Photoelectric Estimation of Binder/Aggregate Stripping*

By

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Özet: Bitüm — agregat karışımlarının su muvacehesindeki stabilitesini karakterize etmek üzere birçok laboratuvarlar tarafından tatbik edilen soyulma tecrübesi göz tahminine dayandığından neticeler büyük hatalara maruzdur. Göz hatalarını bertaraf etmek maksadiyle mukayeseli bir fotoelektrik metod geliştirilmiştir. Metodun prensibi, ϕ_1, ϕ ve ϕ_2 sırasiyle, (eşit yüzeyler gösteren ve eşit olarak aydınlatılan kaplara konmuş) orijinal agregat, soyulmuş nümune ve tamamen bitümle kaplı agregat tarafından aksettirilen ışık akıları olmak üzere, $(\phi_1 - \phi)/(\phi_1 - \phi_2)$ oranını tayin etmekten ibarettir. İki ayrı cins yüzeyden ibaret bir karışımın aksettirdiği ışık akısı bu yüzeylerin yalnız başlarına aksettirdiği ışık akılarının toplamına eşit olsaydı bu oranın soyulmuş nümunedeki bitümle örtülü yüzeylerin kesrini vermesi icap ederdi. Granüle agregatlar takdirinde ise durumun böyle olmadığı görülmekte ve doğru yüzey kesrinin bulunması için adı geçen orandan bir miktarın çıkarılması gerekmektedir.

Tecrübeye tabi tutulacak agregat saydam olmamalı ve bitümlü madde olarak penetrasyon asfaltları veya sıvı bitümlü maddelerin distilâsyon bakiyeleri kullanılmalıdır.

Bu metodla soyulmuş nümunedeki bitümlü satıhların yüzdesi ± 8 kadar bir hata ile tayin edilebilmektedir.

The adhesion of bituminous materials to mineral aggregates in the presence of water is considered as an important problem in bituminous highway construction. It has been observed that

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* The method of estimation presented in this paper is a modified form of that previously summarized in "Highways and Bridges„ (1954), **22**, No. 1064, 8.

the presence of water decreases the stability of compacted bituminous mixtures appreciably, depending upon the character of the aggregate used, and causes certain deteriorations in the bituminous pavements. For this reason the recent specifications require that the aggregates which are highly hydrophilic should not be used for bituminous construction, and it is becoming a wide spread practice to use some additives to promote the adhesion of bitumen to wet aggregates. Therefore, the need has been felt in recent years for a laboratory test which characterizes the sensitivity of bituminous mixtures to water.

To meet this requirement certain stripping tests have been suggested.[1], [2] In one of them the aggregate coated with bitumen is treated with boiling sodium carbonate solutions of increasing concentrations and the minimum concentration which causes the stripping of bitumen off the aggregate is recorded.[3]

Another method which is applied by certain laboratories in various modifications comprises immersing the bituminous mixture made of coarse aggregate in hot water at a specified temperature for a specified period of time. After stripping, the percentage of area of agregate coated with bitumen is estimated visually[4], [5].

In spite of the fact that both methods have been intensely critisized by various authors,[4], [5], [6], [7] especially the latter method has found routine application in many highway laboratories. For instance, this method is applied in the U. S. Public Roads Laboratories as follows[5]. Using 3/8″ — No. 4 sieve material, a bituminous mixture containing 5 percent bitumen is prepared and cured in an oven at 140°F for 24 hours. Then, 25 grams of the mixture are placed in a 250 ml. beaker and covered with distilled water. The beaker is then maintained at 120° or 140°F for 24 hours after which the percentage of surface area of aggregate that remains coated with bitumen is estimated visually.

Pauls etal'.[4], [5] criticism of this method can be summarized as follows:

1. Only the coarse fraction of the aggregate can be tested.
2. Since the test is based on a visual estimation the results are subject to considerable errors

3. The test reflects only the amount of stripping which is visible. There may be cases where a water film is present between the aggregate and the continuous bitumen layer. This has been observed when the less viscous bituminous materials are used.
4. There is no direct relation between the results of such tests and the actual behaviour of the compacted paving mixture when exposed to the action of water.

These authors are in the opinion that an immersion-compression test should replace the stripping tests in the laboratory.

Here, we would like to point out another disadvantage of this method :

5. Under the microscope innumerable droplets of bitumen are observed, which are not visible to the unaided eye, on the surface of aggregate in a stripped sample. This is, of course, another serious source of error.

Now, let us discuss these points in turn. The 1st. point is valid in the case of graded aggregates used in road-mix, asphaltic concrete pavement, etc., especially when fine aggregate differs from the coarse in mineralogical and chemical structure. Where one size aggregate is being used such as in surface treatment and macadam construction the stripping test gives valuable information as to the film retaining properties of the agregate. It is a useful guide to decide on the best coarse aggregate to be used for grading purposes. Also in studying the unti-stripping properties of additives the stripping test is useful.

2nd., 3rd., and 5th. disadvantages are the "estimation errors„. Since the 3rd. disadvantage is limited, it is clear that the 2nd. and 5th points are the most important ones which are the "errors of the eye„. These errors lower the reliability of the stripping test even in the above mentioned fields of application where it would be useful.

The 4th. point which has a fundamental importance appears to be an immature statement. To reach such a conclusion and in general to evaluate the practical use of stripping test, in the first place, it should be freed from the 2nd. and 5th. sources of error.

In this report we present a photoelectric method of estimation in which we attempted to eliminate the "errors of the eye„.

Theory of the Photoelectric Method

In this method we made use of the fact that the light reflecting ability of the surface of bare aggregate is always greater than that of the bituminous material*.

Suppose that a surface S is occupied by two types of surfaces at random. Let S_1 and S_2 be the areas of surfaces having higher and lower light reflecting abilities, respectively, so that

$$S_1 + S_2 = S \qquad \cdots\cdots\cdots\cdots (1).$$

Let us suppose that the surface S is exposed to a constant illumination. Under these conditions, let ϕ be the reflected flux of light. Also, ϕ_1 and ϕ_2 be the reflected flux of light when the surface S is occupied only by surface type (1) and surface type (2), respectively. It follows that,

$$\phi = \phi_1 \, S_1/S + \phi_2 \, S_2/S \qquad \cdots\cdots\cdots\cdots (2).$$

From eqns. (1) and (2) we have

$$\phi = \phi_1 - (\phi_1 - \phi_2) \, S_2/S \qquad \cdots\cdots\cdots\cdots (3) .$$

Let s be the percentage of surface type (2), i. e. $s = S_2/S \; 100$. Then from eqn. (3) we obtain

$$s = \frac{\phi_1 - \phi}{\phi_1 - \phi_2} 100 \qquad \cdots\cdots\cdots\cdots (4).$$

Therefore, it is possible to estimate s, in principle, by measuring ϕ_1, ϕ and ϕ_2. However, owing to certain practical difficulties, we used a different technique which gives the ratio $(\phi_1 - \phi) / (\phi_1 - \phi_2)$ in eqn. (4) instead of measuring ϕ_1, ϕ and ϕ_2 directly. First, let us describe the apparatus used.

Apparatus

The photoelectric set-up used is shown in Fig. 1 (a) and 1 (b). The apparatus consists of a box in 23 × 23 × 30 cms. dimensions made of brass sheet. Inside the box is painted dull black. On one side it has a door for the admission of samples. The above mentioned surface S in the inner base surface of a 9.5 cms. diameter Petri culture dish which sits on a table in the apparatus. This table can be raised or lowered by about 5 cms.

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* Added in proof : We recently became aware of a report by W. J. Arndt and M. R. Royer (Highway Research Board Proc., (1949), **29**, 167.) in which a reference is made to a similar method without any detailed description.

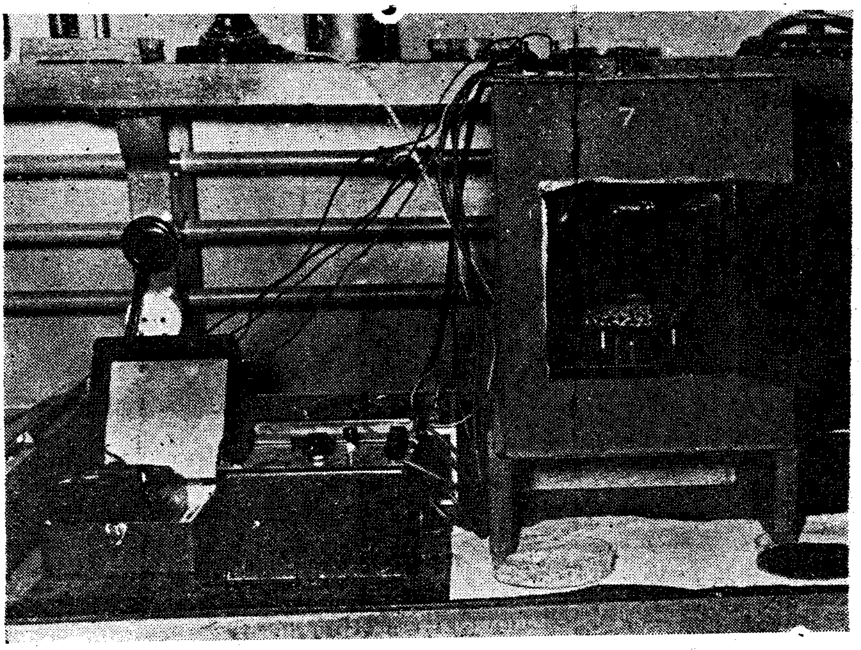

Fig. 1 (a): Photoelectric Apparatus

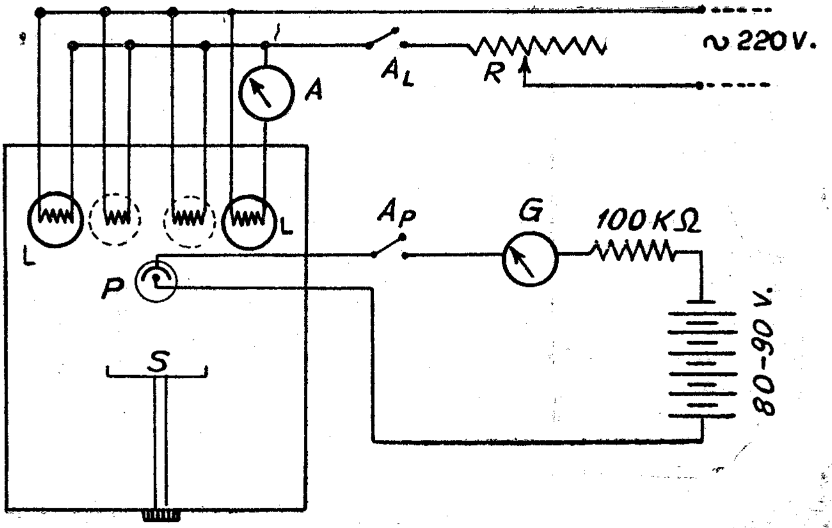

Fig. 1 (b): Photoelectric Circuit

by a hand screw. The surface S is illuminated by four 100 watt bulbs which are mounted on the top near the corners so that their filaments are 21 cms. above the base. P is a photoelectric cell which faces the surface S and situated at a height of 19 cms. from the base. The minimum distance between S and P is 6 cms. The photoelectric cell is protected against lights directly emitted by the bulbs. The bulbs are so located that when a Petri dish filled with water is placed on the table the reflected light from the water surface does not fall onto the photoelectric cell. A galvanometer G indicates the photoelectric cell current.

The total light intensity w can be varied by a 137 ohm. rheostat R. The ammeter A measures the current I passing through one of the bulbs. w is a function of I, viz.,

$$w = f(\mathrm{I}) \qquad \cdots\cdots\cdots\cdots \qquad (5).$$

Method

The illumination of photoelectric cell is proportional to the total flux of light reflected by the surface S and other illuminated surfaces inside the box. Let ϕ_0 be this total. The deflection of galvanometer G is, therefore, a function of ϕ_0

Now, let us consider the following three cases: (a) S is occupied 100 percent by surface type (1); (b) S is occupied by surface type (2) in s percent and by surface type (1) in $100 - s$ percent; (c) S is occupied 100 percent by surface type(2). Suppose that measurements are taken in each case, so that the rheostat R and consequently I and w are so adjusted that the galvanometer G indicates the same (5μA.) cell current. Thus, ϕ_0 will be the same in each case. Let the currents indicated by the ammeter A in these measurements be I_1, I and I_2; and the corresponding light intensities be w_1, w and w_2, respectively. The flux of light f, reflected by surfaces inside the apparatus other than surface S, is proportional to the light intensity w, viz.,

$$f = c\,w \qquad \cdots\cdots\cdots\cdots \qquad (6)$$

where c is a constant. Let f have the values f_1, f and f_2 in these experiments, respectively. All these quantities are tabulated in Table I.

Table I.

	$s=0$	$s=s$	$s=100$
Bulb current	I_1	I	I_2
Light intensity	w_1	w	w_2
Flux of light reflected by surfaces other than S	f_1	f	f_2
Total flux of light reflected	ϕ_0	ϕ_0	ϕ_0
Flux of light reflected by surface S	ϕ_0-f_1	ϕ_0-f	ϕ_0-f_2
Flux of light reflected by surface S_0	ϕ_1^0	ϕ^0	ϕ_2^0

Suppose that we have a standard surface S_0 having a constant light reflectivity instead of surfaces S and that the flux of light reflected by this surface under the conditions of above mentioned three experiments are ϕ_1^0, $\phi^0$and ϕ_2^0, respectively (Table I.). These ϕ^0's are, of course, proportional to w's, viz.,

$$\phi^0 = c_0\, w \qquad \cdots\cdots\cdots\cdots \quad (7)$$

where c_0 is another constant.

Now, instead of varying I and, consequently, w let them be kept constant at standard values, e.g. $I=I_0$ and $w=w_0$, in each experiment. Under these conditions the flux of light reflected by surfaces S are ϕ_1, ϕ and ϕ_2, respectively. Let ϕ_0^0 be the flux of light reflected by surface S_0 in this case. These are tabulated in Table II.

Table II.

	$s=0$	$s=s$	$s=100$
Bulb current	I_0	I_0	I_0
Light intensity	w_0	w_0	w_0
Flux of light reflected by surface S	ϕ_1	ϕ	ϕ_2
Flux of light reflected by surface S_0	ϕ_0^0	ϕ_0^0	ϕ_0^0

By rating the reflecting flux of light in Tables I and II we can obtain the following relationships:

$$\left.\begin{array}{lcl} (\phi_0-f_1)/\phi_1^0 = \phi_1/\phi_0^0 & \text{or} & \phi_1 = \phi_0^0(\phi_0-f_1)/\phi_1^0 \\ (\phi_0-f\,)/\phi^0 = \phi\;/\phi_0^0 & \text{or} & \phi\; = \phi_0^0(\phi_0-f\,)/\phi^0 \\ (\phi_0-f_2)/\phi_2^0 = \phi_2/\phi_0^0 & \text{or} & \phi_2 = \phi_0^0(\phi_0-f_2)/\phi_2^0 \end{array}\right\} \quad (8).$$

From eqns. (6), (7) and (8) we get

$$\left.\begin{aligned}\phi_1 &= w_0\,(\phi_0/w_1 - c)\\ \phi &= w_0\,(\phi_0/w - c)\\ \phi_2 &= w_0\,(\phi_0/w_2 - c)\end{aligned}\right\} \quad \cdots\cdots\cdots\cdots (9).$$

The ratio $(\phi_1 - \phi)/(\phi_1 - \phi_2)$ required can be worked out from eqns. (9) as follows.

$$\frac{\phi_1 - \phi}{\phi_1 - \phi_2} = \frac{w_0(\phi_0/w_1 - c) - w_0(\phi_0/w - c)}{w_0(\phi_0/w_1 - c) - w_0(\phi_0/w_2 - c)} = \frac{1/w_1 - 1/w}{1/w_1 - 1/w_2} \quad (10).$$

It follows from eqns. (4) and (10) that

$$s = \frac{1/w_1 - 1/w}{1/w_1 - 1/w_2}\,100 \quad \cdots\cdots\cdots (11).$$

It is clear that if we can measure only the light intensities w_1, w and w_2 which refer to the experiments (a), (b) and (c), respectively, s can be calculated. In other words if we know the function (5) we can estimate s from I_1, I and I_2.

Now, let us define a new function of bulb current I by

$$A/w + B = F(I) \quad \cdots\cdots\cdots (12)$$

where A and B are arbitrary constants It can be shown from eqns. (11) and (12) that

$$s = \frac{F(I_1) - F(I)}{F(I_1) - F(I_2)}\,100 \quad \cdots\cdots\cdots (13)$$

for any A and B.

It follows that in order to calculate s the function F(I) should be determined, choosing A and B arbitrarily. In other words, the light bulbs should be calibrated.

Calibration

By feeding the photoelectric cell P from a 90 v. battery and keeping the table at a fixed height a circular white paper in 9.5 cms. diameter was placed into the apparatus, The necessary adjustment was made to the rheostat R to read 5.00μA on the galvanometer G, and the bulb current indicated by the ammeter A was recorded ($I_1^0 = 351$ M.A.). The same measurement was made with another circular paper of the same diameter painted in black ($I_2^0 = 470$ M.A.).

The arbitrary constants A and B could be so chosen that

$$\left.\begin{array}{l} F(I_1^0) = 100 \\ F(I_2^0) = 0 \end{array}\right\} \cdots\cdots\cdots \quad (14).$$

Then, several black and white calibration circles of the same diameter were prepared by painting white circular papers in black by known surface percentages to provide definite s values. One of them is shown in Fig.2. The same measurements were made with each calibration circle and corresponding I^0 bulb currents were recorded.

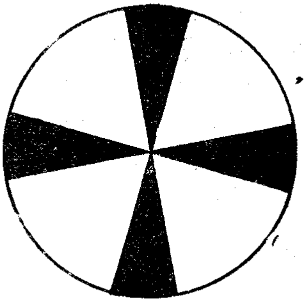

Fig. 2 : A Calibration Circle ($s = 30$)

From eqns. (13) and (14) we obtain

$$F(I^0) = 100 - s \qquad \cdots\cdots\cdots \quad (15).$$

From known s and measured I^0 values we obtained the required curve F (I), by eqn. (15), which is shown in Fig. 3.

To estimate the s value of any sample we should, therefore, find the values $F(I_1)$, $F(I)$ and $F(I_2)$, or in short F_1, F and F_2, corresponding to the bulb currents I_1, I and I_2, respectively, by this curve and insert them into the eqn. (13).

Experiments with Granular Aggregates

In order to check the reliability of this method further experiments were carried out with granular aggregates coated with bitumen in known surface percentages.

One portion of crushed stone passing a No. 8 sieve and retained on a No. 10 sieve was coated hot with 20 penetration asphalt. When it was cool it was mixed with the other portion of the original aggregate in various volume proportions. We assumed that the ratio of volume of aggregate coated with bitumen to the total volume was equal to the ratio of surface coated with bitumen to the total surface. Thus, we prepared samples having various known s values.

70 grams of each sample, including the original aggregate and the aggregate totally coated with bitumen, were placed into identical Petri dishes, and their surfaces straightened out Then measurements were taken with each sample in the above mentioned manner and corresponding *s* values were calculated. These are tabulated in Table III against actual *s* values.

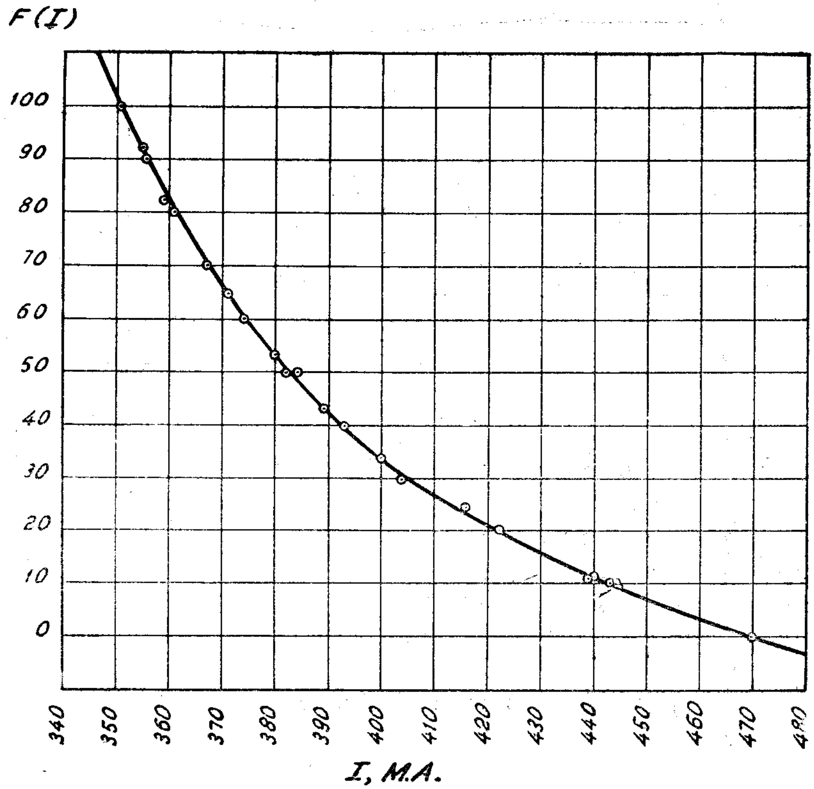

Fig. 3 : Calibration Curve

Table III.

Actual *s*	Estimated *s*	Difference
10.4	17.6	+ 7.2
31.0	43.5	+ 12.5
51.2	65.7	+ 14.5
71.0	80.1	+ 9.1
90,4	94.0	+ 3.6

It will be seen from this table that, with granular samples, i) the percentage of the less reflective surface is always over estimated and ii) the difference between the estimated and actual s vanishes as s approaches both to 0 and 100, exhibiting a maximum in the vicinity of $s = 50$.

Interpretation of Results

The latter observation enabled us to explain these differences. We attribute them to the aggregate surfaces which are illuminated not only directly by the bulbs but also by the light reflected by the neighbouring grains.

Suppose that the aggregate is composed of identical grains closely packed together. The light reflected by each grain can be considered to be the sum of two types of light, namely (i) the light reflected by the surfaces directly illuminated by the bulbs, which is independent of the neighbouring grains, and (ii) the light reflected by the surfaces near the boundaries illuminated indirectly by the neighbouring grains.

Let φ_1 be the flux of light type (i) reflected by an uncoated grain (species (1)) and φ_2 be that reflected by a coated grain (species (2)), under constant illumination. The flux of light type (ii) reflected by a species (1) when the sample consists of the original aggregate would be $z a \varphi_1^2$ and that of reflected by a species (2) when the sample consists of the agregate totally coated with bitumen be $z a \varphi_2^2$ where z is the coordination number of packing and a is a proportionality constant. If the first top layer of the sample contains N grains in every case, then

$$\phi_1 = N(\varphi_1 + z\,a\,\varphi_1^2) \qquad \cdots\cdots\cdots \qquad (16)$$

and

$$\phi_2 = N(\varphi_2 + z\,a\,\varphi_2^2) \qquad \cdots\cdots\cdots \qquad (17).$$

Now, let the sample contain N_1 species (1) and N_2 species (2) in the top layer. Of course,

$$N_1 + N_2 = N \qquad \cdots\cdots\cdots \qquad (18).$$

Let N_{11}, N_{22} and N_{12} be the numbers of (1)—(1), (2)—(2) and (1)—(2) contacts in the mixture, respectively. Then

$$\phi = N_1\varphi_1 + N_2\varphi_2 + 2N_{11}\,a\,\varphi_1^2 + 2N_{22}\,a\,\varphi_2^2 + 2N_{12}\,a\,\varphi_1\varphi_2 \qquad (19).$$

On the other hand, geometrically [8]

$$\left.\begin{array}{l} 2\,N_{11} = z\,N_1 - N_{12} \\ 2\,N_{22} = z\,N_2 - N_{12} \end{array}\right\} \qquad \cdots\cdots\cdots\cdots (20).$$

From eqns. (19) and (20) we obtain

$$\phi = N_1(\varphi_1 + z\,a\,\varphi_1^2) + N_2(\varphi_2 + z\,a\,\varphi_2^2) - N_{12}\,a\,(\varphi_1 - \varphi_2)^2 \quad (21).$$

Let s be the actual and s' be the apparent — i. e. estimated — percentage of bituminous surface in the mixture. From eqns. (16), (17), (18) and (21) we have

$$s' = \frac{\phi_1 - \phi}{\phi_1 - \phi_2} 100 = \frac{N_2}{N_1 + N_2} 100 + \frac{N_{12}}{N_1 + N_2} \cdot \frac{a(\varphi_1 - \varphi_2)}{1 + za(\varphi_1 + \varphi_2)} 100 \quad (22).$$

Since

$$s = \frac{N_2}{N_1 + N_2}\,100 \qquad \cdots\cdots\cdots\cdots (23),$$

from (22) and (23) we have

$$s' - s = \frac{N_{12}}{N_1 + N_2} \cdot \frac{a(\varphi_1 - \varphi_2)}{1 + za(\varphi_1 + \varphi_2)}\,100 \cdots\cdots\cdots\cdots (24).$$

We could show experimentally that this interpretation of the difference between the apparent and actual percentages of bituminous surface, which leads to eqn. (24) was at least qualitatively correct. Equal volumes of original aggregate and that coated with bitumen, weighing 70 grams altogether, were taken separetely. Each were placed in exactly one half of a Petri dish and laid evenly. Thus, the number of contacts between dissimilar aggregates N_{12} was minimized and yet $s=50$ was provided. The measurements with this sample gave $s' = 52$ which was very close to s. In a second experiment the aggregates in the dish were mixed well, and therefore the number of contacts between dissimilar aggregates was increased. s was also equal to 50. However, the estimated s' was 67.

Assuming a random mixing, it can be shown statistically [8] that

$$N_{12} = z\,\frac{N_1\,N_2}{N_1 + N_2} \qquad \cdots\cdots\cdots\cdots (25).$$

Substituting (25) into (24) we obtain

$$s' - s = \frac{N_1\,N_2}{(N_1 + N_2)^2} \cdot \frac{za(\varphi_1 - \varphi_2)}{1 + za(\varphi_1 + \varphi_2)}\,100 \cdots\cdots\cdots\cdots (26),$$

Finally, from (26), (23) and (18) we have

$$s' - s = \frac{C}{100} s(100 - s) \qquad \cdots\cdots\cdots\cdots (27)$$

where

$$C = \frac{za(\varphi_1 - \varphi_2)}{1 + za(\varphi_1 + \varphi_2)} \qquad \cdots\cdots\cdots\cdots (28).$$

C is a characteristic constant of the aggregate.

If the granular size is kept constant, eqn. (27) predicts the followings which are in good agreement with the experimental results:

(1) For a given aggregate the difference $s' - s$ which is always positive is a parabolic function of s vanishing as $s \to 0$ and $s \to 100$ and becoming maximum when $s = 50$. In Fig. 4 the experimental differences $s' - s$ given in Table III are plotted against s. The points fall in a parabola within a reasonable accuracy.

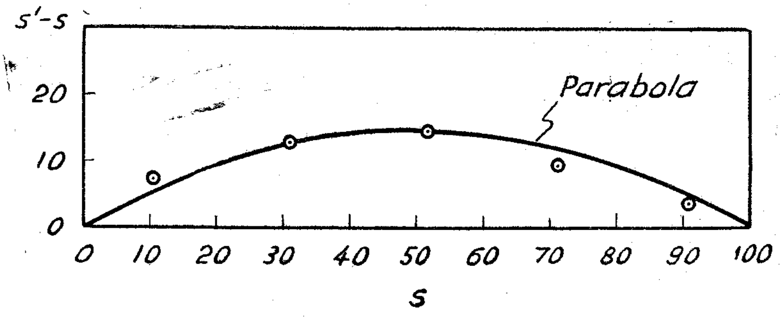

Fig. 4. $s' - s$ Plotted Versus

(2) For a given s, the lighter the colour of aggregate the greater is the difference $s' - s$. The results of experiments made with various aggregates of the same size and s value ($s = 50$) are given in Table IV, which confirm this requirement.

Table IV

Aggregate	Colour	$s' - s$
Andesite	Dark red	9
Limestone	Gray	13
Feldspar	White	25

Generalization of the Results

In the above mentioned experiments and the theoretical considerations each grain was either coated with bitumen completely or not coated at all. But this is not the case in actual stripping tests where each grain may be coated with bitumen partially. However, by similar considerations it can be shown that the difference $s' - s$ in this case is also given by the expression (27).

Having found a general explanation for the difference $s' - s$, we can assume the validity of this relationship in the case of actual stripping tests to obtain actual s values from the values of s' estimated, provided that the aggregate used is of the same size and that C is known for each aggregate.

Evaluation of C

The constant C can be evaluated from eqn. (27) by taking a measurement with a mixture of known s value (e. g. $s=50$) made of the aggregate to be tested in the manner described previously, together with the three main samples. Let the bulb current reading with this mixture of $s = 50$ be I'. Then, from (13) and (27) we have

$$C = 4\frac{F(I_1) - F(I')}{F(I_1) - F(I_2)} - 2 \qquad \cdots\cdots\cdots\cdots (29).$$

Numerical values of C obtained from (29) for various aggregates range from 0.3 to 1.0.

In this manner, the s value of any sample can be calculated from eqn. (27) if s' and C are determined. To avoid the solution of quadratic equation (27), we give a ready-to-use chart in Fig. 5 to find s from s' and C values.

Limitations

It is obvious that this method is not applicable to transparent aggregates. Therefore, one should be conscious of this fact while working with aggregates containing quartz and calcite minerals which exhibit considerable transparency. However, such cases are very rare in actual practice.

Another difficulty when using low viscosity bituminous materials such as cutback asphalts is that after curing, the bituminous film on the aggregate becomes too thin to cover the optical properties of white aggregate surfaces underneath. After stripping, however, the discontinuous bitumen film will be somewhat thicker. Consequently, the bituminous surfaces in the stripped sample will be less reflective than those in the reference sample. This leads to a false result. Therefore, the bituminous material used should be either penetration grade asphalt or distillation residues of cutbacks and road tars.

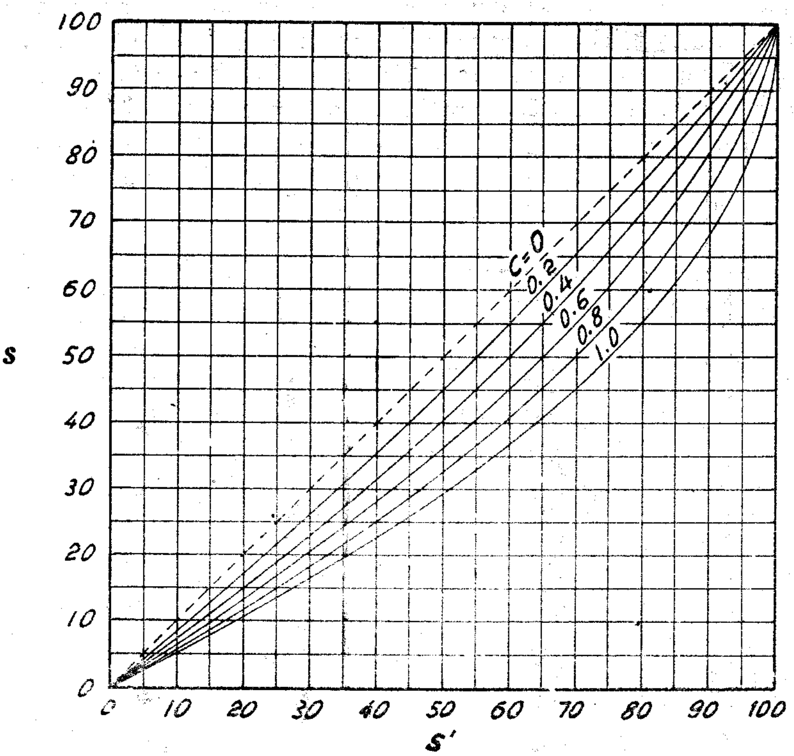

Fig. 5: Correction Chart

Minimum Bitumen Content

Even when penetration asphalts are used a minimum film thickness should be provided to hide completely the optical properties of the aggregate surface underneath. To determine the minimum percentage of bitumen to be added to the aggregate to provide this film thickness the following experiments were made.

Bituminous mixtures with various bitumen contents were prepared, in the manner described below, using 70 grams of crushed white marble passing a No. 8 and retained on a No. 10 sieve, and 150 penetration Raman asphalt and placed in Petri dishes. After cooling they were covered with water and measurements were taken with the photoelectric apparatus. The bulb currents I to yield 5.00 μA cell current were recorded with each sample. The results, as shown in Fig. 6, revealed that 8 percent of bitumen, i. e. 5.6 grams for 70 grams of aggregate, provided the minimum film thickness. For routine work we specify, however, that 7 grams of bitumen should be used for 70 grams of aggregate, to be on the safe side when testing more porous materials.

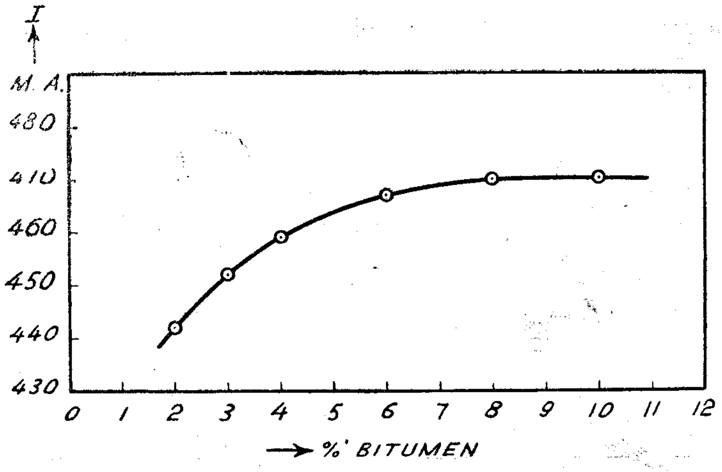

Fig. 6: Bulb Current Plotted Versus Bitumen Content

Procedure

The aggregate to be tested is screened through a No. 8 and a No.10 sieves. The fraction retaining on No. 8 sieve is crushed until all passes this sieve, combined with the original aggregate passing No. 8 and retained on No. 10 sieves, washed on a No. 10 sieve and dried at 105°C. Four representative samples, each weighing 70 grams, are taken from this. Two of them are heated in porcelain casserols in an oil bath at 90—95°C.

Two samples of bituminous material each weighing 7 grams are heated in porcelain casserols in 9 cms. diameter and 5 cms. depth in the same bath. Then, the hot aggregates are poured in these and mixed well for 5 minutes with glass rods. After keeping in an oven at 60°C for 5 hours the mixtures are transferred to two Petri dishes in 9.5 cms. diameter when they are still hot, and evenly laid with a spatula. One of them is covered with distilled water and placed in an oven at 60°C without cover. About 15 minutes later its cover is replaced and it is kept in the oven for 24 hours. The other bituminous mixture is kept as it is at room temperature.

At the end of 24 hours the stripped sample is cooled at room temperature. The water in the dish is renewed until it is clear. The other bituminous mixture is covered with distilled water. The original aggregate which weighs 70 grams is placed in a third Petri dish and covered with distilled water.

One half of the fourth aggregate sample is coated hot with 3.5 grams of a 20—30 penetration asphalt. When it is cool, it is mixed with the other half in the same volume ratio to give a mixture weighing approximately 70 grams. This mixture is also placed in a fourth Petri dish and covered with distilled water *. Now, all four samples are ready for measurement.

The table height and battery voltage are so adjusted that when measurements are taken with the original aggregate and original bituminous mixture the bulb currents I_1 and I_2 should fall into the calibration range in Fig. 3, and at the same time the difference $I_2 - I_1$ should be as large as possible. The dish containing the original aggregate is placed in the apparatus.

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* The floatation can be avoided by pressing the grains downwards by means of a disc made of No. 10 wire gauze to fit into the dish while filling the dish with water.

The door is closed and the rheostat R is set to full resistance. First the switch A_P, then A_L is closed. Now, a small deflection is observed on the galvanometer G. R is adjusted to make this deflection 5.00μA. Then, the current I_1 indicated by the ammeter A is recorded The switches are opened and the same measurements are made with the stripped sample, the mixture of $s = 50$ and original bituminous mixture in turn and corresponding bulb currents I, I′ and I_2 are recorded. All four measurements are repeated in the same order until reproducible readings are obtained.

The values of F_1, F, F′ and F_2 corresponding to the currents I_1, I, I′ and I_2, respectively, are read off the curve in Fig.3. s' and C are then calculated by eqns. (13) and (29), respectively, and the corrected s value is found from the curves in Fig. 5.

Discussion of Errors

It can be shown from eqns. (27), (29) and (13) that the error in s determined in the vicinity of $s=50$ is

$$|\Delta s| < \frac{2\,|\Delta F|}{F_1 - F_2}\,100 \qquad \cdots\cdots\cdots\cdots (30)$$

where ΔF is the possible error in F. Since we always make $F_1 - F_2 \cong 100$, from (30) we obtain

$$|\Delta s| < 2\,|\Delta F| \qquad \cdots\cdots\cdots\cdots (31)$$

The bulb current could be read as accurate as ± 1 M. A.. According to the calibration curve in Fig. 3 this corresponds to $\Delta F = \pm 1$ in the middle of calibration range. Then from (31) we find $|\Delta s| < 2$. Apart from this a systematic error due to the uncertainty in the calibration curve is involved in s. This uncertainty in the smoothed curve corresponds to an error of ± 0.5 in F. Therefore, the total maximum error in s amounts to ± 3.

Reproducibility of Results

The results of four parallel stripping tests made with the same limestone aggregate and 150 penetration Raman asphalt are given in Table V.

Table V

Sample No.	s
1	58
2	58
3	59.5
4	58
Mean	58 5

These measurements were made with the same reference samples and four different stripped samples. It will be seen that the individual results do not differ from the mean by more than 1 which is within the reproducibility of the estimation method (± 2) calculated above. In other words the samples prepared and subjected to stripping under the same conditions exhibit the same percentage of stripping within the estimation errors

Summary

A stripping test is performed by many laboratories to evaluate the stability of bituminous mixtures in the presence of water. Since the test is based on a visual estimation, the results are subject to considerable errors.

In order to eliminate the errors of the eye, a comparative photoelectric method has been developed. In this method we virtually determine the ratio $(\phi_1 - \phi)/(\phi_1 - \phi_2)$ where ϕ_1, ϕ and ϕ_2 are the reflected flux of light by the original aggregate, stripped sample and the aggregate completely coated with bitumen, respectively, placed in containers of the same exposed surface area, under constant illumination. If the total light reflected by a mixture of two types of surfaces were additive of those reflected by each type individually, this ratio would give the required surface fraction of the aggregate coated with bitumen in the stripped sample. We found, however, that this was not the case with granular samples and that a correction term should be subtracted from the above ratio to obtain the actual surface fraction.

The estimated experimental error in the surface percentage determined is ± 3.

The limitations are such that the aggregate to be tested should not be transparent and that the bituminous material to be used should be either a penetration grade asphalt or the distillation residue of a road oil.

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