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Review

New directions in the science and technology of advanced sheet explosive formulations and the key energetic materials used in the processing of sheet explosives: Emerging trends

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ABSTRACT

This review presents the work carried out by the international community in the area of sheet explosive formulations and its applications in various systems. The sheet explosive is also named as PBXs and is a composite material in which solid explosive particles like RDX, HMX or PETN are dispersed in a polymeric matrix, forms a flexible material that can be rolled/cut into sheet form which can be applied to any complex contour. The designed sheet explosive must possess characteristic properties such as flexible, cuttable, water proof, easily initiable, and safe handling. The sheet explosives are being used for protecting tanks (ERA), light combat vehicle and futuristic infantry carrier vehicle from different attacking war heads etc. Besides, sheet explosives find wide applications in demolition of bridges, ships, cutting and metal cladding. This review also covers the aspects such as risks and hazard analysis during the processing of sheet explosive formulations, effect of ageing on sheet explosives, detection and analysis of sheet explosive ingredients and the R&D efforts of Indian researchers in the development of sheet explosive formulations. To the best of our knowledge, there has been no review article published in the literature in the area of sheet explosives.

Contents

Abbreviations: ΔH_f, heat of formation; AFVs, armour fighting vehicles; AP, ammonium nitrate; APFSDS, armour piercing fin stabilised discarding sabot; ATEC, acetyl triethyl citrate; C/M ratio, charge to mass ratio; CAB, cellulose acetate butyrate; CL-20, 2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazaisowurtzitane; CR, crepe rubber; CT sensors, current Transformer sensors; DCE, dichloroethane; DMNB, 2,3-dimethyl-2,3-dinitrobutane; DOA, bis(2-ethylhexyl) adipate; DOP, bis(2-ethylhexyl) phthalate; DPA, diphenyl amine; DSC, differential scanning calorimeter; DTA, differential thermal analysis; Ea, activation energy; EI-MS, electron ionization mass spectroscopy; ERA, explosive reactive armour; EVA, ethyl vinyl acetate; FOX-7, 1,1-diamino-2,2-dinitroethene; GAP, glycidyl azide polymer; GC, gas chromatography; h50, height of 50% explosion; HAZOP, hazard analysis and operation; HD, hazard division; HEMs, high energetic materials; HMX, octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine; HPGe, high-purity germanium; HPLC, high performance liquid chromatography; HTPB, hydroxyl terminated polybutadiene; HyTemp, acrylic copolymer of ethyl and butyl acrylate; IDF, Israeli Defence Force; IGRIS, inelastic-gamma ray & spectroscopy; ISAT, intensified standard alternating trials; KE, kinetic energy; LOVA, low vulnerable ammunition; M.P., melting point; M.W., molecular weight; NATO, North Atlantic Treaty Organization; NC, nitrocellulose; NG, nitroglycerine; NTO, 3-nitro-1,2,4-triazol-5-one; O.B., oxygen balance; PETN, penta erythritol tetranitrate; PIB, polyisobutylene; PU, polyurethane; R&D, research and development, RDX, 1,3,5-trinitroperhydro-1,3,5-triazine; RH, relative humidity; RHA, rolled homogeneous armour; TATB, 1,3,5-triamino -2,4,6-trinitro benzene; Tg, glass transition temperature; TGA, thermogravimetric analysis; TKX-50, dihydroxylammonium 5,5′-bistetrazole-1,1′-diolate; TMETN, trimethylolethane trinitrate; TPE, thermoplastic elastomer; TRION, time-resolved integrative optical neutron; TS, tensile strength; Viton, poly vinylidene fluoride co-hexafluoro propylene; VOD, velocity of detonation; VS, vacuum stability.

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1. Introduction

Sheet explosives comprise of energetic materials/explosives dispersed in polymeric matrix [1]. High energy materials (HEMs) provide the power/energy to accomplish objectives of system. Polymers provide continuum for dispersion of HEMs and play vital role in deciding structural integrity and flexibility as well as sensitivity of sheet explosive compositions. In addition to conventional explosives, insensitive/low sensitive explosives are also potential candidate for sheet explosives to realise low vulnerable formulations. The recent advancements in the science and technology of polymers have led to a major breakthrough in the technology of sheet explosives.

Development efforts for flexible sheet explosives commenced with the objective of realising flexible compositions as alternate to non-flexible explosive composition B based on RDX & TNT [2]. Plastic bonded explosive compositions amenable to calendaring process to obtain sheet in required form are the material of choice. Sheet explosive compositions are tailored depending on need of explosive power, mechanical properties and sensitivity. These properties depend on nature and proportion of explosive/binder/plasticizers.

Advancements in technology of warheads are progressing at fast pace. R&D in the area of shaped charge design has led to emergence of systems capable to achieve higher lethality in terms of penetration to armour posing threats to modern tanks. This requires innovative approaches in designing ERA system with capability to counter threat of advanced shape charge devices. There is also a need to introduce additional capability in modern ERA systems to defeat KE projectiles. Present research programme is undertaken to generate data base on new class of sheet explosives by incorporating polymers and explosives with different chemical structures to counter emerging threats. The work will enable to designing of wide range of sheet explosives for advanced systems.

As RDX and crepe [3] rubber are widely reported as component of sheet explosive compositions for military applications, a systematic data was obtained on 80–90% RDX-Crepe rubber (CR) compositions as reference. TPEs like estane and ethyl vinyl acetate (EVA) with combination of hard and soft block were investigated [3] as binder to assess their effect on characteristics of sheet explosive compositions, particularly with respect to mechanical properties. Cast cured HTPB binder system was also evaluated to realize composition with wide range of characteristics. Authors from HEMRL Pune have also reported the effect of incorporation of TATB [4] and NTO [5].

2. Classification of plastic bonded explosive formulations

Polymer bonded explosive formulations can be classified based on preparation technique.

2.1. Castable PBXs

Cast PBX charges containing high explosive loading with 10–15% inert binder find applications in different type of warhead and underwater application. Cast PBX compositions are prepared by incorporating high explosives like RDX, HMX, CL-20, etc., in a prepolymer along with appropriate cross-linking agent, plasticizers and other ingredients followed by casting in the container. Castable PBXs charges are prepared for use in different ammunition designed primarily to disperse the container fragments to large distances with high velocities, shaped charge effect, etc. use formulations which have high VOD and high detonation pressure. Aluminized explosive compositions are widely used for blast warheads. PBXs containing RDX and HMX along with aluminium have been reported. Ammonium per chlorate (AP) containing PBXs are also widely reported to use for air force bombs and under water applications [6].