Development of a method for testing the wear resistance of friction pairs based on the synthesis of the method of M. V. Lomonosov with the improved method of artificial bases

R V Davydov¹,², A V Tikalov¹, S G Chulkin³,⁴, A D Breki¹,⁴, L B Efremov⁴, V Yu Rud¹,²,⁵, N N Bykova⁶, L R Valiullin²,⁷

¹Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia; ²All Russian Research Institute of Phytopathology, Moscow Region, Russia; ³Saint-Petersburg State Marine Technical University, Saint-Petersburg, Russia; ⁴Institute of Problems of Machine Science of the Russian Academy of Sciences, Saint Petersburg, Russia; ⁵Ioffe Institute, Saint-Petersburg, Russia; ⁶St. Petersburg State University of Economics, St. Petersburg, Russia; ⁷Federal Center for Toxicological, Radiation and Biological Safety, Kazan 420075, Russia.

Corresponding author’s e-mail: davydovroman@outlook.com

Abstract. The article is devoted to improving the method of testing the wear resistance of friction pairs in a wide range of hardness by embedding a roller into a flat surface of the material under study (sample), first proposed by M. V. Lomonosov. The formula for estimating the volumetric wear resistance from linear depending on the specific pressure is proved. According to the new method, the relative wear resistance of materials in a wide hardness range was evaluated.

1. Introduction

At a conference of the Academy of Sciences (May 1752) M.V. Lomonosov proposed to investigate the clutch between body particles by straddling on a brick and particularly stressed the need for metal research [1]. In the same year he constructed a series of instruments, one of which (Figure 1) was intended for the study of the coupling between particles of bodies by «long erasure».

Figure 1. Sharpener Lomonosova (from figure M.V. Lomonosov)[1].
The design of M.V. Lomonosov’s device is incorrectly attributed to Baushinger, who proposed it in the 19th century. This «sharpener», as called by M.V. Lomonosov, was the prototype of modern instruments for research of wear of materials, and the friction scheme is the basis, for example, of the method «block-on-ring» according to the international standard ASTM G77.

Within the limits of this work, the development of the M.V. Lomonosov method is made with the work [2-16] by means of its realization together with the artificial base method and an improved method of calculation of wear characteristics.

### 2. Integrated testing methodology of material’s durability

The integrated methodology is based on the M.V. Lomonosov method. As a result of friction interaction of a pair «shaft-beams» in the sample is formed a segment with chord on the surface \( L \) (Fig. 2), on which conical artificial base is applied.

![Figure 2. Scheme of formation of the chord on friction surface (a) and on real samples of different hardness (b).](image)

As a result of the calculation and application of the series theory in the MathCAD editor, simplified formulas were obtained for calculating the volume of products of wear \( V(L) \) (1) and linear wear \( h(L) \) (2) depending on the length of the chord \( L \).

\[
V(L) = r^2 \frac{\arcsin \left( \frac{L}{2r} \right)}{2} - \frac{L}{2} \left[ \sqrt{r^2 - \left( \frac{L}{2} \right)^2} \right] H_r \Rightarrow \left( \frac{L^3}{12r} + \frac{L^5}{160r^3} + \frac{3L^7}{3584r^5} \right) H_r = \left( \frac{L^3}{12r} \right)
\]

\[
h(L) = \frac{V(L)}{LH_r} = \left( \frac{H_r L^3}{12r(LH_r)} \right) = \left( \frac{L^3}{12r} \right)
\]

where \( r \) – shaft radius; \( H_r \) – beam width. The linear wear resistance \( \varepsilon_L \) was calculated as the ratio of the friction path \( S \) to the linear deterioration \( h(L) \):

\[
\varepsilon_L = \frac{S}{h(L)} = \frac{A_f}{2\pi r n t}
\]

where \( n \) – shaft speed.

The volumetric wear resistance \( \varepsilon_w \) was calculated as the ratio of work friction \( A_f \) to the volume of wear products \( V(L) \):

\[
\varepsilon_w = \frac{A_f}{V(L)}
\]
Hence the main novelty of the M.V. Lomonosov method, which consists in simplifying the estimation of volumetric wear resistance \( \varepsilon_w \) by means of a simpler linear wear-out function \( \varepsilon_L \) taking into account the specific pressure of \( P(L) \):

\[
\varepsilon_w = \frac{A_f}{V(L)} = \frac{FS}{H_x L^2 / 12 r} = \frac{FS}{H_x L h(L)} = P(L) \varepsilon_L
\]  

(5)

where \( F \) – load (set on the friction machine);

Hence the novelty of the presented methodology, which consists in simplifying the method of estimating the volumetric wear resistance \( \varepsilon_w \) through linear \( \varepsilon_L \) by the specific pressure \( P(L) \).

The linear wear function \( \varepsilon_L \) has a simpler and more accurate approach due to the high accuracy of the chord length measurement \( L \).

3. Results and Discussion

To determine the quality of the accuracy of the manufacture of products, it is necessary to measure them. A wide range of hardness tests of real materials were conducted to test the proposed methodology. A comparison of the wear resistance of all investigated materials was made with the same production time \( t_0 = 10 \text{ min} \). As a result of the tests for each of the test materials, using time \( t \) and chord length measurements \( L \) was able to determine the parameters \( a \) and \( b \) of the power function by the least squares method (in the MathCAD editor):

\[
L(t) = a t^b
\]  

(6)

Finally, the relative durability of both linear \( \varepsilon_L \) and volumetric \( \varepsilon_W \) is calculated according to the durability of the reference material \( \varepsilon_{L/R} \) and \( \varepsilon_{V/R} \). The reference material shall be determined for the purposes of the study.

\[
\varepsilon_L = \varepsilon_L / \varepsilon_{L,R}
\]

\[
\varepsilon_W = \varepsilon_W / \varepsilon_{V,R}
\]  

(7)

The efficiency of the considered algorithms will be demonstrated by the example of comparative testing of a number of samples (friction pairs) on the friction machine SMC-2 (Figure 3).

| Abrasive Medium | Sample | Sample | L  | P    | \( \varepsilon_L \) | \( \varepsilon_W \) | \( \varepsilon_{L,R} \) | \( \varepsilon_{V,R} \) |
|----------------|--------|--------|----|------|-------------------|-------------------|---------------------|---------------------|
| Abrasive steel  | 1      | 4.54   | 0.23 | 7.481 | 2.59              | 0.793             | 2056.381            | 0.119               |
|                | 2      | 5.70   | 0.19 | 8.791 | 2.27              | 0.605             | 1369.767            | 0.091               |
|                | 3      | 5.58   | 0.35 | 12.74 | 1.60              | 0.302             | 483.4689            | 0.045               |
|                | 4      | 6.85   | 0.36 | 15.63 | 1.27              | 0.191             | 243.893             | 0.029               |
|                | 5      | 6.30   | 0.28 | 12.10 | 1.67              | 0.327             | 544.8155            | 0.049               |
|                | 6      | 4.62   | 0.43 | 12.57 | 1.61              | 0.305             | 490.1683            | 0.046               |
|                | 7      | 3.9    | 0.19 | 6.03  | 3.31              | 1.292             | 4276.39             | 0.193               |
|                | 8      | 2.56   | 0.20 | 4.104 | 4.93              | 2.863             | 14110.79            | 0.429               |
|                | 9      | 2.39   | 0.26 | 4.326 | 4.60              | 2.491             | 11457.17            | 0.373               |
|                | 10     | 2.38   | 0.24 | 4.113 | 4.84              | 2.755             | 13321.11            | 0.413               |
|                | 11     | 1.46   | 0.26 | 2.532 | 7.53              | 6.676             | 50258.85            | 1.000               |
|                | 12     | 1.05   | 0.15 | 1.501 | 13.48             | 21.42             | 28870.5             | 3.209               |
|                | 13     | 0.67   | 0.22 | 1.114 | 17.88             | 37.6              | 6734284.4           | 5.641               |
|                | 14     | 0.37   | 0.22 | 0.763 | 32.02             | 121.02            | 3878891            | 18.127               |

Figure 3. Results of materials durability tests for a wide range of hardness.
Figure 3 shows the following materials: 1 - carbon steel 20; 2, 6 - gray cast iron 30; 3, 10 - bronze BRAZHNMC 9-4-4-1; 4, 8, 9 - aluminum AMg5M; 5 - tin O1; 7 - composite; 11 - alloy steel 40X; 12 - acid-resistant steel 08X18N10T; 13 - tungsten-cobalt hard alloy VK6; 14 - ceramics Si3N4. The tests were carried out both during abrasive wear on a fine-grained grinding skin according to the state standard 5009-82 of the P600 type state standard P 52381-2005, and during the friction of the sample with the MS-20 lubricant.

![Figure 4. Scheme of formation of the chord on friction surface (a) and on real samples of different hardness (b).]

The linear durability \( L \) of the test materials depends on the test time \( t \): a) - abrasive material wear P600, b) - boundary friction with lubricating material MS-20 (the numbers correspond to the sample numbers in Figure 3).

4. Conclusion
In the proposed version of M.V. Lomonosov’s method, special attention is paid to the functions of not only volumetric but also linear wear and tear. The relationship between volumetric and linear wear resistance through the specific pressure of the friction pair under investigation has been proved.

The effectiveness of the developed method is demonstrated by the relative durability testing of a number of real materials with a wide range of hardness. The developed software and hardware can be widely applied. It is recommended that constant test parameters (reference time \( t_0 \), load \( F \), rotational speed \( n \), etc.) be set taking into account the research objective and operating conditions.

References
[1] Kragelsky I V et. al 1956 Development of the science of friction (Moscow - Publishing House of the Academy of Sciences of the USSR Moscow)
[2] Standard Test Method for Ranking resistance of Materials to Sliding Wear Using Block-on-ring Wear Test, norm G77 – 05 (Reapproved 2010), ASTM International, United States
[3] Davydov V, Dudkin V and Karseev A 2013 Optical Memory and Neural Networks (Information Optics) 22(2) 112–117
[4] Davydov V, Dudkin V and Karseev A 2014 *Optical Memory and Neural Networks (Information Optics)* 23(4) 259–264

[5] Davydov V, Dudkin V and Karseev A 2014 *Optical Memory and Neural Networks (Information Optics)* 23(3) 170–176

[6] Kim N H et. al 2005 *Wear* 258(11) 1787-1793

[7] Davydov V, Dudkin V and Karseev A 2015 *Technical Physics* 60(3) 456–460

[8] Davydov V, Velichko E, Dudkin V and Karseev A 2015 *Instruments and Experimental Techniques* 58(2) 234–238

[9] Khrushchev M M (ed.) 1962 *Methods of testing for wear: proceedings* (Moscow – Publishing House of the Academy of Sciences of the USSR)

[10] Ginzburg B M et. al 2001 *Technical Physics* 46 249–253

[11] Davydov V, Velichko E, Dudkin V and Karseev A 2014 *Measurement Techniques* 57(6) 684–689

[12] Davydov V, Dudkin V and Karseev A 2015 *Journal of Applied Spectroscopy* 82(5) 794–802

[13] Davydov V, Nikolaev D, Moroz A, Dmitrieva D and Pilipova V 2020 *AIP Conference Proceedings* 2308 060005

[14] Davydov V 1999 *Russian Physics Journal* 42(9) 822–825

[15] Davydov V, Cheremiskina A, Velichko E and Karseev A 2014 *Journal of Physics: Conference Series* 541(1) 012006

[16] Khrushchev M M et. al 1959 *Determination of wear of machine parts by the method of artificial bases* (Moscow – Publishing House of the Academy of Sciences of the USSR)