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The Friction of Various Rubber Articles Lubricated with Acid and Alkaline Water

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Friction coefficients have been measured for commonly encountered uses of rubber, involving practical formulations and real surfaces The aim was to see whether the water lubricated friction was sensitive to the acidity or alkalinity of the water Measurements were made on fully compounded black– and silica filled test sheets rubbed against glass concrete and tarmac Measurements were also made for windscreen wipers running shoes and bicycle tyres Results show that the friction in the presence of alkaline water (pH 11) is noticeably lower than for slightly acid water (pH 6) Observations indicate that it is possible to detect an influence of water pH on friction in practical situations as well as under laboratory conditions

The purpose of this work was to measure the coefficient of friction for commonly encountered uses of rubber, involving practical formulations and real surfaces The aim was to see whether under idealised conditions laboratory findings[1,2] on the effect of water pH on friction would be borne out in practice

EXPERIMENTAL

The coefficient of sliding friction was measured using apparatus described in earlier communications[1,3] Unless otherwise stated, measurements were made for the contact between a plane surface and a hemispherical rubber surface of diameter 37 5 mm (see *Figure 1*)

To find the coefficient of sliding friction between rubber and a hard substrate in lubricated contact the bending of the leaf springs due to the frictional force was measured by a four-part strain gauge bridge, the output of which was amplified and recorded The coefficient of friction, μ, is found from

$$\mu = \frac{Fd_2}{Wd_1}$$

where F is the friction force, W is the applied load, d_1 is the distance from the pivot to the point of loading, and d_2 is the distance from the pivot to the point of application of the load, as shown in *Figure 1* (in this work d_1 = 0 1 m, d_2 = 0 23 m)

The liquids used as lubricants were distilled water (pH 6) and buffer solutions at pH 6 and pH 11 The effect of friction reduction seen previously[1] occurred between pH 8 and pH 9 so the buffer solutions at pH 6 and pH 11 were chosen to be equally above and below this transition The surfaces used in these tests were as described in *Table 1* Details for the formulation and vulcanisation of BLACK, SILICA TR and other rubbers are given in *Table 2*

RESULTS

Friction Tests at Constant Speed

Friction measurements were made in dry contact, and lubricated with distilled water and the two buffer solutions The sliding speed was 5 0 mms⁻¹, and the contact loads were 0 25 N, 0 5 N and 1 N

The dry friction, for each contact pair tested, is shown in *Table 3* Also shown in *Table 3* is the roughness of the rubber surface(s) of the contact pair These roughness values were obtained using a Talysurf 10 surface texture measuring

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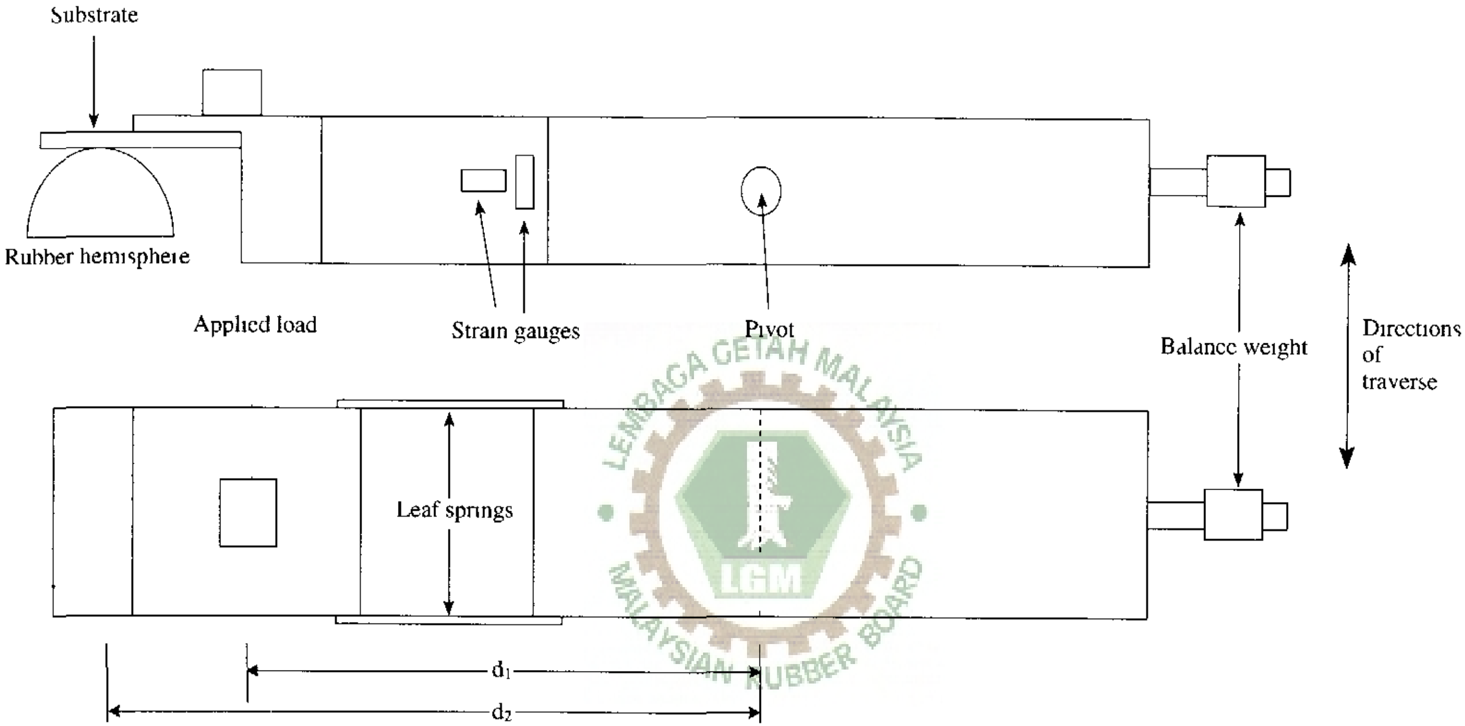

Figure 1 The friction apparatus

instrument (Rank Taylor Hobson), Leicester, UK) This machine measures the average roughness (centre line average, CLA) over three horizontal distances, V_h = 0 08 mm, 0 25 mm and 0 8 mm

The surface roughness of CONCRETE and TAR are 1 0 µm – 2 0 µm and 0 5 µm – 0 8 µm, respectively

As a way of comparing the data for different contact pairs the lubricated friction values were divided by the dry friction value to give a 'relative lubricated friction' The data are shown in *Figure 2* The vertical lines joining the points show the variation in relative friction with contact load

Friction at Constant Load

Using a contact load of 0 5 N, measurements of friction were made at sliding speeds from 0 05 mms^{-1} – 5 0 mms^{-1}, for the lubricated contact of IR, OENR, and TR with CONCRETE and TAR The results are shown in *Figures 3* to *5*

Friction Measurements Using a Windscreen Wiper Blade, a Running Shoe, and Bicycle Tyres

Measurements of friction were made for the following systems

- A windscreen wiper blade in contact with a soda-glass plate The applied load was 0 01 N/mm, a typical in-service load

TABLE 1 THE VARIOUS SURFACES USED IN THE TESTS

GLASS	Optically smooth soda glass track
CONCRETE	Concrete, cast against glass, to form a track
TAR	Bitumen (as used in roof repairs) to form a track
BLACK	A carbon black-filled rubber sheet
SILICA	A silica-filled rubber sheet
IR	2% dicup cured *Cariflex 305* sheet
NR	2% dicup cured SMR L sheet
OENR	An oil-extended black-filled natural rubber sheet
TR	A black-filled sheet of a compound used as a tyre retreading material
TUBING	Natural rubber tubing (Red)
GLOVES	Household washing-up gloves
WIPER	A windscreen wiper blade, based on natural rubber
SHOE	A running shoe tread, based on natural rubber
TYRES	Three bicycle tyres, based on natural rubber

Tyres A and B have carbon black as filler, and Tyre C has silica as filler

TABLE 2 FORMULATIONS FOR RUBBER COMPOUNDS

Compound/Cure condition	Silica	Black	TR	NR	IR	OENR
Natural Rubber (SMR L)	100	100	–	100	–	–
Cariflex 305	–	–	–	–	100	–
Natural Rubber (SMR 20)	–	–	80	–	–	–
Oil extended Natural Rubber (25% aromatic oil)	–	–	–	–	–	85
Polybutadiene (Europrene *cis*)	–	–	20	–	–	15
Zinc oxide	5	5	4	–	–	5
Stearic acid	2	2	2	–	–	2
Sulphur	2.5	2.5	1.2	–	–	1.2
Dicumyl peroxide	–	–	–	2	2	–
Nonox ZA (Permanax IPPD)	1	1	–	–	–	2
Santocure NS	–	0.5	–	–	–	–
Struktol A 82	–	–	1.2	–	–	–
Aromatic oil	–	–	8	–	–	–
Santoflex 13	–	–	2	–	–	–
Santocure MOR	–	–	1.2	–	–	–
P.E.G. 1500	1.5	–	–	–	–	–
SI 69	3.0	–	–	–	–	–
CBS	1	–	–	–	–	1.2
N339 Black	–	–	55	–	–	–
HAF N330 Black	–	50	–	–	–	–
ISAF Black (N220)	–	–	–	–	–	55
VN3 Silica	40	–	–	–	–	–
Cure time (min)	60	60	25	60	60	15
Cure temp (°C)	150	150	150	160	160	150

TABLE 3 DRY FRICTION COEFFICIENT AND SURFACE ROUGHNESS VALUES

Contact pair	Dry friction			Rubber surface roughness, CLA (μm)		
	25 g	50 g	100 g	V_l = 0 08 mm	V_s = 0 25 mm	V_h = 0 8 mm
BLACK/BLACK	5 20	5 20	4 30	007 ± 002	011 ± 005	035 ± 007
BLACK/BLACK(R)	5 00	4 40	3 90	084 ± 009	14 ± 01	29 ± 04
BLACK/GLASS	3 20	2 80	2 35	007 ± 002	011 ± 005	035 ± 007
BLACK/GLASS (R)	3 60	3 30	2 95	084 ± 009	14 ± 01	29 ± 04
SILICA/SILICA	4 80	4 50	3 80	002 ± 001	009 ± 004	027 ± 006
SILICA/SILICA(R)	3 80	3 90	3 63	006 ± 004	017 ± 006	061 ± 015
SILICA/GLASS	3 00	2 90	2 95	002 ± 001	009 ± 004	027 ± 006
SILICA/GLASS (R)	2 60	2 60	2 55	006 ± 004	017 ± 006	061 ± 015
TUBING/TUBING	3 80	3 30	3 00	005 ± 002	021 ± 009	056 ± 0 16
TUBING/GLASS	3 40	2 90	2 45	005 ± 002	021 ± 009	056 ± 0 16
GLOVES/GLOVES	1 20	1 13	1 21	009 ± 003	055 ± 003	24 ± 01
GLOVES/GLASS	0 90	0 65	0 55	009 ± 003	055 ± 003	24 ± 01
IR/GLASS	3 20	3 10	2 50	003 ± 001	010 ± 004	029 ± 005
IR/GLASS(R)	2 80	3 00	2 65	13 ± 05	*	*
NR/GLASS	3 60	2 90	2 55	004 ± 001	012 ± 003	024 ± 005
NR/GLASS(R)	3 60	3 10	2 65	16 ± 07	*	*
IR/CONCRETE(R)	1 60	1 40	1 35	13 ± 05	*	*
IR/TAR(R)	2 60	2 20	2 35	13 ± 05		*
OENR/CONCRETE(R)	0 85	0 88	0 84	07 ± 02	*	*
OENR/TAR(R)	2 20	1 70	1 85	07 ± 02	*	*
TR/CONCRETE(R)	1 50	1 45	1 35	03 ± 01	*	*
TR/TAR(R)	2 10	2 20	1 80	03 ± 01	*	*

(R) Rubber surfaces roughened using glass paper

Roughness values unobtainable due to curvature of surface

Note For BLACK and SILICA, rubber/rubber friction is substantially greater than rubber/GLASS friction Hertz theory[4] predicts a difference of about 60% if it is assumed that the frictional stress per unit area is the same in rubber/rubber and rubber/GLASS contacts

- A running shoe in contact with a plastic floor tile, and with concrete and tar road surfaces.

- Three different bicycle tyres in contact with concrete and tar road surfaces.

The friction of the wiper blade was found using the friction apparatus (*Figure 1*) at 5 mms^{-1} sliding speed. For the running shoe and bicycle tyres a spring balance was used to record the force required to cause tangential movement from stationary contact.

Values for friction coefficient were found in dry contact and for contacts lubricated with distilled water (pH 6) and buffer solutions at pH 6 and pH 11.

The results (averages of three measurements) are shown in *Table 4*. In contact with concrete and tarmac surfaces, the lubricated friction is almost the same for the three lubricants. However, in the contact of the running shoe with the floor tile there is a 35% reduction in friction between pH 6 and pH 11, and with the wiper blade against glass there is a 45% reduction between pH 6 and pH 11. These observations show that it is possible to detect the influence of lubricant pH on friction in practical situations as well as under laboratory conditions.

DISCUSSION

The measurements made at constant speed (*Figure 2*) show that, apart from the contact pairs which include CONCRETE or TAR, the friction at a lubricant pH of 11 is noticeably lower than the friction with the solution at pH 6. The contact pairs in which the effect is most pronounced are BLACK/BLACK and SILICA/SILICA.

With GLASS as one of the contact pair the relative friction is generally lower than with two rubber surfaces in contact, for all lubricated conditions. There is still a definite reduction in friction from the pH 6 solution to the pH 11 solution.

Film thickness measurements[2] on IR in contact with GLASS gave an increase in the equilibrium film thickness with increasing pH. With a solution at pH 6 there was no evidence for an equilibrium film, which means there is contact between the surfaces. However, with a solution at pH 11 there was film support at all pressures tested. This is probably the reason for the observed low friction for contacts involving GLASS and alkaline water as lubricant.

For contact between two rough surfaces, the difference in the relative friction at pH 6 and pH 11 is small, in the case of SILICA/SILICA(R) and BLACK/BLACK(R), or almost non-existent, as in the case of all contacts involving CONCRETE and TAR. For rough surfaces the area within the geometric contact periphery which is actually in contact is far smaller than for smooth surfaces. Rough surfaces will give higher contact pressures at the points where contact is made, so the ability to support a film is reduced.

By considering the coefficient of lubricated friction for the contacts involving CONCRETE and TAR (*Figures 3* to *5*), a feature of the system is revealed which is not apparent from the data of relative friction (*Figure 2*). Almost without exception, over the whole range of sliding speed, the friction of a lubricated Rubber/CONCRETE contact is lower than the lubricated friction of a Rubber/TAR contact.This cannot be attributed to the fact that the TAR surface is only half as rough as the CONCRETE surface, since that would be more likely to lead to higher lubricated friction for CONCRETE. There was very little evidence for an effect of lubricant pH on the friction but it is possible that the pH of the surface itself has some influence. The pH of a surface was found using a Phoenix PHM4 Antimony electrode (CP Instrument Co., Bishops Stortford, UK). The surface pH values for the materials used in these tests were:

TAR	pH 5.2 – 6.2
TR	pH 5.8 – 6.0
OENR	pH 5.8 – 6.2
IR	pH 7.0 – 7.2
BLACK	pH 7.4 – 7.6
SILICA	pH 7.8 – 8.0
CONCRETE	pH 8.7 – 11.0

If the pH of the surface is of consequence in the lubricated friction measurements then it would be expected that CONCRETE would give a lower friction than TAR, which was the observation made.

CONCLUSION

The effect of lubricant pH on sliding friction, as seen initially[1,2] in the contact of two optically smooth unfilled rubber surfaces, has been shown to be noticeable in contacts where the rubber is filled with carbon black or silica, when only one of the surfaces is rubber, and when the surfaces are rough.

In the contact of two surface-smooth, filled natural rubber compounds the difference in friction between lubrication at pH 6 and pH 11 is large, but when the surfaces are roughened the difference is greatly reduced. It would therefore seem that for rubber/rubber contact, smoothness of the surfaces is of far more importance than fillers.

In all rubber/GLASS contacts, the lubricated friction is lower than for the same rubber/rubber contact. Unless a high solution pH draws fatty acids from the rubber, to give a soapy solution, the rubber will not be readily wetted by the

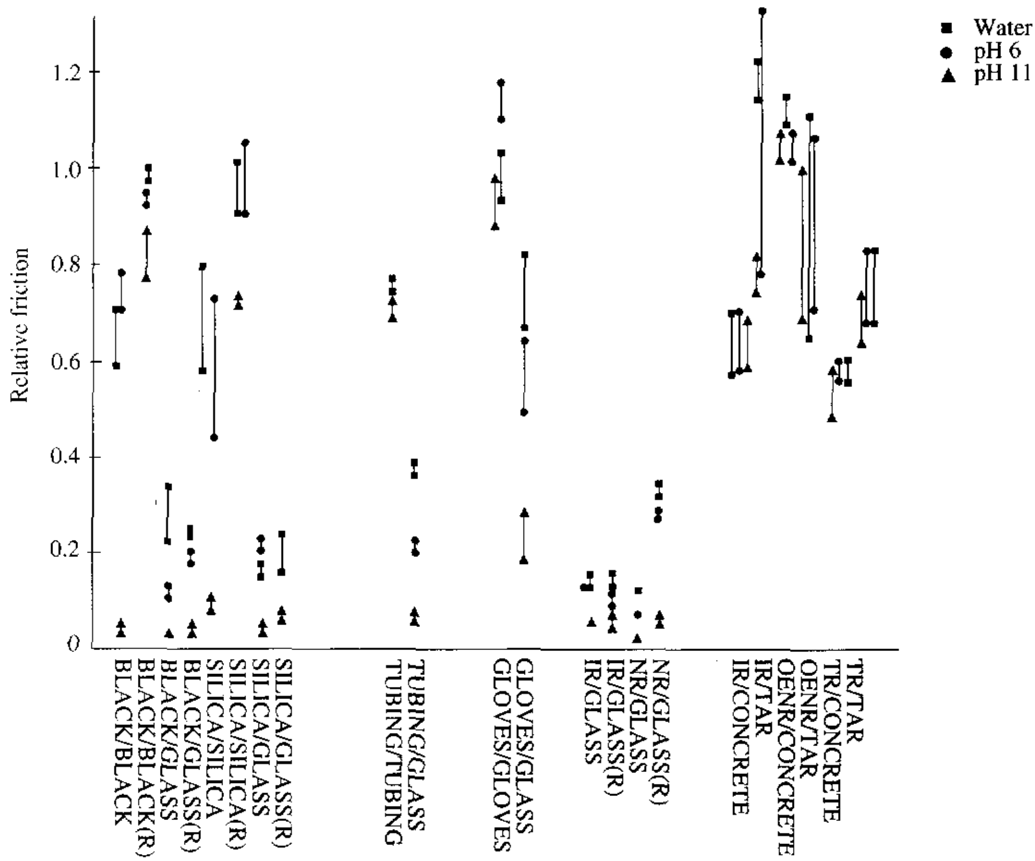

Figure 2. Relative friction in lubricated contact.

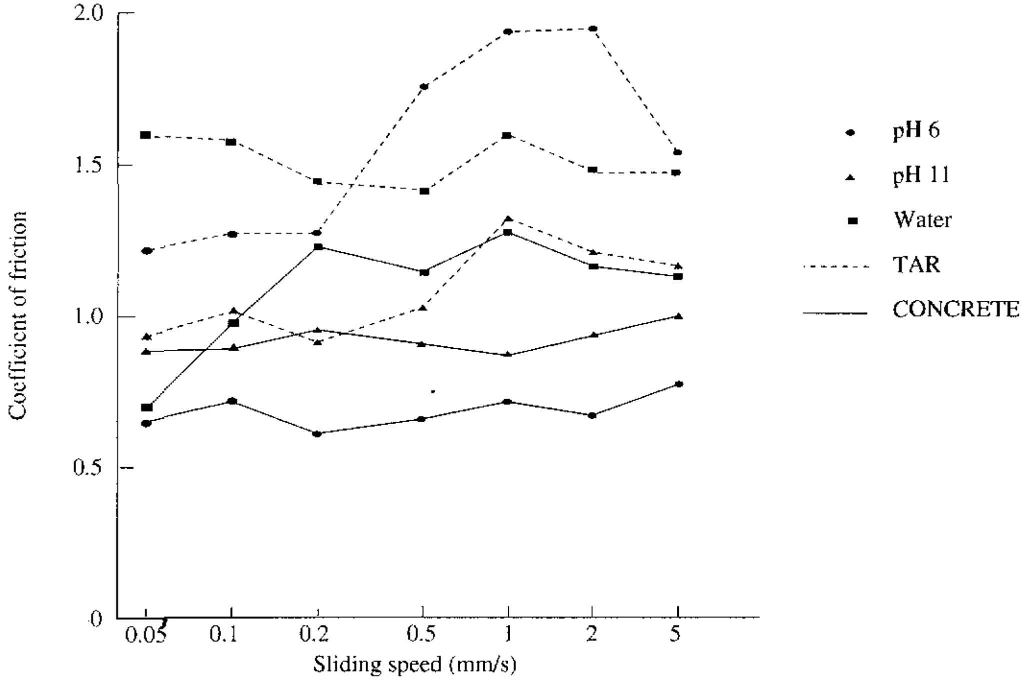

Figure 3. Friction of IR in lubricated contact with TAR and CONCRETE over a range of sliding speeds.

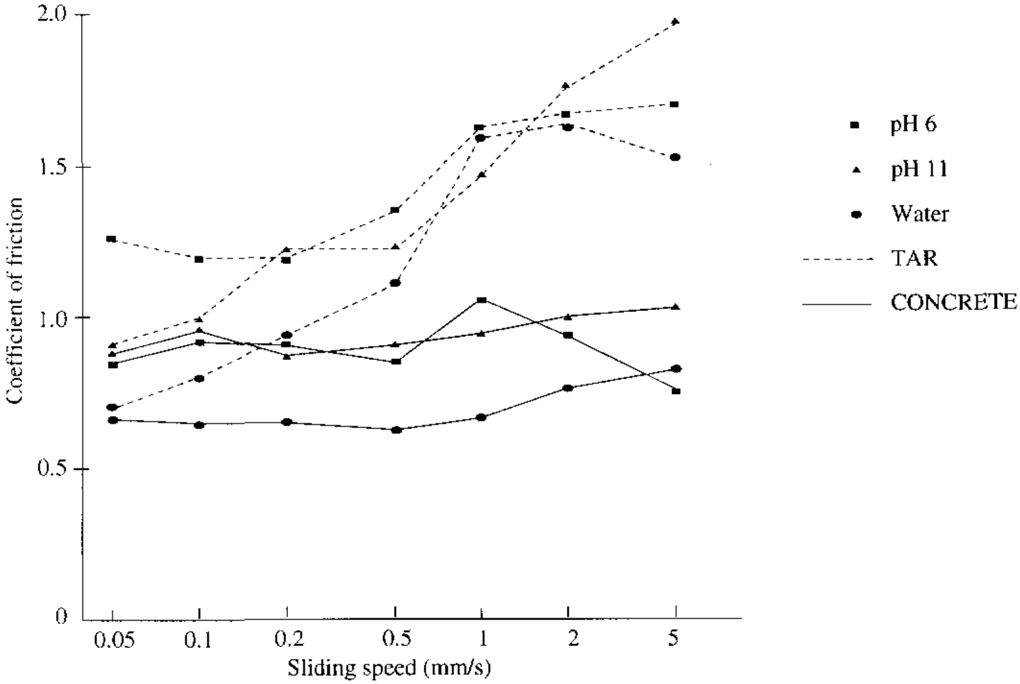

Figure 4. Friction of OENR in lubricated contact with TAR and CONCRETE over a range of sliding speeds.

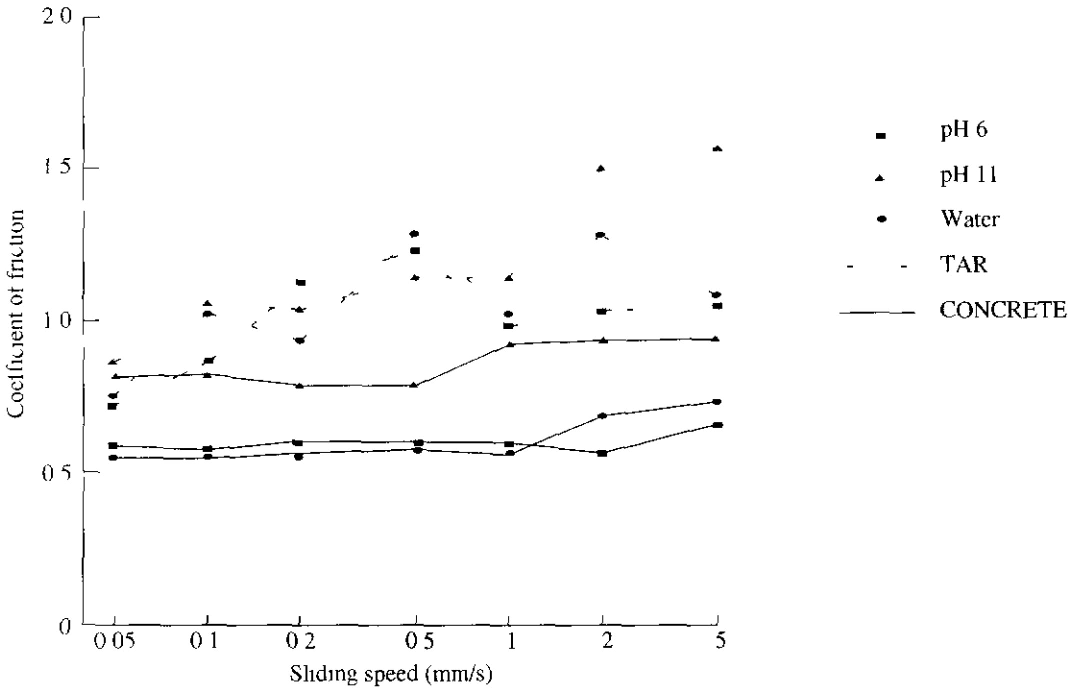

Figure 5 Friction of TR in lubricated contact with TAR and CONCRETE over a range of sliding speeds

TABLE 4 FRICTION COEFFICIENT FOR WIPER BLADE, RUNNING SHOE, AND BICYCLE TYRES

Contact pair	Load	Coefficient of friction Dry	Water	pH 6	pH 11
Wiper blade/glass	0 01 N/mm	1 15 ± 08	0 54 ± 04	0 40 ± 02	0 22 ± 01
Running shoe/floor tile	50 N	1 33 ± 08	1 10 ± 17	1 23 ± 08	0 80 ± 10
Running shoe/concrete	50 N	0 87 ± 08	0 60 ± 03	0 57 ± 03	0 52 ± 03
Running shoe/tarmac	50 N	0 57 ± 06	0 55 ± 05	0 57 ± 06	0 55 ± 05
Tyre A/concrete	16 N	1 19 ± 11	1 08 ± 04	0 92 ± 04	0 92 ± 04
Tyre A/tarmac	16 N	1 36 ± 10	1 15 ± 04	1 23 ± 04	1 13 ± 04
Tyre B/concrete	20 N	0 93 ± 04	1 04 ± 04	0 98 ± 04	0 84 ± 06
Tyre B/tarmac	20 N	1 27 ± 06	1 10 ± 05	1 22 ± 10	1 18 ± 08
Tyre C/concrete	26 N	0 95 ± 12	1 13 ± 09	1 01 ± 04	0 99 ± 04
Tyre C/tarmac	26 N	1 27 ± 04	1 23 ± 02	1 14 ± 02	1 08 ± 08

aqueous lubricants, whereas a cleaned glass surface, of hydrophilic nature, is wetted and more likely to give a low friction.

Wettability may relate to the difference in friction between CONCRETE and TAR since lower friction is seen on the hydrophilic CONCRETE than on the hydrophobic TAR.

The results for contacts involving CONCRETE and TAR show that, by having a rough rubber surface in contact with the rough non-rubber surfaces, the influence of lubricant pH on friction is noticeable, but is not as great as seen when the sliding surfaces are smooth.

It would seem that three conditions may be ranked in the following levels of importance, if the effect of friction reduction in alkaline water is to be observed:

Most important – Smooth surfaces in contact

Intermediate – Two rubber surfaces in contact (unless the non-rubber surface is glass)

Least important – Unfilled rubber.

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