Thermomechanical Analysis of ERTALON 4.6 Polyamide Used in High Thermal Shock Systems

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The paper presents an analysis regarding the use of ERTALON 4.6 polyamide in high thermal shock systems. The behavior of ERTALON 4.6 polyamide mounted on high thermal shock systems was studied using high speed thermal imaging cameras. In the same time its mechanical proprieties were studied with the purpose to determine if it can withstand the stresses that occur during rifle firings.

Keywords: polyamide, thermomechanical analysis, thermal shock, high speed process.

The purpose of this paper is to present an analysis from thermal and mechanical point of view for the use of ERTALON 4.6 polyamide in high thermal shock systems such as combustion of the propellant in a barrel of a rifle.

Firing of a rifle is a very high-speed phenomenon both from mechanical and thermal point of view. The total time of the firing process from pulling the trigger to the projectile coming out from the barrel takes about 0.1s.

During firing phenomena, due to the combustion of the propellant, large amount of heat is generated and some part of this heat is transferred to the barrel or the rifle [1]. In rifle barrels, heat transfer phenomena take the following forms according to Kolkert [2]:

- convection during the combustion of the propellant and the travel of the bullet in the barrel, within a fraction of seconds;
- conduction and radiation from the hot gases to the barrel;
- dissipation of heat in the barrel's wall;
- heat transfer from the barrel to the other parts of the rifle and the surrounding environment.

Taking into account these considerations, the material for the front support of the rifle (fore grip), mounted on the barrel of the rifle, must assure the safety of the shooter regarding the temperatures that occur during firing. Also, this material must have the mechanical proprieties to withstand to forces generated during firing because some accessories (scopes, laser modules, etc.) are mounted on the rifle barrel with the help of this grip. Other materials were taken into prior consideration [3, 4, 9] but the results obtained during simulation did not satisfy this particular case.

Due to the specific weight, mechanical and thermal proprieties, ERTALON 4.6 polyamide has been studied.

Experimental part

Materials and methods

ERTALON 4.6 is a polyamide made by Quadrant Engineering Plastic Products that features a high retention of stiffness and creep resistance over a wide range of temperatures and also a high aging resistance [5]. Therefore, according to the manufacturer, ERTALON 4.6 applications are in products used in high temperature processes (80-150^{o}C) where stiffness, creep resistance, heat aging resistance, fatigue strength and wear resistance characteristics of others polyamides are not so good.

Table 1
TECHNICAL PROPRIETIES OF ERTALON 4.6 POLYAMIDE [5]

Proprieties	**Value**
Colour	reddish brown
Density	1.19 g/cm^2
Thermal proprieties	
Melting temperature	290 ^{o}C
Thermal conductivity at 23^{o}C	0.3 $W/_{K \cdot m}$
Coefficient of linear thermal expansion	
- average value between 23 – 60 ^{o}C	80x10^{-6} $m/_{m \cdot K}$
- average value between 23 – 100 ^{o}C	90x10^{-6} $m/_{m \cdot K}$
Temperature of deflection under load	160 ^{o}C
Maximum allowable service temperature in air:	
- for short periods	200 ^{o}C
- continuously 5.000 / 20.000 h	150 / 130 ^{o}C
Minimum service temperature	-40 ^{o}C
Mechanical proprieties at 23 ^{o}C	

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Tensile strength	105 MPa
Tensile strength at break	25%
Tensile modulus of elasticity	3.400 MPa
Compression:	
- compressive stress at 1 / 2 / 5 % nominal strain	31 / 60 / 102 MPa
Chappy impact strength – unnotched	No break
Chappy impact strength – notched	8 kJ/m^2
Ball indentation hardness	165 N/mm^2
Rockwell hardness	M92

In his studies, Kolkert has treated the problem of one-dimensional heat conduction model for a single shot. Continuing its work, Akcay and Yukselen studied one-dimensional unsteady heat transfer during sustained firing.

Seiler studied, theoretically and experimentally, the action of the hot and highly compressed propellant gas flow on the heat transfer to the inner barrel surface of a powder gun for rapid fire [6].

The heat conduction equation over the barrel assembly is [7]:

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T \tag{1}$$

where:
- T – temperature;
- α – thermal diffusivity for the material.

According to I. Marinescu, S. Verboncu, 28 – 30% of the energy resulted from the combustion of the propellant is used for the movement of the bullet in the barrel. 10% of the combustion energy (E_{ω}) is used for heating the barrel [8].

After shooting the first round, the temperature of the barrel will increase with a following relation [8]:

$$\Delta t = \frac{Q_t}{c \cdot G} = \frac{e_t}{e_0} \cdot \frac{E_0}{427 \cdot c \cdot G} \tag{2}$$

where:
- Q_t – mechanical equivalent of the heat;
- c – thermal conductibility coefficient;
- G – barrel weight;
- e_t – the energy that heats the barrel;
- e_0 – the energy consumed for the movement of the bullet in the barrel;
- E_0 – kinetic energy of the bullet.

From the above equation results that after shooting the first round, the barrel temperature increases with approximately [6]:

$$\Delta t = (1.5 \div 1.8)^0\ C \tag{3}$$

The heat conduction model of barrel rifle for single shot can be simplified as a semi-infinite plate. On the inside wall there is a large temperature gradient and on the outside wall the temperature has small changes [7].

There is large temperature difference between the inside and outside wall of the rifle barrel. Increasing the number of rounds fired, the heat spreads constantly in the barrel [10].

Experimental setup

For the study the rifle barrel heating during firing, thermal measurements were made by filming the firings with a high-speed thermal camera. The rifle was fixed on a bench and the five full auto rounds were fired. The fore grip made from ERTALON 4.6 polyamide was mounted on the rifle. Six measurement points were defined like in figure 4.

The thermal camera used for filming the barrel of the rifle during firings FLIR SC4000 with a 13 mm focal lens. The firings were filmed using different temperature range calibration for the camera and at a speed of 200 fps.

The initial temperatures distribution on the rifle is presented in figure 1. In figure 2, the firing process can be seen (hot gases coming out from the barrel).

Fig. 1. Initial temperatures on the rifle before firings

Fig. 2. The hot gases coming out of the barrel behind the projectile

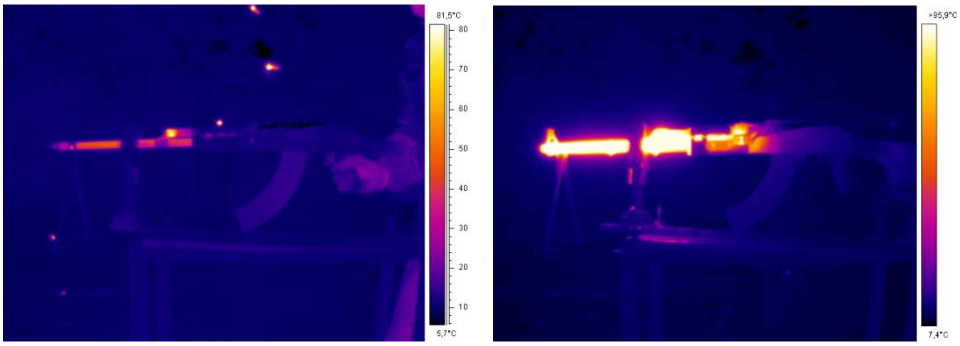

Fig. 3. Barrel heating during firing (left) and after 5 rounds (right)

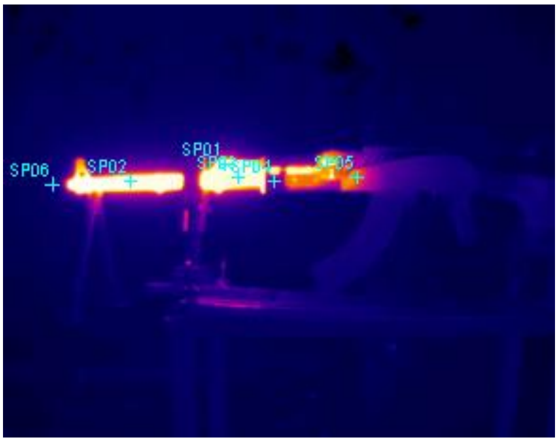

Fig. 4. The temperature measuring points

The measurement points used for the analysis are:
SP01 – the gas port; SP02 – the front part of the barrel;
SP03 – the rear part of the barrel;
SP04 – the fore grip made form ERTALON 4.6 polyamide;
SP05 –the body of the rifle; SP06 – in front of the barrel
to view the hot gases and to count the shots.

Results and discussions

Analyzing the results obtained during the firing of the 5 rounds with the software of the camera, the following curves for the temperature in the measuring points are presented in figure 5. As it can be seen, after firing 5 rounds, the temperature on the fore grip made from ERTALON 4.6 polyamide (point 4) is smaller the temperature on the rifle body (point 5) although the fore grip is mounted on the barrel, being closer to the heat source (the rifle of the barrel in this case).

After firing 5 rounds, the variation of temperature on the fore grip made from ERTALON 4.6 polyamide is small (up to 16.69°C) although the temperature of the rifle barrel rises from to 15.381°C to 41.38°C in the front part of the barrel and from 17.011°C to 40.024°C in the rear part of the barrel.

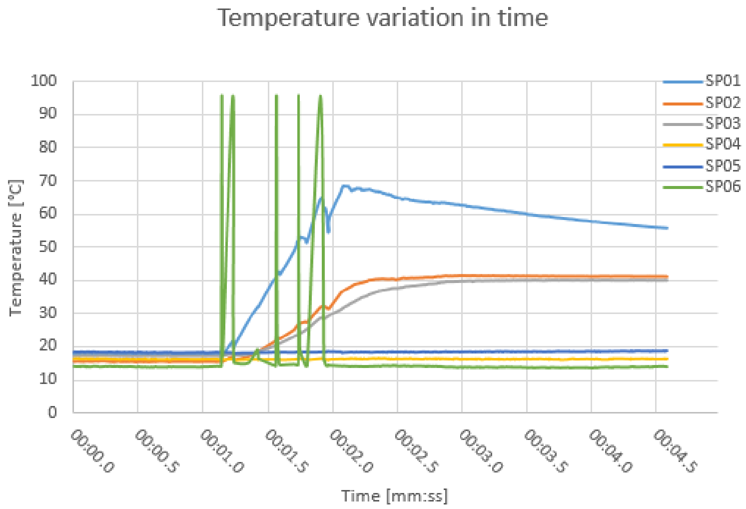

Fig. 5. The variation of temperature of the measuring points during firing of the five rounds

In order to better analyse the behaviour of ERTALON 4.6 polyamide in high thermal shock, two hundred rounds were fired in full auto mode and the firing were filmed with FLIR SC4000 thermal camera at 25 fps.

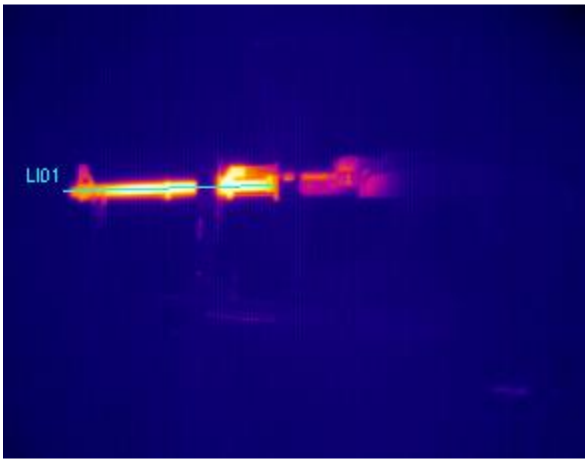

Fig. 6. Temperatures on the rifle after firing 200 rounds in full auto mode

For measuring the temperatures on the barrel of the rifle after firing 200 rounds in full auto mode, line 1 was defines like in the figure 6. The temperature on line 1 is presented in figure 7. The maximum temperature reached is 286.13°C and the temperature is almost constant along the rifle barrel. The drop in the middle of the curve, which can be seen in figure 7, is due to the fixture of the rifle on the measuring bench.

The temperature variation on the fore grip made from ERTALON 4.6 polyamide comparing with the temperature on the body of the rifle (mechanism case) is presented in figure 8.

As it can be seen in figure 8, the temperature on the fore grip made from ERTALON 4.6 polyamide is much lower than the temperature on the body of the rifle (mechanism case). The maximum temperature on the fore grip is 27.7°C and on the body of the rifle is 68.55°C.

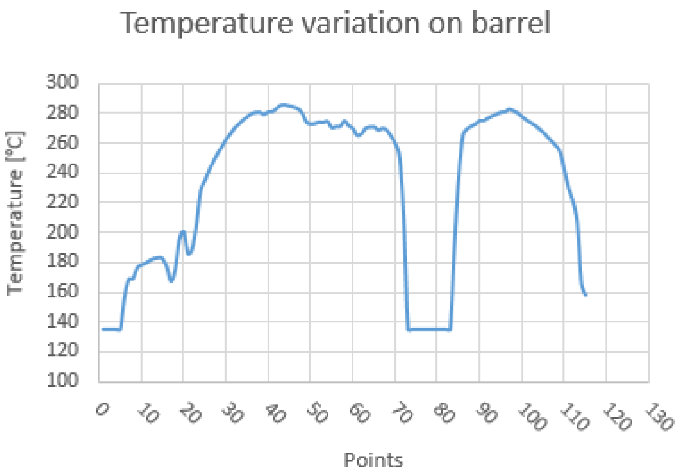

Fig. 7. Temperature on the rifle barrel after 200 rounds in full auto mode

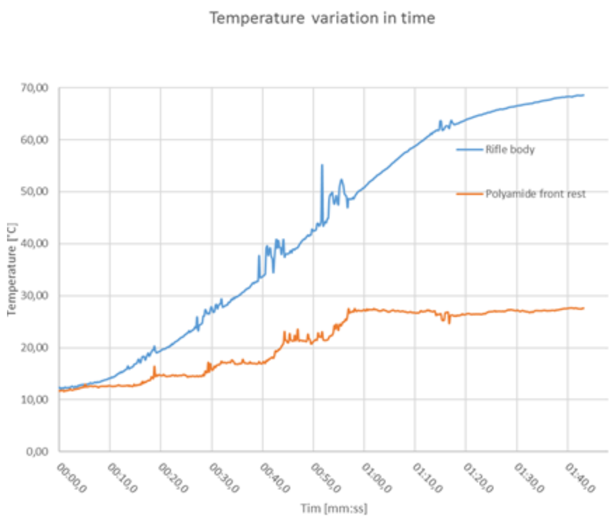

Fig. 8. Temperature on the fore grip and on the rifle body

Conclusions

As it can be seen from the results obtained during firings with rifles having mounted the grip specially made from ERTALON 4.6 polyamide it can be concluded that this material offers a very good solution assuring the safety of the shooter regarding the heat transfer from the rifle barrel to the shooter's hands. The temperature of the barrel may reach temperatures up to 300^{o}C during firing.

Also, analyzing the ERTALON 4.6 polyamide's mechanical proprieties and the firings, it can be concluded that ERTALON 4.6 polyamide has the ability to withstand the stresses resulted during firings. Also, ERTALON 4.6 polyamide is a material that can be processed on cutting machines in the same manner as a metal.

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