Applications of Smart Impact-Resistant Materials in Military Packaging

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Abstract

Military packaging plays a significant practical role in the fields of military equipment support, military logistics, and informationized battlefields. With the advancement of military equipment modernization in China, there is a more urgent demand for the advancement, adaptability, diversity, and durability of functions of military packaging materials. Traditional foam materials have become insufficient to meet the packaging and protection requirements for military equipment and supplies on the modern battlefield. Compared with traditional foam packaging materials, the non-Newtonian fluid-like material EUDE FOAM exhibits excellent impact resistance and self-adaptive properties. Through functional design of material molecular structure, functional modification of polymer macromolecular cross-linked networks, and 3D composite of material macrostructure, EUDE FOAM can achieve multiple additional functions such as antistatic, salt spray corrosion resistance, mildew resistance, flame retardancy, electromagnetic shielding, puncture resistance, waterproof and breathable properties according to actual application scenarios. Currently, EUDE FOAM has been applied in high-performance impact-resistant missile protective shells, providing comprehensive protection for high-value, high-precision missiles. With the development and proliferation of modern military equipment characterized by precision, electronics, and intelligence, EUDE FOAM will have broader application prospects in the field of military packaging and protection.

Full Text

Application of Intelligent Anti-Impact Materials in Military Packaging

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Abstract

Military packaging plays a critical role in military equipment support, military logistics, and informationized battlefield operations. As China' s military equipment modernization advances, there is an urgent demand for packaging materials with superior functionality, adaptability, diversity, and durability—requirements that traditional foam materials can no longer satisfy. Compared with conventional foam packaging materials, the non-Newtonian fluid-like material EUDE FOAM exhibits exceptional anti-impact and adaptive performance. Through functional design of molecular structure, modification of polymer cross-linked networks, and 3D macrostructural composites, EUDE FOAM can be tailored for specific applications to achieve additional functionalities such as anti-static properties, salt spray corrosion resistance, mold prevention, flame retardancy, electromagnetic shielding, puncture resistance, and waterproof breathability. Currently, EUDE FOAM has been applied in high-performance anti-impact missile protective shells, providing comprehensive protection for high-value, high-precision missiles. With the development and proliferation of precision, electronic, and intelligent modern military equipment, EUDE FOAM promises broader application prospects in military packaging and protection.

Military material packaging constitutes a vital component of military equipment support infrastructure. The quality of protective packaging significantly impacts the storage, transportation, and operational use of military equipment. Effective protection ensures that equipment maintains its quality and performance throughout designated storage periods and transportation chains, enhancing operational reliability and playing a crucial role in ensuring combat readiness and mission success. Military packaging differs fundamentally from civilian packaging, particularly regarding modern military equipment storage, transportation, and operational environments, which face greater uncertainty. Given China' s vast territory and dramatic climatic variations, packaging materials must demonstrate adaptability across broader environmental ranges, requiring robust protective performance against high and low temperatures, rain and snow, salinity, and humidity. Military equipment distribution is typically determined by strategic deployment considerations, creating substantial uncertainty in both storage and operational environments. During long-term storage, equipment is vulnerable to adverse environmental factors including temperature, humidity, and salinity, which can cause metal components to corrode, electronic device insulation to fail, plastic and rubber products to age, optical instruments to fog or mold, and cotton military supplies to rot, thereby reducing storage reliability. The storage and operational environments for military materials are extremely complex, and with increasingly diverse methods of military attack and destruction, the battlefield survival environment for high-tech and high-value military equipment has become increasingly harsh. Single-function traditional protective packaging can no longer meet military protection requirements. Improving packaging for high-precision, high-value equipment—replacing primitive, outdated packaging with new materials that integrate electromagnetic protection, radiation shielding, shockproofing, moisture resistance, and mold prevention—has become essential for enhancing multifunctional packaging protection in high-temperature, high-humidity regions. Such improvements increase resistance to harsh marine climates with high temperatures, humidity, rainfall, and salinity, enhance reliability and mission success rates, and elevate technical support capabilities, representing a critical means of protecting enclosed materials in military packaging [1]. Concurrently, with rapid advancements in modern military detection technology and weapon strike capabilities, modern warfare has become increasingly high-tech, and battlefield environments continue to deteriorate. Military packaging protection must extend beyond traditional moisture and humidity resistance to address new environmental factors including vibration, impact, electromagnetic interference, and radiation. Fortunately, scientific progress has enabled the development of various functional materials—including photochemical functional materials, stealth materials, conductive materials, moisture-proof anti-static composite films, and anti-static cushioning materials—providing technical guarantees for achieving comprehensive protective packaging.

2. Current Status and Trends in Military Packaging

With the development of PLA equipment modernization and increasing emphasis on military logistics improvement, particularly the substantial growth in strategic reserve equipment procurement in recent years, protective packaging has gained increasing attention and achieved significant development. China' s military equipment packaging has gradually evolved from traditional methods such as oil sealing, wax sealing, and wooden crates to the application of various modern advanced packaging materials and technologies, substantially extending equipment storage life, reducing maintenance requirements, and improving storage reliability, thereby making significant contributions to reliable equipment reserves. However, we must recognize that China' s military packaging started relatively late, and a clear gap remains compared with European and American developed nations. To rapidly improve protective packaging technology, catch up with or surpass international advanced levels, and meet development needs, we must clearly understand development trends in military packaging, avoid detours, and target advanced foreign standards from a high starting point to accelerate progress in China' s military packaging technology.

2.1 Full-Cycle Protection for Military Packaging

With PLA equipment modernization and improvements in military logistics, the "five-in-one" military packaging design concept was proposed in the 1990s [2], which requires comprehensive consideration of the entire process from packaging production to weapon system deployment, addressing overall environmental adaptability across five stages: packaging, handling, transportation, storage, and operational use. This exposes materials to more complex environments and application scenarios throughout the process, demanding not only higher single-performance protection but also requiring materials to possess multiple special protective and comprehensive protection capabilities. Consequently, traditional packaging materials can hardly meet modern military packaging needs, creating greater demand for developing new packaging and composite materials.

2.2 Precision and Electronicization of Military Equipment

As modern warfare evolves, weapon systems are becoming increasingly modernized, complex, and precise. Even large-scale and high-tech weapon systems (including various combat platforms, electronic warfare platforms, and new weapon systems) continue to emerge. These systems represent complex technological integrations featuring precision manufacturing, complex material composition, high cost, and stringent protection quality requirements [3]. Therefore, selected packaging structures and preservation methods must align with their structural characteristics and physical and chemical properties. Military packaging represents a critical link in ensuring equipment reliability, long service life, and rapid conversion to combat effectiveness during wartime.

2.3 Military Packaging Must Adapt to the Informationized Battlefield Environment [4]

In recent years, military packaging has developed toward technological and informationized directions. Modern warfare exhibits new informationized characteristics, featuring "high technology, high speed, high intensity, and high consumption." Wars erupt suddenly, cover vast spatial dimensions, cause severe destruction, present rapidly changing situations, involve frequent force movements, and employ diverse strike methods. The comprehensive application of advanced technologies such as satellite reconnaissance, precision guidance, and electromagnetic kill has rendered the informationized battlefield unprecedentedly transparent, where being detected means being tracked and destroyed [5]. Consequently, in the informationized battlefield, military packaging design must not only protect against traditional harsh environmental factors (such as natural climate conditions and road conditions) but also track and research new reconnaissance and strike technologies, innovating military packaging protection technologies to comprehensively enhance protective capabilities under informationized warfare conditions.

2.4 Military Packaging Must Support Diverse Military Tasks

In the new historical period, beyond preparing for military struggle and actively defending against potential wars, the PLA also undertakes non-war military operations including emergency response, counter-terrorism and stability maintenance, and disaster relief. Practice demonstrates that military materials, particularly various logistical support equipment and supplies, have become essential for accomplishing diverse military tasks. Such operations feature sudden onset, complex and diverse situations, harsh environmental conditions, and poor road and communication infrastructure. Therefore, military packaging design should also accommodate the characteristics of non-war military operations to facilitate the execution of diverse missions [6].

In summary, military packaging requirements are shifting toward full-cycle and comprehensive protection, with demands for diversified protective performance and overall lightweight, integrated, intelligent, and flexible packaging design. Modern military packaging materials not only substantially extend protection cycles but also significantly enhance protective performance requirements, gradually transitioning from traditional rust and moisture prevention during storage to comprehensive protection focusing on shock and impact prevention during transportation and operational use.

2.5 Protection Scenarios and Systematic Protection for Military Packaging

In storage environments, weapon equipment may be affected by temperature, humidity, air pressure, atmospheric pollutants, mold, insects and rodents, pressure loads, static electricity, and radiation, resulting in corrosion, aging, expansion or contraction deformation, mold growth, insect or rodent damage, and even performance changes or functional failure. In transportation and operational environments, equipment may face even harsher natural conditions, plus additional battlefield-specific hazards including sound waves, shock waves, sand and dust, electromagnetic waves, and various rays or nuclear radiation, which accelerate material corrosion and aging, alter electronic component performance or cause malfunction, impede moving parts, degrade weapon system performance, and even cause loss of combat effectiveness. Military products must undergo numerous stages from factory to battlefield use and consumption, including transportation, handling, storage, distribution, and operation. Packaging design elements must address adverse factors that may be encountered in each of these stages. Weakening any single element creates a "short board in the barrel," substantially reducing overall protective function. Therefore, all design elements must be fully considered to achieve perfect integration, realizing overall protection greater than the sum of individual protective functions [7]. From modern military characteristics, we can see that after years of development, tremendous progress has been made in military equipment storage, while transportation and operational environments face increasingly harsh survival conditions. Bumps, collisions, acoustic vibration, impact, and weapon strikes have become primary factors affecting equipment reliability. Meanwhile, the precision, electronic, and informationized development of modern equipment makes materials more sensitive to shock and vibration, inevitably requiring more effective protection. Consequently, research and application of high-performance anti-impact protective materials will become the main development direction for future military packaging materials.

Anti-impact packaging can absorb or mitigate shocks and vibrations generated during handling, transportation, and operational use from drops, collisions, explosions, and carrier equipment vibration, preventing material damage, structural failure, and functional failure caused by overload or fatigue [8]. Traditional anti-impact packaging materials such as bubble wrap and EPE foam rely on structural characteristics to dampen vibration and impact. When subjected to impact or vibration, the high-density bubbles in these materials act like airbags to provide cushioning and protect internal equipment [9]. However, for increasingly harsh military environments where vibration and impact during transportation, operational use, and storage far exceed normal civilian scenarios, traditional material performance is insufficient to provide effective protection for military equipment. Therefore, improving material anti-impact performance is crucial. Traditional approaches to enhancing anti-impact performance primarily rely on increasing protective layer volume and thickness, yet excessive volume and thickness create inconvenience in storage, transportation, and operational use. Consequently, advanced anti-impact materials with superior performance are needed to meet military packaging requirements.

3. EUDE FOAM Intelligent Anti-Impact Material

3.1 EUDE FOAM Material

Non-Newtonian fluid-like anti-impact materials represent a new class of functional polymer materials developed and applied in recent years [10]. Their anti-impact mechanism relies not only on cushioning structures but primarily on energy absorption through molecular friction and collision at the microscopic level. This special energy-absorbing structure substantially improves anti-impact performance, with D3O generally recognized as the representative high-performance anti-impact material. Invented by British engineer Richard Palmer, D3O is an anti-impact material composed of "intelligent molecules" (a compound of viscous fluid and polymer) that exhibits two mechanical states (hard and soft) under different impact forces. Upon introduction, D3O quickly gained widespread application in outdoor protection, professional sports protection, police, and military fields due to its excellent performance [11]. While D3O' s unique properties attracted extensive attention, related technologies and processes have remained controlled by foreign manufacturers, with few similar products available domestically. After years of research and development, our company has launched the high-performance anti-impact material EUDE FOAM with independent intellectual property rights. Compared with D3O, EUDE FOAM exhibits superior anti-impact performance. Unlike D3O' s gel state structure, EUDE FOAM generally employs functional polymers as the main structural framework, with polymer structures forming cross-linked network architectures in space while anti-impact intelligent small molecules are uniformly distributed within the main network. This structure results in lower density, higher flexibility, simpler processing, and stronger operability. Since functional polymer materials exhibit excellent characteristics and broad adjustment ranges, the material demonstrates strong designability, enabling product design for different scenarios.

3.2 Mechanism of EUDE FOAM Anti-Impact Performance

High-performance anti-impact materials differ from traditional materials. When subjected to external impact, the material deforms, and the closed-cell structure of the material matrix provides cushioning similar to traditional protective materials, absorbing part of the impact energy. Simultaneously, under impact force, the originally uniformly distributed small molecular structures rapidly respond to the impact, locally accumulating and aggregating to produce a jamming phase transition that rapidly hardens the material. During this phase transition, the structure transformation and molecular friction and collision absorb substantial energy, thereby providing superior anti-impact protection. After impact, the material recovers its deformation, the small molecules return to uniformly distributed states, and the material macroscopically returns to a soft state, as shown in Figure 1 [Figure 1: see original paper]. Since energy absorption during impact occurs primarily at the microscopic level through molecular collision and material phase transition, product performance is uniform, stable, and highly reliable. During vibration, the jamming phase transition impedes structural vibration, substantially enhancing anti-impact and vibration resistance capabilities.

The unique structure of EUDE FOAM enables the material to "intelligently" identify and respond to external impacts, exhibiting different physical properties macroscopically. Under normal conditions, the material presents a soft polymer morphology while retaining the inherent stability, chemical resistance, resilience, and mechanical properties of polymer materials, with additional characteristics including lower compression set, thermal insulation, sound insulation, seismic resistance, and good toxicity prevention. When subjected to external impact, the internal microscopic structures rearrange, aggregate, and accumulate, causing the material to macroscopically exhibit high hardness, high strength, and high energy absorption characteristics.

The basic physical performance parameters of EUDE FOAM are shown in Table 1 , with anti-impact performance 2-10 times superior to traditional packaging materials such as EPE foam, while offering advantages including lightweight flexibility, waterproofing, thermal insulation, salt spray corrosion resistance, and excellent formability. Compared with polyethylene foam (PE), ethylene-vinyl acetate copolymer foam (EVA), polyurethane foam (PU), memory foam, and silicone packaging materials of the same thickness, EUDE FOAM demonstrates significantly reduced impact penetration force under 10 J and 20 J drop hammer impact energies, showcasing its excellent anti-impact, cushioning, and energy absorption performance (Figure 2 [Figure 2: see original paper]).

Table 1 Basic Physical Performance Parameters of EUDE FOAM

Property	Unit	Value	Test Standard
Density	g cm^{-3}	0.15-0.45	ASTM D3574-03
Hardness	Shore A	10-50	ASTM D2240-97

Property	Unit	Value	Test Standard
Tensile Strength	N mm^{-1}	0.5-3.0	ASTM D3574-03
Elongation at Break	%	150-400	ASTM D3574-03
Compression Set	%	<5	ASTM D3574-03
25% Compression Strength	kPa	10-100	ASTM D1056-14
Anti-Impact Performance	-	2-10× traditional materials	EN1621-1/EN1621-2
Water Vapor Transmission Rate	$g/m^2/24h$	<10	GB/T 1037-2021
Salt Spray Corrosion Test	-	Pass (168h)	GB/T 10125-2021

Figure 2 Comparison of anti-impact performance between EUDE FOAM and other packaging materials

3.3 Military Packaging Applications and Performance Testing of EUDE FOAM

Although China' s military equipment protective packaging technology has achieved significant progress and development, a substantial gap remains compared with developed countries such as the United States and Europe. For example, U.S. military ammunition packaging requirements specify that after two drops from 2.1 m height, the ammunition must still be capable of safe firing, whereas Chinese requirements mandate separate storage for ammunition dropped from 1.5 m height. Furthermore, U.S. military equipment safe storage periods are evolving from 20 years toward 30 years [12]. Based on EUDE FOAM' s superior performance and targeting the high standards of developed countries, we have designed and manufactured high-efficiency shock-absorbing and anti-impact missile protective shells (Figure 3 [Figure 3: see original paper]), with product performance in anti-impact, moisture resistance, waterproofing, and corrosion resistance reaching world advanced levels.

Figure 3 High-performance anti-impact missile protective shell

With continuous development of new materials and deepening composite material research, greater design space has been created for comprehensive protective materials based on high-performance anti-impact materials. Leveraging EUDE FOAM' s excellent machinability, various methods including coating, filling, grafting, bonding, mixing, and surface treatment can be employed to prepare anti-impact composites with additional characteristics to meet protection requirements such as anti-static, mold prevention, flame retardancy, and electromagnetic interference shielding. Building upon EUDE FOAM anti-impact materials, our company has developed a series of protective products with special properties including puncture resistance, anti-static capability, flame retardancy, electrical conductivity, electromagnetic shielding, and waterproof breathability, substantially improving comprehensive protective performance and broadening application scenarios.

4. Conclusion and Outlook

The ongoing Russia-Ukraine war has captured global attention, not only due to escalating geopolitical risks but also because modern weapon systems have played a decisive role in the conflict. Precision strikes by anti-tank guided missiles and loitering munitions have reshaped the battlefield landscape, with missile-based precision strike capabilities becoming key factors determining war outcomes. For instance, according to foreign media reports, the Javelin anti-tank missile has achieved a 93% kill rate against Russian tanks, further confirming that modern warfare is developing toward technological, precision, and informationized directions. The continuous development of military equipment also drives rapid advancement in military packaging materials [13], particularly with evolving requirements for ammunition packaging. The excellent performance of EUDE FOAM aligns well with the needs and development trends of military packaging, and we believe it will find increasing application in future military packaging fields. We also hope to establish long-term cooperative relationships with all parties to fully understand military protection requirements, further develop comprehensive protective materials targeting specific protection needs, and jointly promote the rapid development of China' s military packaging technology.

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Note: Figure translations are in progress. See original paper for figures.