# IMPACT SENSITIVITY OF ENERGETIC MATERIALS: ESTIMATION OF ENERGY TRANSFERRED TO THE SAMPLE

K. A. Monogarov[1], N. V. Muravyev[1], D. B. Meerov[1], I. V. Fomenkov[2], and A. N. Pivkina[1]

[1]N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation

[2]N. D. Zelinsky Institute of Organic Chemistry of the Russian Academy of Sciences, 47 Leniskiy Prosp., Moscow 119991, Russian Federation

**Abstract:** It is known that the impact sensitivity is not exclusively an internal property of the compound but depends on many factors determined by chemical and physical properties of the sample as well as the type of device and measurement conditions. Therefore, it is difficult to compare sensitivity data obtained on different devices and by various methods. Moreover, even when using the same type of devices but in different laboratories, the discrepancies can be significant. Based on the research carried out almost 90 years ago, the paper proposes a relatively simple but universal technique using a BAM-type device modified to measure the velocity of the falling and rebounding hammer. Combining the results of idle tests and tests with an energy material, the absolute values of energy transferred to the sample and absorbed by it at the impact energy level corresponding to the initiation threshold are obtained. The energy balance obtained during the tests shows the importance of timely maintenance of the device, because the amount of energy absorbed by the test device having even minor mechanical breakdowns can greatly increase in comparison with the proper condition. The proposed technique makes it possible to estimate the difference between the total energy of the load which is now generally accepted as a sensitivity characteristic and the real values of the energy transferred to the sample upon impact and absorbed by the sample. It is concluded that the obtained values of the energy absorbed by the sample at the initiation threshold are more relevant characteristics of the materials than the value of the total energy of the hammer corresponding to 50% of the probability of initiating a reaction in the sample.

**Keywords:** impact sensitivity; energetic material; BAM Fallhammer

**DOI:** 10.30826/CE23160210 **EDN:** OAYEPD

## Figure Captions

**Figure 1** The BAM-type device modified to determine the energy balance: *1* — column; *2* — round anvil; *3* — guide rails; *4* — falling hammer; *5* — test sample; *6* — assembly with sample; *7* — steel rollers; *8* — centering ring; *9* — small anvil; *10* — optical sensor; and *11* — shutter

**Figure 2** Dependence of the energy absorbed by the samples on the melting temperature (impact energy 10 J and sample weight 50 mg): *1* — literature data [12, 24]; and *2* — experimental data of this work

## Table Captions

**Table 1** Acceptable values of the coefficients $q$ and $k$ for the BAM Fallhammer device with a drop height $h = 0.2$ m [22]

**Table 2** Impact sensitivity of the tested compounds (recrystallized samples with a particle size of 0.5–1.0 mm): total impact energy $E_{50}$; energy transferred to the sample $E^*_{50}$; and energy absorbed by the sample $\hat{E}_{50}$

## References

1. Licht, H.-H. 2000. Performance and sensitivity of explosives. *Propell. Explos. Pyrot.* 25:126–132. doi: 10.1002/1521-4087.
2. Fried, L. E., M. R. Manaa, P. F. Pagoria, and R. L. Simpson. 2001. Design and synthesis of energetic materials. *Annu. Rev. Mater. Res.* 31:291–321. doi: 10.1146/annurev.matsci.31.1.291.
3. Zeman, S., and M. Jungová. 2016. Sensitivity and performance of energetic materials. *Propell. Explos. Pyrot.* 41:426–451. doi: 10.1002/prep.201500351.
4. Zhang, C. 2018. On the energy & safety contradiction of energetic materials and the strategy for developing low-sensitive high-energetic materials. *Hanneng Cailiao/Chinese J. Energetic Materials* 26:2–10. doi: 10.11943/j.issn.1006-9941.2018.01.001.
5. Muravyev, N. V., D. B. Meerov, K. A. Monogarov, I. N. Melnikov, E. K. Kosareva, L. L. Fershtat, A. B. Sheremetev, I. L. Dalinger, I. V. Fomenkov, and A. N. Pivkina. 2021. Sensitivity of energetic materials: Evidence of thermodynamic factor on a large array of CHNOFCl compounds. *Chem. Eng. J.* 421:129804. doi: 10.1016/j.cej.2021.129804.

6. Muravyev, N. V., D. R. Wozniak, and D. G. Piercey. 2022. Progress and performance of energetic materials: Open dataset, tool, and implications for synthesis. *J. Mater. Chem. A* 10:11054–11073. doi: 10.1039/D2TA01339H.
7. STANAG 4489. 1999. Explosives. Impact sensitivity tests. Brussels: NATO.
8. Simpson, L. R., and M. F. Foltz. 1995. LLNL small-scale drop-hammer impact sensitivity test. Department of Energy, Lawrence Livermore National Laboratory. LLNL Report UCRL-ID-119665. 30 p.
9. U.K. Manual of Tests. 1988. Sensitiveness Collaboration Committee (SCC No. 3).
10. GOST 4545-88. 1996. *Veshchestva vzryvchatye brizantnye. Metody opredeleniya kharakteristik chuvstvitel'nosti k treniyu pri udarnom sdvige* [High explosive materials. Methods for determining the characteristics of friction sensitivity during shock shear]. Moscow: Standardinform Publs. 15 p.
11. Bowden, F. P., and A. D. Yoffe. 1952. *Initiation and growth of explosion in liquids and solids*. Cambridge University Press. 104 p.
12. Afanas'ev, G. T., and V. K. Bobolev. 1968. *Initsiirovanie tverdykh vzryvchatykh veshchestv udarom* [Initiation of solid explosives by impact]. Moscow: Nauka. 172 p.
13. Mullenger, D. C. 1989. European impact sensitiveness assessment of solid energetic materials. *14th Pyrotechnics Seminar (International) Proceedings*. Jersey. Channel Islands, U.K. 293.
14. Coffey, C. S., and V. F. DeVost. 1995. Impact testing of explosives and propellants. *Propell. Explos. Pyrot.* 20:105–115. doi: 10.1002/prep.19950200302.
15. Zeman, S. 2007. Sensitivities of high energy compounds. *High energy density materials*. Ed. T. M. Klapötke. Berlin–Heidelberg: Springer. 195–271.
16. Dubovik, A. V. 2011. *Chuvstvitel'nost' tverdykh vzryvchatykh sistem k udaram* [Sensitivity of solid explosive systems to impacts]. Moscow: RHTU im. D. I. Mendeleeva. 276 p.
17. Marrs, F. W., V. W. Manner, A. C. Burch, J. D. Yeager, G. W. Brown, L. M. Kay, R. T. Buckley, C. M. Anderson-Cook, and M. J. Cawkwell. 2021. Sources of variation in drop-weight impact sensitivity testing of the explosive pentaerythritol tetranitrate. *Ind. Eng. Chem. Res.* 60:5024–5033. doi: 10.1021/acs.iecr.0c06294.
18. Lee, P. R. 1998. Hazard assessment of explosives and propellants. *Explosive effects and applications. High-pressure shock compression of condensed matter*. Eds. J. A. Zukas and W. Walters. New York, NY: Springer. 259–339.
19. Kondrikov, B. N. 1995. General regularities of explosion initiation in determining impact and friction sensitivity of an explosive. *Combust. Explo. Shock Waves* 31(2):198–206. doi: 10.1007/BF00755749.
20. Brown, G. W., M. M. Sandstrom, D. N. Preston, C. J. Pollard, K. F. Warner, D. N. Sorensen, D. L. Remmers, J. J. Phillips, T. J. Shelley, J. A. Reyes, P. C. Hsu, and J. G. Reynolds. 2015. Statistical analysis of an inter-laboratory comparison of small-scale safety and thermal testing of RDX. *Propell. Explos. Pyrot.* 40:221–232. doi: 10.1002/prep.201400191.
21. Walley, S. M., J. E. Field, and M. W. Greenaway. 2006. Crystal sensitivities of energetic materials. *Materials Sci. Tech.* 22(4):402–413. doi: 10.1179/174328406X91122.
22. Von Oertzen, A., and T. Lehmann. 2016. Considerations on energy deposition with the BAM-Fallhammer. *Cent. Eur. J. Energ. Mat.* 13:273–288. doi: 10.22211/cejem/64955.
23. Khariton, Yu. B. 1940. *Sbornik po teorii vzryvchatykh veshchestv* [Collection on the theory of explosives]. Moscow: Oborongiz. 177 p.
24. Kholevo, N. A. 1974. *Chuvstvitel'nost' vzryvchatykh veshchestv k udaru* [Sensitivity of explosives to impact]. Moscow: Mashinostroenie. 136 p.
25. Baum, F. A., K. P. Stanyukovich, and B. I. Shekhter. 1959. *Fizika vzryva* [Physics of explosion]. Moscow: Fizmatgiz. 800 p.
26. Coffey, C. S., V. F. DeVost, and B. A. Yergey. 1986. Critical initiation energy in at least some propellants and explosives subject to impact. *JANNAF Propulsion Systems Hazards Subcommittee Meeting Proceedings*. Chemical Propulsion Information Agency Publ. 1:579–585.
27. Mellor, A. M., D. R. Stoops, T. P. Rudy, and R. W. Hermsen. 1990. Optimization of spark and ESD propellant sensitivity tests: A review. *Propell. Explos. Pyrot.* 15:1–7. doi: 10.1002/prep.19900150102.
28. Baker, P. J., A. M. Mellor, and C. S. Coffey. 1992. Critical impact initiation energies for three HTPB propellants. *J. Propul. Power* 8:578–585. doi: 10.2514/3.23517.
29. Pepekin, V. I., and Yu. A. Lebedev. 1977. Kriterii otsenki parametrov detonatsii dlya vzryvchatogo veshchestva [Criteria of the detonation parameters estimation for explosives]. *Dokl. Akad. Nauk SSSR* 234(6):1391–1394.
30. Storm, C. B., J. R. Stine, and J. F. Kramer. 1990. Sensitivity relationships in energetic materials. *Chemistry and physics of energetic materials*. Ed. S. N. Bulusu. Dordrecht, Netherlands: Springer. 605–639.
31. Keshavarz, M. H., and T. M. Klapötke. 2018. *The properties of energetic materials: Sensitivity, physical and thermodynamic properties*. 1st ed. Berlin: Walter de Gruyter GmbH. 208 p.
32. Lansford, J. L., B. C. Barnes, B. M. Rice, and K. F. Jensen. 2022. Building chemical property models for energetic materials from small datasets using a transfer learning approach. *J. Chem. Inf. Model.* 62(22):5397–5410. doi: 10.1021/acs.jcim.2c00841.
33. Dixon, W. J., and A. M. Mood. 1948. A method for obtaining and analyzing sensitivity data. *J. Am. Stat. Assoc.* 43:109–126.
34. Šelešovský, J., and J. Pachman. 2010. Probit analysis — a promising tool for evaluation of explosive's sensitivity. *Cent. Eur. J. Energ. Mat.* 7:269–278.


*Received March 16, 2023*

# Contributors

**Monogarov Konstantin A.** (b. 1982) — Candidate of Science in physics and mathematics, senior research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; kostyk3d@mail.ru

**Muravyev Nikita V.** (b. 1985) — Candidate of Science in technology, leading research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; muravyev.nikita@ya.ru

**Meerov Dmitry B.** (b. 1981) — research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; mmeerov@mail.ru

**Fomenkov Igor V.** (b. 1963) — Candidate of Science in chemistry, senior research scientist, N. D. Zelinsky Institute of Organic Chemistry of the Russian Academy of Sciences, 47 Leniskiy Prosp., Moscow 119991, Russian Federation; ootx@ineos.ac.ru

**Pivkina Alla N.** (b. 1958) — Doctor of Science in technology, head of laboratory, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; alla_pivkina@mail.ru