Efficiency analysis of roller squeezing of leather

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Abstract. The study is devoted to the theoretical modeling of the residual moisture in leather, taking into account the phenomenon of its contact interaction with working rolls. Analytical formulas were derived that describe the patterns of changes in moisture content during the process of roller squeezing of leather. A theoretical model of residual moisture in leather during roller squeezing was developed. It was determined that with increasing roll radius and initial thickness of leather, the residual moisture content increases. It was revealed that with an increase in the initial moisture content of leather, its residual moisture content increases and asymptotically approaches a certain value.

1 Introduction

Mechanical operations that involve roller machines are widespread in the leather industry. Among these operations, we can single out the roller squeezing of semi-finished leather products, which maintains the moisture content necessary for subsequent mechanical operations since the cost and quality of the finished product are related to its efficiency. The efficiency of roller squeezing is determined by the residual moisture content of the material being pressed.

The study of the phenomenon of spinning leather is directly related to environmental safety, since modeling the squeezing process is impossible without solving the problem of wastewater from the enterprise.

The residual moisture of the model is determined by three methods: experimental, experimental-theoretical, and theoretical ones. Experimental methods of determining residual moisture are used mainly for their intended purpose. The degree of further application of experimental and theoretical methods of determining residual moisture depends on the empirical dependencies used in it. Theoretical models of residual moisture are obtained by joint solution to two problems: contact interaction of leather with working rolls (contact problem) and filtration of water in leather and felt (elastic coating of rolls) (hydraulic problem).

References [1-20] are devoted to solving contact and hydraulic problems during roller squeezing of wet materials. An analysis of the literature sources showed that a correct theoretical model for determining residual moisture is currently missing. The existing individual models can be used in studies of partial cases of roll pressing [21-26].

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This article is devoted to the theoretical modeling of the residual moisture of leather, taking into account the phenomenon of its contact interaction with working rolls.

An analysis of the design of squeezing machines in the tanneries showed that the two-roll modules of these machines are mainly symmetrical in appearance [26].

We consider a symmetrical two-roll module, in which pairs of rolls with radii R have an elastic coating of technical cloth with a thickness of H, and a layer of leather has an initial thickness of δ_1 (Figure 1).

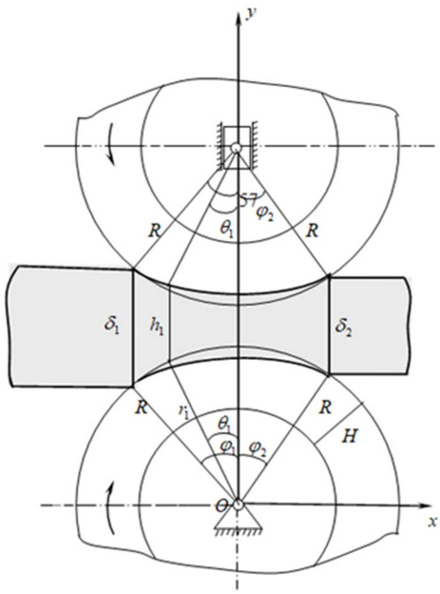

Fig. 1. Scheme of a two-roll module of a squeezing machine

In the considered two-roll module, the leather interacts with pairs of rolls along the roll contact curves. Each roll contact curve consists of compression and recovery zones. The points of the compression zone of each roll are determined by polar coordinates $(r_1;\theta_1)$, and the recovery zones - by $(r_2;\theta_2)$.

From Figure 1, it follows that $-\varphi_1 \le \theta_1 \le 0,\ \ 0 \le \theta_2 \le \varphi_2$, where $\varphi_1, \varphi_2 -$ are the contact angles.

2 Materials and metods

To model the residual moisture of leather during roller squeezing, we will consider leather and cloth as a two-phase medium, consisting of a solid part and water filling the pores between them.

The solid phase of leather consists of fibers and collagen bundles.

The water phase of leather consists of hydration moisture, which is related to skin, moisture of capillary condensation during absorption, and moisture of wetting, filling large pores of leather [26]. Because leather is kept in liquid for a long time during the tanning process, there is no third phase (air).

Technical cloth is also a two-phase system: solid phase - skeleton (wool and synthetic fibers) and water. The cloth up to the contact zone of the squeezing rolls is not always saturated with water and may contain some air in the pores. However, before entering the contact zone, it is saturated with moisture from a water wedge formed as a result of squeezing water in the pressing zone [27].

Compressibility of water and leather and cloth fibers is ignored in the calculation model.

When entering the contact zone of the rollers, the water-saturated skin begins to shrink. Since compression of a water-saturated layer can only occur as a result of squeezing out moisture, then over the entire length of the compression zone of the roll contact curve, water under the effect of hydraulic pressure forces is extruded out of the skin into an area of lower pressure. The water flow along the skin is hampered by the location of its capillaries (fibers and collagen bundles in the skin structure). Therefore, when hydraulic pressure occurs, water flows in the direction of the collagen fiber bundles up and down into the felt.

If the surfaces of the rolls are moisture-impermeable, then filtration in felt occurs only in the horizontal direction [28]. Moreover, water (removed from the squeezing zone along the cloth) is extracted both from the cloth itself and from the leather. Part of the water flows towards the cloth, and part - along the cloth motion.

From the compression zone of the roll contact curve, we select an elementary area of length dl_1 and height h_1 (Figure 1). If the width of the skin is denoted by L, then its elementary volume is:

$$dV_1 = Lh_1 dl_1 . \tag{1}$$

As indicated above, the skin, entering the contact zone of the rolls, is completely saturated with water and represents a two-phase system. Therefore, the elementary volume of the skin is expressed in the following form:

$$dV_1 = dV_{1m} + dV_{1s}$$

or, taking into account equation (2):

$$Lh_1 dl_1 = dV_{1m} + dV_{1s} ,$$

where $V_{1m} -$ is the elementary volume of wet skin occupied by water; $V_{1s} -$ is the elementary volume of wet skin occupied by the solid phase.

Having expressed elementary volumes dV_{1m}, dV_{1s} through the weights of water and solid phase in given volumes dG_m, dG_s, and through the specific weights of water and solid phase γ_m, γ_s, respectively, we write the formula for elementary volume in the following form:

$$Lh_1 dl_1 = \frac{dG_m}{\gamma_m} + \frac{dG_s}{\gamma_s} . \tag{2}$$

Skin moisture content in percent is:

$$W_1 = \frac{100 dG_m}{dG_m + dG_s} .$$

Transforming this expression, we obtain:

$$dG_m = \frac{W_1}{100 - W_1} dG_s . \tag{3}$$

Substituting expression dG_m from equation (4) into equation (3), solving the result with respect to h_1, and taking into account $W_1 = W_{in}$ for $h_1 = \delta_1$, after some transformations, we obtain:

$$h_1 = a_1 \delta_1 \frac{100\gamma_m + (\gamma_s - \gamma_m) W_1}{100 - W_1} , \tag{4}$$

where $a_1 = \dfrac{100\gamma_m + (\gamma_s - \gamma_m)W_{in}}{100 - W_{in}}$, $W_{in} -$ is the initial moisture content of the skin, that is, the moisture content of the skin before squeezing.

From equality (5) we find

$$W_1 = \frac{h_1 - \gamma_m a_1 \delta_1}{h_1 + (\gamma_s - \gamma_m) a_1 \delta_1} \cdot 100. \tag{5}$$

The law of changes in the skin thickness in the compression zone is written as (Figure 1):

$h_1 = \Delta - 2r_1 \cos\theta_1$

It follows that

$\delta_1 = \Delta - 2r_1(-\varphi_1)\cos\varphi_1$,

where $\Delta -$ is the centre distance of the rolls.

Then we have

$$h_1 = \delta_1 - 2(r_1 \cos\theta_1 - r_1(-\varphi_1)\cos\varphi_1). \tag{6}$$

According to [4, 29], the shape of the roll contact curve is described by the following equation:

$$r_1 = \frac{R}{1 + k_1\lambda_1}\left(1 + k_1\lambda_1 \frac{\cos\varphi_1}{\cos\theta_1)}\right), \tag{7}$$

where $k_1 = \dfrac{m_1 H}{m_1^* \delta_1}$, $m_1, m_1^* -$ are the coefficients of hardening of leather cloth points; $\lambda_1 -$ is the index that determines the ratio of the strain rate of cloth and the strain rate of leather.

Considering (8), equalities (7) are written as follows:

$h_1 = \delta_1 - \dfrac{2R}{1 + k_1\lambda_1}(\cos\theta_1 - \cos\varphi_1)$

or in the first approximation

$$h_1 = \delta_1 - \frac{R}{1 + k_1\lambda_1}(\theta_1^2 - \varphi_1^2). \tag{8}$$

Substituting expression h_1 from equality (9) into equation (6) and solving the resulting equation with regard to W_1, we obtain:

$$W_1 = \frac{b_1 - R\varphi_1^2 + R\theta_1^2}{\frac{100}{W_{in}} b_1 - R\varphi_1^2 + R\theta_1^2} 100, \qquad -\varphi_1 \le \theta_1 \le 0, \tag{9}$$

where $b_1 = \dfrac{(1 + k_1\lambda_1)\gamma_s \delta_1}{100\gamma_m + (\gamma_s - \gamma_m)W_{in}}$.

This formula determines the pattern of changes in skin moisture in the compression zone.

The pattern of changes in skin moisture in the recovery zone is determined in the same way:

$$W_2 = \frac{b_2 - R\varphi_2^2 + R\theta_2^2}{\frac{100}{W_r} b_2 - R\varphi_2^2 + R\theta_2^2} 100, \qquad 0 \le \theta_2 \le \varphi_2, \tag{10}$$

where $b_2 = \dfrac{(1+k_2\lambda_2)\gamma_s\delta_2}{100\gamma_m + (\gamma_s - \gamma_m)W_r}$, $W_r -$ is the residual moisture content of the skin, that is, the moisture content of the skin after squeezing, and $\delta_2 -$ is the final thickness of the skin layer.

A number of authors [13,21,30] in their studies have established that during the extraction process, in the deformation zone of the squeezed material, there is a boundary for changing the direction of the flow of extracted water. By changing the position of this boundary, we can regulate the degree of residual moisture of the squeezed material: the closer this boundary is to the line connecting the centers of the rolls, the lower the degree of residual moisture. In this regard, a hypothesis was adopted [13, 30]: behind the point that determines the residual moisture of the squeezed material, one can take the point of the roll contact curve lying on the line of centers, that is, the point where the water changes the direction of flow.

Thus, the residual moisture content of the skin during roller pressing is its moisture content at the end of the compression zone, that is $W_r = W_1(0)$.

From equality (10), it follows that

$$W_r = \frac{b_1 - R\varphi_1^2}{\dfrac{100}{W_{in}} b_1 - R\varphi_1^2} 100. \quad (11)$$

3 Results

Analytical formulas were derived that describe the patterns of changes in moisture content during the process of roller squeezing of leather.

A theoretical model of residual moisture in leather during roller squeezing was developed.

4 Conclusions

Based on the analysis of graphs of residual moisture in leather, it was determined that:

– with increasing radius of rolls, the residual moisture increases, which is related to the increase in the width of the roll contact area;
– with an increase in the initial thickness of the skin, other things being equal, the residual moisture content in the skin increases;
– with an increase in the initial moisture content of the skin, the residual moisture content increases and asymptotically approaches a certain value

References

1. V. Alexa, S. Ratiu, I. Kiss. J. IOP Conf. Series: Materials Science and Engineering **106** 012019 (2016)
2. X. Tan, Friction of plasticity: J. Engineering Tribology **221**, (2007)
3. Sh.R. Khurramov, Jurnal of Physics: Conference Series **1789**, 012004, (2021)
4. Sh.R. Khurramov, F.S. Khalturaev, J. IOP Conf.Series: Earth and Environmental Science **614**, 012097 (2020)
5. E.A. Gerber, I.A. Shadrunova, R.I. Ganichev. News of Universities, Ferrous Metallurgy, Moscow **9**, (2003)

6. Ya.D. Vasilev, Metallurgical and mining industry **1**, (2006)
7. Ya.D. Vasilev, News of Universities. Ferrous metallurgy **5,** (2001)
8. A. Amanov, Sh.R. Khurramov, G.A. Bahadirov, A. Abdukarimov, T.Yu. Amanov, Journal of Leather Science and Engineering **3(1),** (2021)
9. Sh.R. Khurramov, B. Abdurakhmonov, J. AIP Conf. Proc. **2637**, 060003 (2022)
10. R.J. Clos, L.L. Edwars, I.A. Tappi Journal **77**(6), (1994)
11. M.V. Kolychev, N.N. Kokushin, J. Cellulose. Paper. Cardboard **6**, (2015)
12. Sh.R. Khurramov, F.S. Khalturaev, F.Z. Kurbanova, Design and Application for Industry 4.0. Studies in Systems, Decision and Control **342,** (2021)
13. S.A. Polumiskov *Roll impregnator research and development of the method for calculating its design and technological parameters*. Abstract of Diss….Cand. Tech. Sci., Ivanovo (1997)
14. Sh.R. Khurramov, F.S. Khalturaev, F.Z. Kurbanova, Modeling the contact curves of leather squeezing machines Journal of Physics: Conference Series **2373(7)**, 072002, (2022)
15. Sh.R. Khurramov, F.S. Khalturaev, F.Z. Kurbanova, J. Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti **4**, (2021)
16. D. McDonald, R.J. Kerekes, J. Zhao, J. Perspectives on deriving mathematical models in pulp and paper science. BioResources **15** (2020)
17. O. Iliev, G. Printsypar, S. Rief, J. Transport in Porous Media **92,** (2012)
18. Sh.R. Khurramov, G.A. Bahadirov, A. Abdukarimov, J. Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti **1**, (2022)
19. A. Kavalek, J. of materials processing Technology**155,** (2004)
20. A. Kavalek, Journal of achievements in materials and manufacturing engineering **23**(2)**,** (2007)
21. Sh.R. Khurramov, F.S, Khalturaev, F.Z.Kurbanova, J. E3S Web of Conf. **376**, 01053, (2023)
22. Sh.R. Khurramov, F.S. Khalturaev, E.S. Burbev. J. AIP Conf. Proc. **2402,** 030038 (2021)
23. G.A. Bahadirov, G. Tsoy, A. Nabiev, A. Umarov, J. of Recent Technology and Engineering (IJRTE) **8** (2020)
24. K. Turgunov, N. Annaev, A. Umarov, J. of Physics: Conference Series **2373**, 072006 (2022)
25. Sh.R. Khurramov, F.Z. Kurbanova, J. AIP Conf. Proc. **2637**, 060004, (2022)
26. G.A. Bahadirov, *The mechanics of the squeezing roll pair* (Tashkent, 2010)
27. Yu. Wenge, *The Mechanical Properties of Leather in Relation to Softness*: A Thesis submitted for the degree of Doctor of Philosophy (University of Leicester, 1999)
28. N.E. Novikov, *Pressing of paper web* (Moscow, 1998)
29. Sh.R. Khurramov, J. Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti **4**, (2021)
30. G.K. Kuznetsov, *Research and methodology for designing roll squeezing devices for extile machines*: Dis. … Doc. Tech. Sci. (Kostroma, 1970)