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Experimental study on usability of various construction wastes as fine aggregate in asphalt mixture

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HIGHLIGHTS

- Effects of waste materials on performance properties of HMA were evaluated.
- Waste materials satisfy Marshall mix design specifications.
- Ceramic could improve the high-low temperature properties of asphalt mastic.
- Asphalt samples with marble could improve some performance property of HMA.

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ABSTRACT

In this study, some properties of asphalt mixture containing ceramic, marble and redbrick as recycled waste materials were investigated. Because of the low strength, recycled waste materials were used only as fine aggregate and filler. Various tests including moisture susceptibility, Marshall stability, Cantabro, mechanical composition, mineral composition and physical properties test were conducted. In addition, softening point and penetration properties of asphalt mastic containing the above-recycled waste materials as powder were researched. The results indicated marble mixture exhibited better performance than other mixtures, especially in 25% content. In addition, from asphalt mastic test results, ceramic asphalt mastic showed the superiority of high and low-temperature properties.

1. Introduction

Hot Mix Asphalt (HMA) which is consists of bitumen and aggregate is most commonly used construction materials in road construction. Aggregate is usually obtained from natural resources such as granite and limestone. By increasing economic cost and lack of accessibility to natural aggregates, have opened the opportunity to explore locally available waste materials. Several countries and global institutions have been working to minimize and reuse the produced wastes. By using the suitable waste material in the road construction the pollution and disposal problem will decrease.

The use of waste material in road construction becomes an interesting subject for the purpose of green environment and sustainable development. Many investigators have been working to substitute multiple types of waste material such as fly ash [1,2], ceramic [3–6], marble [7,8], construction and demolition wastes [9–12], redbrick [13–15] and recycled tyre rubber [16] as aggregate as well as filler in Hot Mix Asphalt. Ismail et al. [17] used crushed ceramic tiles as an aggregate from the size of 5.0 mm down included filler. The results of this study indicated that the use of ceramic tile can be potentially used in HMA mixture. Especially they mentioned that physical properties tests for waste ceramics were fulfilled the standard requirements [17]. Akbulut and Gürer researched by replacing marble waste in asphalt pavements, they reported the suitability of marble waste in medium traffic roads as well as in binder course [18]. Karasahin and Terzi used marble dust in the asphalt mixtures as filler material. In the study, Marshall test as well as dynamic deformation tests were performed. End of the study, they reported that marble wastes, which are in the dust form could be used as filler material in asphalt mixtures [19]. Wu, Zhong, and Wang investigated on related properties of asphalt mastic by replacing recycled Red Brick Powder (RBP) and stated positive effects of RBP on high-temperature properties of asphalt mastic [20]. Chen and Lin studied by substituting recycled

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red brick powder as filler and concluded the feasibility of using recycled red brick powder as mineral filler in asphalt mixture [21]. It was proved that these types of recycled waste materials gave acceptable results and can be used in HMA. However, some essential problems still exist to use recycled waste materials in road construction.

Antalya is one of the preferred touristic city in Turkey. The city has the fastest population growth in recent years. The immigration increased significantly to this province from other cities, consequently increased construction activity and waste material. According to investigations, it was determined that most of these waste materials are ceramic, marble and redbrick. The aim of present research is to investigate the feasibility of using these waste materials as the fine aggregate as well as filler in HMA. Different waste material contents were used for the preparation of Marshall mixture design specimens. The limestone aggregate was also used as the control in the experimental program. Various laboratory tests including Asphalt mastic tests, Cantabro and moisture susceptibility were conducted to evaluate the related properties of the mixture. In addition, the above issued recycled waste materials also replaced as the powder in asphalt mastic, to evaluate the penetration and softening point of asphalt mastic.

2. Materials and methods

2.1. Natural aggregates

In the research program, limestone was used as coarse aggregate and obtained from Boğaçayı quarry, Antalya. Table1 gives the physical properties of the limestone.

2.2. Bitumen

To prepare testing specimens, the bitumen used in this study has the penetration grade 50/70 and obtained from Aliaga refinery; Izmir/Turkey. Laboratory tests were performed to know the properties of the bitumen. Bitumen was evaluated in two stages: Before aging and after aging. Aging process was performed with TFOT (Thin Film Oven Test) method at 163 °C. Before aging, penetration, softening point and ductility tests were performed in order to determine the performance of bitumen. According to the test results, it found to be within the acceptable limits. Penetration index was calculated for identifying the temperature sensitivity of bituminous binder. According to the calculated result, it can be said that bitumen used in the study is somewhat susceptible against to the temperature. Flash point test was performed with Cleveland open cup method in order to determine resistance against flammability of the bitumen. The obtained result found to be higher than the minimum specification limit. After the short-term aging process, bitumen determined to be within the specification limits. The results of the conventional bitumen tests are shown in Table 2.

2.3. Waste materials

Ceramic, marble and redbrick wastes which were obtained from Antalya city construction sites, used as the fine aggregate as well as filler in this experimental investigation. The chemical and mineral composition of the waste materials were investigated by Wavelength Dispersive X-ray Fluorescence (XRF) and X-ray Diffractometer (XRD). The XRD and XRF results are shown in Table3 and Fig. 1 (a-redbrick, b-marble, c-ceramic) respectively. As indicated in Table 3, SiO_2, Al_2O_3, and Fe_2O_3 are the major components of redbrick and ceramic. However, CaO and LOI compose the main percentage of marble. As shown in XRD patterns the main mineral phase of redbrick is muscovite, quartz and sericite. The major mineral parts of ceramic are quartz and mullite, while marble mainly composed of calcite. Both chemical and mineral compositions prove that redbrick and ceramic are more complex than marble.

Table 2
Experimental results and specification limits related to bitumen.

Test	Specification	Results	Specification limits
Penetration (25 °C; 0.1 mm)	TS EN 1426	59	50–70
Softening point (°C)	TS EN 1427	51 °C	46–54
Penetration index (PI)	–	−0.56	–
Ductility (25 °C; 5 cm/min)	TS 119	>100	–
Flash point, °C (Cleveland open cup)	TS ISO 2592	295 °C	230 (min)
Thin Film Oven Test (TFOT) (163 °C; 5 h)	TS EN 12607-2	0.25	0.5 (max)
Change of mass (%)			
Change of softening point (°C)	TS EN 1427	3.1	9 (max)
Retained penetration (%)	TS EN 1426	62	50 (min)
Specific gravity	TS 1087	1.032	–

Table 3
Chemical composition of redbrick, marble and ceramic, % by mass.

Component	Redbrick	Marble	Ceramic
SiO_2	50.99	1.49	70.6
Al_2O_3	21.54	0.42	18.5
Fe_2O_3	8.8	0.23	2.20
MgO	2.14	0.53	0.60
CaO	6.09	53.3	1.60
Na_2O	0.81	0.08	3.60
K_2O	4.19	0.07	2.10
TiO_2	1.15	0.06	0.20
P_2O_5	0.13	–	<0.1
MnO	0.09	–	<0.1
Cr_2O_3	0.02	–	–
SO_3	1.1	0.09	–
LOI	2.65	43.53	–
A.Za	–	–	0.20
Total	99.7	99.95	99.6

2.4. Preparation of samples

2.4.1. Preparation of asphalt mastic

The asphalt mastic samples were prepared with four type of aggregates (limestone, redbrick, marble, ceramic) and 50/70 penetration bitumen. Aggregates in nearly powder form were sieved with two types of sieve (No 80 and No 200) in order to obtain aggregate with the necessary thinness for the performed experimental study. Waste material and binder ratio was fixed on a ratio of 1:1by weight. After heating bitumen at 160 °C in the laboratory type oven, it was poured into the mixing vessel. Following this, the aggregate was carefully added to the bitumen. Bitumen and aggregate were mixed in the mechanical mixer (IKA RW 20) at 1000 rpm speed for almost 5 min. Finally, performance tests were performed.

2.4.2. Preparation of asphalt mixture

The asphalt mixture samples used in the experimental study were prepared for the binder layer course, as per grading limits specified in Turkish Highway Construction Specification 2013. The gradation curves of the mixture design are shown in Fig. 2.

In the experimental part of the study, initially, the Optimum Bitumen Content (OBC) was determined. Six group of different percentage, from 3% to 5.5%, on the basis of 0.5% increment of bitumen content by weight were prepared. Three speci-

Table 1
Physical properties of limestone.

Property	Specification	Corse Aggregate	Fine Aggregate	Specification limits
Specific gravity	ASTM C127	2.64	2.71	–
Water absorption, %	TS EN 1097/6	0.41	0.49	≤2.5
Soundness of aggregate by use of magnesium sulfate (%)	TS EN 1367-2	12.07	–	≤18
Flakiness index, (%)	BS 812	18.14	–	≤30
Peel strength	TS EN 12697-11	89.00	–	≥60
Los Angeles abrasion %	AASHTO T96	27.00	–	≤30