Tensile Strength of Nylon Netting Subjected to Various Concentrations of Disinfecting Chemicals

This paper presents a study of traditional netting materials subjected to disinfecting chemicals during fish farming and treatment of net cages. A series of tests were performed in order to study the effect of various concentrations of disinfecting chemicals on the tensile strength of Raschel knitted Nylon netting materials. Simulated spill of diluted hydrogen peroxide (HP) to the jump fence during de-lousing did not affect the strength of the applied new and used knotless nylon netting samples. Hydrogen peroxide reacted with biofouling forming gas bubbles, but this did not result in reduced netting strength. The performed tests did not indicate any effect on netting strength from a simulated single, traditional bath disinfection as performed at service stations applying the disinfectant Aqua Des (AD) containing peracetic acid (PAA). However, increasing the AD concentration from 1 to 10% resulted in a strength reduction of 3–6%. Simulated spill of concentrated AD on the jump fence of a net with copper coating residuals resulted in a severe reduction in strength of 45%. This strength loss was probably a consequence of chemical reaction between copper and Aqua Des, and uncoated netting did not experience any loss in strength subjected to the same chemical exposure. These findings from application of AD should also apply to other PAA disinfection chemicals with trade names as, for example, Perfectoxid and Addi Aqua. [DOI: 10.1115/1.4040562]
There is not much available literature concerning chemical damage or degradation of polyamides exposed to hydrogen peroxide and peracetic acid. It is established that sterilization of polyamides using hydrogen peroxide plasma may have noticeable effect on long-term stability of conventional PA 6 [8]. A study of possible effects of diluted hydrogen peroxide vapor disinfection of transportation systems resulted in less than 10% loss of strength of a Nylon textile subjected to 35% hydrogen peroxide [9]. According to technical data, Nylon has a limited resistance toward diluted hydrogen peroxide and acetic acid [1,2]. In addition, acetic acid and PAA may cause metal corrosion (including copper) at very low concentrations [7,10], indicating that copper particles from anti-fouling coating residuals may be involved in chemical reactions with disinfecting chemicals. Both organic materials and heavy metal ions, for instance of copper, will accelerate decomposition of PAA and HP.

As previously described, disinfecting chemicals are applied in closed volumes with seawater until the requested treatment concentration is achieved, which is typically below 1%. However, the chemicals are delivered at significantly higher concentrations, and it is important to investigate whether higher concentrations, spills, and application of concentrated chemicals may damage the net. Possible effects of biofouling and copper particles are also of interest: Fish farmers report that hydrogen peroxide will react with biofouling during de-lousing, resulting in the formation of gas-bubbles, and are concerned that this may affect the strength of netting. Copper is often present at nets through application of anti-fouling coatings, and it is important to investigate whether copper may accelerate chemical reactions involving hydrogen peroxide and/or peracetic acid.

This paper presents a study of traditional netting materials subjected to disinfecting chemicals during fish farming and treatment of net cages. A series of tests were performed in order to study the effect of various concentrations of disinfecting chemicals on the tensile strength of Nylon netting materials. The study included traditional Raschel knitted PA6 multifilament netting, the so-called knotless netting, and nylon coating residues, and disinfecting chemicals containing hydrogen peroxide and peracetic acid.

Materials and Methods

The disinfecting chemicals hydrogen peroxide (from Akso Nobel, Göteborg, Sweden) and Aqua Des (from Aqua Pharma, Lillehammer, Norway) were applied to netting samples with different concentrations and exposure times. Three different netting materials were applied in these tests as described by mesh size and strength in Table 1. All netting materials were traditional Raschel knitted PA6 multifilament netting, the so-called knotted netting. Pictures are given in the Appendix (Fig. 4). Netting N1 was unused and without coating. N1_bf was samples of netting N1 submerged at a Norwegian fish farm for 6 months (Apr.—Sept.), accumulating biofouling consisting of mainly Hydroids in addition to smaller amounts of moss animals, mussels, snails, and barnacles. During the 6-month field trial, the mesh size of the netting was reduced by approximately 10%.

Netting sample N2 had been applied in fish production two times, each time for a period of approximately 10 months. The net was treated with anti-fouling coating containing copper prior to each production period, in total two times. It had been at a service station after each of the production periods. At service, the net was washed in a wet washing machine and treated with disinfecting chemicals.

The applied hydrogen peroxide (H2O2) was of the same type as used during de-lousing at fish farms and was supplied at a concentration of 49.5%. Aqua Des in concentrated form consists of 20–25% hydrogen peroxide, 5–10% peracetic acid, and 10–15% acetic acid. Both chemicals contained stabilizers to prevent unwanted reactions during storing and transport.

Each chemical exposure test included five dry net panels (room conditioned) of 7×7 meshes that were put into a 500 ml mix of filtered seawater and chemicals. All tests were performed in room temperature varying from 18 to 21 °C. After the chemical exposure, the net samples were dried for 24 h before being rinsed in fresh water by letting them soak for 24 h. For the experiments with high concentrations of chemicals, the water was changed at least once during the first hour.

The weight of five panels was approximately 27 and 60 g in room atmosphere for netting N1 and N2, respectively, i.e., the chemical exposure tests involved 54–120 g netting per liter chemicals. In practice, the relationship between amount of netting and disinfection fluid will vary significantly depending on the size of the net and tank. Assuming a 4 ton net and a tank with 20 m3 fluid involves 200 g netting per liter, however, this number may be both higher and lower. The applied relationships between amount of netting and fluid are considered to be within the lower parts of normal conditions, and thus, a conservative condition.

A series of tests were performed, involving several combinations of the tree netting materials and different concentrations of the two applied chemicals. Different tests are presented in Table 2, where X marks a tested combination, and the following note indicates the period of time for which the netting samples were immersed in the given chemical concentration. The various concentrations were achieved by diluting with filtered seawater.

First, uncoated netting with and without fouling (N1 and N1_bf) were immersed in a fluid of 15% H2O2, which is equal to the concentration of applied de-lousing chemical. The samples were left in the fluid for two hours to study the reaction. Next, spilling of high concentration chemicals to parts of the net above water was simulating by submerging netting samples for 5–10 s and letting them dry in air. This would allow for air (oxygen and carbon dioxide) to participate in chemical reactions, and resulting development of, e.g., heat, oxidants, and acids may be concentrated on the netting surface. Finally, disinfection of nets at service stations was simulated, both as a “worst case” normal disinfection and by applying high concentration of Aqua Des.
(peracetic acid). For the normal disinfection, netting was submerged in a solution of 1% Aqua Des for 1 h. In order to study the possible effect of higher concentrations of Aqua Des during disinfection, the same test was performed with a concentration of 10% Aqua Des. The acidity of the fluid was measured during these tests using a digital pH-meter with an accuracy of ±/− 0.2, calibrated at pH 4.0. The tests with 1% and 10% Aqua Des were repeated using samples from another part of N2 and 25 replicates. The results from the chemical exposure tests were compared with reference samples not subjected to any chemical exposure tests.

The effect of chemical exposure was evaluated through tensile testing. The netting samples were wetted in tap water for 16–48 h. Traditional mesh strength tests were performed [11], and changes in strength, dimensions, and stiffness were assessed. All strength tests were performed with at least 20 replicates, and average values, standard deviation, and 95% confidence interval were calculated for each test and reference samples. Statistical differences were investigated using analysis of variance, assuming normal distribution, and applying a t-test and a significance level of 0.05.

Scanning electron microscope (SEM) was applied to study the surface of netting N2, including the reference sample and samples subjected to 15% hydrogen peroxide or concentrated Aqua Des. Each SEM-sample consisted of a piece of a netting twine, which was coated in gold for improved conductivity.

Results

Mesh Strength. Figure 1 shows the strength of netting materials subjected to hydrogen peroxide relative to the average strength of the reference test. Assessing the confidence intervals of different tests indicates that there are no significant differences between the calculated average strength values. Thus, the tests performed in this work do not identify any effect on netting strength due to spill of 15–30% hydrogen peroxide.

Figure 2 shows the relative strength of netting materials subjected to Aqua Des. Assessing the confidence intervals of different tests of unused netting, N1, indicates that there are no significant differences between the calculated average strength values. Thus, the tests performed in this work do not identify any effect on netting strength due to spill of 50–100% Aqua Des on unused netting without coating.

The “worst case” disinfection test involving 1% AD had no effect on the strength, stiffness, or color of used netting (N2). The panels subjected to the high concentration disinfection involving a fluid of 10% Aqua Des had an average strength 3% lower than the reference tests, and the analysis of variance test indicates that the reduction in strength was significant. The tests with 1% and 10% Aqua Des were repeated using samples from another part of N2 and 25 replicates. Mesh strength test resulted in a significant average strength reduction of 6% after treatment with 10% Aqua Des compared to treatment with 1% Aqua Des. It is thus probable that a disinfection applying a relatively high concentration of 10% Aqua Des will reduce the strength of netting with copper residuals by a few percentage. Used netting subjected to concentrated Aqua Des had a reduction in strength of 45%.

Dimensions and Stiffness. Figure 3 shows force-elongation curves for single tests, which represent the average of the full test series. The used netting experienced several drops in tensile force during the final stages of stretching before the ultimate force was reached. This is common in used netting and is due to local structures in individual bundles of filaments prior to global fracture of the twine. Unused netting, N1, exposed to 100% Aqua Des showed a reduction in mesh size of 2 mm and correspondingly increased elongation at break. Apart from this, no changes in dimensions or stiffness were observed for any of the netting samples after exposure to chemicals. This includes netting N2 subjected to concentrated Aqua Des, which in spite of the 45% reduction in mesh strength showed no changes in dimensions or stiffness: The force-elongation curves from the mesh strength tests were similar to the reference sample up to the point where local fractures started to occur.

Netting with biofouling, N1_bf, had an initial mesh size that was 10% smaller than the unused N1, and its stiffness (slope of force-elongation curve) was increased by approximately 50%.

Observations. For all chemical exposure tests with 1 or 2 h immersion, development of gas bubbles was observed. The formation of gas was most prominent for netting with biofouling and used netting in 10% Aqua Des.
N1 had no effects of chemical exposure visible to the eye, i.e., no changes in color or shine. Hydrogen peroxide exposure had some visual effects on fouled netting; the panels with biofouling (N1_bf) were bleached and a lot of the biofouling was removed (Fig. 5). Microscopy showed that parts of hydroids growing into the netting were still present (Fig. 6). The used netting, N2, obtained a brownish tint after the hydrogen peroxide exposure, while exposure to 100% Aqua Des gave the netting of a blue-green tint.

Temperature was measured during chemical exposure, and apart from N2 in 10% AD, the fluid temperature was constant. A gradual increase in temperature from 20.5 to 22.5 °C was observed for N2 in 10% Aqua Des. Simultaneously, an increase in pH from 2.7 to 3.1 was measured. However, this is on level with the accuracy of the pH gauge, so no firm conclusions can be made. For the 1% AD test, the temperature was 21 °C throughout the exposure time, and pH was measured to be 4.0 at the beginning and 4.1 at the end of the test. After the simulated bath disinfections (1% and 10% Aqua Des), the fluid had a turquoise color.

For the high concentration chemical spill tests, i.e., test with 5–10 s immersion duration (Table 2), temperature was not measured during immersion, but during drying in air. Except for used netting in 100% AD, no change in temperature was observed. For N2 in 100% AD, fume emission was observed during drying after chemical exposure. After a few seconds, the fuming ended and the temperature was measured as 60 °C. During the drying, the color of the netting changed from gray to a mixture of brown and turquoise spots. After 24 h, the netting had regained its gray color with distinct turquoise areas (Fig. 7).

Discussion

The results from this work show no indications of reduced netting strength due to de-lousing operations with hydrogen peroxide (HP). No damage was observed after simulated spills of relatively highly concentrated HP, and bath disinfection at much lower concentrations should not have any immediate effect on netting quality. However, it cannot be disregarded that other net materials and coatings, and even higher concentrations of HP may lead to damages to the net cage; in particular, due to spills from accidental or incorrect application of chemicals to parts of the net above the water surface.

It has been shown that hydrogen peroxide may oxidize fouling organisms on the net during de-lousing, resulting in formation of gas bubbles as observed by fish farmers. Effects of repeated exposure to H2O2 have not been studied, however the results from this study and other studies of used netting do not indicate that de-lousing with low concentrations (approximately 0.2%) of hydrogen peroxide may damage the net. Further, test involving repeated and long-term exposure is required to make firm conclusions in this matter. The possible effect of amount of copper residuals in the net should also be investigated, as increased copper content may increase chemical damage.

These tests did not indicate any effect on netting strength from a simulated single, traditional bath disinfection as performed at service stations. However, the application of disinfecting chemicals with peracetic acid, such as Aqua Des, Perfectoxid, and Addi Aqua, should be performed with care. Concentrated Aqua Des may severely damage netting, and also diluted peracetic acid at relatively high concentrations may affect the strength of netting.

Based on the observed residual products of blue-green color and published investigations of copper corrosion by acetic acid [10], it is probable that Acetic acid in Aqua Des reacts with copper forming copper acetate. Copper acetate are crystalline solids that are soluble in water. Other insoluble crystals containing copper, like cuprite, may also have been formed [10]. Using a light microscope, it was observed that parts of the netting fibers had acquired a turquoise color (Fig. 8). Nylon is known to absorb peracetic acid, and uncoated netting did not experience any loss in strength subjected to the same chemical exposure. These findings from application of Aqua Des should also apply to other peracetic acid disinfection chemicals with trade names as, for example, Perfectoxid and Addi Aqua.

Conclusions

This work did not identify any reduced strength in traditional Raschel knitted nylon netting due to simulated spill of diluted hydrogen peroxide to the jump fence during de-lousing. Hydrogen peroxide may react with biofouling, but this did not result in reduced netting strength.

The performed tests did not indicate any effect on netting strength from a simulated single, traditional bath disinfection as performed at service stations applying the disinfectant Aqua Des containing peracetic acid. However, increasing the Aqua Des concentration from 1 to 10% resulted in a strength reduction of 3–6%. Simulated spill of concentrated Aqua Des on the jump fence of a net with copper coating residuals resulted in a severe reduction in strength of 45%. This strength loss was probably a consequence of an exothermic reaction between copper and Aqua Des, and uncoated netting did not experience any loss in strength subjected to the same chemical exposure. These findings from application of Aqua Des should also apply to other peracetic acid disinfection chemicals with trade names as, for example, Perfectoxid and Addi Aqua.

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Appendix
Pictures of netting samples

Fig. 4  Netting materials subjected to chemical exposure tests. From left: N1, N1_bf, and N2.

Fig. 5  Netting with biofouling (N1_bf) before (left) and after (right) exposure to hydrogen peroxide
Fig. 6  Detailed view of a selected area of netting before (a) and after (b) exposure to hydrogen peroxide, seen through a light microscope.

Fig. 7  Used netting with copper residuals, N2, subjected to 10% Aqua Des (left) and concentrated Aqua Des (right)
Fig. 8  Dying of Nylon fibers by reaction products containing copper

Fig. 9  Scanning electron microscope of used netting, N2, (a) before chemical exposure test, (b) after 15% hydrogen peroxide test, (c) and (d) after 100% Aqua Des test
References


