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Enhancing the Functional Properties of Sportswear Fabric based Carbon Fiber

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ABSTRACT
The objective of the present study is to design functional insulation sportswear fabrics. The design is based on a thorough investigation into the construction of sportswear fabrics and factors associated with. Twill and Satin structures were employed to achieve the new design of sportswear fabrics using various ratios of carbon fiber. Furthermore, qualitative and quantitative evaluations of the two kinds of structure were performed, in order to clarify their functional properties.

Key words: Carbon fiber, functional properties, sportswear, thermal insulation

INTRODUCTION
The 1980s was a period of highly fruitful innovation in sportswear garments (Rupp, 1998). Some reasonably simple microfibers and coated fabrics were developed; variants of which have met the needs of many sports garments. The innovation of new materials and garments was so successful that in many sports the fundamental performance requirements have been identified and largely satisfied (Bohringer, 1998). Nowadays, from very simple microfibers to much more complex fabrics are effectively used in active sportswear. The latest textile materials are much more function for fulfilling specific needs in different sports activities (Umbach, 1993). The desirable attributes of functional comfort sportswear are as follows (Mayer *et al.*, 1989):

- Optimum heat and moisture regulation
- Good air and water vapor permeability
- Rapid moisture absorption and conveyance capacity
- Absence of dampness
- Rapid drying to prevent catching cold
- Low water absorption of the layer of clothing just positioned to the skin
- Dimensionally stable even when wet
- Durable
- Breathability and comfort
- Easy care performance
- Lightweight
- Soft and pleasant touch
- Smart and functional design

It is not possible to achieve all of these properties in a simple structure of any single fiber. The right type of fiber should be in the right place. The behavior of the fabric is mainly depending on its base fibers properties. The most important properties are: fiber type; weave construction; weight or thickness of the material and presence of chemical treatments (D'Silva and Anand, 2000).

Synthetic fibers can have either hydrophilic (wetting) surfaces or hydrophobic (non wetting) surfaces. Synthetic fabrics are generally considered to be the best choice for sportswear as they are able to provide a good combination of moisture management, softness, lightweight, insulation and dry relatively quickly. It is generally agreed that fabrics with moisture wicking properties can regulate body temperature, improve muscle performance and delay exhaustion (Anonymous, 1996).

Polyester has outstanding dimensional stability and offer excellent resistance to dirt, alkalis, decay, mold and most common organic solvents. Being durable, yet lightweight, elasticity and a comfortable smooth feel, these are all important qualities to consumers for wide variety sportswear applications. Excellent heat resistance or thermal stability is also an attribute of polyester (Adanur and Sears, 1995). It is the fiber used most commonly in base fabrics for active sportswear because of its low moisture absorption, easy care properties and low cost.

Otherwise, cotton provides a good combination of softness and comfort. However, cotton is not recommended for use in active sportswear because of its tendency to absorb and retain moisture (Sule *et al.*, 2004). When wet, cotton fabrics cling to the skin causing discomfort. The slow-to-dry and cold-when-wet characteristics of cotton make this material unsuitable in conditions in which there are high levels of moisture-either perspiration or precipitation-and where the ambient temperature is low.

Carbon Fiber is one of the most recent developments in the field of composite materials. There are many different grades of carbon fiber available, with differing properties, which can be used for specific applications (Bahl *et al.*, 1998).

The desirable physical properties of carbon fiber include its resistance to corrosion, fire and high tensile strength as well as its chemical inertness. With the decrease in its cost over recent years, it is fast becoming one of the leading materials in many areas, including performance sport equipment and garments (Hongu *et al.*, 2005).

The use of carbon fiber as the main structural material in the sport has filtered through the various varieties of motor sport even at the most basic levels and is now becoming increasingly used in the construction of road cars. Many sports utilize the physical properties of carbon fiber (as rival companies constantly compete to produce high performance equipment. Another area where carbon fiber is being used is in the construction of yacht masts. Recently, Carbon fiber has entered the textile market for use in increasing the thermal comfort of garments. In such extreme applications of textiles as diving suits, ski wear and active sportswear, Carbon fiber can impart outstanding properties to garments. Its thermal insulating properties, high tensile strength and less weight makes it popular for making sportswear as it prevents the wearer from fatal consequences (Zhao and Gou, 2009).

Combinations of cotton, polyester and carbon fiber gave sportswear fabrics with better functional properties than a single fiber type and with greatest performance properties. The aim of this study is to design active sportswear fabrics with better functional properties. To achieve the goal, the ratio of carbon fiber blended with cotton and polyester, construction of the fabrics and parameters associated with, methods of evaluation and areas of application are discussed.

MATERIALS AND METHODS

Specimen: Woven structures have the greatest history of application in sportswear manufacturing. Warp and weft yarns in a woven fabric could be interlaced in various ways that is called a weave structure. A cover factor is the fraction of the total fabric area that is covered by the component yarn. Fabric area density and cover factor affected strength, thickness, stiffness, stability, porosity, filtering quality and abrasion resistance of fabrics (Gokarneshan, 2004).

Most common structures are Twill and Satin weave. Twill is a weave that produces diagonal lines on the face of a fabric, as shown in Fig. 1. The direction of the diagonal lines viewed along the warp direction can be from upwards to the right or to the left making Z or S Twill. Compared to Plain weave of the same cloth parameters, Twills have longer floats, fewer intersections and a more open construction.

A weave where binding places arranged to produce a smooth fabric surface free from twill lines is called Satin, as shown in Fig. 2. The distribution of interlacing points must be as random as possible to avoid twill lines. The smallest repeat of Satin weave is 5, while the most popular are Satins of 5 and 8 repeats. The 5 ends Satin is most frequently used for providing firm fabric in spite of having moderate cover factor.

Mechanical and physical properties of woven fabrics, which are especially important for sportswear, depend on: type of raw materials, type and count of warp and weft yarns, yarn density and the type of weave structure. The strength of the woven fabric is the highest in warp and weft direction. While in bias, the fabrics show lower mechanical and physical properties, higher elasticity and lower shear resistance. In order to increase the mechanical and physical properties, a different ratio of carbon fiber is constructed using the previous structures.

Six different samples were produced. Three samples were produced as Satin (5) weave; another three samples were produced as Twill (2/1) weave fabrics. The difference between each three samples depends on the ratio of carbon fiber and fabric composition. The various specifications of these samples construction are given in Table 1.

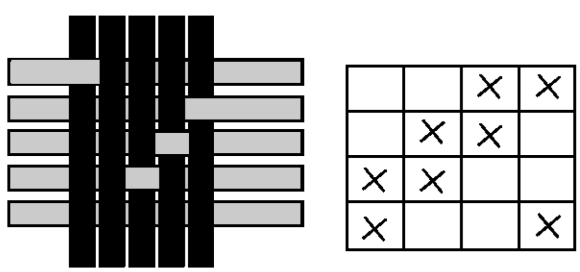

Fig. 1: Twill (2/1) weave structure

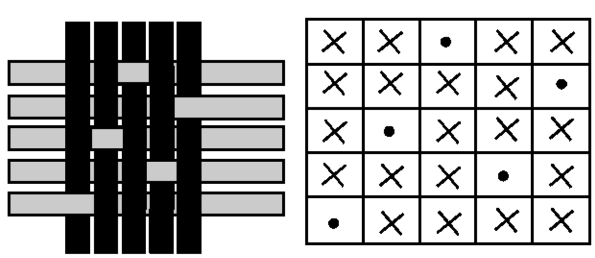

Fig. 2: Satin (5) weave structure

Table 1: Specification of the produced samples

	Yarn count nec		Yarn set (yarn/inch)			Fabric composition (%)				
No.	Warp	Weft	Warp	Weft	Structure	Cotton	Polyester	Carbon	Thickness (mm)	Weight (g m^{-2})
1	36/2	24/1	109	60	Satin 5	65	17.5	17.5	0.59	280
2	36/2	24/1	109	60	Satin 5	65	28.5	6.5	0.59	280
3	36/2	24/1	109	60	Satin 5	65	35.0	0.0	0.59	280
4	36/2	36/2	93	53	Twill 2/1	65	17.5	17.5	0.44	214
5	36/2	36/2	93	53	Twill 2/1	65	28.5	6.5	0.44	214
6	36/2	36/2	93	53	Twill 2/1	65	35.0	0.0	0.44	214

Measurements of manufactured samples: Several tests were carried out in order to evaluate the fabric properties. These tests include mechanical and physical properties tests.

Thickness test: The thickness samples were measured by the Teclock tester under a pressure 0.2 kg f/cm^2 according to the ASTM D1777-96 (2007).

Weight test: This test was carried out by using Mettler H 30 apparatus according to the ASTM D3776-96 (2002).

Breaking strength and elongation (grab) test: This test was carried out for all samples by using the grab method according to the ASTM D5034-09 (2009).

Air permeability test: This test was carried out for all samples, according to the ASTM D-737-04 (2008).

Water resistance test: This test was carried out for all samples, according to the AATCC 2008.

Thermal insulation test: This test was carried out for all samples, according to the ASTM D-1518-85 (2003).

Thermal behavior test: This test was carried out for all samples, according to the ISO 6942 (2002).

RESULTS AND DISCUSSION

Since, the main aim of this study is to design active sportswear fabrics with better functional properties, different fabric types with various structure parameters were made. Test results were addressed and discussed in order to optimize the sportswear design parameters.

Breaking strength and elongation: Figure 3 shows the effect of carbon fiber ratio on warp breaking load values (kg) for all experimental samples.

It is observed that, as shown in Fig. 3, there is a direct relation between the carbon fiber ratio in the fabric and its warp breaking load values. As the carbon fiber ratio increases, the warp breaking load values increase in all produced samples.

To get a mathematical relationship between the carbon fiber ratio (%) in the Satin (5) samples on the warp breaking load values (kg), a linear regression technique was used to get this relationship. The following equation is applied on the warp breaking load values:

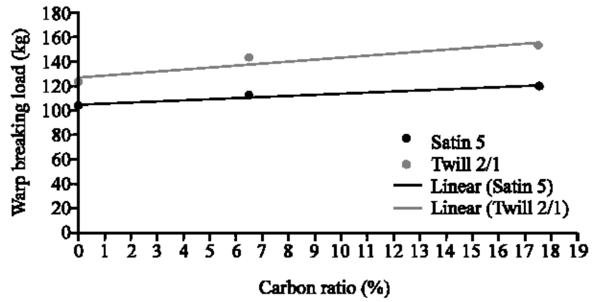

Fig. 3: The effect of carbon fiber ratio on warp breaking load values (kg) for experimental samples

$$y = 0.8581x + 105.53 \tag{1}$$

Where:
y = Warp breaking load values (kg)
x = Carbon fiber ratio (%)

As R = 0.98560585, the correlation is considered too high which means that the regression equation is reliable for prediction of the warp breaking load values (kg) in the carbon fiber ratio (%) range using Satin (5) structure.

To address a mathematical relationship between the carbon fiber ratio (%) in the Twill (2/1) samples on the warp breaking load values (kg), a linear regression equation was used and applied on the warp breaking load values:

$$y = 1.6323\,x + 126.81 \tag{2}$$

Where:
y = Warp breaking load values (kg)
x = Carbon fiber ratio (%)

As R = 0.947217993, the correlation is considered too high which means that the regression equation is reliable for prediction of the warp breaking load values (kg) in the carbon fiber ratio (%) range using Twill (2/1) structure

Figure 4 shows the effect of carbon fiber ratio on weft breaking load values (kg) for all experimental samples.

It is cleared that, as shown in Fig. 4, there is a direct relation between the carbon fiber ratio in the fabric and its weft breaking load values. As the carbon fiber ratio increases, the weft breaking load values increase in all produced samples.

To get a mathematical relationship between the carbon fiber ratio (%) in the Satin (5) samples on the weft breaking load values (kg), a linear regression technique was used to get this relationship. The following equation is applied on the weft breaking load values:

$$y = 0.6438x + 43.817 \tag{3}$$

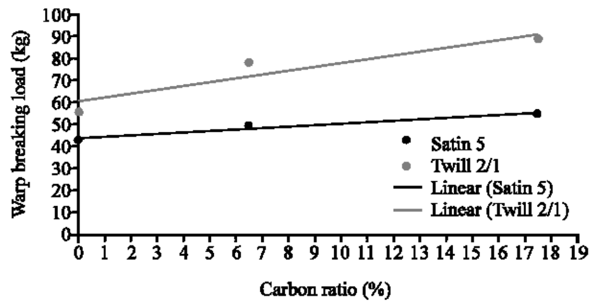

Fig. 4: The effect of carbon fiber ratio on weft breaking load values (kg) for experimental samples

Where:
y = Weft breaking load values (kg)
x = Carbon fiber ratio (%)

As R = 0.98063556, the correlation is considered too high which means that the regression equation is reliable for prediction of the weft breaking load values (kg) in the carbon fiber ratio (%) range using Satin (5) structure.

To address a mathematical relationship between the carbon fiber ratio (%) in the Twill (2/1) samples on the weft breaking load values (kg), a linear regression equation was used and applied on the weft breaking load values:

$$y = 1.7923\,x + 59.995 \quad (4)$$

Where:
y = Weft breaking load values (kg)
x = Carbon fiber ratio (%)

As R = 0.943581938, the correlation is considered too high which means that the regression equation is reliable for prediction of the weft breaking load values (kg) in the carbon fiber ratio (%) range using Twill (2/1) structure.

Figure 5 shows the effect of carbon fiber ratio on warp breaking extension values (%) for all experimental samples.

It is cleared that, as shown in Fig. 5, there is a direct relation between the carbon fiber ratio in the fabric and its warp breaking extension values. As the carbon fiber ratio increases, the warp breaking extension values increase in all produced samples.

To get a mathematical relationship between the carbon fiber ratio (%) in the Satin (5) samples on the warp breaking extension values (%), a linear regression technique was used to get this relationship. The following equation is applied on the warp breaking load values:

$$y = 0.0387x + 2.1574 \quad (5)$$

Where:
y = Warp breaking extension values (%)
x = Carbon fiber ratio (%)

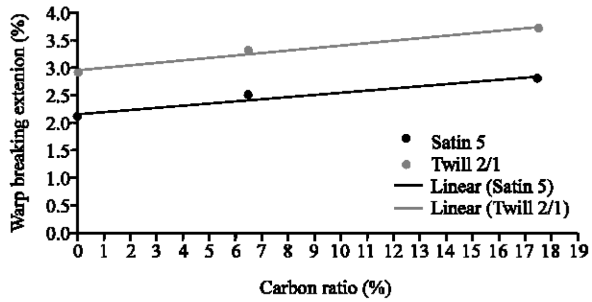

Fig. 5: The effect of carbon fiber ratio on warp breaking extension values (%) for experimental samples

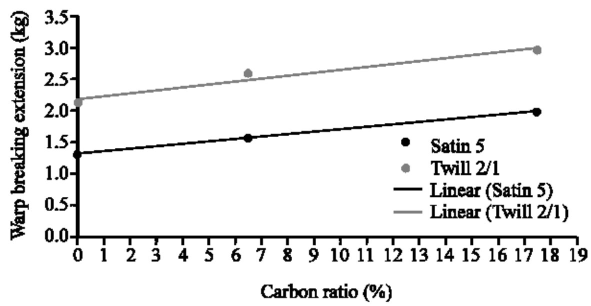

Fig. 6: The effect of carbon fiber ratio on weft breaking extension values (%) for experimental samples

As R = 0.97374, the correlation is considered too high which means that the regression equation is reliable for prediction of the warp breaking extension values (%) in the carbon fiber ratio (%) range using Satin (5) structure.

To address a mathematical relationship between the carbon fiber ratio (%) in the Twill (2/1) samples on the warp breaking extension values (%), a linear regression equation was used and applied on the warp breaking load values:

$$y = 0.0447x + 2.9422 \tag{6}$$

Where:
y = Warp breaking extension values (%)
x = Carbon fiber ratio (%)

As R = 0.989158, the correlation is considered too high which means that the regression equation is reliable for prediction of the warp breaking extension values (%) in the carbon fiber ratio (%) range using Twill (2/1) structure.

Figure 6 shows the effect of carbon fiber ratio on weft breaking extension values (%) for all experimental samples.

It is observed that, as shown in Fig. 6, there is a direct relation between the carbon fiber ratio in the fabric and its weft breaking extension values. As the carbon fiber ratio increases, the weft breaking extension values increase in all produced samples.

To get a mathematical relationship between the carbon fiber ratio (%) in the Satin (5) samples on the weft breaking extension values (%), a linear regression technique was used to get this relationship. The following equation is applied on the weft breaking extension values:

$$y = 0.0331x + 1.1219 \tag{7}$$

Where:
y = Weft breaking extension values (%)
x = Carbon fiber ratio (%)

As R = 0.99996, the correlation is considered too high which means that the regression equation is reliable for prediction of the weft breaking extension values (%) in the carbon fiber ratio (%) range using Satin (5) structure.

To address a mathematical relationship between the carbon fiber ratio (%) in the Twill (2/1) samples on the weft breaking extension values (%), a linear regression equation was used and applied on the weft breaking extension values:

$$y = 0.0387x + 1.8574 \tag{8}$$

Where:
y = Weft breaking extension values (%)
x = Carbon fiber ratio (%)

As R = 0.97374, the correlation is considered too high which means that the regression equation is reliable for prediction of the weft breaking extension values (%) in the carbon fiber ratio (%) range using Twill (2/1) structure.

Based on the results obtained in Fig. 3-5 and 6 and by applying the statistics regression, signify that:

- Carbon fiber ratio (%) has a significant effect on both; breaking load and breaking extension values in both directions warp and weft for all tested samples
- Twill (2/1) structure causes better more breaking load and breaking extension properties in both directions warp and weft than Satin (5) structure by using the same carbon fiber ratio (%)

Air permeability: This test was carried out for all samples; Fig. 7 shows the effect of carbon fiber ratio on its air permeability values ($cm^3/cm^2/sec$) for all experimental samples.

It is clear that, as shown in Fig. 7, there is difference in air permeability values according to the carbon fibers ratio of all produced samples. As the carbon fiber ratio increases, the air permeability values increase in all produced samples.

To get a mathematical relationship between the carbon fiber ratio (%) in the Satin (5) samples on the air permeability values ($cm^3/cm^2/sec$), a linear regression technique was used to get this relationship. The following equation is applied on the air permeability values:

$$y = 0.0468x + 12.979 \tag{9}$$

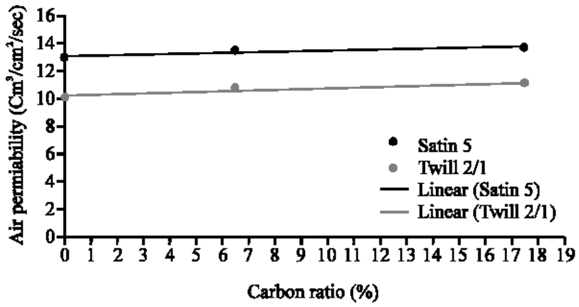

Fig. 7: The effect of carbon fiber ratio on air permeability values ($cm^3/cm^2/sec$) for experimental samples

Where:
y = Air permeability values ($cm^3/cm^2/sec$)
x = Carbon fiber ratio (%)

As R = 0.94917507, the correlation is considered too high which means that the regression equation is reliable for prediction of the air permeability values ($cm^3/cm^2/sec$) in the carbon fiber ratio (%) range using Satin (5) structure.

To address a mathematical relationship between the carbon fiber ratio (%) in the Twill (2/1) samples on the air permeability values ($cm^3/cm^2/sec$), a linear regression equation was used and applied on the air permeability values:

$$y = 0.0545x + 10.1849 \tag{10}$$

Where:
y = Air permeability values ($cm^3/cm^2/sec$)
x = Carbon fiber ratio (%)

As R = 0.949584468, the correlation is considered too high which means that the regression equation is reliable for prediction of the air permeability values ($cm^3/cm^2/sec$) in the carbon fiber ratio (%) range using Twill (2/1) structure.

Based on the results obtained in Fig. 7 and by applying the statistics regression, signify that:

- Carbon fiber ratio (%) has a significant effect on air permeability values for all tested samples
- Satin (5) structure causes better more air permeability properties than Twill (2/1) structure by using the same carbon fibers ratio (%)

Water resistance: This test was carried out for all samples; Fig. 8 shows the effect of carbon fiber ratio on the water absorption time (s) for all experimental samples.

It is observed that, as shown in Fig. 8, there is a direct relation between the carbon fiber ratio in the fabric and its water absorption time. As the carbon fiber ratio increases, water absorption time increases in all produced samples.

To get a mathematical relationship between the carbon fiber ratio (%) in the Satin (5) samples on the water absorption time (s), a linear regression technique was used to get this relationship. The following equation is applied on the water absorption time:

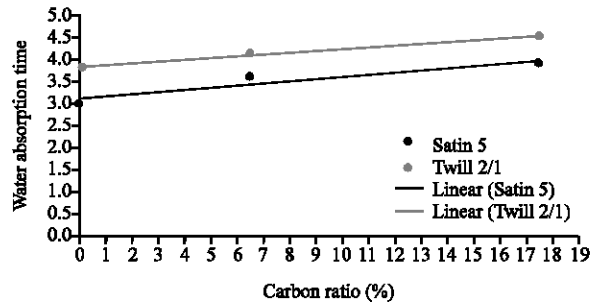

Fig. 8: The effect of carbon fiber ratio on water absorption time (sec) for experimental samples

$$y = 0.0489x + 3.1089 \tag{11}$$

Where:
y = Water absorption time (sec)
x = Carbon fiber ratio (%)

As R = 0.94358194, the correlation is considered too high which means that the regression equation is reliable for prediction of the water absorption time (s) in the carbon fiber ratio (%) range using Satin (5) structure.

To address a mathematical relationship between the carbon fibers ratio (%) in the Twill (2/1) samples on the water absorption time (s), a linear regression equation was used and applied on the water absorption time:

$$y = 0.0396x + 3.8164 \tag{12}$$

Where:
y = Water absorption time (s)
x = Carbon fiber ratio (%)

As R = 0.997882223, the correlation is considered too high which means that the regression equation is reliable for prediction of the water absorption time (s) in the carbon fiber ratio (%) range using Twill (2/1) structure.

Based on the results obtained in Fig. 8 and by applying the statistics regression, indicates that:

- Carbon fiber ratio (%) has a significant effect on water absorption time (s) for all tested samples as the carbon fiber ratio (%) increases it will improve the water proof properties of the fabric
- Twill (2/1) structure causes better less water absorption properties than Satin (5) structure by using the same carbon fiber ratio (%)

Thermal insulation: This test was carried out for all samples; Fig. 9 shows the effect of carbon fiber ratio on the thermal insulation factors for all experimental samples.

It is observed that, as shown in Fig. 9, there is a direct relation between the carbon fiber ratio in the fabric and its thermal insulation factors. As the carbon fiber ratio increases, thermal insulation factors increase in all produced samples.

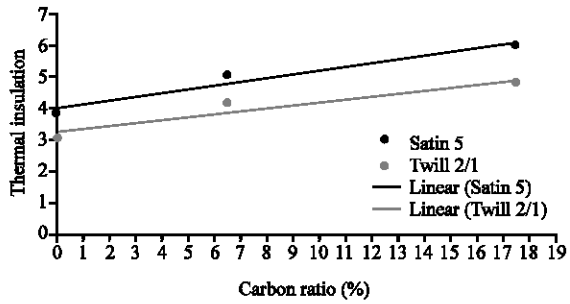

Fig. 9: The effect of carbon fibers ratio on thermal insulation values for experimental samples

To get a mathematical relationship between the carbon fiber ratio (%) in the Satin (5) samples on the thermal insulation factors, a linear regression technique was used to get this relationship. The following equation is applied on the thermal insulation factors:

$$y = 0.12x + 3.9497 \tag{13}$$

Where:
y = Thermal insulation factors
x = Carbon fiber ratio (%)

As R = 0.9760939, the correlation is considered too high which means that the regression equation is reliable for prediction of the thermal insulation factors in the carbon fiber ratio (%) range using Satin (5) structure.

To address a mathematical relationship between the carbon fiber ratio (%) in the Twill (2/1) samples on the thermal insulation factors, a linear regression equation was used and applied on the thermal insulation factors:

$$y = 0.0937x + 3.2273 \tag{14}$$

Where:
y = Thermal insulation factors
x = Carbon fiber ratio (%)

As R = 0.94917507, the correlation is considered too high which means that the regression equation is reliable for prediction of the thermal insulation factors in the carbon fiber ratio (%) range using Twill (2/1) structure.

Based on the results obtained in Fig. 9 and by applying the statistics regression, signify that:

- Carbon fiber ratio (%) has a significant effect on thermal insulation factors for all tested samples
- Satin (5) structure causes better more thermal insulation properties than Twill (2/1) structure by using the same carbon fiber ratio (%)

Thermal behavior: Figure 10 shows the effect of carbon fiber ratio (%) on the samples burning behavior at different heat degrees.

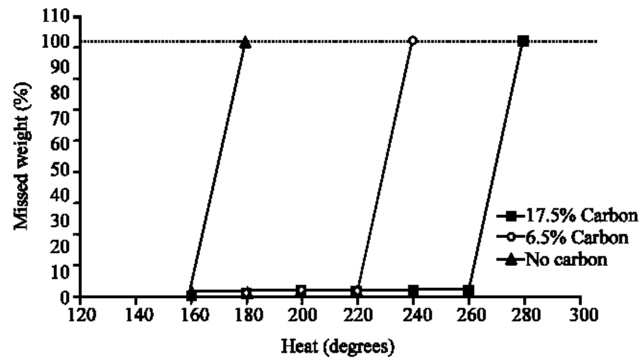

Fig. 10: The effect of carbon fiber ratio (%) on the samples burning behavior at different heat degrees

Table 2: The effect of heat on samples weight and performance

Samples No.	Samples burning behavior (°C) 160	180	200	220	240	260	280
1	Will not burn. It loses .08% from its weigh	Will not burn. It loses 1.1% from its weigh	Will not burn. It loses 1.4% from its weigh	Will not burn. It loses 1.7% from its weigh	Will not burn. It loses 1.9% from its weigh	Will not burn It loses 2.4% from its weigh	Will burn
2	Will not burn. It loses 1.3% from its weigh	Will not burn. It loses 1.5% from its weigh	Will not burn It loses 1.9% from its weigh	Will not burn It loses 2.3% from its weigh	Will burn		
3	Will not burn. It loses 2.5% from its weigh	Will burn					
4	Will not burn. It loses .08% from its weigh	Will not burn. It loses 1.1% from its weigh	Will not burn. It loses 1.4% from its weigh	Will not burn. It loses 1.7% from its weigh	Will not burn. It loses 1.9% from its weigh	Will not burn. It loses 2.4% from its weigh	Will burn
5	Will not burn. It loses 1.3% from its weigh	Will not burn. It loses 1.5% from its weigh	Will not burn. It loses 1.9% from its weigh	Will not burn. It loses 2.3% from its weigh	Will burn		
6	Will not burn. It loses 2.5% from its weigh	Will burn.					

It is observed that, as shown in Fig. 10, the carbon fiber ratio (%) in the fabric has a significant effect on the heat resistance properties for all tested samples.

Table 2 shows the effect of heat on the samples weight and performance.

The results of Table 2 indicate that:

- The heat resistance properties can refer only to the ratio of carbon fiber in the fabric which used to reduce the rate of heat transfer. For both given structure Satin (5) and Twill (2/1), all samples provide better heat resistance properties as the ratio of carbon fiber in the fabric increases. According to these results, samples (1, 4) provide the best heat resistance properties
- The other factors of the sample's construction structure, weight, thickness, yarn count, yarn set... etc did not affect the results of the heat resistance test

CONCLUSIONS

Carbon Fiber is one of the most recent developments in the field of composite materials. It is fast becoming one of the leading materials in sportswear applications with the decrease in its cost over recent years, its resistance to heat, thermal insulation, high strength, excellent air permeability as well as its water proof desirable properties. Combinations of cotton, polyester and carbon fiber gave sportswear fabrics better functional properties than a single fiber type with greatest performance properties. The carbon fibers ratio (%) in the fabric has a significant effect on improving the mechanical and physical properties for the Satin and Twill structures in the sportswear fabrics.

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