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EXPERIMENTAL AND FINITE ELEMENT ANALYSIS OF COMPOSITE GUN BARRELS

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Abstract: *In this work experimental and numerical investigation of composite gun barrels was studied. The history of the stress-induced deformations located at the center of gun barrels on the outer surface generated by impact loading was measured for six types of barrels. The obtained signals were subsequently evaluated using wavelet transformation. Finally, the finite element analysis in Abaqus and MARC software for optimum composite material M46J was performed.*

Keywords: composite gun barrels, contact-impact analysis, drop weight tester, air cannon

1. Introduction

The accuracy of gun barrels is one of the main indicators of their quality. A shot dispersion of a general firearm is greatly influenced by the barrel vibration during the firing process. An improvement of the accuracy can be achieved by increasing the rigidity of the barrel, see, e.g., (Katz, 2006), or using modern materials such as composites instead of conventional steel materials, see, e.g., (Ting, 1996). In this work, an experimental and computational assessment of different types of composite gun barrels subjected to impact loading was performed.

2. Experimental analysis

The experimental analysis involved six composites gun barrels. The barrels had the length $L = 660\,\mathrm{mm}$ and the outer diameter $d_2 = 29.1 \div 30.6\,\mathrm{mm}$ depending on the type of winding. The composite barrels winding comprises 14 or 16 layers on the steel tube with the outer diameter $12\,\mathrm{mm}$ and wall thickness $2\,\mathrm{mm}$. The history of the stress-induced deformations was captured by semiconductor strain gauges located at the center of gun barrels on the outer surface. The individual types of gun barrels have been identified by the manufacturer as follows: $XN60\_bend$, $XN60\_radial$, $XN80\_bend$, $XN80\_radial$, $XN90\_bend$, and $M46J$. The dynamic load applied on the forehead of barrel was realized in two ways:

- using a "drop weight tester" which enabled to measure the history of the generated impact force on the front of the composite barrel (task 1)
- using an "air cannon" with known muzzle velocity of the projectile (roller) (task 2)

and thus measure the deformation induced at the site under consideration. From the semiconductor strain gauges used in the measurement, voltage waveforms were obtained. The precise evaluation of the structural design of the individual composite windings was evaluated for these voltage waveforms, from which the axial strain distributions were subsequently determined.

Fig. 1 shows the measured waveforms on the steel core and composite barrel $M46J$, both driven by the drop weight tester. It can be seen that the speed of the longitudinal waves is higher in the composite material in comparison with steel.

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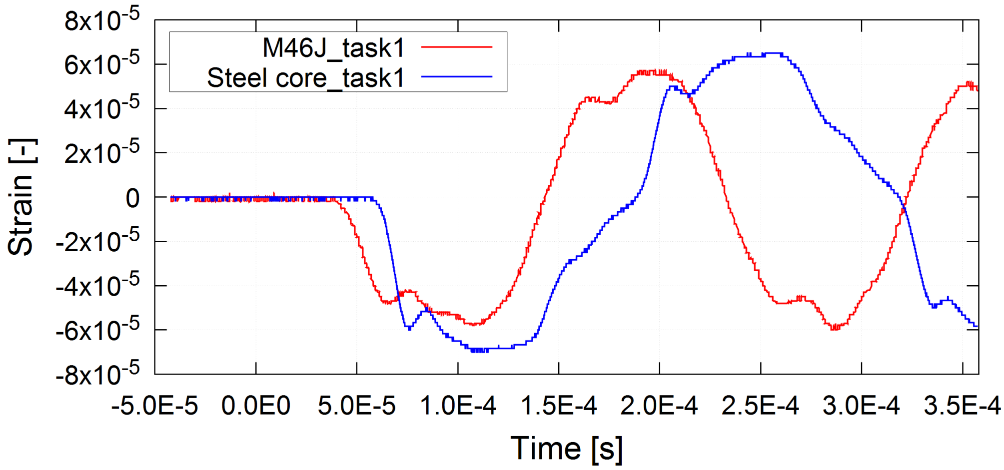

Fig. 1: Axial strain distributions generated by drop weight tester: steel core versus composite barrel M46J

After the measurement of time deformation distributions on the centre of composite barrels by semiconductor strain gauges, the evaluation of obtained signals was performed in order to find the optimal type of composite winding. Generally, the initial powder explosion followed by a pressure spike causes the barrel vibrations during firing. To optimize hitting the target, the bullet should exit when the barrel muzzle is at its least amount of motion and in the same place as it moves to the firing cycle. That presumes the timing the exit of the bullet with the most stable position of the harmonic shift of the barrel to obtain accurate repeatable results. According to those facts, a barrel with a better capability to dampen especially higher frequency vibrations is more stable and hence preferred. Such a barrel should be also more suitable for further "tuning" by changes of mounting technique or by using various harmonic dampeners.

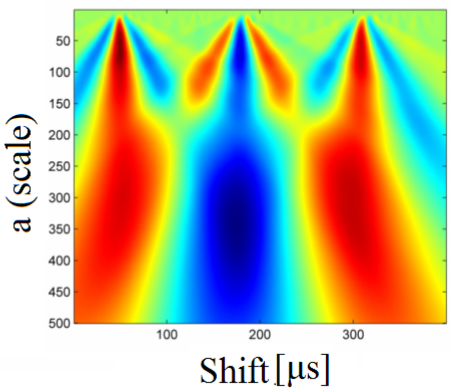

Fig. 2: Wavelet signal transformation measured on the steel core - task 2

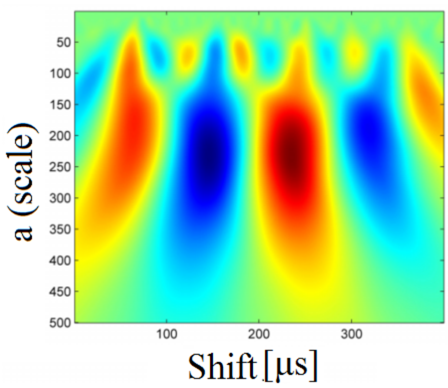

Fig. 3: Wavelet signal transformation measured on composite M46J - task 2

For illustration of signal time-frequency information, a spectrogram plot is commonly used. However, since it does not provide sufficient frequency resolution, especially when increasing the time precision using shorter time windows, it is more appropriate to apply the wavelet transform. The result is the matrix of correlation coefficients of the signal x(t) with translated (coefficient b) and dilated (coefficient a) short pulse ψ called wavelet

$$X_w(a,b) = \frac{1}{|a|^{1/2}} \int_{-\infty}^{\infty} x(t)\, \overline{\psi} \left(\frac{t-b}{a} \right) \mathrm{d}t \tag{1}$$

The wavelet analysis illustrates very well the time-frequency content of signals, especially the arrival of pulses of different time scales–see Fig. 2 and 3, where the dark colour grades highlight high correlations while red or blue colour represents opposite signal phases. It is possible to distinguish the individual peaks of the resonance frequencies and, above all, the strong detection of the wave packets (low frequency part illustrated by higher scale parameter values) reflecting off the barrel ends. In reference to the material dimensions, the time delay between the packets corresponds to the elastic wave velocity in appropriate environment (steel or composite). For comparison, the wavelet transform of signal measured on the steel core and M46J composite barrel is shown in Fig. 2 and Fig. 3, respectively. The M46J composite barrel differs from other variants by the speed of the longitudinal wave propagation. The advantage of this variant lies in a lower occurrence of high frequencies (see Fig. 3), which could affect the accuracy of hitting the target. Considering these benefits the M46J variant was further investigated computationally in the finite element software Abaqus and MARC.

3. Finite element analysis of composite gun barrels

The composite barrel M46J is schematically shown in Fig. 4. The inside diameter is $d_1 = 8\,\mathrm{mm}$, the outer diameter is $d_2 = 30.2\,\mathrm{mm}$ and the length is $L = 660\,\mathrm{mm}$.

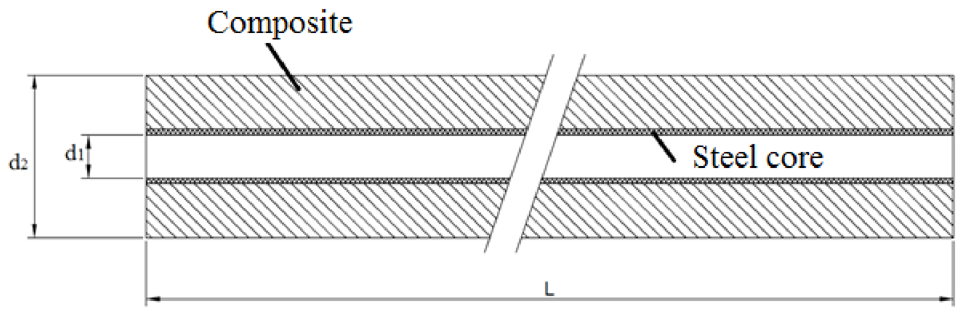

Fig. 4: Scheme of composite barrel M46J

As in the experiment, the following two loading modes were considered. First, the steel core was loaded by prescribed force taken from the experiment (task 1) and the second, head-on impact of the punch with prescribed velocity $14\mathrm{m/s}$ onto composite barrel was considered (task 2). The composite material is considered as linear orthotropic material defined by nine elastic constants E_x, E_y, E_z, G_{xy}, G_{yz}, G_{xz}, ν_{xy}, ν_{yz}, ν_{xz} and density ρ for each layer. The finite element analysis of composite barrel M46J was performed in the Abaqus and MARC software.

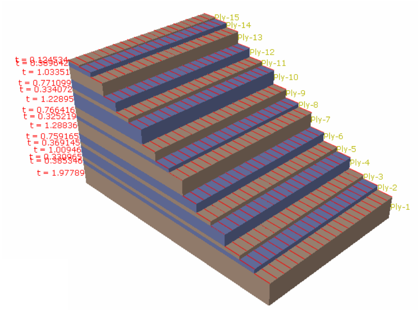

Fig. 5: Abaqus shell model

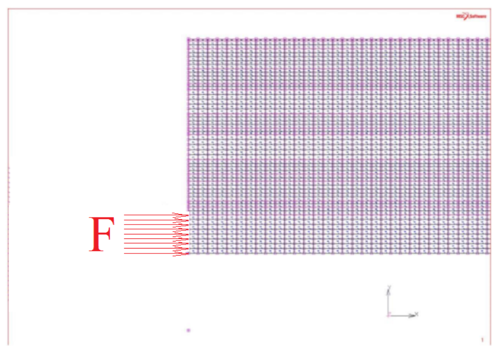

Fig. 6: Finite element mesh (MARC)

The Abaqus program offers the possibility to use the so-called shell model to analyze thin composite structures. The method is based on the definition of the individual layers of the composite barrel, which are subsequently assigned thicknesses and position in the global model (see Fig 5). The shell model in Abaqus consists of two shells (steel core and composite shell) connected together so that only the steel core can be excited by prescribed loading. The elements "S4R" (linear elements with reduced integration) were used. In MARC software the problem was treated as axisymmetric one modelled by regular mesh with type of elements "10" (quadrilateral isoparametric elements with a bilinear interpolation function)—see Fig 6. In both analyses, the central difference method was used for the integration of the equation of motion with the lumped mass matrix—see, e.g., (Kolman, 2013). The time step was automatically choosen in both programs: $\Delta t = 1{,}107\,73 \cdot 10^{-7}\,\mathrm{s}$ (Abaqus) and $\Delta t = 1{,}386 \cdot 10^{-8}\,\mathrm{s}$ (MARC).

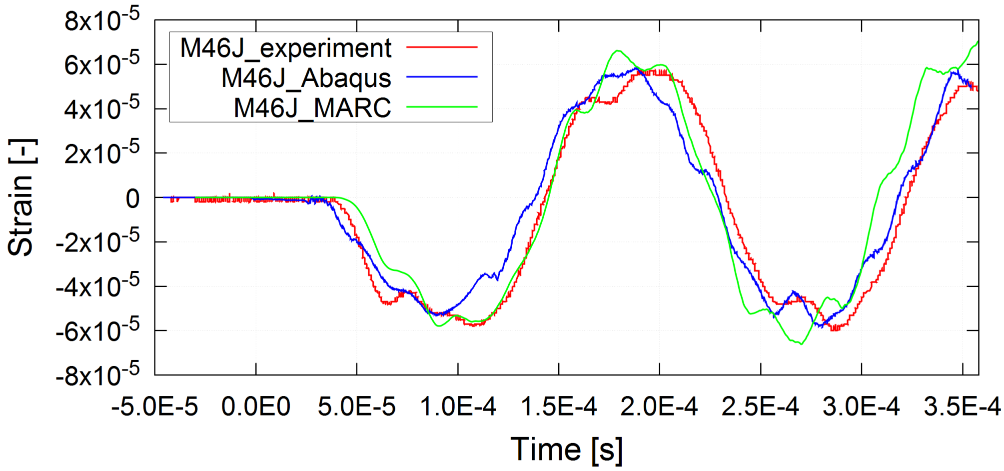

Fig. 7: Axial strain distributions in composite barrel M46J generated by drop weight tester: experiment versus finite element solution (Abaqus and MARC)

4. Conclusions

The aim of the work was to compare six composite gun hybrid barrels to assess their suitability for the design of the main weapon. In the first part, the time history of the deformations at the center of the composite barrel caused by the impact loading was experimentally determined. The impact loading was realized in two ways. The first one using drop weight tester (task 1) was perfectly repeatable, but the excitation of the high frequency components of the load force was difficult. In the second one using air gun punch (task 2), there was a problem with accurate repeatability of measurement. On the other hand, the excitation of high-frequency components of the loading force was possible. The spectral analysis and, above all, continuous wavelet transformation has proved significant differences in measured signals. These ones does not differ only in amplitude (independent of the speed of the exciter impact), but also with respect to the time-frequency content. As an optimal design solution, the composite barrel M46 was detected. The advantage of this variant is that there are not too high frequencies here, which could affect negatively the resulting accuracy of the firing. Finally, numerical simulations of composite barrel M46J were performed in the Abaqus and MARC finite element software. Quite a good agreement between results of both numerical analyses and experimental data was observed—see Fig. 7.

Acknowledgments

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