## CHAPTER VI.

## ROAD AGGREGATES OBEY RITTINGER'S LAW DURING CRUSHING.

A mathematical analysis of the fracture of aggregates has been attempted by Koster (89). He suggests that fracture is not determined by a definite load but by a definite rate of deformation. In a crushing operation the crystal lattice providing cohesion in a rock must be elastically deformed. Koster maintains that even the most brittle substances will adjust themselves to a load which is applied sufficiently slowly, and fracture will not occur until the rate of load application or deformation has reached a certain amount.

Thus crushing depends upon the rate of load application and it can be stated that the energy required to produce fracture will be less with rapidly applied loads. This is probably the reason why impact crushing produces less fines than slow compressive crushing. (See also 15.a). The impact crusher gives more cubed particles than gyratory crushers which tend to produce flats and elongations.

Investigations concerned with the relationship between the size distribution of the feed and the product from primary crushers, have engaged many workers. Sheppard (149), found that at the same crusher setting the product from crushing friable stone contained more fines than the product from crushing hard, tough stone. These observations have been substantiated by the writer who has found that in a jaw crusher dolerite and basalt were more resistant to reduction in size than dolomite, quartzite, and norite, respectively. It has also been shown with sieve analyses of the crushed material that, for the same crusher setting, more fines are produced by the less resistant stones.

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Many investigators have attempted to explain the mechanism of crushing, the work of Fahrenwald (44) and Gaudin (50) being especially worthy of mention. Gaudin classifies rocks, from the point of view of comminution, into two general classes, (a) those which are structurally homogeneous (fracture takes place through grains and grain boundaries alike); and (b) those which are structurally heterogeneous (fracture passes in preference through grain boundaries). Reference is made to Heultein's slow-motion moving pictures which indicate how cubical blocks are broken in rolls.

Miller and Serjant (107 a) have studied the abrasive character of rocks affecting crushing machinery, and conclude that the abrasive value of a rock is indicated best by a consideration of the crushing strength and impact value.

The establishment of a law of crushing is recognised as being of primary importance. Von Rittinger stated a law of crushing as follows, in 1867:

"The energy necessary for reduction of particle size is directly proportional to the increase of surface (173)."

Rittinger's law, which was deduced from rather crude observations, may be assumed to have been definitely proved by Martin and co-workers (106), Gross and Zimmerley (60), and by Dean, Gross, and Wood (31).

A controversy arose when Kick (80) introduced his crushing law which states that

"Equal changes in configuration demand equal output of work."

Thus to reduce a cube of edge $x_f$ to cubes of edge $^{x_f}/_{2^n}$ would demand n times as much work as to reduce it to cubes of edge $^{x_f}/_{2}$. It would seem, however, that Gaudin, Gross and Zimmerley (53) have shown experimentally and graphically that Kick's hypothesis cannot possibly hold.

## INVESTIGATION OF THE RITTINGER LAW OF CRUSHING.

New light has been thrown on the Rittinger law of crushing by its employment by the writer for the elucidation of comminution phenomena in the breakdown of road aggregates.

From observations of the crushing of five types of road aggregate under variable compressive force, the writer feels justified in stating that Rittinger's law has been proved to hold under certain conditions. (Only the tests under constant load will be treated here.)

The results of the successive crushing tests in chapter III serve as excellent examples for this study. It has been explained how -½ in. + 3/8 in. cubical stones were crushed in a 2 in. dia. steel cylinder under 2500 lb. per sq.in. for 16 cycles in succession. (See p.11).

Surface Area Calculations.

The literature dealing with surface area determinations was reviewed for an understanding of the factors involved, whence a method was developed for the calculation of surface area factors.

Most of the methods thus far employed for surface area measurements have been devoted to the evaluation of the properties of materials in the subsieve range. Schwoyer and Work (142.a) have briefly reviewed the methods that have been proposed to measure these properties, which include analyses by means of the microscope, ultramicroscope, centrifuge, supercentrifuge, elutriator, turbidimeter, and by means of sedimentation, adsorption, and permeability.

It has been realized that the work expended on subsieve sizes during a crushing operation represents a very large part of the total work input. For the determination of the surface area, therefore, the various assumptions as to whether the particle shape approximates to the sphere, the parallelepiped or the cube, play a subordinate role. The important factor is the particle grading in the range of the finest particles, particularly when the fine material occurs in relatively large amount. It will be noticed that the proportion of fines in the materials crushed by the writer, was relatively low.

In computing the work done in crushing, it is necessary to establish surface area factors. The "average size" of -200 mesh material has frequently been taken as 0.037 m.m. (50), i.e. half the aperture of the Tyler 200-mesh screen. The procedure of assigning a definite diameter to the -200 mesh material has been rejected by Bond and Maxson (20), since it is known that different samples, all of -200 mesh, might have widely different grain diameters. Instead, the "median diameter" method has been developed.

Surface Area Factors.

The values used by the writer for the calculation of surface area are shown in table VIII, the values for the different types of stone being related to each other by the ratios of their specific gravities. These surface area factors show good correlation with those selected by Shelburne (144). He assumed that all the material passing the No. 4 sieve was spherical, and that that retained was one-third cubes and two-thirds parallelopipeds with sides of 1:2:4 proportions.

Graphical Representation of Rittinger's Law.

Using the surface area factors in table VIII and the data of the successive crushing tests described in chapter III, surface area figures were calculated. Table IX is an example showing the first three cycles for the crushing of basalt in detail.

In figure 17 the number of cycles of crushing has been plotted against the surface area increase in sq.cM. per gm.

Results:-

(i) A series of straight lines results from the plotting of the calculations.

(ii) For each aggregate tested, there is a straight line relation up to a certain point, here called the "change point", at which stage another straight line relation comes into effect for all the aggregates except norite.

(iii) The dolerite and basalt lines lie relatively close to each other and so do the norite, dolomite, and quartzite lines.

Conclusions:

(a) The slopes of the first series of lines, i.e.

TABLE VIII SURFACE AREA FACTORS.

| FRACTION OF MATERIAL | TYPE OF AGGREGATE | | | | |
|---|---|---|---|---|---|
| | DOLERITE | BASALT | DOLOMITE | QUARTZITE | NORITE |
| | SPECIFIC GRAVITY | | | | |
| | 3.00 | 2.83 | 2.87 | 2.65 | 3.02 |
| | SURFACE AREA FACTORS IN SQ. CM. PER GM. | | | | |
| -½" + 3/8" | 1.94 | 2.06 | 2.03 | 2.20 | 1.93 |
| -3/8" + No.4 | 3.53 | 3.74 | 3.70 | 4.00 | 3.51 |
| -No.4 + No.10 | 7.06 | 7.49 | 7.40 | 8.00 | 7.02 |
| -No.10+U.S.40 | 24.70 | 26.20 | 25.85 | 28.00 | 24.60 |
| -U.S.40+No.100 | 88.30 | 93.60 | 92.40 | 100.00 | 87.80 |
| - No. 100 | 353.00 | 374.00 | 370.00 | 400.00 | 351.20 |

TABLE IX THE EFFECT OF THE NUMBER OF CYCLES OF CRUSHING ON THE SURFACE AREA INCREASE OF BASALT.

(NOTE: For the sake of brevity, only the first three cycles of crushing of basalt are shown for illustration of the method of calculation).

| CYCLE NUMBER | STANDARD SIEVES | % By Wt. Ret. | Area Factors in sq. cms.per gm. | Surface Area in sq. cms. | Surface Area increase in sq.cm./gm. |
|---|---|---|---|---|---|
| | 3/8" | 74.1 | 2.06 | 152.7 | |
| | No. 4 | 17.5 | 3.74 | 65.5 | |
| | No.10 | 5.0 | 7.49 | 37.4 | |
| 1 | U.S.40 | 2.3 | 26.20 | 60.3 | |
| | No.100 | 0.6 | 93.60 | 56.2 | (559.1-206)/100 |
| | - 100 | 0.5 | 374.00 | 187.0 | |
| | | 100.0 | | 559.1 | = 3.5 |
| | 3/8" | 57.8 | 2.06 | 119.1 | |
| | No.4 | 25.4 | 3.74 | 95.1 | |
| | No.10 | 10.0 | 7.49 | 74.9 | |
| 2 | U.S.40 | 4.9 | 26.20 | 128.3 | |
| | No.100 | 1.0 | 93.60 | 93.6 | (847.6-206)/100 |
| | - 100 | 0.9 | 374.00 | 336.6 | |
| | | 100.0 | | 847.6 | = 6.4 |
| | 3/8" | 44.3 | 2.06 | 92.4 | |
| | No.4 | 30.5 | 3.74 | 114.0 | |
| | No.10 | 14.7 | 7.49 | 110.1 | |
| 3 | U.S.40 | 7.1 | 26.20 | 186.0 | |
| | No.100 | 1.6 | 93.60 | 149.7 | (1138.4-206)/100 |
| | - 100 | 1.3 | 374.00 | 466.2 | |
| | | 100.0 | | 1138.4 | = 9.[illegible] |

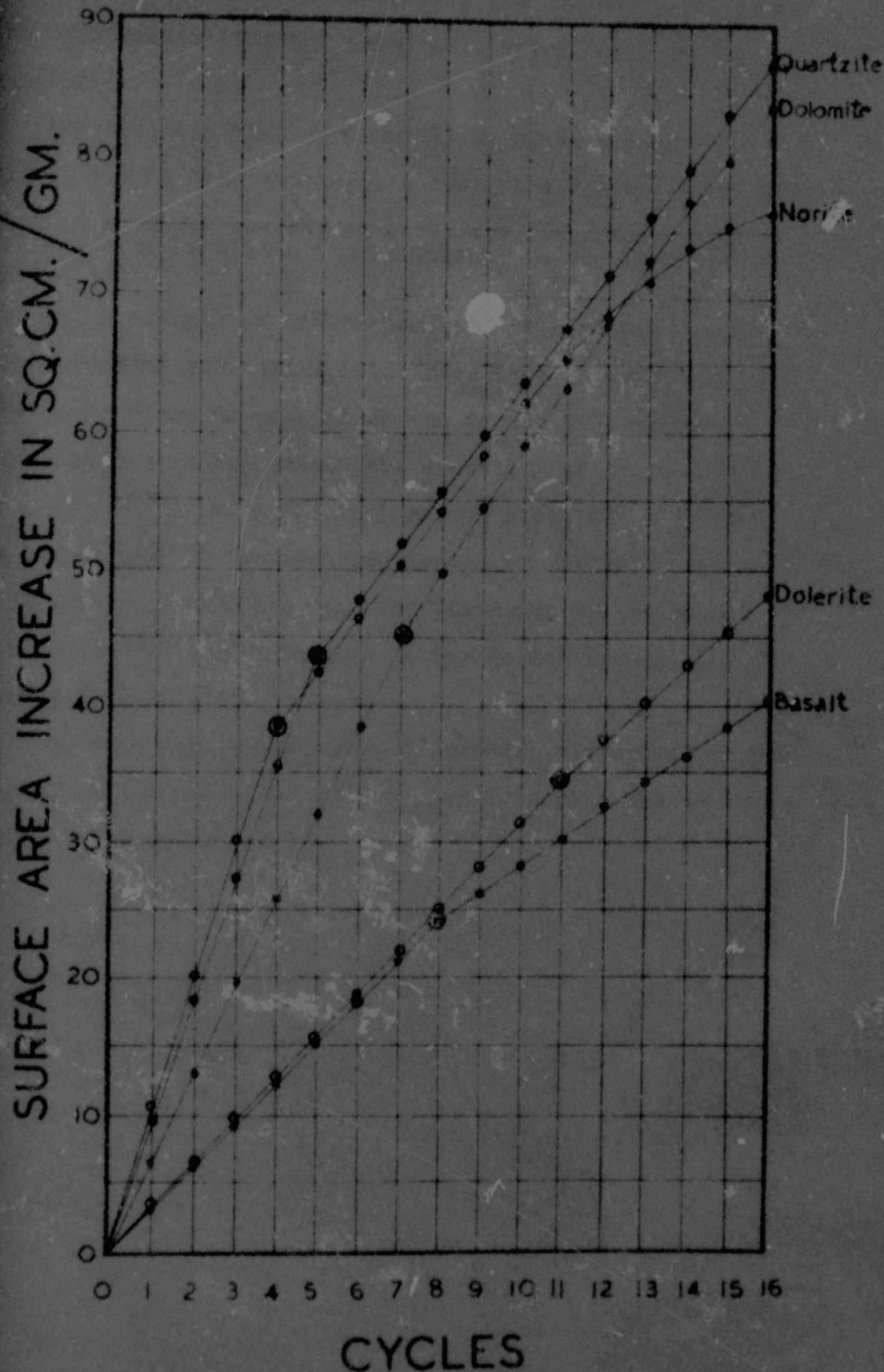


FIGURE 17. Relation between Number of Cycles of Crushing and Surface Area Increase.

those from the origin to the "change points" indicate the crushing susceptibilities of the aggregates. They lie in the order (1) basalt, (2) dolerite, (3) dolomite, (4) quartzite, (5) norite from the point of view of resistance to crushing.

(b) The fact that straight lines emanate from the origin, proves that Rittinger's law holds for the five aggregates, i.e. that "the energy necessary for reduction of particle size is directly proportional to the increase of surface (173)".

(c) A perusal of the "change point" gradings and the Fuller grading in table X, discloses that the gradings are relatively close to each other and to the Fuller grading. Since the latter represents the densest grading possible for stone of $-\frac{1}{2}$ in. + 3/8 in. maximum size, the Rittinger law seems to hold for the comminution of uniformly-sized stone during successive crushing (as described in Chapter III), until a grading approximating to the Fuller grading has been reached.

(d) From the "change point" onwards, different straight line relationships come into being; for norite the new relationship follows a curve.

**TABLE X "CHANGE POINT" GRADINGS.**

| | TYPE OF AGGREGATE | | | | | |
|---|---|---|---|---|---|---|
| | Dolerite | Basalt | Dolomite | Quartzite | Norite | FULLER GRADING |
| | NUMBER OF CYCLE | | | | | |
| SIEVE FRACTIONS | 11 | 8 | 7 | 5 | 4 | |
| | Quantities as Percentages by Weight | | | | | |
| -½"+ 3/8" | 16.0 | 17.5 | 15.3 | 26.2 | 13.5 | 16 |
| -3/8"+No.4 | 33.5 | 36.4 | 28.3 | 21.9 | 30.6 | 25 |
| -No.4+No.10 | 22.1 | 21.8 | 24.1 | 19.8 | 21.0 | 24 |
| -No.10+U.S.40 | 17.1 | 16.3 | 18.6 | 19.2 | 21.5 | 17 |
| -U.S.40+No.100 | 4.1 | 4.0 | 4.7 | 6.2 | 6.6 | 7 |
| -No.100 | 7.2 | 4.0 | 9.0 | 6.7 | 6.8 | 11 |
| Per Cent - No.10 | 28.4 | 24.3 | 32.3 | 32.1 | 34.9 | 35 |

## CHAPTER VII.

### A CORRELATION OF THE FIELD BEHAVIOUR OF ROAD AGGREGATES WITH LABORATORY FINDINGS.

The degradation of aggregates during the rolling of road surfaces often frustrates the results contemplated in the design. The formation of new surface area consequent on the breakage of the stone in a bituminous mixture may result in a lean mix lacking sufficient coating and susceptible to ravelling under traffic.

If the amount of comminution likely to occur be known prior to construction, due allowance may be made in the design for the extra surface created. Conversely, a denser grading of aggregate may be adopted if an open grading of the particular aggregate causes excessive crushing.

The degree of breakdown in any road stone under the roller may be predicted in advance by making use of the crushing test, designed by the writer and described in the preceding chapters. It is, however, necessary to correlate beforehand the service conditions with the crushing test.

Since the writer's crushing test is carried out on a rigid base using a relatively small amount of aggregate confined laterally in a rigid steel cylinder and compacted by uniform compression, a study of the disintegration of stone particles under road rollers becomes an investigation of the effect of a variation in these factors in practice. The base is not necessarily rigid, except in the case of a concrete foundation. The superficial area of the aggregate undergoing compaction is usually relatively large, and lateral spread of the material is often possible. Moreover, a kneading action takes place under the roller allowing for orientation of the stone particles.

Review of the Literature.

The Function of the Roller.

Gray (59.a) has furnished an answer to the question

"What is rolling?" The function of the roller is to apply such pressure on a road surface that subsequent traffic stresses are unlikely to produce further distortion. In the case of surface treatment, rolling assists bonding of the aggregate and reduces the inconvenience to traffic by permitting the use of quickly drying bituminous materials. In general, the roller should be heavy enough to compact the aggregate without crushing it: for hard, tough aggregates heavy rollers up to say 14 tons are permissible. It has been suggested that chippings might be set very firmly in position if a rubber-tyred roller were employed, but the cost of fitting a roller in this way is prohibitive, in view of the limited use of such a machine (76.a). The disadvantages of using ordinary pneumatic-tyred vehicles for compaction is the rutting that is often caused by the relatively narrow tyres.

Research on the Rolling of Aggregates.

In 1926 the U.S. Bureau of Public Roads undertook a study of construction methods on bituminous concrete highway projects (134.a). In studying finishing operations, the basis of comparison was the "rolling factor" =

$$\frac{\text{Wheel width} \times \text{total distance covered}}{\text{Area of section covered}},$$

roughly representing the number of times each unit area was traversed by a roller wheel. With regard to the reduction in thickness of base and surface courses, it is suggested that, in general, the weight of the roller and the number of rollings above a certain minimum have less effect on density than has the grading of the aggregate. It has been discovered that rolling for compaction should be longitudinal, and for smoothness, transverse.

A circular testing track was used by Goldbeck and Coworkers (58) to illustrate the resistance to crushing of aggregates under road rollers. After 200 passes of a roller over one inch layers of stone, the percentage passing a No. 4 sieve was used as an index of crushing. Tramper (168) tested the resistance of stone to breakage under rolling by means of a roller breakage test. The stone samples were rolled in a small rectangular box and a "breakage factor" was obtained. The disadvantages of these tests are that factors are encountered which do not appear in the field, including.

(i) a pronounced edge effect of narrow rollers,

(ii) the large angle of nip (144) of small diameter rollers, and

(iii) the twisting action induced by small diameter circular tracks.

The difficulties were surmounted by Shelburne (144) by finding the crushing produced by road rollers in compacting typical surface-treatment aggregates. Two types of bases were used,

(a) a flexible base, size 9 feet by 50 feet, consisting of a pre-mixed bituminous mat and

(b) a rigid base, size 8 feet by 50 feet, consisting of a concrete slab.

It was found that, on an average, 2.5 times more degradation took place on the concrete slab than on the flexible base when the degree of degradation was measured in terms of the increase in surface area of the aggregate.

<u>Field tests by the writer</u>.

Verification in the field under construction conditions was considered essential for conclusive proof of the laboratory results.

<u>Preparation of the Aggregates</u>:-

Five different types of aggregate, dolerite, basalt, dolomite, quartzite, and norite, were crushed in a jaw crusher until a large amount of -½ in. + 3/8 in. material was available. The flakes and elongated particles were discarded by using the gauges described in B.S.S. 812-1938 (24).

Wooden frames were prepared with ½ in. by 1 in. laths of Pinus Insignis, the purpose of the frames being to separate the different types of aggregate from each other under the roller. A soft wood was chosen because it would offer but slight resistance to vertical deformation while the stone was being crushed by the force, supplied by the weight of the roller. The frames were 6 in. square inside and one inch high.

The binder-coated aggregates were prepared by mixing the five types of aggregate with 1.5 per cent (by weight) of binder, two types of binder being used. The first, a 200 penetration straight-run bitumen, was chosen to represent a binder which is relatively viscous at normal atmospheric temperatures. The second, an RC - 2 cut-back bitumen was representative of a binder which was fairly fluid at normal atmospheric temperatures and would provide lubrication to the chippings during compaction.

The bituminous mixtures were placed into their respective containers in a loosely, compacted state before being transported to the testing site. The upper surfaces of the mixtures projected just above the upper level of the wooden frames, while the lower surfaces were flush with the framework.

Preparation of Foundation:-

The road base was constructed on a subgrade of satisfactory bearing value. An area 9 feet by 40 feet was selected for the laying of a water-bound macadam foundation composed of Reef quartzite, $-2\frac{1}{2}$ in. + 2 in. in size.

Placing of the Aggregates:-

The frames containing the bituminous mixtures were laid on the prepared base and the frames for the uncoated aggregates were placed in line with them. The centre line of the frames was parallel to the length of the foundation and about 2 feet from the edge nearer to it. The five types of aggregate, $-\frac{1}{2}$ in. + 3/8 in. cubical stones, were compacted loosely into individual frames with their upper surfaces just protruding above the frames and at approximately the same height as the bituminous mixtures.

An inferior quality Reef quartzite was spread over the remainder of the foundation. The quartzite chippings employed for this purpose were -¾ in. + ½ in. in size and were spread to a depth of approximately one inch (when loosely compacted), and were accordingly on a level just lower than the uncompacted test specimens. This procedure was adopted to facilitate the running of the roller and to maintain the back wheels of the roller on the same height during compaction.

Test Procedure.

A 10 ton Diesel roller was selected for these experiments. One of its back wheels was allowed to pass over the test specimens at a slow speed, and samples of the aggregates were taken at intervals.

Sampling:-

Samples of the crushed aggregates were taken by removing the total contents of the 6 in. by 6 in. specimens and replacing them with -¾ in. + ½ in. quartzite chippings to the same height.

(i) Uncoated Aggregates.

Samples were taken from all five types of uncoated aggregate after 2, 4, 8, and 16 roller passes. These were mechanically analysed in the laboratory with the object of illustrating the effect of the number of roller trips on the comminution of the aggregates. Comparisons between the different types of aggregate showed the effect of the type of aggregate on the amount of degradation under the roller.

(ii) Coated Aggregates.

It had been found in the laboratory that the temperature of the binder had an effect upon the crushing of aggregates in bituminous mixtures (see figure 9), so that in the field the temperature was as far as possible kept constant by working in the shade and by performing the work as quickly as possible.

After 4 roller passes the bituminous mixtures were removed and were extracted in the laboratory by means of benzol before the aggregate was analysed mechanically. A comparison was thus obtained between the effects resulting from the use of two types of binder possessing totally different viscosity charecteristics and also between coated and uncoated aggregates.

Results:-

Table XI is a typical example of the results obtained in the field, showing the analysis of the crushed uncoated dolerite, while table XII gives a comparison between crushed quartzite in the dry and in the binder-coated states after 4 roller trips.

Figure 18 shows the number of roller passes plotted against the crushing ratio, for all the uncoated aggregates.

The percentage surface area increase was calculated for all the uncoated aggregates (as shown in table XI) and represented against the number of roller trips in figure 19.

Conclusions:-

A. See figure 18.

(a) For all the aggregates tested the amount of breakdown increases with the number of roller passes.

(b) the curves indicate that the aggregates tested lie in the order dolerite, basalt, dolomite, quartzite, norite, from the point of view of increase in crushing susceptibility.

(c) in general, the curves are steeper for a small number of passes, proving that a larger amount of comminution occurs while the gradings are still open.

B. See figure 19.

(d) For all the aggregates tested, the surface area increases with the number of roller passes.

(e) The quartzite and norite curves are much steeper, relatively, than those for dolomite, basalt, and dolerite, indicating larger increases of surface in the former for the same crushing force.

(f) If the dolerite, basalt, and dolomite curves are extended, they intersect the values calculated for the percentage surface area increase after one cycle in the writer's crushing test at 17, 20, and 16 roller passes, respectively.

It would therefore appear that a single cycle of compression at 2500 lb. per sq.in. in the writer's crushing

TABLE XI. EFFECT OF NUMBER OF ROLLER PASSES ON CRUSHING RATIO AND SURFACE AREA INCREASE OF -½" + 3/8" DOLERITE.

| NUMBER OF ROLLER PASSES | STANDARD SIEVES | Cum.% Ret. | % By Wt. Ret. | Area Factors in sq.cms. per gm. | Surface Area in sq.cms. | % Surface Area Increase |
|---|---|---|---|---|---|---|
| | 3/8" | 94.5 | 94.5 | 1.94 | 183.5 | |
| | No.4 | 99.0 | 4.5 | 3.53 | 15.9 | |
| | No.10 | 99.9 | 0.9 | 7.06 | 6.4 | |
| 2 | U.S.40 | 100.0 | 0.1 | 24.70 | 2.5 | 208.3 |
| | No.100 | 100.0 | 0.0 | 88.30 | 0.0 | 194.0 |
| | | | | | | 14.3 |
| | - 100 | 493.4 | 0.0 | 353.00 | 0.0 | |
| | | | 100.0 | | 208.3 | i.e.7.4% |
| | Crushing Ratio $=\frac{493.4}{500.0} = 0.987$ | | | | | |
| | 3/8" | 91.5 | 91.5 | 1.94 | 177.5 | |
| | No.4 | 98.1 | 6.6 | 3.53 | 23.3 | |
| | No.10 | 99.6 | 1.5 | 7.06 | 10.6 | |
| 4 | U.S.40 | 99.8 | 0.2 | 24.70 | 4.9 | 260.4 |
| | No.100 | 99.9 | 0.1 | 88.30 | 8.8 | 194.0 |
| | | | | | | 66.4 |
| | - 100 | 488.9 | 0.1 | 353.00 | 35.3 | |
| | | | 100.0 | | 260.4 | i.e.34.2% |
| | Crushing Ratio $=\frac{488.9}{500.0} = 0.978$ | | | | | |
| | 3/8" | 89.4 | 89.4 | 1.94 | 173.6 | |
| | No. 4 | 97.1 | 7.7 | 3.53 | 27.2 | |
| | No.10 | 99.2 | 2.1 | 7.06 | 14.8 | |
| 8 | U.S.40 | 99.7 | 0.5 | 24.70 | 12.3 | 307.3 |
| | No.100 | 99.8 | 0.1 | 88.3 | 8.8 | 194.0 |
| | | | | | | 113.3 |
| | - 100 | 485.2 | 0.2 | 353.00 | 70.6 | |
| | | | 100.0 | | 307.3 | i.e.58.4% |
| | Crushing Ratio $=\frac{485.2}{500.0} = 0.970$ | | | | | |
| | 3/8" | 83.9 | 83.9 | 1.94 | 163.0 | |
| | No.4 | 96.0 | 12.1 | 3.53 | 42.7 | |
| | No.10 | 99.0 | 3.0 | 7.06 | 21.2 | |
| 16 | U.S.40 | 99.6 | 0.6 | 24.70 | 14.8 | 356.4 |
| | No.100 | 99.7 | 0.1 | 88.30 | 8.8 | 194.0 |
| | | | | | | 162.4 |
| | - 100 | 478.2 | 0.3 | 353.00 | 105.9 | |
| | | | 100.0 | | 356.4 | i.e.83.8% |
| | Crushing Ratio $=\frac{478.2}{500.0} = 0.956$ | | | | | |

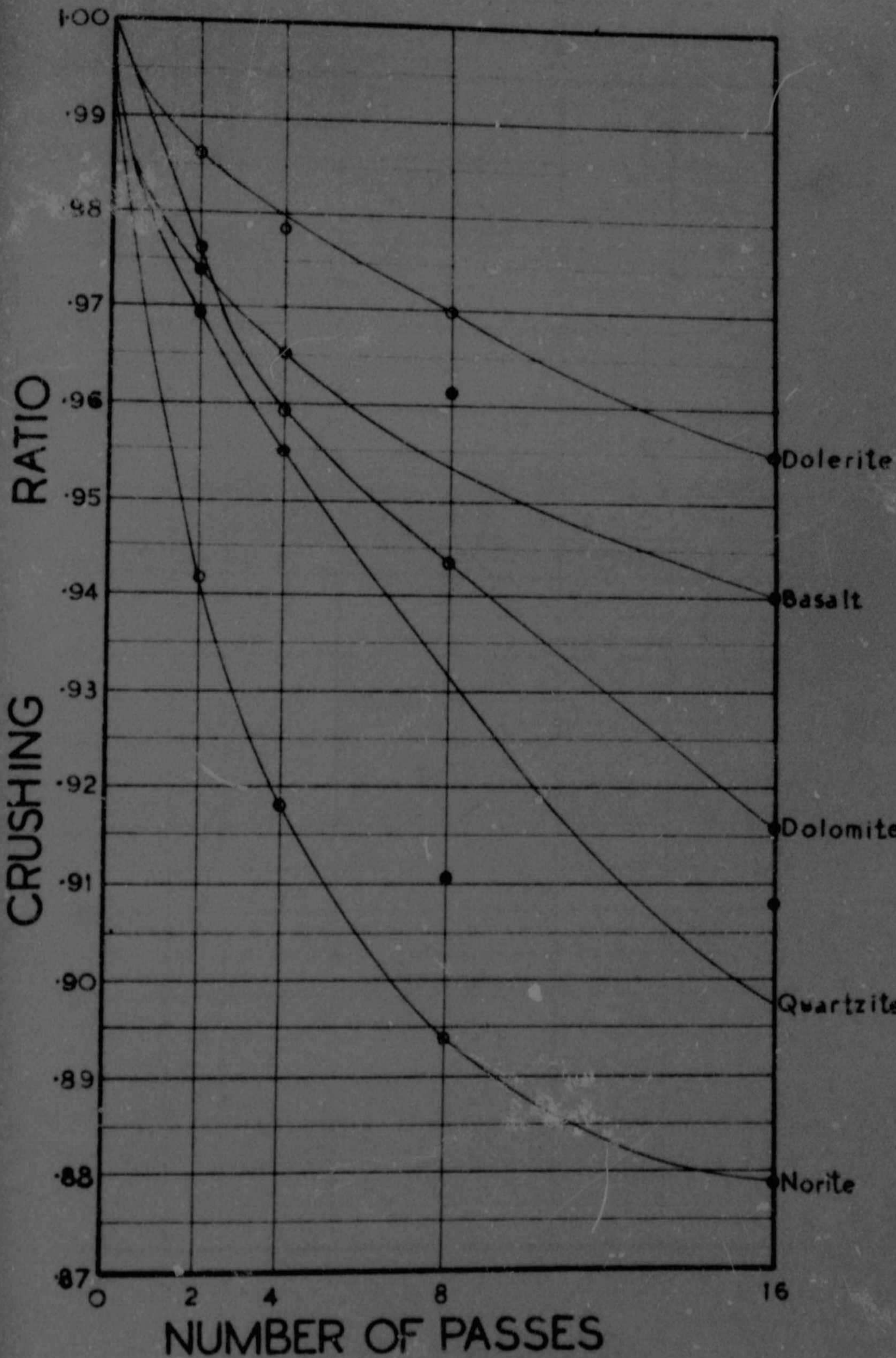


FIGURE 18. ROLLER TESTS - Effect of Number of Passes on Crushing Ratio.

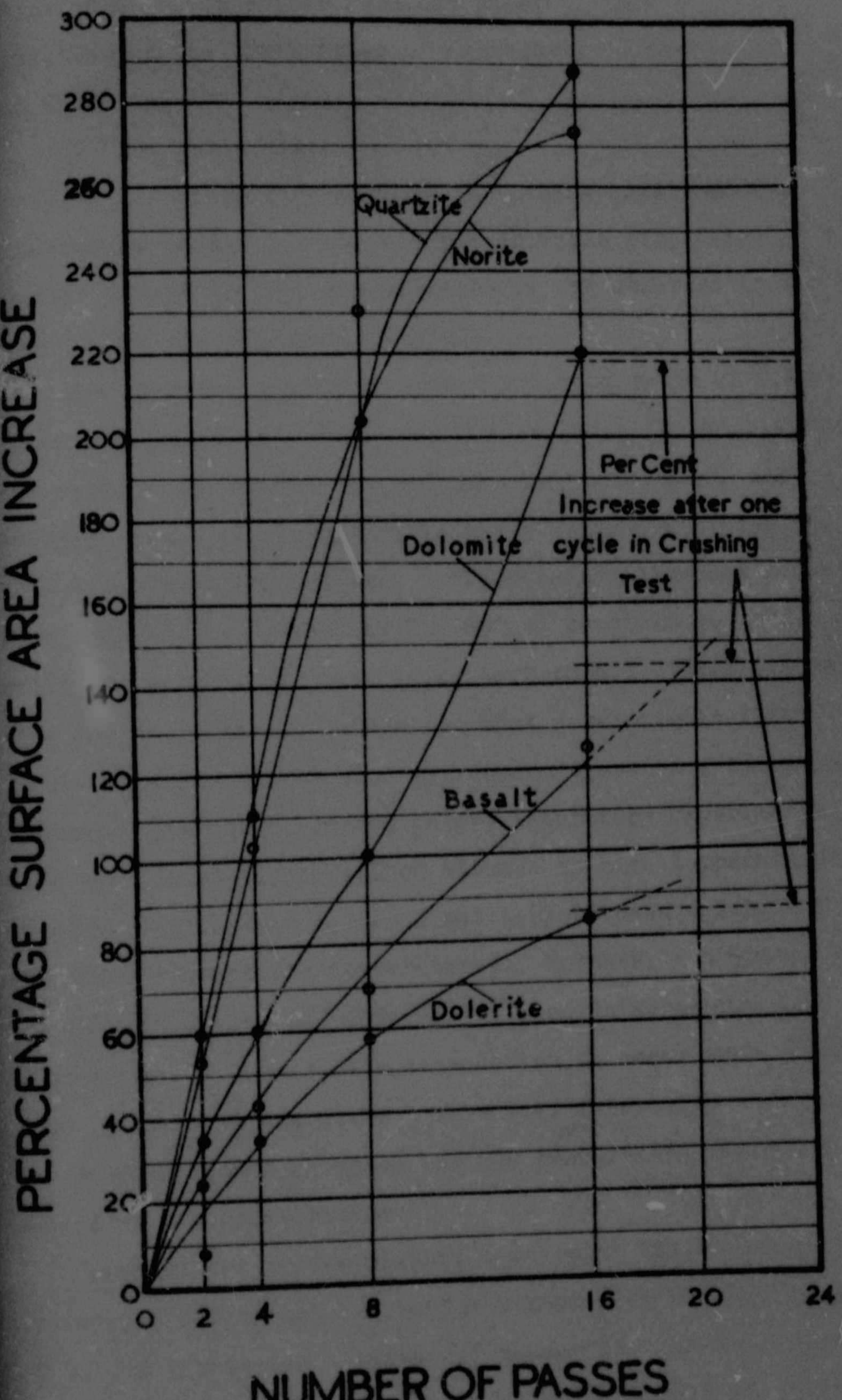


FIGURE 19. ROLLER TESTS—Effect of Number of Passes on Surface Area Increase.

test corresponds to an average of about 18 single roller trips of a 10 ton roller from the point of view of the degradation of the three types of aggregate, dolerite, basalt, and dolomite.

C. See table XII.

(g) The bituminous mixture containing quartzite was arbitrarily chosen for the example in table XII, although a similar effect to that described below was observed in the case of all the aggregates tested.

The uncoated quartzite gave a crushing ratio of 0.955 after 4 roller passes (see also figure 18). In the bituminous mixture containing the 200 penetration bitumen, the crushing ratio was 0.962 and in the mixture containing the RC - 2 cut-back bitumen, the corresponding value was 0.943. (The temperature in the field remained constant at 19°C. while the experiments were being performed.) These values bear out the writer's contention that a relatively fluid binder provides lubrication to the aggregate in a bituminous mixture. The fluid binders in the laboratory experiments were tar and straight-refined bitumen at high temperatures; in these experiments it was a cut-back bitumen which is fluid at normal atmospheric temperatures. Further, the writer believes that a viscous binder has a cushioning action on aggregates and causes less degradation to occur than in the case of uncoated aggregate. This belief has also been borne out in these tests in which the 200 penetration bitumen served as a viscous binder.

With regard to the mixture containing the RC - 2 binder, the writer's findings are that a binder with the consistency of RC - 2 lubricates a stone and causes increased degradation in the mixture under superimposed load. The writer therefore disagrees with Shelburne who states that

"a bituminous coating (RC - 3) afforded but slight protection against degradation of the aggregates (147)".

It is assumed that the cut-back asphalt employed by Shelburne in the field was relatively fluid during the