FINISHING OF POLYAMIDE FABRIC 6 AND POLYAMIDE 6.6 FABRIC WITH SOME BORON COMPOUNDS

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Abstract: *Textile finishing and dyeing processes consume large amounts of water, dyes and chemicals, which can have a negative impact on the environment. Therefore, alternative, less toxic and biodegradable chemicals are intensively researched. Textile products should be designed so that their production and maintenance cause minimal damage to the environment, while taking care of waste after use. Chemical finishing includes various treatments of fabrics to improve aesthetic and performance properties, including anti-creasing, water repellency, flammability and micro-organism finishes. Boron compounds, such as boric acid and borax, are used in industry for their antibacterial and functional properties. This paper investigates the optimal finishing processes for polyamide fabrics. Treatments are performed in the presence of boric acid and sodium tetraborate in order to increase the hydrophilicity and retarding the burning of polyamide fabrics.*

Keywords: polyamide, sodium tetraborate, boric acid, finishing.

DORADA POLIAMIDNE TKANINE 6 I POLIAMIDNE TKANINE 6.6 NEKIM BORNIM JEDINJENJIMA

Apstrakt: *Procesi dorade i bojenja tekstila troše velike količine vode, boja i hemikalija, što može negativno uticati na životnu sredinu. Zbog toga se intenzivno istražuju alternativne, manje toksične i biorazgradive hemikalije. Tekstilni proizvodi treba da budu dizajnirani tako da njihova proizvodnja i održavanje minimalno štete životnoj sredini, uz vođenje računa o otpadu nakon upotrebe. Hemijska dorada uključuje različite obrade tkanina radi poboljšanja estetskih i eksploatacionih svojstava, uključujući dorade protiv gužvanja, vodoodbojnosti, zapaljivosti i mikroorganizama. Jedinjenja bora, poput borne kiseline i boraksa, koriste se u industriji zbog svojih antibakterijskih i funkcionalnih svojstava. Ovaj rad istražuje optimalne procese oplemenjivanja poliamidnih tkanina. Obrade se vrše u prisustvu borne kiseline i natrijum tetraborata radi povećavanja hidrofilnosti i usporavanja gorenja poliamidnih tkanina.*

Ključne reči: poliamid, natrijum tetraborat, borna kiselina, dorada.

1. INTRODUCTION

In the processes of finishing and dyeing textile materials, large amounts of water, dyes and chemicals are consumed, which can cause danger to the environment. For this reason, alternative substitutes for harmful chemicals that are less toxic and biodegradable have been intensively analyzed for many years [1].

Many chemicals are banned or have limited use. A textile product should be designed in such a way that processes and raw materials that minimally harm the environment are used for its production and care, and already during design care should be taken to store waste when the textile product has passed its useful life [2-4].

Chemical processing includes a number of different treatments of products made of natural and chemical fibers. There are a large number of chemical agents intended for the finishing of fabrics. Depending on the chemical composition of these agents and their ability to react with the fiber, different properties

of fabrics are achieved and aesthetic and exploitation values are increased [5, 6].

Special chemical finishes include: anti-creasing finishing, finishing to achieve water repellency and waterproofing (hydrophobic and oleophobic), finishing against flammability, finishing against microorganisms, finishing to improve feel and sliding [1].

Boron compounds have been used for many years. Babylon is believed to have imported pine from the Far East for the gold industry 4,000 years ago, and borax was used for mummification, various treatments and metallurgical applications in ancient Egypt. Borax is known to have been used in the 8th century, and the mineral was brought by Arab traders. The Arabs also produced medicines from pine salts in 875 AD. The first production of boric acid began in 1830 in Italy, and the first industrial exploitation of borax began in 1852 in Chile [7-10].

The functionality of boron-containing compounds such as boric acid and its alkyl or aryl substituents (boric acid), borax, diazaborine and potassium tetraborate as antibacterial agents have been widely studied because they are commonly used as fertilizers, insecticides, detergents and buffers, etc. Boron nanoparticles of high purity find application in more advanced fields such as medicine, for boron neutron capture therapy, and thus their syntheses and characterizations have become more significant in the last few decades [11].

7-18% of environmental boron comes from several major "anthropogenic" sources. Boric acid and its chemical relatives are pesticides derived from the element boron. Boron rarely occurs alone and is usually found in combination with other elements; common combinations are boric acid and borax. Unlike many pesticides that are synthetic compounds, boric acid and related pesticides are compounds of natural origin [12-14].

Gaye Cakal et al. used boric acid, borax pentahydrate, disodium pentaborate decahydrate for flame resistance of cotton fabric. The results of this study showed that borax pentahydrate is more effective than boric acid for flame retardancy [9]. Hassan et al. have analyzed the use of a mixture of borax, boric acid and disodium hydrogen phosphate dihydrate as flame retardants on a cotton/polyester fabric blend. The results of this study confirm the effectiveness of boron-containing compounds and di-sodium hydrogen phosphate dihydrate in enhancing the flame retardancy of blended fabrics. This improvement ensures their suitability for a range of applications, including protective clothing for firefighters, industrial workers, and military personnel, as well as healthcare textiles [14]. Cheng et al. used a mixture of boric acid, sodium hypophosphite and citric acid solution to flame retardancy of silk fabric. The treated fabrics obtained higher LOI values of 28.6% and showed self-densification due to the inflated residue of the char mass during the vertical burning test, and then left the char region retaining the original fiber shape [15].

In this paper, an attempt was made to find the most suitable textile refining processes based on the latest data from scientific research over the last ten years. Tests will be made to find the optimal conditions for the selection and application of appropriate procedures for refining polyamide fabric in laboratory conditions. These are treatments that improve hydrophilicity, flammability, etc.

2. EXPERIMENTAL

2.1 Materials

In the experimental part, two types of fabrics were used: 100% raw polyamide 6 fabric (PA 6) and 100% raw polyamide 6.6 fabric (PA 6.6) which were kindly donated from Yumco (Vranje, Serbia). The basic characteristics of raw polyamide 6 and polyamide 6.6 fabrics are shown in tables 1 and 2. Boric acid (Zorka, Šabac, Serbia) and sodium tetraborate (Zorka, Šabac, Serbia) were used for finishing fabrics. Sarabid DLO detergent obtained from CHT GmbH (Tübingen, Germany) was used to wash the fabrics.

Table 1: Basic characteristics of raw, unprocessed polyamide 6 fabric

Polyamide 6			
Propeties	Unit	Value	
Fabric density	cm^{-1}	Warp	14
		Weft	12
Mass per unit area	$g \cdot m^{-2}$	282	
Weave	/	Plain	
Fineness	tex	Warp	100
		Weft	83

Table 2: Basic characteristics of raw, unprocessed polyamide 6.6 fabric

Polyamide 6.6			
Properties	Unit	Value	
Fabric density	cm^{-1}	Warp	52
		Weft	40
Mass per unit area	$g \cdot m^{-2}$	96	
Weave	/	2/1 twill	
Fineness	tex	Warp	10.85
		Weft	11.11

2.2 Methods

Before finishing, the mass of the sample was measured. The mass of the polyamide 6 fabric was 0.7 g, while the mass of the polyamide 6.6 fabric was 0.2 g. Raw fabrics were washed with detergent (Sarabid DLO, 2 g·L^{-1}) for 30 minutes at 50-60 °C. Washing was performed on samples whose dimensions were 10×10 cm. The samples were then air-dried for 24 hours, the mass after drying was measured, and finally the samples were stored for further chemical processing.

The finishing of polyamide fabrics was carried out in a time interval of 15 minutes at a temperature of 40-50 °C, bath ratio R 1:20, in solution of 5% boric acid (H_3BO_3) and 5% sodium tetraborate ($Na_2B_4O_7{\cdot}10H_2O$), separately, calculated on the weight of the textile sample. This was followed by abundant rinsing and drying. Drying was carried out in a dryer (Instrumentaria, Zagreb, Croatia) at 100 °C for 15 minutes. After that, the samples were submitted for analysis according to the methods mentioned below. The processing scheme of polyamide fabrics is shown in figure 1.

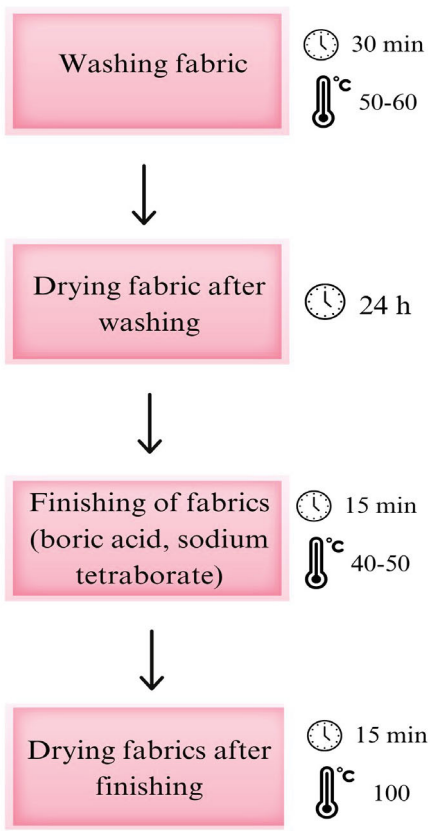

Figure 1: Processing scheme of polyamide fabrics

Water absorption (capillarity) is expressed in mm or cm. The dimensions of the sample are 1×5 cm in the direction of the warp, and in the direction of the weft. 1 cm from the beginning of the sample is marked on the sample, then it is immersed, up to that mark, in water for 1 minute, after which it is taken out and the length of the wet part is measured.

Capillarity is expressed by the height (in mm) of water rising in the test tube. Water absorption was carried out according to the SRPS F.S2.042 standard.

Water absorption based on the difference in mass was also measured (SRPS F.S2.041:1985). The amount of absorbed water is calculated from the difference in the mass of the sample before and after processing:

$$AV = \frac{m_v - m_s}{m_s} \cdot 100 \ (\%) \qquad (1)$$

where: A_V – (%) amount of absorbed water, m_v – (g) mass of wet sample after immersion, m_s – (g) mass of absolutely dry sample.

The wettability was determined via the water droplet test according to the AATCC standard. In the test, the wetting time was determined by placing a drop of distilled water on a sample of the straightened material sample, measuring 5×5 cm, from a pipette held 1 cm from the material. The time for the formation of a water mirror on the surface (the time for which a drop of water loses the power of reflection) was measured.

The flammability of fabric samples was performed according to the ISO 6941:2003(E) standard. A controlled flame from a designated burner is applied for 10 seconds to either the surface or the bottom edge of a vertically oriented textile sample. The time taken for the flame front to travel between marker threads, which are placed near the surface of the test specimen at three specific distances from the ignition point, is measured and recorded in seconds.

3. RESULTS AND DISCUSSION

3.1. Water penetration - capillarity

The capillarity or water absorption-penetration of raw, washed and treated polyamide fabrics with boric acid (5%) and sodium tetrabroate (5%) per warp and weft is given by the diagram in figures 2 and 3. The raw polyamide fabrics had similar values, PA 6=12 mm, PA 6.6=10 mm per warp. Washed samples of polyamide fabric 6 and 6.6 showed the same values per warp, ie. 45 mm, while the values per weft were higher for the polyamide 6.6 fabric, i.e. 50 mm. The biggest change was observed in the processed samples of polyamide 6 fabric with H_3BO_3 (5%), the value of which is 50 mm per warp and 42 mm per weft. The results confirm that it is a multiple increase in hydrophilicity, which is one

of the main goals of such textile treatments. Boric acid has a mild detergent effect, whereby it can increase hydrophilicity.

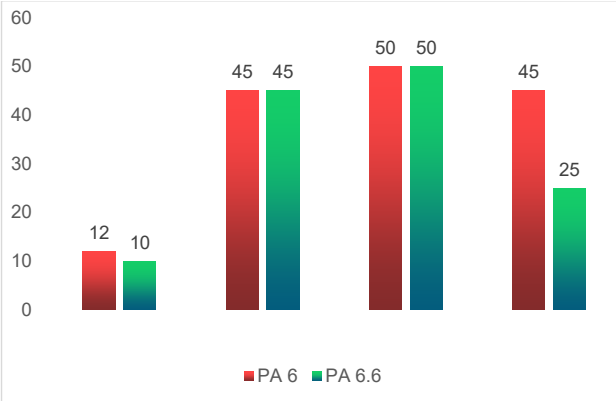

Figure 2: Capillary of raw, washed and PA fabrics treated with boric acid (5%) and sodium tetraborate (5%) per warp

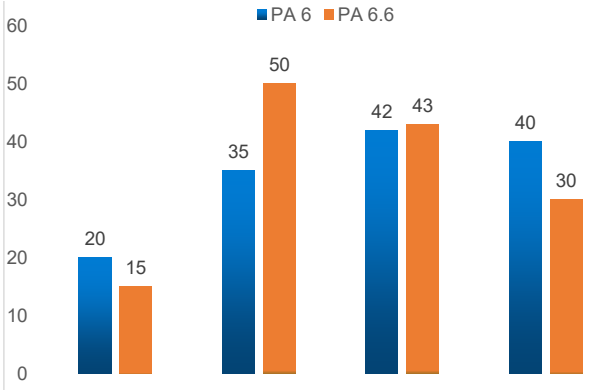

Figure 3: Capillary of raw, washed and PA fabrics treated with boric acid (5%) and sodium tetraborate (5%) per weft

3.2 Wetting time

The results of the wetting time of the raw, washed and treated polyamide fabrics with boric acid (5%) and sodium tetraborate (5%), shown in figure 4. The longest wetting time was observed for the raw polyamide 6.6 fabric, 9.28 s. After washing raw fabrics, a longer wetting time was observed for polyamide 6 fabric, i.e. 2.63 s. After treatment with boric acid (5%), the polyamide 6.6 fabric showed a longer wetting time, i.e. 4.28 s. The results reveal that the slowest wetting was for the raw polyamide 6.6 fabric, and the fastest for the washed polyamide 6. fabric, i.e. 1.53 s, which was expected. It appears that the presence of boron compounds on the washed textiles allowed faster wetting of the fabric surface as the washed samples showed a shade slower while the raw samples showed almost twice the slower wetting, meaning the fabric became more hydrophilic.

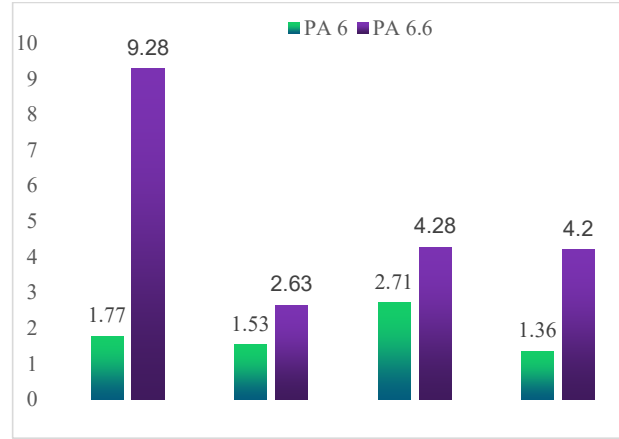

Figure 4: Wetting time of raw, washed and PA fabrics treated with boric acid (5%) and sodium tetraborate (5%)

3.3. Water absorption

The water absorption (%) of raw, washed and treated polyamide fabric with boric acid (5%) and sodium tetraborate (5%) is given by the diagram in Figure 5. In raw fabrics, a higher percentage of water absorption was obtained with polyamide 6 fabric 42.09%, whose mass before immersion in water was 2.82 g, and after immersion was 4.00 g. In the washed fabric, a greater increase in absorption was obtained in the polyamide 6 fabric 39.93%, whose mass before immersion was 2.88 g, and after immersion in water 4.03 g. The highest increase in absorption was observed in the sample of polyamide 6 fabric 64.18%, after treatment with boric acid (5%). After treatment

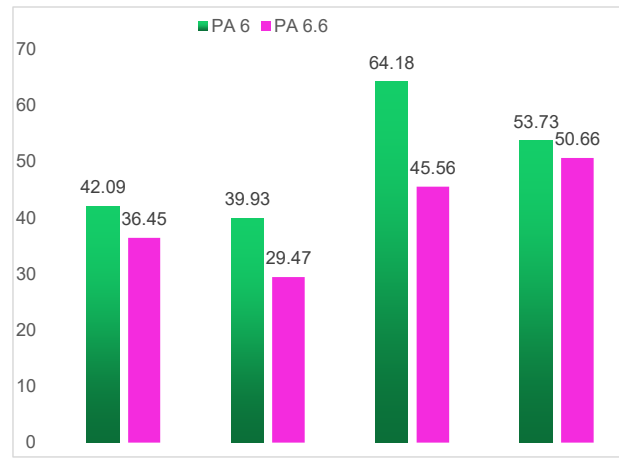

Figure 5: Water absorption for raw, washed and treated with boric acid (5%) and sodium tetraborate (5%)

with sodium tetraborate, a higher percentage of water absorption was observed in polyamide 6 fabric, i.e. 53.73%. In general, treated polyamide fabrics have a much higher percentage of water absorption compared to the raw fabric, which is expected and is related to the removal of impurities and similar substances from the surface of the polyamide fibers in the fabric.

3.4. Flammability

The shortest burning time was observed for raw polyamide fabric samples (PA 6=6 s, PA 6.6=7 s). After washing, the burn time increased for both fabrics. When the PA 6 sample was treated with 5% sodium tetraborate, the burning time was extended to 55 s. 61 s This sample starts burning after 18 s and burns until 61 s leaving most of the sample untouched. The longest burning time is noticeable in the treated sample with 5% boric acid, i.e. 61 s The sample starts burning after 16 s and burns until 61 s, leaving most of the sample intact.

Table 3: Flammability results (s) of raw, washed and PA fabrics treated with boric acid (5%) and sodium tetraborate (5%)

Type of fabric	Treatment			
	Raw	Washed	5% H_3BO_3	5% $Na_2B_4O_7 \cdot 10H_2O$
PA 6	6	40	61	55
PA 6.6	7	29	38	33

4. CONCLUSION

During chemical processing, one should be careful when designing the final form, considering that the textile material is a complex system with a very large number of variable parameters. For the textile material, in addition to the aesthetic appearance, it is important that it also has satisfactory characteristics during use and maintenance, which depends on the previous treatments.

Based on the obtained results of research in the laboratory and statistical data, the following conclusions can be drawn:

- The hydrophilicity of polyamide fabrics increases after treatment with boric acid (5%) and sodium tetraborate (5%);
- Processing with these chemicals leads to an increase in water absorption, ie. capillarity and water absorption, as well as much faster wetting;
- When testing the flammability of the fabric, it is noticeable that the raw fabric is difficult to ignite and burn, due to the presence of auxiliary substances that are applied to the polyamide yarn during production. By washing and removing these substances, polyamide fabrics become more combustible, that is, they burn continuously until the complete combustion of the entire samples. Treated PA fabrics begin to burn and self-extinguish after a few seconds, which is longer than for raw fabric samples. Treated polyamide 6 fabric with 5% boric acid proved to be the most resistant to burning.

The results indicate the possibility of applying boric acid and sodium tetraborate in the process of refining polyamide fabric, all in favor of better effects, savings and environmental protection. By additional analysis of the obtained statistical data, information can be obtained that will point to the definition of more successful breeding conditions, which will achieve greater utilization of chemicals.

REFERENCES

[1] Radivojević, D., Đorđević, M., Trajković, D. (2016) Ispitivanje tekstila, Visoka strukovna škola za tekstil, Leskovac.

[2] Miwa, K., Fujiwara, T. (2010). Boron transport in plants: co-ordinated regulation of transporters. *Annals of Botany*, *105*(7), 1103-1108.

[3] Bolt, H. M., Duydu, Y., Başaran, N., Golka, K. (2017). Boron and its compounds: current biological research activities. *Archives of Toxicology*, *91*, 2719-2722.

[4] Kabu, M., Akosman, M. S. (2013). Biological effects of boron. *Reviews of environmental contamination and toxicology*, 57-75.

[5] Soriano-Ursúa, M. A., Das, B. C., Trujillo-Ferrara, J. G. (2014). Boron-containing compounds: chemico-biological properties and expanding medicinal potential in prevention, diagnosis and therapy. *Expert opinion on therapeutic patents*, *24*(5), 485-500.

[6] Ozturk, M., Sakcali, S., Gucel, S., Tombuloglu, H. (2010). Boron and plants. *Plant adaptation and phytoremediation*, 275-311.

[7] Larsen, P. B., Nielsen, B. S., Fotel, F. L., Kortegaard, P., Slothuus, T., Hjelmar, O. (2015). Survey of Boric acid

and sodium borates (borax). *The Danish Environmental Protection Agency*, 978-87.

[8] Sokmen, N., Buyukakinci, B. Y. (2018, September). The usage of boron/boron compounds in the textile industry and its situation in Turkey. In *CBU International Conference Proceedings* (Vol. 6, pp. 1158-1165).

[9] Cakal, G. O., Gögebakan, Z., Coşkun, S. (2011). Investigation of synergistic effect of boron on fire retardancy of cotton fabrics. *Tekstil Ve Konfeksiyon*, 3/2011, 265-271.

[10] Qin, G., Zong, Y., Chen, Q., Hua, D., Tian, S. (2010). Inhibitory effect of boron against Botrytis cinerea on table grapes and its possible mechanisms of action. *International Journal of Food Microbiology*, *138*(1-2), 145-150.

[11] Yilmaz, M. T. (2012). Minimum inhibitory and minimum bactericidal concentrations of boron compounds against several bacterial strains. *Turkish Journal of Medical Sciences*, *42*(8), 1423-1429.

[12] Marzik, J. V., Lewis, R.C., Nickles, M.R., Finnemore, D. K., Yue, M., Tomsic, M., Sumption, M.D. (2010). Plasma synthesized boron nano-sized Powder for MgB2 wires, *AIP Conference Proceedings*. American Institute of Physics, 295-301.

[13] Shin, W. G., Calder, S., Ugurlu, O., Girshick, S. L. (2011). Production and characterization of boron nanoparticles synthesized with a thermal plasma system. *Journal of Nanoparticle Research*, *13*, 7187-7191.

[14] Cheng, X. W., Wu, Y. X., Huang, Y. T., Jiang, J. R., Xu, J. T., Guan, J. P. (2020). Synthesis of a reactive boron-based flame retardant to enhance the flame retardancy of silk. *Reactive and Functional Polymers*, *156*, 104731.

[15] Hassan, M. N., Abdullah, T. S., Mou, M. B., Towsif, H. R. (2024). Analysis of the flame retardancy effect of boron-containing compound on polyester-cotton blended fabric. *Heliyon*, *10*(13).

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