Effects of Using Kota Stone as Filler on Mechanical Properties of Asphalt Concrete Mixes

Sarvesh Singh, Jayvant Choudhary, Brind Kumar and Ankit Gupta

Abstract This study utilized waste dimension limestone (viz. Kota stone) dust as a surrogate filler to conventional stone dust in asphalt concrete mixes. Primary characterization of both fillers was done through specific gravities, particle size distribution, German filler values, X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), plasticity index, hydrophilic coefficient and pH value tests. Asphalt mixes were designed and tested as per Marshall test procedure recommended in Indian paving specification. Retained stability values and Marshall Quotient of both mixes were determined at their optimum binder contents. Kota stone mixes displayed superior mechanical properties and rutting resistance, which was attributed to the lower their relatively lower apparent film thickness. Kota stone mixes displayed and improved the resistance against moisture permeation due to the presence of Calcite, which improved aggregate–bitumen adhesion.

Keywords Asphalt concrete · Filler · Kota stone · Marshall properties · Moisture resistance

1 Introduction

India is a developing country having a large road network that primarily consists of flexible pavements which usually adopt asphalt concrete mixes in their surface course. Filler can be termed as the finest part of aggregate, having particle sizes finer

S. Singh · J. Choudhary (✉) · B. Kumar · A. Gupta
Department of Civil Engineering, IIT (BHU), Varanasi, India
e-mail: Jayvant.chaudhary.civ13@iitbhu.ac.in

S. Singh
e-mail: Sarveshs.civ16@iitbhu.ac.in

B. Kumar
e-mail: Kumar_brind.civ@iitbhu.ac.in

A. Gupta
e-mail: Ankit.civ@iitbhu.ac.in

A. S. Kalamdhad (ed.), *Recent Developments in Waste Management*,
Lecture Notes in Civil Engineering 57,
https://doi.org/10.1007/978-981-15-0990-2_19

than 0.075 mm. As per Indian specifications, filler should be devoid of organic particles, active clay content and its plasticity index value should not exceed to four [1]. Filler type and its quantity in asphalt mixes influence the economy as well as the asphalt mix's behaviour against various primary distresses and thus influence pavement's behaviour from the construction stage to the end of its service life [2]. Filler displayed dual behaviour in asphalt mixes, where coarser filler particles behave as non-reactive material which fills voids in between various aggregates in the mix, while finer filler particles become part of asphalt mastic and affect its viscosity as well as consistency [3]. The asphalt mix's performance against primary pavement problems like ageing, cracking, fatigue, ravelling, rutting and moisture susceptibility are dependent on filler's physical properties (particle size, particle shape, particle surface texture, particle gradation and void contents, etc.), chemical properties (quantity of active clay and mineralogy, etc.) and to filler binder interaction [2, 3]. Hence, it is necessary to choose appropriate filler for ensuring optimum performance of asphalt mixes. Today, researchers are showing interest in adopting various wastes and by-products from different sources as fillers in order to counter growing environmental problems and increase of the cost of standard fillers (cement, hydrated lime and stone dust). Various wastes like dimensional stone wastes, sewage sludge ash, rice straw ash, copper tailings, carbide lime, etc., have improved performances of asphalt mix in various aspects when utilized as filler [4–7].

According to ASTM C-119, Dimension stone can be defined as natural stone, which is produced to the specific size and size with or without having one or more mechanically finished surfaces and can be used in building components, pavement surfaces, monuments and various other industrial products [6, 8]. At the global level, dimensional limestone is considered as one of the popularly used dimension stone because of its cheap cost as well as its ability to get polished as good as that to marble [9]. Dimension limestone is usually recognized in India by the name of its place of origin (Kota) as Kota stone [6]. During the cutting and polishing of large slabs of Kota stone, water is utilized as the coolant, which cools the saw blades and removed the powdered dust. The water forms slurry with the suspended dust which travels through drains to the nearby sedimentation tank. This settled slurry is being disposed of to landfills where water gets evaporated, leaving behind fine dust which gets airborne with the wind and causes contamination which leads to the problems regarding the bronchial, skin and vision disorders in the residents of their neighbouring areas [6]. There are several studies which assess the prospect of recycling stone waste in different purposes [9, 10]. However, studies concerning the usage of waste dimension limestone slurry in flexible pavement are very limited. This novelty of this study is that it investigated the possibility of utilizing waste Kota stone dust from dimension stone industry as replacement filler in asphalt mixes. Recycling of slurry waste as filler not only ensures its environmental-friendly disposal but also conserves conventional fillers (hydrated lime, cement and stone dust) as well as ensures economic pavement construction.

2 Material Properties and Experimental Investigations

2.1 Material Properties

Aggregates. This study utilized the aggregates which are crushed, angular and of dolomite origin. All aggregates were obtained from the quarry located in the Sonbhadra region of the Uttar Pradesh state of India. All aggregates were properly washed and sieved over their respective sieve to remove additional fine dust adhered to them. Table 1 displayed the characterization properties of aggregates. The gradation of mix was chosen according to the guidelines specified the Indian specifications [1] and is given in Table 2.

Asphalt. VG 30 (Viscosity Grade 30) asphalt, similar to 60/70 penetration grade asphalt, was locally collected and used. Various properties of asphalt were evaluated according to IS:73 (2013) specification and displayed in Table 1.

Filler. Dolomite stone dust was taken as standard filler and obtained locally. Kota stone dust was taken from the municipal dumping ground situated in the Kota city of the India state of Rajasthan. Both fillers were dried in the moisture oven for overnight and sieved on 0.075 mm sieve. Only the filler portion which is finer than 0.075 mm sieve is used for the analysis. Various physical characterization parameters such as specific gravity, plasticity index, particle size distribution and fractional void content were assessed using specific gravity test [11], plasticity

Table 1 Characteristics of the aggregates and the asphalt

Component	Physical characteristic	Testing specification	Obtained result
Aggregates	Bulk specific gravity of coarse aggregates	ASTM C127	2.795
	Apparent specific gravity of coarse aggregates		2.820
	Water absorption (%)		0.374
	Bulk specific gravity of fine aggregates	ASTM C128	2.702
	Apparent specific gravity of fine aggregates		2.747
	LA Abrasion Value (%)	IS:2386 (Part IV)	13.40
	Aggregate Impact Value (%)		11.10
	Combined Flakiness and Elongation Index (%)	IS: 2386 (Part I)	21.30
Asphalt	Absolute viscosity at 60 °C (poise)	IS: 73(2013)	2692
	Softening Point (°C)		51.5
	Penetration at 25 °C (0.1 mm)		62
	Ductility at 27 °C (cm)		>100
	Specific gravity		0.999

Table 2 Mix Gradation

Sieve size (mm)	Recommended range (Cumulative % passing)	Gradation selected (Cumulative % passing)
19	100	100
13.2	90–100	91
9.5	70–88	78
4.75	53–71	67
2.36	42–58	52
1.18	34–48	45
0.6	26–38	35
0.3	18–28	23
0.15	12–20	13
0.075	4–10	4.0

index test, particle size analysis [12] and German filler test value, respectively. Methylene blue value test [13] was used to calculate the harmful clay present in the filler. Mineralogy and morphology of fillers were studied with the help of X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM) analysis. Apart from these, pH value and hydrophilic coefficient [14] analysis were performed to determine affinity of both fillers towards asphalt. The results of various tests are stated in Figs. 1, 2, 3 and in Table 3.

2.2 Design and Experimental Evaluation of Asphalt Concrete Mixes

Mix design of the asphalt concrete mixes. This study adopted the procedure of the mix design stated in MS-2 [15] specification to calculate the Optimum Binder Content (OBC) of prepared mixes. OBC is defined as binder content of the mix corresponding to the air void content of 4%. According to this procedure, mixes with chosen gradation (Table 1) and different binder contents (5–7% at 0.5% interval) were prepared. All ingredients were heated at the mixing temperature chosen according to the MS-2 specification to achieve uniform binder coating on aggregates. The Marshall specimens of diameter 101.5 mm and 63.5 mm thickness mixes were prepared after the compaction of mixes using standard Marshall Compactor which provided 75 blows on each side. 15 specimens (3 at each binder content), were designed for each filler and various properties like stability, flow value, Voids in Mineral Aggregates (VMA), Voids Filled with Binder (VFB) and air voids (VA) were determined. Apparent Film Thickness (AFT) of every asphalt mix was determined at their OBC according to the procedure suggested by NCHRP Report 567 [16]. AFT was calculated as per the Eq. 1.

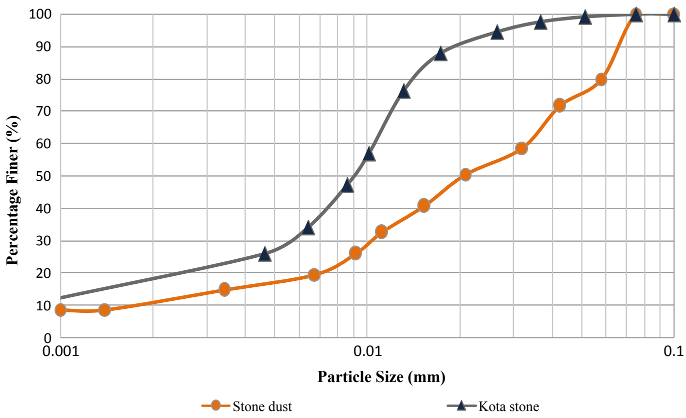

Fig. 1 Gradation of both fillers

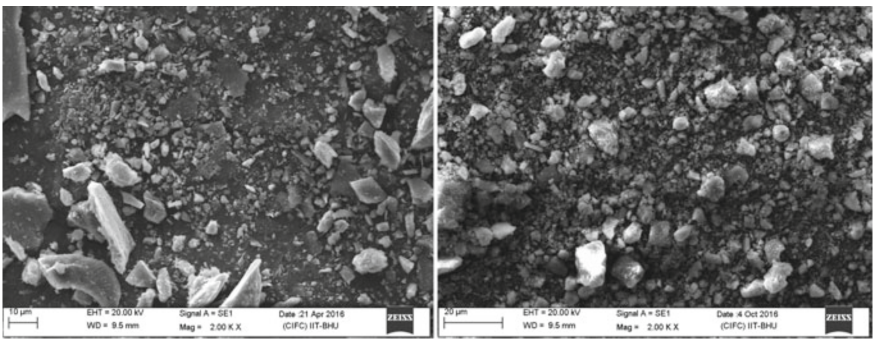

Fig. 2 SEM of stone dust (left) and Kota stone dust (right)

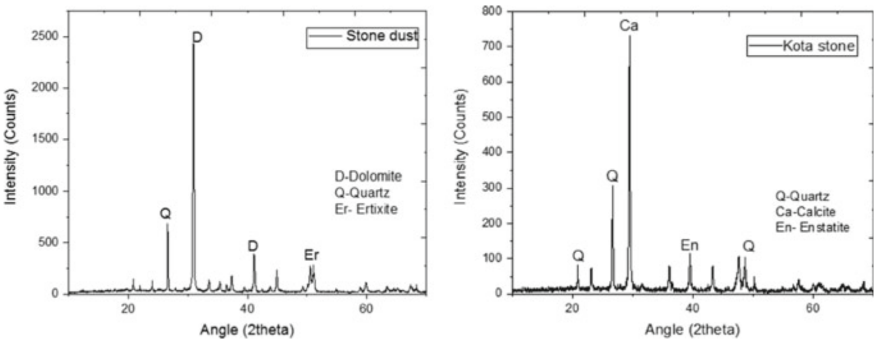

Fig. 3 XRD test results of stone dust (left) and Kota stone dust (right)

Table 3 Various filler characteristics

Property	Kota stone dust	Stone dust	Inferences
Specific gravity	2.65	2.70	Both materials have similar specific gravities and thus both will occupy almost similar volume in asphalt mixes
Plasticity index	4.0	2.3	Both fillers satisfied criteria for plasticity index as per Indian specifications
Methylene Blue Value (MBV) (mg/g)	3.75	3.25	Both materials have low harmful clay contents (<20 mg/g)
German filler test value (g)	97	85	Stone dust have relatively higher fractional voids per unit weight and thus expected to have higher optimum binder content
Fineness modulus	3.03	5.38	Kota stone can be considered as finer filler than stone dust
Shape and texture	Small size, granulous and somewhat subrounded grains having relatively rough texture	Angular grains having texture varying from rough to smooth	Kota stone has relatively small and granular size particles with rough texture. This may led to greater bitumen absorption
Primary Mineralogical Composition (XRD)	Calcite ($CaCO_3$); Quartz (SiO_2); Enstatite ($Mg_2Si_2O_6$)	Ertixite ($Na_2Si_4O_9$); Quartz (SiO_2); Dolomite ($CaMg(CO_3)_2$);	Both fillers constituted calcite and dolomite in their composition which are calcium-based insoluble mineral having good bitumen adhesion. No expansive clay mineral was found in both materials. Thus satisfactory stripping resistance is expected from both
Hydrophilic coefficient	0.80	0.77	Both material displayed hydrophobic nature
pH	8.74	12.58	Both materials displayed alkaline nature and showed decent affinity towards binder

$$AFT = \frac{1000VBE}{S_s P_s G_{mb}} \quad (1)$$

where

VBE (Effective binder content) (% of the total mix volume); S_s (specific surface area of aggregates) (m^2/kg); P_s (percentage of the aggregates) (% of total weight of the mix); G_{mb} (mix's bulk specific gravity)

Rutting resistance. Marshall Quotient (MQ) can be termed as the ratio of Marshall stability (kN) to flow (mm) in the mixed at OBC. MQ is used to determine the stiffness of the mix, which also an indirectly measures the resistance of asphalt mix against rutting. Asphalt mix having higher MQ value usually displayed superior resistance against permanent deformation or rutting.

Moisture susceptibility tests. Retained Marshall Stability (RMS) test was conducted to determine the moisture susceptibility of both mixes. For each type of mix, a total of six Marshall specimens were prepared at OBC which were divided in two groups, each having three specimens. The first group (unconditioned specimen) was placed in water maintained at 60 °C for 30 min. Similarly, the second group (conditioned specimens) was placed submerged in water maintained at 60 °C for 24 h. Both set of specimens were loaded to failure at constant compression rate of 51 mm/min using curved steel loading plates. The RMS was determined by taking mean stability values of each sample group according to the equation

$$RMS = \frac{MS_{cond}}{MS_{uncond}} \times 100 \quad (2)$$

where MS_{uncond} is the average Marshall stability for unconditioned specimens (kN); and MS_{cond} is mean Marshall stability for conditioned specimens (kN).

3 Test Results

3.1 Analyses of Marshall and Volumetric Properties

Analysis of mix's properties are given in Table 4 and in Fig. 4a–f. It was observed that Kota stone mix (5.96%) has relatively lower OBC than conventional mix (6.29%) (Fig. 4a). This was attributed to the relatively lower porosity of Kota stone, since it has higher German filler value (97 gm) than stone dust (85 gm) [6]. Because of the lower porosity of Kota stone dust, its mixes seemed to have lower values of VMA as well as air void contents at same binder contents (Fig. 4a and d). This may

Table 4 Various parameters of mixes at OBC

Mix	OBC	Marshall stability	Flow	Bulk specific gravity	VMA	VFB	AFT (μ)
Stone dust	6.29%	12.51 kN	3.51 mm	2.423	17.26%	74.70%	8.14 μ
Kota stone	5.96%	12.44 kN	3.38 mm	2.438	16.7%	74.90%	7.91 μ
Requirements	–	9 kN (minimum)	2–4 mm	–	14% (minimum)	65–75%	–

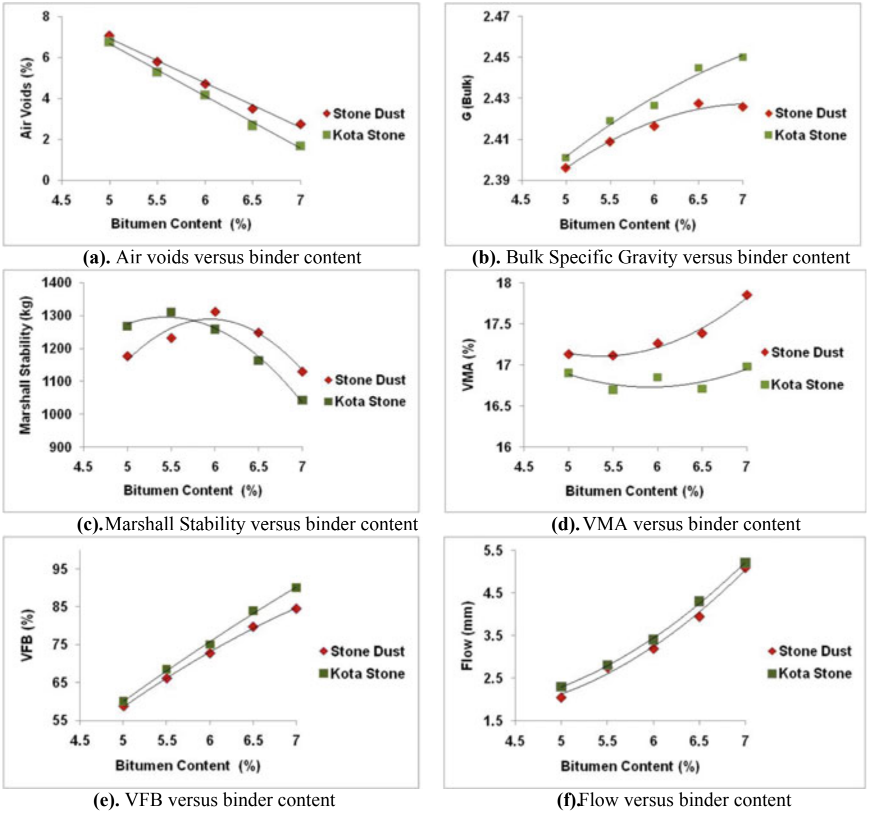

Fig. 4 Properties of mixes at different binder contents

justify their lower requirements of binder to reach the air void content of 4%, which may be responsible for their relatively lower OBC than stone dust mixes.

Lower air voids in Kota stone mixes may also lead to their higher bulk specific gravities (Fig. 4b). Marshall stability is defined as the load resisting capability of the asphalt mix and depends on its ingredient as well as on the interaction between them. Kota stone is the finer filler than the stone dust since it has lower fineness modulus (3.03) than the stone dust (5.38). Hence it seemed that Kota stone modifies the binder at a greater extent and produced Marshall stability equivalent to the stone dust mixes at the relatively lower OBC (Fig. 4c). Stone dust and Kota stone mixes have VFB values equal to 74.9% and 73.57%, respectively. Since VFB value of Kota stone mixes is lower than stone dust mixes, Kota stone dust may be preferred especially in the region having hotter ambiance. Average AFT of Kota stone mixes (7.91 μ) was also relatively lower than conventional mixes (8.14 μ), which might be due to the lower OBC of their mixes.

3.2 Analysis of Marshall Quotient

Marshall Quotient (MQ) value of Kota stone mix (3.68 kN/mm) was marginally higher than standard mix (3.56 kN/mm). Lower AFT of an asphalt mix is a responsible factor for its superior performance against rutting [16]. It was stated earlier that the Kota stone mixes has lower AFT than conventional mix, which may be responsible for its higher rutting resistance (Fig. 5).

3.3 Retained Marshall Stability Test

Both mixes fulfilled the minimum requirement of 75% Retained Marshall Stability (RMS) as suggested by Indian specification [7]. Kota stone mixes (96.41%) had slightly higher RMS values than conventional mixes (93.19%), which might be due to the good quantity of water insoluble calcite in the mineralogy of Kota stone dust.

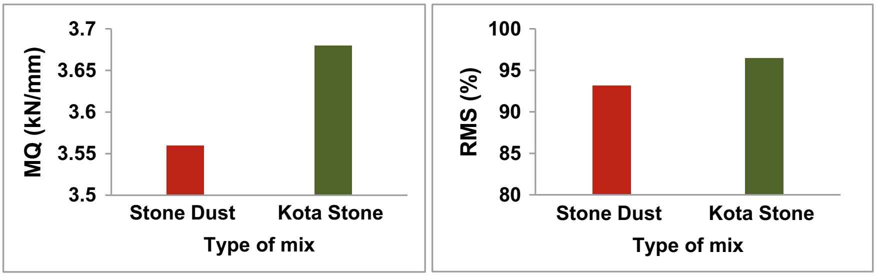

Fig. 5 Marshall Quotient (left) and Retained Marshall Stability (right) of studied mixes

4 Conclusions and Discussions

The following conclusions can be derived.

- Asphalt concrete mixes prepared with Kota stone has fulfilled all Marshall and volumetric criteria specified by Indian paving specification. It also has almost equivalent Marshall stability than stone dust that mixes with lower OBC. The Kota stone mixes have lower OBC due to the lower porosity of the filler.
- Kota stone mixes have higher MQ value which signifies its superior resistance against rutting than standard mix. This may be due to the finer nature of Kota stone and lower AFT of their mixes in comparison to the conventional stone dust mixes.
- Kota stone fulfilled the minimum retained stability requirements, i.e., 75% with a higher margin. This indicated its satisfactory performance against moisture permeation. This might be due to the lower harmful clay content, hydrophobic nature and presence calcite in the mineralogy of Kota stone dust which promotes binder–aggregate adhesion.

References

1. Ministry of Road Transport and Highways (MORTH): Specifications for Road and Bridge Works, Section 500, Fifth Revision. Indian Roads Congress, New Delhi, India (2013)
2. Suhaibani, A., Mudaiheem, J., Fozan, F.: Effect of filler type and content on properties of asphalt concrete. In: Effect of Aggregate and Mineral Fillers on Asphalt Mixture Performance, pp. 107–130. ASTM STP 1147, American Society for Testing and Materials, West Conshohocken, PA (2004)
3. Huang, B., Shu, X., Chen., X.: Effects of mineral fillers on hot-mix asphalt laboratory-measured properties. Int. J. Pavement Eng. **8**(1), pp. 1–9 (2007)
4. Chandra, S., Choudhary, R.: Characterization of fly ash bituminous concrete mixes performance characteristics of bituminous concrete with industrial wastes as filler. J. Mater. Civ. Eng. **25**, 1666–1673 (2013)
5. Choudhary, J., Kumar, B., Gupta, A.: Laboratory evaluation on recycling waste industrial glass powder as mineral filler in hot mix asphalt. In: Proceeding of Civil Engineering Conference—Innovation for Sustainability, Hamirpur, India, pp. 352–359 (2016)
6. Choudhary, J., Kumar, B., Gupta. A.: Use of dimension limestone sludge as filler in asphalt mix. In: Proceedings of the Institution of Civil Engineers-Construction Materials. https://doi.org/10.1680/jcoma.18.00022 (2018)
7. Choudhary, J., Kumar, B., Gupta. A.: Application of waste materials as fillers in bituminous mixes. Waste Manage. **78**, 417–425 (2018)
8. ASTM C119–16: Standard Terminology Relating to Dimension Stone. ASTM International, West Conshohocken, PA (2016)
9. Rana, A., Kalla, P., Csetenyi, L.J.: Recycling of dimension limestone industry waste in concrete. Int. J. Min. Reclam. Environ. **31**(4), 231–250 (2017)
10. Torres, P., Fernandes, H.R., Olhero, S., Ferreira, J.M.F.: Incorporation of wastes from granite rock cutting and polishing industries to produce roof tiles. J. Eur. Ceram. Soc. **29**(1), 23–30 (2009)

11. ASTM D854-14: Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. American Society for Testing and Materials, West Conshohocken, USA (2014)
12. ASTM D422-63: Standard Test Method for Particle-Size Analysis of Soils. American Society for Testing and Materials, West Conshohocken, USA (2007)
13. EN 933: Tests for Geometrical Properties of Aggregates—Part 9—Assessment of Fines Methylene Blue Test. British Standards Institution, London, UK (1999)
14. MTPRC (Ministry of Transport of P.R. China): Test Methods of Aggregate for Highway Engineering (JTG E42–2005). China Communications Press, Beijing (2005)
15. Asphalt Institute: Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types: Manual Series No. 2 (MS-2), 6th edn. Lexington, KY (1999)
16. Christensen, D.W., Bonaquist, R.F.: Volumetric Requirements for Superpave Mix Design, vol. 567, p. 57. Transportation Research Board, National Research Council, Washington DC (2006)