Journal of Macromolecular Science, Part A
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597274

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To cite this Article Yanhao, Zhou , Jingzhe, Li , Weidong, Wu and Zhihong, Sun(1991) 'A New Method of Characterising Lubricating Property of Rubber Libricants', Journal of Macromolecular Science, Part A, 28: 1, 31 — 36
To link to this Article: DOI: 10.1080/00222339108054380
URL: http://dx.doi.org/10.1080/00222339108054380

MACROMOLECULAR REPORTS, A28(SUPPL. 1), 31-36 (1991)

A NEW METHOD OF CHARACTERISING LUBRICATING PROPERTY OF RUBBER LUBRICANTS

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ABSTRACT

Recently there has been great significance attached to rubber lubricants because they are associated with high output, good product quality and low energy consumption. However, existing methods for characterising lubricating property are too apparent. According to a rheological method based on the Rabinowitsch equation and capillary wall slip correction, the 'slip coefficient--β' and 'slip velocity--Vs' at the metal wall can be determined. Therefore it is possible to characterise quantitatively the external lubricating property of various rubber lubricants with β and Vs.

INTRODUCTION

Rubber lubricants are compounding ingredients that help improve compound processabilities, such as flow property, filler dispersion and mold release of product, yet have no detrimental effects on the rubber. Friction among rubber macromoloecules and friction between compound and metal surface of processing machine are reduced during processing by the use of lubricants, the former effect is called the internal lubricantion, and the latter the external lubrication.

In recent years, the variety of rubber lubricants has increased. The attention given to flurochemical lubricants, multi-purpose SAPAs and complex lubricants has been doubled(1-4). Although the rubber industry is in urgent need of a new method for characterising lubricating property, there has not been enough work done in this respect.

By lubricating properties we mean both external and internal lubrication properties. King(5) used the 'internal lubrication index'$-\triangle Tg \cdot Vl$ (where Vl is the percentage by volume of lubricant, and $\triangle Tg$ is the decrease in glass transition temperature after the addition of lubricant) to evaluate internal lubricating property of lubricants for PVC. The higher value of $\triangle Tg \cdot Vl$, the

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Based on a paper presented at the 21st International Rubber Conference, Praha, Czechoslovakia, Aug. 28-Sept. 1, 1989 better the internal lubricating property. However, this method is not suitable for rubber, for the glass transition temperature of rubber is too low to be measured easily. It was also to put forward that internal lubricating efficiency in plastics could be assessed with the 'plastic deformation value' given by a Brabender Plastograph(6). Haverland and Hofmann(7) had studied the effect of some lubricants on the viscosity of EPDM, CR, NBR, NR and SBR compounds with a high pressure capillary viscometer as a means of assessing the internal lubricating efficiency. External lubricating property is generally characterised by the change in extrusion output, which includes the 'lubrication value' (extrusion output per unit torque and unit time) measured with a Brabender Plastograph and the extrusion output in a capillary, etc(6). The Garlock Flow Tester can be also utilised to assess external lubrication(1). But all these method are either not quantitative enough, too inconvenient, or too apparent to be of practical significance.

Recently, Leblanc(8) indicated that lubricants could enhance wall slippage of rubber compounds because of their external lubricating property, and that the wall slippage velocity could be utilised to assess external lubricating property. Häberlein(9) has recently studied the wall slippage behavior of rubber compounds with the modified Mooney viscometer, the results showed that the wall slippage behavior was related to shear rate and viscosity of compound. As stated above, the drop in viscosity is related to internal lubrication, so wall slippage velocity can be utilised to characterise internal as well as external lubrication. Thus, it can be seen that the study of wall slippage will possibly provide a comprechensive means for quantitative evaluation of lubricating properties. In addition, this is also one of the tasks of surface rheology, which has been taken seriously increasingly in recent years(10).

We have made a comprehensive study of the effect of 11 lubricants on the properties of rubber compounds(11). On this basis, we have developed a new method based on rheological principles, --the wall slippage coefficient method, to characterise lubricating property quantitatively.

MATERIALS AND METHODS

1. Materials and formulation

SBR-1500 provided by Jilin Chemical Industrial Company Organic Synthesis Plants, Jilin Prov., China;

Lubricants; Aflux-42 and Vanfre provided by Rhein-Chemie Rheina GmbH, F.R.G;

Formulation (phr); SBR 100, sulfur 1.8, CZ 1.2, ZnO 3, stearic acid 1, HAF 50, lubricant 2.5 (There is no lubricant in control compound).

The rubber compound is mixed in laboratory mill under normal conditions.

2. Equipment

The rheological data for the rubber compounds are obtained by using the MPT (Monsanto Processability Tester) in the '00' program mode(12).

3. Principle and Method

3a. Principle

According to the principle of rheometry (13), if the slip velocity (Vs) of compound at the wall of a capillary in the extrusion is zero, the Rabinowitsch equation is given by

$$Q = (\pi R^3)/(\tau_w^3) \int_0^{\tau_w} \tau^2 \dot{\gamma}\, d\tau \qquad (1)$$

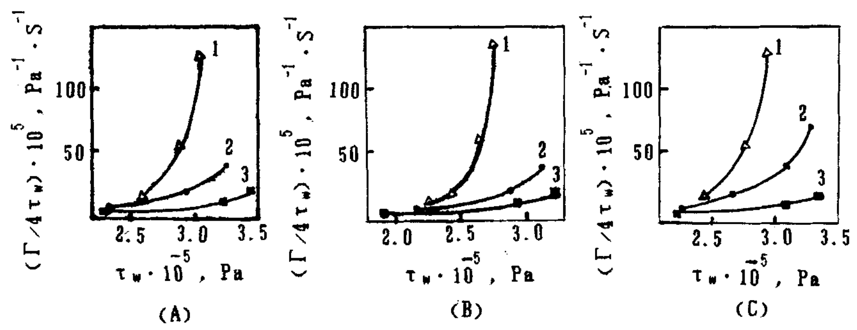

Fig. 1 A plot of $(\Gamma/4\tau_w)$ vs τ_w for SBR compount without lubricant (A), containing Aflux (B), containing Vanfre (C); Diameter of capillary, 1--1mm, 2--1.5mm, 3--2mm.

Where Q is the volume flow rate, τ the shear stress and τ_w the shear stress at the wall, $\dot{\gamma}$ the shear rate and R the radius of capillary. If there is slip at the wall, $Vs \neq 0$, equation (1) should be modified to include a term representing 'plug flow', viz,

$$Q = \pi R^2 Vs + (\pi R^3)/(\tau_w^3) \int_0^{\tau_w} \tau^2 \dot{\gamma}\, d\tau \qquad (2)$$

Dividing equation (2) by $\pi R^3 \tau_w$ on both sides, we get,

$$Q/\pi R^3 \tau_w = (Vs/\tau_w)\cdot(1/R) + (1/\tau_w^4) \int_0^{\tau_w} \tau^2 \dot{\gamma}\, d\tau \qquad (3)$$

Introducing the 'wall slip coefficient' $\beta = Vs/\tau_w$ and the apparent shear rate $\Gamma = 4Q/\pi R^3$, equation (3) can be written,

$$\Gamma/4\tau_w = \beta\cdot(1/R) + (1/\tau_w^4) \int_0^{\tau_w} \tau^2 \dot{\gamma}\, d\tau \qquad (4)$$

3b. Method

(1) Data of τ_w and Γ are obtained using a set of capillaries with different radii but the same length. If there is no slip at the wall, a plot of $(\Gamma/4\tau_w)$ vs τ_w for different R yields a single curve. If slip exists at the wall, a distinct curve for each R can be obtained (see Fig. 1).

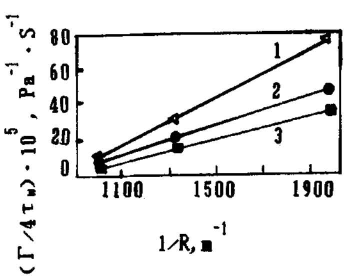

Fig.2 A plot of $(\Gamma/4\tau_w)$ vs τ_w for SBR compounds containing Vanfre at contain τ_w (1--$2.85\cdot 10^5$ Pa, 2--$2.75\cdot 10^5$ Pa, 3--$2.65\cdot 10^5$ Pa)

(2) From a plot of $(\Gamma/4\tau_w)$ vs τ_w, we can get the values of $\Gamma/4\tau_w$ corresponding to different R values for a number of τ_w. From equation (4) we can see that at constant τ_w the $\Gamma/4\tau_w$ should be a linear function of 1/R with slop β (see Fig. 2).

(3) A plot of β vs τ_w for different lubricants can be used to compare lubricating property (see Fig. 3).

(4) The slip velocity Vs of rubber compound at the wall of metal capillary can be determined according to $Vs = \beta \cdot \tau_w$.

In our experiments, we used a set of capillaries of diameters 2mm, 1.5mm and 1mm but the same length of 30mm. The testing temperature was 90℃.

RESULTS AND DISCUSSION

1. Slip phenomenon

The curves of τ_w vs $(\Gamma/4\tau_w)$ at different R for SBR compounds which contain the lubricants Aflux, Vanfre and no lubricant (control compound) are shown in Fig. 1.

From Fig. 1, it can be seen that the curves obtained for different R are distinct showing that slip of the rubber compound at the wall does exist. In other words, the standard equations in capillary rheometry should be modified accordingly.

By the way, our experiments showed that not only SBR but also other rubbers, such as NR, exhibit the wall slip phenomenon. So the effect of rubber compound at the metal wall on rubber processing such as mixing, extrusion etc should be taken seriously.

2. Slip coefficient and slip velocity

From Fig.2, it can be seen that between $\Gamma/4\tau_w$ and 1/R there is a good linear relationship. This is consistent with equation (4) above. The slip coefficients β obtianed from the slops of the straight lines at different τ_w are shown in Tab. 1.

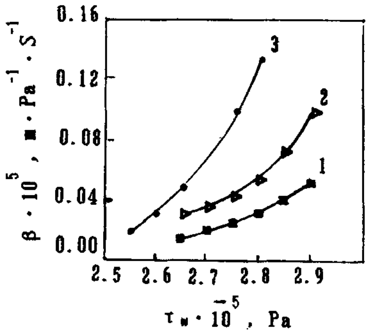

Fig.3 A plot of β vs τ_w for SBR compounds containing different lubricants (1--Control, 2--Vanfre, 3--Aflux)

TABLE 1.
Slip coefficient β at different shear stress τ_w for SBR compounds
($\beta \cdot 10^{-5}$, $m \cdot Pa^{-1} \cdot S^{-1}$)

compound	$\tau_w \cdot 10^{-5}$, Pa				
	2.60	2.65	2.70	2.75	2.80
control	0.0087	0.0134	0.0187	0.0246	0.0310
containing Vanfre	0.0224	0.0314	0.0349	0.0422	0.0527
containing Aflux	0.0299	0.0480	0.0698	0.0962	0.1323

TABLE 2.
Slip velocity Vs ($m \cdot S^{-1}$) at different shear stress τ_w for SBR compounds

compound	$\tau_w \cdot 10^{-5}$, Pa				
	2.60	2.65	2.70	2.75	2.80
control	0.0226	0.0355	0.0505	0.0677	0.0871
containing Vanfre	0.0634	0.0832	0.0942	0.1160	0.1480
containing Aflux	0.0777	0.1270	0.1880	0.2650	0.3700

A plot of slip coefficient β vs τ_w for SBR compounds containing different lubricants is shown in Fig.3, and Tab.2 shows values of slip velocity Vs at different τ_w for the same compounds.

From Fig.3 and Tab.2, we can see that Vs and β increase with τ_w. Fig.3 shows that for SBR compounds the lubricating efficiency of Aflux was higher than that of Vanfre. This is consistent with results we obtained previously (11). The slip behavior of other rubber compounds follows similar trend.

It should be pointed out that when there is slip at wall, the equations in capillary rheometry can be modified according to

$$\Gamma_{no\ slip} = \Gamma_{slip} - (4Vs/R) \qquad (5)$$

where $\Gamma_{no\ slip}$ and Γ_{slip} are the Newtonian(apparent) shear rate before and after correction for slip at the wall respectively.

CONCLUSIONS

1. Slip of rubber compounds at the wall of metal capillary exists.
2. The 'slip coefficient' method can be used to determine the slip velocity and slip coefficient. Both the slip velocity and slip coefficient increase with τ_w.
3. Either the slip velocity or the slip coefficient can be used for quantitative characterisation of lubricating properties. Aflux-42 is a better lubricant for SBR than Vanfre.

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