ISSN: 2692-5397
Modern Concepts in Material Science
DOI: 10.33552/MCMS.2023.05.000612
Iris Publishers

Research Article

An Overview on Physio-Mechanical Properties and Applications of Synthetic Fibers

Samiul A Khan, Mohammad A Amin, Farjana Islam and Ruhul A Khan*

Polymer Composite Laboratory, Institute of Radiation and Polymer Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh.

***Corresponding author:** Ruhul A Khan, Polymer Composite Laboratory, Institute of Radiation and Polymer Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh.

Received Date: October 09, 2023

Published Date: October 25, 2023

Abstract

Emerging research is concerned mainly with environmental and economic issues related to the design of paramount materials for future industries. Synthetic fiber composites are considered one of the most promising and preeminent materials now accessible in the twenty-first century due to their superior mechanical, thermal, and biological properties. Currently, composites reinforced with high-performance fibers of synthetic materials are gaining traction as the market needs such adroit materials with high strength characteristics and lightweight. Outstanding performance not only does a fiber-reinforced polymer composite have a high strength-to-weight ratio, but it also exhibits excellent traits such as increased durability, stiffness, damping property, flexural strength, corrosion resistance, wear, impact, and fire. Synthetic fiber composites have been found using in various industrial sectors, including mechanical, construction, aerospace, automotive, biomedical, marine and so on. Because of their constituent elements and fabrication techniques which primarily determine the performance of composite materials, it is necessary to investigate the functional properties of various fibers available worldwide, their classifications, applications, pros and cons, etc. The aim of this review is to give a thorough overview on synthetic fibers and synthetic fiber reinforced composite materials, their major physical and mechanical properties and potential applications.

Keywords: Radiation; Synthetic Fibers; Natural Fibers; Polymers; Classifications; Applications; Physio-mechanical properties; History; Compatibility; Pros and cons

Introduction

A polymer is a type of substances composed of very large molecules, called macro-molecules, which are multiples of smaller chemical units called monomers. Polymer is derived from the Greek prefix "poly" which means "many" and the suffix "mer" which means "single units (monomers)". Polymers make up many of the materials in living organisms and are the basis of many minerals and man-made materials. The polymer comprises a backbone of atoms to which atoms or groups of particles are attached. Polymers are macro-molecules, which are massive molecules. Simple molecules have chemical characteristics that are comparable to those of these molecules [1]. One of the major concepts of the twentieth century is the concept of polymers. It is a relatively new discipline which deals with natural and synthetic fibers, rubbers, coatings, adhesives, sealants, etc.; all of these materials nowadays have become very common [2]. Fibers can be naturally or synthetically produced depending on the polymer employed in their production. Fibers that are generally obtained from plant, animal, or cultivated are called Natural Fibers (NFs) [3] such as jute, ramie, sisal, hemp, flax, cotton, coir, grewia optiva, silk, bamboo, etc. On the other hand, fibers that are manufactured through various man-made processes are called synthetic fibers (SFs) such as carbon, kevlar, glass, etc. Both natural and SFs have their own merits and demerits with respect to the polymer used for the fabrication of the composite [4, 5].

In the beginning, fibers came from nature; mostly from animals: skins, hair, wool, silk from silkworms, and plants: flax, hemp, cotton, ramie, kenaf, sugarcane, etc. The utility of flax and hemp twines was recognized even in the Stone Age. Flax fabrics were used in per-dynastic Egypt (fine linen cloth being woven in 3800 BC) and in Neolithic lake dwellings in Switzerland. References to hemp and ramie (fibers raised in temperate latitudes, and unidentified to ancient Egyptians and Hebrews or to earlier Greeks) occur in Chinese writings dating 2800 BC and in early Sanskrit literature. Jute shows up to have been cultivated in Bengal from the most ancient times. Historically the culture of silk began in 2640 BC in China, where for many centuries its origin and the art of manipulating it were kept concealed (it did not reach Japan until AD 300). There are Sanskrit records dating from 1000 BC that refer to the working of silk in prehistoric India. Wool sheep appear to have emerged as mountain animals in Mesopotamia. It is well known that their wool was utilized for clothing at least 5000 years ago [6]. For centuries, all textiles that came from fibers that were accumulated from a plant, animal or insect. Then, at the end of the 19th and beginning of the 20th century, people discovered that they could create textile fibers of their own. Those early fibers still originated from a natural source, cellulose from wood pulp, but soon enough, in the 1930s, 1940s and 1950s, a stream of SFs came on the scene that owed their origin in chemical plants instead of plants that could be grown in the field [7].

Initially, attempts at creating SFs were really just attempts at recreating natural fabrics and possibly improving them. Augmentation of artificial silk from 1855 onwards became known as viscose around in 1894, and finally rayon in 1924, a hugely popular synthetic fabric today, is incredibly soft, moisture-absorbing and easily dyed. A variation of rayon known as modal has also gained popularity recently. A similar product known as cellulose acetate was discovered in 1865. Rayon and acetate are both artificial fibers, but not truly synthetic, they are being extracted from wood. Also in the 1800s, PVC was discovered. Manufacturers often choose PVC because of its durability. Carothers is recognized as the inventor of the first SF, known as nylon 66. Nylon 66, made from a diamine and diacid, each with six carbons, was commercialized before 1940 and continues to grow in importance today [8]. Although these artificial fibers were discovered in the mid-nineteenth century, successful modern manufacture began much later and have been substantially improved over the years [2].

This paper presents an in-depth review of the recent advances on SFs, categorization on the basis of their physical and mechanical properties. Throughout the review, key fiber parameters have been identified and their influence provides a summary of distinct qualities and uses in various sectors. To explain the observations of these properties, fundamental data analyses of the composites and fibers are also presented.

Fiber: Numerous Categories

Fibers are structural units and reinforcing agents of the composite materials, main part of the composite system that carries structural loads. These are a class of hair-like materials that are continuous filaments or are indiscreet elongated pieces, similar to pieces of thread. They may be spun into rope, thread, or filaments. They can be matted into sheets to create goods like paper or felt. Basically fibers are divided into two main categories: natural and synthetic. SFs are generally petrochemical products. NFs are obtained from plants or animal's organs. Both natural and SFs offer strength and rigidity and serve as reinforcement in fiber-reinforced composite materials. NFs like wood and some synthetic composites, like: viscose, have been used by humans for innumerous years [9, 10].

Natural Fibers

Natural fibers (NF) have been in existence since the beginning of the earth. NFs come from a variety of sources, including plants, animals, and minerals. NFs, as the name suggests, are a particular substance that exist naturally and are not man-made. Being renewable, NFs are assumed as a good substitute for traditional materials. Because of their higher aspect ratio and high strength, NFs are gaining greater attention in the automotive sectors for structural applications [11]. In addition, NFs are also gaining interest in the field of textile, medical implantation, building structures, aviation, etc. New plant fibers are being examined by researchers seeking their fascination in developing lightweight, renewable, economical, and socially beneficial for replacing traditional materials. It has been found that composites are produced by using NFs that hold good electrical resistance, better mechanical properties, decent thermal and acoustic insulating properties, and higher resistance to fracture in some cases [12-14].

NFs can be categorized based on origins and popularity are discussed below [10, 15]:

Classification of Natural Fiber

There are various types of natural fibers found worldwide. Nonetheless, NFs are explicitly available in three forms: Animals, Plants/Cellulose and Minerals as shown in Figure 1 [16, 17].

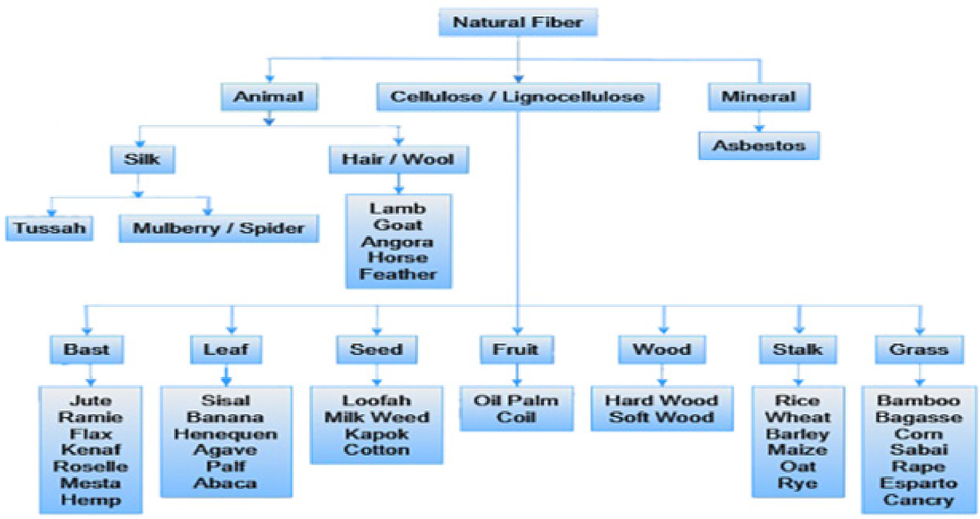

Figure 1: Classification of NFs.

Animal fibers

Animal fibers are one of the most commonly used NFs. Protein-rich animal fiber can serve as potential reinforcement in composite materials. Alpaca, angora, mohair, wool, and silk are a few examples. Animal fibers included feathers, silk, and hair or wool from animals. Animal hair such as sheep wool, goat hair, alpaca hair, horse's hair, etc. is collected from hairy mammals. With a variety of diameters, it is a multipurpose fiber that may be used to produce textiles, household fabrics, and apparel. The protein fibroin makes up silk fiber, which is stronger than any NF available. When making cocoons, fiber is accumulated from the dried saliva of bugs or other insects. Animal fibers that come from birds are known as avian fibers. In general, feathers and feathers fiber are avian fiber [1].

Plant/Cellulose Fibers

Cellulose makes up a large number of plant fibers, frequently with other substances like lignin. Cotton, coir, jute, flax, ramie, sisal, and other materials are some examples. Seed fiber, leaf fiber, fruit fiber, and bast fiber are other subcategories of this fiber. Seed fiber is collected from the seed and seed case, for example, cotton and kapok. Seed fiber is often referred to as cellulose-based fiber. Most frequently, the fiber is spun into yarn or thread to create textiles. Leaf fiber is collected from the cell of the leaves like sisal and agave. Ropes are manufactured using leaf fibers. They are the hardest fibers, which is probably a result of their higher lignin content. Fruit fibers are those that are collected from fruits, such as coir fiber. The fruit's unused portion is full of cellulose and lignin. Bast fibers come from the skin or bast that surrounds the stem of a particular plant, such as jute or banana. Phloem fiber is the other name for bast fibers. Compared to other fibers, these fibers have a higher tensile strength [18].

Mineral fibers

Mineral fibers are either naturally occurring fibers or fibers that have undergone minor modifications. These can be divided into three categories: metal fiber, asbestos, and ceramic fiber. The only naturally occurring mineral fiber is asbestos. Asbestos provides durability, fire resistance, chemical resistance, and heat resistance. Because of their beneficial properties, asbestos fibers are frequently used in industrial and commercial applications. One of the filament fibers with the smallest dimensions used in textile and other industries is ceramic fiber. It is capable of withstanding heat [18].

General Applications

In terms of performance and sustainability, the improved NFs reinforced polymer composite contributes to the advancement of biocomposites. Biocomposites have created significant commercial markets for value-added products. Composites, on the other hand, must meet high-quality performance, serviceability, durability, and reliability criteria in order to grow into other areas such as commercial buildings and consumer goods. NFs are environment-friendly, meaning that they are biodegradable. Being renewable, NFs are assumed as a good substitute for traditional materials.

Among all the NFs, jute fibers are one of the most common, most useful, inexpensive and commercially available lignocellulose fibers. Jute fiber offers high strength-to-weight ratio, high aspect ratio, good thermal properties, excellent insulating qualities, excellent mechanical capabilities, and excellent thermal properties [19]. Jute fiber-based composite has been used for making a door, window, furniture, automotive, aircraft, water pipes, false roofing, floor tiles, etc [20]. Jute fiber is used as packaging material (bags), carpet backing, ropes, door, furniture, floor tiles, yarns, and also used for wall decoration [21]. Hemp fibers always provide excellent mechanical strength and young's modulus. Hemp fiber is used in textile, paper, rope, oil production, rug and carpet manufacturing, used for ship cordage, interior design, apparel fabrics, also hemp fiber is used for blocking the sun's harmful ultraviolet rays industries [9]. Kenaf has many advantages such as used for fabricating composites, produce twin, rope, sackcloth, paper production, animal foods, manufacture oil, medicine, food additive, and also used for industrial applications, platform for mushroom farming, environmental cleaning, absorbents, automotive industries and textiles, building materials, oil and chemical absorbents [20, 22]. Bagasse can be used to produce animal feed, furfural, and bio degradable composite materials [23]. Bamboo has wide application area such as food, paper, textile, furniture, construction, manufacturing bathroom products, decorating items, hygiene products, etc. [9].

Coir fiber reinforced composites used for packaging material, helmets, rope, finishing nets, brushes, mattresses, automotive interior, paneling and roofing as building materials, postboxes, mirror casing, storage tank, projector cover, voltage stabilizer cover [24, 25]. Abaca is one of the strongest cellulose fibers which is used for marine applications, resistant to saltwater, commonly used for fishing nets, meat casings, tea bags, high-quality paper, machinery filters, hospital textiles, electric conductor, etc. [26, 27]. Cotton is generally used as secondary fiber in green hybrid-composites [28]. There are thousands of different fibers in the world and in fact only few of these fibers have been studied. Most research has been carried out to study the potential use of NFs for technical applications and reinforced composites materials. It should be mentioned that there are also shortcomings; a lack of consistency of fiber qualities, high levels of variability in fiber properties related to the location and time of harvest, processing conditions, as well as their sensitivity to temperature, moisture and UV radiation. A multi-step manufacturing process is required in order to produce high quality NFs, which contributes to the cost of high-performance NFs as well as the improved mechanical properties of the composites [4].

Synthetic Fibers as Artificial Fibers

An artificial fiber, also known as a synthetic fiber, is a threadlike substance developed by humans. Such fibers do not exist naturally. Most SFs are polymers. Polymers are the building blocks of SFs and of many other things. A polymer is a chemical compound formed when one or two tiny molecules combine with one other repeatedly. A monomer is the first molecule employed in the formation of a polymer. Artificial or chemical fibers are fibers whose chemical composition, structure, and properties are significantly modified during the manufacturing process.

SFs or artificial fibers are made by humans through chemical synthesis, as opposed to NFs that are directly derived from living organisms. They are the result of extensive research by scientists to replicate natural occurring animal and plant fibers. SFs are produced by humans through a series of processes that begin in a laboratory setting. The procedures to make SFs typically involve the use of petroleum- or coal-derived polymers and other artificial chemical materials. Many forms of SF are popular for their attractive aesthetics, and many are actually produced to imitate the appearance of NFs such as cotton, wool, or silk. The polymers that constitute SFs are prized for their strength, toughness, resistance to heat and mildew, and ability to hold a pressed form, they are often smooth to the touch, lightweight, cost-effective, and wrinkle-resistant.

Chemically synthesized fibers are SFs, and they are further classed as organic or inorganic, depending on their composition. Because the fibers' stiffness and strength are so much greater than the matrix's, they serve as a load-bearing component in composite structures [29-31].

History of Synthetic Fibers

For centuries, all textiles originated from fibers that were harvested from a plant, animal, or insect. Subsequently, at the end of the 19th and beginning of the 20th century, humans discovered that they could create textile fibers of their own. Those early fibers still originated from a natural source, cellulose from wood pulp, but soon enough, in the 1930s, 1940s and 1950s, a stream of SFs came on the scene that owed their origin in chemical plants instead of plants that could be grown in the field [8]. The idea for manufacturing artificial fibers seems to have been advanced first by R. Hooke in his Micrographia, published by the Royal Society in 1665. In 1833 Braconnot described the nitration of various celluloses and Liebeg established the tendency of nitrated cellulose to decompose violently when heated. In 1847 Schonbein augmented the nitration process by using sulfuric acid as catalyst. The first fibers based on nitrated cellulose were generated by Swan. In 1890 Count Hilaire de Chardonnet obtained so-called "artificial silk" based on this modified cellulose [32]. In 1894 Cross and Bevan discovered that cellulose can be converted by alkali and carbon disulfide to the water-soluble xanthate from which cellulose can be regenerated by various reagents.

The new artificial fibers known as "viscose" had two advantages over nitrated cellulose: they did not require (i) denigration and (ii) the use of expensive solvents in their manufacture [32, 33]. The commercial viscose (a process that is still in use) was not developed until 1903. The name rayon was accepted by all producers of regenerated cellulose fibers in 1924 [34]. Carothers is recognized as the inventor of the first SF, known as nylon 66. In 1929, he presented his polycondensation theory and related it to polyaddition. His preliminary research on aliphatic polyesters was completed and published before discovering the aliphatic polyamide with a higher melting point; this one could be spun into a practical clothing fiber appropriate for many of the same purposes as natural silk. Nylon 66, made from a diamine and diacid, each with six carbons, was commercialized before 1940 and continues to grow in importance today [35]. In 1941 Whinfield and Dickson acquired an aromatic polyester, PET, and discovered it to have enormous potential as a fiber- and film-making polymer. Its large-scale manufacture started in 1953 [10, 36]. Acrylonitrile (AN) was prepared by Moreau in 1893. Poly(acrylonitrile) (PAN) was developed for fibers in 1940; patents based on the utilization of concentrated aqueous solutions (in Germany) and organic liquids (USA) were obtained in 1942. PAN pilot manufacturing began in the United States in 1943, and the first acrylic fiber (Orlon) was created in 1948 and commercialised in 1950. By definition acrylic fibers contain 85% or more AN. Along with PAN was developed a class of fibers known as modacrylic. By definition they are based on co-polymers containing less than 85% but more than 35% AN by weight. Their production started in 1949. Such kind of fibers often contain as co-monomer a high amount of vinyl chloride, vinylidene chloride or vinylidene cyanide [7, 37]. Polyvinyl alcohol (PVA) was produced in 1924 by the saponification of polyvinyl acetate (PVAc). PVA fibers (Vinylon) were produced in 1951 in Japan by coagulating the extrudate from an aqueous PVA solution in an aqueous sodium sulfate solution. Their insolubilization is done by treatment with formaldehyde [38]. Based on the discovery of heterogeneous stereospecific catalysts by Ziegler, Natta obtained in 1954 crystalline polypropylene (PP). Commercial production of PP fibers and filaments commenced in 1957. The excellent wear and resistance to staining associated with low cost led to the use of such fibers for various applications [39].

The first aromatic polyamide (aramid) fiber based on poly (m-phenylene isophthalamid) (MPD), known as HT-1 and later re-named, was commercialized under the trade name Nomex by DuPont in 1967.These aromatic polyamides have at least 85% of the amide linkages attached directly to two aromatic rings. In 1973, DuPont started production of another aromatic polyamide fiber, a poly (p-phenylene terephthalamide) marketed as Kevlar; this fiber has exceptional strength competitive with glass, steel and carbon fibers [40]. Carbon fibers, first used as light bulb filaments in 1879, trace their modern history back to about 1942. The first commercially produced carbon filament was made from a cellulosic precursor for its application as incandescent lamp filament. Union Carbide began investigating systematic work on the carbonization of rayon and PAN yarns and textiles during WWII. In 1959 and 1961, two techniques for producing high-strength, high-modulus carbon fibers from rayon and PAN were developed almost simultaneously. Later, in 1963, a high-modulus fiber was created using pitch. Since 1980, ultra-high-strength fibers from PAN and ultrahigh-modulus fibers from pitch have been developed and are used extensively in the aircraft and spacecraft structures [38, 41-43].

Spandex was accidently produced by scientists in the late 1950s while attempting to manufacture a new form of synthetic rubber. It is a lightweight, robust, and elastic polyester-polyurethane that maintains its form after stretching. Spandex is most popularly used in athletic gear and sportswear because it does not absorb moisture and oils from the skin while exercising [38]. Glass wool, which is one product called “fiberglass” today, was invented sometime between 1932 and 1933 by Games Slayter of Owens-Illinois, as a material to be used as thermal building insulation. It is marketed under the trade name Fiberglas, which has become a genericized trademark. When glass fiber used as a thermal insulating substance, is specially constructed with a bonding agent to engulf many small air cells, resulting in the typically air-filled low-density “glass wool” family of products.

Types of Synthetic Fibers

Synthetic Fibers are basically classified into three major categories: organic fibers, inorganic fibers, and others, which are further sub-classified according to their origin. The broad classification of SFs are illustrated in Figure 2.

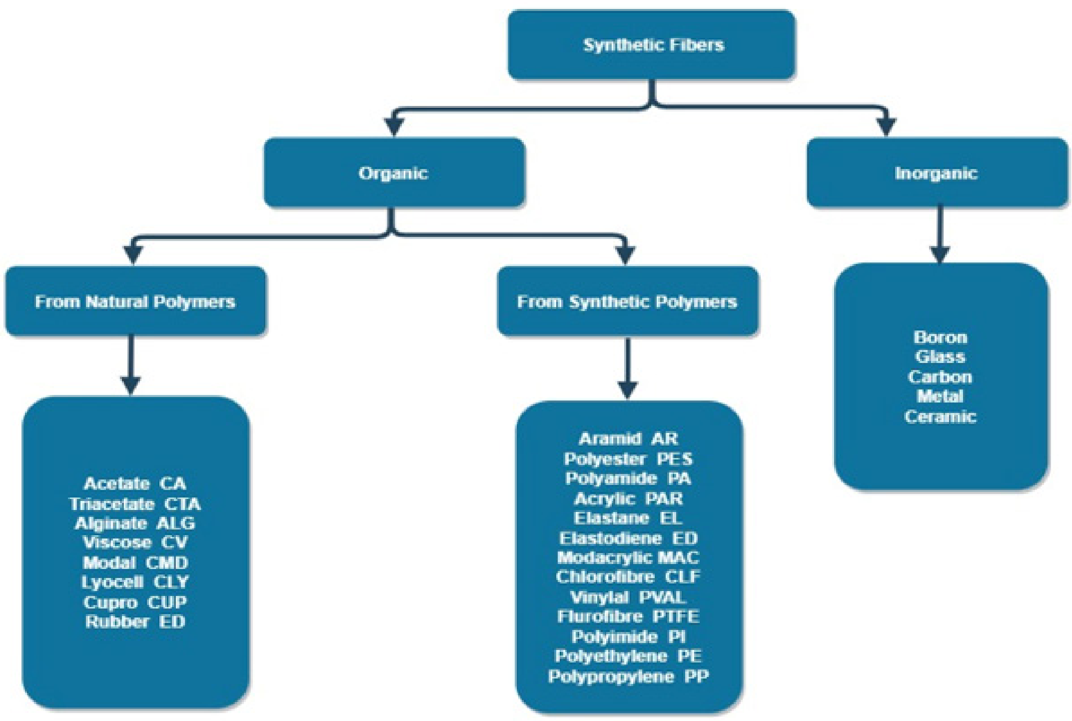

Figure 2: Classification of SFs.

Organic Synthetic Fibers

Organic fibers are derived from a product that grows in the soil, is collected from animal skin, or is produced by an insect. Abaca, camel hair, jute, hemp, coir, aramid, and silk are some popular examples of biological fibers, and the softness of items created from these fibers varies greatly. Silk is a fantastic fiber that grows from the cocoon and is acquired from the cocoons of a specific caterpillar that feeds on mulberry. Organic SFs are generally thermoplastic, with some being elastomeric and just a few being thermosets. Organic SFs are also extracted from natural polymers and SFs [44-46]. Some regular and important organic SFs are discussed below:

Synthetic Fibers from Natural Polymers

Acetate Fiber

Cellulose acetate is a natural-based man-made fiber with distinct qualities that allow for the development of attractive, practical, and pleasant textiles when used alone or in combination with other natural, artificial, or synthetic yarns or fibers. Acetate yarns were originally employed in the textile industry in the early twentieth century. Acetate yarns have increased in favour of the fashion sector since then. Acetate yarns are still widely used in weaving and knitting today. Acetate yarns' qualities allow them to be utilized to suit the demands of both mass-market items like linings and high-end textiles in more demanding markets "niche" products [47-49].

Application: Acetate fiber is used in formal wear, nightgowns, coats, accessories for Japanese dresses, neckties, blouses, sweaters, scarves, blankets, bedclothes, fabrics for curtains, umbrellas, cigarette filters, etc.

Triacetate Fiber

Cellulose triacetate is a cellulose-based SF. In 1865, Schutzenberger was the first to discover cellulose triacetate. This early acetate, on the other hand, was a stiff, hard plastic with a high acid content that could only be dissolved in costly chlorinated solvents. As a result, cellulose triacetate was not economically feasible until the mid-1950s, when more cost-effective solvents became available. Triacetate is a durable fiber that is resistant to stains, chemicals, direct sunlight, insects, and moisture. It should not be dry cleaned, but it will not be damaged by regular laundry. It dries rapidly in air or cold dryers and retains its form without the need for ironing. Triacetate is a strong, crisp fabric that is typically seen in taffetas and suits [47-50]. It is used to make drip-dry garments, tablecloths, skirts, and pants. It's frequently used to enhance the washability and crease retention of wool blends. It is soluble in chloroform, methylene chloride, m-cresol, 90% phenol, insoluble in acetone, unaffected by dilute acids, alkalis, and bleaches, and exhibits longitudinal striations in the fiber.

Applications: Triacetate is a substance that can be found in woven and knitted fabrics that don't shrink or cockle, as well as undergarments and lingerie that are warp-knit and retain their shape. Triacetate is used with cotton and viscose to make textiles that are entirely stable and create permanent pleats, and it is mixed with wool to give the blend non-shrink properties. The permanent pleating qualities achieved in triacetate textiles when combined with viscose rayon staple or cotton are particularly appealing for applications such as skirts and trousers. Triacetate is mixed with wool to make textiles that combine wool's warmth with triacetate's heat setting and drip-dry qualities [47-50].

Alginate Fiber

In 1883, English scientist C. Stanford found that common brown seaweeds had a chemical that functioned similarly to cellulose in terrestrial plants. This molecule, now known as alginic acid, is a d-mannuronic acid polymer with a molecular weight greater than 15,000 times that of water.

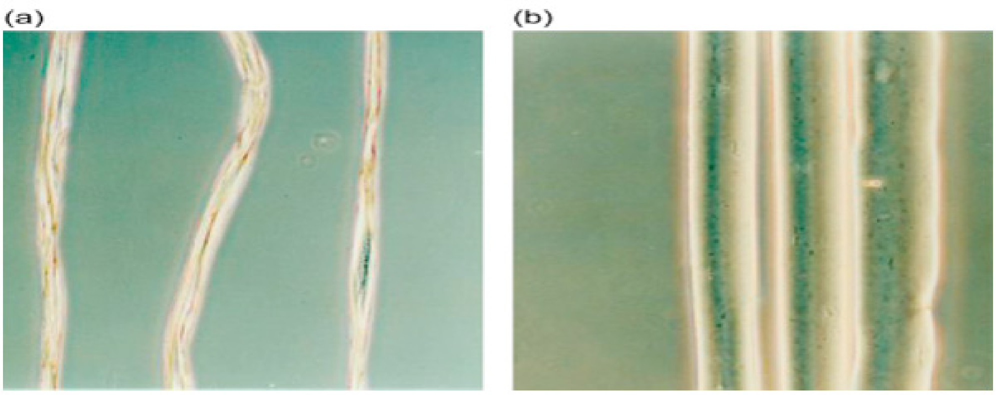

Figure 3: Photomicrographs of alginate fibers: (a) wet in water; (b) wet in saline [49].

Alginic acid accounts for one-third or more of the dry weight of many seaweed species, and it may be found in nearly infinite quantities among the millions of tonnes of weeds that litter the world's beaches. The sodium salt, sodium alginate, is generated when alginic acid is treated with caustic soda. The alginic acid present in seaweed can be obtained by treating it with caustic soda or other alkaline solutions, and sodium alginate is soluble in water, which forms a viscose solution [48].

Applications: It's non-flammability is a valuable property that has led to it's use in theatre curtains. Washable alginate fabric would be particularly appealing for children's clothing. Alginate fibers' alkali solubility has led to a variety of specialized applications, such as: strength providers in loosely spun wool yarns. Alginate fibers are dissolved after knitting, leaving a fluffy light-weight fabric that is not possible to make using traditional methods. Calcium alginate yarn is very appealing to the hosiery sector. A few courses of alginate yarn are used to connect the toes of the socks, which are produced continuously. The socks are detached by cutting the alginate yarn, which is then dissolved. This technique produces flawless welts in all types of socks. A calcium/sodium alginate yarn produces styptic elastic dressings and dressings that are hemostatic, non-toxic, and absorbable in the bloodstream for medical application. It is used in dental surgical treatment for plugging cavities [48-51].

Viscose Fiber:

Among all fibers, rayon, commonly known as viscose or viscose rayon, is arguably the most permeable to consumers. It has cotton-like end applications, as well as rich velvets and taffetas. It may be used to add strength to absorbent hygiene and incontinence pads, as well as tire cords. Rayon is created from wood pulp, which is a reasonably affordable and renewable resource, but its production consumes a lot of water and energy and pollutes the air and water [52]. The availability of raw resources, together with the upgrading of manufacturing plants and methods, has boosted Rayon's market competitiveness.

Applications: Used in various applications:

Yarn types include embroidery thread, chenille, cord, and novelty yarns.

Crepe, gabardine, suiting, lace, outerwear fabrics, and lining for fur coats and outerwear are examples of fabrics.

Blouses, dresses, saris, jackets, lingerie, linings, millinery (hats), slacks, sports shirts, sportswear, suits, ties, and work clothes are examples of apparel.

Textiles used in homes include tablecloths, curtains, draperies, sheets, slipcovers, bedspreads, and upholstery.

Industrial textiles: Braided cord, tape, conveyor belts, and other mechanical rubber products (such as hoses, conveyor belts, and tires) are all made of high-tenacity rayon [52].

Modal Fiber

Modal fiber is a regenerated fiber and the next generation of rayon fiber. This fiber is manufactured from wood chips from a "beech tree" (European Schneider Zelkova species). It's a "high wet modulus fiber" that was created using a modified viscose process and modified precipitating baths. Modal fibers have a greater wet strength than conventional viscose fibers. It is abrasion-resistant while remaining soft to the touch. It's also an excellent drape cloth. Through this process, fiber properties are improved, including wear, dry and wet strengths, and dimensional stability. The modal fiber contains modified cellulose from beech trees.

Applications: Modal fiber is used to get comfort and aesthetics, sheen, shine and naturality. Therefore, it is used to make products such as: T-Shirts, Socks, Sport wear, Bed sheets, Underwear, Towels and Bathrobes, etc.

Cupro Fiber

Cellulose dissolves in cuprammonium liquor, a solution of copper salts and ammonia, and regenerated cellulose fibers are formed by extruding this solution into a coagulating bath. The yarn manufactured by the cuprammonium process consists of regenerated cellulose; it has since become widely recognized by the name of cupro.

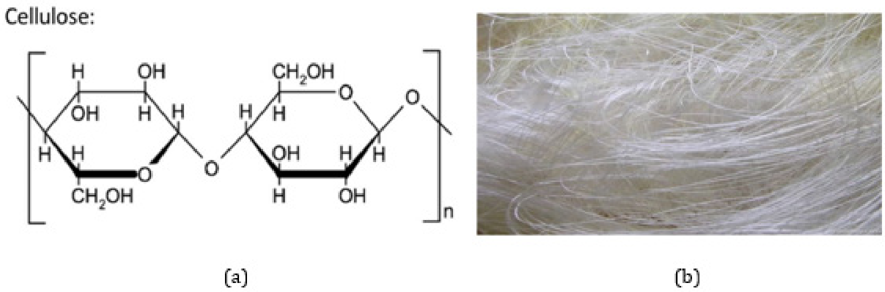

Figure 4: a) Cellulose chemical structure, b) Cupro fiber.

Applications: Cupro is adopted to create chiffons, satins, nets, ninons, as well as other sheer fabrics. A wide part of this yarn is used in underwear, dress fabrics, and linings. Slub yarn, for instance, is used in an extensive variety of applications, particularly as weft. Slub yarns are used in a variety of fabrics, including dress fabrics, sportswear, and fine drapery fabrics. The manufacturing of yarn-dyed fabrics for high-quality silk-like linings, dresses, and upholstery fabrics is a specialty end use. Reel-spun yarns are suitable for these applications since they are produced in skeins that are ready to dye in the untwisted state. The dyed yarn is used for both the weft and the warp, with the weft being untwisted and the warp being twisted [47-48].

Rubber

Rubber is a natural polymer produced from the coagulation of latex produced by particular species of plants, most notably the rubber tree Hevea brasiliensis, which evolves in tropical climates. Rubber is a resilient, elastic material that softens and becomes plastic and dough-like when heated up. Rubber is kneaded and mixed in powerful mills while processing. This softens the rubber, making it more thermoplastic and eradicating the raw polymer's elasticity [48,50]. In the meantime, milling allows other materials, such as sulfur, to be mixed into the rubber, that is used in the subsequent vulcanization or curing technique.

Figure 5: Tires made of synthetic rubber.

Applications: Artificial rubbers are mostly used in Tire industry (car, aircraft and bicycle tires), Corsetry, Swimwear, Footwear, Surgical hosiery, Men's and children's hosiery, underwear and outerwear.

Lyocell Fiber

Lyocell fiber (U.S. brand name Tencel) is another type of regenerated cellulose fiber made from wood pulp. Lyocell rayon fiber is produced by directly dissolving cellulose into the solvent N-methylmorpholine-N-oxide (NMMO). Lyocell rayon is an emerging generation of regenerated cellulose fiber with environmentally amiable processing and improved fiber properties. Current production of lyocell fiber nevertheless is still limited, at less than 5% of the rayon fiber market. Its longitudinal surface is quite smooth and cylindrical despite any striation. Lyocell rayon fiber has distinct characteristics from viscose rayon in fiber shape and appearance, and this differentiation enables lyocell rayon fabrics to exhibit better fabric feel and drape [52].

Applications: This fiber is vastly used in:

As a substitute for cotton and silk - used to make dresses, towels, underwear, etc.

For commercial uses - used as fabric parts of conveyor belts

For medical applications - used in medical dressings

Used as filtration materials

Synthetic Fibers from Synthetic Polymers

Kevlar as Aramid

Kevlar is a manmade fiber, it is a naturally occurring fiber in the aromatic polyamide family. The distinctive properties and very different chemical composition of wholly aromatic polyamides (aramids) distinguish them from other man-made fibers. Kevlar fiber has a unique arrangement of high strength, high modulus, toughness, and thermal stability. It was constructed for demanding industrial and advanced-technology applications. At the moment, numerous kinds of Kevlar are produced to meet a broad range of end-users [47].

Applications: Kevlar fibers are used in:

Brake pads: Brake pads built from Kevlar pulp are well equipped to endure the wear and tear that friction creates with their enhanced thermal stability and inherent abrasion resistance; reinforced brake pads made of Kevlar are designed for a long lifespan and safe, quiet braking.

Clutches: Kevlar is also efficient in clutches, which are subject to severe frictional stress. Evaluations have shown that clutch linings with Kevlar do not require service or replacement as often as standard clutch linings.

Vehicle armor: Kevlar offers an effective, lightweight armor solution that assists in protecting against ballistic attack, allowing cars and light trucks to retain most of their original handling characteristics while stopping multiple rounds. Law enforcement agencies, cash security companies, and people who live or work in hostile circumstances trust Kevlar armor to help boost security in vehicles where weight is a critical factor.

Marine Composites: Kevlar reinforcement helps reduce weight despite compromising strength in marine, energy, and maritime vessel composite materials.

Aerospace, Marine, & Rail: Kevlar aids manufacturers in the aerospace, marine, and rail industries to construct aircraft, ships, and rail carriages. Performance features associated with Kevlar can help to increase fuel efficiency and decrease maintenance and operating expenses.

Military Helmets: Kevlar fiber is a very significant part of the military's assets. By incorporating its inherent safeguarding technology into military helmets, it has helped to save thousands of human lives.

Ropes & Cables: From land to sea to space, learn how Kevlar brand fiber has enabled strengthened ropes and cables to stand up to extreme temperatures and harsh conditions.

Sporting Goods Apparel & Accessories: The pursuit of lighter, stronger, and safer sporting goods has made Kevlar a common choice for both equipment manufacturers and consumers [47, 48, 53].

Nomex Fiber as Aramid:

DuPont invented Nomex, a flame-resistant meta-aramid substance, in the early 1960s, and it was first commercialized in 1967. Nomex is comprised of the monomers m-phenylenediamine and isophthaloyl chloride in a condensation reaction. It's obtainable in both fiber and sheet form, and it's used as a fabric where flames and heat resistance are necessary. A nomex sheet is a calendered paper that is formed in the same way [51-53]. The first Nomex paper was created, and it was one of the higher volume grades produced, mostly for electrical insulation produced in the USA.

Applications: It used in sandwich panel applications, like as:

Aircraft flooring – ranging densities depending on the level of duty.

Aircraft interiors – that vary from side walls galleys and ceilings, involving commercial aerospace, and business to interiors.

Helicopter rotor blades, cargo liner, leading and trailing edges of aircraft, as well as fuselage parts.

Nomex is utilized in gloves, hoods, driver protection, driving shoes and protective clothing, firefighter protection sacks, filtering material [47].

Polyester Fiber:

Polyester fiber is made from poly (ethylene terephthalate), sometimes known as PET polymer. One of the most significant SFs is polyester fiber. The molecular mass of PET polymer employed in the preparation of polyester is in the range of 20,000-40,000. Dimethyl terephthalate (DMT) or terephthalic acid (TPA) and mono-ethylene glycol (MEG) are the basic ingredients used to make polyester. Because high purity TPA necessary for polymerization was not available, most of the early facilities relied on DMT as a raw ingredient. However, technologies for producing pure TPA are now accessible, and TPA is increasingly being used as a raw ingredient in the manufacture of polyester [47-51, 53].

Applications: It does has several uses, such as: It is used for making sweaters and tracksuits, boots and gloves, furnishing fabrics and carpets, it is also used to make fur and many different knitted clothes.

Polyamides

Polyamides are polymers which comprise recurring amide groups as vital components of the main polymer chains. Polyamides are naturally found in protein fibers such as silk and wool. Synthetic Polyamide fiber is one of the most significant kinds of textile fiber, commonly referred to as "Nylon." Synthetic polyamides are produced by a condensation reaction. Nylon 66 and nylon 6 are two key members of the polyamide family of polymers [47]. The building blocks of polyamide are joined together by an amide, -NH-CO-, group. Nylon is a polyamide that is frequently made from aliphatic monomer(s). The US Federal Trade Commission, however, has denied nylon as a manufactured fiber in which the fiber-forming substance is a long-chain synthetic polyamide in which less than 85% of the amide linkages are connected directly to two aromatic rings, whereas an aramid is a polyamide in which at least 85% of the amide links are joined to two aromatic groups. [48-52].

Applications: Synthetic polyamides are broadly used in textiles, automotive industry, carpets, kitchen utensils, sports wear, etc. The transportation manufacturing industry is the primary consumer, accounting for 35% of polyamide (PA) consumption.

Acrylic Fiber:

Next to polyester and polyamides, acrylic fibers occupy an eminent position in the family of SFs. The significance of acrylic fibers has been demonstrated by their phenomenal growth and their popularity throughout the world. Acrylic fibers have largely supplanted wool in a variety of significant uses, most notably hand knitting and hosiery clothing. Acrylic fiber competes with wool in blankets and carpets due to its great elasticity, colour brilliance, voluminosity, ease of washing, pill resistance, and good light and colour fastness. Acrylic fibers have grown exponentially since their debut by Du Pont, USA, in 1950. Acrylic fibers are created with acrylonitrile as one of the primary monomers [50-52].

Modacrylic Fiber:

Modacrylics are synthetic copolymer fibers featuring less than 85% but at least 35% acrylonitrile by their weight. A modacrylic fiber called Vinyon N is composed of 60% vinyl chloride and 40% acrylonitrile. The staple fiber is commonly referred to as Dynel. Taklan is yet another fiber created from acrylonitrile-vinylidene copolymer. Fundamental properties are built into modacrylics over the fiber-forming technique. The procedure variables particularly in the after-treatment following spinning are key variables in determining modacrylic properties [50].

Application of acrylic and modacrylic fiber: The best-performing fake furs are produced from modacrylic and acrylic fibers, which are widely used in hairpieces and doll hair. Both fibers are beneficial for outdoor applications such as awnings due to their superior sunlight resistance, with modacrylics offering additional flame resistance. Regardless of the low softening temperature, modacrylics' low flammability presents a measure of safety; end uses based on this property include airline blankets and military sweaters. Acrylic fibers can be utilized as raw materials in the manufacture of carbon (graphite) fibers [50].

Polyethylene Fiber

Chemically polyethylene (PE) is the simplest polymer as the repeating unit of the polymer is ethylene ($-CH_2-CH-$). However, due to the tetravalent carbon atom, the formation can be linear structure or a branched structure [53].

Applications: HDPE are used in low-molded bottles for milk, grocery bags, construction film, agricultural mulch, injection-molded pails, caps, appliance housings, and toys; LDPE are used in Packaging film, garbage and grocery bags, agricultural mulch, wire, and cable insulation, squeeze bottles, toys, and housewares; LLDPE are used in Liquid containers, paperboard packaging, stronger films, etc. And many more like: Medical implants, Cable and marine ropes, Sail cloth, Composites like Pressure vessel boat hulls, Sports equipment, Impact shields, Fish netting, Concrete reinforcement, Protective clothing, Radar protective cover due to its low dielectric constant, etc. [48-50].

Polypropylene Fiber:

Polypropylene is produced by the polymerisation of propylene using a catalyst in solution, mass or gas phase. For the polymer, propylene monomer is polymerized to produce polypropylene. The reaction is set up when a propylene molecule is added to an organometallic influential center [48]. Propagation takes place by adding monomers at the active organometallic center. The reaction terminates either by monomer transfer, metal alkyl transfer, or hydride ion movement, along with realkylation of the catalyst [49-50].

Applications: Usage of polypropylene fibers in Industrial pavements, Highly resistant concrete, Industrial grounds, Tunnels, Roads, Special mortars, Precast concrete [50].

Inorganic Sythetic Fibers

Nowadays inorganic fibers are becoming more and more popular. Some most common fibers manufactured from inorganic synthetic materials are glass, carbon, boron, and ceramics, etc.

Boron Fiber:

Boron fiber is an amorphous elemental boron outcome that is greatly adopted in aerospace utilization due to its high strength and lightweight characteristics. It is fabricated by chemical vapor deposition (CVD) of boron at a temperature of 1000°C on a substrate and obtained fiber is called boron fiber. Due to the internal residual stresses in the boron fiber, a significant impact on the fiber mechanical properties takes place at the time of CVD as the boron trichloride (BCl3) is mixed with hydrogen and boron.

Applications: The structure of boron fiber depends mainly on temperature, gas composition, and gas dynamics. The downside of boron fiber is its high cost in comparison to other fibers; it is primarily utilized in numerous US military aircraft, namely the F-14 and F-15, as well as the space shuttle. Furthermore, it may be utilized for metal construction rehabilitation [31].

Glass Fiber:

Glass fibers (GFs) are manufactured by melting silica sand, limestone, boric acid, and some other ingredients at a very high temperature of about 1200°C above. Additionally, in the obtained composition some oxides of multiple metals are added. Glass fiber is exceptionally fine, lightweight, high strength, and also very robust material.

Types and forms of fiber glass

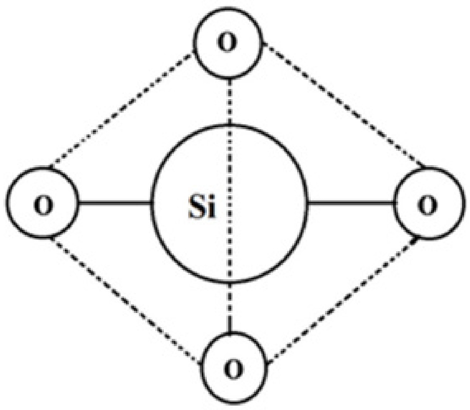

Figure 6: Chemical structure of glass fiber.

Depending on the raw materials used and their proportions to make fiberglass, fiberglass can be classified into following major types [4, 31]:

A-glass: A glass is also called as alkali glass and is reluctant to chemicals. Due to the composition of A glass fiber, it is close to window glass. In some regions of the world, it is used to make process equipment.

C-glass: C-glass offers very reliable resistance to chemical impact and is also called as chemical glass.

E-glass: Also called as electrical glass that has very good insulator of electricity.

EC-glass: It is also called electronic glass fiber, has well waterproofing ratio, high mechanical strength, electrical acidic and alkali corrosion resistance.

R-glass: R-glass is a reinforcement glass made of calcium aluminosilicate used where higher strength and acid corrosion protection are required.

AR-glass: This is alkali resistant glass. They contain alkaline zirconium silicates. They are viable to prevent concrete cracking.

S-glass: S-glass is normally used for polymer matrix composites that necessitate improved mechanical characteristics. S-glass fiber is used for high-performance systems.

Applications: Glass fibers them are used for various purpose, such as: Beverage industry, Car washes, Chemical industry, Cooling towers, Docks and marinas, Food processing, Fountains and aquariums, Manufacturing, Metals and mining, Power generation, Plating plants, Pulp and paper industry, Automotive industry, Aerospace and Defense and so on. There are certain glass fibers that can resist heat upto 7200°C and can withstand forces having speed of 15,000 miles per hour. These types of glass fibers are used as: Filament winding around rocket cases, Exhaust nozzles, Heat shields for aeronautical equipment, etc [47-51].

Carbon Fiber:

Carbon fiber (CF) is made of thin, resilient crystalline carbon filaments, and aims to strengthen the established composite materials [54]. The diameter of the carbon fiber can extend up to 5 microns (sometimes below), increasing its strength when twisted collectively like yarn. CF can sometimes be recognized as a graphite fiber. CF has many advantages such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance, and low thermal expansion. These facilities have made CF very prominent in space, architecture, military, motor sports. CF is twice as rigid as steel and five times stronger. All these attributes make this material ideal for the manufacture of different components [55]. CF is created using a combination of chemical and mechanical processes. Light heating of the polymer to 600 C in the chemical approach, which discharges hydrogen gas and neighbouring polymer chain detonators. Different chains can merge because they excrete more hydrogen and nitrogen when heated to 1300 C; the remaining pure sheet is made up of carbon atoms [47, 48].

Applications: The carbon fibers are an essential part of many products, and new functions are being developed every year. Carbon fiber-reinforced composite substances are used in the automotive and aerospace sector, sports, and numerous additional elements where lightweight and high strength are required. Carbon fibers are used in the following fields: Aeronautical industry, Automobile industry, Recreation industry, Civil Engineering, Medical field, Power plant, Audio equipment, Prosthetic surgery, Textile machinery, Additional applications like missiles, aircraft, antennae, telescopes, etc. [47-51].

Ceramic Fiber:

Ceramic Fiber is a man-made SF manufactured from small-dimension filament consisting of high-purity aluminosilicate materials. It is also known as ceramic wool or refractory product, cause it has a heat-resistant property white and odorless substances [47].

Applications: Ceramic fibers are often in high-temperature insulation covers and gaskets, Thermal shields, Fire barriers, Fire Retardant Fabric, Protective blankets, and Wrapping, Composite strengthening, electrical insulation [47, 48, 56].

Table 1: Mechanical properties of SFs [4, 31, 47-51, 56-58].

Fibers	Tensity (MPa)	Elongation at break %	Young's modulus (GPa)	Density (g/cm^3)	Melting point (°C)	Moisture regain %
Acetate	122.7-145.2	23-30% (dry); 35-45 % (wet)	3.25	1.29	232	6.50%
Triacetate	128.2-163.1	25-35% (dry); 30-40% (wet)		1.32	3000	2.5-3.5%
Alginate	62.1-79.8	2-6 % (dry); 25% (wet)	5.05	0.45	>130	>16%
Viscose	336.8-449.1	13%	5-Mar	1.59	>150	11 – 13%
Modal	2970.8-5401.5 (dry); 513.1-675.2 (wet)	7% (dry); 8.5% (wet)		1.53		11.80%
Cupro	226.5-302.0 (dry); 146.5-179.7 (wet)	10-17% (dry); 17-33% (wet)		1.54	250	12.50%
Rubber	62.8; Spandex: 97.3	700-900%, Spandex: 700-800%	1.04	1.2 (NBR)	>108	0%
Lyocell	586.9 (dry); 534.8 (wet)	15-18% (dry); 18-19% (wet)	1.6	1.33	>150	11-13%

Kevlar	K-29	2923.2	3.60%	69.9	1.44		6
	K-49	2943.5	2.80%	121.6	1.45	560	4.3
	K-68	2923.2	3.00%	99.1	1.44		4.3
	K-119	3050.3	4.40%	54.6	1.44		
	K-129	3391.4	3.30%	95.9	1.45		
	K-149	2335.4	1.50%	142.7	1.47		1.5
Nomex		397.2-873.8	20 – 35%	11.35	1.8	350	
Polyester		426.3-852.6	15-30%	13.1	1.38	255-265	0.40%
Polyamids		452.8-583.6 (dry); 452.1-513.1 (wet)	23–42.5% (dry); 27–34% (wet)	3.5-5.0	1.14	223	4.0-4.5%
Acrylic		68.9	4.50%	3.32	1.19	195	1.0-2.5%
Modacrylic		258.2-464.7 (dry); 206.5-413.1 (wet)	27–48%		1.17	330 – 340	2.0-4.0%
Polyethylene	LDPE	82.9-248.8	20-80%		0.93	105-115	Negligible
	LLDPE	165.9-414.8	20-50%	0.2-0.3	0.94	115-135	<0.01%
	HDPE	290.3-622.2	10-45%		0.95- 0.96	120-140	
Polypropylene		278.0-357.5	25-30%	36-40	0.9	325-225	0.30%
Boron		344.1	0.80%	320	2.58	2000	
Glass	A	3300	4.8	68.9	2.44		
	C	3300	4.8	68.9	2.52		
	E	3448	4.7	72.3	2.58		
	EC	3400	4.8	85.5	2.72	1335 (approx.)	0%
	R	4400	5.1	85.5	2.54		
	AR	1700	4.4	73.1	2.7		
	S	4600	5.7	86.9	2.46		
Carbon		1.7-1.85	0.3–1.8%	200-500	1.75-1.96	3650-3700	0%
Ceramic		3000		210	3.9	1790	0%

Natural Fibers Vs Synthetic Fibers

The necessity for Synthetic Fibers (SFs) is advancing globally, as it is a highly significant form of material for fiber-reinforced composite structures. The growing demand for lightweight and unique composite materials increases the need for SFs due to their excellent characteristics. There is strong competition between Synthetic Fibers and NFs. Due to the environmental sustainability, NFs are employed as a standby for SFs. Some favourable cases of NFs over SFs are [59]:

1. They are environment-friendly, meaning that they are biodegradable, and unlike glass and carbon fibers, the energy consumption to produce them is very small.
2. The density of NFs is in the range of 1.25-1.5 g/cm3 compared with 2.54 g/cm3 for E-glass fibers and 1.8–2.1 g/cm3 for carbon fibers.
3. The modulus–weight ratio of some NFs is greater than that of E-glass fibers, which means that they can be very competitive with E-glass fibers in stiffness-critical designs.
4. NFs composites provide higher acoustic damping than glass or carbon fiber composites, and therefore are more suitable for noise attenuation, an increasingly important requirement in interior automotive applications.
5. NFs are much less expensive than glass and carbon fibers.

Table 2: The basic property comparison between natural and synthetic fibers [4].

Properties	Natural fibers	Synthetic fibers
Density	Low	Twice that of natural fibers
Cost	Low	High, compared to natural fiber (NF)
Renewability	Yes	No
Recyclability	Yes	No

Energy consumption	Low	High
Distribution	Wide	Wide
CO_2 neutral	Yes	No
Abrasion to machines	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not biodegradable

Table 3: Compares some of the qualities and features of SFs to NFs [1].

Synthetic Fibers	Natural Fibers
Artificially generated	It happens on its own (Naturally occur)
Depending on the reaction circumstances, chain lengths might vary greatly	Molecules with comparable chain lengths
Repetition of a single, identical element	Repetition that is similar but not identical
By manipulating the reaction, it is possible to get highly designed qualities	The qualities are regulated by the natural response.
Biodegradability exists in several synthetic polymers	Biodegradable is usually the case
Carbon makes up the majority of the backbone	The backbone may be composed of carbon, oxygen, or nitrogen

Table 4: Comparison of mechanical properties of natural and synthetic fibers [44, 60].

Fiber	Density (gcm^{-3})	Diameter (μm)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Flax	1.5	40-600	345-1500	27.6	2.7-3.2
Hemp	1.47	25-500	690	70	1.6
Jute	1.3-1.49	25-200	393-800	13-26.5	1.16-1.5
Kenaf			930	53	1.6
Ramie	1.55		400-938	61.4-128	1.2-3.8
Sisal	1.45	50-200	468-700	9.4-22	7-Mar
Abaca			430-760		
Cotton	1.5-1.6	Dec-38	287-800	5.5-12.6	8-Jul
Coir	1.15-1.46	100-460	131-220	6-Apr	15-40
E- glass	2.55	<17	3400	73	2.5
Kevlar	1.44		3000	60	2.5-3.7
Carbon	1.78	7-May	3400^{a}-4800^{b}	240^{b}-425^{a}	1.4-1.8

[a]Ultra-high modulus carbon fibers; [b]Ultra-high tenacity carbon fibers.

On the other hand, the selection of NFs depends on the availability in local level and after that is seeking to property requirements. It is seen that the mechanical properties of NFs are moderate as compared to those of SFs; similarly, in opposite manner, the thermal and moisture sensitivity of NFs is higher than that of the SFs. NFs exhibit superior mechanical properties such as flexibility, stiffness, and modulus compared to glass fibers.

In an environmental point of view, the major factor of selection of NFs to the SFs is that recyclability of NFs is better than the SFs [61]. The physical and mechanical properties of NFs are not as attractive as those of SFs. However, if we compare these properties, it can be well stated that SFs can be replaced for some but not all areas of the polymer composites. These areas can be interiors of automobile, dashboard, rooftops, tiles, etc., where the load bearing requirement is low [4, 5].

SF is that which is made from different types of polymers. SFs are all produced using the same fundamental processing technique called Polymerization [62]. In principle, a polymer fluid is forced through a series of fine holes that create the basic shape. The fluid is then encouraged to harden through cooling, chemical, or thermodynamic processes, which lead to a solid filament. There are four methods of spinning filaments of manufactured fibers: wet, dry, melt, and spinning [62, 63].

SFs are not fundamentally better than NFs, as their superiority depends on particular applications and preferences. Both types of fibers have their own benefits as well as drawbacks, and the preference between them often comes down to factors such as cost, performance, sustainability, and intended use. Here are some reasons why SFs may be considered better in particular circumstances:

i. SFs are recognized for their strength and durability, making them suitable for use in clothing, furniture, and other household items.

ii. SFs are usually less expensive than NFs, making them accessible to a broader range of consumers.

iii. SFs are less likely to wrinkle, shrink, and fade compared to NFs, making them beneficial for use in clothing and other items that necessitate a smooth, wrinkle-free appearance.

iv. SFs are less likely to be damaged by pests like moths and beetles than NFs, causing them suitable for use in clothing and other items that require a consistent appearance.

v. SFs can be used in a wide range of products, including clothing, upholstery, and industrial materials.

vi. Various SFs are made from petroleum products and do not require the use of animals, as NFs do.

vii. Some SFs are hypoallergenic and can affect people with sensitive skin.

However, it's essential to consider the downsides of SFs as well:

i. SFs are not biodegradable, which means they will not degrade naturally in the environment. This can result in pollution and wildlife damage.

ii. The production of SFs requires a significant quantity of energy, which can contribute to greenhouse gas stemming and climate change.

iii. Some SFs are hypoallergenic. People may experience allergic reactions to SFs, such as itching or rashes.

iv. SFs are not as breathable as NFs, which makes them uncomfortable to wear in warm conditions.

v. SFs are more prone to producing static electricity, which can be a nuisance and cause clothing to cling to the body.

vi. Many SFs are difficult to recycle and may end up in landfills, causing pollution and waste.

Radiation Effect on Synthetic Fibers

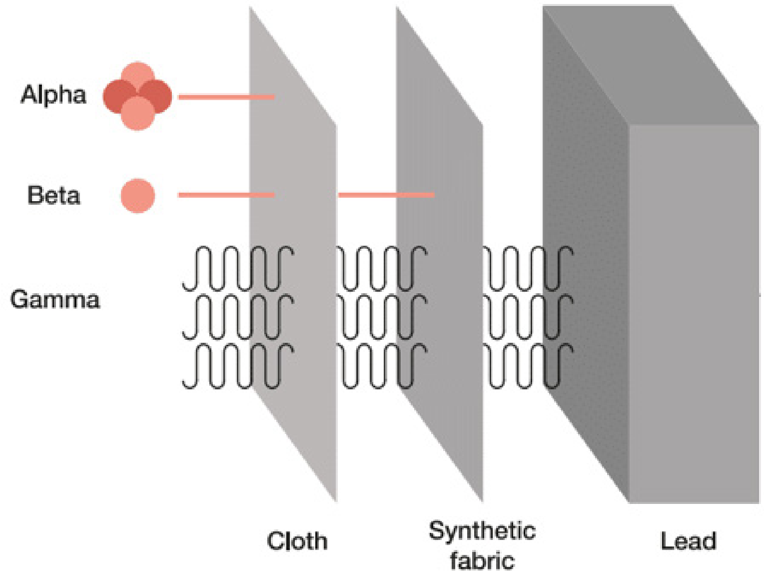

Figure 7: Radiation Shielding.

High-energy radiations such as alpha and beta particle emissions, X-ray or gamma ray electromagnetic radiation, or neutron particle emissions are frequently used or encountered (as a byproduct) in a variety of sectors such as nuclear power plants, healthcare, and aerospace. Unwanted exposure to any of these radiations may be lethal [64]. In industrial processes, gamma rays and electron beams are two major ionizing radiation sources. Gamma rays of 1.17 and 1.33 MeV are continually released from radioactive sources such as cobalt-60, whilst electrons are created from an accelerator to form an electron beam. The energy of electrons varies depending on the machine and might range from 200 keV to 10 MeV. High-energy radiation from standard gamma or e-beam sources is an appropriate tool for polymer material modification via degradation, grafting, and cross-linking [65]. Polymer long molecular chains can be broken by absorbing a quantum of energy beyond the energy of the primary carbon chain's covalent bond, which is commonly in the 5-10 eV range. The energy of beta and gamma photons of 1 to 10 MeV surpasses by many orders of magnitude this minimum value, indicating a high likelihood of affecting all kinds of polymers, naturals, and synthetics as well. Radiation, being a non-selective, very effective ionization tool, may produce excited sites, ions, and free radicals in practically any material. Radiation therapy of polymer mixtures, even if they are (partially) incompatible, gives a chance for bridge-forming bonds [66]. Depending on the kind and intensity of the radiation, as well as the unique properties of the synthetic material, radiation can have a variety of impacts on SFs such as [67-70]: Ionizing radiation, for example, gamma rays or X-rays, may break chemical bonds within SFs' polymer chain.

This procedure, known as polymer chain scission, may cause the material to weaken. Over time, this issue can end in decreased tensile strength and increased brittleness. Conversely to chain scission, ionizing radiation can further result in to cross-linking of polymer chains on a few SFs.

Cross-linking is capable of enhancing the strength, heat resistance, and chemical resistance of a material. This technique is often used in the curing of certain synthetic materials for specialized uses involving radiation. The color of SFs can be altered by radiation exposure. Certain SFs could turn discolored or yellowed after being exposed to certain forms of radiation, especially ultraviolet (UV) radiation from the sun. ultraviolet (UV) radiation can cause fading or color variations by breaking down the dye molecules applied in the fibers. Depending upon the dose and category of radiation, SFs may experience shifts in their mechanical characteristics, such as stiffness, flexibility, and elasticity. These modifications can have an effect on the material's functionality for various applications. Some SFs are better resistant to radiation than others. Certain high-performance SFs, for instance, aramid/kevlar, and polyethylene, are recognized for their radiation durability and are employed in situations where radiation exposure is a concern, such as protective garments for nuclear employees. Radiation exposure can raise the temperature of synthetic substances, particularly if the radiation is absorbed and turned into heat. This has a tendency to damage the material's qualities, especially if it is exposed to excessive amounts of radiation over an extended period of time. Radiation may lead to chemical modifications in SFs, possibly leading to shifts in their chemical composition. This can influence their inability to respond to chemicals or ecological factors.

It's necessary to remember that the consequences of radiation on SFs may differ significantly depending on the specific category of SF, its chemical structure, and the conditions of radiation exposure. In certain circumstances, SFs may be made to tolerate certain types of radiation, but in others, exposure to radiation may be a major concern. Manufacturers and scientists are extensively investigating these impacts in order to develop materials with specialized radiation-protective qualities for applications such as nuclear and other sectors where radiation exposure is a major concern.

Conclusion

The properties of SFs rely on the type of used fiber and its fabrication process. Because, compared to traditional fibers, SFs have superior mechanical, tribological, thermal, and chemical durability, their application for various purposes has been continuously increasing globally. Depending upon the chemical composition, SFs are categorized into organic, inorganic fibers, and others. Since prehistoric times organic fibers have existed in our regular applications. On the other hand, compared to organic fibers, inorganic fibers are recently invented and have been demonstrated to have remarkable properties, thus having a high potential for future studies. The primary advantages of SFs are long-lasting, stretchable, waterproofing, moisture resistance, strain as well as wear resistance; while they also have numerous drawbacks such as being flammable, not being suitable for hot washing, cause for micro plastic pollution, having poor insulation capacity, melting swiftly, being prone to heat damage, and not being eco-friendly. For the SFs to be used to their optimum potential they must be compatible with the matrix, to have physical and mechanical properties superior to the matrix, to offer the optimal orientation in composite, and to make chemical or adhesion bonds with the matrix.

The greatest difficulty confronting manufacturers in terms of SF is its non-biodegradability and lower melting point. In addition to such safety and ecological concerns, SFs are lagging behind in the market. There is a fantastic possibility to concentrate on the research of SFs for the advancement of more technologies to provide better technical and safety features. Furthermore, significant consideration should be paid to the integration of beneficial changes in SFs with less or no harmful influence on the environment some important emphasis has to be made. In accordance with these challenges, studies should be determined on SF-reinforced bio-plastics, plastic nanocomposites, self-healing polymers, plastic electronics, smart and reactive polymers. Ongoing cross-disciplinary studies will improve the biodegradation and biorecycling selections of SFs.

Acknowledgment

The research work was supported by the Annual Development Project (ADP) of Bangladesh Government. The title of the project is: "Strengthening of existing gamma source of Bangladesh Atomic Energy Commission". Special thanks to The Ministry of Science and Technology and The Ministry of Planning, Government of the People's Republic of Bangladesh.

Conflicts of Interest

All authors state that there is no conflict of interest.

References

1. Maisha I Alam, Kazi M Maraz, Ruhul A Khan (2022) A review on the application of high-performance fiber-reinforced polymer composite materials. GSC Advanced Research and Reviews 10(2): 1-17.
2. Feldman D (2008) Polymer History. Designed Monomers and Polymers. Informa UK Limited 11(1): 1-15.
3. Saira T, Munawar MA, Khan S (2007) Natural Fiber Reinforced Polymer Composites. Proceedings of the Pak-Istan Academy of Sciences 44(2): 129-144.
4. B Gangil, L Ranakoti, S Verma, T Singh, S Kumar, et all. (2020) Natural and Synthetic Fibers for Hybrid Composites. Hybrid Fiber Composites pp. 1-15.
5. Faruk O, Bledzki AK, Fink HP (2012) Biocomposites Reinforced with Natural Fibers: 2000-2010. Progress in Polymer Science 37(11): 1552-1596.
6. W J Roff, J R Scott (1971) Fibers, Films, Plastics and Rubbers. Handbook of Common Polymers. London: Butterworth-Heinemann p. 1.
7. J Park (2007) Engineered textile colour standards. Coloration Technology 123: 1-7.
8. M J Lerman, J Lembong, S Muramoto, G Gillen, J P Fisher, et al. (2018) The Evolution of Polystyrene as a Cell Culture Material. Tissue Engineering Part B: Reviews 24(5): 359-372.
9. A Saha, K M Maraz, R A Khan (2022) Physio-mechanical properties and applications of natural fiber reinforced bio-composites. GSC Advanced Engineering and Technology 3(1): 1-10.
10. US Bongarde, VD Shinde (2014) Review on natural fiber reinforcement polymer composites. International Journal of Engineering Science and Innovative Technology (IJESIT) 3(2): 431-436.

11. M Jawaid, H P S Abdul Khalil (2011) Cellulosic/synthetic fiber reinforced polymer hybrid composites: A review. Carbohydrate Polymers 86(1): 1-18.

12. B Gangil, L Ranakoti, S Verma, T Singh, S Kumar, et al. (2020) Natural and Synthetic Fibers for Hybrid Composites. Hybrid Fiber Composites pp. 1-15.

13. MR Sanjay, GR Arpitha, LN Laxmana (2016) Natural Resources 7: 108.

14. Y Deng, D Paraskevas, Y Tian (2016) Journal of Cleaner Production 133: 427.

15. R Gunti, RP Atluri (2013) Study on effect of chemical treatments and concentration of jute on tensile properties of long and continuous twisted jute/polypropylene composite. Advanced materials manufacturing and characterization 3(1): 395-398.

16. HM Akil, MF Omar, AAM Mazuki (2011) Materials and Design 32: 4107.

17. M R Sanjay, P Madhu, M Jawaid, P Senthamaraikannan, S Senthil, et al. (2018) Characterization and properties of natural fiber polymer composites: A comprehensive review. Journal of Cleaner Production 172: 566-581.

18. Sonali S, Farzana M, Haque MM, Saha A, Khan RA, et al. (2023) Natural fiber reinforced polymer-based composites: importance of jute fiber. GSC Advanced Research and Reviews 15(1): 1-9.

19. Staiger MP, Tucker N (2008) Natural-fiber composites in structural applications. Properties and Performance of Natural-Fiber Composites. Cambridge: Woodhead Publishing Limited and CRC Press LLC 269-300.

20. Bilash N, Sivapragash M (2013) Environmental benefits of eco-friendly natural fiber reinforced polymeric composite materials. International Journal of application or innovation in Engineering and management (IJAIEM) 2(1): 53-59.

21. Athijayamani A, Thiruchitrambalam M, Natarajan U, B Pazhanivel (2009) Effect of Moisture Absorption on the Mechanical Properties of Randomly Oriented Natural Fibers/Polyester Hybrid Composite. Materials Science and Engineering: A 517(1): 344-353.

22. Charoenvaisarocha AC, Jongjit H, Joseph K (2009) Materials and mechanical properties of pretreated coir-based green composites. Composites: Part B Engineering 40(7): 633-637.

23. A Pandey, C R Soccol, P Nigam, V T Soccol (2000) Biotechnological potential of agro-industrial residues. I: sugarcane bagasse. Bioresource Technology 74(1): 69-80.

24. Nadir A, Songklod J, Vallayuth F (2011) Coir Fiber Reinforced Polypropylene Composite Panel for Automotive Interior Applications. Fibers and polymer 12(7): 919-926.

25. Verma D, Gope PC, Shandilya A (2013) Coir Fiber Reinforcement and Application in Polymer Composites: A Review. Journal of Material Environment science 4(2): 263-276.

26. Nguong CW, Lee SNB, Sujan D (2013) A Review on Natural Fiber Reinforced Polymer Composites. International Journal of Materials and Metallurgical Engineering 7(1): 52-59.

27. Rohit K, Dixit S (2016) A Review - Future Aspect of Natural Fiber Reinforced Composite. Polymers from Renewable Resources 7(2): 43-59.

28. GA Constable, MP Bange (2015) The yield potential of cotton (Gossypium hirsutum L.). Field Crops Research 182: 98-106.

29. Rahman R, Zhafer Firdaus SPS (2019) Tensile properties of natural and synthetic fiber-reinforced polymer composites. Mechanical and Physical Testing of Biocomposites. Fiber-Reinforced Composites and Hybrid Composites pp. 1-22.

30. Jawaid M, Thariq M, Saba N (2019) Fiber-Reinforced Polymer Composites: Manufacturing, Properties, and Applications. Polymers, an International Journal 11: 4-5.

31. D K Rajak, P H Wagh, E Linul (2022) A Review on Synthetic Fibers for Polymer Matrix Composites: Performance, Failure Modes and Applications. Journal of Materials Research and Technology 15(14): 1-28.

32. Morawetz H (1985) Polymers. The Origins and Growth of a Science. Wiley, New York, NY. Wiley-Interscience.

33. D Fengel and G (1984) Wegener, Wood Chemistry, Ultrastructure, Reaction. Walter de Gruyter, Berlin.

34. R B Seymour (1989) Pioneers in Polymer Science. Dordrecht. Kluwer Academic Publisher.

35. F Rodriguez, C Cohen, C Ober, L A Archer (2003) Principles of Polymer Systems. (5thEdn). New York, NY. Taylor and Francis.

36. P Morgan (2005) Carbon Fibers and Their Composites. Boca Raton, FL. Taylor and Francis.

37. E J Deyrup (1986) High Performance Polymers: Their Origin and Development. New York, NY. Elsevier.

38. R B Seymour (1993) Manmade Fibers: Their Origin and Development. London. Elsevier Applied Science.

39. D Feldman, A. Barbalata (1996) Synthetic Polymers: Technology, Properties, Applications. London. Chapman and Hall.

40. M B Polk, S A Kumar (2008) Designed Monomers and Polymers 11(1): 1-15.

41. R Bacon, C Moses (1986) High Performance Polymers: Their Origin and Development. Elsevier 341-354.

42. O P Bahl, Z Shen, J G Lavin, R A Ross (1998) Carbon Fibers. Marcel Dekker 3: 1-84.

43. P Morgan (2005) Carbon Fibers and Their Composites. Taylor and Francis, Boca Raton, FL.

44. A Shahzad, S U Nasir (2016) Mechanical Properties of Natural Fiber/Synthetic Fiber Reinforced Polymer Hybrid Composites. Green Biocomposites pp. 355-396.

45. Warheit DB, Hart GA, Hesterberg TW, Collins JJ, Dyer WM, et al. (2001) Potential Pulmonary Effects of Man-Made Organic Fiber (MMOF) Dusts. Crit. Rev. Toxicol 31(6): 697-736.

46. G D Goh, Y L Yap, S Agarwala, W Y Yeong (2018) Recent Progress in Additive Manufacturing of Fiber Reinforced Polymer Composite. Advanced Materials Technologies 4(1): 1-58.

47. J WS Harle (2001) High-performnace fibers. Woodhead Publishing Ltd. England, UK.

48. J G Cook (1984) Handbook of Textile Fibres: Man-Made Fibres. Elsevier. England, UK.

49. L V Langenhove (2007) Smart Textiles for Medicine and Healthcare: Materials, Systems and Applications. Elsevier.

50. J E McIntyre (2004) Synthetic Fibres: Nylon, Polyester, Acrylic, Polyolefin. Elsevier.

51. Y Nawab, K Sharker (2016) Textile Engineering - An Introduction. De Gruyter. Germany.

52. J Chen (2015) Chapter 4 - Synthetic Textile Fibers: Regenerated Cellulose Fibers. Woodhead Publishing. TX, USA.

53. S P Mishra (2000) A Textbook of Fiber Science and Technology. New Age International.

54. W Qu, J Yang, X Sun, X Bai, H Jin, et al. (2021) Towards producing high-quality lignin-based carbon fibers: A review of crucial factors affecting lignin properties and conversion techniques. Int. J. Biol. Macromol. 189: 768-784.

55. M Aamir, M Tolouei-Rad, K Giasin, A Nosrati (2019) Recent advances in drilling of carbon fiber–reinforced polymers for aerospace applications: A review. Int. J. Adv. Manuf. Technol 105: 2289-2308.

56. T Ishikawa (2019) Ceramic Fibers and Their Applications. Jenny Stanford Publishing.

57. S Prashanth, S Km (2017) Fiber Reinforced Composites-A Review. J Material Sci Eng 6(3): 1-6.

58. F I Mahir, K N Keya, B Sarker, K M Nahiun, R A Khan, et al. (2019) A brief review on natural fiber used as a replacement of synthetic fiber in polymer composites. Materials Engineering Research 1(2): 1-12.

59. Verma D, Gope PC, Shandilya A (2013) Coir Fiber Reinforcement and Application in Polymer Composites: A Review. Journal of Material Environment science 4(2): 263-276.

60. D Ndapeu (2020) Elaboration and Characterization of a Composite Material Based on Cores with a Polyester Matrix. Materials Sciences and Applications 11(3): 204-215.

61. Nguong CW, Lee SNB, Sujan D (2013) A Review on Natural Fiber Reinforced Polymer Composites. International Journal of Materials and Metallurgical Engineering 7(1): 52-59.

62. A Khan, S M Rangappa, M Jawaid, S Siengchin, A M Asiri, et al. (2020) Hybrid Fiber Composites. Wiley.

63. P K Mallick (2007) Fiber-Reinforced Composites: Materials, Manufacturing, and Design. 3rd ed. CRC Press.

64. S Nambiar, J T W Yeow (2012) Polymer-Composite Materials for Radiation Protection. ACS Applied Materials and Interfaces 4(11): 1-10.

65. R L Clough (2001) High-energy radiation and polymers: A review of commercial processes and emerging applications. Nuclear Instruments & Methods in Physics Research Section B-beam Interactions With Materials and Atoms. Elsevier 185(1-4): 8-33.

66. N L del Mastro (2016) Radiation influence on Ediable Materials: Radiation Effects in Materials. Croatia: INTECH p. 161.

67. A L Andrady (2023) Effects of UV radiation on natural and synthetic materials. Photochemical and Photobiological Sciences.

68. V L Karpov, V G Yurkevich, L M Kavalerova, N Petrova, Y V Glazkovskii, et al. (1969) The radiation stability of some synthetic fibers. Fiber Chemistry 1(1): 1-4.

69. W A Monteiro (2016) Radiation Effects in Materials. Croatia: INTECH.

70. F L Vook (1975) Effects of radiation on materials. Physics Today. American Institute of Physics 28(9): 34.

Citation: Samiul A Khan, Mohammad A Amin, Farjana Islam and Ruhul A Khan*. An Overview on Physio-Mechanical Properties and Applications of Synthetic Fibers. Mod Concept Material Sci. 5(3): 2023. MCMS. MS.ID.000612. DOI: 10.33552/MCMS.2023.05.000612