REVIEW STUDY ON MECHANICAL PROPERTIES OF HIGH VELOCITY IMPACT RESISTANT MATERIALS

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ABSTRACT

We find several materials which are resistant to high velocity impact projectiles. These materials are used in manufacturing bulletproof vest, bulletproof glass and several other ballistic applications. The determining factor for the materials to be classified as better high velocity impact resistant materials are their mechanical properties. This paper gives the readers a vivid idea about the mechanical properties a high velocity impact resistant material should possess. Due to the high impact strength and tensile strength materials like Kevlar and Carbon composites have they are widely used in ballistic applications. To explain the properties of these materials is the main of this paper. To resist high velocity impacts, these materials need high tensile strength and high impact strength. Alloys like steel and Titanium alloys also have high tensile strength and compressive strength which are also discussed about, in this paper. Few materials, like Kevlar, are classified under soft armour due to their light weight hence are most effectively used in bullet proof vest while, the hard armours are used in bulletproof structures and also in aerospace and military applications. In military aircrafts, materials like carbon composites are also used. Generally, steel is used as extra protection in certain bulletproof vests. In ancient times, alloys of titanium were found useful and were widely used in this aspect.

Keywords

Kevlar; Carbon fibre composites; Titanium; Steel; Impact strength; Tensile strength.

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1. Introduction

The material property of Fibre composites is very important for ballistic applications. The material should possess low density, high tensile modulus and high tenacity[1]. Friction also plays one of the major roles in affecting the energy absorbing property moderate coefficient of friction around 0.06-0.2 will have maximum energy absorbing property. Crimp of fibre should be less because when crimp of material is high the fabric stretches more and it shows less resistance against impact. A comparison of tensile strengths of various fibres is shown in fig 1.1.

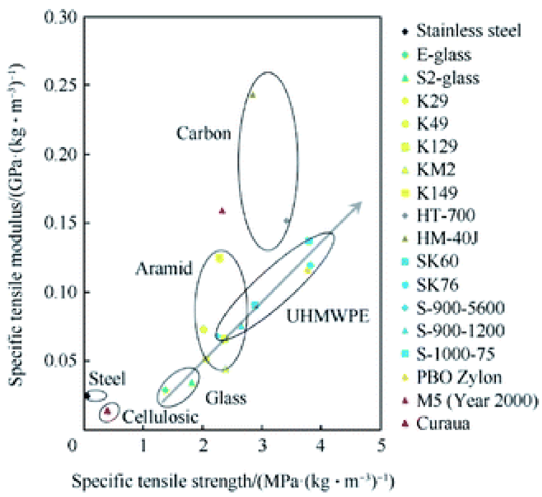

Fig 1.1 Tensile strength of various composite materials[1]

When a projectile strikes a fibre transversely, two waves emerge simultaneously one is longitudinal wave and other one is transverse wave as shown in fig 1.1.1.

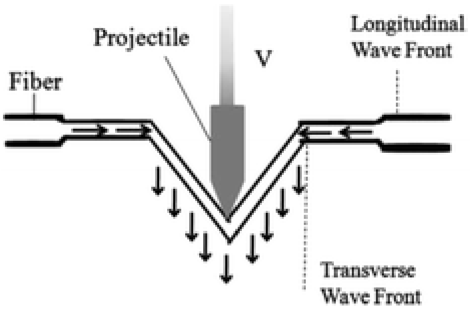

Fig 1.1.1 projectile impact on fibre[1]

Fig 1.1.2 gives a picture of weaved fabric trapping a projectile creating a 'wedge through'.

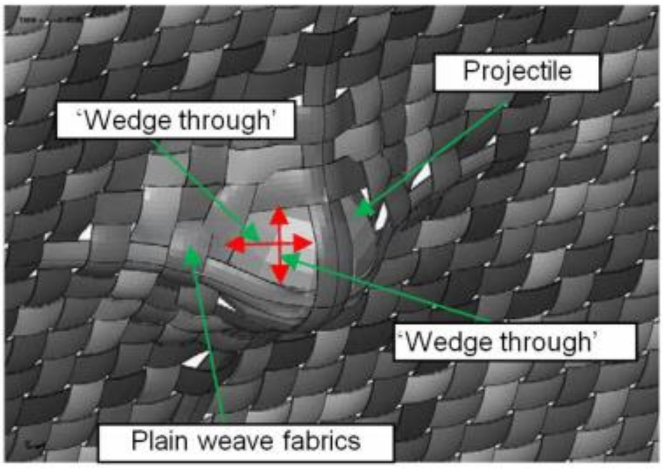

Fig. 1.1.2 Trapping of ballistic projectile by the plain-weave fabrics[12].

In metals and alloys, certain mechanical and properties are the basic requirements for them to be used as high velocity impact materials. They should also possess good energy absorption capacity. The strength and toughness of these metal alloys should be high. Toughness is the ability of a material to resist breaking when the force is applied and strength is the amount of force that can be applied before the material deforms. The fibre orientation, ply thickness and the fibre volume fraction will influence the strength of fibre reinforced laminates[2].This paper discusses about these properties of different alloys and fibre composites and provides a comparison between a few properties of the materials.

2.MATERIALS

The materials which are briefly discussed in this journal are Kevlar, Carbon fibre composite, Titanium alloy, Steel.

2.1 Kevlar

Kevlar-29 fibres are being used in different applications because of their exceptional mechanical properties. Aramid fibres like Kevlar have high strength, high modulus and also toughness when compared to other fibres[3]. The tensile strength of Kevlar is very high(3260MPa). The structural rigidity of material is so high that is it has low elongation to break high modulus. Kevlar has excellent mechanical properties because of the molecular structure. The spinning process aligns the molecular chains parallel to the fibre axis which leads to a highly ordered structure with a high degree of crystallinity. Kevlar's high degree of toughness, along with the failure mechanism of aramids, and damage tolerance promotes good impact performance. When aramid fibres break, they do not fail by brittle cracking, like glass or carbon fibres. Instead, the aramid fibres fail by a series of small fibril failures, where the fibrils are molecular strands that make up each aramid fibre and are oriented in the same direction as the fibre itself. These many small failures absorb much energy and, therefore, result in very high toughness[4].Kevlar has high temperature resistance (decompose only at 450˚C). Kevlar has high strength to weight ratio[4][5].

(a) (b)

Fig 2.1 (a)Unwound Kevlar fibres, (b)Woven kevlar fibre[10]

The density of kevlar is also less around 1.44 gram per cubic centimetre when compared to steel which is around 8 grams per cubic centimetre therefore a large volume of kevlar weighs much lesser when compared to steel of same volume. This material has high toughness. It has excellent dimensional stability. Kevlar has High resistant to abrasion. The fibres of kevlar and spun tightly and is very difficult to separate them therefore when high velocity projectile hits the surface of kevlar the energy is dissipated among the surface. Unlike Carbon fibre or glass fibre which fail by brittle cracking aramid fibres like kevlar do not fail by breaking because they are made of fibrils. They are mostly used in soft body armour cause of their light weight and easy mobility. Kevlar also has high resistance to fatigue[6].

Some of the grades of Kevlar used in ballistic applications are Kevlar K129 Kevlar K149, Kevlar KM2. Refer Table 2.1.1 for Mechanical property of several grades of Kevlar. During the last couple of decades there are several researches to enhance the energy absorbing property of these high velocity impact materials, one of the very common method is by adding shear thickening fluid(STF). Below table shows the results of increase in the peak load after adding shear thickening fluid (nanosilica).

Table 2.1.1 Mechanical properties of several grades of Kevlar

Grade	**Density (g/cm3)**	**Tensile Modulus (GPa)**	**Tensile Strength (GPa)**	**Elongation (%)**
29	1.44	83	3.6	4
49	1.44	131	3.6-4.1	2.8
149	1.47	186	3.4	2.0

2.2 Carbon fibre

Carbon fibre reinforced composites have varied uses due to their extremely high strength to weight and stiffness to weight ratio. The density of standard carbon fiber is 1.77g/cm^3. Also, they are chemically inert, electrically conductive and infusible. The stiffness and modulus of elasticity of the carbon fibre composites range from the values of glass to the three times the values of steel. Of all reinforcing fibres, carbon fibres offer the highest specific modulus and strength.

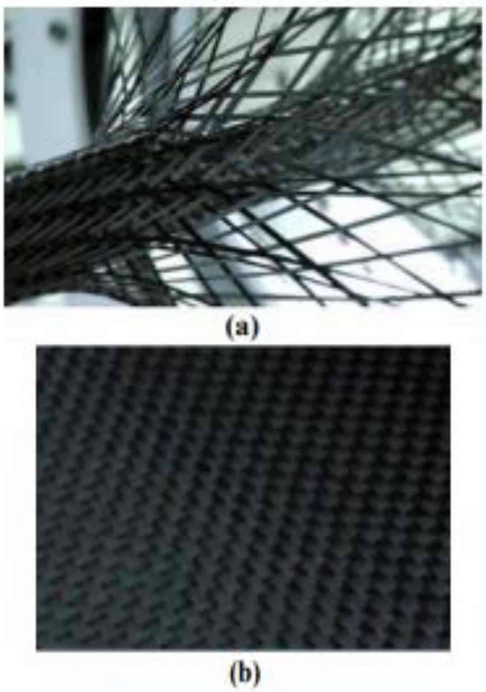

Fig2.2: (a) Unwound carbon fibres (b) Woven carbon fibres[10]

The carbon fibres offer a maximum strength of 7GPa, axial compressive strength is 10-60% of their tensile strength and transverse compressive strength is 12-20% of their axial compressive strength. The tensile strength of glass, carbon and Kevlar fibres is similar. Table 2.2.1 gives the Basic comparison of different types of Carbon fibre with Epoxy.

Table 2.1.2 Percentage of increase in peak load after adding various amount of STF[15]

Nanosilica particles loading	**Peak load**	**Increase in peak load(%)**
Neat fabric	8.33	-
Kevlar/STF(15 wt % nanosilica)	10.6	27.2
Kevlar/STF(25wt% nanosilica)	13.2	58.5
Kevlar/STF(35 wt% nanosilica)	16.3	95.7
Kevlar/STF(45 wt% nanosilica)	18.1	117.3

The melting or decomposing temperature of carbon fibers is >1200˚C [11].

For improved energy absorption, superior impact resistance and higher residual strength the fibers should be stacked in a multidirectional way i.e., -45̊ to +45̊ when compared to other multidirectional and unidirectional composites[10].

Based on elastic modulus, carbon fibers are classified into five types which are, ultra-high elastic modulus type (UHM), high elastic modulus type (HM), intermediate elastic modulus type (IM), standard elastic modulus type (HT) and low elastic modulus (LM). The tensile elastic modulus is the highest in UHM type whereas tensile strength is highest in IM and LM types. Table 2.2.2 gives the Mechanical property of Carbon fibre.

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2.3 Titanium

Even though pure titanium is not used for ballistic resistance purposes, an alloy of titanium, Ti-6Al-4V is used. Ti-6Al-4V is the most widely used titanium alloy. The alloy Ti-6Al-4V has good mechanical and corrosion resistance properties. There are three major categories of alloys based on the microstructural orientation/phases which are α-alloys, β-alloys and α+β alloys. Ti-6Al-4V is an α+β alloy. Table 2.3.1 gives the Physical properties of pure Titanium.

Table 2.3.1: Mechanical properties of Ti-6Al-4V

Hardness (HV)	300-400
Elastic modulus (GPa)	110-140
Yield strength (MPa)	800-1100
Tensile strength (MPa)	900-1200

The Ti-6Al-4V alloy exhibits good fatigue strength, and acceptable fracture toughness, it merges a set of interesting properties, good workability and production experience, and high commercial availability. To improve the fracture toughness furthermore it is heat treated and used. Fig 2.3 shows an optical micrograph of Ti-6Al-4V part.

Fig 2.3: Optical micrograph of Ti-6Al-4V part built in a vertical direction[7].

The α+β alloys have high strength. Ti-6Al-4V also called Ti-64 is annealed (a heat treatment process) to increase its fracture strength and fracture toughness. Ti-64 is also used for military purposes for parts of aircraft, missiles and armour plating. As the purification and extraction processes are made simpler and shows significant weight reduction, it is replacing steel in many applications.

2.4 Steel

As discussed above pure steel is also not used for ballistic applications instead hardened steel (mostly made of iron and carbon) and also steel fibre reinforced concrete is used. Based on the hardness of steel it is classified. Table 2.4.1 gives the Classification of Steel. Ultra-high hardness steel (HB 580-640) is used as protection against armour piercing bullets. HB denotes the Brinell hardness of the steel. Just a few millimetres thickness of steel is highly effective in resisting high velocity projectiles.

Table 2.4 Classification of steel

High Hardness Armour (HHA)	500 Brinell steel (HB477-540)
Very High Hardness Armour (VHH)	550 Brinell steel (HB530-590)
Ultra-High Hardness Armour steel (UHH)	600 Brinell (HB580-640)
Extreme High Hardness Armour steel (XHH)	650 Brinell (HB630-700)

The modulus of elasticity of pure steel is 200GPa.The tensile strength of case-hardened steel varies based on composition of carbon and also by the method of hardening with maximum of 1320MPa. In general Steel fibre reinforced Concrete composites are also used for ballistic applications. This type comes under hard armour as the density of steel is high when compared to kevlar. The density of steel is around 7.75-8.05 gram per cubic centimetre therefore making it heavy and cannot be used in bulletproof vest but instead used in other ballistic applications. There are some results of impact test of plain concrete and steel. The number of impacts for failure for plain concrete is one and for steel fibre is five. The mean peak force for plain concrete is 28900N whereas for steel fibre it is 29108N[9]. Steel fibres are good in impact testing and energy absorption when compared to any other fibres. When compared to Kevlar they have good compression strength.

3.RESULTS AND DISCUSSION

The main property of a material that is focussed on ballistic application is its impact strength, that is the amount of energy that a material can withstand when a load is supplied. Whenever a high velocity particle is projected into a material the amount of energy it absorbs is important so that the displacement the projectile travels in the material is reduced. This paper focuses on four materials namely Kevlar, Carbon fibre, Titanium, Steel out of which Carbon fibre possess high impact strength. The other important property of material that should be considered is its tensile strength, that is the resistance of material to break down under tension. Again, Carbon fibre has high tensile strength when compared to other materials discussed. Though carbon fibre composites has higher tensile strength and impact strength compared to Kevlar, carbon fibre composites are not used in bulletproof vests due to their brittleness. It is also noted that among the four materials Steel has less impact and tensile strength but due its high compressive strength when compared to Kevlar they are widely used in buildings.

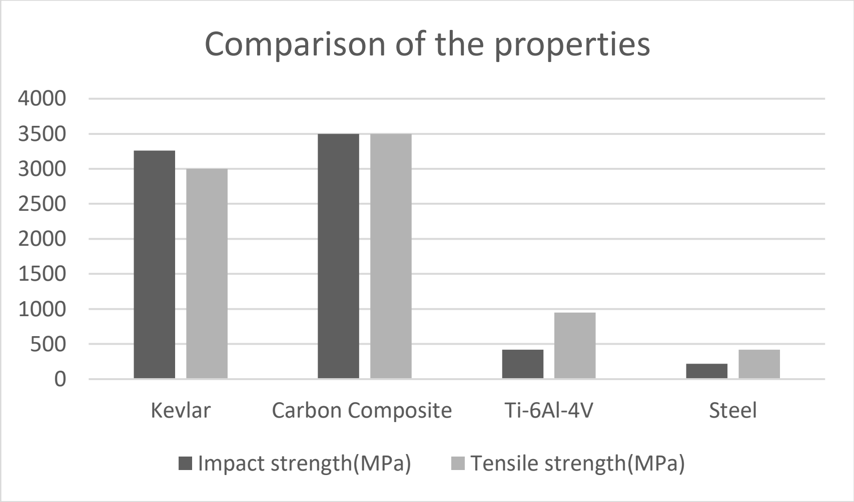

Fig 3.1.1: Comparison of the properties of Kevlar, Carbon composite, Ti-6Al-4V, Steel

4.CONCLUSION

When it comes to flexibility, Kevlar are more flexible which helps to dissipate the impact energy. When compared to Kevlar, carbon fibre composite is rather stiff. But both the materials have been proven to have shown ballistic resistance. Kevlar is widely used in bulletproof vests while carbon fibre composite is used to make parts of military vehicles and transport aircrafts.

Ti-6Al-4V was used in the body armour in the 1900s. Titanium’s relatively poor shear strength and heat transfer properties makes it not very reliable for bulletproof vests, but are used in hard plate reinforced vests. Steel is considered to be hard body armour. Some bulletproof vests contain steel plates for extra protection. Both titanium alloy and steel are used to make parts of military vehicles.

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