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EFFECT OF RUBBER FILLERS ON THE COEFFICIENT
OF STATIC FRICTION

By S. B. Ratner

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- USSR -

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EFFECT OF RUBBER FILLERS ON THE COEFFICIENT
OF STATIC FRICTION

- U S S R -

Following is a translation of the article
"Vliyaniye napolniteley reziny na koeffit-
sient staticheskogo treniya" (English ver-
sion above) by S.-B. Ratner and V. D. So-
kol'skaya in Doklady Akademii Nauk SSSR
(Reports of the Academy of Sciences of the
USSR), Vol LXXXVI, No 1, 1952, pages 121-
-124.

(Submitted to Academician P.A. Rebinder
on 11 July 1952)

1. It has been demonstrated by one of the authors
(1) that, in instances of static friction of rubber
against metal and plexiglass, the friction coefficient
 μ decreases as the load N increases, according to
formula

$$\mu = \mu_{\infty} + \frac{A}{N},$$

(1)

where μ_{∞} - minimal value of friction coefficient of
rest, which is valid when $N \rightarrow \infty$ or when $A \ll N$; A is
the tangential component of forces of molecular inter-
action of the working pair in friction.

It was shown in the above-cited work that a
change in the type of metal and of surface temperature
effects a change of A and μ_{∞} not in proportion to one
another, i.e., contrary to the B.V. Deryagin formula

(2).

The present work examines the question of the effect on the quantity A (as well as on μ_{∞} , and consequently upon the friction coefficient μ as a whole) of various rubber fillers, the quantity and character of which determine the magnitude of interaction between a sample of rubber and its lining in the state of static friction.

2. As is known, one of the most useful ingredients of rubber mixtures is soot in the capacity of an active filler. An increase in the amount of soot leads to increased hardness of rubber, as a result of which a lessening of interaction between rubber and its inflexible lining (metal, plexiglass) may be expected owing to a decrease of the actual true area of contact between them. Therefore, a higher amount of soot in rubber may bring about a diminution of the friction coefficient at the expense of a decrease in quantity A . On the other hand, no apparent causes can be foreseen a priori for the variations in quantity μ_{∞} if one takes as point of departure the interpretation of the binomial law of friction supplied by B.V. Deryagin (2).

Experimental research data are offered in Fig. 1.

Just as in the preceding work (1) they are expressed in coordinates $\mu = f\left(\frac{1}{N}\right)$ for the purpose of

checking the validity of formula (1), which requires a linear dependence in this system of coordinates, if A does not depend on load N .

It can be seen from Figure 1 that the linear requirement is sufficiently well met, i.e., formula (1) is valid for all examined rubbers.* This allows one to define from the diagram μ_{∞} as the initial ordinate and A as tangent of the angle of inclination of the straight lines.

With regard to the quantity of the tangent of the forces of adhesion A , experience shows that: first, lesser amounts of soot lead to a steeper inclination of the straight lines (A increases), secondly, this inclination is preserved when a switch is made to another metal, and even to plexiglass, for each rubber containing the assigned amount of soot.

* We shall not stop to examine the problem of deviations from linearity - of special relevance for soft rubbers - because this has no effect on the nature of our conclusions.

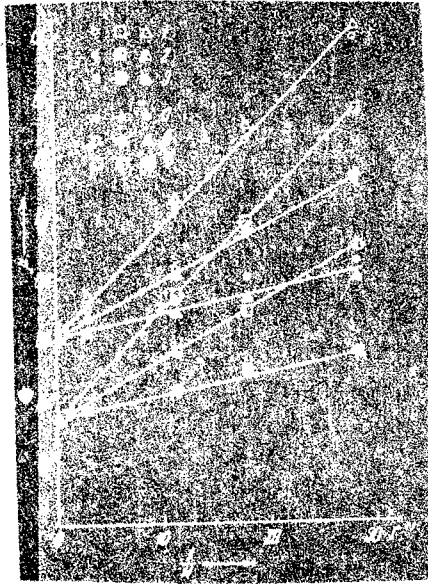


Figure 1. Dependence of the friction coefficient of soot-filled rubbers on reverse load. 1 - rubber contains 10 parts by weight of gas soot; 2 - 45 parts by weight; 3-60 p.w.; a - friction of rubber against plexiglass; b - against steel; c - against aluminum-containing alloy AMG. Coarseness of steel is greater than that of AMG.

The first circumstance is in correspondence with considerations of the role of hardness of rubber listed above.

The second circumstance (already noted in the preceding work (1) when comparison was drawn between friction of rubber against two different metals) indicates that forces of adhesion are determined, in the main, by an adaptation of the surface of the softer component of the pair in friction (rubber) to the surface of the harder component, so that a change of the latter (substitution by another metal or even plexiglass), which serves as a hard lining, has no effect on the forces of adhesion and, consequently, on quantity A as well.

3. Concerning quantity μ_{∞} , it follows from experimental data that it is independent of the amount of soot in rubber (see Fig. 1). μ_{∞} varies only when the lining is switched. This circumstance confirms, through a number of examples, the absence of connection between A and μ_{∞} , as noted in the preceding work (1).

It is interesting that a case, not unlike ours, of an increase in A (with a maintained constancy of μ_{∞}) was noted by B. V. Deryagin and V. P. Lazarev (3) in the presence of an increased quantity of multimolecular layers of acid soap of barium and calcium, serving as lubrication in the friction of glass against paraffin.

The independence of μ_{∞} from the amount of soot testifies to the fact that the friction coefficient is determined only by the micro-coarseness of the pair in friction, when conditions nullify the effect of the forces of adhesion, which are connected with the hardness of rubber (because $A \ll N$). Inasmuch as all samples of rubber, regardless of soot content, are vulcanized in one and the same pressform, μ_{∞} is preserved as a constant in friction against any given lining by all of these rubbers manufactured on the basis of one caoutchouc. Because the particles of the filler become coated with caoutchouc, we may expect, by preserving the latter, constancy of μ_{∞} (so long as the coating remains sufficiently complete).

From here it follows that substitution of fillers will not affect or alter the quantity μ_{∞} , because the quality of the filler is not supposed to play a role, inasmuch as its quantity doesn't either. An experimental check of this assumption is given in Fig. 2.

The diagram indicates that, regardless of quantity and quality of fillers of rubber, μ_{∞} preserves its value in friction against a given lining. From the corresponding point on the ordinate axis the straight lines for rubbers containing equal and differing amounts of various fillers are radiated in the manner of rays. The presence of this fact (in utilization of fillers of differing character) speaks of the general nature of the noted phenomenon for both the inactive fillers (chalk) and the active ones (such as soot of diversified types).

4. It must be noted that, despite the varied character of the fillers used, the effect of quantity of each one of them on the constant A (which characterizes the forces of adhesion and increases with decrease in

hardness) is uniform: decrease in the quantity of any given filler increases the angle of inclination, increases the role of the forces of adhesion, and increases the summary friction coefficient μ .

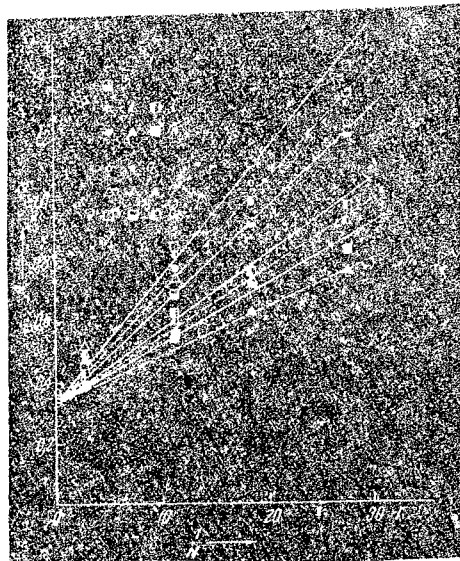


Figure 2. Effect of fillers of rubber on the dependence of the coefficient of friction against metal (AMG) on load. 1 - 10 weight parts; 2 - 25; 3 - 45; a - chalk, b - white soot, c - gas soot.

In connection with this arises the question of extreme values of the quantity A: on one hand, concerning only one value of A, corresponding to a complete absence of any filler; on the other hand, concerning the various minimal values of A corresponding to the maximal quantities of various fillers. Let us not tarry here to consider the first circumstance - the single value of maximal quantity A - because it is qualitatively fully obvious. But the second question is connected with the well-known ability of one or another filler to mix in differently with a given caoutchouc, which determines the limit of compatibility, i.e., the extreme permissible amount of ingredient in the rubber mixture;

beyond these limits of compatibility the above-noted coating of particles with caoutchouc film apparently becomes disrupted.

In the vicinity of these limits of compatibility the portion of filler near the surface of the sample may turn out to be very weakly tied with the sample, or even serving as a lubricant. Such phenomenon becomes clearly manifested when graphite, with its generally known lubricating capability, is used as a filler.

In this case our experiments have shown the character of the effect of graphite as filler on the friction coefficient of rubber to be the very same as of other (mentioned) fillers. The specifics of graphite find their expression in that it reveals the decrease of quantity μ_{∞} , when its own quantity is sufficiently increased.

Conclusions

1. When static friction of rubber against metals and plexiglass takes place, the constants A and μ_{∞} in formula (1) vary independently from one another: A -- at the expense of the amount of filler, μ_{∞} -- at the expense of a switching of lining.

2. The amount of tangential forces of A, connected with the molecular interaction of surfaces, increases when the amount of any filler is decreased, whether it be an active filler (soot, silicon dioxide) or an inactive one (graphite, chalk) in parallel with the decrease in hardness of rubber.

3. Quantity A is identical for friction of a given rubber against different materials (metals, plexiglass).

4. Changes in quantity and quality of a rubber filler do not have an effect on the minimal friction coefficient μ_{∞} .

5. Quantity μ_{∞} can decrease when the amount of filler becomes significant, e.g. graphite, which commences to take on the role of a lubricant in the vicinity of its limits of compatibility with caoutchoucs.

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