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# Crushed Brick in Road Construction

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SYNOPSIS

*There are large areas in Pakistan where stone aggregate is not available in the vicinity of road construction. Long haulage of stone makes the road construction expensive. Similar conditions exist elsewhere in many parts of the world. Work has been done at the Road Research Institute Lahore to investigate the use of aggregate obtained from crushing burnt brick in such areas for use in road construction.*

*This study has been directed towards the discussion on the existing practices relating to use of bricks in road construction, use of crushed brick in substitution of whole bricks, and replacement of stone aggregate with crushed brick wherever economically feasible. Brick aggregate made by crushing building bricks has been checked for its use in subbase, base and asphaltic concrete mix. Experimental roads were built on the basis of results obtained in the Laboratory. Results of the both Laboratory and field experiments have been detailed, which indicate that brick aggregate offers good prospects of replacing crushed stone in the areas of stone scarcity and is a better structural substitute for whole brick in conventional road construction.*

## 1. Present use of Bricks in Road Construction

Building bricks have been used as a part of the pavement since the advent of black-top roads in areas now forming Pakistan. It is used as a course just above the sub-grade in one or two layers laid flat or on edge and designated as "Brick soling". It is covered with a layer of stone and surfacing.

Roads built with this design were observed in many places where failures had occurred. At such places, bricks had settled differentially under load, especially in areas where the sub-grade moisture conditions were adverse.

## 2. Stress Distribution in Pavements

It is generally accepted that a flexible pavement depends for its function of distribution of loads on internal friction of separating layers forming the pavement. The pavement may therefore consist of an adequate wearing surface to distribute the wheel load sufficiently and to provide necessary wearing surface. It is however possible that due to flat interface of the brick course where neither friction nor cohesion acts, the load distribution does not take place within the brick course. Each wheel load thus creates a concentration which is not relieved within this layer resulting in overstressing of the subgrade. (1). The distribution of stress through two pavements consisting of (*i*) 4½" thick brick soling, 4" crushed stone and ½" of surface treatment (*ii*) 9" thick layer of granular material, have been worked out according to the theory of load distribution (2) as given in Table I.

It would be observed that the distribution of stresses in a pavement 9 inches thick using 4½" thick brick soling is less than 1/2.5th of the stress distribution of a pavement of equivalent thickness with granular material.

### 3. Use of Crushed Brick and Test Results

As a result of better distribution of stress through granular materials, it was proposed to use the conventional building brick after crushing. Before it could be applied in the field, it was necessary to test the engineering properties of crushed brick. Following tests were carried out:—

| | | |
|---|---|---|
| 1. | Los Angeles abrasion | .. AASHO T96-60 |
| 2. | Aggregate crushing value | ... BSS. 812-60 |
| 3. | Attrition value | .. BSS. 812-48 |
| 4. | Compressive strength | ... AASHO T32-60 |
| 5. | Water absorption | .. AASHO T85-60 |
| 6. | Sulphate soundness | .. AASHO T104-57 |
| 7. | Stripping test | .. AASHO T182-57 |

Twenty samples from 9 kilns of Lahore area were included in the investigation. These bricks are burnt in country-made "Bull's Trench Kiln" without any systematic temperature control, and therefore the quality of bricks is generally variable. However, these bricks can be classified broadly as over-burnt, well-burnt or under-burnt from their physical appearance. The test results have been listed as Table II. A brief description of the tests appears as Appendix "A".

From a perusal of the results in Table II, it is observed that:—

(*i*) overburnt bricks have an average Los Angeles wear of 30% and aggregate crushing value of 27% which well conforms to the strength requirements of subbase, base and surface of all types of roads. The soundness vlaue is within limits. The water absorption (6.21% by weight) and bitumen requirements are high. The water absorption for non-absorptive aggregate

TABLE I. *Analysis of Stress at Subgrade in Pavement Using Brick Soling as Compared to Pavement Using Granular Material only (For 10-20 in. tyre).*

| Wheel Load | Inflation pressure psi | Tyre contact area sq. in. | Aver. surface pressure psi. | Dia of equivalent contact circle in. | Dia of stress cricle sq. in. at 9" depth. | Area of stress circle psi. | Stress below surface psi. | Reduction | Ratio (*) |
|---|---|---|---|---|---|---|---|---|---|
| | (A) Stress distribution in a pavement 9" thick, using 4½" brick soling and 4½" stone plus surfacing. | | | | | | | | |
| 4000 | 50 | 70.1 | 57.1 | 9.44 | 27.44 | 591.00 | 6.76 | 1/9 | 1/2.75 |
| 4000 | 70 | 60.9 | 65.7 | 8.80 | 26.80 | 563.80 | 7.10 | 1/9 | 1/3.0 |
| 8000 | 50 | 110.4 | 72.5 | 11.84 | 29.84 | 699.00 | 11.44 | 1/6 | 1/2.5 |
| 8000 | 70 | 93.8 | 85.3 | 10.92 | 28.92 | 656.55 | 12.18 | 1/7 | 1/2.6 |
| | (B) Stress distribution in a pavement 9" thick using granular material only. | | | | | | | | |
| 4000 | 50 | 70.1 | 57.1 | 9.44 | 45.44 | 1621.00 | 2.46 | 1/24 | .. |
| 4000 | 70 | 60.9 | 65.7 | 8.80 | 44.80 | 1575.00 | 2.54 | 1/26 | .. |
| 8000 | 50 | 110.4 | 72.5 | 11.84 | 47.84 | 1797.00 | 4.45 | 1/16 | .. |
| 8000 | 70 | 93.8 | 85.3 | 10.92 | 46.92 | 1728.00 | 4.62 | 1/18 | .. |

(*) Ratio of reduction as compared to pavement using granular material only.

TABLE II. *Physical Properties of Brick Aggregate and Stone.*

| Sr. No. | Test. | Range of Test Values and their Averages. | | | | |
|---|---|---|---|---|---|---|
| | | Overburnt bricks | Well-burnt bricks | Underburnt bricks | Shahkot stone | Hasanabdal stone |
| 1. | Los Angeles abrasion % | 27.10-34.54 | 29.6-51.8 | 60.7-95.1 | 19.1-38.7 | 18.0-26.6 |
| | Average: | 30 | 40 | 80 | 29 | |
| 2. | Aggregate Crushing Value % | 24.4-31.2 | 27.2-37.10 | 40.7-55.3 | 12.6-30.6 | 12.0-20.8 |
| | Average: | 27 | 32 | 48 | 22 | 16.4 |
| 3. | Attrition Value % Dry. | 4.7-11.3 | 9.1-20.2 | 23.32-36.50 | 3.3-5.7 | 3.0-4.2 |
| | Average: | 8 | 15 | 30 | 4.5 | 3.6 |
| | Wet. | 5.4-8.6 | 12.4-22.2 | 27.3-50.8 | 4.0-7.3 | 3.6-6.5 |
| | Average: | 7 | 17 | 39 | 5.6 | 5.0 |
| 4. | Compressive Strength psi. | 1993-3135 | 1859-2533 | 698-1601 | .. | .. |
| | Average: | 2564 | 2196 | 1150 | | |
| 5. | Soundness ($MgSo_4$) | 2.24-5.7 | 2.96-6.7 | 4.5-10.0 | 2.5-7.8 | 1.7-2.9 |
| | Average: | 3.97 | 4.83 | 7.2 | 5.1 | 2.3 |
| 6. | Specific Gravity | 1.98-2.18 | 2.11-2.34 | 1.97-2.26 | 2.60-2.68 | 2.66-2.69 |
| | Average: | 2.08 | 2.22 | 2.11 | 2.64 | 2.67 |
| 7. | Water Absorption % by wt. | 3.40-9.02 | 11.4-14.3 | 13.45-18.8 | 1.09-1.62 | 0.593-0.752 |
| | Average: | 6.21 | 12.8 | 16.12 | 1.35 | 0.672 |
| 8. | Flakiness index. | 8.0-10.2 | 10.1-15.7 | 13.1-17.2 | 27.8-56.8 | 15.2-20.3 |
| | Average: | 9.1 | 12.9 | 15.1 | 42.3 | 17.7 |
| 9. | Bitumen adhesion (requirements for good bond) | 13.1* | 15.0 | 17.0 | 5-7% | 5-7% |

*In dense asphaltic concrete mixtures the normal asphalt content for this class of brick aggregate is 9-13%. Bitumen adhesion test is for complete coating of single size aggregate ½″ pass 3/8″ retained.

should be below 2.0%. The high absorptive quality of the brick aggregate results in higher bitumen requirements as is evident from bitumen absorption of 13.0% by weight for complete and satisfactory retention of bitumen in stripping test, although it is 9-13% for this class of aggregate in dense graded asphaltic concrete.

(*ii*) Well-burnt bricks have an average Los Angeles wear of 40% and a corresponding aggregate crushing value of 32.0%. The brick aggregate obtained from this class has sufficiently high strength for its use in subbase, base or surface course if quality control is exercised in the selection of bricks.

(*iii*) under-burnt bricks have an average Los Angeles loss of 80.0% and an aggregate crushing loss of 48.0%; attrition losses are 30%; compressive strength is 1150 psi and water absorption is 16.12%. All these values make the under-burnt bricks unfit for use in subbase, base and surface course.

**4. Use of Crushed Brick in Subbase**

Since aggregate from crushed bricks of well-burnt and over-burnt quality conforms to the requirements of base material, it can be used safely as a subbase material. Possible forms in which crushed bricks can be used are:—

(*i*) crushed aggregate without any admixture.
(*ii*) crushed aggregate mixed with soil.
(*iii*) crushed brick with sand and soil.
(*iv*) crushed brick with soil cement mixture/soil lime mixture.

Size of crushed brick and its percentage can be determined by AASHO designation M-147-49 for subbase. Quantity of crushed brick to be mixed with other admixtures or stabilizer can also be determined through Laboratory experiments for soil aggregate or soil cement aggregate mixture and will vary according to the soil type and admixture.

Limited experiments carried out on the local soil at Road Research Institute Lahore, indicate that there is an improvement of CBR values from 20 to 80 with 0 to 50 % addition of brick aggregate.

Field experiments have been conducted using soil brick aggregate mixture at the following places:—

| | Soil Aggregate | Length of Experiment |
|---|---|---|
| Daska-Pasrur Road | .. 60 : 40 | 1/4 mile |
| Lahore-Lyallpur Road | .. 60 : 40 | 1/4 mile |
| Bahawalnagar-Sulemanki Road | ..10-20 : 90-80 | 2 miles |

Although no direct tests have been used (Field CBR, Deflection Beam, etc.) to evaluate the behaviour of such subbases after construction, visual site observations show that pavement performance on these roads is good even after 2-3 years.

## 5. Crushed Brick in Base Course

Strength properties of overburnt and well burnt bricks make these suitable for use in granular bases. As the base course is generally covered with a bituminous surface, excessive absorption of the aggregate may interfere with the performance of the coming surface. With thick overlays of asphaltic concrete, temperature susceptibility is low and hence absorption of asphalt by bricks is low. However, prime coat of 20 lbs/% sq. ft. cut-back laid before asphaltic concrete satisfies bond requirements for such conditions.

In surface treatments, first application of bitumen may be absorbed by the brick aggregate under elevated temperatures, resulting in dryness and oxidation of the bituminous surface. The absorption of bitumen, an important factor in the use of brick aggregate for base course, can be met with by increasing the quantity of bitumen in first application up to 40 lbs/% sq. ft. as against 24 lbs/% sq. ft. in conventional triple surface treatment to compensate for the bitumen absorption of brick layer. In the alternative a prime coat of 15-20 lbs/% sq. ft. cut back should be laid before carrying out surfacing.

Crushed brick was used as soil-brick aggregate base course on Daska Pasrur road in a length of 2 furlongs. The grade of bitumen used was 200/300 penetration. No drying or oxidizing of surface or stripping has been observed even after three years of performance.

It is relevant to point out here that crushed brick has been used extensively in East Pakistan as a base-course material. Very large mileage of roads built there with brick aggregate have performed satisfactorily. In West Pakistan, amongst others, road between Muzaffargarh-Panjnad (Length 60 miles) on the West Pakistan National Highway (constructed 1942) and Multan-Basti Maluk road length 21 miles (constructed 1949) has used crushed brick as base-material.

Failures have occurred in roads using brick aggregate but these failures have been primarily due to:—

(*i*) under design of the pavement,
(*ii*) use of soft brick aggregate,
(*iii*) lack of maintenance.

The pavement failures in such cases therefore cannot be attributed to the use of crushed brick as such.

Brick course laid with brick aggregate should preferably be rolled with a light roller 6 to 8 tons or a light vibratory roller. The material should be properly graded. Where graded material is not available, it is a good practice to use a cushion of sand or crushed brick chippings on aggregate before rolling is started. Wetting should be done using 15 to 20% of water by weight of base material. The sand or crushed brick chipping should be allowed to work down during rolling. Base course in such cases be flushed with a prime coat of 15-20 lbs/% sq. ft. of cut-back before applying surface.

**6. Crushed Brick as Surface Course**

Due to absorptive nature of brick aggregate, it was further tested for adhesion, absorption studies, stripping test to ascertain its behaviour under field conditions as a material for surface courses. Behaviour of aggregate was also studied in the Laboratory for various types of bituminous surface given as under:—

1. Penetration Macadam Surface.
2. Bituminous Surface treatment.
3. Asphaltic Concrete Mixtures.

Results of these are given in Appendix "B". Briefly these are:—

(*i*) Stripping tests shows 13% bitumen by weight for coating the particles completely;

(*ii*) Bitumen showed no absorption at working temperature for bituminous penetration Macadam except when heated in an oven at 140°F.

(*iii*) For triple surface treatment using brick aggregate, tack coat and first application of bitumen was absorbed under accelerated heating tests.

(*iv*) The asphaltic contents for Marshall's stability for 2400 lbs. is 17% (Fig: I). The corresponding asphalmic content for crushed stone varies between 5.0 to 5.8% for stability of 1750 lbs. The values of flow and voids for crushed brick are lower than corresponding mixes with stone, Table III. Requirements for surface courses against Marshall's stability is 750 lbs as against 2400 lbs obtained with crushed brick for 17%. A lower value of asphalt can therefore be used to obtain the Marshall's stability which is not absorbed by brick aggregate and yet satisfy traffic requirements. 13% asphalt gives a value of 1950 Marshal stability using crushed brick as coarse and fine aggregate, whereas 9% asphalt is sufficient with the same stability value if coarse brick aggregate is used with Harrow sand as fine aggregate.

TABLE III. *Marshall's Stability Results of Crushed Brick and Stone Aggregate*

| Mix. No. (*) | Optimum asphalt content | Marshall's Data | | | |
|---|---|---|---|---|---|
| | | Stab. lbs. | Flow .01" | Unit Weight lbs/cft. | Voids in Mis.% |
| 1.* | 16.5 | 2400 | 19.5 | 122 | 1.75 |
| | 13.0 | 1950 | 13.0 | 118 | 2.5 |
| 2.* | 5.0 | 1750 | 17.0 | 142 | 4.0 |
| 3.* | 5.8 | 1750 | 17.0 | 141 | 6.0 |

| Mix | Mix. No. 1 | Mix. No. 2 | Mix. No. 3 |
|---|---|---|---|
| Coarse Aggregate | Overburnt bricks | Shahkot stone | Hasanabdal stone |
| Fine Aggregate | Overburnt bricks | Shahkot stone | Lawrencepur sand |
| Filler | Overburnt bricks | Shahkot stone dust | Portland cement |

In mixes prepared with burnt brick and Shahkot stone as coarse and fine aggregate no expensive filler like portland cement has been added and this fraction comes from aggregate itself. The optimum asphalt content for overburnt aggregate mix is 13% which is the same as for stripping test. The high asphalt content can only be justified if compensated by the low cost of brick aggregate, which is discussed elsewhere. However because the unit weight of mixtures prepared with overburnt brick aggregate is about 118 pcf against that of stone mixture being 142 pcf, in comparison the asphalt content for same volume of brick aggregate mix is actually 10.4%.

## 7. Field Studies for Asphaltic Concrete Mix Using Brick Aggregate

To confirm the behaviour of overburnt brick aggregate in asphaltic concrete mixes, experimental lengths were laid on Club Road in Lahore in August, 1965, using crushed brick as coarse aggregate in combination with fine aggregate of crushed brick or coarse river (Harrow) sand. For comparison, two other mixes containing Shahkot stone and Hasanabdal stone were also laid side by side.

Barber Greene's Continuous Mixing Plant was used for the preparation of mix and a paver was used to lay the hot mix. Strict quality control was exercised on gradation, percentage of asphalt, and temperature in all mixes. Mixes were sampled and tested for stability, flow, asphalt content and gradation of the aggregate. Results of the Marshall Stability for each mix taken from the plant is given in Table IV.

TABLE IV. *Showing Asphalt mixes laid on Club Road, Lahore.*

| Mix. | Coarse Aggr: | Fine Aggr: | Filler | Bitumen % | Marshall Stability |
|---|---|---|---|---|---|
| 1. | Brick Aggr: 41% | Brick Aggr: 42% | Brick dust 4% | 13% | 1950 |
| 2. | Brick Aggr: 41% | Harrow Sand 46% | Cement 4% | 9% | 1900 |
| 3. | Shahkot Stone 43% | Shahkot Sand 48% | Stone dust 4% | 5% | 1750 |
| 4. | Hassanabdal stone 54% | Harrow Sand 36% | Cement 5% | 5% | 1750 |

The mixes were tested for temperature before laying and no mix was allowed to be laid below 225°F. Rolling was allowed at a minimum temperature of 150°F. The finished pavement was tested for percent compaction which worked out to be 95-96%.

The experimental test on Club Road with a total area of 25,000 sq. ft. out of which 6,000 sq. ft. was laid with crushed brick aggregate has now withstood light to heavy traffic for over two years. The total number of vehicles which have used this area up to date (December 1967) would exceed 1 million. The area using crushed brick as an aggregate has shown no sign of distress. Performance of crushed brick as a material for asphaltic concrete mixtures is suggested under controlled conditions in combination with natural sand to reduce bitumen content.

## 8. Economics of Brick Aggregate

Economics of using brick aggregate versus complete brick or crushed stone has to be worked for each individual site. Stone is available only in certain parts of East and West Pakistan. Its carriage to the site of work involves long haulage through train and/or trucks whereas country-made brick kilns can be established all along the road, and therefore cost of brick is fairly low at work-site.

The cost of crushed stone has been compared with crushed brick near some important cities in West Pakistan as per Table V. Figures in Table V indicate that the cost of crushed brick varies between Rs. 70-75 per % cft. whereas the crushed stone costs between Rs. 87 to 150 per % cft. in different areas.

Use of crushed brick in sub-base at most places is economically competitive with brick soling of equivalent thickness depending upon the percentage of soil/cement mixed. Brick aggregate as a base course would be economical in areas where stone is more expensive. Cost of brick aggregate will be marginal with brick soling of equivalent thickness, but minor excess in cost is more than offset by better distribution of loads in the crushed material.

TABLE V. *Cost (Rs.) of Crushed Stone and Crushed Brick Near some Important Cities in West Pakistan.*

| Station | Distance of job site from Rly. Stn. | Cost per % cft. of aggregate from different quarries at job site. | | | | | Crushed brick (%) cft. at job site |
|---|---|---|---|---|---|---|---|
| | | Rohri stone | Shahkot stone | Sangla Hill Stone | Chiniot stone | Sikhan wali stone | |
| Lahore | 20 miles | .. | 128 | 102 | 107 | 110 | 70—75 |
| Multan | 20 miles | .. | 137 | 105 | 117 | 112 | 70—75 |
| Lyallpur | 20 miles | .. | 110 | 87 | 88 | 97 | 70—75 |
| Bahawalpur | 20 miles | 150 | .. | .. | .. | .. | 70—75 |

For the cost analysis of hot mix asphalt treatment on Club Road Lahore, it was observed there was a saving of 5% in the use of mix with crushed brick as coarse and fine aggregate, 10% with crushed brick and natural sand due to reduced bitumen content, 15% with Shahkot stone a coarse and fine aggregate when compared to Hassanabdal stone as coarse aggregate, Lawrencepur sand as fine aggregate, and cement as a filler, which is till now a conventional material for hot mix jobs.

## 9. Conclusions

Brick aggregate has been tested for its engineering properties. Tests indicate that material obtained from well burnt and overburnt bricks conforms to the specifications laid down for base coarse and surface material.

On the basis of laboratory tests and field experiments, crushed brick can be recommended as a material for sub-base with or without mixing with soil or soil cement admixture. Graded material can be used for base courses with quality control on the manufacture of bricks. The base should be rolled with a light or vibratory roller. A prime coat of 15-20 lbs. cut-back should be laid before surfacing.

For premix asphaltic carpets as surfacing, crushed brick can be used as coarse aggregate in areas of stone scarcity. Mixes with brick aggregate and harrow sand using 9% asphalt give encouraging results. Quantity of asphalt required for optimum content will vary with quality of bricks and mix components. Bricks used in mix should be well burnt to over-burnt. Proper quality control should be exercised during design and construction of asphalt mix jobs.

## 10. Acknowledgement

Thanks are due to Mr. Jalil-ur-Rehman who did laboratory testing for engineering properties of the aggregate and Marshall's test. Laboratory field staff helped in carrying out the field experiments. The paper is presented with the permission of West Pakistan Government.

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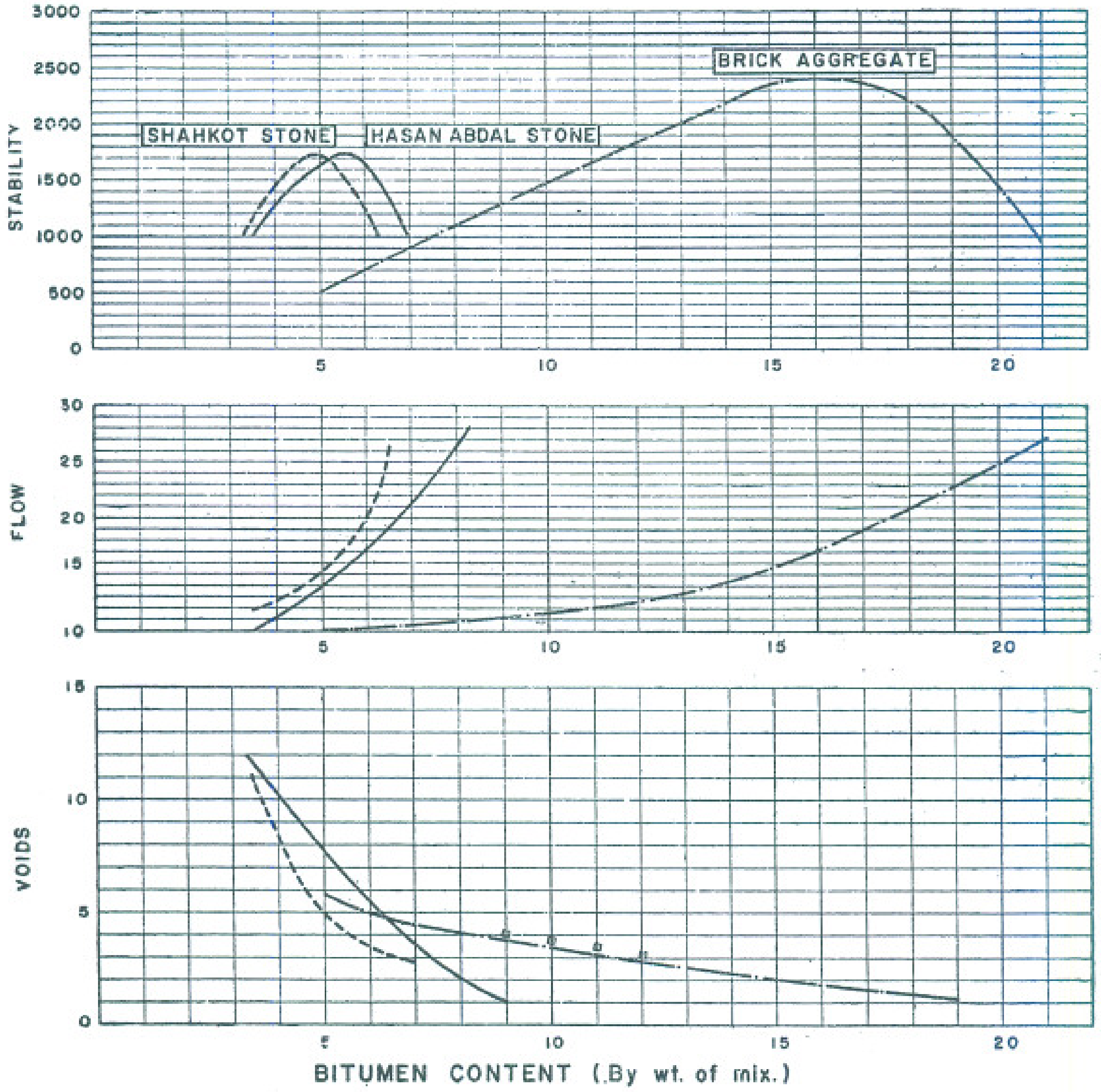
RESULTS OF MARSHALL TEST FIG-1

FOR STABILITY, FLOW & VOIDS OF BRICK & STONE AGGREGATE



## APPENDIX "A"

## DESCRIPTION OF THE TESTS CARRIED OUT ON CRUSHED BRICK AGGREGATE

### 1. Los Angeles Abrasion Test (T. 96-60)

The test is conducted on coarse aggregate to evaluate the resistance to abrasive forces through the action of wheeled traffic on the roads and the wearing through internal disturbance of adjacent particles. It is an index of the toughness of the aggregate and its resistance to abrasion. 5000 gms of specified gradation of aggregate are taken and placed in a rotating drum with an additional charge of 12 steel balls of standard size and weight. The drum is made to revolve about a horizontal axis for 500 revolutions at the rate of 30-33 rpm after which the sample is sieved on a No. 12 ASTM (BSS No. 10) sieve. The percent loss of weight is designated to Los Angeles wear. Requirements for surfaces are 40% max. and for base and subbase 50% max.

### 2. Crushing Value (B.S.S. 812)

Crushing value BSS 812 is the percentage loss through No. 7 B.S. sieve after crushing a sample of 1/2" to 3/8" size in a standard mould under a load of 40 tons applied vertically at the rate of 4 tons per minute. The test measures the resistance of aggregate against crushing forces. Specifications lay down the following crushing values for,

| | | |
|---|---|---|
| (*i*) | roads surfaces for heavy traffic | 17% max. |
| (*ii*) | roads surfaces for medium traffic | 23% max. |
| (*iii*) | roads surfaces for light traffic and in lower courses of all types of roads | 30% max. |

### 3. Attrition Tests (Wet and Dry Attrition)

The test resembles Los Angles and is conducted by using 5000 gms of aggregate size $2\frac{1}{2}''$—$1\frac{1}{2}''$ put in a steel cylinder inclined at an angle of 30° to a frame that rotates about a horizontal axis. The cylinder in the frame is made to revolve for 10,000 revolutions at a rate of 28-33 rpm after which the sample is washed dried and sieved on No. 10 B.S. sieve. The percent loss by weight of original sample is taken as the attrition value. For wet attrition, an equal volume of distilled water is added to the sample. Maximum allowable losses through the test are 5 to 10% respectively for dry and wet attrition.

**4. Compressive Strength Test (AASHO T-32-60)**

The test is carried out by taking the whole brick and subjecting it to direct compression test for determining its crushing strength.

**5. Soundness Test**

In this test, the aggregate is subjected to five cycles of heating at 100-110°C and immersing in a saturated solution of sodium sulphate or magnesium sulphate. The weighted average loss through respective sieves is taken as the soundness loss. The test is performed to measure the resistance of aggregate to the action of injurious salts that in solution form come in contact with the structure. Test is valuable for areas where salt water or frost action appears.

## APPENDIX "B"

## TEST RESULTS FOR BRICK AGGREGATE FOR USE AS SURFACE COURSE MATERIAL

The following tests were carried out to evaluate the use of brick aggregate as surface course material. The results are shown below:—

**1. Stripping Test**

Brick aggregate was used as standard aggregate and the stripping test was carried using 80/100 asphalt. During the test, it was observed that normal quantity of bitumen is absorbed by aggregate during mixing and 13% bitumen by weight is required for coating the particles completely. Test has shown abnormally high bitumen required for brick aggregate for surface treatment.

**2. Behaviour under Accelerated Heating**

In this test, whole of bitumen is absorbed by brick aggregate under accelerated heating test on 140°F. in an oven. This happened within the first few hours.

**3. Treatment with Viscous Oils**

Because of absorptive nature of brick aggregate, it was saturated with cheaper oil which could decrease the bituminous requirements. This treatment needed 13-14.5% by weight of oil in 72 hours without reducing the bituminous requirements substantially.

**4. Behaviour in Various Types of Bituminous Surface**

Behaviour of the aggregate was further studied in the laboratory in various types of bituminous surfaces. These included:

1. Penetration macadam surface.
2. Bituminous surface treatment.
3. Asphaltic concrete mixture.

**Bituminous Penetration Macadam**

Bituminous penetration macadam specimens were prepared in 12"×12"×4" trays, under a pressure of 2000 psi maintained for two minutes. Over-burnt brick aggregate was used as coarse aggregate in the first spreading, followed by gravel as choke and cover. As the aggregate in this type of construction was used unheated, there was no visible absorption of bitumen by the brick aggregate. After heating at 140°F in the oven, most of the bitumen in the first layer was absorbed by the brick aggregate within first two hours and l with the oncoming gravel was almost destroyed.

Following quantities of material were used in the experiment:

| | |
|---|---|
| First spreading of coarse aggregate (overburnt bricks) | 2 cft. |
| First application of bitumen (80/100) grade | 10.0 lb/sq. yd. |
| Second spreading of aggregate (gravel) | 0.3 cft/sq. yd. |
| Third spreading of cover aggregate (gravel) | 0.2 cft/sq. yd. |

**Surface Treatment (Triple):**

Specimens were prepared again in 12″×12″×4″ trays. A 4″ thick soil aggregate base was provided which was well compacted, primed and tack coated, the bituminous surface was consolidated under a pressure of 500 psi maintained for two minutes. Brick aggregate was used in the first coarse of the surface treatment.

Behaviour under accelerated heating test was similar to the penetration macadam. Tack coat and the oncoming bitumen application were absorbed by the brick aggregate and the bond was almost finished.

**Asphaltic Concrete Mixtures**

Behaviour of over-burnt brick aggregate in asphaltic concrete mixtures was quite different from penetration macadam and surface treatments. Marshall's stabilometer was used for design and testing of these mixtures and the properties were compared with similar mixtures prepared with Shahkot stone (sand stone) and Hasanabdal stone (high quality lime stone) using same type of bitumen *i.e.*, asphaltic cement of 80/100 penetration and same gradations. The combinations included:

| | | |
|---|---|---|
| 1. | Coarse aggregate | Crushed overburnt brick. |
| | Fine aggregate | Crushed overburnt brick. |
| | Filler | Crushed overburnt brick dust. |
| 2. | Coarse aggregate | Shahkot stone |
| | Fine aggregate | Shahkot stone. |
| | Filler | Shahkot stone dust. |
| 3. | Coarse aggregate | Hassanabdal stone. |
| | Fine aggregate | Harrow river sand. |
| | Filler | Portland cement. |

Gradation of aggregate combination in all these trials has been as below:

| Sieve | % Passing | Limits |
|---|---|---|
| 1" | 100 | 100 |
| 3/4" | 90.0 | 80-100 |
| 1/2" | 84.0 | .. |
| 3/8" | 75.0 | 60-80 |
| No. 4 | 51.0 | 48-65 |
| No. 8 | 42.0 | 35-50 |
| No. 16 | 32.0 | .. |
| No. 30 | 27.0 | 19-30 |
| No. 50 | 16.0 | 13-23 |
| No. 100 | 10.0 | 7-15 |
| No. 200 | 5.0 | 0-8 |

Results of Marshall Stability Tests are as under:

MARSHALL'S STABILITY RESULTS

| Mix No. | Optimum asphalt content | Marshall's Data | | | |
|---|---|---|---|---|---|
| | | Stab. lbs. | Flow .01" | Unit Weight lbs/cft. | Voids in mix.% |
| 1.* | 16.5 | 2400 | 19.5 | 122 | 1.75 |
| | 13.0 | 1950 | 13.0 | 118 | 2.5 |
| 2.* | 5.0 | 1750 | 17.0 | 142 | 4.0 |
| 3.* | 5.8 | 1750 | 17.0 | 141 | 6.0 |

| Mix. | Mix. No. 1 | Mix. No. 2 | Mix. No. 3 |
|---|---|---|---|
| Coarse Aggregate | Overburnt bricks | Shahkot stone | Hasanabdal stone |
| Fine aggregate | Overburnt bricks | Shahkot stone | Lawrencepur sand |
| Filler | Overburnt bricks | Shahkot stone dust | Portland cement |

## APPENDIX "C"

## ACTION OF WATER AND ACCELERATED HEATING ON ASPHALTIC CONCRETE MIXES USING BRICK AGGREGATE

Brick aggregate is highly absorptive. Nothing from amongst the weathering agencies is more severe than water on bituminous pavements. Keeping in view this important factor, detailed studies were carried out to determine the effect of water on cohesion of asphaltic concerete mixture.

Compressive strength tests on 4″×4″ cylinderical specimens were carried out in accordance with A.S.T.M.D.—1075-54 and D-1074-60 with some severity of conditions as summarized below:

Brick aggregate and bitumen 80/100 were heated to 325∓5°F in an overn and mixed in a bowl for 1½ to 2 minutes in a mechanical mixer. The mixture was placed in cylinderical mould of specified dimensions to give compacted specimens of 4″ diameter and 4.0∓0.1 in height. The mixture was compressed under an initial load of about 150 psi for initial setting and finally a load of 3000 psi was applied for 2 minutes. The specimens were all air cured at 60∓1°C (40∓1.8°F) for 24 hours. They were segregated in three groups of 8 specimens and each group was further treated and tested as below:

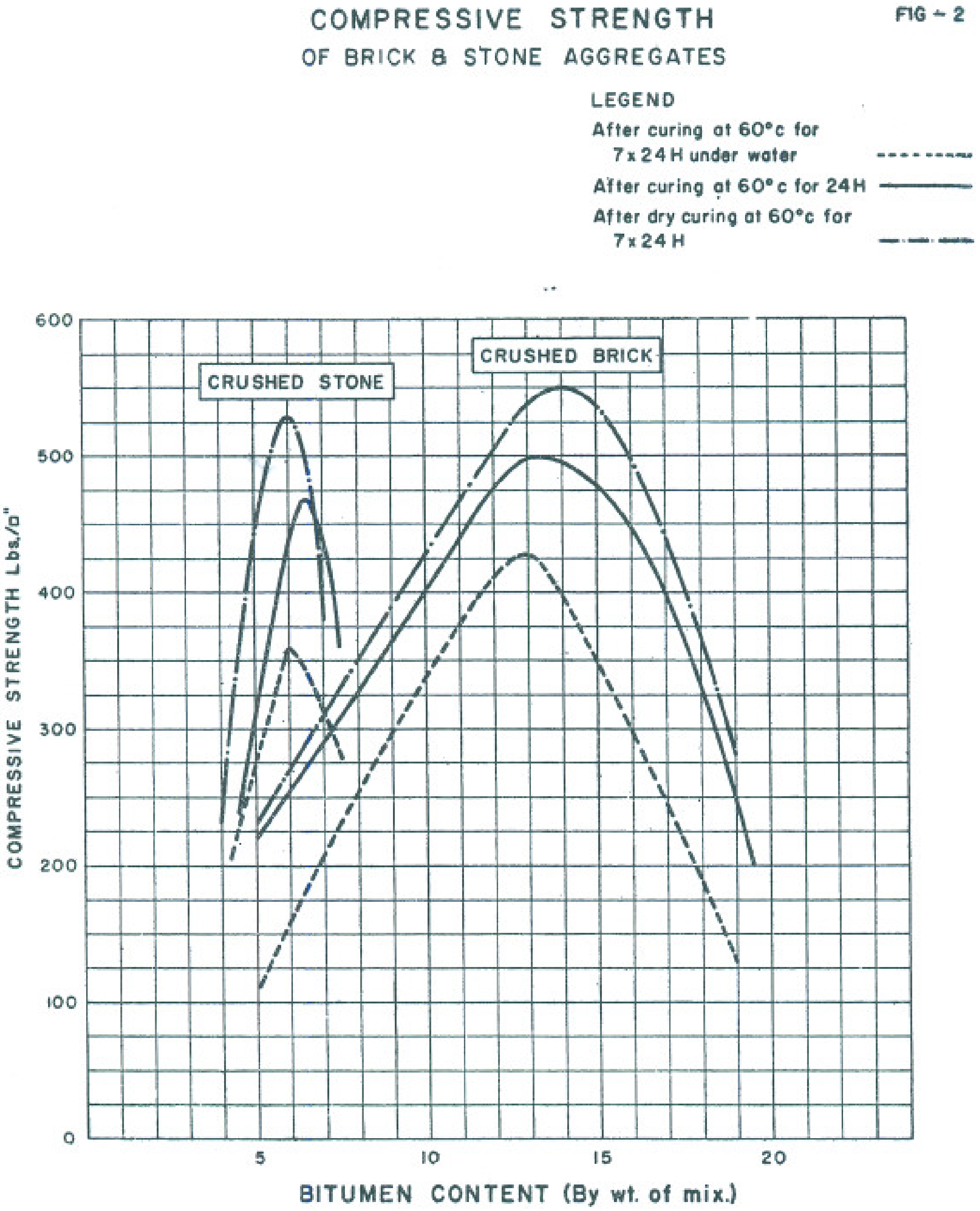
(*a*) Group No. 1 The specimens were brought to the test temperature of 25∓1°C (77∓1.8°C) by storing in an air bath at this temperature for a period of 5 hours. After this curing, the specimens were tested for compressive strength in a compression machine at a uniform rate of vertical deformation of 0.02 inch per minute.

(*b*) Group No. 2. The test specimens were immersed in water for 7 days at 60∓1°C (140∓1.8°C). After this period, the specimens were transferred to another water bath for 2 hours maintained at 25∓1°C (77∓1.8°F). They were then tested for compressive strength as in Group 1 above.

(*c*) Group No. 3. The test specimens were brought to a temperature of 60∓1°C (140∓1.8°F) for 2 hours. At this temperature the specimens were tested for compressive strength as above. The results have been given in Fig. 2.

### Discussion on Compressive Strength Results

The compressive strength data is not used for design or control of bituminous mixtures. In these studies also, the data has not been adopted for



COMPRESSIVE STRENGTH
OF BRICK & STONE AGGREGATES
FIG – 2
LEGEND
After curing at 60°c for 7x24H under water
After curing at 60°c for 24H
After dry curing at 60°c for 7x24H
CRUSHED STONE
CRUSHED BRICK
COMPRESSIVE STRENGTH Lbs./□"
0
100
200
300
400
500
600
5
10
15
20
BITUMEN CONTENT (By wt. of mix.)

design studies but for studying the effect of water and accelerated heating on bituminous mixtures. The effect was determined in terms of percent compressive strength retained after a certain treatment.

$$\text{Percent compressive strength retained} = \frac{\text{compressive strength at } 25 \mp 1^\circ\text{C after treatment}}{\text{compressive strength at } 25 \mp 1^\circ\text{C before treatment}} \times 100$$

TABLE VII. *Compressive Strength Data of Hot Mix Asphaltic Concrete.*

| Sr. No. | %asphalt by wt. of aggr. | %asphalt by wt. of mix. | Compressive strength at 25∓1°C after | | | Retained compressive strength after 7 days % | |
|---|---|---|---|---|---|---|---|
| | | | Oven curing at 60∓1°C for 24 hrs. | Oven Curing at 60∓1°C for 7 days | Curing under water at 60∓1°C for 7 days | Oven curing at 60∓1°C | Curring under water at 60—1°C |
| 1. | 5.26 | 5 | 225 | 230 | 110 | 102 | 49 |
| 2. | 7.53 | 7 | 290 | 313 | 206 | 108 | 71 |
| 3. | 9.89 | 9 | 357 | 395 | 293 | 110 | 82 |
| 4. | 12.36 | 11 | 440 | 471 | 351 | 107 | 80 |
| 5. | 14.95 | 13 | 505 | 544 | 429 | 108 | 85 |
| 6. | 17.65 | 15 | 488 | 541 | 354 | 110 | 73 |
| 7. | 20.48 | 17 | 415 | 429 | 235 | 103 | 57 |
| 8. | 23.46 | 19 | 227 | 274 | 130 | 120 | 57 |

From the data in Table VII it is seen that unlike the penetration Macadam aggregate and single size particles coated with bitumen, heating the mix specimens in an oven at 140∓1.8°F for 7 days rather improved the compressive strength and the increase in compressive strength ranged from 2 to 20%. However there was a drop in compressive strength when the specimens were stored under water at 140∓1.8°F for 7 days. The retained compressive strength for specimens with 9.5 % to 14.00 % asphalt content by weight of mix ranged from 82 to 85 approximately which is quite acceptable. The encouraging performance of the mix under accelerated heating test is due to the denseness and close gradeness of the mix that retarded the action of heat and water making the mix impervious and less exposed to these agencies. This again suggests the acceptability of brick aggregate for dense graded asphaltic concrete mixtures.