# Influence of Spindle Air Pressure and Its Direction on the Quality Characteristics of Polyester/Cotton Vortex Yarn

Sankara Kuthalam, Senthikumar P.

Anna University, PSG College of Technology, Coimbatore, Tamilnadu INDIA

Correspondence to:
Sankara Kuthalam email:sankar_kuthalam@yahoo.co.in

**ABSTRACT**

The influence of spindle air pressure and its direction on the properties of Polyester/Cotton vortex yarn was studied. The spindle air pressure direction was changed in both Z and S directions on the Z twist yarn of Ne 40s Polyester/Cotton vortex yarn (50:50 polyester: cotton) and these yarns were then tested for their properties such as tensile, unevenness, and hairiness. It was found that unevenness was lower with normal spinning condition and increased when the spindle air pressure increased in both directions. Imperfections were also found to be minimum with normal spinning condition and increased with increase in spindle air pressure. The yarn tenacity and elongation at break found to be lower at normal spinning condition. When the spindle air pressure increased yarn tenacity and elongation at break also increased with increase in spindle air pressure. At the same time spindle air pressure in the same direction of basic yarn twist gave less increase in tenacity and elongation than opposite direction of basic yarn twist. Hairiness index, H and hairiness in different length classes continuously increased as the spindle air pressure increased in opposite direction of basic yarn twist.

**Keywords:** Polyester/Cotton yarn, hairiness, MVS yarn, spindle air pressure, tenacity.

**INTRODUCTION**

Yarn characteristics mainly depend on two factors: fiber properties and yarn structure. Yarn structure includes the number of fibers in the cross section, packing density, fiber migration, fiber extend along the yarn length, irregularity of fiber displacement, twist, and outer form of the yarn [1]. In vortex spinning yarn structure plays the major role in determining the properties of the yarn. The advantage of ring like structure, lower hairiness, reduced fabric pilling, better abrasion resistance, higher moisture absorption, better color fastness, and fast drying characteristics have been made by the machinery manufacturer. Though lower hairiness seems to be an advantage of vortex yarn, many issues related to working performance of vortex yarn have been raised by knitters and weavers. Due to its very low hairiness, vortex yarn causes more variations in unwinding tension which causes holes, vertical line formation in knitting, and yarn jumping and higher breakages in the warping stage of the weaving process. Even though the hairiness of the vortex yarn can be increased by changing the spinning parameters, simultaneously it will reduce the tensile properties of the yarn while increasing the hairiness. Numerous studies have been carried out on yarn structure, process, and property relationship of vortex yarns [1-7, 10, 12-13].

Basal G and Oxenham W [1] studied the influence of spinning parameters and vortex yarn properties and they reported that increase in spinning speed, reducing nozzle pressure, and increase in spindle diameter will result in increased hairiness. But they found the tenacity of the vortex yarn reduces while attempting to increase the hairiness. Suat Canoglu et al [2] reported that the fiber bundle has more freedom to move inside the spindle of large diameter. Hence some twist is lost, wrapper fiber become looser, and yarn gets hairier. Compared to yarn produced by air jet spinning, the higher number of wrapper fibers and decrease in unwrapped sections have significantly improved characteristics such as better tensile properties, better evenness, and lower hairiness on vortex yarn. Nazam Erdumlu et al [3] found that, the tenacity of vortex yarn is dependent on both the ratio of wrapper and core fibers and the wrapping length of the sheath fiber.

Ortlek H.G et al [7] studied the effect of spindle diameter and spindle working period, and as per their findings higher spindle diameter resulted in a significant increase in yarn unevenness and hairiness values. The possible explanation for such unevenness properties is that fibers have more freedom to arrange themselves with a larger spindle diameter. Due to this reason some twist is lost, wrapping become looser, and yarn gets hairier. At the same time larger spindle diameter results in lower tenacity, elongation at break, and breaking work. This is mainly due to lower friction between fibers within the yarn, which is produced with larger spindle diameter.

Zou et al [14] analyzed the generation of yarn thin placed in vortex yarns. They found that when the nozzle pressure is too high, the separated fibers are easily taken out of the fiber bundle by the high speed air flow, which produces more wild and waste fibers and deteriorates the uniformity of the vortex spun yarn. Halil et al [15] compared vortex and rotor yarn properties and found that vortex yarns have better evenness and hairiness than rotor spun yarns. The reason being that vortex core fibers, which are highly oriented in parallel, have almost no twist and more than half of the surface area of the vortex yarn is covered and packed by a layer of wrapper fibers.

The flow pattern of the air vortex inside the nozzle and its influence on yarn properties has been studied by many researchers [8, 16-19]. According to their air flow analyses, increasing the nozzle pressure results in a radial velocity increase, which reinforces the expanding effect of the fiber bundle, producing more open trail end fibers. The higher the radial velocity, the bigger the expanding effect on the fiber bundle, thereby produces more wrapper fibers in the vortex yarn. At the same time, when the nozzle pressure is too high, the separated fibers are easily taken out of the fiber bundle by the high speed air flow, which produces more wild and waste fibers and deteriorates the uniformity of the vortex spun yarn. The tangential velocity which is perpendicular to the fiber axis and generates the cross flow part acts on the wrapper fibers. Increasing the tangential velocity benefits the twisting of open trial end fibers and, while decreasing it, results in weakening the twisting effect of open trial end fibers.

When the nozzle pressure increases, both the axial and tangential velocity increases. As a result the fiber bundle receives more twist and the yarn became stronger. A lower nozzle angle results in better evenness due to the increasing axial velocity of air flow [10].

Tyagi et al [20-22] analyzed the effects of spinning parameters on the low stress characteristics of vortex yarn and woven fabrics as well as thermal comfort properties

The main objective of this study was to examine the possibility of increasing yarn hairiness without compromising the tensile properties of vortex yarn. An attempt has been made by altering the spindle air pressure and thereby increasing the hairiness of vortex yarn.

**Spindle Air Pressure**

During vortex yarn formation, the fiber bundles that come out from the front rollers are grouped together and sucked in to the spiral shaped orifice. These fiber bundles then come under the influence of the spiral air jet stream of the spinning nozzle in the widening nozzle chamber and they spread out. When the fiber bundles come under the influence of the spiral air jet stream, the back end of the fibers that split out at the nip point of the front roller begin to twist. At this stage, the vortex yarn is not formed by this twisting of the fibers. The vortex yarn is now formed by the pulling force exerted by the additional nozzle kept inside the spindle, called as N2 nozzle. The air, which is supplied through this N2 nozzle, is called "Spindle air pressure". In normal spinning conditions, during yarn formation the N2 nozzle pulls the rotating fibers between nozzle and spindle surface through the tip of the spindle and pass the initial yarn to the delivery roller. After initial yarn formation, the air pressure supplied through the N2 nozzle is stopped and the continuous yarn formation is done only by the pulling force exerted by the delivery roller. During this study in addition to the pulling force by the delivery roller, continuous air pressure was supplied through the N2 nozzle (spindle air pressure) during yarn formation and the properties of the vortex yarns were analyzed with different spindle air pressure values and its directions. The principle of spindle air pressure on the vortex yarn is given in *Figure 1*.

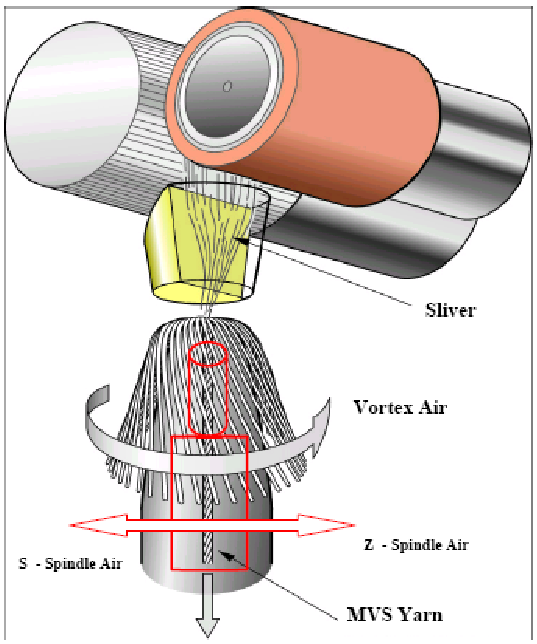


FIGURE 1. Spindle air pressure application during vortex yarn formation.

## MATERIALS AND METHODS

### Preparation of Yarn Samples

In this study, Ne 40s Polyester/Cotton vortex yarn samples with 50:50 blend ratios were produced in Z twist direction. Yarn samples were made without spindle air and with 0.04 and 0.08Mpa in both Z and S directions. The polyester fiber selected for this study was 32mm length and 1.0 denier fineness and its properties are given in *Table I* Combed cotton of Sankar-6 variety was selected for the cotton portion. The cotton fiber properties were determined by using Uster HVI and Uster AFIS and the results are given in *Table II.*

TABLE I. Properties of polyester fiber.

| Fiber Properties | Values |
|---|---|
| Fiber profile | Circular semi dull |
| Fiber length (mm) | 32.0 |
| Linear density (denier) | 1.0 |
| Tenacity (g/d) | $6.7 \pm 0.5$ |
| Breaking extension(%) | $20 \pm 5$ |

TABLE II. Properties of cotton fiber.

| Fiber properties | Average value |
|---|---|
| **HVI** | |
| Spinning consistency index (SCI) | 182 |
| Micronaire, Mic | 4.3 |
| Upper half mean length (UHML), mm | 30.9 |
| Uniformity index, UI | 85.4 |
| Short fiber index, SFI (<12.7mm) | 6.67 |
| Strength, G/tex | 39.4 |
| Elongation, % | 3.2 |
| Reflectance, Rd | 85.0 |
| Yellowness, +b | 7.1 |
| Color grade, C-G | 11-2 |
| **AFIS** | |
| Neps, cnt/gr | 43 |
| Seed coat nep (SCN), cnt/gr | 2 |
| Mean length by weight, mm | 26.12 |
| Upper Quartile length by weight (UQLw), mm | 32.00 |
| Short fiber content by weight (SFCw), % | 6.0 |
| Short fiber content by numbers (SFCn), % | 15.3 |
| Maturity ratio (MR) | 0.95 |

The polyester and combed cotton fibers were mixed together with 50:50 blend ratio at mixing and processed through the blow room, carding, and three passage drawing before reaching the vortex spinning machine. The finisher drawing sliver was produced by a Rieter auto leveler drawframe at 500 meter/min delivery speed, the linear density of the finished drawing sliver being adjusted to Ne 0.140. The drawn slivers were spun in to Ne 40/1 Polyester/Cotton yarn by using a Murata vortex spinning machine (MVS 861) with different spindle air pressure combinations. The process parameters of MVS 861 machine used for the production of yarn samples are given in *Table III.*

TABLE III. Process parameters of vortex spinning machine.

| Parameters | Values |
|---|---|
| Count | Ne 40/1 |
| Spinning speed (m/min) | 360 |
| Total draft | 286 |
| Break draft | 3 |
| Main draft | 44 |
| Intermediate draft | 2.16 |
| Drafting setting - Top (Front to back) | 49-35-38 |
| Drafting setting – Bottom (Front to back) | 44.5-35-38 |
| Feed ratio (FR) | 0.97 |
| Take up ratio (TUR) | 1.030 |
| Tension ruler ratio (TRR) | 1.025 |
| Condenser (mm) | 3 |
| Nozzle to spindle distance (mm) | 20.0 |
| Nozzle type | STAR |
| Spindle size (mm) | 1.0 |
| Needle holder | L8Z |
| Twist direction | Z |
| Nozzle pressure (Mpa) | 0.50 |

## Test Methods

The yarn samples produced by varying the spindle air pressure were tested for Unevenness, Imperfections, and Hairiness index, H on a Uster Tester 5 (UT5) at a speed of 400m/min. The Tenacity and Elongation properties were measured by using a Uster Tensorapid UTR4 at a speed of 5000mm/min with a gauge length of 500mm.The average values of 10 test results were presented for yarn unevenness, imperfections and hairiness for each yarn sample and the average of 120 readings were taken for tensile properties of each yarn sample The protruding hairs of yarn with different length were measured by a Zweigle hairiness tester, Zweigle G567 at a speed of 50m/min for the length of 100 meter per each sample.

The analysis of variance (ANOVA) was used to study the main effect of spindle air pressure. All statistical analyses were carried out at 99% confidence level.

# RESULTS AND DISCUSSION

## Mass Irregularity and Imperfections

TABLE IV. Properties of polyester/cotton vortex yarn with different spindle air pressure and direction.

| Count (Ne) | Ne 40/1 Polyester/Cotton (50/50) | | | | |
|---|---|---|---|---|---|
| Spindle air pressure (Mpa) | 0.08 | 0.04 | 0 | 0.04 | 0.08 |
| Spindle air direction | Z | Z | 0 | S | S |
| Actual count (Ne) | 39.9 | 39.9 | 39.8 | 39.9 | 39.9 |
| Unevenness, U% | 11.66 | 11.35 | 11.26 | 11.47 | 11.69 |
| Thin(-50%) / 1000m | 53 | 44 | 24 | 40 | 72 |
| Thick(+50%) / 1000m | 65 | 48 | 48 | 54 | 72 |
| Neps(+200%)/ 1000m | 95 | 88 | 77 | 87 | 93 |
| Tenacity (cN/tex) | 14.16 | 14.03 | 13.62 | 14.13 | 15.01 |
| Elongation at break, % | 6.45 | 6.20 | 6.02 | 6.16 | 6.63 |
| Hairiness, H | 3.45 | 3.42 | 3.69 | 3.71 | 3.83 |
| Zweigle hairs, 1mm/100m | 1465 | 1425 | 2147 | 2481 | 3388 |
| Zweigle, S3 value | 3.3 | 3.0 | 3.0 | 5.5 | 16.7 |

The results of yarn unevenness and imperfections with different spindle air pressure combinations are shown in *Table IV*. It can be seen from *Figure 2* that vortex yarn made with normal condition shows lower unevenness than yarn made from spindle air pressure with Z and S twist directions. The unevenness values increases as the spindle air increases in both directions. The reason for the increase in unevenness when the spindle air pressure is increased in the same direction of yarn twist (Z) may be due to too high twisting force by the combination of nozzle pressure and spindle air pressure. Some of the wrapper fibers which are taken out of the fiber bundle by the high speed airflow cause the uneven structure. These results prove the finding of Zhuan Yong Zou et.al. [8]. While the spindle air pressure is increased in opposite direction of basic yarn twist, the axial air velocity reduces and causes increase in unevenness, which has been proved by the findings of Basal G [10]. The increase in unevenness is statistically significant as per ANOVA analysis shown in *Table V*.

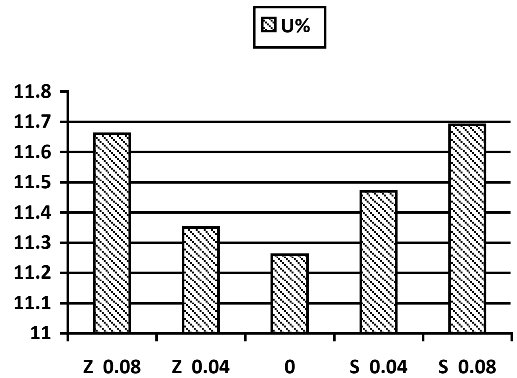


FIGURE 2. Influence of spindle air pressure on unevenness u%.

TABLE V. Anova results of effects of spindle air pressure on polyester/cotton vortex yarn properties. [if -table value – 4.04 at 99% confidence level]

| **Count ( Ne)** | **F critical for 40/1 Polyester/Cotton** | |
|---|---|---|
| Unevenness, U% | 6.42 | s |
| Thin (-50%) / 1000m | 8.83 | s |
| Thick (+50%) / 1000m | 1.29 | ns |
| Neps (+200%) / 1000m | 1.56 | ns |
| Tenacity (cN/tex) | 7.87 | s |
| Elongation at break, % | 4.95 | s |
| Hairiness, H | 163.70 | s |
| Zweigle hairs, 1mm/100m | 122.27 | s |
| Zweigle , S3 value | 23.19 | s |

s - Significant: ns – Non significant

Interestingly imperfections were also found to be lower with zero spindle air pressure (*Figure 3, 4 & 5*). Thin, thick, and neps increased when the spindle air pressure was applied on the surface of the yarn. When the spindle air pressure is applied on same direction (Z direction) of basic yarn twist, it further supports the twisting action of the wrapper fibers at the yarn formation zone. Due to the additional air pressure, the uneven vortex yarn has more wild fibers and causes higher imperfections. In case of spindle air pressure (S direction) with the opposite direction of basic yarn twist, it disturbs the wrapper fibers as the fibers enters the tip of the spindle and causes higher imperfections. The increase in thin places is statistically significant, whereas the increase in thick and neps are not significant.

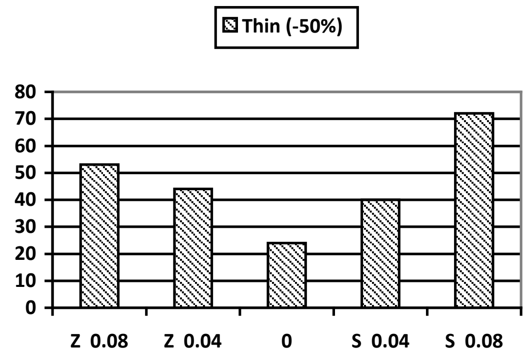


FIGURE 3. Influence of spindle air pressure on thin places (-50%).

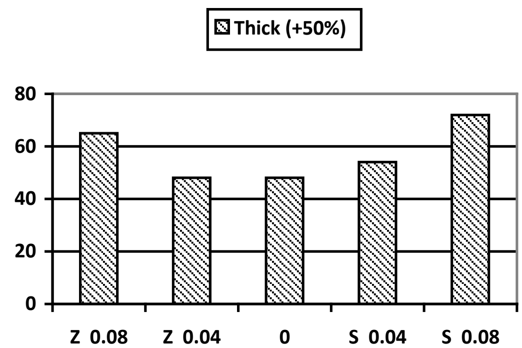


FIGURE 4. Influence of spindle air pressure on thick places (+50%).

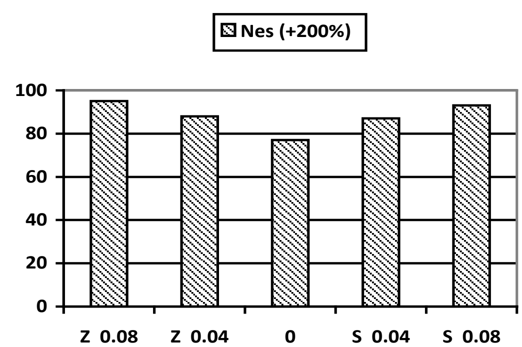


FIGURE 5. Influence of spindle air pressure on neps (+200%).

During application of Spindle air pressure in same direction of basic yarn twist, additional suction pressure will be formed at the spindle tip. Therefore in addition to the pulling force exerted by the delivery rollers, the spindle air pressure in the same direction of the basic yarn twist gives additional pulling force to the fibers which are whirling around the spindle by the pressure applied by the main nozzle. When the spindle air pressure is applied in the opposite direction of basic yarn twist, the pulling force exerted by the delivery roller is reduced and thereby disturb the free movement of fibers during its path through the hollow spindle.

**Tensile Properties**

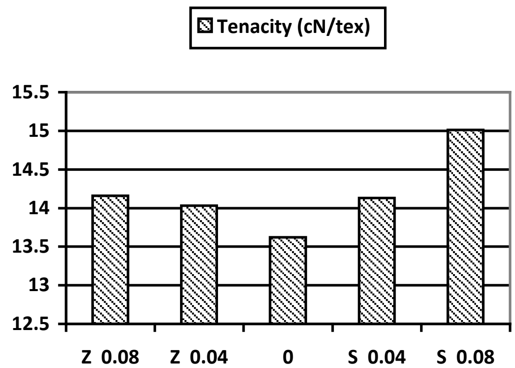


FIGURE 6. Influence of spindle air pressure on tenacity (cn/tex).

The tensile properties of 50:50 polyester/cotton vortex yarns made from five different combinations are shown in *Table IV*. It can be seen from *Figure 6* that the tenacity of the vortex yarn is influenced by the spindle air pressure. The tenacity of the vortex yarn is lower with zero spindle air pressure. Increase in spindle air pressure in same direction (Z direction) of basic yarn twist increases the yarn tenacity which may be due to tighter wrapping of fibres by the additional spindle air pressure. Interestingly the highest tenacity values were observed while the spindle air pressure was increased in the opposite direction of basic yarn twist. The reason for this increase in tenacity may be due the achievement of ideal wrapper to core fiber ratio. This result supports the findings of Nazan Erdumlu et. al. [3] that, the tenacity of vortex yarn is dependent on both the ratio of wrapper and core fibers and the wrapping length of the sheath fibers. The wrapper to core ratio plays the more important role than the tightness of the twist for deciding the tenacity of the vortex yarn.

The application of spindle air pressure forms a negative pressure at spindle tip. Since the needle holder is just above the spindle tip and guides the fiber strand in the direction of yarn twist, the negative pressure directly pass through the needle holder till the front roller nip. Therefore in addition to the negative pressure formed by the main nozzle air, the additional negative pressure by the spindle air pressure changes the fiber orientation and flow of fibers to the main twisting zone and thereby changes the structure of the vortex yarn and its characteristics. The internal structure of vortex yarn with different spindle air pressure combinations are shown in *Figure 7***.**


FIGURE 7. Structure of vortex yarn with different spindle air pressure.

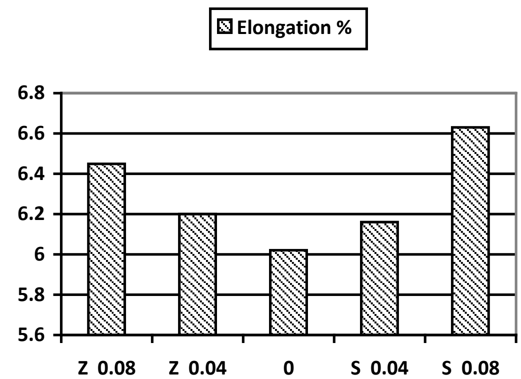


FIGURE 8. Influence of spindle air pressure on elongation %.

The elongation% also altered by the application of spindle air pressure (*Figure 8*). The elongation of the yarn increases when the spindle air pressure increases in the same direction of yarn twist and the reason is due to the higher wrapper fibers. Also the elongation increases as the spindle air pressure is supplied in the opposite direction of yarn twist. But this increase is higher compare to spindle air pressure supply in the same direction of yarn twist. From the above results we can understand that the negative pressure formed by the spindle air pressure in opposite direction of basic yarn twist changes the orientation of main core fibers and the wrapping length of the sheath fibers. Due to this reason, the spindle air pressure increases the tenacity and elongation properties of the vortex yarn. The difference in tenacity and elongation at break are statistically significant at 99% confidence level.

**Hairiness**

The variation in hairiness of Polyester/cotton vortex yarn by varying the spindle air pressure is shown in *Figure 9 to Figure 11*.

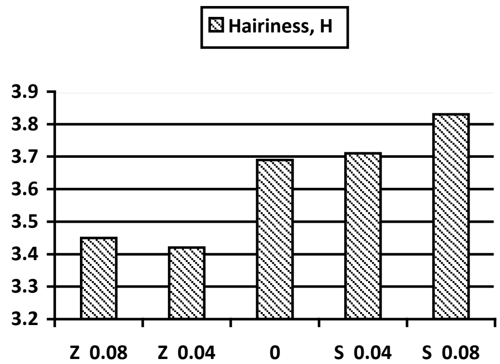


FIGURE 9. Influence of spindle air pressure on hairiness index, h.

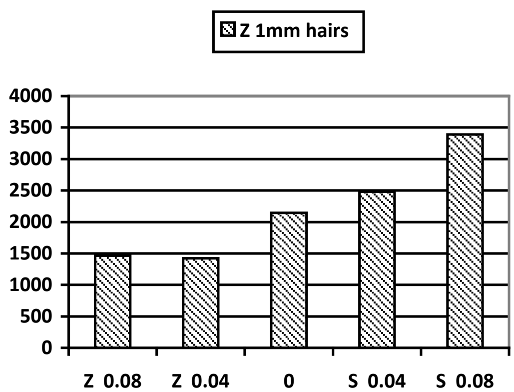


FIGURE 10. Influence of spindle air pressure on zweigle 1mm hairs.

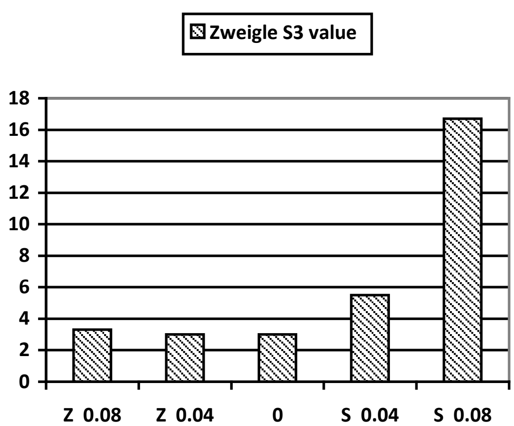


FIGURE 11. Influence of spindle air pressure on zweigle s3 value.

The hairiness index, H was found to be higher when the higher spindle air pressure was supplied in opposite direction of basic yarn twist direction. Due to more twisting by the spindle air pressure when supplied in the same direction of yarn twist, the hairiness index H had lower values. The hairiness by length distribution measured by Zweigle tester also show that, the number of protruding hairs increased with the increase in spindle air in opposite direction of yarn twist. Zweigle hairs of 1mm, 2mm, 3mm hairs and S3 values, all show the same results. During application of spindle air pressure in opposite direction of basic yarn twist, the pulling force exerted by the delivery roller is reduced and causes less tension to the fibers at the spindle tip. Due to this lesser tension on the fibers during twisting, even though the tenacity values are increased by the achievement of ideal wrapper/core fiber ratio, the number of protruding ends of the wrapper fibers become higher and supports to increase the yarn hairiness in terms of Hairiness index H and Zweigle hairs. The number of open trail end fibers increases by the reduction in tangential velocity as the spindle air pressure is increased in the opposite direction of basic yarn twist and thereby increases the hairiness of the vortex yarn. The same findings were observed by Zhuan Yong Zou et.al [8] that, the tangential velocity can change the efficiency of twisting the open trail end fibers.

## CONCLUSION

The findings from this experimental study show that various properties of Polyester/Cotton vortex yarns are significantly influenced by the spindle air.

The vortex yarn evenness and imperfections are greatly influenced by the application of spindle air pressure. Increase in spindle air pressure in either direction of basic yarn twist increases the yarn unevenness and imperfections.

Contrary to many research findings, this study shows that vortex yarn tenacity and elongation at break can be changed by the spinning parameters. The highest tenacity was achieved with opposite direction of the spindle air pressure due to changes in yarn structure. The tensile properties of the vortex yarn were mainly influenced by the wrapper/core fiber ratio.

Interestingly, In addition to increase in yarn tenacity and elongation at break, the spindle air pressure in opposite direction of basic yarn twist increased the hairiness of yarn. This study reveals that vortex yarn hairiness can be increased without reducing its tensile properties. However a detailed study is recommended to understand and verify phenomenon further by using different fiber types and yarn counts.

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**AUTHORS' ADDRESSES**
**Sankara Kuthalam**
**Senthikumar P.**
Anna University
PSG College of Technology
Peelamedu, Coimbatore
Coimbatore, Tamilnadu 641004
INDIA