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Laboratory investigations on hot mix asphalt containing mining waste as aggregates

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HIGHLIGHTS

- Limestone mining waste was used as replacement of conventional aggregates in HMA.
- The waste was used in two type of HMA i.e. BC (grade 2) and DBM (grade 2).
- This study provide a sustainable solution for disposal problem of the mining waste.

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ABSTRACT

In the present study, limestone (famous as Kota stone) mining waste reformed into aggregates of size between 19 mm and 0.075 mm were used to make bituminous concrete (BC) and dense bituminous macadam (DBM) by replacing conventional (Basalt) aggregates. Properties of LSW as aggregates was evaluated on the basis of physical parameters and mix performance. The mixes were evaluated on the basis of strength, durability, resistance to moisture and rutting. Results indicated suitability of LSA (Kota stone aggregates) as pavement material. Up to 50% replacement of conventional stone (CS) by LSA in BC mixes and 25% in DBM gave satisfactory results for moisture susceptibility, resistance to rutting and low temperature cracking. It was recommended to use LSA for making medium to low traffic roads.

1. Introduction

India is one of the fastest growing economies in the world and has 2nd largest road network after U.S.A. [1] About 6604 km of national highways were constructed in the year 2016–17 alone, and as part of its infrastructure reforms, Government of India is aiming to double its National Highways to 200,000 km [2]. Since natural aggregate contributes to more than 90% by weight of pavement, it is evident that excavation and consumption of natural stone like basalt, andesite, and limestone will increase exponentially [3]. This mining process is already having a derogatory effect on the environment. On one side extraction of natural resources is leading toward a rapid decrease in available natural resources and on another side, massive extraction of these resources is generating an enormous quantity of waste [4]. Rajasthan is bestowed with a variety of decorative stone like granite, marble, sandstone, etc. all across its topography [5]. Kota stone is one such variety of splittable type flaggy limestone found in this area, and over the years it has gained tremendous popularity among buyers and sellers for flooring and cladding purposes.

In the recent past, Kota stone mining waste (LSW) has emerged as a serious threat to the biodiversity of this region. The genesis of this waste is quarry waste, generated from in situ mining, and, cutting and polishing waste produced during its manufacturing process. Piles of this waste are stretched over kilometers in the area. This has created a nuisance for residents, mine owners, workers, nearby flora, and fauna. Respiratory diseases are common among residents close to mining sites [6]. The unmanaged, unplanned dumping of slurry waste has polluted the local ecosystem by intermixing with nearby soil, degrading fertility of the agricultural land

Abbreviations: BC, bituminous course; DBM, dense bitumen macadam; HMA, hot mix asphalt; LSW, Kota stone mining waste; LSA, lime stone (Kota stone) aggregates, C-bc, 25L-bc, 50L-bc, 75L-bc, 100L-bc and C-dbm, 25L-dbm, 50L-dbm, 75L-dbm, 100L-dbm are mix designations representing different percentage replacement of LSA with conventional stone (CS) in bituminous concrete and dense bituminous macadam with percentage Kota stone aggregate replacements; ITS, indirect tensile strength test; TSR, tensile strength ratio; VFB, void filled with bitumen; SEM, scanning electron microscopic analysis; MoRT&H 2013, Ministry of Road Transport and Highways.

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and aquatic life [7]. To control this situation and regulate the dumping of waste on nearby areas government agencies have imposed strict environmental control policies and penalties over the opening of new quarries. However this is having little effect on the situation, the reason being no solution is available for the accumulated waste in the area [8]. The scarcity of dumping land has resulted in increased hauling distance, transportation cost, and pollution. This situation demands a concrete step to eliminate the accumulated waste.

In recent past, the feasibility of using mining waste as partial to full replacement of traditional aggregates in HMA have been studied. In a study by Kalla et al. (2006) black cotton soil was mechanically stabilized using LSW and fly ash from Kota thermal power plant. Twenty-seven mixes using soil-flyash, LSW-soil and LSW-flyash-soil combination were prepared. Improvement in soil strength (CBR, density, and plasticity) characteristic was observed in most of the mixes [9]. Pawan Patidar (2017) studied granular sub-base (GSB grading I–VI) made with LSW as aggregate. Results of this study showed suitability of this waste as aggregate for the above-mentioned purpose. However, authors suggested that LSA reformed aggregates were highly flaky and elongated above 20 mm [10]. Another study on the use of LSW as aggregate in asphaltic mixes was carried out by Mohit (2015). In his research LSW as aggregate was used to prepare BC, DBM, and cold patching mixes. The results of stability water sensitivity, resilient modulus, adhesion and indirect tensile strength tests on HMA and cold patching mixes indicated its strong resistance against moisture attack, thermal and fatigue cracking, with the best interlocking between particles. However, high creep and poor workability test results showed lower resistance of these mixes against permanent deformation [11]. Karasahin et al. (2007) used marble dust as filler in HMA between 0 and 10%. Results suggested that the use of marble dust as filler in asphalt mixtures however slightly higher plastic deformations were observed [12]. Another study by Ibrahim et al. (2009), in their study, tried to improve mechanical properties of the asphaltic mix by replacing basalt aggregate with limestone. Results showed optimal mix with basalt coarse aggregate and limestone fine aggregate. The optimal mix showed superiority, over the other mixes, on the basis of evaluated properties such as stability, indirect tensile strength, stripping resistance, resilient modulus, dynamic creep, fatigue, and rutting [13]. A study by Choudhary et al. (2010), evaluated hot mix asphalt properties containing marble and granite dust. Results of stability creep and moisture susceptibility tests indicate the suitability of dust as filler in bituminous construction [14]. Kofteci et al. (2014), also demonstrate the possibility of using marble waste (0, 50 and 100%) as a substitute of conventional aggregate in HMA. On the basis of improved stability and flexibility values of mixes containing marble waste, it was found suitable to replace conventional aggregate completely [15]. Resende et al. (2003) used quarry waste in pavement construction. The material was first evaluated in the lab which was followed by field study by laying road of 80 m stretch. The result showed that with time performance indices of road constructed by waste decreased, but no structural damage was observed. The study also recommended use of quarry waste for low volume roads [16].

Above studies shows tremendous potential of LSW as aggregate for bituminous and non-bituminous pavement layer. LSW as aggregate has been considered alone; its combination with other stones has not been explored earlier. Preliminary studies on use of LSW are based on mix design parameters, long term performance based test were not conducted. In the present study performance test including ITS, rutting, resilient Modulus have been carried out on ten composite mixes containing Kota stone waste.

2. Material and methods

2.1. Aggregate and asphalt binder content

The quarry waste used in this study was obtained from mining areas of Jhalawar and Ramganj Mandi, Kota, Rajasthan. Waste was crushed and transformed into aggregates of different sizes using commercial Jaw crusher in Jaipur city. The crushed aggregate produced in size ranging from size 19 mm to .075 mm, VG-30 bitumen was used as a binder in the study. Properties of the binder are summarized in Table 1. Conventional aggregates and stone dust was procured from a local supplier at Jaipur.

2.2. Aggregate testing

LSA was tested for aggregate shape as per (IS: 2386 Part I), for strength (IS: 2386 Part IV), water absorption and stripping (IS: 2386 Part III and IS: 6241), bulk specific gravity of aggregates and fines (IS: 2386 Part III). Properties of LSA were compared with conventional aggregate and fines used in this study; it reveals potential results summarized as shown in Table 2.The texture of LSA observed smoother than conventional aggregates as can be seen in Fig. 1. From physical property testing, it was established that LSA has all the desired property as required for a pavement material

2.3. Chemical properties test

The chemical composition of Kota stone was determined at Centre for Development of Stones, Jaipur (Rajasthan), as shown in Table 3. Primarily it consists of SiO2, CaO, MgO and traces of $Fe2O_3$.

2.4. Gradation

Gradation plays a vital role for an HMA to have proper strength and durability [17]. For bituminous concrete, dense bituminous macadam gradation type 2 was used as specified by section 505 and 507 of MoRT&H 2013. Hit and trial approach was used to achieve the required gradation. The procedure used to obtain LSA gradation was as per Montegomry et al. [18] and ASI et al. (2016) [19]. After crushing LSW, aggregates were washed, dried and sieved through standard sieves. Sieved material was then mixed to obtain gradation similar to that obtained using conventional aggregates. This procedure eliminates any chance of change in aggregate gradation and variation of gradation on binder content for analysis of durability and mechanical property of these mixes. The gradation obtained for bituminous concrete and dense bituminous macadam as shown in Fig. 2 and Fig. 3 respectively.

3. Experimental setup and procedure

3.1. Sample preparation

Ten different composites were prepared to replace conventional aggregates by LSA at an interval of 25% by weight ranging from 0 to 100% in BC and DBM. Marshall mix design method was adopted for sample fabrication with 75 blows each side as per MS-2 asphalt mix design method [38]. Blended aggregate sample weighing about 1200 gm was kept in the oven along with cast moulds for 24 h. The sample was then mixed with bitumen at mixing temperature of 150–160 °C till they are uniformly coated as per MoRT&H 2013. The mix was then placed in a preheated mould and subjected to 75 blows on both sides by hammer weighing 4.9 kg from a height of 45 cm. First trial percentage of bitumen was kept 5.4% for BC and 4% for DBM by weight of aggregates and increased subsequently by 0.5%. Three samples were prepared for each bitumen content, and the average value was adopted for calculation.

Table 1
Binder properties.

Properties	Value	Test method
Penetration value at 25 °C (.1 mm, 5 s)	38	IS 1203-1978 [30]
Softening point	60 °C	IS 1205-1978 [31]
Flashpoint	220 °C	IS 1209-1978 [32]
Density	1.09	IS1202-1978 [33]