Flame-resistant pure and hybrid woven fabrics from basalt

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Abstract. This work has been formulated to investigate the burning behavior of different type of fabrics. The main concentration is to see how long the fabric resists after it catches the fire and the propagation of fire can be reduced by using flame resistant fiber i.e basalt. Basalt fiber is an environmental friendly material with low input, high output, low energy consumption and less emission. The goal of present investigations is to show the dependence of fabric flammability on its structure parameters i.e weave type, blend type etc. Fabric weaves have strong effect on flammability properties. Plain weave has the lowest burning rate as the density of the plain weave fabric is more and the structure is tight which gives less chances of flame passing through the fabric. Thermal stability is evaluated with TGA of all hybrid and non-hybrid fabrics and compared. The thermal stability of the basalt fiber is excellent. When comparing thermal analysis curves for hybrid samples it demonstrates that thermal stability of the samples containing basalt is much higher than the non-hybrid samples. Percentage weight loss is less in hybrid samples as compared to non-hybrid samples. The effectiveness of hybridization on samples may be indicated by substantial lowering of the decomposition mass. Correlation was made between flammability with the infrared radiations (IR)

1. Introduction

The safety of human beings has become a prime consideration in recent years. A considerable part of textile sector is involved with developments of fibers and fabrics. Organic materials which are generally excellent fuels play a major role in our daily life and textiles. Organic materials mainly consist of carbon, a dominant majority contains hydrogen, in addition to this, oxygen, nitrogen and other elements are present in variable quantity. Flammability of a material, considered as a complex property, consists of a combination of combustion, ignition and fire propagation; organic materials are flammable and bear potentially high fire risks. An involvement of complex combination of physical and chemical reactions which involve inter-conversion of condensed and gaseous phases results in flammability.

A number of new developments involving fibers and fabrics are carried out to cop the challenge of fire exposure. Flame retardant fabrics are developed with a property of natural resistance against fire as they may burn or char but won’t propagate flame. The essential requirement is a material that bear low propensity to ignition and low heat barrier in order to have fire resistance [1]. Textile fabrics are used in protective clothing, some of the uses are, flexible insulation panel in building construction, fire blockers for upholstery and seats, brattice cloth in mines used primarily for ventilation, furnishing for public halls and transport etc. Polypropylene (PP) and Polyester (PET) are two among the top ten polymers in use with their main uses in battery trays, air ducts, instrument panels etc [2].
When a fabric is exposed to fire, it generates heat energy which leads to heat transfer through conduction, radiation and convection. Heat generated and transferred varies greatly depending on fiber content. An addition of heat of burning and fabric weight describes quantity of available heat. Thermoplastics like polypropylene, polyester and nylon, when heated after melting point, contract by surface tension which results in minimization of surface area and degree of burning [3].

A mixture of radiant and convective heat creates a hot environment. Flame retardant fibers like glass provide good protection against heat as they have low coefficient of thermal conductivity i.e. 0.034-0.04 W/m K, the heat passes slowly and spread of flame is reduced leading to decrease in material destruction. Basalt fibre is mainly composed of SiO$_2$, Al$_2$O$_3$, CaO, MgO, Fe$_2$O$_3$, FeO, Na$_2$O, and K$_2$O. The main presence of SiO$_2$ results in chemical stability and excellent mechanical properties. High mass ratio of Al$_2$O$_3$ gives the fibre chemical and thermal stability, durability and higher tensile properties. Ferric oxide gives fibre brown color and affects melting parameters and conductivity [4]. Low thermal conductivity coefficient of basalt fibres i.e. 0.031-0.038 W/m.K provides good protection. Their high diameter is irrespirable and they can replace asbestos in many applications [5]. These fibres have also good mechanical strength, non-flammability (LOI value of fibre is 430) and good electrical and insulation properties.

It is particularly important to determine the extent to which fibre and fabric structure affects the final burning behaviour of the product. This will allow designing final products with suitable physical and burning properties for end use. There are studies regarding many flame retarding materials application on textiles [1-3]. However little work is done on study of effect of hybridization of flame-resistant fibres with flammable fibres. This study evaluates the influence of hybridization on the flammability and thermal stability of fabrics. The presence of inherent flame resistant material in fabrics is expected to improve flammability properties. In addition effect of weave structures on flammability characteristics were also taken into account. A correlation was established between the flammability and IR radiations which opens new horizon for flame resistant fabrics.

2. Material & Methods

The polyester (PET) and jute yarn used in our study were available commercially. Polypropylene yarn was taken from Synthetic (Pakistan). The basalt yarn was used as received from Kamenny Vek (KV) (Russia). The research was focused on the flammable properties of hybrid fabrics with Basalt (B) in warp /weft and Polypropylene (PP), Polyester (PET) and Jute (J) yarns in weft and vice versa. Fabrics were prepared in three type of weaves i.e. Plain weave, Matt weave and 1/3 Twill. Pure fabrics were made for the comparison with other fabrics. All fabrics were made on the CCI sample loom with the same density, 12 threads/cm in warp and 8 threads/cm in weft. The flammability of the samples was investigated using the horizontal test method according to standard DIN 50050-1:1986, which is applicable to all textile materials. The thermal behavior of hybrid and non-hybrid woven fabrics were studied under thermo gravimetric analysis (TGA). The thermo gravimetric analysis was performed on Mettler Toledo in air from 30 °C to 600 °C at a heating rate of 10 °C/min. SEM was used for investigating the degradation of samples. Attenuated total reflection (ATR) infrared spectroscopy (NicoletiZ10, Thermo Fisher Scientific Corporation) was used in order to understand the co-relation of IR and flammability for PP and PET fiber.

3. Results and discussion

3.1. Flammability Analysis

Ignition and flammability are not the same; ignition typically refers to how quickly a fabric will ignite if exposed to an ignition source, while flammability or rate of flame refers to how quickly the fire will spread. For textiles, the critical factor in determining flammability ratings for varying construction techniques is the availability of oxygen. Combustion is accelerated if air can permeate a fabric easily.
Porosity has significant effect on availability of oxygen. The weight, thickness, fabric density and weave of fabric can affect the material to ignite and burn. Fabrics with more of the fiber surface area exposed to air have more oxygen available to support burning and therefore burn more easily. The plain weave shows the highest weave factor of the order of 1 as compared to remaining weave (i.e. 0.84 for both matt and twill). Plain weave fabric has a maximum number of interlacement per unit area. Hence the empty spaces are less as compared to other weaves, as the empty spaces between yarns decrease, the weave structure become tight. Plain weave structure is tightly woven structure due to less float, so it will burn more slowly as compared to other fabrics of the same material. Matt and twill has same weave factor but matt has less burning rate because of its structural parameters. When the length of float increases, the ignition decreases [6-7]. Thickness has also effect in single layer fabric [8]. Twill weave take more time to ignite as it has long float than other weaves and it may be because of thickness as twill has more thickness because of its diagonal line structure. Although this difference is not so significant. A comparison of burning rate of different type of fabrics is shown in Figure 1. The flammability of textiles is influenced by the inherent characteristics of different types of fibers. Fiber combustion is decided by two conditions, first the composition and structure of fiber directly affects its thermal decomposition temperature and second the Oxygen supply circumstance, the fiber combustion performance is judged by LOI [6]. The chemical composition of the polymer exerts the greatest influence on its burning behavior. Mode of decomposition and the nature of the decomposition products (solid, liquid, and gaseous products) depend on the chemical nature of the fiber. The thermal decomposition products determine the flammability of polymers (e.g., fibers or modified fibers).

As mentioned in Table 1 and in Figure 1, basalt fibre does not melt and shrink when it approaches flame. It will curl slightly and redden like an iron wire when it is contacted with the flame [8] so B/B structures has no effect of flame.

| Sample name | Flame formation | Melt dripping | Smoke formation | Char formation | Time to ignition (sec) | Burning rate (sec) | Comment |
|-------------|----------------|--------------|----------------|----------------|----------------------|-------------------|---------|
| B/B PW      | X              | X            | X              | X              | X                    | X                 | Not Burn |
| B/B BW      | X              | X            | X              | X              | X                    | X                 | Not Burn |
| B/B TW      | X              | X            | Almost No      | No             | 15                   | 120               | Totally Melt |
| PP/PP PW    | Late           | Higher       | Almost No      | No             | 16                   | 110               | Totally Melt |
| PP/PP BW    | Late           | Higher       | Almost No      | No             | 17                   | 100               | Totally Melt |
| PP/PP TW    | Late           | Higher       | Almost No      | No             | 17                   | 100               | Totally Melt |
| PET/PET PW  | Moderate       | Moderate     | Moderate       | Lower          | 10                   | 110               | Totally Melt |
| PET/PET BW  | Moderate       | Moderate     | Moderate       | Lower          | 11                   | 107               | Totally Melt |
| PET/PET/TW  | Moderate       | Moderate     | Moderate       | Lower          | 12                   | 105               | Totally Melt |
| J/J PW      | Higher         | No           | Lower          | Higher         | 2                    | 95                | Only Char Left |
| J/J BW      | Higher         | No           | Lower          | Higher         | 3                    | 90                | Only Char Left |
|         |       |      |      |      |       |                  |
|---------|-------|------|------|------|-------|------------------|
| J/J TW  | Higher| No   | Lower| Higher| 4     | 84               |
| B/PP PW | Late  | Moderate| Medium| No   | 18    | 180              |
| B/PP BW | Late  | Moderate(More Than Pw) | Medium | No   | 18.5  | 169              |
| B/PP TW | Late  | Moderate | Medium | No   | 19    | 152              |
| B/PET PW| Moderate| Lower | Moderate | Lower | 13    | 162              |
|         |       |      |      |      |       |                  |
| B/PET BW| Moderate| Lower | Moderate | Lower | 14    | 150              |
| B/PET TW| Moderate| Lower | Moderate | Lower | 15    | 145              |
| B/J PW  | High  | No   | Lower| Higher| 5     | 120              |
| B/J BW  | High  | No   | Lower| Higher| 5.5   | 110              |
| B/J TW  | High  | No   | Lower| Higher| 5.7   | 105              |
| PP/B PW | Late  | Higher | Low | No   | 17    | 158              |
| PP/B BW | Late  | Higher | Low | No   | 18    | 152              |
| PP/B TW | Late  | Higher | Low | No   | 17.5  | 135              |
| PET/B PW| Moderate| Lower | Moderate | Lower | 12    | 132              |
| PET/B BW| Moderate| Lower | Moderate | Lower | 12.5  | 128              |
| PET/B TW| Moderate| Lower | Moderate | Lower | 12    | 125              |
3.2 Thermal Analysis

To evaluate the thermal stability of fabrics, the TGA analysis was applied and pursued by presenting comparative analysis between different types of fabrics as shown in Fig. 2.

The total weight loss of BB/BB (basalt) sample is very less in the process of being heated from room temperature to 600 °C. Basalt has good thermal stability during the TGA. This is consistent with the behaviour of basalt in flammability test, i.e. Keeps shape after burning. Basalt fibres are almost flame resistant. With the addition of basalt yarn, in other compositions, thermal degradation decreased for all hybrid structures. Thermal degradation of PP structure is earlier than PET structure because of its low melting temperature. At temperature above melting point, molecular movement increased a lot, the components of the long chain backbone of the polymer can begin to separate (molecular scission) and react with one another to change the properties of the polymer. So initiation of thermal decomposition starts earlier in PP structure but PP is long chain polymer so high bond dissociation energy, its heat of decomposition is more than PET. Generally, the lower the respective Tc (combustion) and usually Td (decomposition) temperature and the hotter the flame, the more flammable is the fibre (i.e 320-400 °C for PP and 285-305 °C for PET) [9] so its ignition temperature is higher i.e 570 °C as compared to PET 450 °C and its volatiles gaseous which fasten the combustion

Figure 1. Samples behavior during flame application

Figure 2. TGA curves for different type of fabric samples
process are less as compared to PET so its flammability is less[7]. This is also verified by FTIR analysis.

3.3 ATR–FTIR analysis

The flammability is correlated with the infrared radiations. The total energy absorbed by the PET is two times greater than PP by calculation. Beer-Lambert law was applied to support the results. On the basis of this equation, the total energy absorbed by the samples under IR radiations was calculated. The results from this equation follow the same trend. The total energy absorbed by PET is two times greater than PP. So, it is concluded on the basis of results obtained that PET is more flammable as it absorbs more energy than PP and there is a correlation between the flammability and IR radiations.

![Figure 3. (a) IR Spectra of fabric samples (b) Total energy absorbed by fabric samples](image)

4. Conclusions

Given its importance to consumer safety, fire resistant textiles/fire retardant textiles are one of the fastest growing sectors in industrial textiles. Fabric weaves have strong effect on flammability properties. Plain weave has least burning rate as the density of the plain weave fabric is more and the structure is tight which gives less chances of flame passing through the fabric. The thermal stability of the basalt fiber is excellent. When comparing thermal analysis curves for hybrid samples it demonstrates that thermal stability of the samples containing basalt is much higher than the non-hybrid samples. Percentage weight loss is less in hybrid samples as compared to non-hybrid samples. Thermal analysis results were compared with flammability parameters. Good agreement was observed between two except PP and PET due to material properties. It is also verified by co-relation between flammability and IR. In all hybrid samples burning rate is less than their non-hybrid samples as high thermal stability also reduces the burning (heat release) rate. It is novel approach to reduce flammability and thermal degradation by fire resistance materials.

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