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Polyester Usage for Automotive Applications

Canan Saricam and Nazan Okur

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<http://dx.doi.org/10.5772/intechopen.74206>

Abstract

Textile materials used in automobiles have a large contribution in the production of automobile carpets, seating fabrics, side, roof, floor and door panels, safety belts, tires, airbags, air filters, fuel filters, insulation materials and so on. Whereas these materials are largely manufactured by using man-made fibers, polyester (polyethylene terephthalate [PET]) is the predominant fiber used in the manufacturing of automotive textiles. This chapter deals with the use of polyester fiber in automotive applications in different forms such as knitted, woven and nonwoven textile structures and as a component of composite structures discussing the basic properties and performance aspects of the fiber.

Keywords: polyester, automotive, applications, automobile carpets, seat covers, pre-assembled interior components, tires, filters, safety equipment, engine compartment items

1. Introduction

The amount of fiber usage in a standard passenger car is sizable, reaching around 25 kg; even the safety and comfort requirement can increase this amount [1]. In the automotive industry, fibers are used in the manufacturing of textile products, which are given and described in **Table 1** [2].

In the automobiles, fibers are used in different forms of textile materials such as circular knitted, warp knitted, woven and nonwoven structures. Fibers are also used as a component in multi-layer composite structures. Textile products used in automobiles are expected to fulfill different performance requirements regarding the application area. These requirements are generally fulfilled by using man-made fibers as summarized in **Table 2** [3].

As shown in **Table 2**, polyester (mainly polyethylene terephthalate—PET—but also polybutylene terephthalate—PBT—and polyethylene naphthalate—PEN) is the predominant fiber

Textile products used in automobiles	Description of product
Car tire cords	Fabric reinforcement for car tires
Drive belts	Fabric reinforcement for automotive drive belts
Hose	Fabric reinforcement for automotive hoses
Filters	Filter media for engine filters, air intake filters, fuel filtration
Seat belts	Narrow woven safety belt fabric
Airbags	Fabric for air bags
Automobile carpets face fabric	Tufted or needle punch face fabric for floor covering
Automobile carpet backing	Primary and secondary carpet backing
Trim	Woven, knitted and nonwoven trims for bootliners, head liners, parcel shelves and door panels
Seat cover	Woven and knitted seat covers and backing fabrics

Table 1. Textile products and their descriptions used in automobiles.

Textile products used in automobiles	Requirement	Fibers used
Seat covers	Abrasion and UV resistance, attractive design	Polyester, wool, polyamide, acrylic
Carpets	Light fastness, moldability	Polyamide, polyester, polypropylene
Seat belts	Tensile strength, abrasion and UV resistance	Polyester
Airbags	Ability to withstand high temperature inflation gases, durability to storage in compacted state over many years	Polyamide 6.6, Polyamide 4.6
Hoses, belts	Heat resistance, tensile strength, dimensional stability, adhesion to rubber and chemical resistance	Polyester, aramid
Composites (Headliner, Bootliner)	Stiffness, strength, light weight, energy absorbing and thermal stability	Glass, carbon, aramid, polyester and polyethylene

Table 2. Performance requirements of textile products and fibers used.

used in manufacturing of automotive textiles. It has a share of 42%, whereas polyamide 6.6 (PA 6.6) has a share of 26%. These fibers are preferred because of their good physical properties and high mechanical performances, being dyeable as well as inexpensive [1]. This chapter deals with the use of polyester in automotive applications by discussing the basic properties and performance aspects of the fiber. It presents the recent studies about the production of textile-based automobile components made of polyester and recycled polyester fibers. In addition, recyclability of automotive components made of polyester fiber as well as the usage of polyester in the production of natural fiber composites enabling reuse of waste materials is indicated.

2. Properties and performance aspects of polyester with regard to automotive textiles

The physical and mechanical properties of PET make it widely preferred for textiles used in automobiles because of [4]:

- high resistance to temperature (short-term exposure from 210 to 240°C)
- high strength, hardness and good chemical resistance
- excellent sliding properties and good electrical insulation properties
- high resistance to abrasion and low absorption of humidity
- modulus range in tension is between 1700 and 17,000 MPa depending on modifications

Advantages and disadvantages of textile fibers commonly used in automotive applications are summarized in **Table 3** [1, 5, 6]. As stated before, polyester and polyamide are the leading fibers in automotive applications; however, the very low cost of polypropylene makes it attractive; thus, it is also included in the table. Besides, as a natural fiber, wool is also preferred even in low amounts in automotive applications.

Although PP seems to be a good choice for several automobile components with its low cost and lightweight, this fiber has several disadvantages in terms of use, such as low melting point and moderate abrasion resistance. Besides, difficulty in PP's dyeability overshadows the advantage of low cost [5].

When compared to PP, PET and PA fibers have better dyeability characteristics, temperature resistance and dimensional stability. For example, 3 M™ Thinsulate™ acoustic insulation

Fiber type	Advantages	Disadvantages
Polyester (PET)	<ul style="list-style-type: none"> • High abrasion resistance • High UV resistance • High stiffness • Low cost 	<ul style="list-style-type: none"> • Low moisture absorbency • Low compression resilience • A little less in wearing resistance
Polyamide 6 (PA 6) and 6.6 (PA 6.6)	<ul style="list-style-type: none"> • High strain recovery • High elongation • Good thermal absorptivity • High toughness and wearing resistance 	<ul style="list-style-type: none"> • Moderate UV resistance • High energy consumption for fiber production
Polypropylene (PP)	<ul style="list-style-type: none"> • Low density • Very low cost • Low energy consumption for fiber production • Excellent resistance to chemicals 	<ul style="list-style-type: none"> • Low melting point • Moderate abrasion resistance • Low moisture absorbency • Low heat resistance
Wool	<ul style="list-style-type: none"> • Good thermal comfort • High resilience 	<ul style="list-style-type: none"> • High cost • Low UV resistance

Table 3. Advantages and disadvantages of textile fibers commonly used in automotive applications.

material is composed of 35% of PET staple fibers and 65% PP fibers. While the material has low weight, thanks to the polypropylene fiber, the unquestionable role of PET fiber is strengthening of the material for enhancing its usability in automobiles [7].

PA has greater toughness, excellent tensile strain recovery and excellent adhesiveness when compared to PET [1]. However, PET has higher modulus, higher heat stability, higher resistance to color change, higher durability to sunlight exposure and it is less expensive than PA.

Wool fiber provides a high level of thermal comfort owing to its high moisture absorption ability. Together with its high level of resiliency, these features make wool fiber attractive and appropriate especially for seat cover fabrics. However, due to its high cost, PET has been replaced with that fiber and has become the predominant fiber used in seat cover fabrics. Thus, wool fiber is generally used only in high-end cars [5, 6]. Despite the inappropriateness of polyester fiber for use in applications where thermal comfort has priority, its low moisture absorption property can be an advantage when dimensional stability is required under changing environmental conditions (e.g. when it is used in seat belts). Although it is not shown in **Table 3**, cellulosic fibers can also be used especially in seat covers due to their good esthetic and thermal comfort properties. However, very good abrasion resistance of PET provides durability and makes that fiber appropriate for use in seat cover fabrics [5].

In addition to mechanical performance properties, PET has good sound insulation property, which is important for carpets and pre-assembled interior components such as headliners, bootliners, parcel shelves and door panels because of the requirements for increased driving and traveling comfort. PET fiber has a potential for use to increase sound transmission loss within a wide range of frequency (i.e. 100–500 Hz) similar to that achieved by using fiberglass [8]. Besides, nonwovens produced with a high percentage of hollow PET fibers (e.g. 45–50%) in the blends with PET fiber has demonstrated higher sound absorption rate when compared to the samples produced from 100% PET fibers [9, 10].

Moreover, due to the increasing environmental awareness to protect resources, reuse and recycle of the products have gained importance in the manufacturing of automobile components. Polyester fiber can be used in the recycled form in car upholstery, especially in the automobile carpets and seat covers [11, 12]. Polyester nonwovens can be recycled to produce new materials [13]. Moreover, polyester resin can be used as a matrix material for especially the natural fiber composites, enabling the reuse of waste materials used in the pre-assembled parts of the automobiles such as headliner, bootliners and parcel shelves [14, 15]. Thus, polyester can be considered as a select fiber for recycling and sustainability.

3. Use of polyester in automotive textiles and components

3.1. Automobile carpets

Carpets used in the automobiles are basically required to be durable against soil and abrasion with high color fastness and they are expected to insulate the noise as well as having a pleasing

appearance [16]. In addition, environmental friendliness is a recent trend found in automobile carpets. In this regard, lightweight carpets for decreasing the total weight of the car and carpets from recycled materials have been developed for decreasing the environmental pollution [11].

Carpets used in automobiles basically can be categorized into two types: needle punched nonwoven carpets and tufted carpets. Fifty-five percent of the interior carpets are composed of nonwoven fabrics, whereas 45% are tufted carpets, depending on the car-manufacturing region or country [16, 17]. In both types of carpets, PET is mainly used in the facings [1]. On the other hand, needle punch facings are made from PET fibers in Europe and from PP fibers in the USA. In PET velour constructions, different fiber linear densities can be blended together to provide stability of the piles and esthetic appearance [17]. Carpets produced by using tufting method have backing surfaces for supporting the piles on the facing surface. In the backing surfaces, thermally bonded spunlaid PET and/or PP nonwovens are used [16]. For example, Colback[®] backings are thermally bonded spunlaid nonwovens, made from bi-component filaments with a PET core and either a PP or a PA surface. The product offers processing stability, high tear strength and uniform elongation as well as excellent thermal and dimensional stability [18]. For many years, automotive carpets have been produced by molding to the shape to match the dimensions where the carpet is used [19]. PET and/or PET blended nonwovens are appropriate to meet this requirement, since they can easily be molded into shape at relatively low temperatures and have outstanding dimensional stability [16].

Recently, the most important trend in automobile carpets is using recycled PET in order to reduce the environmental pollution and promote sustainability and efficient use of resources. The analysis of sound transmission loss of needle punch nonwoven automotive carpets made up of recycled PET revealed that comparable quality levels and specifications could be achieved using recycled PET instead of pure PET in terms of mechanical properties [11].

Made from recycled PET, Freudenberg Performance Materials from Germany produces automobile carpets with an environmentally friendly production process. In addition to using recycled fiber, they have eliminated the use of chemical binders and also obtained lighter carpets when compared to conventional automobile carpets, which promotes further environmental protection [12].

3.2. Seat covers

The required characteristics of the seat covers used in automobiles can be durability, soil resistance, UV resistance and appearance retention [17].

Automobile seats are produced in a three-layer structure. Seat cover is at the uppermost layer, a foam layer is in the middle and a scrim backing at the bottom, and these three different components are connected with adhesive layers. The seat cover at the top layer is usually made from woven, warp knitted or circular knitted fabrics, in which PET is used as a dominant fiber. Since late 1990s, PET has been used in 95% of seat covers in automobiles due to its high strength and modulus, high performance against abrasion, UV radiation and heat, outstanding anti-aging performance, good shape retention and dimensional stability and low cost [20]. PET

is generally used in pure form; however, sometimes it is blended with wool. Other characteristics that make PET appropriate for seating fabric are high tear resistance, easy care property and wrinkle resistance. On the other hand, very low moisture absorption capability of PET fiber (around 0.4%) is a disadvantage in terms of thermal comfort, especially in hot weather [5, 21]. In the usage of 100% PET constructions, fabrics are also produced from waste materials blended with thermoplastic to meet price points [16].

Banex is a fabric that uses a special type of PET yarn used as a seat cover that achieves the cushioning effect of springs with the machine-made warp knitting and finishing [22].

The foam layer beneath the top layer is generally made from polyurethane (PU) and acts as an adhesive agent [23]. However, the materials composed of PET and other polymeric fibers have been recently used in order to replace the foam material [17]. Nonwoven PET fabrics made from recycled fibers and the knitted structures can be used in the cover laminate instead of PU foam. Major knitted structures preferred over PU foam are the spacer fabrics, knit, multiknit and struto. Within these knit structures, multiknit comprises two stitch layers with piles in between, whereas knit consists of a stitch layer with a pile on the top [24].

The third layer at the bottom is the backing layer, which is generally produced from either PET or PA [5, 23, 25]. In the backing layer, bolster fabrics and reinforcement nonwovens such as needle punch, hydroentangled and spunbond nonwoven fabrics are preferred [17].

3.3. Pre-assembled interior components

Pre-assembled parts are the fixtures in the car other than upholstery and carpeting, which are produced by molding in shape and covered with a fabric. Among them, there are headliners, bootliners, door panels and parcel shelves. In the production of these components, knitted, woven and nonwoven fabrics are used generally as the facing layer. On the other hand, polyester can also be used as a thermoset resin with vinyl ester in the production of natural fiber composites in automotive applications such as door panel, seat backs, headliners and dashboards. Whereas the natural fiber composites produced using vinyl esters are tougher, the orthophthalic polyester provides rigid products with low heat resistance and isophthalic polyester provides moisture resistance [14, 15].

3.3.1. Headliners

Headliners are the parts which are tightly fitted into the interior roof from the rear window to the front of the car. They are usually produced by molding and are given the shapes to house sunroofs, lamps and coat hooks [16].

The characteristics, which are expected from headliners, include esthetic properties, sound absorption, thermal insulation and cushioning. Moreover, they are required to be produced from lightweight materials. The headliners are also required to be soil resistant [17].

Headliners are produced to have at least three layers, which are esthetic-facing fabric, a foam backing and the core [17]. As the facing fabric for covering, knit tricot fabrics and woven materials are used in majority. Nonetheless, nonwoven linings can also be preferred in the

headliners as the facing fabric. Whereas knitted and woven linings provide better appearance, nonwoven materials are cheaper, easy to process and they show more resistance to abrasion. The other components of headliners are selected from porous structures such as PET foam sheets and fiber-reinforced porous polymer sheets, since the sound absorbing capability and heat insulation is needed [24].

On the other hand, the construction of the materials used in the production of headliners may change in different regions. For instance, regarding the facing fabrics, it is stated that half of the facing fabrics are made up of warp-knitted tricot fabrics, which are followed with needle punched and stitch bond fabrics in Europe [17]. Contrary to this, PA and PET warp-knit tricot fabric or woven materials are selected as facing fabrics to cover the headliners [16]. Nonetheless, having the ability to be easily assembled into the roof, headliners covered with dope dyed 100% PET needle punch fabrics seem to replace conventional warp-knitted fabrics. The other reason for this selection is the cost advantage, acceptable abrasion resistance and good thermal molding characteristics of the needle punch fabrics. Moreover, the weight of the needle punch fabric can be decreased by decreasing the fiber linear density. In parallel with this weight reduction, the softness of the fabric increases as well [16]. The other fabric type which drew attention is the hydroentangled fabrics because of better durability and softness. Being made up of spunlaid and hydroentangled splittable PA/PET bicomponent fibers, Evolon® fabric has excellent strength and softness. Produced using Apex technology and used in the production of headliners, Miratec fabric can copy the fabric patterns of 3D textiles and they have high strength in both horizontal and vertical directions [17, 26].

There are also some studies in which the headliner was produced solely from polyester fiber. The headliner material was formed from two layers of polyester fibers which include the binder and non-binder fibers. Whereas the layer including 20–30% binder fiber provided the loftier part and better sound absorption properties, the layer including 40–60% binder fibers provided rigidity to the headliner material [27].

In fact, polyester fiber is suggested to be a convenient material for the recycling process because of its thermoplastic characteristics. The headliners, which are produced from PET fibers, can be ground, melted and spun into new headliners [13]. Besides, needle punch PET facing fabrics were developed with PET core as an alternative to foam type materials. Although the foam type materials control the stiffness, increase the sound absorption and provide the cushioning effect, their recycling processes are complicated. By bonding directly the facing fabric to the core, the use of foam type materials can be eliminated [17].

3.3.2. *Boot (trunk) liners*

The boot of the car can be considered as the extension of the cabin. The coverings such as rubber matting and a carpet joined to hardboard base is preferred as the bootliners [16].

The required properties for the bootliners can be wear resistance, abrasion resistance, durability, stiffness, lightweight and ease of cleaning. Moreover, the bootliner should not have excessive recovery since this may result in a tendency to shrink over time [16] and this property gains importance within the useful life of the product.

PP and PET are the mostly used fibers in the boot linings. Whereas PP is partially stable and because of this reason less preferred, PET is more dimensionally stable since it can be molded at high temperatures.

Because of economic concerns, nonwovens are mostly used in boot and luggage compartments. Again, in the nonwoven structures, PET is the preferred fiber for bootliners. Bootliners are usually produced from needle punch fabrics for which the facing fabric is made from a staple fiber PET or needle punch fabrics in either flat or velour construction [17].

On the other hand, the sound insulation properties of the bootliners can be improved with the underlay fabric produced from fiber batts composed of recycled fibers [17]. The fibers obtained from clothing wastes can be the blends of PET, PA, PP and acrylic or natural fibers such as wool, coconut, sisal jute and hemp [16].

The other application of polyester in the bootliners is the integration of it into the natural fiber composite materials. While natural fiber composites are preferred in automobiles since they cause a reduction in weight, energy production and cost at 10, 80 and 5%, respectively, polyester is used as a matrix material for these types of composites. Even different materials other than textile materials like sunflower can be used as the core material of these composites [28].

3.3.3. Door panel

The door panels are the third type of preformed structures within the car interiors. The lower section of the door panel is produced as an extension of floor covering and the upper part is upholstery fabric or vinyl [16].

Having higher modulus, good heat stability, excellent resistance to color change and high durability for sunlight degradation and being less expensive, PET is used for making door panels [17].

For the panel trim in the door including the inserts or bolster, both the underlying reinforcement fabrics and lower facing fabrics can be constructed from nonwovens. The facing fabric can be selected from flat or random velour needle punch or hydroentangled materials [17].

Whereas needled fabrics produced from PP are used in the USA, the fabrics produced from fiber spun dyed PET fiber are preferred in Europe and Japan. Since interior fabrics are subjected to UV exposure, spun dyed fibers are preferred. But, in fact, spun dyed PET fiber has lower abrasion resistance when compared with PP fiber [17].

The second component of the door trim is usually made of hydroentangled fabrics. They are joined with the facing fabric or foamed PU and usually composed of 100% PET, 75% PET, 25% viscose or 50% PET/50% PP [17].

In fact, polyester is used in the door panel constructions which have parts differing from the ones explained earlier. In a study, the vehicle door panel was patented, which is mainly made up of rigid plastic panel, a paper-backing material attached with rigid plastic panel, a polyester fiber pad providing a cushioning surface, a cloth membrane and nylon adhesive membrane placed on the cloth and finally a vinyl membrane supported by cloth fabric [29].

3.3.4. Parcel shelf

The parcel shelf is the part of the car that encloses the area between the rear seats and boot. The requirements of this part are light fastness, lightweight and sound absorption to some extent.

Usually a needled fabric made up of PA, PET or PP fibers is used in the parcel shelf [16]. Often matt is included in the parcel shelf structure to increase the sound absorption.

3.4. Tires

Tires are the interface between the car and the road. The components of tires can be classified as the tread, belt package, ply, inner liner, apex, bead bundle, sidewalls and chafer [30]. Other than the rubber and steel components, textile fibers such as rayon, PA, PET or Kevlar are used in the ply component of the tire coated with rubber.

The tire ply cords are classified into three parts, which are named as bias, belted bias and radial ply cords according to their configuration. In diagonal (bias) tires, ply cords are laid at angles less than 90° to tread centerline. Belted bias tires have the belt added in the tread region. The radial tires have body ply cords, which are laid radially from bead to bead at 90° to the centerline of the tread [16]. The ply and tire ply cords transmit the braking and steering forces and withstand burst loads [30]. The requirements of the ply cords are thus tenacity, flexibility, shrinkage at high temperature, heat resistance, wear and abrasion resistance [16, 31]. Being used on the rougher roads, and requiring lower wearing resistance, PA fiber is used in bias tires as ply cord because of its excellent toughness. On the other hand, PET fiber is used in radial tires as ply cord because of having higher modulus and reducing the flat spotting [1]. PET is strong and stiff, and it provides excellent dimensional stability [16]. Moreover, it has high tenacity, good heat resistance, good wet resistance and low water absorption [32]. When compared to PA tire ply cords, the thermal shrinkage and flat spotting characteristics are superior. However, it lacks bonding with rubber when compared to PA [24]. The PET fiber type used in the tire cord is a multifilament fiber with high modulus and low shrinkage [1]. In radial tires, rayon is also used because of its superiority to PA in high-speed impact [33]. PET is also good at high-speed impacts but loses modulus and strength faster than viscose [33]. When these three fibers, PET, viscose and PA, are compared to each other, PA has the highest tenacity, whereas viscose has the least shrinkage at 160°C . On the other hand, heat generation is very low in rayon and it depends on driving conditions for the PET fiber [16].

In comparing PA 6, PA 6.6 and PET, Naskar et al. [34] applied cyclic compression and tension onto the cord-reinforced rubber composite specimens at different strain levels and time intervals on Goodrich compression and tension fatigue tester and found out that PET tire ply cords had excellent dimensional stability but poor fatigue resistance.

PET fibers are also developed to have distinguishing properties for being used as tire ply cords. A high modulus yarn was prepared by spinning polyethylene naphthalate (PEN) or other semi-crystalline PET polymers to an optimum crystallinity state. The resulting yarn had high tenacity, dimensional stability of less than 5% and shrinkage lower than 4% [35].

Finally, PET fibers were proposed to be used in the other parts of the automobile tires rather than tire ply cords. A limited twisted PET yarn having low polymerization degree was used in the belt breaker [32].

3.5. Filters

An average car involves many different types of filters to prevent air, fuel, oil and water from contaminants such as carburetor air filter, cabin interior filter, crank base breather filter, ABS wheel/brake filter, power steering filters, engine oil filters, fuel tank filter, transmission filters, wiper washer screen filters, air conditioning recirculation filter and diesel/soot filters [16].

3.5.1. Air filters

The basic air filters in the automobiles can be classified as the engine air filter and the cabin air filter. The major purpose of air filters is cleaning the air and preventing the impurities within the air, which is used by the engine during combustion. Thus, the air filters indirectly protect the components of the engine from wear. Cabin air filter prevents the airborne pollutants and allergens within the cabin and they improve the quality of cabin air.

The air intake filters are usually produced from wet-laid, resin-impregnated cellulose papers. The other media used in the air filters are PU foam, nonwovens from synthetic, natural fibers or both in hybrid systems. In fact, the usage of nonwovens in air filtering is advantageous because they are more durable and have higher bursting strength. Besides, it is possible to control the parameters such as thickness, porosity and fiber diameter [17]. Moreover, the nonwoven filter media can be constructed to have specific characteristics such as being flame retardant, antibacterial property and so on.

PET fiber can be used in different forms as a filtration media. Mainly made up of PET fiber, QualiFlo[®] is developed as a gradient filtration media which is produced to have a trilaminate structure. It has exceptional dirt/dust-holding capacity consisting of continuous filament PET web with filaments having a trilobal cross section in one outer section and fully bonded air-permeable high loft batt with a randomly dispersed blend of crimped PET fibers in the other outer section. Moreover, requiring no additional binder, StarWeb, which is made up of spunbond PET, was proposed to be used in filtration with Qualiflo[®]. StarWeb is constructed as a trilaminate filter medium containing PET fibers as in the case of Qualiflo[®]. Within this filter, a top layer was produced from trilobal PET spunlaid fabric, the middle layer was produced from 100% PET homopolymer and copolymer PET filaments and the bottom layer was produced from high-loft PET crimped fiber fabrics with isotropic fiber arrangement [36].

Although there are filtration media produced only from PET fiber as is discussed in previous examples, PET is also preferred to be used in nonwoven and hybrid nonwoven structures in the air filter media.

A high-capacity hybrid, multilayer automotive air filter was developed and patented [37]. This air filter was designed to have a fluid filter media containing porous natural fibers and a porous synthetic fiber media containing absorbent spunbond PET. In the natural fiber filter

media, two cotton mesh layers with different densities were used in a way that the first cotton mesh, which was placed closer to receiving end of the air stream, has lower density than the second cotton mesh layer, which was placed closer to the filtered effluent air stream. In parallel with this, synthetic fiber filter media, the first spunbond PET fiber filter placed closer to the second cotton mesh has lower density than the second spunbond PET mesh placed closer to the filtered effluent air stream creating a gradient density.

3.5.2. Fuel filters

Placed between the fuel reservoir and the engine, the fuel filters are also used to protect the engine of the cars from dirt, water and the other contaminants.

The fuel filter media is usually made from PA. The reason for this is that, although the thermoplastic materials such as fluoropolymers, PET and ethylene-vinyl alcohol copolymers are resistant to fuels, the impact toughness especially at low temperatures is not found as satisfactory as PA [38]. Nonetheless, PET fiber can be used in different forms as a component of fuel filter media.

In fact, in a patent for a multilayer plastic fuel filter having at least three layers, the inner and outer layers are suggested to be produced from plastic material, which is made conductive using additives (PA6, PA6.6, PA11 and PA12). Embedded between them, PET was listed as one polymer which can be used with the other plastics which is not made conductive (fluoropolymer other than PVDH, PET or impact-modified PET) [38].

In a patent for developing depth media in-tank fuel filter with extruded mesh shell [39], it is stated that an in-tank fuel filter is developed to have two panels of filtration media. Each panel is comprised of an outer layer of extruded mesh, a pair of spunbond filtration media and an inner layer of meltblown filtration media in between. PET is used in both the spunbond and the meltblown filtration media.

Moreover, a diesel fuel filter is patented with a smoke suppressant for which the smoke suppressant is adsorbed onto the strip of nonwoven PET fiber, which is placed equidistantly around the round container [40].

3.6. Safety equipment

Seat belts and airbags are the two main items used as safety equipment in automobiles. A seat belt is used to fix the passengers on their seats and decrease the impact shock by absorbing [1]. High tensile strength and stability under static and dynamic loadings are needed in seat belts. The narrow fabric used in seat belts has mostly the weave structures such as plain weave, twill weave and sateen weave used in single-layer or double-layer structures. Seat belts are manufactured in a needle loom where the weft is inserted through the warp sheen and a selvage is formed. On the other hand, filament yarns made of PA or PET are used to produce seat belt webbing [24].

Although PA was used as a major fiber in seatbelts for years, PET has been replaced with PA due to some advantages [40]. Having higher-impact energy-absorbing capability, less

discoloration against sunlight and better dimensional stability under changing temperature and humidity conditions, PET is preferred to PA [1, 41].

When the static and dynamic loads have been applied on the seatbelts made from multifilament PET and PA yarns and compared, it has been observed that PET is superior due to lower extensibility that prevents stretching of the belts under loading during impact situations and higher stiffness [24, 41, 42].

As one other important safety equipment in automobiles, airbags are required to have extremely low gas permeability by means of a combination of high-density weaving and a thin coating treatment to resist high temperature, to have high extensibility and to be durable for storage in a compacted state for many years [43].

Demands for airbag yarns have been increasing recently, as a result of global rise in safety requirements in automobiles. Airbags are usually made up from PA 6.6 filament yarns. Nonetheless, there are some attempts to find alternative fibers. There is a noticeable trend toward PET and PA 4.6 filament yarns for the airbag fabrics and sewing threads [44, 45].

In **Table 4**, characteristics of the fibers used in airbag yarns are given [44].

North America's airbag market in 2014 comprised around 45,000 tons of PA 6.6-based fabrics and an additional 4000 tons of PET-based alternatives. On the other hand, in Europe, the use of PA 6.6-based fabrics has stayed around 33,000–35,000 tons per year while the use of PET fabrics has increased. It is forecasted that around 12,000–13,000 tons of PET will be employed in European airbags by 2020 [46].

Textile materials are used in engine compartment items such as driving belts (V-belt, synchronous belts and serpentine belt), hoses (brake and clutch hoses) and lines (power steering lines and bonnet lines).

In automobiles, the mechanical parts of the engines are driven by belts. The belts used in engine compartment of automobiles are required to be resistant to fatigue, abrasion, heat, chemicals as well as have high tensile strength and good dimensional stability [16].

A typical V-belt cross-sectional scheme is shown in **Figure 1**.

In order to enhance the fatigue properties of the belts that proposed mechanical and thermal loads, cords are used for reinforcement. The major reinforcing element used in the belts is PET

Characteristic	PA 6.6	PA 6	PET
Density (kg/m ³)	1140	1140	1390
Specific heat capacity (kJ/kg°K)	1.67	1.67	1.3
Melting point (°C)	260	215	258
Softening point (°C)	220	170	220
Heat to melt (kJ/kg)	589	522	427

Table 4. Characteristics of the fibers used in airbag yarns.

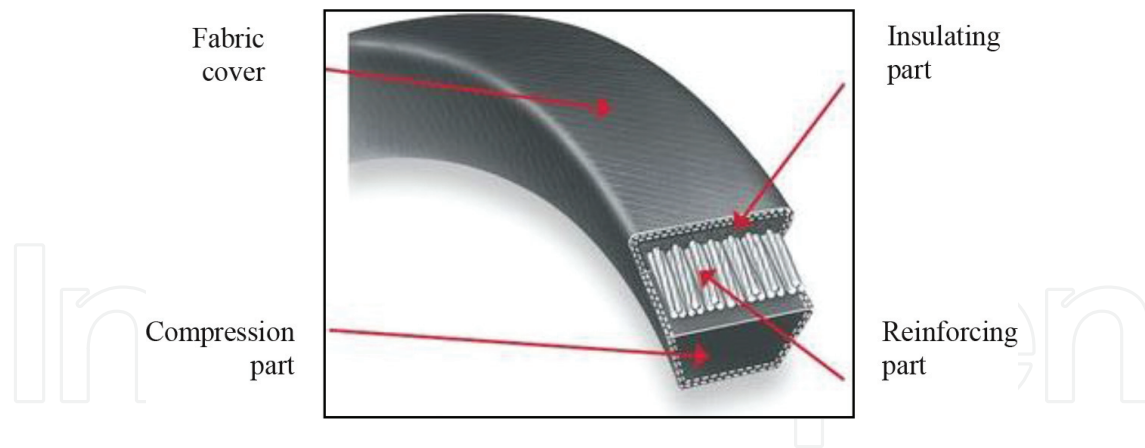


Figure 1. V-belt [47].

cord, which is composed of twisted filament yarns [16]. PET fiber is applied both in the cord of V-belt and in the fabric cover of its upper part, whereas p-Aramid fiber is applied to the cords of V-belts, V-ribbed belts and metal-combined belts [1].

The bonnet line and the fabric linings with it in the engine compartment require both thermal and sound insulation functions and it usually is constructed from metal or fiber-reinforced plastic composite. PET spunbond is usually used as a nonwoven facing to cover stiffening components such as glass fiber foam or resin bonded nonwoven fabric [17].

The brake and clutch hoses are required to prevent absorption of the lubricant fluid and to resist the fluid. As an example of those kinds of hoses supplied by Fenox, the PET yarn is used as the reinforcement component that prevents fluid absorption and extends the service life of the fluid and also it improves the ability of the hose to withstand pressures as a result of increased rigidity [48].

4. Conclusion

Although attempts have been made to investigate the use of different textile fibers such as cotton, viscose, wool, acrylic, aramid and bast fibers in automobile applications, these fibers are used in a small amount by specific automobile manufacturers. The industry is still served by manmade fibers, in particular PET fiber, due to its good physical properties, enhancing mechanical performances, functionality and durability.

Polyester fiber can be used in many forms in the automotive industry, such as knitted, woven or nonwoven fabrics, especially needle punch and stitch bond fabrics used as facing materials; woven fabrics in the airbags and seat belts; nonwoven material used as a filling material for especially improving the sound insulation property in multilayer structures in the car interiors; spunbond or meltblown nonwoven structures either used solely or in combination with other layers in the filtration media; as reinforcing material in the tire cords and engine compartment items such as V-belt and hoses; and finally as a component for resin-impregnated composites either as a core material or as a matrix material.

In future, it is expected that polyester will remain as the leading fiber that will be used in the production of automotive textiles. Besides, considering the increase in natural fiber composites with the purpose of weight reduction and environmental friendliness and increasing amount of recycled material in the automobile parts, the usage of polyester resin in natural fiber composites is expected to increase. Nonetheless, the performance and functionality of materials made of polyester should be improved in parallel to the trends, probable changes in future expectations and requirements, as for the materials produced from other types of fibers and polymers.

Author details

Canan Saricam* and Nazan Okur

*Address all correspondence to: saricamc@itu.edu.tr

Istanbul Technical University, Istanbul, Turkey

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