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Compact Spinning in Cotton-based Core-spun Yarn: A Review

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Abstract

In today's world, textile outfits are chosen not only for their functional properties but also for their comfort. As cotton is synonymous with comfort in textile industries, cotton-based core-spun yarn is becoming increasingly popular day by day, where the core element satisfies the functional properties and the cotton sheath provides a good hand feel and comfort. At the beginning of the twenty-first century, researchers developed a new spinning modification known as the compact spinning system to improve yarn quality. In cotton-based compact core-spun yarn, reduced hairiness, unevenness (U%), thick place, thin place, neps, and increased strength are achieved. This will also lead to significant abrasion and piling resistance, higher air permeability, lower thermal resistance, and higher Relative Water Vapor Permeability (RWVP). This review paper illustrates the advantages of spinning cotton-based core-spun yarn in the compact spinning system.

Mots clés: Cotton, Comfort, Core-Spun Yarn, Compact Spinning, Hairiness, Spinning Triangle

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Introduction

Core spun yarns have a structure in which one of the constituents, usually a mono or multifilament synthetic filament, is shielded by another part, the staple fiber sheath (Alsaid Ahmed Almetwally, 2014; Babaarslan, 2001; H. Helali, Babay, 2012; Kumar, 2014; Yang, 2009). The majority of core-spun yarns are made on ring and friction spinning machines. Ring spinning has been prioritized over other spinning technologies, howbeit friction spinning has also been portrayed as quite effective, despite the major drawbacks of false-twisted core material and poor core-sheath spillage resistance (Harper, 1986; H. J. Kim, Yang, 2009; Ruppenicker, 1989). The primary aspect of using core-spun yarn is to reap the benefits from each of its components' features. The process of manufacturing core-spun yarn is very straightforward, and core and cover materials can be chosen from a variety of fibers with predetermined end uses.

Clothing comfort is characterized as a comfortable state arising from physiological, psychological, and physical harmony between a human being and the environment, which is a fundamental and universal need for consumers (Raj & Sreenivasan, 2009). Clothing comfort is usually divided into three groups in the literature: (a) aesthetic comfort, (b) thermo-physiological comfort, and (c) tactile comfort (Yoon, 1984). Customer tastes are influenced by subjective emotions and fashion trends, which affect aesthetic appeal or psychological comfort. Thermo-physiological comfort, on the other hand, refers to the fabric's ability to sustain thermal equilibrium between the human body and the environment. The mechanical contact between the clothing material and the human body is connected to tactile comfort. The fabric tactile properties have long been assessed using a subjective approach known as fabric handle (Kawabata & Niwa, 1989, 1991), but a recent study shows that friction plays a significant role in the hand of fabrics (Ramkumar, 2000). Hence, the true quality of apparel fabrics will be dictated by the Hand value combined with the weighed transport properties.

Cotton is undoubtedly responsible for moisture absorption, heat resistance, air permeability (H. J. Kim, Yang, 2009; Ruppenicker, 1989) as well as hairiness, unevenness, and other characteristics when a mixture of cotton and any filament is used (Erez & Çelik, 2014; Hua, 2018). On the other hand, the filament has strong tensile properties (Matsumoto, 1990; Merati, 2012). Thermal behavior, moisture vapor interaction, surface characteristics, and other fabric characteristics all affect clothing comfort (B. K. Behera, 1997; A. Das, 2007; B. Das, 2007, 2009; Oğulata, 2007).

So, if we can improve the moisture absorption, heat resistance, air permeability, hairiness, unevenness, and other characteristics of cotton by different spinning techniques, we can improve the comfort of clothing.

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Discussion

Core yarns are becoming increasingly popular as a result of the combination of two distinct material properties in a single yarn. Thousands of studies on core-spun yarn and fabric manufactured from it can be found in the literature, demonstrating its significance in the textile industry. Researchers have used lycra, dorlastan, spandex, T400 (elastic fiber), and Elastane to enhance the stretchability and elongation property (Adeli, 2011; Bedez Ute, 2019; H. Helali, Babay Dhouib, 2012; Kadoğlu, 2016; Kakvan, 2007; Su, 2020; Yanhong, 2019), polyester, nylon, and kevlar to improve rigidity and high strength (Ferreira, 2004; Gharehaghaji, 2007; M. Miao, 2010; Shanbeh, 2011), and Polyvinyl acetate (PVA) to produce hollow yarn because it is soluble in boiling water (A. Das, 2004; Javazmi, 2014), copper, stainless steel, and carbon fiber (CF) to generate conductive yarn and fabric (Lou, 2005; Yuan, 2019; Zaidi, 2018). Researchers employed several natural fibers (Chakraborty & Chatterjee, 1994; Dang, 2008; Doran & Sahin, 2020) such as cotton, wool, and silk to take advantage of their inherent properties. For example, wool and silk are good thermal insulators, whereas cotton is breathable, absorbent, and lightweight, increasing comfort. Different man-made synthetic fibers, such as nylon, polyester, polypropylene, and acrylic, are also used by researchers (Bar , 2018; du , 2015; Menghe Miao, 1996; Pourahmad & Johari, 2009) for their quick-dry ability, durability, colorfastness, and strength. When it comes to the comfort criteria of fabrics, cotton outperforms all other fibers. After over four decades of experimenting with synthetics, most people would agree that there is no comparison to cotton in terms of comfort, even though synthetics may be more long-lasting and have a better aesthetic look. Cotton, as a natural fiber, has basic fiber properties that are innately heterogeneous. It is the most prevalent natural fiber used in the textile industry, so using cotton as a sheath material in the core-spun yarn is becoming more prominent. Furthermore, because of its good core coverage, 100% cotton sheath provides excellent aesthetics, absorbency, and thus comfort, as well as crucial substrate properties, particularly in the application of special chemical finishes and adhesives (Sawhney & Ruppenicker, 1997). Cotton-based core-spun yarn can be classified into three categories such as (a) cotton-based elastane core-spun yarn (b) cotton-based rigid core-spun yarn (c) cotton-based conductive core-spun yarn.

Lycra, Dorlastan, Spandex, T400 (elastic fiber), and other elastic synthetic fibers are used in cotton-based core-spun yarn (Akankwasa, 2016; Bouhjar , 2012; Choi & Kim, 2004; H. Helali, Babay Dhouib, 2012; Houda Helali, 2013; Jaouachi, 2011) (Gorjanc & Bizjak, 2014; Sinha, 2017). These elastic fibers have such a polyurethane polymer chain that allows them to stretch between 400 and 800% Since elastic synthetic fibers are used as the core element, the fabric produced from these yarns possesses high elasticity and elastic recovery (Gazi Ortlek & Ulku, 2007; H, 2013; Wang, 2016), as well as dimension stability (Ertaş, 2016; B. Qadir, 2014; Sitotaw, 2018), which lessens bagging deformation in fabrics (Herath & Kang, 2008; Hyun, 1997; Jabbar, 2020). Cotton elastane core yarn fabrics are becoming more common in denim fabric (Stretch, Super stretch) thanks to the above-mentioned properties (Realff, 2015; Şengöz, 2004). Cotton elastane yarns are used to create knitted (Ertaş, 2016; M. B. Qadir, 2020) (Single Jersy, Rib, Interlock), and woven (Gokarneshan & Thangamani, 2010; Oparin, 2010; Sitotaw, 2018) fabrics. Leisurewear, hosiery, and underwear are produced from these fabrics (Kaynak, 2017; B. Qadir, 2014).

Nylon, Polyester, PVA, Dyneema, and other rigid synthetic fibers are used in cotton-based core-spun yarn (Jeddi, 1997; H. J. Kim, Kim, 2009; Merati, 1998; Merati & Okamura, 2001, 2003; Naeem, 2019; Sawhney & Ruppenicker, 1997). These rigid fibers are used to enhance the yarn's strength, while the cotton sheath provides excellent comfort (Harper, 1986; Pramanik & Patil, 2009; Radhakrishnaiah & Sawhney, 1996; Ruppenicker, 1989; Sawhney, 1989; Sawhney, Robert, 1992). These yarns are now used to make non-stretch denim (Ertaş, 2016; Sarıoğlu & Babaarslan, 2017), knitted (su , 2007), and woven fabrics (Harper & Ruppenicker, 1987; Radhakrishnaiah, 1993; Sawhney, Harper, Robert, 1991; Sawhney, Harper, Ruppenicker, 1991). These types of yarn are used to produce sewing threads and protective cloths (Military fabric, Military Tent, Abrasive drill fabrics) that demand substantial strength to function accurately (Sawhney, Ruppenicker, 1992). US Army Tents are built of cotton-based Dyneema core-spun yarn fabrics (Sawhney & Ruppenicker, 1997). High abrasive fabrics that are industrial abrasive cloth, are heavy duty and used as foundation cloth in industries (Sawhney & Ruppenicker, 1997).

Cotton-based electrically conductive yarns can be produced using conductive elements as a core, such as stainless steel (Perumalraj, 2009; Perumalraj & Dasaradan, 2009, 2010; Ramachandran & Vigneswaran, 2009), copper (Yu, 2017), and so on. Another method is to treat textiles with conductive materials including carbon nanotube (CNT) (Sun, 2016; Wang, 2016). Because of the better characteristics of conductive polymers, thermal expansion, density, and chemical (corrosion and oxidation resistance) properties, these textiles are used to shield and restrict Electromagnetic Interference (EMI) and Electrostatic Discharge (ESD) (Chen & Tsai, 1989; Hoeft & Tokarsky, 2000; Perumalraj & Dasaradan, 2009). These electrically conductive yarns are used to build knitted and woven fabrics that are used in military, medical, telecommunication, and health care apparel, as well as power cloth (Ramachandran & Vigneswaran, 2009; Yu, 2017). These fabrics are also used to protect household appliances, FM/AM radio broadcast sets, wireless phones, cellular phones, computers, buildings, secret rooms, and a variety of electronic equipment (Perumalraj, 2009).

All of these cotton-based core-spun yarns and fabrics are primarily designed for functional purposes with little regard for hand feel and comfort, as well as how the consumer feels when using those products manufactured from them. Since the beginning of the twenty-first century, researchers have been emphasizing comfort properties alongside functional properties, and they have been attempting to develop new techniques or methods to enhance the comfortability of fabric, as buyers and consumers have prioritized good comfort and hand feel property. One significant advancement is known as compact spinning. Compact spinning is a ring spinning phenomenon that reduces the spinning triangle to minimize yarn hairiness and help boost yarn tenacity (Fu, 2021; Jiang, 2012; Krifa & Ethridge, 2006; Regar, 2017; T. Siddiqua, M. A. Reza, and H. Altaf, 2019). The primary distinction in the compact spinning system is that the drawing section of the compact spinning machine ends with a condensation zone, which facilitates the minimization of the spinning triangle (Abou-Nassif, 2014; Basal & Oxenham, 2006; Beceren & Nergis, 2008; Elite & Gmbh, 2019; Jiang, 2012; Liu, 2019; Loganathan, n.d.; M. A. Shahid, M. D. Hossain, M. N. U. Hasan, and M. A. Islam, 2014; Ma, 2012; Messiry, 2013; Ramakrishnan, 2006; Taylor, Liu, 2014; Yilmaz, 2013). Yarn tenacity, number of twists, hairiness, Imperfection Index (IPI), Yarn diameter, Packing density (Gokarneshan, 2005; Raja, 2012; Taylor, Raja, 2014), etc. are affected by compact spinning (Tyagi, Bhowmick, 2010).

Advantages of Compact Spinning

Low Twist, Higher Yarn Strength, Higher Production Rate

Table 1 demonstrates that introducing a low amount of twist results in an increased yarn strength. Compact spinning eliminates the spinning triangle, enabling more short fibers to participate in yarn construction, leading to higher yarn strength and lower twist insertion as a result the output rate increases (F. Göktepe, D. Yilmaz, and Ö. Göktepe, 2015; Józkowicz & Drobina, 2010; Özdil, 2005; T. N. Shaikh, R. Radadiya, and A. Rawal, 2017) as a low twist is applied (Abou-Nassif, 2014; Ahmad, 2009; El-Sayed & Sanad, 2007, 2010; Taylor, 2012; Wu, 2009).

Reduced Hairiness, Unevenness, Thin Place, Thick Place

Table 1 illustrates that compact yarn shows a downward trend compared to ring yarn in hairiness, unevenness, thin place, thick place. The spinning triangle is eliminated in compact spinning, and as a result, protruding short fibers participate in forming yarn that does not engage in the conventional ring system. And because of that, hairiness, unevenness (U%, CV%), thin place, thick place, and neps are significantly lowered when

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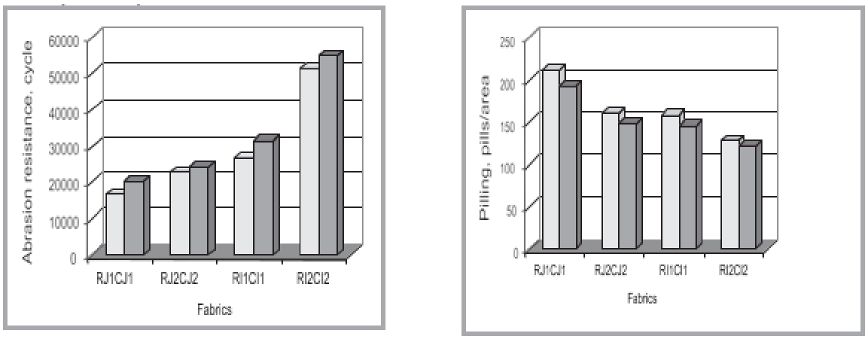
compared to conventional ring yarn (Alsaid Ahmed Almetwally, 2015; Dash, 2002; H. A. Kim & Kim, 2018; M. Krifa, E. Hequest, and D. Ethridge, 2002; Mamun, 2017; Murugan & Shenmugam, 2021; Nikolić, 2003; Özgüney, 2008; P. Çelik, and H. Kadoğlu, 2004; Suzan, 2011; Uddin & Jalil, 2015; Zou, 2011).

	30 Ne	40 Ne	30 Ne	40 Ne
Twist, turns/m	820	924	750	846
Tenacity, cN/tex	17.31	16.08	20.54	18.81
Breaking elongation, %	4.68	4.6	4.82	4.92
Hairiness (Uster), H	5.79	5.7	5.04	4.36
Unevenness (Uster), % U	9.15	9.97	8.9	9.73
Thin places (50%), km	0	1.2	0	1.2
Thick places (+ 50 %), km	7	9.4	4	10.4

Table 1. Properties of different count's yarn (Akaydin, 2009).

Better Abrasion and Pilling Performance

Pilling and Abrasion curve in Figure1 indicates better performance for compact fabric. The compact fabric has better abrasion resistance and pilling resistance because of the yarn's low hairiness and compact structure (Akaydin & Can, 2010; Barzoki, 2017; G. Manonmani, C. Vigneswaran, K. Chandrasekaran, and T. Ramachandran, 2013; Jackowski & Cyniak, 2004; Manonmani, 2010; Omeroglu & Ulku, 2007; Özdil, 2005; Özgüney, 2008; Ozturk & Nergis, 2008; Sowrov & Ahmed, 2014; Tyagi, Bhowmick, 2010; Wan, 2014).



RJ1, RJ2, RI1, RI2- Fabric Produced from Ring Yarn
CJ1, CJ2, CI1, CI2 – Fabric Produced from Ring Yarn
Figure 1. Pilling and Abrasion Resistance of compact fabric (Akaydin & Can, 2010)

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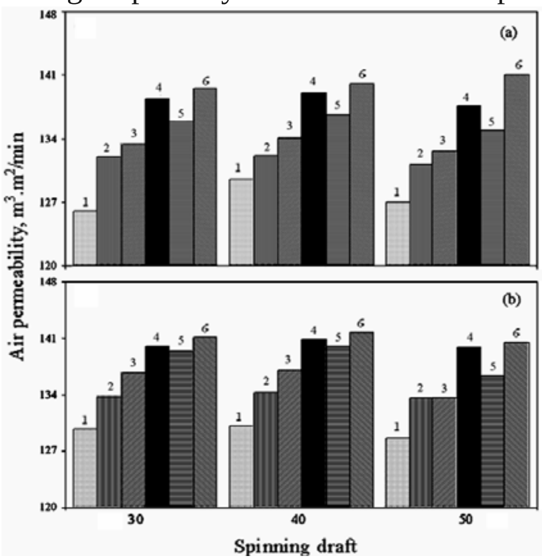
Higher Air Permeability

Fabric made from compact yarn has greater air permeability (Ali & Nassif, 2017; Alsaid A Almetwally & Salem, 2010; Taylor, 2011), Figure 2 shows that the compact fabric has greater air permeability than the ring. This is largely attributable to the compactness of the yarn, which decreases the yarn diameter (Altas & Kadoğlu, 2012; Dash, 2002; Ishtiaque, 2009; Yilmaz, 2007) and yarn hairiness (Altas & Kadoğlu, 2012; Bijoya Kumar Behera, 2020; Divya, 2016; Elmogahzy, 2006; Eng, 2013; Haleem & Wang, 2015; Hasan, 2016; Tyagi, Bhattacharyya, 2010a; Z. Xia, X. Wang, W. Ye, and W. Xu, 2015), resulting in a higher porosity of the fabric in compact fabric.



1,3,5 – Fabric Produced from Ring Yarn.
2,4,6 – Fabric Produced from Compact Yarn
Figure 2. Air permeability (Tyagi, Bhattacharyya, 2010b)

Good Thermal Properties (Relative Water Vapor Permeability and Thermal Resistance)

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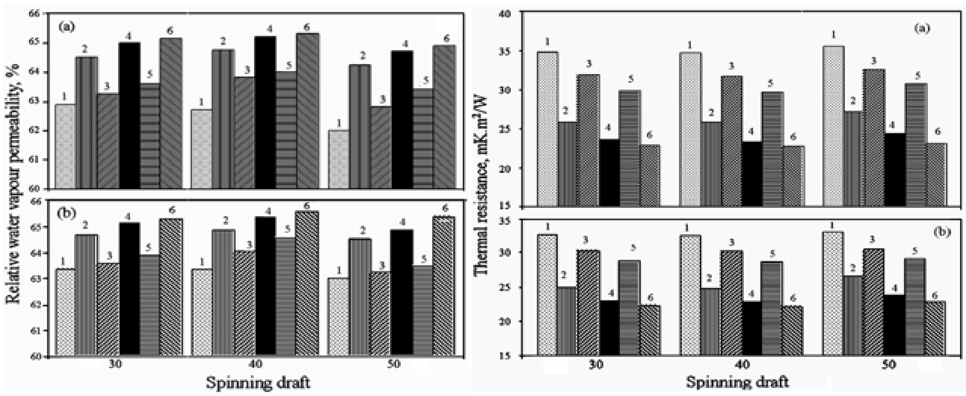

1,3,5 – Fabric Produced from Ring Yarn
2,4,6 – Fabric Produced from Compact Yarn
Figure 3. Relative water vapor permeability, and thermal resistance of compact fabric (Tyagi, Bhattacharyya, 2010b)

Figure 3 shows that Relative Water Vapor Permeability is higher and thermal resistivity is lower for compact fabric in all three comparisons. Thermal resistance values are lower in compact fabrics when Relative Water Vapor Permeability (RWVP) values are higher due to its low hairiness, reduced yarn diameter, and increased porosity of the fabric (A. Das, 2007; Tyagi, Bhattacharyya, 2010b).

Lower Fabric Thickness and Better Hand Feel

The fabric manufactured with compact yarn is thinner (H. Zhang, and X. Su, 2017). This is largely due to the compactness of the yarn, which reduces yarn diameter (Altas & Kadoğlu, 2012; Dash, 2002; Ishtiaque, 2009; Yilmaz, 2007) and yarn hairiness (Altas & Kadoğlu, 2012; Bijoya Kumar Behera, 2020; Divya, 2016; Elmogahzy, 2006; Eng, 2013; Haleem & Wang, 2015; Hasan, 2016; Tyagi, Bhattacharyya, 2010a; Z. Xia, X. Wang, W. Ye, and W. Xu, 2015). Hairiness, unevenness (U%), thin place, thick place, and neps are all much lower in compact yarn, (Alsaid Ahmed Almetwally, 2015; Dash, 2002; H. A. Kim & Kim, 2018; M. Krifa, E. Hequest, and D. Ethridge, 2002; Mamun, 2017; Murugan & Shenmugam, 2021; Nikolić, 2003; Özgüney, 2008; P. Çelik, and H. Kadoğlu, 2004; Suzan, 2011; Uddin & Jalil, 2015; Zou, 2011) resulting in a fabric with a better tactile feel. (Manonmani, 2010; Singh & Nigam, 2013).

Because of its exceptional features, compact yarn is increasingly being used in a wide range of applications nowadays (Kane, 2007). Compact spinning is a modified version of ring spinning that provides a novel yarn structure; the advancement of compact spinning has set new yarn configuration benchmarks (Abou-Nassif, 2014). The application of core-spun

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yarns in fabric manufacturing and the clothing industry has grown dramatically. The spinning parameters have a major impact on market specifications, such as comfort behavior (A Das & S M Ishtiaque, 2004; A. Das & Chakraborty, 2014). The comfort behavior of any clothing has a substantial effect on the wearer's performance. As comfort is essential in the twenty-first century, using a compact spinning technology to produce cotton-based core-spun yarn can reduce hairiness, unevenness, and the imperfection index of the yarn, as well as improve thickness, air permeability, and MVPR, all of which will have a serious influence on the comfort properties of the end-use items manufactured from cotton-based core-spun yarn.

Conclusion

Cotton has no contender when it comes to comfort. Since cotton has better core coverage, it is possible to use a reasonable amount of special chemical finishes and adhesives, which are the main catalysts for aesthetics and comfort in fabrics. We can attain some favorable circumstances by using a compact spinning process in cotton-based core-spun yarn.

- Less hairiness, unevenness, and IPI (thick place, thin place, and neps of yarn) will be obtained in cotton-based compact core-spun fabric, ensuring soft and good hand feel, as well as low pilling and high abrasion resistance.
- Lower thickness, higher air permeability, lower thermal resistance, and higher Relative Water Vapor Permeability (RWVP) will contribute to a cooler fabric with good comfort characteristics, which can be produced utilizing cotton-based compact core-spun yarn.
- Cotton-based core-spun yarn will be low in hairiness, which will facilitate fabric production. Needles on knitting machines will be simpler, and less waste will be generated, leading to lower maintenance costs and increased machine longevity.
- Cotton-based core-spun yarn produced in compact spinning will ensure good comfort property alongside have higher production of yarn resulting in saving money, time, and energy.

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