Mechanical Assessment of Fire-off on CO/PET Fabrics

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Abstract. The present study investigates the mechanical properties of newly developed FR chemical Fire-off in order to assess textile service-life features. 350 g/L Fire-off finished bath was prepared and CO/PET fabric samples were treated via impregnation method. In order to investigate FR performance of treated fabrics LOI test was performed. Subsequently, fabric strength, abrasion properties and outward appearance; tensile properties, abrasion, pilling performance and whiteness of Fire-off treated fabrics were tested and evaluated. Mechanical test results showed that there was a slight increase in strength, elongation, abrasion and pilling. On the other hand, whiteness and air permeability of fabrics were decreased after Fire-off treatment.

1. Introduction
Imparting flame retardancy to cotton/polyester (CO/PET) fabrics is difficult because of well-known scaffolding effect between PET and cotton when burned. PET (thermoplastic) shrinks at its melting point and run away from the fire, whereas cotton forms char. The molten PET generally tends to wick on cotton char, and prevent its melt dripping [1-10]. It is known that phosphorous based flame retardancy (FR) products can enhance polyester and cellulose FR properties through such FR mechanisms of dehydration, phosphorylation, and phosphate-ester decomposition. They form a network crosslinking the cotton and PET, suppress the release of volatile combustible fragments and thus enhance the formation of char [11].

Nowadays, scientific community have mainly focused on the development of less or nontoxic phosphorus-based FRs, which represent an adequate alternative to their highly toxic halogen-based counterparts [12-15]. A remarkable research papers has attempted to develop formaldehyde-free FR replacements due to the formaldehyde concern. Despite the efficiency of already existing FR treatments such as Proban, Pyrovatex, Trevira CS, researchers from various disciplines from both academia and industry are still looking for alternative choices, while taking into consideration the requirements such as ease of application, durability, comfort, cost effectiveness, lower or non-toxicity and comparable textile service-life features. Development of any new flame retardant compound, in general, should comprise both material performance and toxicity levels for a complete assessment [11, 16].

In our previous studies, a novel halogen-free FR chemical called Fire-off was synthetized and applied to cotton, polyester and CO/PET blend fabrics. According to the findings, the thermal stability of the fabrics and their flammability behaviours strongly affected by Fire-off finishing and all treated samples lead to favour formation of char [17]. Fire-off is also an eco-friendly product not containing formaldehyde, either. Besides its thermal and toxicity assessments, durability, comfort, tensile
properties and appearance of FR treated fabrics are also in significance for practical end uses and that should be further stage for commercialization of a developed FR product.

In the present of the study, mechanical properties of Fire-off has been investigated in order to assess textile service-life properties. Concerning to fabric strength, abrasion properties and outward appearance; tensile properties, abrasion, pilling performance and whiteness of untreated and Fire-off treated fabrics were tested and evaluated. Thermal test results showed that there was a slight increase in strength, elongation, abrasion and pilling. On the other hand, whiteness and air permeability of fabrics were decreased after Fire-off treatment.

2. Materials and Method

2.1. Materials
The experiments were conducted using scoured 50/50% CO/PET fabrics (227 and 292 g/m², twill) supplied from Ata Textile in Turkey. 50/50 % was chosen, because flammability of this blend is much more critic with flammability and burning behaviour than other blend ratio of CO/PET fabrics such as 70/30, 65/35 etc. As chemical, Fire-off (PVP (PR)-P-DCDA) supplied from Eksoy Chemical was used for FR treatments of fabrics.

2.2. Fabric Finishing Procedure
FR bath with 350 g/L Fire-off was prepared in water. The fabric samples were impregnated by 2 dip-2 nip padding using a laboratory padder at room temperature. The wet pick-up was approximately 100±2%. After padding process, they were dried at 100°C for 3 min, and subsequently cured in an oven at 180°C for 3 min.

2.3. Evaluation of flame retardancy
Limiting Oxygen Index (LOI) test was performed for cotton and CO/PET blends according to BS EN ISO 4589-2 standard using Concept Equipment Oxygen Index Module to assess their FR properties. Before to test, specimens were conditioned for 24 h under the temperature of 20 ±2°C and relative humidity of 65±5%.

2.4. Determination of tensile property
Tensile Properties of treated and untreated CO/PET fabrics were tested according to ISO 13934-1 (2013) using an Instron Tension tester to assess fabric strength and elongation alteration due to the FR treatment with Fire-off.

2.5. Determination of abrasion and pilling resistance
ISO 12947-2 (2017) and ISO 12945-2 (2002) standard procedures were carried out to assess abrasion and pilling properties of untreated and treated CO/PET fabrics, respectively.

To perform abrasion test, the fabric samples were subjected to 50,000 or 100,000 abrasive cycles in a Martindale apparatus with a pressure of 9 kPa. In piling test, 125, 500, 1000, 2000, 5000 and 7000 cycles were performed, respectively. Visual evaluation values were determined by 3 observer and average results of 3 specimens were calculated.

2.6. Determination of air permeability
The air permeability of untreated and treated fabrics were measured by Prowhite Air Test II with a pressure applied of 100 Pa, according to ISO 9237 (1995). Average results of 5 specimens were calculated.

2.7. Determination of whiteness
The whiteness index values of untreated and treated fabrics were measured on a spectrophotometer with a commercial name of Datacolor. The whiteness index values evaluated according to the CIE lab.
3. Results and Discussion

3.1. Evaluation of the flame retardancy
To evaluate FR properties of the treated fabrics, LOI of untreated and treated samples was also tested and the data obtained were given in Table 1.

| Fabric Type                  | Untreated fabrics | Fire-off treated fabrics |
|-----------------------------|-------------------|-------------------------|
| CO/PET (227 g/m²)           | 18.7              | 27.1                    |
| CO/PET (292 g/m²)           | 18.8              | 26.7                    |

The LOI values of fabrics were increased from around 18.5 to 27 after Fire-off treatment that indicate FR properties.

3.2. Determination of tensile property
Tensile Properties of CO/PET fabrics before and after treatment were given in Table 2.

| Fabric Type                  | Untreated fabrics | Fire-off treated fabrics |
|-----------------------------|-------------------|-------------------------|
|                            | (N)               | (%)                     |
|                            | (N)               | (%)                     |
| CO/PET (227 g/m²)           | 1376.51           | 21.07                   |
| CO/PET (292 g/m²)           | 1365.52           | 19.59                   |

Even though, it is expected that FR treatments deteriorate tensile properties of the fabrics, it is clearly seen from the data in Table 3.4, tensile strength of CO/PET samples do not change considerably. On the other hand, elongation values of CO/PET samples increase slightly after the Fire-off treatment.

3.3. Determination of abrasion and pilling performance
Abrasion resistance results can be seen in Table 3 and Figure 1.

| Fabric type                       | FR (g/L) | 25,000-30,000 cycles | 30,000-35,000 cycles | 35,000-40,000 cycles | 40,000-45,000 cycles | 45,000-50,000 cycles |
|----------------------------------|----------|----------------------|----------------------|----------------------|----------------------|----------------------|
| CO/PET (227 g/m²)                | -        | +                    | -                    | -                    | -                    | -                    |
| CO/PET (292 g/m²)                | -        | +                    | +                    | +                    | +                    | +                    |
| CO/PET (227 g/m²) 350            | 350      | +                    | +                    | +                    | +                    | +                    |
| CO/PET (292 g/m²) 350            | 350      | +                    | +                    | +                    | +                    | +                    |
Untreated lightweight CO/PET (227 g/m²) fabric failed in 30,000 and 35,000 cycles. However, 292 g/m² CO/PET fabric did not have any breakage after 100,000 abrasion cycles. On the other hand, treated fabrics passed to abrasion test with no breakage and all demonstrated a super resistance to abrasion. Visual assessment results of pilling test are shown in Table 4.

Visual assessments show that there was no pilling occurrence on CO/PET fabric surfaces after Fire-off treatment while lightweight untreated CO/PET fabrics (227 g/m²) have hairiness, heavier weight of untreated CO/PET fabric (292 g/m²) have hairiness and also pilling on some part of fabric surface. After treatment of Fire-off, little or no hairiness was observed on fabric samples.

3.4. Determination of air permeability
Air permeability results of fabrics were given in Table 5. Air permeability should be maintained in any ideal chemical treatment. However, results indicate that fabrics after FR treatment are less permeable to air (> 12-23%) due to the chemical deposition onto surface, as it is expected.

3.5. Determination of whiteness
Table 6 exhibits the effects of Fire-off treatment on fabric whiteness index. Fire-off tends yellowing effect on the fabric (35-41 %), it may be due to acidic condition (pH =3-4) that in the agreement of Li et al (2011) [9].

CO/PET (227 g/m²)  CO/PET (292 g/m²)  CO/PET (227 g/m²)  CO/PET (292 g/m²)
A: Untreated samples after 50,000 cycles. B: Treated samples after 100,000 cycles.

Figure 1. Untreated and treated sample pictures after abrasion test.
4. Conclusion
In order to detect any change on strength, elongation, pilling and abrasion values, whiteness index of fabrics, Fire-off treated fabrics were tested mechanically for product quality. Moreover, relative handles of the Fire-off treatments was observed for their practical application, particularly for apparel end uses. Tensile test results demonstrated that treated fabric strength did not drastically changed and elongation of CO/PET increased after Fire-off treatment. It was found that Fire-off treatment significantly increase abrasion resistance of CO/PET fabrics. As a result of visual assessment of pilling test, treated samples had none pilling and only little hairiness on surface of fabrics as opposed to untreated ones. Concerning to air permeability, treated fabrics showed lower permeability to air as expected. Although, Fire-off induces yellowing effect on fabrics, the change on whiteness of treated fabrics were not dramatic. Furthermore, FR treatment in 350 g/L concentration is quite high chemical add-on the fabrics; it was surprisingly observed that fabric handles were not affected drastically from the treatment.

To sum up, changes in mechanical properties of fabrics after the Fire-off treatment demonstrate a definitive trend of increasing elongation, abrasion, pilling properties and decreasing air permeability and whiteness.

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