Review of Composite Materials and its Ballistic Applications

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ABSTRACT

This review focuses on the necessity for composite materials over conventional materials. Composites prominent features are lightweight, relative stiffness, and strength properties which held some advantages over those conventional materials.Physical properties, material properties, tooling, design, inspection, and repair are all important aspects of composites. Airships, helicopters, and rockets are examples of military vehicles that rely on high-strength, light-weight, and cost-effective materials. In the ammunitionindustry, substantial efforts have been made to design economical, simply constructed, easily wearable, and biocompatible bulletproof armors, the ballistics performance of composites is also quite commendable. While conventional metallic materials that had been doing their part till now definitely have remarkable mechanical properties, but now their use is doomed. Rapidly gaining popularity of composites in industries and their play to expand their market to a variety of applications.Latest, light-weight developing composites and theirvarious manufacturing techniques offered a procurable result for a wide range of applications in all industries present.

Keywords – Composites, ballistic, light-weight, polymers

1. INTRODUCTION

Composites or composite materials can be called upon as the composition of two or more materials that are macroscopically nested in each other and sometimes there may be the treatment of coupling agent for properties enhancement and have a great deviation in their physical, chemical, and mechanical properties from their core materials. Constituent materials have significantly altered properties from that of the engineered composite. The engineered composite also has different arrangements and their volume fraction are also distinctive.For matching the benchmark of different industries for different purposes such as aerospace, biomedical, ammunitions and also for aesthetic values, various composites can be easily fabricated using different manufacturing techniques.These synthetic materials are used in a wide range of applications, including construction (e.g., buildings and bridges), automotive (e.g., car bodies), marine (e.g., ships and boats), and dental practices. Composites, in contrast to commonly used materials such as metal and wood, can offer a distinct advantage. [1]. Composites have many fundamental advantages, including high strength, light weight, and relative stiffness. Less weight contributes to more fuel savings and increased power output in transportation. In sporting applications, lightweight composites enable players to perform better because they are easier to play with. When it comes to wind energy, the lighter a blade is, the more power the turbine can generate.The ballistic performance of a composite means the capacity of energy absorption of stress during a high-velocity impact. In the defense industry, there have been strenuous efforts spent to develop economical, simply fabricated, easily wearable, and biocompatible bulletproof armors. Different progressive efforts have been developing to improve the ballistic performance. In combat systems to eliminate various threats, the light-weight armors play a significant role.

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1.1 Requirement of Composite and their advantages over conventionalmaterials

When two or more base materials are mixed together, composite materials are the result. The matrix, also known as the binder, is one of the materials. It binds fragments or fibers of the remaining material together, commonly known as reinforcement. Producers can achieve the best properties of each material by fusing them together.One material is more likely to provide increased strength and durability, while the other is more likely to provide corrosion and moisture resistance. In 2019 the predicted size of global composite market is USD 89.04 billion and is anticipated to grow at an annual rate (CAGR) of 7.6% from 2020 to 2027 completely. Listed below are the reasons to provide better understanding why composites are proving their worth.

- Flexibility in design
- Strength
- Lightweight
- Corrosion resistance
- Durability
- Reduced maintenance

For an instance the armor that is to be designed should be able to restrain the bullets from entering into the area.Fabricated armor should possess the qualities such as simple manufacturing techniques, easily accessible and effortlessly repairable.Previously, thick steel plates have been running the game in armoring sector. However, when multilayer armor was developed over time it significantly increased the resistance/weight ratio relative to steel and the resistance to infiltration also improved.The outer ceramic layer deflects bullets, the artificial fibers retain bullet particles, and the metal portion stops bullets in multilayered armors. This type of armor is much lighter than one-layer solid steel armors that provide equivalent protection [2].

Compared to previously used metals and woods, composites are lightweight, and this plays a significant factor in the automobile, construction, military and aerospace industries. Better efficiency and durability can be achieved by reducing the weight of the component. Engineers at many facilities such as in NASA and Boeing are conducting an experiment on a composite cryogenic tank, used to carry fuel on deep space missions. The result of this experiment is to cut out expenses by 25% and to cut down the weight by 30%.

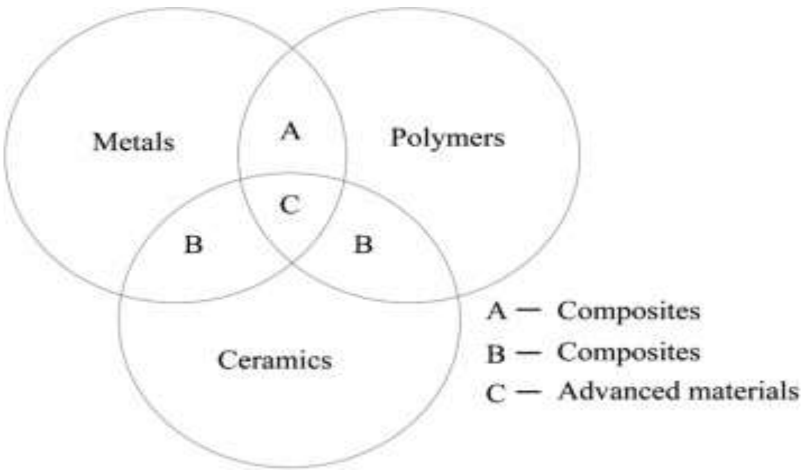

Fig.1.Classification of Materials

1.2Applications of composites

Significant advancement in technology and many manufacturing techniques in past few decades are also being developing to meet the requirement of the different sections of the markets. In today's scenario composite has spread their market into all of the area, out of which some are given below.

- airships,
- automobile,
- construction,
- marine,
- corrosion resistant equipment,
- defense,
- consumerproducts, appliance/business

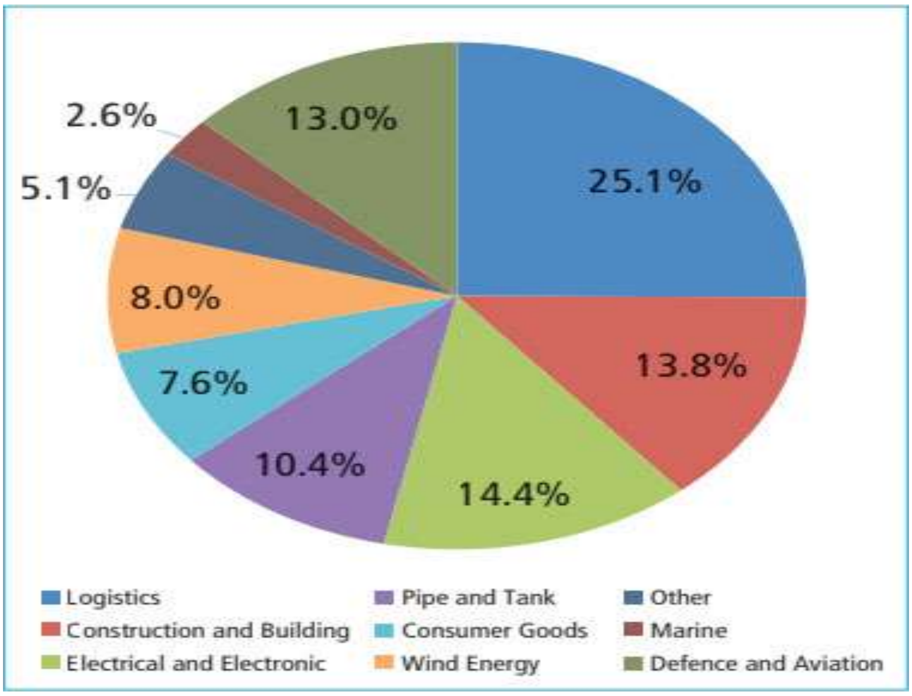

Fig.2.composites applications in various areas

1.3 Composites in ballistics

The primary goal of a composite manufacturer is to improve material performance by making them thinner, lighter, and stronger. A multilayer of material that protects an individual or an item from being fired is referred to as ballistic armor.Bullets of different speeds (e.g., from shotguns or rifles), airborne fragments (e.g., from bombs or IEDs), and rockets can all be used.Depletion of energy can occur in Multi-layer Composite materials due to a variety of mechanisms, including delamination, fiber-matrix de-bonding, fiber elastic deformation or tensile failure, and polymer matrix cracking or plastic deformation. In reality, however, a complex inter-layer mechanism is involved. Woven fabric, dry fibers or fibers that are reinforced with thermosets or thermoplastics can be used for multiple layering. According to the requirement, budget and functionality of the armor various composite solutions came up with variety in their design and there is no limit to it. In the recent development it is seen that thermoplastic materials are quite promising in producing efficient ballistic materials. Heat and pressure, when sometimes are used with the adhesive layers to enhance the bonding between layers and which can result in good finishing product. It is common belief that the protective armors should be uniformly solidified and must be void free but rather than producing void free material it can lead to the production of the material which is absorbing more energy under impact.Traditional body armor materials consist of a number of layers of Kevlar fibers with some ceramic inserts, but their uses are limited due to the extra weight and stiffness [3].Low density, high strength, and high energy absorption are only a few of the characteristics of Kevlar. However, to protect against high-level threats, additional layers are needed, making Kevlar fabrics bulky and stiff. There is a search for a material that can provide comparable ballistic performance to current body armor materials while being considerably more compact, low cost, comfortable, and flexible [4].

2. Literature Review

Bulletproof material protects the user not only from high-speed bullets but also from cannon rounds, mortars, bombs, and other fragmenting devices. In space many debris or foreign material is flying out at very high velocity so to protect the space shuttle from these ailments the exterior of these spacecrafts is fabricated such that they'll protect it any cost. High strength fibers are the key of any existent ballistic material such as helmets, bullet proof glass etc.

2.1 Reinforcement for ballistic performance

Graphite fibers, nylon fibers, glass fibers, are some common Aramid fibers which are strong synthetic and heat resistant fibers that are traditionally used for ballistic rated body armor fabric. Knitted or woven fabric fibers are used for bullet proof jackets or parts of jacket and many other parts applications. The fibers are embedded or fixed into a composite material for many other specifications like in aerospace and in military field. When we compare hemp jute with flex composites, flex composites excel at energy absorption criteria, and it was found by Wambua. Generally, to improve the ballistic properties of hemp jute, we use a mild steel plate and it is used such that it is facing and backing the body armor [5].Safri [6-9] investigated the behavior of glass fiber reinforced composites for both low and high velocity impact, finding that the number of fiber layers plays a major role in withstanding higher impact energy. The greater the number of layers the greater impact it can withstand.Because synthetic fibers are expensive, researchers believe that PMC reinforced with natural fiber would be a good alternative for impact applications. Natural fibers are lightweight and have satisfactory mechanical properties when compared to synthetic fibers [10]. Natural fibers are attracting the attention of many researchers as a reinforcement in composite materials due to their fundamental advantages such as low density, low cost, ease of availability, and high specific strength. [6-9].Another advancement in reinforcing material for ballistics are Ceramics. Ceramic armor has been used overly and all its properties has been completely recuperated. New technologies have been come into light which require the armor to accomplish lowest possible areal densities. Productive means of fusing ceramic workpieces at low temperatures so the bonds thus formed will have high performance, refine microstructures and that could lead to the diversification in the structure of armor such as honeycomb structure or, multilayered ceramic materials or embedded with metals or cermet.[11]

2.2 Matrix material used for ballistic performance

N. Puneeth contemplated that various combinations of metals and ceramics are used to create aluminum metal matrix. In his work, he developed hybrid Al-based $Al2O3/Al2SiO5$ by incorporating Taguchi method.Tensile power, impact strength, hardness, and the J integral test were among the tests he performed. For the fracture test, he used a single edge notch geometry. The Taguchi method was effective in predicting the most affecting parameter on composite properties using the ANOVA technique [12].In MMCs the cost of constituent materials and their processing cost is quite high when compared with other matrix material. The higher performance reinforcements (mostly fibers) are expensive,and lower cost reinforcements (mostly particulate) when used the performance improvements are not that significant.*Kairos et. al* uses several technologies for producing armors of different shape or variable thickness, he combined Metal matrix composites with three-dimensional woven fiber composites. This technique leads to the production of light-weight, economical armors that can be used for any kind of vehicles such as land, air and water.[13].7.62 NATO projectiles impacted on ceramic faced composite armors supported by a fibrous armor, according to *C. Navarro*. AD-96 alumina with boron nitride and silicon nitride was the ceramic he used to perform the experiment.A composite plate with aramid fibers embedded in a vinyl ester matrix or polyethylene fibers embedded in a polyethylene resin matrix served as the backing. According to the results of the experiment, the model can fairly accurately estimate the ballistic limit of composite armors backed by fibrous steel. [14]. Thermoset and Thermoplastic resins are suitable matrix material for PMcs. However, it is necessary to select the right material for the Polymer based composites because the properties of final product highly depend on this selection [15]. During the development period of PMC, thermoset based matrix played a huge role in advancement of composites in military aircraft applications. However, the material fabricated with the thermoset resin has outstanding mechanical properties but there were also some flaws present when epoxy resin is used. Therefore, thermoplastics came in role as matrix material for PMCs [16]. Presently, thermoplastics are being used as matrix thein PMC and find their applications at grand scale, thermoset still can be used with PMC for some cases. Various properties of thermosets and thermoplastics and how they are distinguished from each other are tabulated in Table 1 [17].

Table 1 Properties of thermoset and thermoplasticresins.

Property	Thermoset	Thermoplastics
Modulus	High	Average
Service temperature	High	Average
Toughness	Average	High
Viscosity	Low	High
Processing temperature	Low	High
Recyclability	Average	Good

2.3 Ballistic testing

Ballistic testing is a standard testing process which is used worldwide where products are examined if they meet protection, safety and performance criteria. Ballistics testing are generally complying with commercial research programs, development programs, military applications, law enforcement etc. If any product causing obstruction to ballistics, the product testing should be done. Here are some common applications of this type of testing:a) Personal protective equipment — Bulletproof vests and other equipment worn out by military personnel and law enforcement.b) Vehicle and structural armor — Sufficient ballistic testing should be done for both, Bulletproof vehicles as well as bulletproof glass. c)Firearms and munitions — Both should be tested well enough to ensure about their safety.

A confined area with facilities of firing ammunitionat standard velocities. For investigating the projectile motion of bullets, the process is videotaped with high-speed velocities capturing techniques.Calibration of ammunitions that are used is usually done after completion of every round and with right amount of weighted propellent is used and then loaded to acquire the desired velocities. According to the need of the customers multiple shots can be fired to test the different specimens. To evaluate the back face signature measurement support can be provided and that support is made up of mineral or polymeric clay to strengthen the backing.

Military organizations (NATO), highly industrialized states where military testing is a priority, formed some of the main families of standard tests (USA, European Community, Asian countries, South Africa). Such notable standards include DIN (German Institute for Standardization), -Norm (Austrian Standards Institute), and SNV (Swiss Standards Association). Different types of armors such as hard body armors must adhere to these regulations so the testing of products can be done easily so that suitable products can be manufactured.In 2007, the US Army began a series of ballistic tests against hard body armor, conducted analyses of the results, and developed a statistically-based test process, resulting in the most effective protection against bullet penetration and Backface signature (BFS)[18]. Following standards that are widely accepted at CEN, a technical committee 33 namely: EN 1063:1999 [19], EN 1522:1998 [20] EN 1523:1998 [21]. ISO16935:2007 (reconfirmed in 2017) [22] and is responsible to maintain the standards which concern ballasting protection and evaluating procedures for determining obstruction of materials and products which falls under the category to provide protection under ballistic impact.

Preliminary tests are conducted first, followed by those that meet the criteria for the Standards test requirements, with Particular consideration is given to those who are linked to attacks (projectile type and its mass and impact velocity).In contrast to non-standard test, the results concurred from that of standard results are quite different because of the manufacturing technologies of sample size to be selected.[23].

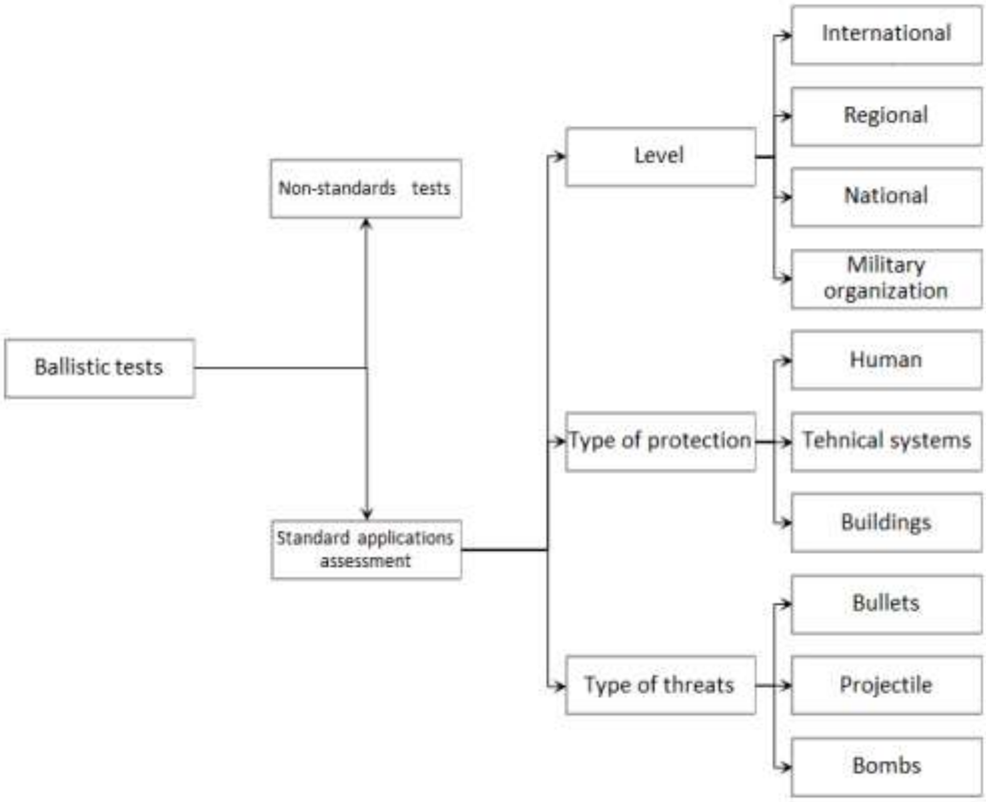

Fig.3.Standard ballistic Testing

3. Concluding remarks

Composites are now widely used in various engineering applications as replacements for traditional metals and alloys due to their growing popularity.This review focuses on the widespread adoption of composites as a result of their appealing mechanical and physical properties, which are now being used in the automobile, aerospace, ammunition, and construction industries, among others.For all types of composites, new fibers, polymers, and manufacturing methods are constantly being developed. Many modifications have already been made to increase the ballistic resistance of armors by using different composites, and this practice is widely accepted on a large scale. Laminated armors get the credibility for being durable and light-weight in nature. Previously,In the ballistic armor industry, Kevlar and steel are widely used materials, particularly in structural armor typesbut with the advancement in materials and manufacturing techniques studies shows the development of lightweight armor systemsand theiramplifying ballistic performance in Ammunition industries, spacecraft industries, for bullet proof vest, helmets, vehicles, glass panels and so on. Glass fiber have excellent mechanical properties and wear resistance behavior and also, they are quite economical so the researchers keep digging on this material.Due to some significant concerns about the environment and for the substantiality of material Natural Fibers are also stepping up in their game. Hence, this review contemplates that the recent trends towards PMCs has been observed for major engineering applications.

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