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K. K. Turgunov ✉; E. S. Buriev; N. U. Annaev

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Residual Moisture Content in Leather

K. K. Turgunov[a)], E. S. Buriev and N. U. Annaev

Tashkent Institute of Architecture and Civil Engineering, Navoi Street, 13, Tashkent, 100011, Uzbekistan

[a)]Corresponding author: shavkat-xurramov59@mail.ru

Abstract. The article deals with the issues of roller pressing of the skin. The analytical expression of residual moisture is determined depending on the parameters of the squeezing machine. It was found that at the beginning of the pressing process, moisture is removed faster, after which the rate of its growth decreases significantly, and at the end of the process they stabilize. It is established that the value of humidity depends on the position of the point, moisture changes direction.

INTRODUCTION

In the theory of roller squeezing of materials, such problems as contact and hydraulic ones are solved.

Works [1-9] are devoted to the study of contact problems. One of the main hydraulic tasks is to determine the expression of residual moisture.

In the theory of roll squeezing of materials, studies to determine the expression of residual moisture are carried out in three directions. The first is experimental, based on experimental data, using the methods of mathematical statistics and experiment planning, obtained in the form of empirical or regression dependencies [10-12].

The second is experimental-theoretical, which is built by theoretical research on the basis of experimentally obtained empirical dependences [12,13].

The third one is theoretical, it is built by theoretical studies, based on the study of hydraulic phenomena occurring in the process of roller squeezing [13-15].

An analysis of the literature sources showed that the models of residual moisture obtained by experimental methods are used mainly for their intended purpose. The degree of further application of the residual moisture content formula obtained by the experimental-theoretical method depends on the empirical dependencies used. A correct model of residual moisture content obtained by theoretical methods is not currently available.

ANALYTICAL SOLUTION TO THE PROBLEM POSED

A pair of working rolls (roll pair) and a layer of semi-finished leather after tanning (leather layer) together will create a roll pair of squeezing leather machines.

The analysis of leather roller squeezing machines [16] showed that roller pairs of squeezing leather machines basically have a symmetrical appearance.

We consider the roller pair of squeezing leather machines shown in Fig. 1.

Since the two-roll module considered is symmetrical, we will investigate the contact interaction of leather with any roller, for example, with the lower one.

The lower roll contact arc (arc A1A2) consists of two sections A_1A_3 and A_3A_2. In the area A_1A_3, the skin and the roll cover are compressed, and A_3A_2- the deformation is restored.

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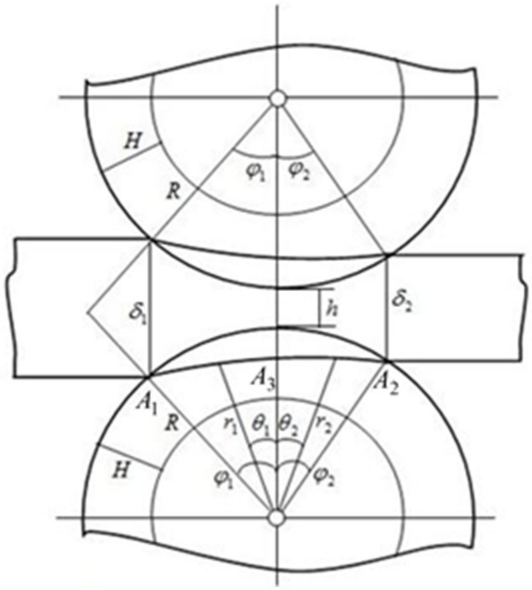

FIGURE 1. Scheme of a two-roll module.

First, consider the process of moisture filtration in the area A_1A_3.

The radius of the contact arc in the compression section and its derivative for the considered roll pair have the form [6]:

$$r_1 = \frac{R}{1+k_1\lambda_1}\left(1 + k_1\lambda_1 \frac{\cos\phi_1}{\cos\theta_1}\right), \quad r_1^{'} = \frac{k_1\lambda_1 R}{1+k_1\lambda_1}\cos\phi_1 \frac{\sin\theta_1}{\cos^2\theta_1}, \quad -\phi_1 \le \theta_1 \le 0, \tag{1}$$

where $k_1 = \frac{n_1}{m_1}, \lambda_1 = (B_1A_1^{-1})^{\frac{1}{m_1}}$, here A_1, n_1- are the strain and strain-hardening coefficients of the roller coating under compression, B_1, m_1-are the strain and strain-hardening coefficients of leather under compression.

In are A_1A_3, the leather is compressed, so the fluid squeezed from the leather flows into the roller coating at a polar angle [14, 16].

The skin speed in the wring area and is equal to v_m. The moisture velocity in the compression section is [14,18]:

$$u_{1\theta} = -b_1(\theta_1^3 + \phi_1^3), \quad -\phi_1 \le \theta_1 \le 0. \tag{2}$$

where $b_1 = \frac{2v_m R\cos^2\phi_1}{3\delta_1(1+k_1\lambda_1)(1+k_1\lambda_1\cos\phi_1)}$

As is known [17], the amount of removed fluid flowing along the roll contact curve can be determined by the following expression

$$dG = B\rho u_\theta dh, \tag{3}$$

where B -is the width of the skin; ρ -moisture density; u_θ-is the filtration rate in the θ direction.

The deformation of the skin in the area of compression is determined by the expression

$$h_1 = R\cos\phi_1 - r_1\cos\theta_1$$

Hence, taking into account expressions (1), we have

$$h_1^{'} = \frac{R}{1+k_1\lambda_1}\sin\theta_1 \approx \frac{R}{1+k_1\lambda_1}\theta_1. \tag{4}$$

According to formulas (2), (3) and (4), we find

$$dG_1 = -\frac{\rho BRb_1}{1+k_1\lambda_1}(\phi_1^3 + \theta_1^3)\theta_1 d\theta_1. \tag{5}$$

Integrating (5) and using boundary condition $G_1(-\phi_1) = 0$, we obtain

$$G_1 = \alpha_1(3(\phi_1^5 - 2\theta_1^5 - 5\phi_1^3\theta_1^2), \quad -\phi_1 \le \theta_1 \le 0, \tag{6}$$

where $\alpha_1 = \frac{\rho v_m BR^2 \cos^2\phi_1}{15\delta_1(1+k_1\lambda_1)^2(1+k_1\lambda_1\cos\phi_1)}$, and v_m -is the feed rate of the material.

The amount of removed moisture that has flowed through the surfaces of the compression zone is determined by its outflow at the point of the center line, that is, by moisture content$G_1(0)$:

$$G_1(0) = 3\alpha_1\phi_1^5. \tag{7}$$

In the area A_3A_2, the skin, restoring the deformation, can absorb moisture from the roll cover. In this case, moisture, to the left of a certain point A_4 areaA_3A_2, moves from the skin to the swath cover, to the right - into the leather. Depending on the design of the squeezing machine roll and its coating, the point ... can coincide with any point A_4 of the deformation recovery zone [14].

Let the point be determined by the angle $\phi_4 = \varsigma\phi_2, \quad 0 < \varsigma \le 1$. The point A_4 divides the section A_3A_4, into two sections: the first section A_3A_4, where $0 \le \theta_2 \le \phi_4$ and the second section A_4A_2, where $\phi_4 \le \theta_2 \le \phi_2$.

In the area $A_3A_4$the filtration rate $u_{12\theta}$ is described by the formula [14]:

$$u_{12\theta} = -b_2(\phi_4^3 - \theta_2^3),\ 0 \le \theta_2 \le \phi_4 \tag{8}$$

The strain of the wet material is described by the following expression

$$h_2 = r_2\cos\theta_2 - r_2(0). \tag{9}$$

Considering expressions (8) and (9), and using condition $G_2(0) = G_1(0) = 3\alpha_1\phi_1^5$, we obtain

$$G_2 = 3\alpha_1\phi_1^5 + \alpha_2(5\phi_2^3\theta_2^2 - 2\theta_2^5), \tag{10}$$

where $0 \le \theta_2 \le \varphi_4$ $\alpha_2 = \frac{\rho v_m BR^2 \cos^2\phi_2}{15\delta_2(1+k_2\lambda_2)^2(1+k_2\lambda_2\cos\phi_2)}$.

The amount of fluid removed that has flowed through the contact surfaces of the compression zone and the first section of the strain recovery zone of the lower roller is determined by the moisture content $G_2(\phi_4)$:

$$G_2(\phi_4) = 3\alpha_{11}\phi_1^5 + 3\alpha_2\phi_4^5. \tag{11}$$

Taking into account the relationships

$$u_{12\theta} = -b_2(\phi_4^3 - \theta_2^3), \quad h_2 = r_2\cos\theta_2 - r_2(\phi_4), \tag{12}$$

obtained in [14] for section A_4A_2 of the strain recovery zone and condition $G_2(0) = 3\alpha_{11}\phi_1^5$, we find

$$G_2 = 3\alpha_1\phi_1^5 + \alpha_2(5\phi_4^3\theta_2^2 - 2\theta_2^5), \quad \phi_4 \le \theta_2 \le \phi_2, \tag{13}$$

where $\alpha_2 = \frac{\rho v_m BR^2 \cos^2\phi_2}{15\delta_2(1+k_2\lambda_2)^2(1+k_2\lambda_2\cos\phi_2)}$.

Generalizing formulas (10) and (13), we obtain

$$G_2 = 3\alpha_1\phi_1^5 + \alpha_2(5\phi_4^3\theta_2^2 - 2\theta_2^5), \tag{14}$$

where $0 \le \theta_2 \le \phi_2,\ \phi_4 = \varsigma\phi_2, \quad 0 < \varsigma \le 1$.

The amount of fluid removed from the leather through the contact surfaces of the lower roller is determined by its outflow at point A_2, i.e. by moisture content $G_{12}(\phi_{12})$:

$$G_2(\phi_2) = 3\alpha_1\phi_1^5 + \alpha_2(5\phi_4^3\phi_2^2 - 2\phi_2^5). \tag{15}$$

The amount of moisture removed from the leather during the squeezing process equals to the sum of the amount of moisture removed through the contact surfaces of the lower and upper rollers.

Knowing that the two-roll module of the leather roll squeezing is symmetrical, we obtain

$$G_{y\partial} = 2(3\alpha_1\phi_1^5 + \alpha_2(5\phi_4^3\phi_2^2 - 2\phi_2^5)). \tag{16}$$

Knowing the amount of fluid removed, the moisture removed from the fibrous material during squeezing is determined by the following expression [17]:

$$W_{уд} = \frac{G_{уд}}{\rho B v_m} 100\%. \quad (17)$$

The following equation holds during roller squeezing

$$W_{ост} = W_{нач} - W_{уд}, \quad (18)$$

where $W_{ост}$, $W_{нач}$ - are the residual and initial moisture content of the fibrous material [20].

Taking into account expressions (17) and (18), we write

$$W_{ост} = W_{нач} - \frac{2}{\rho B v_ь}(3\alpha_1 \phi_1^5 + \alpha_2(5\phi_4^3\phi_2^2 - 2\phi_2^5). \quad (19)$$

This formula determines the residual moisture content of the roller squeezing of leather. The effect of two-roll module parameters on the residual moisture of leather is determined by the contact angles, ϕ_1 and ϕ_2. Then, the contact angles are expressed by two-roll module parameters.

From Fig. 1 it follows that

$$2R \cos\phi_1 + \delta_1 = 2R + h. \quad (20)$$

Hence, we find

$$\phi_1 = \arccos\frac{2R + h - \delta_1}{2R}. \quad (21)$$

As seen from Fig. 1, boundary condition$r_1(0) = r_2(0)$ holds at point A_3:

Then, from equation (1), it follows

$$\frac{R}{1 + k_1\lambda_1}(1 + k_1\lambda_1 \cos\phi_1) = \frac{R}{1 + k_2\lambda_2}(1 + k_2\lambda_2 \cos\phi_2).$$

After a series of transformations, we obtain

$$\boldsymbol{\cos\phi_2 = \frac{k_2\lambda_2 + k_1\lambda_1(1 + k_2\lambda_2)\cos\phi_1}{k_2\lambda_2(1 + k_1\lambda_1)}}.$$

Hence, with expression (20), we have

$$\phi_2 = \arccos\frac{2Rk_2\lambda_2 + k_1\lambda_1(1 + k_2\lambda_2)(H - \delta_1)}{2Rk_2\lambda_2(1 + k_1\lambda_1)}. \quad (22)$$

Thus, an analytical dependence of the residual moisture content of leather on the parameters of the two-roll squeezing of leather was obtained.

CONCLUSION

The analytical expression of the residual moisture content of the leather during roll pressing has been determined. It was revealed that the value of residual moisture of the leather depends on the parameter $\zeta = \sqrt[3]{0{,}4} = 0{,}74$:

- for $0 < \zeta < 0{,}74$, it will be greater than the moisture at the end of the compression area, which is explained by the reverse movement of moisture from the coating to the leather;
- for$0{,}74 \leq \zeta < 1$, it will be less than moisture at the end of the compression section, which is associated with the removal of moisture in the deformation recovery area;
- for $\zeta = 1$, the residual moisture content of the leather is the lowest and equals:

$$W_о = W_н - \frac{1}{\rho B v_m}(3\alpha_1\phi_1^5 + 3\alpha_2\phi_2^2)100\%.$$

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