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INFLUENCE OF YARN TWIST ON THE ABRASION RESISTANCE OF TWARON® 2D BRAIDED COMPOSITES

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ABSTRACT

Aramid braided composites are used in marine applications due to their high strength and low weight. Composites braided into a cylinder can be used in remotely operated underwater vehicle (ROV) umbilical cables. When used as underwater cables, aramid tubular braids often fail by abrasion. Twisting yarns about their longitudinal axis has been shown to improve the abrasive properties of tubular composite braids (TBCs). Consequently, the objective of this study was to determine the influence of the braided composite yarn twist on its abrasion resistance. These results suggest that while there was no statistically significant difference in abrasion resistance, the 5° sample did not erode as much as the lesser twisted samples. Further testing should be completed at more time intervals, with different twist angles, braid angles, yarn thicknesses and with different resin matrices to investigate this further and confirm the initial findings of this study.

1 INTRODUCTION

Development in the field of marine robotics has made deep sea ocean exploration possible. Remotely operated underwater vehicles (ROVs) can go to depths that are fatal to divers [1]. These robots are used to investigate shipwrecks, maintain offshore oil rigs and collect data and observations for scientific use [2]. ROVs are controlled from the surface through an umbilical control cable.

At depths greater than 4000 m, these umbilical cables must be made of lightweight materials. At these depths, the weight of traditionally used steel cables sinks most ROVs [3]. Aramid TBC cables are used as an alternative to provide the required tensile strength while reducing overall weight.

Aramid TBCs are made by interlacing textile yarns on cylindrical mandrels into textile structures known as preforms. Once braided, these preforms are impregnated with a matrix and cured. Braid parameters can be altered during production to tailor the composite for intended applications. One important parameter that influences the mechanical properties of TBCs is braid angle defined as the angle between the fibers and the longitudinal axis of the TBC. A smaller braid angle makes the composite perform stronger in tension and a larger braid angle reinforces it in hoop stress [4].

Another parameter that has been shown to influence the properties of TBCs is yarn twist. Yarns can be twisted around their axes before they are braided. Adding small amounts of twist to aramid yarns can increase yarn strength, breaking tenacity and elongation at break [5], [6].

Twist configuration describes the pattern of yarn twist in the braid. Yarns can be twisted in either a Z or S configuration. A counter twist configuration uses both S and Z twisted yarns, woven into the braid in opposite directions so that they overlap each other. When yarns are twisted, their cross section becomes elliptical, reducing the area it covers on the surface of the braid.

One of the leading causes of failure in cables using braided aramid tubes is abrasion damage [7]. Abrasion damage is created when materials rub against each other, wearing down their contacting surfaces. The damage occurs in braids from both the interacting yarns and external contacting materials. The application of twisting the yarns has shown to improve abrasion resistance, but an optimal twist angle has not yet been determined for aramid TBCs [8]. By researching optimal twist angles, this research may help to create aramid cables that are more abrasion resistant.

2 LITERATURE REVIEW

The effect of yarn twist on abrasion resistance has been studied with various materials. Palaniswamy and Mohamed investigated the effect of twist on yarn-to-yarn abrasion resistance of cotton [9]. Results showed that as yarn twist increased, yarn-to-yarn abrasion resistance improved [9]. The addition of twist, up to 5°, to aramid yarns increased yarn strength [5].

The effect of twist on abrasion resistance has also been studied using chenille yarns. Yarns were tested using a chenille yarn abrasion device that erodes yarns with a silicon carbide abrasive paper. Results found that abrasion resistance improved with increasing yarn twist which is consistent with studies conducted on other materials [10].

DuPont has extensively studied and developed Kevlar® aramid fibers. They found that twisted yarns impregnated with polyurethane resin led to enhanced abrasion resistance in comparison to uncured, untwisted yarns [7]. Adding 5-10% paraffin wax lubricant to this combination can further improve abrasion resistance. A study conducted by Friedrich found that aramid fibers provided the greatest enhancement in abrasion resistance in an epoxy matrix composite in comparison to glass and carbon fibers [11].

Fiber orientation has also been shown to have a significant effect on the abrasive wear rate of carbon fiber composites [12]. A similar study conducted on aramids found that fiber orientation could be altered to provide greater wear resistance [13].

While the DuPont study established that twists improve abrasion resistance, it did not discuss an optimal twist angle. That study focused on the difference in abrasion resistance between samples with different matrices. For each type of matrix, samples with zero and 3 twist per inch were created [7]. It concludes that twist improves abrasion resistance but does not study how different twist angles change abrasion resistance. It also focused on cycles to failure whereas this study focuses on abrasion rate over fixed time intervals. To address these gaps, this study will investigate the influence of the twist angle on the abrasion resistance of aramid TBCs and determine whether twist is a viable option to improve abrasion resistance in aramid braided ROV cables.

3 METHODOLOGY

3.1 Material Selection

Twaron® 7100 denier (Teijin Aramid, Arnhem, Netherlands) aramid yarns were selected as the fiber while castable urethane Part A (NR-906 Part A Normac, Burlington, Ontario, Canada) and castable urethane Part B (NR-906 Part B

Normac, Burlington, Ontario, Canada) were used as resin. Polyurethane improves abrasion resistance and ensures that the cable remains flexible for underwater applications [7].

3.2 Sample Preparation

Three sample types with varying twist angles of 0°, 2.5°, and 5° were prepared. These twist angles fall under the tensile strength limit of 5° as established [14]. To create the samples, two strands were twisted together into each yarn. Each of these twisted yarns was loaded onto the Maypole braiding machine (Steeger HS140/36- 91, Steeger GmbH and Co., Wuppertal, West Germany). These were braided into a preform with a 45° braid angle in a counter twist configuration. These parameters were chosen for continuity between braids and repeatability of manufacturing. When braided onto a 7/16-inch mandrel, these yarns will create a closed mesh tubular braided preform. This prevents the erosive particles from hitting the inside of the braid, ensuring a constant distance from the sandblaster nozzle to the point of contact on the sample which meets the requirements of ASTM G76 [15].

Once braided, the preforms were manually impregnated with Castable Urethane and partially cured. After partial curing, the samples were cut into 4.45 mm pieces. Subsequently, the inner surface was impregnated. The samples were cured in two stages to ensure that the insides of the braids were fully impregnated. The total cure time for the samples is seven days [16]. Three samples for each twist angle were tested.

3.3 Sample Testing

Prior to testing, the inner and outer braid diameter, sample length, and braid angle were measured and recorded. An average of five measurements taken at various locations of the braid were calculated. The inner diameter was measured using a telescopic gauge and a Vernier micrometer. The outer diameter was measured using Vernier micrometer. The sample length was measured using a ruler. The braid angle was measured using ImageJ (Wayne Rasband, ImageJ bundled with 64-bit Java).

Sample surface roughness was analyzed using an Axio CSM 700 Confocal Microscope and Axio CSM 700 software before and after testing. This was done to qualitatively observe the effect of abrasion on the braids. The confocal microscope emits light onto the sample and uses reflected light to measure roughness which then displays a topographical image as seen in Figure 1. The image of the sample's surface shows higher to lower regions with gradients of lighter gray to darker gray. Dark spots were excluded from analysis because they can be caused by machine errors. Dark regions were also excluded because they show sample curvature.

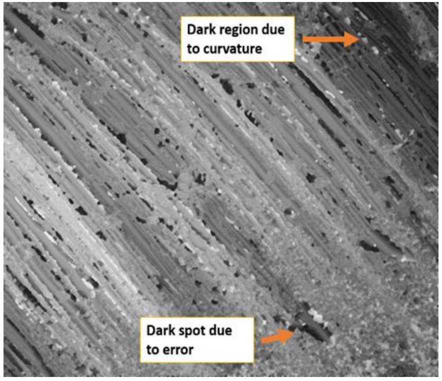

Figure 1: Confocal Microscope Topographical Roughness Measurement Image of the third 5° sample

Samples were weighed five times on a four-decimal scale with an accuracy of ±0.01 mg. An average of the five measurements was taken. A fixed length of 12 mm was measured in the middle of the braid to be sandblasted. The ends were covered with a synthetic fabric and electrical tape to prevent the area beyond the measured distance from being affected by impingement as shown in Figure 2a.

After initial measurements, the braids were abrasion tested using a sandblaster (Dry Blast Model 487BP, Serial No. 66775, Trinco, Michigan, U.S.) following the ASTM G76 standard [17]. Requirements of this standard include a proper nozzle diameter to length ratio, constant impingement angle, constant impact velocity, a uniform particle feed and uniform particle composition. Time intervals for impingement (4, 8, 12 and 16 minutes) were chosen according to this standard.

To ensure the sample was held at a constant angle of 90° and distance of 80 mm from the gas jet nozzle, an abrasion stand was fabricated. The structure is made of aluminum sheet metal and the nozzle sits in a 3D printed PLA holder. Samples were then positioned inside the sandblaster which operated at a constant temperature. After sandblasting, the end coverings were removed, entrapped sand particulates were removed using high pressure air and a dust collector. Samples were then weighed five times after each time interval. Images of the braids before and after abrasion are shown in Figure 2.

(a) (b)

Figure 2: TBC samples before (a) and after (b) abrasion

The surface roughness was measured for each sample after abrasion testing using the same process used prior to abrasion.

4 RESULTS AND DISCUSSION

Abrasion rate data was compared using a single factor ANOVA test. Abrasion rates were calculated using initial mass, final mass and abrasion time. Abrasion rates were grouped according to testing time intervals. A confidence interval of 5% was chosen and the p-values are displayed in Table 1. The null hypothesis of this study is that there is no significant difference in abrasion rate between the samples of different twist angles. Based on the results shown, there was no statistically significant change in abrasion resistance when yarn twist is changed.

Table 1: P-values to analyze abrasion rate data

Time Interval (min):	***4***	***8***	***12***	***16***
P-value	0.39	0.38	0.21	0.43

There is discrepancy between the results of this work and results from previous studies. The studies mentioned in the literature review involved twist greater than what was done in this paper. It is possible that yarn twist angle must be greater than 5° to create a significant difference in abrasion resistance. Application of braids with greater yarn twist will require consideration of tensile strength at greater twist angles as it has been shown to decrease above a twist angle of 5°.

Results show that the surface roughness and texture of the 0° and 2.5° twist samples appear to decrease more compared to the 5° twist sample. The 0° sample after abrasion has a less textured surface than the 5° sample after abrasion which has retained more of its initial fiber structure. In the 5° sample after abrasion image, the direction of the fibers is far more visible than in the 0° sample. The greater range from light to dark suggests greater surface roughness. A more worn-down braid will show less surface roughness. This suggests that the 5° samples were more resistant to abrasion.

The qualitative observation from collected images contradicts what was found from the abrasion data. This could be due to the scale of the observation. The abrasion data came from a global analysis of the braid. There was not a significant difference between the mass loss of each sample. The microscope, however, looks at a local portion of the braid. These images show a difference in the change in the braid due to testing that the mass measurements may not have been sensitive enough to observe.

Further testing could be undertaken to see if the trends in this study persist. Samples with greater twist angles could be tested to see if there is a connection between the increasing twist angle and change in surface roughness. The time intervals under abrasion could be increased to determine how the composition of the braids would be affected over longer durations of time. Tests that go to failure could be conducted which would involve more abrasion against the aramid fibers and not the polyurethane matrix. Additionally, other matrix options could be tested. This further testing will determine whether aramid cables can be better suited to marine applications.

5 CONCLUSION

This study explored the effect of yarn twist on the abrasion resistance of aramid TBCs for potential use in ROV cables. TBC samples were manufactured at three twist angles (0°, 2.5°, and 5°) and sandblasted for four set periods of time (4, 8, 12 and 16 minutes). The mass lost during the process was measured and recorded. Confocal images of the sample surfaces were also taken before and after testing. From the quantitative data, it was found that there is no statistically significant change in abrasion resistance. From the qualitative data, however, the surface roughness and texture were seen to be rougher in the 5° twist sample compared to the 0° twist sample. This may suggest a possibility for higher abrasion resistance as the twist angle increases. The quantitative data gathered considers the entire braid whereas qualitative images only look at a small portion of it. At greater twist angles, the abrasion resistance may increase. Further studies such as increasing sample size and duration, and use of other matrix options could be implemented to determine their effects on the abrasion resistance of braids.

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