

"BITUMINOUS MIXTURES"

by

HOWARD M. W. CROESER



DECLARATION.

I declare that this dissertation is my own work and that it has not been submitted as a dissertation for a Master's degree of another University.

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University of the Witwatersrand,
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November 20th, 1944.

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BITUMINOUS MIXTURES
WITH SPECIAL REFERENCE TO

- (i) THE COMMINUTION CHARACTERISTICS OF THE MINERAL AGGREGATE INGREDIENT;
- (ii) THEIR STABILITY CHARACTERISTICS;
- (iii) THE FILLERIZATION CHARACTERISTICS OF THE BITUMINOUS BINDER COMPONENT.

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BITUMINOUS MIXTURES.

PART I.

THE COMMINUTION CHARACTERISTICS OF THE MINERAL AGGREGATE INGREDIENT.

CHAPTER I.

INTRODUCTION.

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The writer has observed that some considerable degree of crushing of road aggregates takes place during rolling and under traffic, particularly when a low grade aggregate is employed.

It appears that during consolidation by the roller and by subsequent traffic, the aggregate is shuffled about, the sharp edges on stones are ground off, and fracture occurs. Stones which are initially sharp-edged and flaky, become rounded and cubical, while the tendency is towards orientation of the component fragments into positions of stable equilibrium and towards a progressive increase of the internal stability of the mixture.

The crushing of aggregates in a road has been systematically investigated by Allison (7), Endersby (41), Goldbeck (58), Macnaughton (103), Pauls and Goode (124), and Shelburne (144) in the United States, by Wilhelmi (184) in Germany, and by Mathieson and Gawith (107) in Australia. Observations have also been made by Hanson (61) in New Zealand, by Knight (88) in South Africa, and by Wilson (185) in England.

Mathieson and Gawith report that the aggregate in a road bed, unless prevented from movement by a rigid mortar like Portland Cement, moves under traffic, causing a certain amount of attrition and fracture. Endersby believes that such

break-down results unfavourably in the reduction of size and perhaps also of the stability due to the large particles, but favourably in the production of a denser grading and more angular particles and flat faces, facilitating further compaction.

Pauls and Goode illustrate that direct compression of road aggregates results in crushing sufficient to alter materially the original grading of the aggregates. By compacting laboratory specimens of bituminous mixtures both by direct compression and by means of a high frequency tamper, Macnaughton, too, has found that a large amount of crushing of aggregate particles takes place.

Shelburne reports a series of studies on the degradation produced by road rollers in compacting typical surface-treatment aggregates both on a bituminous mat and on a concrete base. His results show that the degradation of aggregates under conditions of mixing, rolling, and traffic, approaches a maximum density curve as an ultimate.

Wilhelmi and other investigators have shown that dry screenings and asphaltic mixes, when subjected to repeated compression or to compaction by repeated blows while confined in a mortar, approach in their gradings straight lines having slopes between $\tan \frac{1}{2}$ and $\tan \frac{1}{3}$.

Mathieson and Gawith sampled some road sections, six months after construction and have found that what was originally an open grading approached the grading of asphaltic concrete. This observation shows good collation with that of Knight, who found that within a few years 20 per cent of the particles in a section of heavily trafficked road in Sophiatown (Johannesburg) were reduced from chipping size to -100 size.

The writer has studied the comminution of road aggregates in bituminous mixtures and in the uncoated state both in the laboratory and in the field. Continual inspection of roads in the Witwatersrand area has led to the conclusion that,

while the crushing of the aggregate in a road bed may render the surface susceptible to ravelling owing to the formation of uncoted areas of aggregate in the mixture, it may produce quite the opposite effect: it is possible that the closer gradings formed during degradation may lead to increased stability due to the cohesion of the bituminous binder, since a larger area of adhered surfaces between particles is produced.

It has been the repeated observation of the writer that road surfaces with open gradings may attain highly desirable characteristics in the process of comminution. Stones which are reduced to fragments by the roller and by traffic, form dust which is injected into the binder, thus giving rise to a stiffened binder-filler mixture. Attrition and fracture of the aggregates in direct contact with traffic produce particles which combine with the filled binder, producing further stability. Provided that conditions are favourable, such a surface may eventually become a smooth and stable mosaic which is impermeable to moisture and resistant to ravelling and rutting.

CHAPTER II.

NOTES ON THE GEOLOGICAL FEATURES OF ROAD AGGREGATES.

For a complete understanding of the comminution of road aggregates, a study of their geological characteristics is essential.

Knight (82) has shown conclusively in "Road Aggregates" that a microscopic study of a stone as well as a thin section analysis is an absolute necessity for correct interpretation of its behaviour in physical tests and in service. A study of this work may be supplemented by a perusal of Stiny's book (161) which deals fully with the particle size determination of minerals and with microscopic and chemical investigations.

Choice of Aggregates.

After an examination of the road stones which occur in the Union of South Africa had been made, five types were selected which range from fair to excellent in their structural strengths and are representative of the aggregates employed in South African road building practice.

A brief description of the five aggregates chosen by the writer for his researches, follows below.

1. Witwatersrand Quartzite.

The quartzite used in the investigations was selected from an East Rand source which lies in the Witwatersrand System. From the viewpoint of structural strength and mineralogical composition it is a typical example of the type of aggregate used on many of the roads and streets on the Reef.

Petrological Character:- The rock is coarse-grained and contains about 85 per cent quartz, the grains being uniform in size. Abundant bubble inclusions and minute cracks are visible in the quartz particles. Chlorite and muscovite occur

in small quantities.

The rock is relatively resistant to hammer blows on an anvil owing to the hard, well-interlocked quartz grains.

2. Orange Free State Dolerite.

The dolerite was obtained from a quarry in the Beaufort Series of the Karo System.

Petrological Character:- The dolerite is a fine-grained rock and contains labradolite felspar laths enwrapped in augite in a manner known as ophitic. The plagioclase and the pyroxene minerals each constitutes about 50 per cent by volume of the rock.

As a result of the excellent interlock of its fine-grained, tough constituents, the dolerite is exceptionally resistant to impact in chipping size.

3. Amygdaloidal Basalt.

The basalt was quarried from a sill in the Ecca Series of the Karo System.

In thin section the basalt appears as a highly altered rock, none of its original minerals remaining unaltered. Some highly altered augite is present but no primary quartz. Chlorite and secondary silica occur as a mixture.

The basalt deposit contained a small amount of quartz amygdaloids which were separated from the basalt in the laboratory and discarded.

The rock is fine-grained and is so tough that it emits an almost metallic sound when fractured by means of a light hammer on an anvil.

4. Transvaal Dolomite.

The dolomite, which occurs in the Pretoria Series of the Transvaal System, has been investigated in detail by Kupferburger (91). The rock is blue-grey and finely crystalline, displaying small intergrown crystals of dolomite when examined in thin section under the microscope.

5. Norite.

This rock belongs to the Bushveld Lopolith in the

Pretoria Series of the Transvaal System and has been described by Lombard (28), du Toit (32), and Laburn (32),

In general the morite is medium-grained and remarkably uniform in character, similar to a granite in appearance, but showing a certain amount of orientation of the crystals of felspar and augite. The essential mineral constituents are labradorite, diagenite, and hypersthene. Small quantities of biotite, magnetite, hornblende, apatite, and quartz are present as accessory minerals.

The writer has shown that if morite is finely crushed and the crushed particles sieved after separation in bromoform, a larger percentage of the brittle felspar is reduced to dust than the more resistant pyroxene.

Partridge (123) used a bromoform separation method to analyse morite and determined a felspar content of 60 per cent and a pyroxene content of 40 per cent. (Knight (83) used the same method in England to separate heavy and light crop minerals. It is a more accurate method than that of areal measurement by means of the Shand integrator.)

CHAPTER III.

SUCCESSIVE CRUSHING.

It is common knowledge that road aggregates break down in size during the processes of mixing and roller compaction. The results of periodic sampling of bituminous mixtures by previous investigators have indicated that progressive degradation of the aggregates is also produced by traffic.

A mass of stone in a confined space will, when subjected to repeated pressure, assume a grading which is best suited for that particular stone and which provides maximum inherent stability.

It has already been observed by Rothfuchs (136) and by Wilhelmi (184) that when a quantity of dry screenings is subjected to maximum consolidation by impact or compressive stresses, a definite particle grading - the "natural" grading - automatically results.

Since most road mixtures contain at least 90 per cent of stone by weight, a study of the comminution characteristics of uncoated aggregates should be valuable in the investigation of the reduction in size of aggregates which occur in bituminous mixtures. The writer accordingly developed a crushing test for dry stone and also used this test to crush binder-coated aggregates.

Experimental Procedure.

Scope:-

1. This method of test was intended for determining
 - (a) the change in grading of a crushed aggregate, and,
 - (b) the extent to which compaction occurred during crushing.

Apparatus:-

2. (a) A cylindrical thick-walled steel mould 2 in. internal diameter and $4\frac{1}{2}$ in. high, which could be split longitudinally to facilitate removal of its contents. A collar was fitted round the outside of the mould to prevent relative movement of its components. The plunger was 1.98 in. dia. and $4\frac{1}{2}$ in. long, while the detachable base plate was 4 in. square.

(b) A universal testing machine.

(c) A balance of 10 K.gm. capacity sensitive to 0.1 gm.

(d) A dial gauge, graduated in thousandths of an inch, suitable for measuring the vertical height of the specimens before and after compression.

(e) Miscellaneous equipment including mixing bowls, spoons, etc.

Preparation of Sample:-

3. A representative sample of the crusher-run stone to be tested was oven-dried to constant weight at 100°C to 110°C . The dried material was sieved on standard sieves, sorted by means of flakiness and elongation gauges, and proportioned to suit the test in hand.

Method:-

4. (a) A 200 gm. test sample was weighed into a mixing bowl to an accuracy of 0.1 gm.

(b) The stones were lightly tamped into the mould, a few at a time, by means of a dessert spoon.

(c) The height of the specimen was measured and the void space calculated.

(d) With the piston in position, a compressive force of 2500 lb. per sq.in. (unless otherwise stated) was applied to the stone mass.

(e) After compression the height of the specimen was measured and the void space again determined.

(f) The mould was split, the contents sieved, and the sieve fractions weighed.

Successive Crushing:-

5. The sieved material was mixed uniformly and replaced in the mould, a little at a time, by means of a dessert spoon. The compression and sieving operation was repeated until the stones had been subjected to 16 successive cycles of crushing.

Crushing Ratio.

For a sensitive determination of the reduction in size after crushing, it was necessary to evolve a crushing formula which would evaluate correctly all the fragments fractured during crushing.

A perusal of the literature on the subject showed that such a formula had already been given some thought. The Road Research Institute at Milan (27.b) tests stone chippings by subjecting them to rolling on a plain, rigid surface, and calculate the crushing from a "crushing co-efficient", F.

$$F = \frac{100}{A} (nA - na - (n-1)b - (n-2)c - (n-3)d - \dots - s),$$
 in which n is the number of sieves employed, A is the total weight of material tested, and a, b, c, d, ..., s the respective weights of material retained on the sieves.

In a strength test of aggregates by means of a 14 Kgm. tup falling on selected stone placed on an anvil, the Swedish Road Institute at Stockholm (159.a) calculates a "coefficient of brittleness" by summing the percentages of material passing each sieve.

The result of the freezing and thawing test for soundness of aggregates (conducted in Kansas (56)) is expressed as the ratio of the sum of the cumulative percentages retained on each of the sieves after freezing and thawing, to the sum of the cumulative percentages before the test.

The writer has made use of a "crushing ratio" which is defined as the ratio:

The sum of the cumulative percentages retained on each of the sieves (given below) after crushing.
The sum of the cumulative percentages retained on each of the sieves before crushing.

The sieves referred to above, are the following:

Standard Tyler Designation	Size of Aperture in Inches
$\frac{1}{2}$ in.	0.525
$\frac{3}{8}$ in.	0.371
No. 4	0.185
No. 10	0.065
No. 35 (U.S. No. 40)	0.0164
No. 100	0.0058

For material which has not been crushed at all, the formula gives a crushing ratio of 1.0; if $\frac{1}{2}$ in. + $\frac{3}{8}$ in. material undergoes sufficient disintegration for it all to pass the No. 100 sieve, the crushing ratio is $\frac{0}{500} = 0$. It was stated that a formula for crushing should be sensitive and this is true for the writer's crushing ratio: a quantity of $\frac{1}{2}$ in. + $\frac{3}{8}$ in. cubical aggregate which had been crushed only once in a jaw crusher and was sharp-edged, gave a crushing ratio of 0.86 when tested in the crushing test. A sample of the same size and shape, however, which had been passed through the crusher continuously until the particles were rounded, gave a crushing ratio of 0.83, a difference of over 3 per cent, showing that the rounded aggregate was somewhat more resistant to comminution.

Flakiness and Elongation.

The sensitivity of the crushing test to differences in the shape of an aggregate necessitated that a distinction be made between cubical, flaky, and elongated particles. For the separation of crushed and sieved stone into the three predominant shapes, the gauges described in B.S.S. 812-1938 (24) were used.

Flaky particles are defined as those passing through the standard thickness gauge. Cubical (angular) particles are those which pass through the standard length gauge and are retained on the thickness gauge, while elongated particles are

retained on the standard length gauge and on the thickness gauge.

SUCCESSIVE CRUSHING.

Two hundred gms. sorted - $\frac{1}{2}$ in. + $\frac{3}{8}$ in. cubical dolomite was subjected to the successive crushing test described before.

It was noticed that the density of the crushed specimen increased until, eventually, there was no measurable increase. The results are given in figure 1 and table I, from which the following results are apparent:-

(i) In general, the areas between successive grading curves and thus the crushing ratios, too, decrease progressively from cycles 1 to 16, until ultimately

(ii) gradings are reached at which little crushing and only a small increase in density take place during the compaction process.

Conclusions:-

(a) Open gradings break down more than dense gradings since the latter provide larger areas of contact and consequently better load distribution.

(b) The aggregate tested possesses a maximum density grading which also represents a stable grading, in so far as it does not alter much under pressure.

The Effect of the Type of Stone.

The previous test was repeated with - $\frac{1}{2}$ in. + $\frac{3}{8}$ in. cubical norite, dolerite, quartzite, and basalt. The results shown in figure 2 and table II illustrate the following:-

(i) The shapes of the grading curves of norite, dolomite and quartzite are approximately similar after 16 cycles of successive crushing.

(ii) The final gradings of basalt and dolerite are coarser than the gradings of the other three aggregates which contain more fines.

Conclusions:-

(a) The basalt and dolerite are more resistant to reduction

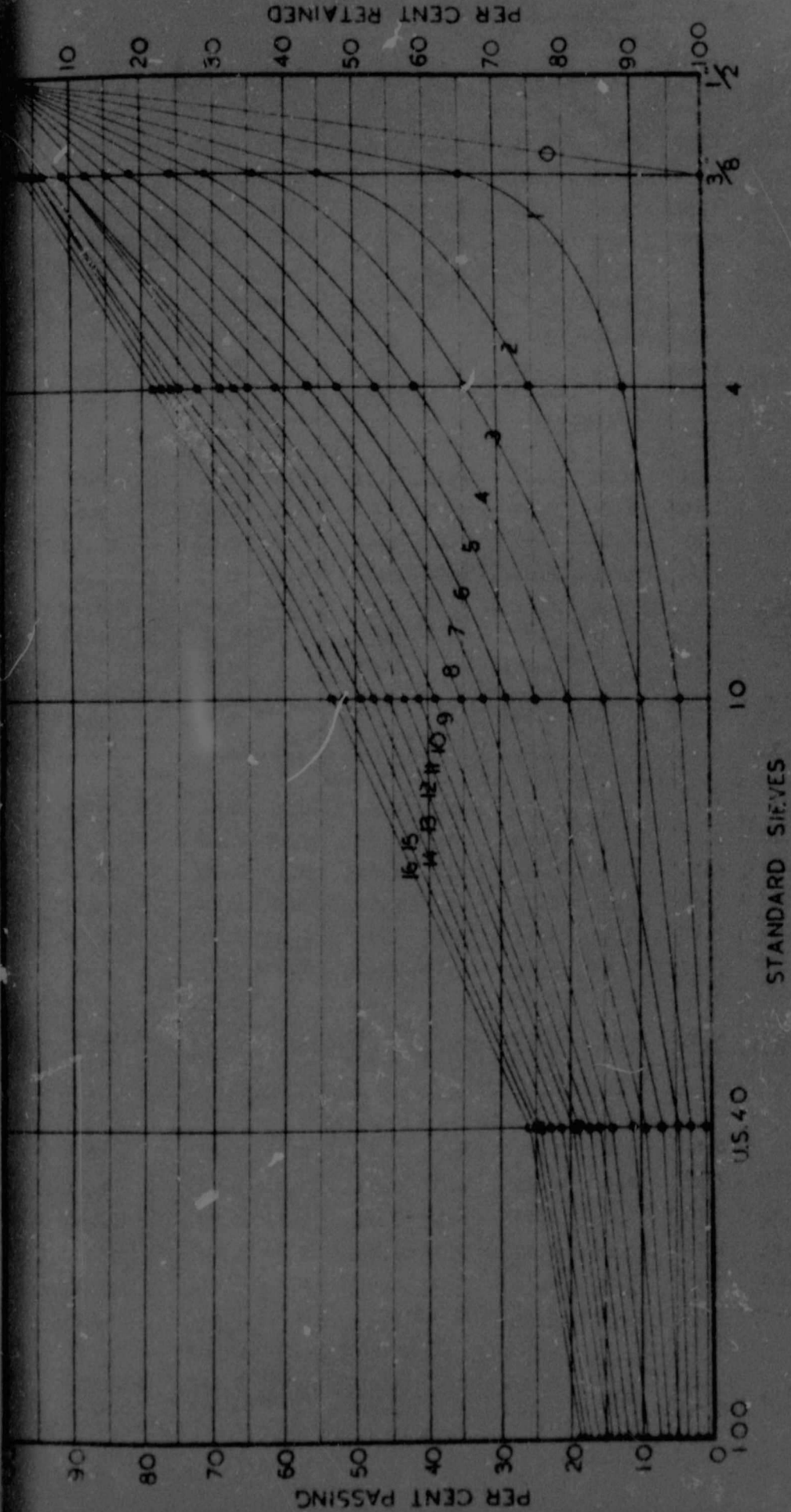


FIGURE 1. Successive Crushing of $\frac{1}{2}$ " $\frac{3}{8}$ " Dolomite.

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