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Improvement of the Process of Mechanical Dehydration of Five-Layer Semi-finished Wet Leather Products

Auezhan T. AMANOV[1*], Gayrat A. BAHADIROV[2], Gerasim N. TSOY[2], Ayder M. NABIEV[2]

[1]Department of Mechanical Engineering, Sun Moon University, Asan, 31460, Korea

[2]Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, 100125, Uzbekistan

*avaz2662@sunmoon.ac.kr

Article

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ABSTRACT

To improve the process of mechanical dehydration of semi-finished wet leather products, a multilayer dehydration using felt materials – monshons was experimentally investigated. The process is conducted by vertical feed of semi-finished wet leather products on a base plate between rotating squeezing rollers. The D-optimal method of mathematical planning of the experiment and the Kano design matrix were used for conducting experiments. The multi-layer package consists of five layers of semi-finished wet leather products and two layers of moisture-removing materials between each layer, folded over the base plate. The studies were carried out in laboratory conditions on an experimental bench, taking into account the production parameters of processing. As a result of the study, mathematical dependences of the amount of removed moisture for each of five layers of semi-finished wet leather product on the feed speed and the pressure of the squeezing rollers were derived. The analysis of the results showed that, with the existing parameters of mechanical dehydration, it was possible to simultaneously squeeze out moisture from five layers of the semi-finished leather product with a minimum pressure of the squeezing rollers and an average feed speed. The productivity of the technological process was more than five times higher in comparison with the productivity of similar roller machines. In the near future, this research methodology will be used to determine the technological factors affecting the extraction of excess moisture from a package consisting of ten semi-finished wet leather products and moisture-removing materials.

KEYWORDS

Squeezing out five layers of leather, Semi-finished leather product, Moisture-removing material, Vertical feed, Productivity

INTRODUCTION

In the production of genuine leather, the process of squeezing out excess moisture from a semi-finished leather product is one of the most important in its mechanical processing. It gives the semi-finished leather product a uniform moisture content throughout its topography. From an economic point of view, it is advisable to squeeze the moisture out of semi-finished wet leather products on roller machines. Roller squeezing machines are used to squeeze semi-finished leather products and hides after tanning and dyeing. According to the method of processing semi-finished leather products, the roller machines are subdivided into pass-through machines (wringing occurs over the entire surface of the semi-finished leather product in one passage between the squeezing rollers) and non-passage ones (wringing takes place by parts for several feeds of semi-finished leather between the rollers).

There are various designs of roller squeezing machines, for example those with horizontal or vertical feed of material into the processing zone and many others. One of the problems of horizontal roller squeezing machines is the impossibility of a multilayer mechanical dehydration of moisture-saturated semi-finished leather products. In contrast to the horizontal one, a vertical roller squeezing machine has the ability to squeeze out several layers of semi-finished wet leather products using a base plate and squeezing rollers. Consequently, the study and substantiation of the effectiveness of the simultaneous multilayer pressing of semi-finished wet leather products are relevant. The trend of the modern development of leather processing shows the relevance of increasing the productivity of technological processes with minimization of labour, energy consumption and other costs when performing various mechanical processing of leather.

Witt et al. conducted a study of heat development at the knife roller during leather shaving in industrial conditions, where temperature measurements were made with Wet Blue and Wet White materials [1]. The results showed a change in the heating temperature on the knife roller in the process of leather shaving. The authors calculated the maximum temperature in the contact zone between the screw knife and the leather by computer simulation using a finite element method for the entire shaving process. When shaving the Wet Blue and Wet White leathers on the knife roller, the heating temperature was approximately 103 °C and 81 °C, respectively, corresponding to a 14% increase in temperature for the Wet Blue leather compared to that of the Wet White leather. The authors of the studies explained the difference in temperature due to the different feed rates, the initial and final thickness of the leather layer. In addition, Shardabek et al. developed a belt conveyor with a concave bearing surface for reloading raw materials produced in light industry, in particular for shipping raw materials from vehicles to warehouses, and back for loading. In the study conducted by Omar Gamal et al., the authors describe the control of the process of hot rolling of bar and wire, with the control of the required clearance between the shafts [2,3]. The results can be useful in improving the design of roll machines for processing sheet materials with variable thickness and surface [4,5]. A study conducted by Krylov et al. presented the results of the analysis of factors affecting the power consumed by the drive of the roll module [6]. Krylov et al. experimentally determined the costs of power and the moment of resistance spent in the contact zone of the shafts of the modules under the strain of their coatings and the processed material [7].

In a study conducted by Podyachev and Boyko, a dynamic analysis of the shafts of roller textile machines was carried out on the basis of a numerical method [8]. An algorithm was developed for studying roll modules with an arbitrary number of shafts. In a study conducted by Krylov et al., the coefficients of static friction and sliding were experimentally determined for various materials [9]. The dependences of the friction coefficients on the rotation frequency and the value of the friction of the shafts were obtained. In a study conducted by Appiah-Brempong et al., the process steps and materials used in traditional leather production in Ghana, and the scientific principles underlying each process were described [10]. The traditional and modern processes of tannery are compared and studies in the field of artisanal leather production were studied. In a study conducted by Navarro et al., a review and analysis of scientific articles devoted to the research of production processes, mechanical processing of materials, waste processing and a long-term strategy for the development of the leather industry were made [11]. The authors note the importance of possessing scientific and practical knowledge for the improvement and implementation of technological operations in the processing of raw materials.

In a study conducted by Dorokhov, the author analysed existing and new technologies of pressure treatment and revealed signs that determine the complex local loading of the deformation zone [12]. A mathematical model was developed for the processes of metalworking by pressure with complex local loading of the deformation zone. The stress-strain state and the pattern of plastic flow of the material in the deformation zone were determined. In a study conducted by Gribkov, the author investigated the relationship between stresses, density and strains for cases of a stressed state arising in the rolling and drawing of powder materials, which made it possible to increase the accuracy of calculating the stress-strain state during the aforementioned technological operations [13]. The influence of the shape, material and thickness of the shell on the geometric characteristics of the deformation zone was established. The influence of the thickness and material of the shell of the powder-coated belt on the energy-power parameters of the crimping process was established. In a study conducted by Radnaeva and Sovetkin, new technologies for processing leather and fur were studied [14]. The ratio of hydrophobic and hydrophilic solvents for the processing of semi-finished leather products by the rate of dehydration was experimentally determined. The rate of dehydration by the amount of liquid removed from the semi-finished leather product per unit of time was determined. The results showed that an increase of up to 20%, in the amount of a hydrophilic solvent in the total mixture contributed to an increase in the rate of dehydration of a chrome-plated semi-finished leather product. The values of internal stresses during the pressing of the chrome-plated semi-finished leather products were also experimentally determined. The internal stress, in comparison with the control semi-finished leather products, was 900 kPa; in the samples treated with solvents, it decreased to 700 kPa. Studies have shown an increase in the usable area of treated leathers by 10% and tensile strength by 4.8% compared to the control leather samples. In a study conducted by Bahadirov et al., a roller machine for squeezing wet fibrous materials was developed, which ensures uniform removal of excess moisture in all topographic sections of the material with non-uniform thickness and surface [15]. In a study conducted by Amanov et al., the design of the pressure device between the working shafts for the processed materials with significant thicknesses was improved [16]. In a study conducted by Bahadirov and Nabiev, new types of base plates for a vertical roller machine were developed and the most rational options were recommended to improve the technological process of pressing wet sheet materials [17]. In a study conducted by Bahadirov et al., the process of simultaneous squeezing of moisture from five layers of semi-finished wet leather products under mechanical pressure of rotating squeezing rollers with a diameter of 300 mm was experimentally investigated [18]. At that, one layer of LASCH brand moisture-removing material was additionally placed between each layer of a semi-finished leather product, folded on the base plate. The package consisted of 10 layers. The experiment showed that with the simultaneous squeezing of moisture from five layers of semi-finished leather with moisture-removing materials, it was enough to provide the pressure of the squeezing rollers of 32 kN/m, and the feed rate of the semi-finished leather products of 0.25 m/s, which makes it possible to increase the productivity of the technological process five times or more. Hence, the experimental studies were conducted to increase the efficiency of the squeezing process of the semi-finished wet leather products. In this study, the process of simultaneous squeezing of moisture out of five layers of semi-finished wet leather products under mechanical pressure of rotating squeezing rollers with a diameter of 300 mm was experimentally investigated. Two layers of LASCH brand moisture-removing material were placed between each layer of the semi-finished leather, folded on the base plate. The package consisted of 15 layers.

EXPERIMENTAL

Materials and Methods

In the leather industry, the analytical characteristics of a batch of raw materials and semi-finished leather products are usually determined. The selection of samples and the processing of the results are carried out by the method of the average sample. A batch can consist of several hundred semi-finished leather products, and only a few of them are selected for analysis. To determine the physical and mechanical parameters of semi-finished leather products, 3 pieces are selected from a batch of 100 semi-finished leather products, 5 pieces are selected from a batch of 100 – 625 leather products, and 10 pieces are selected from a batch of 625 and more, and then the number of leather samples selected is determined.

For comparability of the research results of various factors or technological parameters, it is necessary to exclude the influence of the topography of the semi-finished leather product. In this case, the asymmetric fringe method is used to take the average sample. The required number of research options is marked and the number of samples (strips) included in the group intended for each option is specified (usually at least 5). The larger the number of samples, the more reliable the average value characterizing the option. The sample size is predetermined by a set of physical-mechanical or physical tests to be conducted, and all samples must fit into a rectangle inscribed in the butt morphological section. Therefore, we need to select five groups of five samples each, 5×5=25. In the middle part of the unhaired hide, excluding the backbone and peripheral areas, two rectangles are outlined and divided into 30 strips (15 on each side). The strips are numbered on the left side from bottom to top, and on the right side from top to bottom (that is why the method is called asymmetric).

The first group contains any of the first five strips; all subsequent ones are taken after another 5 strips. The method of the asymmetric fringe, depending on the number of options studied and the desired degree of reliability, can be slightly modified in relation to several semi-finished leather products [19]. Thus, in each of the 9 experiments, 5 semi-finished leather products were selected and made up a package of 5 layers of semi-finished leather products and 2 layers of LASCH monshons between each leather layer (see Figure 1). In total, we made 45 packages of semi-finished leather products for the experiment. The experiment was conducted on a roller squeezing bench under laboratory conditions (Figure 2).

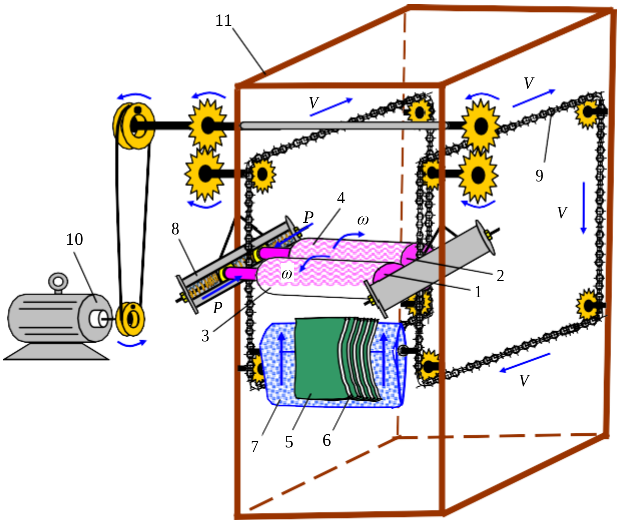


Figure 1. Diagram of an experimental bench for multilayer pressing of semi-finished wet leather products in a package with moisture-removing materials (1, 2 - squeezing rollers, 3, 4 - BM moisture-removing materials, 5 - semi-finished leather products, 6 - LASCH moisture-removing materials, 7 - base plate, 8 - pressure mechanism, 9 - conveyor chain, 10 - electric motor, 11 – frame)

The directions of motion of the parts of the scheme are indicated in Figure 1, where *V* is the linear velocity of the conveyor chain, *P* is the linear pressure of squeezing rollers pressing, and ω is the angular velocity of the squeezing rollers. The study took into account two factors: x_1 – the pressure of the rollers *P*, kN/m; x_2 – the sample feed rate *V*, m/s. In total, we made 45 packages of semi-finished leather products for the experiment. The experiment was conducted on a roller squeezing bench under laboratory conditions (Figure 2).

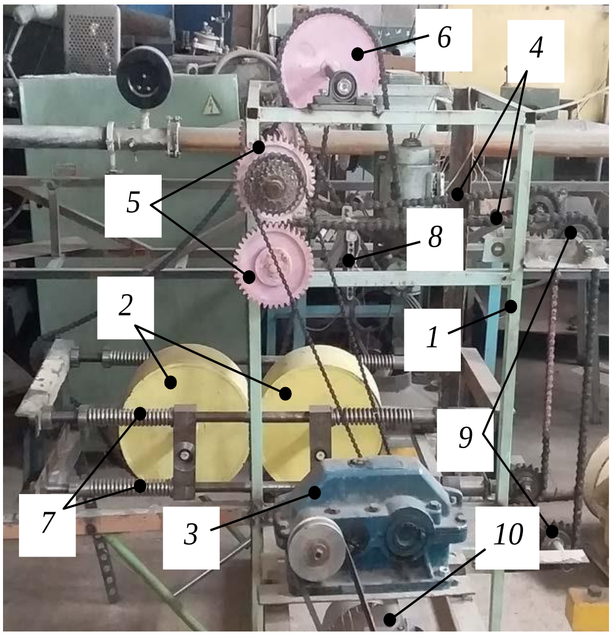


Figure 2. General view of an experimental roller bench for mechanical dewatering of semi-finished wet leather products (1 - bed frame, 2 - working rollers, 3 - gearbox, 4 - conveyor chains, 5 - gear wheels, 6 - drive sprocket, 7 - springs, 8 - base plate, 9 - sprockets, 10 - electric motor)

The pressure and the rotation speed of the squeezing rollers were taken from the parameters of well-known roller squeezing machines of various designs, for example VOPM-1800-K (Russia), Svit (Czech Republic) and others. The diameter of the squeezing rollers was chosen so that they are suitable for squeezing a multilayer package of semi-finished leather products, depending on the conditions for their capture. Figure 3 shows a fragment of the vertical feed of a package of five layers of a semi-finished leather product with moisture-removing materials on a base plate between rotating squeezing rollers.

Figure 3. The process of implementing a five-layer squeezing of semi-finished wet leather products

Moisture-removing materials of the BM brand felt are pre-wound on the squeezing rollers. For the experiment, a planning matrix was made using the Kano method (Table 1).

$$S_{er}^{2} = \frac{\sum_{1}^{n}(y-\bar{y})^{2}}{n-1} \quad (1)$$

$$\sum_{1}^{N} S_i^2 = \frac{\sum_{1}^{N}\sum_{1}^{n}(y-\bar{y})^{2}}{N(n-1)} \quad (2)$$

$$G_{cal} = \frac{S^{2}_{\max}}{\sum^{N} S_i^2} \quad (3)$$

Then, the mean variance estimate S_{er}^{2}, the sum of all variance estimates $\sum_{1}^{N} S_i^2$, the calculated Cochran test G_{cal}, and the greatest of the variance estimates $S^2_{\max}$ were calculated.

To ensure the reproducibility of the experiment, the value of the Cochran's test G_{cal} must not exceed the tabular value of G_T=0.38. It should be noted that in this case, the repetition of this experiment is reproducible. From the calculations, we get the following values:

$$G_{cal1} = \frac{11.96}{46.11} = 0.2593; \quad G_{cal2} = \frac{17.8675}{74.945} = 0.2384; \quad G_{cal3} = \frac{10.16}{50.925} = 0.1995;$$

$$G_{cal4} = \frac{7.645}{42.965} = 0.1779; \quad G_{cal5} = \frac{12.475}{61.64} = 0.2023$$

$G_{cal1}=0.2593<G_T=0.358$; $G_{cal2}=0.2384<G_T=0.358$; $G_{cal3}=0.1995<G_T=0.358$;
$G_{cal4}=0.1779<G_T=0.358$; $G_{cal5}=0.2023<G_T=0.358$; $G_{cal5}=0.2023<G_T=0.358$

Table 1. Experiment planning matrix

No	P, x_1	V, x_2	No. of leather sample	Measurement results in %						$\sum_1 (y-\bar{y})^2$	S^2_{er}	y_{cal}	$\bar{y}-y_{cal}$	$(\bar{y}-y_{cal})^2$
				y_1	y_2	y_3	y_4	y_5	$\bar{y}$					
1	0	0	1	20.6	21.2	20.2	24.2	21.8	21.6	10.12	2.530	21.79	0.79	0.6241
			2	22.2	19.1	17.9	22.1	21.2	20.5	13.90	3.475	20.32	0.1797	0.0322
			3	22.5	23.2	19.8	18.0	20.2	20.7	17.84	4.46	20.73	0.03	0.0009
			4	19.4	24.1	22.2	16.2	18.8	20.1	34.60	8.65	20.31	0.2114	0.01055
			5	20.8	19.1	22.3	22.3	20.5	21.0	9.28	2.32	21.22	0.22	0.0484
2	+	+	1	23.9	25.2	23.8	19.6	20.5	22.6	18.30	4.575	22.51	0.09	0.0081
			2	21.9	21.8	25.3	23.8	22.8	23.2	10.93	2.7325	22.58	0.6195	0.3837
			3	25.0	25.2	21.5	19.3	20.0	22.2	38.94	9.735	22.78	0.58	0.3364
			4	20.6	22.9	17.5	20.6	25.8	21.5	30.58	7.645	21.78	0.4243	0.1800
			5	23.2	25.0	19.5	16.9	17.2	20.4	49.90	12.475	21.24	0.84	0.7056
3	–	+	1	18.2	17.4	15.0	17.9	15.5	16.8	8.46	2.115	16.92	0.18	0.0324
			2	14.0	18.6	19.6	13.0	16.3	16.3	33.36	8.09	16.81	0.5125	0.2626
			3	18.3	15.5	14.3	14.7	16.2	15.8	9.96	2.49	14.65	1.15	1.3225
			4	14.4	14.3	19.1	17.8	12.9	15.7	27.46	6.865	15.15	0.5517	0.3043
			5	15.8	13.9	14.1	17.9	16.0	15.5	10.62	2.655	15.07	0.42	0.1764

№	P, x_1	V, x_2	No. of leather sample	Measurement results in %						$\sum_1^n (y-\bar{y})^2$	S^2_{er}	y_{cal}	$\bar{y}-y_{cal}$	$(\bar{y}-y_{cal})^2$
				y_1	y_2	y_3	y_4	y_5	$\bar{y}$					
			1	21.5	20.1	19.9	22.4	18.6	20.5	8.74	2.185	19.83	0.67	0.4489
			2	23.0	21.2	18.2	22.6	16.0	20.2	33.04	8.26	20.74	0.5447	0.2966
4	–	–	3	20.8	18.4	18.0	20.3	18.5	19.2	5.74	1.435	17.91	1.29	1.6641
			4	17.3	18.6	20.3	19.0	16.8	18.4	7.18	1.795	17.98	0.4225	0.1785
			5	18.1	15.2	20.4	15.0	22.3	18.2	40.9	10225	17.41	0.79	0.6241
			1	25.4	27.0	27.0	26.4	25.9	26.3	1.96	0.49	25.53	0.77	0.5929
			2	30.5	23.0	24.5	20.7	30.6	25.8	71.47	17.868	25.21	0.5873	0.3449
5	+	–	3	28.8	24.9	23.0	23.4	26.1	25.2	21.94	5.485	26.20	1.00	1.00
			4	23.9	26.5	25.7	24.1	27.8	25.6	10.80	2.70	25.02	0.5751	0.3307
			5	30.2	23.5	22.8	23.4	28.0	25.6	44.46	11.115	2483.	0.76	0.5776
			1	22.4	24.2	27.3	20.3	24.8	23.8	27.62	6.905	23.88	0.08	0.0064
			2	25.9	20.4	24.2	20.1	27.0	23.5	39.67	9.918	23.31	0.1874	0.0351
6	+	0	3	26.2	24.8	20.5	24.6	21.2	23.5	24.48	6.12	24.5	1.00	1.00
			4	22.0	25.0	23.3	19.9	21.8	23.4	8.74	2.185	23.00	0.3974	0.1579
			5	25.0	24.3	24.1	22.8	20.6	23.4	12.06	3.015	23.15	0.25	0.0625
			1	16.5	24.3	22.5	16.8	20.9	20.2	47.84	11.96	22.34	0.14	0.0196
			2	21.4	17.6	21.6	21.1	13.6	19.1	48.04	12.01	19.26	0.1632	0.0266
7	0	+	3	17.0	18.6	17.4	24.6	17.4	19.0	40.64	10.16	19.09	0.090	0.0081
			4	21.3	17.1	18.9	19.6	18.5	19.1	9.49	2.373	19.20	0.1043	0.0108
			5	20.9	18.4	22.8	20.7	17.2	20.0	20.11	5.028	19.94	0.06	0.0036
			1	20.4	22.8	15.0	17.5	16.8	18.5	38.44	9.61	18.19	0.31	0.0961
			2	15.4	17.6	18.9	20.0	21.5	17.8	25.54	6.385	18.19	0.3946	0.1557
8	–	0	3	18.2	14.4	16.0	20.1	18.7	17.4	20.58	5.145	16.66	0.74	0.5476
			4	21.0	18.5	14.7	16.8	15.0	17.2	27.38	6.845	16.16	1.0448	1.0916
			5	19.3	21.3	13.9	16.1	14.2	17.0	34.20	8.55	16.98	0.02	0.0004
			1	25.5	22.7	23.5	18.9	22.9	22.7	22.96	5.74	23.44	0.86	0.7396
			2	24.3	19.6	23.5	25.2	20.3	22.5	24.78	6.195	22.55	0.0454	0.0020
9	0	–	3	22.5	21.7	26.6	20.7	20.8	22.5	23.58	5.895	22.36	0.14	0.0196
			4	23.1	20.9	24.1	25.8	19.1	22.6	15.63	3.908	22.23	0.3664	0.1342
			5	19.9	20.5	26.2	22.8	23.2	22.5	25.03	6.258	22.28	0.22	0.0484
										Σ 184.44	Σ 46.11			Σ 2.2245
										Σ 299.78	Σ 74.95			Σ 1.5394
										Σ 203.70	Σ 50.93			Σ 5.8994
										Σ 171.86	Σ 42.97			Σ 2.3982
										Σ 246.56	Σ 61.64			Σ 2.2460

The results of the experiment correspond to the conditions of reproducibility. Thus, we determine the regression coefficients in coded form for each layer of the semi-finished leather product in the appropriate order:

1) $b_0 = 22.3674$; $b_{11} = -1.0821$; $b_1 = 2.8460$; $b_{22} = 0.2179$; $b_2 = -1.5050$; $b_{12} = -0.0025$
2) $b_0 = 20.3203$; $b_{11} = 0.4333$; $b_1 = 2.5590$; $b_{22} = 0.5840$; $b_2 = -1.6411$; $b_{12} = 0.325$
3) $b_0 = 21.3089$; $b_{11} = -0.6282$; $b_1 = 4.0691$; $b_{22} = -0.3286$; $b_2 = -1.6323$; $b_{12} = -0.0750$
4) $b_0 = 20.3114$; $b_{11} = -1.3270$; $b_1 = -3.4137$; $b_{22} = 0.4076$; $b_2 = -1.1546$; $b_{12} = -0.1$
5) $b_0 = 21.6260$; $b_{11} = -1.3694$; $b_1 = 3.1127$; $b_{22} = -0.3349$; $b_2 = -1.7990$; $b_{12} = -0.625$

Table 2. Determination of regression coefficients in the experiment

#	P, x_1	V, x_2	Coefficients factors b_0	b_{11}	b_{22}	b_1	b_2	b_{12}	Leather sample	$\bar{y}$
1	0	0	0.5772	–0.3234	–0.3234	0	0	0	1	21.6
									2	20.5
									3	20.7
									4	20.1
									5	21.0
2	+	+	–0.1057	0.1691	0.1691	0.1961	0.1961	0.25	1	22.6
									2	23.2
									3	22.2
									4	21.5
									5	20.4
3	–	+	–0.1057	0.1691	0.1691	–0.1961	0.1961	–0.25	1	16.8
									2	16.3
									3	15.8
									4	15.7
									5	15.5
4	–	–	–0.1057	0.1691	0.1691	–0.1961	–0.1961	0.25	1	20.5
									2	20.2
									3	19.2
									4	18.4
									5	18.2
5	+	–	–0.1057	0.1691	0.1691	0.1961	–0.1961	–0.25	1	26.3
									2	25.8
									3	25.2
									4	25.6
									5	25.6
6	+	0	0.2114	0.1617	–0.3383	0.1078	0	0	1	23.8
									2	23.5
									3	23.5
									4	23.4
									5	23.4
7	0	+	0.2114	–0.3383	0.1617	0	0.1078	0	1	20.2
									2	19.1
									3	19.0
									4	19.1
									5	20.0
8	–	0	0.2114	0.1617	–0.3383	–0.1078	0	0	1	18.5
									2	17.8
									3	17.4
									4	17.2
									5	17.0
9	0	–	0.2114	–0.3383	0.1617	0	–0.1078	0	1	22.7
									2	22.5
									3	22.5
									4	22.6
									5	22.5

$\bar{y}$ – the arithmetic mean of the result of repetition in each experiment

The regression equations in a coded form for each layer of the semi-finished leather product are written in the following order:

$$y_1 = 21.7902 - 0.7587x_1^2 + 0.1419x_2^2 + 2.846x_1 - 1.505x_2 - 0.0025x_1x_2 \quad (4)$$

$$y_2 = 20.3203 + 0.4333x_1^2 + 0.5840x_2^2 + 2.5590x_1 - 1.6411x_2 + 0.325x_1x_2 \quad (5)$$

$$y_3 = 20.7313 - 0.3048x_1^2 - 0.0048x_2^2 + 4.0691x_1 - 1.6323x_2 - 0.075x_1x_2 \quad (6)$$

$$y_4 = 20.3114 - 0.7424x_1^2 + 0.4076x_2^2 + 3.4137x_1 - 1.5146x_2 - 0.1x_1x_2 \quad (7)$$

$$y_5 = 21.2220 - 1.1593x_1^2 - 0.1093x_2^2 + 3.0823x_1 - 1.1718x_2 - 0.625x_1x_2 \quad (8)$$

According to Fisher's criterion, the error of the experiment was 0.05 [20-22]. Therefore, using Tables 1 and 2, we calculated the variance of the adequacy S^2_{ad} and the variance of the reproducibility of the research results obtained $S_i^2\{y\}$ for each layer of the semi-finished leather product and we obtained the following:

$S^2_{ad1} = 3.7075$; $S_1^2\{y\} = 5.1233$; $F_{cal1}=0.7236<F_T=2.87$

$S^2_{ad2} = 2.5656$; $S_2^2\{y\} = 8.3272$; $F_{cal2}=0.3080<F_T=2.87$

$S^2_{ad3} = 9.8323$; $S_3^2\{y\} = 5.6583$; $F_{cal3}=1.7376<F_T=2.87$

$S^2_{ad4} = 3.9970$; $S_4^2\{y\} = 4.7738$; $F_{cal4}=0.8372<F_T=2.87$

$S^2_{ad5} = 3.7433$; $S_5^2\{y\} = 6.8488$; $F_{cal5}=0.5465<F_T=2.87$

The results of the calculation by Fisher's criterion based on the results of the experiment show that for all five layers of semi-finished leather products, the calculated value according to the experiment is less than the tabular value. This shows that the regression equations [4–8] adequately describe the experimental data with a confidence level of 95 percent.

RESULTS AND DISCUSSION

The natural values of the pressing force of the squeezing rollers x_1 and the sample feed rate x_2 were substituted into the regression equations [4–8]. The regression equations [4–8] were, after their decoding, written for each layer of the semi-finished leather product in the following order in the named form:

$$\Delta W_1 = 18.8701 - 0.0007P^2 + 19.6400V^2 + 0.1787P - 7.6318V - 0.0009PV \quad (9)$$

$$\Delta W_2 = 29.0553 + 0.0004P^2 + 80.8294V^2 - 0.0015P - 68.1329V + 0.1188PV \quad (10)$$

$$\Delta W_3 = 16.6600 - 0.0002P^2 - 0.6635V^2 + 0.1597P - 17.1052V - 0.0275PV \quad (11)$$

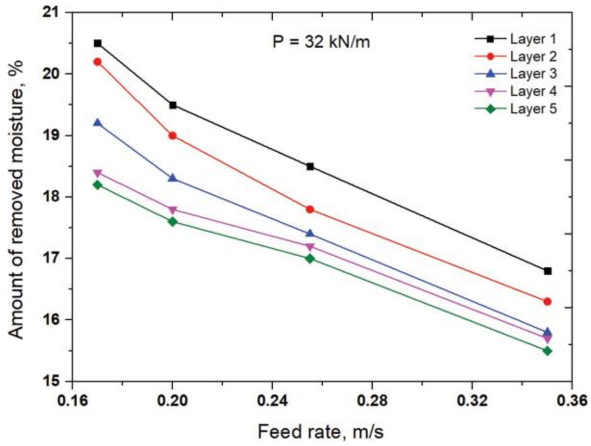
$$\Delta W_4 = 18.1326 - 0.0007P^2 + 56.4141V^2 + 0.2054P - 44.2003V - 0.0369PV \quad (12)$$

$$\Delta W_5 = 9.1732 - 0.0011P^2 - 15.1270V^2 + 0.2956P + 8.6655V - 0.2297PV \quad (13)$$

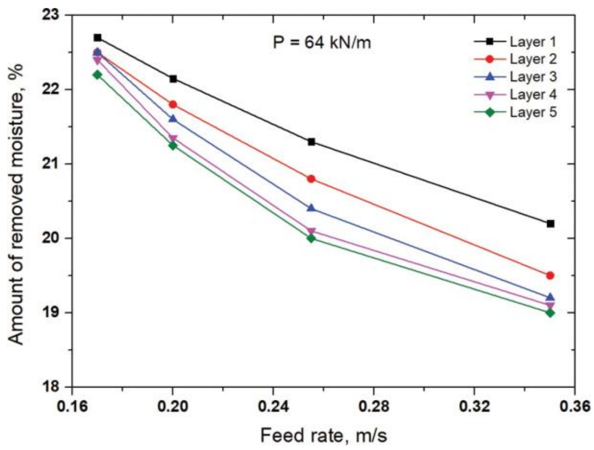
Then, we plotted the dependence of the amount of removed moisture on the feed rate of samples of each layer of semi-finished leather products and the pressure of the squeezing rollers (Figure 4).

The results of the experimental studies showed an increase in the productivity of the process of simultaneous pressing of five layers of semi-finished wet leather products with two layers of moisture-removing material between them in comparison with the squeezing of five layers of semi-finished leather products using one layer of moisture-removing material between them, which we have described in our other study [18].

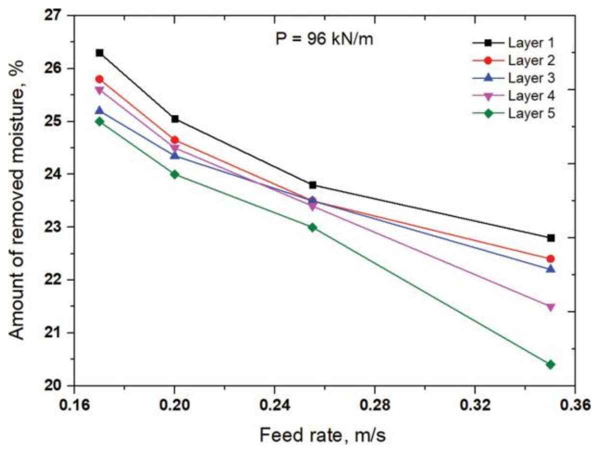
The increase in the amount of removed moisture under squeezing using two layers of moisture-removing material of the LASCH brand, in comparison with the use of one layer of LASCH between five layers of semi-finished leather products, averaged at *P*=32 kN/m – 5.95%; at *P*=64 kN/m – 4.4% and at *P*=96 kN/m – 3.6%. The regression equations obtained for the first layer (9), the second layer (10), the third layer (11), the fourth layer (12) and the fifth layer (13) of semi-finished leather products fully describe the dependence of the amount of moisture removed from each semi-finished leather product on their feed rate and the pressing force between the rotating squeezing rollers.



(a)



(b)



(c)

Figure 4. Dependence of the amount of removed moisture (ΔW) on the feed rate (V) of each of the five layers of leather semi-finished products under the pressure of the squeezing rollers: (a) P = 32 kN/m, (b) P = 64 kN/m, (c) P = 96 kN/m (1 – first layer; 2 – second layer; 3 – third layer; 4 – fourth layer; 5 – fifth layer of semi-finished leather products)

Technological parameters, for example the feed rate of semi-finished leather products, or the pressing force of the squeezing rollers, can be used when choosing rational operating modes of the roller squeezing machine. In the near future, the plan is to use this method of multilayer processing during the experimental squeezing of ten layers of semi-finished wet leather products. Mathematical expressions of the amount of moisture removed from semi-finished leather products were obtained depending on the pressing pressure of the squeezing rollers and the feed rate for each of the five layers of the semi-finished leather product in coded form (9–13) during simultaneous extracting excess moisture on a roller bench. The graphs of the dependence of the amount of removed moisture from semi-finished wet leather products on the pressure of rollers and the feed rate were obtained (Figures 4, (a), (b), (c). According to the results of the experiment and the method of their mathematical processing, mathematical dependences in the named form (9–13) of moisture removal from semi-finished wet leather products were obtained for each layer and the average of five layers, depending on the pressing force of the squeezing rollers and the feed rate. Analysis of the graphs of the dependence of the amount of moisture removed from a multilayer package of samples of semi-finished wet leather products on a squeezing roller pair shows that the intersecting lines of the graphs of different layers at P=64 kN/m (b), P=96 kN/m (c) in Figure 4, are a consequence of non-uniform parameters in thickness and density within the same and different topographic sections (butt, belly) of semi-finished leather products used in the experiment.

CONCLUSIONS

The experiments were carried out using fibrous moisture-removing materials, a rigid base plate, and squeezing rollers pre-coated with moisture-removing materials. The multi-layer package consisted of five layers of semi-finished wet leather products and two layers of moisture-removing materials between each layer, folded over the base plate. The results showed that with a five-layer pressing of semi-finished wet leather products, the efficiency of moisture removal increases in comparison with single-layer processing. It was noted in our other study [18] that for the bovine skin of medium weight, after it has undergone chrome tanning, the maximum moisture content in the topographic sections of the belly leather reaches up to 73%, and in the butt leather up to 65%. The residual moisture content of the semi-finished leather product after its pressing should be within 55–60%, which may vary depending on its further use.

When squeezing out semi-finished wet leather products, the removal of excess moisture of at least 15.5% and a maximum of 26.3%, against the required 13%, is ensured, which indicates that the goal set by the authors was achieved. Thus, we recommend squeezing out the excess moisture simultaneously from five layers of semi-finished wet leather products using two layers of the LASCH materials between each of them, while ensuring the following technological process parameters: roller pressure from 64 to 96 kN/m at a feed rate of more than 0.34 m/s. Analysis of the results of the experiment shows that, with a five-layer squeezing, the maximum productivity of the technological process is 550% higher. In general, the technological process of multilayer squeezing of moisture from semi-finished wet leather products is more efficient in comparison with existing pressing technologies. The obtained results of the experimental study can be used by designers and technologists in the development and design of a squeezing roller machine for multilayer mechanical processing of semi-finished wet leather products.

Author Contributions

Conceptualization – A.A., G.B., G.T. and A.N.; methodology – A.N. and A.A.; formal analysis – A.N. and G.T.; investigation – A.N.; resources – A.N.; writing-original draft preparation – A.A., G.B.,G.T. and A.N.; writing-

review and editing – A.A. and A.N.; visualization – G.B.; supervision – G.B. and A.A.; All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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