Application of rotor wrapping twister for making ply yarn from nonwoven selvedges

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A novel rotor wrapping twister has been used for preparing ply yarn consisting of polypropylene nonwoven selvedges, copper wires and polyester filaments. It is observed that the ply yarn produced with this rotor twister possesses superior electrical and mechanical properties due to the natural characteristics of the filaments. The ply yarn has been produced on the rotor wrapping twister under different conditions of twister count and rotor speed and then woven on a rapier loom. By varying manufacturing parameters, the helix angle and tightness of the twist-wrapped yarn can also be changed to enhance its mechanical properties and electromagnetic shielding effectiveness. The optimal conditions for producing the ply yarn wrapped with metallic filaments are 8000 rpm rotor speed and 2.5 turns/cm warping count, and that for wrapped with polyester filaments are 6000 rpm and 1.0 turn/cm.

Keywords: Metallic fibre, Nonwoven selvedge, Ply yarn, Polyester, Polypropylene, Rotor wrapping twister

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1 Introduction

A survey conducted by the Taiwan Environmental Protection Administration in 1998 revealed that approximately 18 million metric tons (~500 tons/km²) of industrial waste is produced in Taiwan each year which is 650 tons/km² in Japan 1. According to the Waste Disposal Act 2, the generators of industrial waste need to manage the waste themselves or may have contract for industrial treatments with qualified companies to dispose of their industrial waste. However, 96% of the enterprises in Taiwan are small or medium sized. Many of them still need skills, manpower, economic scales, technology, equipment and pioneering vision for industrial waste management. Therefore, in order to reduce environmental loading and to effectively use resources, promotion of recycling and reuse of industrial waste are very important 3.

In a previous research, Aspiras and Manalo 4 tried to mix textile waste cuttings and cement as binder to produce a unique composite material that looked like concrete but could be cut or nailed like wood. The composite exhibited certain physical and mechanical properties, indicating its potential of low cost and light weight.

Recently, Lin et al. 5,6 innovated rotor twister to make the ply yarn. The rotor wrapping twister can wrap the selvedges with other filaments using different rotor speeds and wrapping counts to make the ply yarn 7.8 In the present work, this novel rotor wrapping twister has been used for preparing ply yarns from polypropylene nonwoven selvedges, copper wires and polyester filaments. The core materials and wrapping materials were changed to investigate the maximum breaking strength and elongation of the fabrics.

A promising way to add the economic value of the plied yarn is to combine the nonwoven selvedges and reinforcement materials which are manufactured using the twist-wrapping techniques. After combining with selvedges, polyester and copper can offer several advantages for their high tenacity, high modulus and high electrical conductivity. As for the nonwoven selvedge, it is hard to weave without any finishing because of its flat appearance and unevenness. However, the aforementioned innovated rotor twister

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can combine the selvedges and other filaments directly. The highest speed of the rotor twister can exceed 30,000 rpm, which can assist in reducing the waste pollution. In addition, the influence of processing parameters on mechanical properties and electromagnetic shielding effectiveness of the fabrics has also been studied.

2 Materials and Methods

Polypropylene nonwoven selvedges, polyester filaments and copper wires with basic properties as shown in Table 1 were selected for study. All the three components were commingled simultaneously. Polypropylene nonwoven selvedges were used as the core yarn and polyester filaments and copper wires as the core or wrap yarn respectively. The combinations of the core and wrapping materials are shown in Table 2. The rotor wrapping twister was used to wrap the core materials with the wrapping materials. The rotor speed and take-up speed of the machine were measured and detected by the infrared device (Microtech 8400). In addition, the tensioning device (SHARP Limit 2000 gf) was set on the machine to control and adjust the tension of the system.

The twist-wrapping process of the rotor wrapping twister is described as follows. A tangent belt of the motor drives the rotor spinning device of the rotor wrapping twister. The front side of selvedges and wrap yarn are dragged by a take-up roller. The tension-controlled roller holds the other end of the selvedges. When the wrap yarn is untied, the waste passes through the middle of the rotor spinning device at the same time. The wrap yarn gets twisted and wraps the waste along with the rotation of the rotor spinning device and then finishes the nonwoven selvedges twist-wrapping process. The twist-wrapping mechanism of the rotor wrapping twister is shown in Fig. 1.

To spin ply yarn successfully and efficiently, the rotor speed had to correspond with the materials. The experiment was carried out using different rotor speeds (6000, 7000 and 8000 rpm) and wrapping counts (1, 1.5, 2 and 2.5 turns/cm). The maximum production speed was 80 m/min under these conditions. The rotor speeds and wrapping counts on the maximum breaking strength and elongation of ply yarn are shown in Table 3. The ply yarns were then woven into fabrics on a Rapier loom (Italy Somet AC2/S) using 1/1 plain weave, 35.4 ends/10 cm warp density and 19.6 ends/10 cm weft density. The warp was polypropylene tape and the weft was ply yarn as shown in Fig. 2. Thermally bonded polypropylene nonwoven selvedges (Fig. 3) were used as the core material to produce ply yarn (Fig. 4).

Tensile properties of the experimental yarns and fabrics were determined by using a computer servo control material testing system (Hung Ta Instrument Co. Ltd HT-9101). The fabrics were tested according to ASTM D 5035 (strip method) standards. The settings were used on the testing system for the ply yarn according to ASTM D 2256. A coaxial transmission line method was used to test the EMSE (electromagnetic shielding effectiveness) of conductive woven fabrics. The measurement was
Table 3—Maximum breaking strength and elongation of Type A and Type B ply yarns

<table>
<thead>
<tr>
<th>Yarn</th>
<th>Wrapping count</th>
<th>Max. breaking strength, N</th>
<th>Max. breaking elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>turns/cm</td>
<td>6000 rpm</td>
<td>7000 rpm</td>
</tr>
<tr>
<td>Type A</td>
<td>1.0</td>
<td>75.90</td>
<td>79.08</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>70.41</td>
<td>72.58</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>66.03</td>
<td>68.54</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>60.55</td>
<td>67.41</td>
</tr>
<tr>
<td>Type B</td>
<td>1.0</td>
<td>71.36</td>
<td>74.20</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>75.38</td>
<td>77.37</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>78.31</td>
<td>79.52</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>80.01</td>
<td>81.88</td>
</tr>
</tbody>
</table>

*Rotor speed in rpm

3 Results and Discussion

Table 3 shows the maximum breaking strength of the two types of ply yarn. The maximum breaking strength of the ply yarn wrapped with polyester filaments (Type A) increases with the increase in rotor speed. This is because that the centrifugal force from wrapping rotor makes the structure tight. However, the polyester filaments are the main source supplying the strength to the whole ply yarn. A greater twist-wraping angle of the ply yarn wrapped with polyester filaments would results in a decrease in force in axial direction. Therefore, the maximum breaking strength of the ply yarn decreases with the increase in twist-wrapping counts.

When the polyester wrapping filaments are substituted with copper wires to produce ply yarn, a different mechanical tendency is observed. The maximum breaking strength of ply yarn wrapped with copper wires (Type B) increases owing to the tightness of the yarn because of the increased rotor speed and twist-wrapping counts.

The maximum breaking strength of the Type A fabrics decreases with the increase in wrapping counts.
Fig. 4—Ply yarns [rotor speed, 8000 rpm and wrapping count, 1.0-2.5 (in 0.5 step) in unit length]

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Wrapping count</th>
<th>Max. breaking strength, N</th>
<th>Max. breaking elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>turns/cm</td>
<td>6000°</td>
<td>7000°</td>
</tr>
<tr>
<td>Type A</td>
<td>1.0</td>
<td>296.71</td>
<td>320.50</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>272.66</td>
<td>289.50</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>243.62</td>
<td>265.62</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>218.57</td>
<td>251.15</td>
</tr>
<tr>
<td>Type B</td>
<td>1.0</td>
<td>230.91</td>
<td>252.05</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>253.37</td>
<td>272.32</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>268.43</td>
<td>286.71</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>289.80</td>
<td>305.44</td>
</tr>
</tbody>
</table>

$^\circ$ Rotor speed in rpm

at the same rotor speed (Table 4). Because the wrapping angle between the core and wrapping materials increases with the wrapping counts, the axial component of the wrapping filaments diminishes and the maximum breaking strength of the ply yarn decreases. Therefore, the maximum breaking strength of the fabrics made of the ply yarn also decreases. However, the maximum breaking strength of the fabric increases while increasing the rotor speed, though the wrapping counts are the same. With the increase in rotor speed, the wrapping filaments are subjected to higher centrifugal force. Consequently, the ply yarn is wrapped more tightly and its structure becomes even.

Similarly, the maximum breaking strength of Type B fabrics increases with the rotor speed (Table 4). When the rotor speed is increased, the ply yarn is subjected to higher centrifugal force, resulting in an increase in its modulus. At the same time, the maximum breaking elongation of the fabrics also increases.

The maximum breaking elongation of ply yarn wrapped with polyester filaments and copper wires is shown in Table 3. The core part of the ply yarn was composed of polypropylene nonwoven selvedges and copper wire. The maximum breaking elongation of ply yarn decreases while the twist-wrapping count increases. It could be attributed to the centralized yarn wrapped by polyester filaments with a promoting twist-wrapping level. Thus, the extended ability of the core part of ply yarn is limited. Table 3 also shows that the maximum breaking elongation of ply yarn with a core composed of polypropylene nonwoven selvedges and polyester filaments increases with the increase in twist-wrapping counts. It could be attributed to the smooth surface of copper wires with a low interfacial friction between polypropylene nonwoven selvedges and polyester filaments. Low frictional force would lead to increase in the extended ability of the core part of ply yarn.

A higher rotor speed gives a greater maximum breaking elongation of the core part in ply yarn (Table 3). It shows the excellent stability performance of ply yarn wrapped with copper wires. The ply yarn also exhibits higher maximum breaking elongation than the fabrics since the polyester filaments with superior mechanical properties are wrapped in the center of the ply yarn.

The maximum breaking elongation of the fabrics woven with ply yarn wrapped by polyester filaments or copper wires is shown in Table 4. The maximum breaking elongation of the fabrics is approximately
the same as that of the original ply yarn. The maximum breaking elongation of the Type A fabrics decreases with the increase in twist-wrapping counts. When the rotor speed increases, the ply yarn is subjected to higher centrifugal force resulting from the wrapping motion. Therefore, the compact structure of ply yarn was created and the axial stress of the core materials (polypropylene nonwoven selvedges and copper wires) was increased, resulting in the increase in maximum breaking elongation.

Table 4 shows that for the Type B fabrics (copper filament as wrapping yarn), the influence of materials, by varying the twist-wrapping counts of the hybrid fabrics, on the maximum breaking elongation is so obvious that the maximum breaking elongation of ply yarn increases with the increase in twist-wrapping counts. It could be attributed to the low frictional coefficient of copper wires that causes tight structure of the core part of ply yarn. Therefore, the ply yarn could endure more stress. Owing to the excellent mechanical performance of the ply yarn, the variation in maximum breaking elongation of hybrid fabrics is small.

Table 5 shows the strength utilization factors of Type A and Type B fabrics. When the rotor speed increases, the utilization factors also increase relatively. The ply yarn would possess an even structure when it is wrapped at a high rotor speed and, therefore, the whole fabric made of the ply yarn shows an even and flat structure due to the excellent strength utilization factors. Moreover, the variations in strength utilization factors of Type A and Type B fabrics with different wrapping levels show similar trends and reasons as to those of the ply yarn.

The electromagnetic shielding effectiveness (EMSE) of the ply yarn fabric was measured in the range of 30-3000 MHz. As shown in Fig. 5, the wrapping material of the ply yarn fabric is a copper wire with the wrapping count of 2.0 turns/cm and rotor speed of 8000 rpm. The copper wire (4.45 wt%) is used for the fabric weight of 305.65 g/m² and a shielding level of 10-20 dB can be achieved.

4 Conclusion

Rotor wrapping twister has been used successfully without the restrictions of yarn count and number of folds. Multifunctional ply yarn has been prepared by combining selected materials (copper wires, polyester filaments and nonwoven selvedges) at over 6000 rpm speed. The reinforced filaments show different physical properties, irrespective of whether they are inner or outer of the ply yarn. It also shows that the physical properties of the functional ply yarn and fabrics are influenced by the materials and the producing process. The electromagnetic shielding effectiveness of the fabrics is found to be 10-20 dB for copper filament (4.45% by weight). The optimum conditions of the ply yarn wrapped with the metallic filaments are 8000 rpm rotor speed and 2.5 turns/cm wrapping count, and of that wrapped with polyester filaments are 6000 rpm and 1.0 turn/cm.

References
2 Waste Disposal Act (Environmental Protection Administration, Taiwan), January 2000.