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Research of the Felting Process of Modified Eco-Wool

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General description of paper

Topicality of research. Wool has been used by people since time immemorial. It is believed that the felt was the first textile product manufactured from wool. A belief persists that the first spread out felt canvas was created in the Noah's Ark as a result of tcompacting the fallen sheep hair. This story has an objective basis. In particular, when studying the morphological structures of wool (wool fibers), it has been determined that it has a relief, the so-called "fish scale" structure, by means of which, and as a result of friction and mechanical load, the fiber surfaces are becoming interwoven, and ultimately this results in the formation of material with a single consolidated structure. The quality of the felt, in addition to the artistic design, is determined by the properties of raw material – wool, and coloration technology. Together with the development of humanity, there were also developing the technologies for wool processing and producing various types of textiles. Today, changes in the wool fiber are made more profo-undly - at an elementary level. Such changes affect both the nature of fibers, and products made of it. It is noteworthy that the unprocessed natural wool fibers are hardened very well, but felt obtained at this time is coarse, greased and un-colorful (whitish-yellowish, gray, brown or black).

Over the centuries, the felt manufacturing methods have been improved and new technique have been developed. In particular, along with traditional wet method of hardening, there have also been developed methods of dry hardening: a needle-sticking, inserting and sticking method. The latest innovation in this field was recorded in the 1990s, when a new type of felt was created.

With the passage of time, the requirements to the functional, consumer and aesthetic characteristics of felt have been significantly increased, the satisfaction of which is associated with change in the physical-mechanical and coloristic properties of wool fiber.

It is noteworthy that production of the aesthetically pleasing felt with functional and good consumer characteristics requires to find optimal solution to the compromise problem, since any kind of processing involves more or less damage to the structure of fibers, and unpro-cessed, undamaged fiber is a prerequisite for good hardening. Therefore, the solution to this compromise problem is to use different ways, which are aimed, on the one hand, to maintain the fiber structure as much as possible, and, on the other hand, at assisting in obtaining product with the desired physical-mechanical and coloristic properties.

The properties of wool fiber have a significant impact on the process of hardening and on the quality of hardening itself. Therefore, we think that the change in the physical-mechanical characteristics and chemical properties of wool fiber will have some impact on the capacity and quality of hardening.

New unique methods of modification and coloration of wool fibers have been developed by the scientists and specialists of ATSU in the field of textile technology and design. There has been developed method of modification of wool fiber using the boric sheets. Studies have shown that after a modification, the physical-mechanical and structural properties of wool are changed significantly, and since the

properties of wool fiber have a significant impact on the process of hardening and the quality of hardening itself, we can assume that the process of hardening the modified wool will also occur in a different manner, and as a result, we will obtain the felt resistant to a high-degree bio-destruction.

In addition, there has been studied the process of coloring the modified wool with synthetic dyestuffs, and method of coloring has been developed. It has been established that the obtained colorations are distinguished by the improved coloristic and consumer properties. We believe that when coloring the modified wool with natural pigments, it is also possible to obtain good coloristic charac-teristics and stable colorations. At the same time, a new method has no need for using heavy metals as the color fixators, and the process is environmentally clean and safe.

It is important that the process of wool modification is not complex from the technological standpoint, and can be used both in production and home conditions in improvised manner.

In the light of these arguments, we believe that study of the problem of hardening the modified wool and its coloring with with natural pigments is of high relevance both in terms of creating new theoretical knowledge and building practical capabilities.

Aim and objectives of research. The research aims to study the processes of hardening the modified wool fibers and coloring them with natural pigments.

The basic areas of research are as follows:

- A direct impact of a wool modification on the process of felting and its quality.

- The impact of a wool modification on coloration with natural dyes (pigments).

The main phases of research are as follows:

- Studies of the impact of a wool modification on the capacities and quality of hardening.
- Establishing optimal conditions of the wool fiber harde-ning and coloration for obtaining high-quality wool felt product.
- Assessing environmental safety and economic feasibility of the production of felt from modified wool.

Studies have shaped a new systemic knowledge on the possibilities of changes in the properties of the wool fibers modified with boric sheets, its manifestations and on the possibility its practical application.

Novelty of research:

- For the first time, there has been studied the impact of the structural, physical-mechanical and elastic-creep properties changing of modified wool by boric sheets on a felting quality.
- For the first time, there has been studied the impact of a wool modification on the process of its hardening and quality.
- For the first time, there has been studied of a wool modification on on the process of coloring with natural pigments and the quality of obtained coloration.
- Using a method of mathematical modeling, for the first time, there have been determined rational parameters hardening and modifying the wool with boric sheets, which will ensure obtaining of high-quality felt products.

Practical bearing of research. A new method of producing the felt has been developed, which will provide the production of the aesthetically pleasing and environ-mentally safe products with improved consumer properties artistic design. A new method of a wool modification and hardening of modified wool can be used both in a textile enterprise and small decorative-applied plants.

Approbation of work. The main resuts of dissertation paper have been presented and discussed at international scientific conferences held in Batumi and Kutaisi:

- Internationl Scientific-Practical Conference "Modern Engineering Technlogies and Environmental Protection", ATSU, 2016.
- Internationl Scientific Conference "Culture and Art: Research and Management", Batumi, September, 2015.

Publications. The main findings and considerations of research are pubished in 8 scientific articles.

Volume and Structure of Dissertation. Dissertation includes Introduction, three chapters, conclusions, and list of References. The proposed work comprises 102 printing pages, 22 illustrations, 18 tables, and 101 published literature titles.

Brief content of dissertation by chapters

Introduction formulates topicality of research, its scientific and practical appropriateness, and defines aim and objectives of research and its practical bearing.

In the first Chapter, the dissertation reviews the wool fiber's structure and physical-mechanical properties affecting the hardening capacity, as well as analyzes research works performed in various research centers for the purpose of wool processing; the determining factors for the process of hardening and analysis of performed research investigations on the process of hardening; peculiaritie of the process of coloring with natural pigments and analysis of the latest research works performed in the field of coloring with natural pigments.

The second chapter provides description of the research subjects and methods, methods of studying the quality and parameters of hardening, study of fiber's weaving and surface structure, study of changes in the area of section, and changes in the density (the weight of 1 cm^2); the chapter also considers methods used for studying the changes in the characteristics of coloration of fiber; determination of selectivity of dyestuff from dyeing solution and determining the quality of colorant fixation, determining coloration stability and coloration intensity; there is also given the assessment methodology for antimicrobial properties of wool and resistance to bio-destruction; method of experimental design and mathematical modeling.

The third chapter describes the experimental works: study of the process of hardening of modified wool; establishing rational conditions for wool modification and hardening; study of coloration of modified wool with natural pigments; study of the resistance of modified wool to bio-destruction; assessment of using modified wool and environmental safety of its coloring, as well as the economic appropriateness of the production of felt from modified wool.

With a view to studying the impact of a modification of the wool fiber on the quality of hardening, there have been studied the impact of the intensity of the concentration and hardening of modifying agents on the quality and the effectiveness of hardening. The density of felt (g/cm^2) was selected as a determining parameter of the quality of hardening, and the effcetiveness of hardening process

was evaluated by the relative change in the density index (with the density rate).

Analysis of the density indices of felt produced from pre-processed wool in the modifying agents A and B revelas that, as expected, an increase in the intensity (the nimber of cycles of hardening) of hardening leads to increasing the density of felt. In addition, an increase in the density index in the initial phase of hardening occurs faster, and by the end of hardening (fourth phase) the compression speed goes down. This is natural as the process of hardening cannot be open-ended. At a certain stage, the structure of the material is stabilized and the compression process is minimized (Table 1, Table 2).

As to the relationship between the hardening capacity of wool and the concentration of the modifying agent, Table 1 and Table 2 show that when processing wool in a 0.5% modifying agent, density of felt exceeds the density of standard (unprocessed) sampse. With an icrease in the intensity of hardening, the hardening capacity of wool increases slowly.

Table 1

The densityindex of felt produced from wool pre-processed in the modifying agent A

The density of initial sample, g/cm^3	The intensity of hardening, (cycles)	The direction of hardening in terms of the edges of sample	Density, g/cm^3			
			The concentration of a modifying agent, %			
			0	0,5	1,0	2,0
9,76	Face side 200 cycles	I	31,84	34,87	37,83	27,34
		II	36,34	35,84	40,07	29,65
		III	36,73	38,48	42,76	30,07
		IV	37,29	38,46	43,67	30,45
	Back side 200 cycles	I	43,26	40,95	44,65	34,65
		II	43,91	46,62	48,58	35,56
		III	48,1	47,44	50,85	35,10
		IV	46,62	47,38	52,02	39,17
	Face side 100 cycles	I	59,4	58,12	58,84	46,20
		II	60,46	63,35	62,99	50,05
		III	64,1	65,10	64,46	50,12
		IV	64,1	64,13	66,11	52,18
	Back side 100 cycles	I	65,23	75,75	68,43	55,44
		II	70,39	78,20	73,49	61,77
		III	72,62	78,14	74,38	64,38
		IV	73,81	79,48	84,07	72,59

In addition, the values of the hardening speed are virtually identical. An increase in the concentration of modifying agents results in accelerated hardening. However, the final density index of felt is less than the standard value. Based on the results of the research, it can be said that the best prperties of hardening are characteristic of wool processed in a 0.5% - 1% modifying agent. The quality of hardening, which is expressed in n the density of felt, when processing in a modifying agent A is increased by 7.57% -13.90%, while when processing in a modifying agent B it is increased by 9,0% -13,94%.

Table 2

The density index of felt produced from wool pre-processed in the modifying agent B

The density of initial sample, g/cm^3	The intensity of hardening, (cycles)	The direction of hardening in terms of the edges of sample	Density, g/cm^3			
			The concentration of a modifying agent, %			
			0	0,5	1,0	2,0
9,76	Face side 200 cycles	I	31,84	34,05	37,02	26,34
		II	36,34	35,22	40,07	29,65
		III	36,73	37,67	42,76	30,07
		IV	37,29	39,42	43,67	30,45
	Back side 200 cycles	I	43,26	41,35	44,65	34,65
		II	43,91	45,47	48,58	35,56
		III	48,1	46,75	50,84	35,10
		IV	46,62	47,88	52,01	39,16
	Face side 100 cycles	I	59,4	57,19	58,84	46,20
		II	60,46	63,87	62,99	50,05
		III	64,1	63,67	64,46	50,12
		IV	64,1	65,18	66,11	52,18
	Back side 100 cycles	I	65,23	74,13	70,43	55,44
		II	70,39	78,34	75,49	61,77
		III	72,62	79,14	77,38	64,38
		IV	73,81	80,48	84,10	62,59

For the purpose of evaluating the effectiveness of the process of hardening, there was studied a relative change in the density of felt (Fig. 1, 2). Figure 1 illustrates a relative change in the density of felt

made of a pre-processed wool in the modifying agent A. Figure 1 outlines that the process of hardening of wool processed in the the modifying agent A and and in the 0.5% -1% modifying agent is practically uniform. In addition, attaining appropriate level of a maximum value of relative density of felt produced from unprocessed wool in the 0.5% -1% modifying agent, is possible 300 times less during processing in A, under hardening conditions with 2100 cycles.

The same pattern is observed after processing in the modifying agent B. The corresponding effect of a relative change in the density of felt produced from unprocessed wool is reached under hardening conditions of wool in the 0.5% -1% modifying agent with modulator 2100, or 300-400 less cycles (Fig. 2).

Thus, hardening of pre-processed wool in the 0.5% - 1% modifying agents A and B is carried out similarly to the ptocess of hardening of unprocessed wool. In addition, obtaining the quality of hardening appropriate with the quality of felt produced from the unprocessed wool after processing in the modifying agent is possible under conditions of 10-12% lower intensity. In practice this means that less time and physical efforts (human or mechanical) will be needed for hardening.

When modifying during the process of hardening, as well as in pre-processing in the modifying agent, an increase in the intensity of hardening leads to an increase in the intensity of felt. In addition, the quality of hardening of modified wool suring the process of hardening is better than the quality of pre-processed wool. At the same time, the hardening quality and speed when hardening modified wool are higher than during hardening in standard mode. In case of modification during the process of hardening of wool, the best hardening capacity is characteristic of samples processed in the 0.5% -1% modifying agent. The quality of hardening - the density of felt whtn processing in A increases by 16,5% -25,5% in the modifier, while during processing in B it increases by 13,4% -19,36%.

The evaluation of the effectiveness hardening of wool during the hardening process is also carried out by a relative change in the density of felt (Fig. 3, Fig .4). These Figures illustrate that when modifying in the process hardening, the process of hardening of wool processed in the modifying agents with different concentrations is more effective, which is expressed in a higher value of a relative change of the density of felt. In addition, when using the wool processed in the 0.5% -1.0% modifying agents providing the quality appropriate with felt produced from unprocessed wool is possible under conditions of 1700, that is 700 cycles lower.

Thus, the process of hardening of wool processed during hardening in the 0.5% -1.0% modifying agents A and B goes more effectively than hardening of unprocessed wool. At the same time, providing the quality appropriate with the quality of felt obtained from unprocessed wool is possible under conditions of the 25-28% lower intensity. In practice this means that lesser time and physical efforts (human or mechanical) will be needed for hardening.

The process of hardening is affected by the elastic-deformation properties of fibers. That is why we have studied the change in the elastic-deformation properties of wool after processing in the modifying agents (Table 3).

Table 3

Complete relative deformation of fibrous material

Fibrous material	**Complete relative deformation, %**		
	ε[illegible]	ε[illegible]	ε[illegible]
Processed in the modifying agent A	9,4	38,0	52,6
Processed in the modifying agent B	10,1	39,9	50,0
Unprocessed	50,0	22,0	28,0

Table 3 shows that the share of the elastic deformation in unprocessed wool is dominant. After modification, the elastic and plastic constituents of deformation are increased, which contributes to an increase in the area of contact of fibers during friction, and as a result the quality of hardening is improved and the process becomes more effective.

The microscopic study of the flexuosity and surface structure of the wool fibers has shown that the flexuosity of fiber is grown during processing in the modifying agents. Moreover, the surface structure (scaly layer) is not damaged (Fig. 5).

It can be said that boric sheets have a "soft" impact on fibers. In particular, boric sheets produce complex compounds together with different elements in the primary structure of the main polymer of the wool fiber - keratin, which cause the changes in protein at the level of the primary structure. In addition, the mentioned boric complexes

represent an additional active center dyestuff, and they do not cause damage to the surface structure of fiber, and, therefore, they do not stand in the way of the process of hardening, but the colorations obtained when coloring with natural pigments are more intensive and the coloring qualityis higher as well.

For the purpose of establishing rational conditions of modification and hardening of wool, there was implemented design of the second-order two-factorial experiment. The concentration of the modifying agent and the intensity of hardening have been selected as factors. As the output parameters, there have been selected – the value characterizing the quality of hardening – the density of felt. The reflecting surfaces obtained on the basis of the experimental data processing show that the function is of a paraboloidal nature. (Fig. 6). At the same time, to reach the best quality of hardening, the optimum value of the concentration of modifying agent is in the center of the experiment (1,0% -1,5%), but the optimum value of the intensity of hardening is in the field 0-1 (2000-2400 cycle range).

The second main are of the research is study of coloring the modified wool with natural pigments. The following natural pigments have been selected for research: madder, onion leaf, turmeric and hibiscus. The study of the intensity of coloration showed that the intensity values of fiber processed in the 0,5-1,0% modifying agent were 15-19% higher compared with unprocessed wool (Table 4). We believe that an increase in the intensity of coloration is associated with the existence of the additional active centers created by boric sheets.

Table 4

The intensity values of coloration of wool fiber colored with natural

Modifying agent		A				B			
Dyestuff		0%	0,5 %	1,0 %	2,0 %	0%	0,5 %	1,0 %	2,0 %
Madder	Acidic	39,45	53,65	55,35	54,36	35,26	50,78	53,55	47,87
	Neutral	41,12	56,85	57,14	57,36	39,54	49,74	53,58	52,65
	Alkaline	42,15	54,15	58,67	58,88	40,11	52,85	57,62	55,16
Onion leaf	Acidic	36,12	52,48	52,34	50,65	35,25	49,10	50,23	50,95
	Neutral	36,90	54,76	53,87	52,96	37,93	53,14	53,95	53,78
	Alkaline	38,15	55,56	57,47	56,85	38,60	5,37	56,64	51,37
Turmeric	Acidic	27,90	41,78	43,95	41,15	26,75	39,75	42,67	42,98
	Neutral	28,75	43,15	44,51	43,67	27,87	39,22	45,17	41,35
	Alkaline	30,45	47,25	46,44	45,43	30,11	44,33	46,87	46,48
Hibiscus	Acidic	36,15	47,78	53,16	52,04	33,12	48,45	49,88	50,11
	Neutral	36,65	49,67	54,32	53,26	38,86	50,24	55,14	50,85
	Alkaline	37,12	50,35	56,38	54,65	39,98	53,78	57,56	51,64

With continued growth in the concetration of the modifying agents the intensity of coloration goes down. We believe that the establishment of molecular interconnections in a wool polymer happens through the boric sheets, and the additional active centers "intended" for the dyestuff serve the the creation of molecular interconnections. As a result, fiber becomes more structural and oriented, and the number of joined pigments is reduced.

Studies of the quality of selectivity of pigments from dyeing solution and fixation on fiber revealed that the quality of selectivity different dyestuffs by modified wool increases by 3-16% (Table 5), and the quality of fixation is improved by 3-15% (Table 6). At the same time, selectivity of dyestuff and fixation on fiber are the best for wool processed with a 0,5-1,0% modifying agent.

Table 5

The quality of dyestuff selectivity

Modifying agent		A				B			
Dyestuff		0%	0,5 %	1,0 %	2,0 %	0%	0,5 %	1,0 %	2,0 %
Madder	Acidic	26,7	33,3	30,0	28,3	4,4	9,4	9,3	6,2
	Neutral	10,0	18,3	20,0	20,0	6,2	10,3	12,5	12,5
	Alkaline	51,8	53,1	58,1	56,25	0,6	3,1	3,2	3,2
Onion leaf	Acidic	55,6	62,5	65,0	61,25	72,5	73,1	74,4	76,2
	Neutral	25,0	31,2	26,2	21,9	29,3	23,0	23,0	12,5
	Alkaline	15,6	18,7	21,9	21,8	0,6	2,5	3,1	1,2
Turmeric	Acidic	44,6	46,0	47,1	49,6	43,5	44,6	44,6	46,0
	Neutral	46,4	48,2	50,0	51,8	46,4	48,2	46,4	46,4
	Alkaline	46,4	48,2	53,2	64,2	50,0	51,8	53,5	53,5
Hibiscus	Acidic	18,0	30,0	24,0	22,0	21,3	34,7	27,2	26,5
	Neutral	16,0	24,0	30,0	22,0	20,0	17,3	25,7	24,5
	Alkaline	11,8	14,8	18,5	17,4	14,6	15,9	18,1	18,2

Table 6

The quality of fixation

Modifying agent		A				B			
Dyestuff		0%	0,5 %	1,0 %	2,0 %	0%	0,5 %	1,0 %	2,0 %
Madder	Acidic	38,3	45,0	46,7	43,3	40,0	50,0	49,4	46,9
	Neutral	41,7	41,7	41,7	38,7	43,7	50,0	50,0	46,8
	Alkaline	65,0	68,1	68,7	69,3	28,7	41,25	37,5	31,25
Onion leaf	Acidic	72,5	73,12	74,4	76,2	76,2	76,6	73,7	73,7
	Neutral	50,0	53,7	53,2	53,2	61,2	56,2	53,1	43,7
	Alkaline	31,2	34,3	37,5	40,6	12,5	15,6	21,8	25,0
Turmeric	Acidic	50,0	50,7	51,7	50,0	64,8	64,9	71,0	67,8
	Neutral	67,1	67,8	71,4	67,9	49,6	53,5	52,5	51,7
	Alkaline	64,2	67,8	71,4	67,8	57,1	58,9	60,7	64,4
Hibiscus	Acidic	32,0	34,0	37,0	36,0	33,8	36,0	38,5	37,0
	Neutral	34,0	40,0	42,0	40,0	35,3	42,8	45,1	43,2
	Alkaline	34,7	43,7	44,4	35,6	35,9	46,1	47,4	45,7

Enhanced quality of dyestuff on fiber finds its is practical expression in improving the quality of coloration.

Studies have shown that the resistance of modified wool colored with pigment dyestuffs during wet processing compared with standard (unprocessed) samples, is not worsening, in most cases it is improved by 0,5-1 scores. The resistance of modified wool is also improving by 0,5-1 scores towards the light of coloration of modified wool.

A significant result has been obtained in natural conditions in terms of resistance to bio-destruction. When assessing the the surface of fiber of modified and non-modified wool placed in a humid environment for a month, it has been established that fiber processed in a modifying agent A was virtually kept unchanged, without damaging. Its resistance to the influence of microorganisms can be assessed maximally a 5 rating. The wool fiber unprocessed and processed in a modifying agent B were damaged partially, and their stability was given a 2-3 rating.

As for the study of the resistance of modified wool to aphid, we preserved it in natural conditions together with the damaged fibers for a year. As expected, the unprocessed wool was significantly damaged by aphid, but wool processed in the modifying agents A and B had a good stability to damage by aphid.

It is noteworthy that the modified wool is environmentally safe. The external impact of the boric sheets on the skin is absolutely safe. Even if they are absorbed into the blood, they remain safe for people, because are within the daily norms. At the same time, the color fixators (heavy metal salts) have been removed from coloration formula. Thus, the colored material is safe from both human and environmental standpoints.

In addition, the use of modified wool during the hardening is economically sound. The coloring formulas for both uncolored wool and wool colored with natural pigments are cheaper.

Main results and general conclusions

Based on the studies carried out within the dissertation work, there has been obtained a new systemic knowledge on change in the properties of wool fiber modified with boric sheets, as well as on the possibilities possibilities of its identification and practical application.

Based on a reliable, objective and qualified analysis, there have been made the following conclusions:

1. Processing in the modifying agents A annd B significantly affects the quality and effectiveness of hardening. In particular,

- During pre-processing in the modifying agents A and B, the quality of felt is imroved – the density of felt is increased by 7-13%;
- During hardening in the modifying agents A and B, the quality of felt is imroved – the density of felt is increased by 13-25%;
- During processing in the modifying agents A and B (during both pre-processing and hardening) the effectiveness of the process of hardening – a relative change in the density of felt is increased. As a result, providing the quality appropriate with felt produced from unprocessed wool is possible under conditions of 700 cycles lower, that is, the intensity of hardening is reduced by 25-28%. In practice this means that less time and physical efforts (human or mechanical) will be needed for hardening.

2. Processing in the modifying agents A and B causes change in the elastic-deformatiing properties of wool fibers. In particular, the share of elastic and plastic constituent of deformation increases, which, results in an increase in the effective area of fiber during the external impact. As a result, the contact surface of the interaction of fibers and the effectiveness of hardening during griction are icreased.

3. Processing in the modifying agents A and B causes A and B the qualitative and quantitative changes in the flexiosity of wool fiber. In addition, the impact of a modifying agent B is more effective:

- In the case of local sheep wool, the share of fibers with wave-like and flat flexuosity is increased, but the number of smooth fibers is not considerable;
- In the case of merino sheep wool, the share of fiber with flat and normal flexuosity is increased;
- The modifying agents A and B have a "soft" impact on fiber: they do not cause the damage to the suface structure – damage to "scaly layer". In addition, the structure of fiber itself becomes more organized and oriented, which leads to increasing its purity. As a result, the quality of hardening is improved.

4. Based on the two-factor non-linear rotatable design, it has been established that rational conditions for hardening of wool processed in the modifying agents A and B consist in processing and hardening with 2000 cycles in a 1,5% modifying agent.

5. The color tone obtained and intensity of color absorption obtained during coloring modified and non-modulated wool with natural pigmentby modified and non-modulated wool pigments and its intensity depend largely on coloring conditions (pH, time, temperature):

- Coloration obtained when coloring in the acid environment is less intensive, and color tone is moved to the lengths of the long waves, and the intensity of coloration of fiber colored in the alkaline medium is higher, color tone is moved to the lengths of the short waves,

coloration is deeper and more saturated; the intensity of coloration of wool modified is icreased by 15-19%;

- Access to the maximum intensity under conditions of cold coloring it is carried out quicker. In addition, the intensity of coloration obtained after cold coloring is higher, than the intensity coloration obtained as a result of coloring at the temperature of 85-90^{0}C.

6. The quality of selectivity of different pigments by modified wool is improved by 3-16%, and the quality of fixation is improved by 3-15%. At the same time, selectivity of dyestuff and fixation on fiber are the best for wool processed in a 0,5-1,0% modifying agent.

7. Colorations of modified wool towards the light and wet processing (washing in soap-soda solution) are characterized by the better stability characteristics, and the resistance is also improving by 0,5-1 scores.

8. Modified wool is characterized by improved characteristics towards biological destruction:

- The resistance of wool modified in a modifying agent A to the influence of microorganisms can be assessed maximally a 5 rating; but the wool fiber unprocessed and processed in a modifying agent B were damaged partially, and their stability was given a 2-3 rating;
- Wool processed in the modifying agents is characterized by a good stability to damage by aphid, and preseves the structure undamaged when storing in natural condtions;

9. The use of modified wool is environmentally safe in terms of both human and environmental impacts:

- The external impact of the boric sheets on human skin is safe; even in case of getting in house, it is safe, because the amount of used boric

sheets (≈ 1 mg) is lower than the daily demand rate of boron (0,2-4 mg);

- Color fixators (heavy metal salts) have been taken from the coloring formula, so the colored aterial is safe in terms of both human and environmental impacts;
- The amount dyestuffs in wastewater remained after coloring modified wool products with natural pigments is reduced by 5-30%. In addition, the reuse of dye-bath and wastewater remained remained after coloring and washing modified wool is not difficult in practice.

10. Taking into account the improved consumer properties, the use of modified wool in hardening is economically feasible. Considering market prices, in both cases, during hardening of uncolored wool, as well as when producing colored products, the costs are reduced, since the various substances and color fixators are removed from the formula. In addition, the color of the desired coloristic characteristics can be obtained in the conditions of saving 10-15% of natural pigments.

Recommendations for the production

The developed method for hardening modified wool can be used both in the textile enterprise and decorative-applied small plants.

The main publications relating to the dissertation topic

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2. L. Khvadagiani. History of Georgian decorative felt. // Periodic scientific journal "KHANDZTA", No 11(16). Kutaisi-Tbilisi, 2015. (on Georgian)

3. L. Khvadagiani, K. Goginovi, M. Sharabidze. The issues of environmental safety of coloring modified wool. International Scientific-Practical Conference "Modern Engineering Technologies and Environmental Protection", ATSU, 2016. (on Georgian)

4. Goginovi K.M., Khvadagiani L.S. The "singing" textile compositions. International Scientific Conference "Culture and Art: Research and Management". Batumi, 2015, September. (on Georgian)

5. L. Khvadagiani, K. Goginovi, M. Sharabidze. RESEARCH OF DYEING OF MODIFIED WOOL BY NATURAL PIGMENTS. // EUROPEAN RESEARCH. International center for scientific cooperation "Science and education", 7 November, 2016. P. 61-65. (on English)

6. L. Khvadagiani, M. Sharabidze. Research of the influence of deformation properties on the process of felting of modified wool. // International scientific journal "Young Scientist", No 23 (157), 2017. pp. 180-183. (on Russian)

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International center for scientific cooperation "Science and education", 12 June, 2017. pp. 26-29 (on Russian)

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