strain rate on selected mechanical parameters of solid propellants.

Typical viscoplastic materials such as metals or plastomers do not exhibit an impact of a strain rate on Young modulus values. Basing on data depicted in Figure 8a we cannot clearly evaluate the impact of the strain rate on Young modulus values of tested solid propellants. To define a reliable characteristic $E = f(\dot{\varepsilon})$ much more experiments have to be carried out.

It has been observed that both parameters: breaking stress and strain (Figures 8b and 8c) have a tendency to rise for higher values of applied strain rate.

Temperature influence

In Figure 9 the influence of temperature on typical hardening curves of solid propellants is depicted.

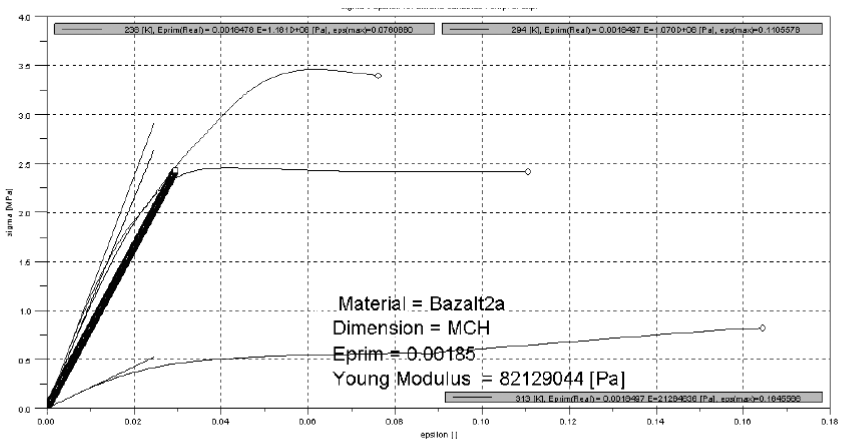
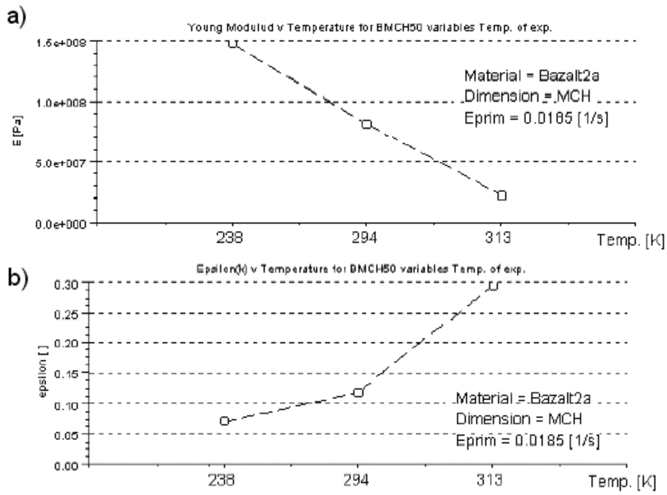


Figure 9. The impact of temperature on homogeneous solid rocket fuel specimens.

Higher temperature causes the decrease of corresponding stress hardening curves (Figure 9). Additionally, it has been noticed that tested homogeneous solid rocket fuels tend to decrease Young modulus values for higher temperature (Figure 10a). Such a phenomenon is not recognizable for classical structural materials.

Like most viscoplastic materials, solid propellants have a tendency to increase the breaking strain and, at the same time, decrease the breaking stress for higher values of temperatures (Figures 10b, c).



c)

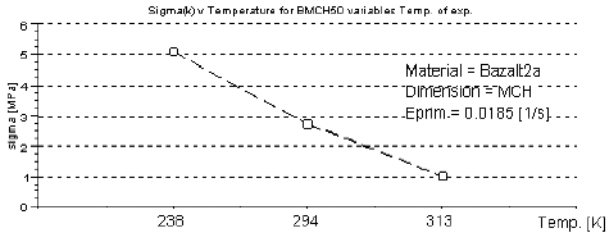


Figure 10. The influence of temperature on selected mechanical parameters of solid propellants.

Conclusions

In this paper typically experimental results of uniaxial tensile tests, carried out on samples made of homogeneous solid rocket fuels, are presented. Various strain rates and temperatures were taken into consideration.

Detailed description of a strain rate and temperature influence on selected mechanical parameters such as Young modulus, breaking stress and strain has been presented. Obtained characteristics have to be treated with care. To define more reliable characteristics, numerous additional experiments have to be conducted.

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