Tensile properties of various cotton and Dyneema® blend yarns

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A series of ring- and rotor-spun yarns has been produced from the low-level blends of Dyneema®, a gel-spun ultra-high molecular weight, high-density polyethylene fiber (HDPE) of varied types, with selected white and naturally colored cottons and the tensile properties of blended yarns studied. The Dyneema® fiber is commonly referred to as high performance polyethylene (HPPE) due to its exceptionally high strength. The addition of small quantities of certain HPPE fibers substantially increases the yarn tenacity and breaking elongation of certain cotton blended yarns, particularly those made from naturally colored cottons. The resultant yarn tenacity appears to be influenced by the fineness of the constituent fibers and the level of yarn twist. The effect is more pronounced for the colored cottons than for the HPPE blends with white cotton. Whereas the yarn strength tends to increase for the pure brown and white cottons as the twist increases, it decreases in the green cotton yarns with the increase in twist within the range studied. However, the addition of small quantities of HPPE fiber results in substantial increase in tenacity for all at a constant level of twist. Finer HPPE fibers provide a greater improvement in yarn strength as compared to coarser HPPE fibers. The different frictional properties and geometries of the constituent cottons and synthetic fibers play a role in their blending and associated resultant yarn strength. The use of small quantities of 1-denier HPPE fiber significantly increases the strength and elongation of cotton blended yarns, particularly those made from brown cotton, with the minimal change in observed color. Such cotton and Dyneema® blends may find application in special purpose denims, where pure cotton yarns (whether white or naturally colored) or the traditional cotton-rich blends with conventional synthetics may not meet the performance requirements for fabric strength.

Keywords: Cotton, Dyneema®, High performance polyethylene, Yarn strength

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1 Introduction

Despite stiff competition from popular synthetic fibers such as polyester and nylon, cotton retains a very significant market share in the apparel sector worldwide, mainly because of its excellent comfort (ability to absorb, transport and dissipate moisture) and substrate properties. However, pure cotton fabrics tend to exhibit deficiencies such as high shrinkage, low strength and durability, lack of easy-care properties, and inferior laundered appearance. Smith1, Hamburger2, and Peirce3 were the earliest scientists who studied the importance of inherent properties of the basic fibers of which textile structures of desired functional performance are made. Hamburger2 demonstrated the effect of blending two fibers of different mechanical characteristics (mainly strength and extensibility) on the mechanical behavior of the blended yarn composed thereof. He was one of the earliest investigators to study the importance of stress-strain relationships of different fiber blends for industrial applications. He calculated the “strength efficiency” of constituent fibers of a composite/blend yarn to demonstrate the beneficial importance of blending different fibers to achieve textile structures of desired attributes. However, since then many good studies on blending (intimate, draw-frame, or double- roving) of fibers of different types and / or qualities have been reported. In fact, industrial blending of cotton with polyester and other strong synthetic fibers has been popular for decades to reduce some of the above stated fabric deficiencies and to produce blended fabrics that are much stronger than those made from pure cotton. However, such blended fabrics typically contain 65% polyester and 35% cotton, although 50:50 polyester/cotton blends are also common. These fabrics obviously do not provide the appearance, comfort and excellent substrate properties of 100% cotton fabrics. For some textile applications such as specialty denims, it is desirable to maintain the appearance and comfort of cotton, thereby requiring higher percentages of cotton in the blends. However, the specific high strength requirements of the fabrics cannot be met with low

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levels of the popular synthetic fibers. To meet the challenge of attaining superior durability of predominantly cotton fabrics, Sawhney et al. demonstrated that the addition of merely 10% ultra gel-spun polyethylene (PE) Dyneema® staple fibers to cotton significantly increases the tensile and tear properties of the blended fabric. In this paper, the effects of blending nominal percentages of Dyneema® of varied geometry with white as well as naturally colored cottons has been reported. The use of colored cotton has been curtailed by its relative weakness, despite increasing consumer demand for such ecological materials that do not require chemical dyeing. Although the present production of colored cotton in the United States is minimal, there is a substantial and growing market especially in Western European countries for colored cottons grown in Peru, China, Israel and a few other countries.

2 Materials and Methods

Dyneema® gel-spun high performance polyethylene (HPPE) staple fiber was obtained from DSM High Performance Fibers, Netherlands. This material is of high molecular weight, and extremely high molecular orientation, strength and modulus. The specifications of HPPE fiber used are shown in Table 1. The properties of cotton fibers were measured by HVI as per the ASTM standards and are shown in Table 2. The HPPE fibers were blended in 10, 15 and 20% proportions by weight with Delta and Maxxa varieties of white cotton and with naturally colored green and brown cottons.

The fibers were processed into yarn on laboratory-scale commercial equipment using standard procedures. Cotton control yarns containing no HPPE fiber were spun from each fiber across the range of twist. For the experimental yarns, the cotton and Dyneema® fibers were separately opened and carefully blended in a SpinLab Opener/Blender in the designated proportions by weight. The blended materials were processed into 37 tex (Ne 16/1) yarns. The ring yarns were spun at 3.6, 4.2, and 4.8 TM and the rotor yarns at several twist levels between 3.0 TM and 6.0 TM. Numerous series of yarns were spun reflecting each cotton in different blend levels of a variety of HPPE fibers. All the yarns were tested on an Uster Tensorapid 3 instrument in accordance with ASTM procedures and the selected results are reported.

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<td>Green 14</td>
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<td>77.9</td>
<td>16.34</td>
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</table>

3 Results and Discussion

The tenacities of the pure cotton ring and rotor yarns as a function of twist are shown in Figs 1 and 2. The ring yarns show maximum twist strength in the vicinity of 4.2 TM for the brown and white cottons and at <3.6 TM for the very fine, low micronaire green cotton. The only plausible explanation for the green fiber (weakest) producing the strongest yarn at a relatively low TM is that the extreme fineness or the lowest micronaire (2.9) of the fiber permit relatively the highest number of fibers (green) in the yarn cross-section, resulting in comparatively greater overall inter-fiber cohesion and consequently greater yarn tensile strength. The impurity content (honey dew sugars, waxes, minerals, etc.) of the various fibers, which possibly could also have had some influence in the processing and ultimately on the yarn strength, has not been investigated in this study. The rotor-spun yarns show increasing strength with added twist for the brown and white cottons but no discernable trend for the green cotton. The ring and rotor yarns approach similar levels of maximum tenacity although the latter require more twist for comparable strength. A set of yarns spun from the same cotton with greater quantities of the same HPPE fiber generally shows increasing yarn strength. Where 10% blends of 1-denier HPPE fiber may cause considerable improvements in strength, 15% blends of the same fibers may impart dramatic increase in strength. However, 20% levels of 1-denier HPPE derive little or no added benefit. The addition of
suitable HPPE fiber tends to benefit the Maxxa cotton more than the Delta cotton. Selective data are shown in Figs 3-7. In general, the longer HPPE fibers produce stronger yarns at comparable blend levels of the same fibers in the ring yarns (Fig. 3), but these tend to be associated with relatively greater variability (Fig. 4). The shortest HPPE fibers produce relatively more uniform yarns. Additional trials were focused on the 1-inch cut length staple HPPE fiber for the two levels of fineness. The coarser 2-denier HPPE fiber is proved to be much less effective in improving yarn strength, and actually decreased yarn strength in some fiber/blend combination yarns. For example, among the 10% 1-inch staple HPPE blended yarns, the finer 1-denier HPPE fiber enhances the strength of the brown, white, and green cotton blends, but the coarser 2-denier HPPE fibers actually reduces the strength of the brown cotton blended yarns and the low-twist white cotton blended yarns. The tenacity of ring-spun yarns (Fig. 5) is found to be more consistent than the rotor-spun yarns, whose slivers lost varying amount of HPPE fiber to the opening rollers (precise fiber waste data not available). Figures 6 and 7 show the comparison of cotton/HPPE blended ring-spun yarns with their respective cotton control yarns. The changes were most dramatic for the brown cotton, increasing tenacity between ~20% and 50% among the 3.6, 4.2, and 4.8 TM yarns. The trends for the change in elongation were similar for a given set of yarns.

Fiber properties and/or yarn geometry may also play a part in the differential changes in tenacity of the white, brown, and green cotton blended yarns. In general, the improvements by the addition of HPPE are notable for the white cotton blends and very
significant for the brown cotton blends, even at only 10% level of HPPE fiber. The respectable strength of the pure green cotton (control) yarns may argue against the inclusion of HPPE fibers, although their addition still provides modest improvement in yarn strength. The extreme fineness of these fibers probably called for reducing twist rather than the usual increase to achieve greater yarn tenacity. The high wax level and low frictional resistance of green cotton may induce irregular drafting in the green cotton/HPPE blends, and/or allow greater slippage among constituent fibers of the yarns under loading. Unfortunately, the specific stress-strain relationships of the yarns’ constituent fibers, which were not thoroughly investigated in this particular study, could also be significant factors in this aspect. Interestingly, the strength of the pure colored cotton yarns is found to be greater than the strength of the white cotton controls. Previous work also has witnessed the “compensatory effect” of more and finer colored fibers in yarns of matched linear density.

In general, above experimental findings appear consistent with those of other researchers who studied the blending of cotton fibers. More uniform blends of fiber length and fineness have been found to be associated with more uniform products, although a definitive relationship between fiber irregularity and yarn irregularity has yet to be established. Greater uniformity of the blends is presumed to contribute to the generally higher strength and greater uniformity of the cotton blended yarns containing shorter and finer HPPE fibers. Since the greater uniformity of color in colored cotton blended yarns has been shown to be an indicator of the uniformity of blending, color readings of the resulting yarns may provide some additional insight. The ring yarns tend to be stronger and show more predictable trends than the rotor yarns. The rotor yarns tend to be weaker and are not necessarily more uniform, perhaps due, in part, to the variable losses of HPPE fiber during spinning or the inherently low coefficients of friction of the constituent fibers (coefficients of friction of Dyneema® and green cotton are ~0.16 and 0.21 respectively) or the factors of fiber/yarn geometry.

4 Conclusions

The use of low percentages of suitable high performance gel-spun polyethylene Dyneema® staple fiber can dramatically improve the yarn tenacity in blends with both white and naturally colored cottons. In general, the longer HPPE fibers result in stronger but less uniform yarns, whereas the shorter staple and finer HPPE fibers produce substantial increase in tenacity with relatively greater uniformity. The improved yarn tenacity and uniformity of the blended yarns are partly attributed to the degree of homogeneity of the fiber mixtures within the associated yarns.

The merit of using these very high strength HPPE fibers differ for the different cottons they are blended with. Whereas the brown cotton derives great benefit from the Dyneema® fibers, the white cottons are benefited less. The variation in yarn strength may be an indication of the mass variability or blend non-uniformity of the constituent fibers in these blends. By contrast, the green cotton blends with HPPE generally gain less strength with less consistency in the ranges of blend and twist witnessed. This probably was because of the variability imposed during
processing due to the known low frictional characteristics of both fibers. Unfortunately, such outcomes cannot be precisely explained or predicted except by repeated experimental trials, which simply could not be conducted due to the time and budget constraints for the project.

The improved tensile strength of the Dyneema®/cotton blended yarns, the brown cotton in particular, may reveal up new applications for these cottons; although more expensive, these yarns provide an attractive and environment-friendly alternative to white cotton. Selective naturally colored cotton blends with Dyneema® staple fiber may be useful in those applications where the appearance, texture and comfort pure cotton are essential along with the high fabric strength and durability. Visual comparisons evidenced very little if any perceivable change in color with the addition of HPPE fiber in blends. One possible application might be colored denims, where comfort and durability are critical and the hue, softness, luster, and ecological appeal of naturally colored cottons may provide an economic and marketing advantage.

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