Mechanism of explosive formation of high-velocity elongated projectiles from steel segment lining

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The study focuses on the results of mathematical simulation of the explosively formed projectiles done with numerical methods of continuum mechanics. In this paper we consider some options for improving the projectiles efficacy and describe the results of computational experiments with various design parameters of the steel segment lining. Mathematical models of projectiles of two standard sizes were studied in two-dimensional and three-dimensional formulations. Findings of the research show that the best characteristics of the high-velocity elongated projectiles can be obtained by using the spherical-conic lining and the lining with a developed chamfer. The models with different physical and mechanical properties of the lining, in particular, demonstrate the mechanism of projectile forming from the lining with radial gradient ductility. The study substantiates the application of the elastoplastic deformation model and the failure criterion in the form of the Smirnov—Alyaev criterion.

Keywords*: explosively formed projectiles, numerical simulation, high-velocity elongated projectiles*

REFERENCES

[1] Kolpakov V.I. *Nauka i obrazovanie — Science and Education*, 2012, no. 2, pp. 31. Available at: http://old.technomag.edu.ru/doc/334177.html (accessed December 10, 2016).

[2] Kolpakov V.I., Bascacov V.D., Shikunov N.V. *Oboronnaya tekhnika — Enginery*, 2010, no. 1–2. pp. 82–89.

[3] Potapov I.V., Kolpakov V.I., Shikunov N.V., Yakimovich G.A. Matematicheskoe modelirovanie vzrivnogo formirovaniya stalnykh porazhayuschykh elementov [Mathematical modeling of explosive formation of steel projectiles]. *Shock Waves in Condensed Matter: Int. Conference*. Saint-Petersburg – Novgorod (Russia), 2010, pp. 184–188.

[4] Kolpakov V.I. Osobennosti deformirovaniya i razrusheniya udlinennykh porazhayuschykh elementov pri vzrivnom nagruzhenii kumulyativnykh oblitsovok [Features of deformation and destruction of elongated projectiles during explosive loading of shaped lining]. *Trudy mezhdunar. konf. "XIII Kharitonovskie tematicheskie nauchnye chteniya. Ekstremalnye sostoyaniya veschestva. Detonatsiya. Udarnye volny" (Sarov, 14–18 marta 2011 g.)* [Proc. Int. Conf. "XIII Kharitonov thematic scientific readings. Extreme states of matter. Detonation. Shock Waves" (Sarov, March 14–18, 2011)]. Sarov, RFNC–VNIIEF Publ., 2012, pp. 532–536.

[5] Kolpakov V.I. Analiz konstruktivnykh osobennostey zaryadov s nizkimi segmentnymi kumulyativnymi oblitsovkami iz tantalovykh splavov [Analysis of design features of charges with low segment shaped linings made of tantalum alloys]. *Trudy mezhdunar. konf. "XVII Kharitonovskie tematicheskie nauchnye chteniya. Ekstremalnye sostoyaniya veschestva. Detonatsiya. Udarnye volny". (Sarov, 23–27 marta 2015 g.)* [Proc. Int. Conf. "XVII Kharitonov thematic scientific readings. Extreme states of matter. Detonation. Shock Waves" (Sarov, March 23–27, 2015)]. Sarov, RFNC–VNIIEF Publ., 2012, pp. 288–290.

[6] Kolpakov V.I., Goryunov V.V. *Oboronnaya tekhnika — Enginery*, 2011, no. 2–3, pp. 30–34.

[7] Selivanov V.V., ed. *Boepripasy. V 2 tomakh. Tom 1* [Ammunition. In 2 vols. Vol. 1]. Moscow, BMSTU Publ., 2016, 506 p.

[8] Bender D., Chouk B., Fong R., Ng W., Rice B., Volkmann E. Explosively Formed Penetrators (EFP) with Canted Fins. *19th International Symposium on Ballistics (Interlaken, Switzerland, 7–11 May, 2001). Proc. in 3 vols.* 2001, vol. 2, pp. 755–762.

[9] Held M. The Shaped Charge Potential. *20th International Symposium of Ballistics (Orlando, FL, USA, 23–27 September, 2002)*. 2002, vol. 1, pp. 841–843.

[10] Orlenko L.P., ed., *Fizika vzryva. V 2 tomakh. Tom 2* [Physics of explosion. In 2 vols. Vol. 2]. Moscow, Fizmatlit Publ., 2002, 656 p.

[11] Liu J., Gu W., Lu M., Xu H., Wu S. Formation of explosively formed penetrator with fins and its flight characteristics. *Defense Technology*, 2014, no. 10, pp. 119–123. DOI: 10.1016/j.dt.2014.05.002

[12] Hussain G., Hameed A., Hetherington J.G., Malik A.Q., Sanaullah K. *Prikladnaya mekhanika i tekhnicheskaya fizika — Journal of Applied Mechanics and Technical Physics*, 2013, vol. 54, no. 1, pp. 13–24. https://link.springer.com/article/10.1134/S0021894413010021

[13] Pappu M., Murr L.E. Hydrocode and microstructural analysis of explosively formed penetrators. *Journal of Materials Science*, 2002, no. 37, pp. 233–248.

[14] Li W., Wang S., Chen K. *Prikladnaya mekhanika i tekhnicheskaya fizika — Journal of Applied Mechanics and Technical Physics*, 2016, vol. 57, no. 5, pp. 151–157.

[15] Hussain G., Hameed A., Hetherington J.G., Barton P.C., Malik A.Q. Hydrocode Simulation with Modified Johnson-Cook Model and Experimental Analysis of Explosively Formed Projectiles. *J. of Energetic Materials*, 2013, 31, vol. 2, pp. 143–155. DOI: 10.1080/07370652.2011.606453

[16] Mikhalev A.N., Podlaskin A.B. *Izvestiya RAN — Bulletin of the Russian Academy of Sciences*, 2009, no. 1(59), pp. 3–9.

[17] Mikhalev A.N. Formiruemye vzryvom snaryady: aerodinamicheskie svoystva i metodiki formirovaniya (obzor po dannym zarubezhnykh rabot) [Explosively fromed projectiles: aerodynamic properties and methods of formation (a review of the foreign works data)]. *Preprint of the Ioffe Institute*, 2004, 1775, 38 p.

[18] Mikhalev A.N., Podlaskin A.B. Issledovaniya obtekaniya i aerodinamiki udarnykh yader na ballisticheskoy ustanovke [Studies of the flow and aerodynamics of explosively formed penetrators on a ballistic installation]. *Fundamentalnye osnovy ballisticheskogo proektirovaniya: Sb. tr. Vseros. nauch.-tekhn. konf.* [Fundamentals of ballistic design: a collect. proc. all-Russ. sc. and tech. conf.]. St. Petersburg, 2011, vol. 1, pp. 100–108.

[19] Andreev S.G., Boyko M.M., Klimenko V.Yu. *Vestnik MGTU im. N.E. Baumana. Ser. Mashinostroenie — Herald of the Bauman Moscow State Technical University. Series Mechanical Engineering*, 2013, no. 2, pp. 108–126.

[20] Sokolov S.S., Sadovoy A.A., Chayka T.I. *VANT, ser. Matematicheskoe modelirovanie fizicheskikh protsessov — Voprosy Atomnoy Nauki i Tekhniki (VANT), series Mathematical Modeling of Physical Processes*, 2004, no. 3, pp. 54–61.

[21] Kruglov P.V., Bolotina I.A. *Inzhenerny zhurnal: nauka i innovatsii — Engineering Journal: Science and Innovation*, 2017, no. 9. Availble at: http://dx.doi.org/10.18698/2308-6033-2017-9-1674

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