

Utilization of Recyclable Concrete and Ceramic Waste as Filling Material in Hot Mix Asphalt

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Abstract

A significant issue that researchers have been addressing recently is the recycling of various waste materials from different industries. Annually, millions of tons of waste are released. Pollution and safe, cost-effective disposal are critical issues with these waste materials. This study aims to investigate usability of concrete waste (COW) and ceramic waste (CEW) as filler material in Hot Mix Asphalt (HMA). Firstly, in this direction, a series of tests were conducted to determine the optimum bitumen content. Five different bitumen contents (i.e., 4.5%, 5%, 5.5%, 6%, and 6.5%) were used to prepare asphalt concrete samples. The Marshall Stability (MS) test was then performed on the prepared samples using various filler ratios, including limestone (LS), concrete waste (COW), and/or ceramic waste (CEW). Selecting the series of asphalt with 4% filler that has provided the maximum stability, COW or CEW was replaced with LS filler at rates of 25%, 50%, 75%, and 100%. Consequently, the use of COW or CEW as a mineral filler in HMA was found to be suitable.

Keywords

recycling, ceramic waste (CEW), concrete waste (COW), hot mix asphalt (HMA)

1 Introduction

It is possible to occur environmental concerns by reason of the fact that a vast amount of waste is left directly in the environment. In this direction, the reuse of waste materials is encouraged by many countries to decrease harm to the environment because of waste materials. Waste materials can be utilized either by generating new products or as admixtures so as to use natural resources efficiently and protect the environment from the detrimental effects of waste. In Turkey, the annual aggregate use for road construction is approximately 100 million tons; also, these aggregates have some significant qualities such as service life, mechanical strength, and environmental and safety issues [1, 2].

Advancements in the road industry and an enormous rise in the number of vehicles lead to the encouragement of utilizing existing resources in constructing better roads with longer service life. When traditional raw materials like bitumen, unbound aggregate mixtures, and crushed aggregates started to become limited in the 1980s, alternative construction materials in road construction were initiated [3, 4]. It has been stated that recycled materials can be used in road construction at the different compounds and varying road layers.

Reducing the negative effects of processing natural resources on the environment is the key objective of using waste materials in the sector of road construction to relieve the load on authorities in both developing and developed countries that must set up landfills and other arrangements for such wastes and to reveal the industry's commitment to better road services and riding quality [4, 5].

Many experimental and research studies have been conducted to examine how waste materials might be utilized in road construction. Numerous studies have revealed that some compositions of these waste materials can successfully be reused and recycled in pavement structures. In literature, various waste materials were employed as filler material in asphalt mixtures, including pumice dust [6, 7], coal dust [8], fly ash [9–13], marble waste dust [14, 15], sewage sludge ash [16], and rice husk ash [17, 18].

In their study, Kofteci and Nazary [19] investigated the potential use of ceramic, redbrick and marble waste materials in asphalt concrete as fine aggregate. They found that ceramic waste considerably improved the Marshall stability value. Furthermore, they also emphasized that high and low-temperature properties in ceramic asphalt mastic

are more advantageous. Kara and Karacasu [20] investigated usability of the ceramic waste in hot mix asphalt. They deduced that the Turkish Highway Construction Specifications were fulfilled, and the additions of up to 30% ceramic waste for the binder course and up to 20% ceramic waste for the wearing course can be used in HMA. Muniandy et al. [21] investigated the usability of recycled ceramic waste as aggregate by substituting the granite aggregate with ceramic waste in different proportions. According to the control sample, they detected a 25% increase in the stability value when substituting granite aggregate with 20% ceramic waste. They also concluded that substitution of granite aggregate with 20% ceramic waste exhibited optimal resilient strength according to the control sample. Silvestre et al. [22] examined the utilization of ceramic waste as aggregate and declared that a 30% waste ceramic percentage was ideal in terms of aggregate weight. Shamsaei et al. [23] explored the compatibility of ceramic waste as filler material in hot mix asphalt. They conducted the experimental study by substituting limestone filler material with ceramic waste powder in different proportions. They emphasized that Marshall stability was improved in all waste ceramic dosages, and maximum improvement in the stability value (23%) was observed when ceramic waste was replaced entirely with limestone filler. They also concluded that 100% ceramic waste rate enabled fatigue life and rutting resistance. Also, they concluded that the use of a 100% ceramic waste rate enabled an increase in rutting resistance and fatigue life.

It is known that the enterprises in the ceramics industry want to get rid of these wastes that occupy unnecessary space in open areas or large warehouses, and that these enterprises do not expect any financial income from the wastes in general. On the other hand, a similar problem in concrete wastes occurs during the disposal of wastes. In this study, these waste materials, which can generate both economic gain and environmental and visual pollution, are evaluated by considering the use of ceramic and concrete wastes in HMAs and road pavement design and manufacturing, taking into account the transportation cost.

This study investigates the behavior of hot mix asphalt (HMA) concrete when concrete waste (COW) and ceramic waste (CEW) are utilized as filler materials. The ability of concrete and ceramic waste materials as filler to enhance the physical and mechanical properties of asphalt concrete was investigated. First, for this purpose, a series of tests were conducted so as to determine the optimum bitumen content. The experimental results, in general, showed that the mixes modified with concrete waste or ceramic waste were found to have improved high stability and suitable physical properties.

2 Material and method

In this section, the information about aggregate, bitumen, concrete waste, and ceramic waste as used in experimental studies is presented.

2.1 Aggregate

The physical and mechanical characteristics of aggregate utilized in the tests were determined according to American Standards [24, 25]. The properties of aggregate are presented in Table 1.

Sieve analyzes were conducted, and the available grading curve for the aggregate utilized in this study was close to the binder layer course as shown in Table 2. After the laboratory experiments, it was determined that the aggregate and bitumen used in the study are suitable for road construction.

2.2 Bitumen

The Marshall samples were prepared with asphalt cement with a penetration of 60–70. Table 3 lists the physical characteristics of the bitumen utilized in this study [26–30].

2.3 Ceramic waste

Ceramic wastes were obtained from a ceramic manufacturing factory as defective manufacturing product. These ceramic wastes were pulverized, ensuring to reach the size of filler material. After that, the pulverized material was sieved to pass through the 200 microns for use in asphalt concrete as a filler.

Table 1 Properties of aggregate, concrete waste, and ceramic waste used in the tests

Test name	Sieve diameter (mm)					Standard
	12.5–4.75	Aggregate 4.75–2.0	2.0–0.075	COW <0.075	CEW <0.075	
Specific gravity (g/cm ³)	2.666	2.686	2.755	2.660	2.355	ASTM C 127-88 [24]
Water absorption (%)	0.602	1.01	6.817	-	-	
Abrasion loss (%) (Los Angeles)	23	-	-	-	-	ASTM C 131 [25]

Table 2 Sieve analyses test result of aggregate

Sieve Diameter (mm)	Gradation of mixture % passing	Weight (gr)
19 (3/4")	100	0
12.5 (1/2")	85	187.5
9.5 (3/8")	70	187.5
4.75 (No. 4)	40	375
2.00 (No. 10)	25	187.5
0.425 (No. 40)	10	187.5
0.180 (No. 80)	6	50
0.075 (No. 200)	4	25
Filler	0	50
Total	100	1245

Table 3 Characteristics of Bitumen

Characteristics of Bitumen		
Test Name	Average Values	Standard
Penetration (25 °C)	60–70	ASTM D5 [26]
Flash Point	180°C	ASTM D92 [27]
Fire Point	230°C	ASTM D92 [27]
Softening Point	45.5°C	ASTM D36 [28]
Ductility (5 cm/minute)	>100 cm	ASTM D113 [29]
Specific Gravity	1.031	ASTM D70 [30]

2.4 Concrete waste

To produce COW fillers, hardened concrete waste and/or construction concrete debris of the concrete plants were supplied and pulverized. COW filler material was obtained by passing the pulverized material through the 200 microns for use in asphalt concrete as a filler.



Fig. 1 Preparation of waste materials

2.5 Preparation of waste materials

In this study, ceramic and concrete wastes obtained from the solid waste landfill (Fig. 1(a)) were first broken into smaller pieces with a hammer (Fig. 1(b)) and then ground with a jaw crusher (Fig. 1(c–d)). The ground samples were turned into filler material by a ball mill (Fig. 1(e–f)).

3 Research and findings

In the current study, the usability of the concrete waste (COW) and ceramic waste (CEW) as filler material in hot mix asphalt (HMA) was investigated. The flowchart of this experimental study is presented in Fig. 2. As can be understood from Fig. 2, firstly, optimum bitumen content was determined. Then, CEW-LS and COW-LS rates were determined.

A number of tests were conducted so as to determine the optimum bitumen content. Asphalt mixture samples were prepared at five different bitumen contents as 4.5%, 5%, 5.5%, 6%, and 6.5%. Fifteen samples were properly

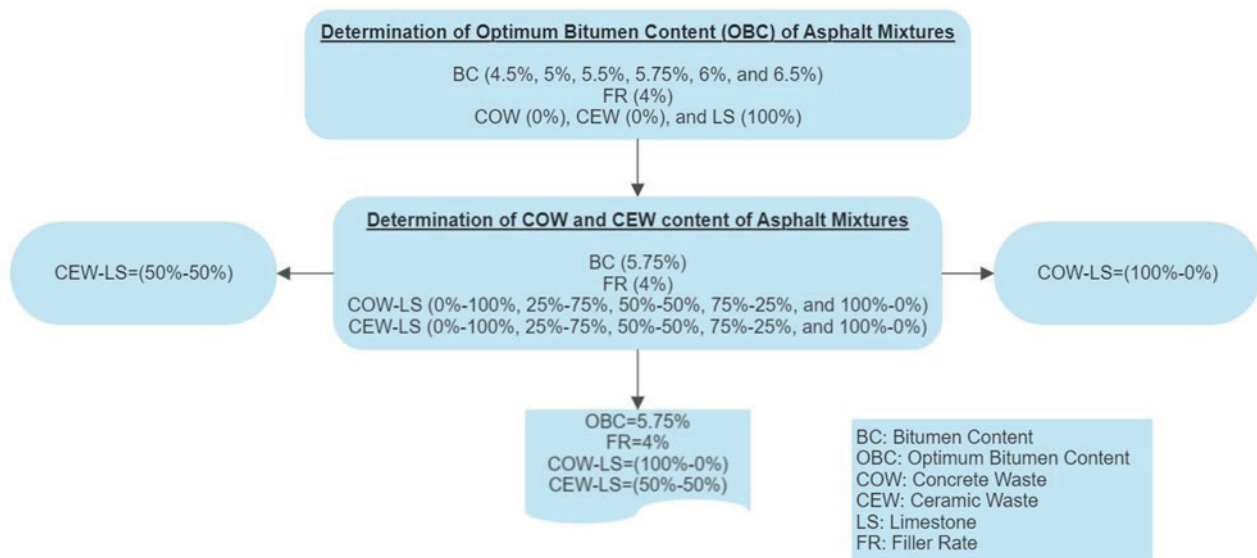


Fig. 2 Flowchart of this study

prepared for the Marshall Stability (MS) tests since three samples were prepared for all bitumen contents to determine the optimum bitumen content. Fig. 3 illustrates the asphalt concrete sample preparation and MS test. Determination of MS, void percentages (Vf), Void volume values (Va), voids in mineral aggregate (VMA) values, and flow value was made from these samples. Then, many graphs derived from the test results were evaluated. The variation in the MS values with bitumen content is shown in Fig. 4(a).

Durability is enhanced by obtaining a sufficient film thickness for any bitumen and aggregate mixture. Larger film thickness in the sense of effective bitumen content will result from coarser aggregate gradation. Reducing or



Fig. 3 Asphalt concrete sample preparation and Marshall Stability Test

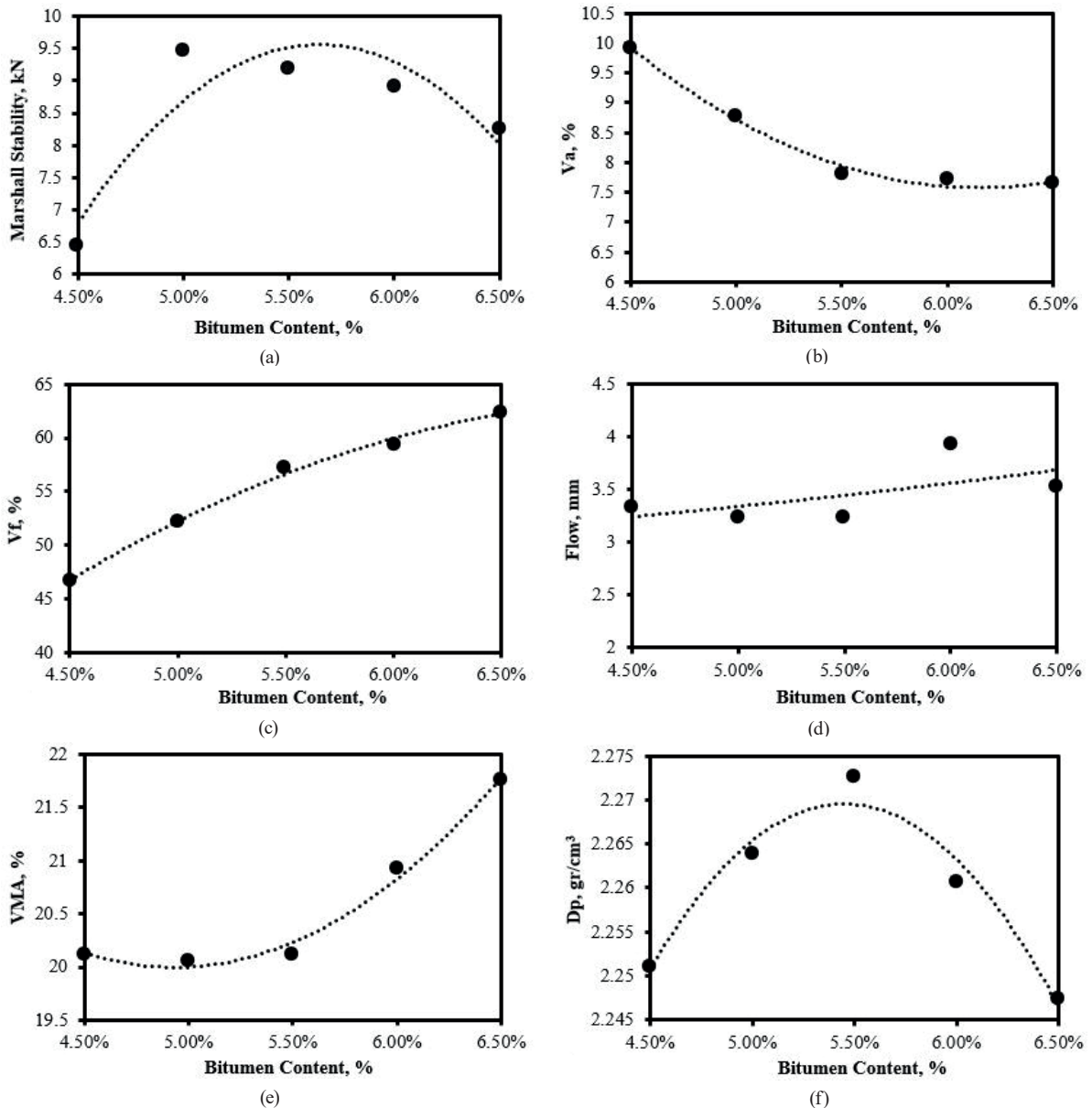


Fig. 4 Changes in a) MS value, b) Va, c) Vf, d) flow, e) Dp, f) VMA with different bitumen content

minimizing the percentage of fines is the most effective strategy to accomplish this. To achieve a sufficient film thickness without excessive asphalt bleeding or flushing, adequate Voids in Mineral Aggregate (VMA) must be established both during the mix design process and in the field [31].

Fig. 4(b) shows that in this study, while bitumen content increased, air voids in mixtures decreased. Additionally, as bitumen content increased, bitumen-filled voids also increased (Fig. 4(c)).

The flow value depicts the asphalt mixtures' plasticity and flexibility. In order to show flow, as well as the value of mixing and flow with the value of internal friction, Marshall samples that correspond to the deformation of load are broken. A linear inverse relationship exists between internal friction and flow [1, 32].

Fig. 4(d) illustrates the relationship between flow and bitumen content. The experiment's findings showed that asphalt bitumen content and flow of the mixture had a good relationship. The flow value increases while the bitumen content increases.

- Bitumen content that corresponds to the highest level of stability
- Bitumen content that corresponds to the highest bulk specific gravity
- Bitumen content that corresponds to the median of the designed limits of the percentage air voids in the total mix (i.e., 80%)
- Bitumen content corresponding to the median of specification designed limits of percentage voids filled with bitumen in the total mix (i.e., 70%)

Limestone aggregates optimum bitumen content for 4% filler rate as follows:

$$\frac{5 + 5.50 + 6 + 6.50}{4} = 5.75. \tag{1}$$

Accordingly, optimum bitumen content of limestone aggregate was found as 5.75%. MS tests were conducted by replacing the limestone with CEW or COW in different proportions, such as 25%, 50%, 75%, and 100%, with the obtained optimum bitumen content value. Three samples were also produced for each COW and CEW rate. MS tests were carried out to establish whether or not the addition of COW or CEW could result in a superior stability value and which COW or CEW rate would do so.

Fig. 5 demonstrates the stability results for the asphalt mixtures. In the experimental studies, when all filler materials were used as crushed stone aggregate, it was deter-

mined that the Marshall Stability (MS) value was around 9.34 kN as a result of the tests. When 25% of the filler materials were replaced with COW or CEW, it was observed that the stability values increased in both groups. In the case where the fillers in the mixture are CEW, the highest stability value was achieved in samples with 50% CEW and 50% LS (MS 12.51 kN). On the other hand, the same stability value was obtained in mixtures where 100% COW was used. This was also the highest stability value obtained at the end of all experiments. While the stability value of the CEW added mixes increased continuously up to 50% CEW rate, it tended to decrease for mixtures greater than 50% CEW rate. However, even with 100% CEW added mixtures, approximately 33% better performance than the reference value was obtained. In mixtures with COW added, Marshall stability increased with the COW rate in the mixture increases. It was understood that in the case of 50% CEW and 100% COW being used, a maximum performance increase of 34% is achieved.

Fig. 6 shows the flow values of the asphalt samples. Fig. 6 illustrates that the flow value for all samples is larger than 2 mm, the specification's lower limit value, and less than 4 mm, which is thought to be the upper limit value. Additionally, it was realized that all flow values are greater than 3 mm for all waste rates. The lowest flow value was

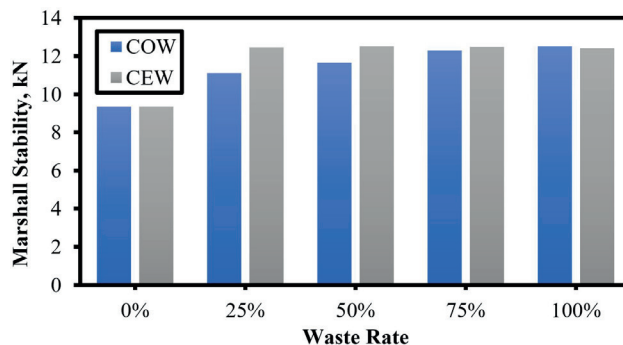


Fig. 5 Variation of MS value with different waste rate

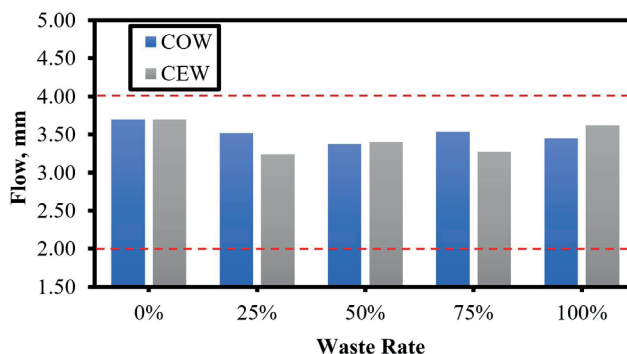


Fig. 6 Variation of flow with different waste rate

obtained from samples with 25% CEW. As a result of the experiments, the highest flow value of 3.62 mm was obtained in the samples with waste additives in the groups with a 100% CEW rate.

The D_p values of the asphalt samples is illustrated in Fig. 7. When the density values of the samples were examined, it was determined that the sample densities increased in all groups with the addition of waste to the mixtures. An increase in the (i.e., 1.98%) was obtained in the sample with a 50% CEW rate, where the density value was the highest, compared to the reference sample. In the COW added groups, the maximum density was reached at the 100% COW rate and the density increase in this group was 1.75% compared to the reference sample.

In consequence of the study, with the addition of waste materials to the mixture, it is seen that the V_a decreases in parallel with the increase in the density (Fig. 8). The lowest void volume was achieved with the addition of 25% waste in mixtures with COW and CEW additives. It is seen that the void volume of the mixtures first falls below the reference group and then increases with the waste additive. While the lowest air void was observed at 7.84% in the CEW mixtures with 25% additives, the highest air void occurred at 9.82% in the CEW mixtures with 100% additives.

The change of the VMA with waste rate is presented in Fig. 9. It is stated in the road construction specifications that the minimum VMA value required in HMA is 16%. A VMA value above this limit was reached in all groups with both CEW and COW additives used in the study. When Fig. 9 is examined, it is seen that the VMA value first decreases and then increases in both waste groups. While the lowest VMA value was obtained as 19.95% in CEW added groups, it was determined as 20.15% in COW added groups. In addition, the highest VMA value among all groups was reached in 100% CEW added groups.

The graph showing the voids filled with asphalt (V_f %) is presented in Fig. 10. The fact that the voids are filled with asphalt increases the homogeneity and has a positive effect on the strength. As a result of the study, while the highest V_f values were reached in the 25% CEW added groups, the lowest V_f values were reached in the 100% CEW added groups. While the highest V_f value was seen to be 60.69%, the lowest V_f value was determined to be 54.94%. Considering the COW-added groups, the lowest V_f value was observed in the 100% waste rate while the highest V_f value was in the 25% waste rate.

The ratio of a sample's stability to its flow value is known as the Marshall Quotient (MQ).

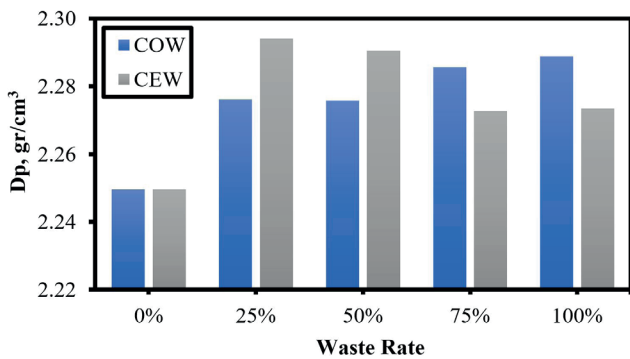


Fig. 7 Variation of D_p with different waste rate

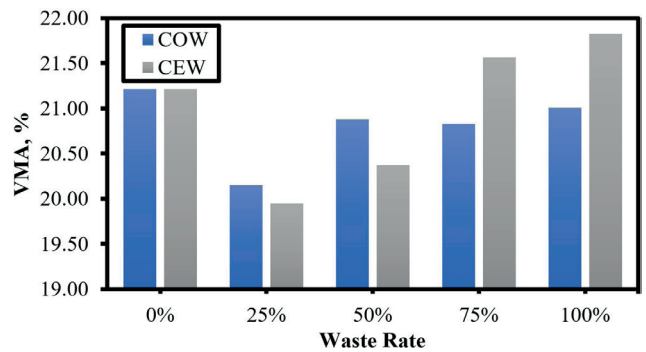


Fig. 9 Variation of VMA with different waste rate

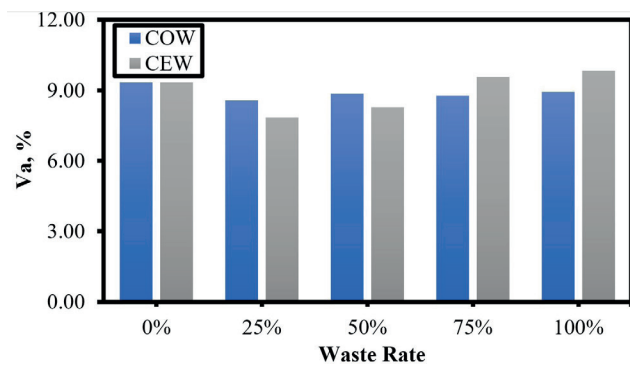


Fig. 8 Variation of V_a with different waste rate

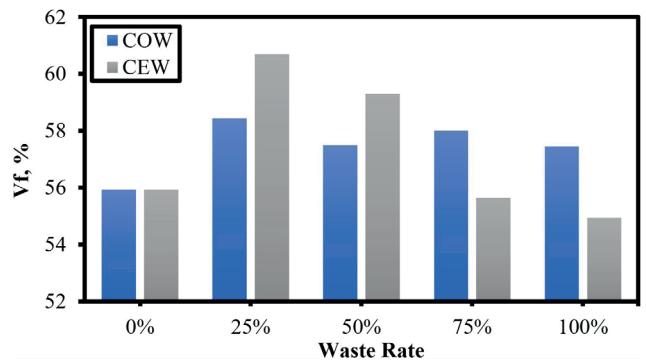


Fig. 10 Variation of V_f with different waste rate

$$MQ = \frac{MS}{F}, \tag{2}$$

where *MQ* is Marshall Quotient, *F* is the flow value, and *MS* is Marshall stability.

Fig. 11 illustrates samples' Marshall Quotient values at different waste rates for both COW and CEW. It is evident from Fig. 11 that the addition of waste material to the samples enabled an increase in the MQ values regardless of waste type as compared to reference sample. Moreover, it can be seen from Fig. 11 that the highest MQ values, which are 1.53 and 1.44 times the MQ of the reference sample, were obtained at 25% and 100% waste rates for CEW and COW, respectively. Accordingly, it can be inferred from this behavior that asphalt mixtures containing CEW and COW exhibit higher resistance to permanent deformations due to their increased stability. Additionally, a higher MQ value suggests that mixtures containing COW and CEW can be utilized in pavements where a stiff bituminous mixture is required.

Table 4 presents some mechanical-physical data for comparing the best-performing COW and CEW-added samples and reference samples.

4 Conclusions

This paper investigates of the usability of ceramic waste (CEW) and concrete waste (COW) as filler material in hot mix asphalt (HMA).

The current study has concentrated on primarily two sections. Firstly, tests have been repeated on samples produced with determined optimum bitumen content (OBC) and comparative graphs have been created. Secondly, asphalt concrete samples were produced at 5.75% OBC with 4% filler rates (FRs). Thus, it was ensured that the most appropriate waste type and waste rate for filler was determined.

In the study, CEW and COW were replaced with determined 4% FR limestone (LS) in proportions of 25%, 50%, 75%, and 100%. Then, the optimum CEW and COW substitution ratios were determined by comparing the results. Following that, MS tests were carried out on the prepared samples, and thus the findings were assessed. Consequently, it was inferred that CEW and COW could

be utilized as mineral filler in HMA. 50% CEW and %100 COW have shown a significant improvement in asphalt concrete behavior. According to all test results, it was observed mixtures that were prepared with 50% CEW and 50% LS filler rate had the best MS when assessed in the sense of MS. While the highest MS value was obtained as 12.51 kN from the samples prepared with 50% CEW and 100% COW filler, the lowest MS values were obtained as 11.09 kN and 12.42 kN from the samples prepared with 25% COW and 100% CEW, respectively. However, even the lowest MS value appears to be higher than the MS value of the reference groups (%100 LS). Besides, maximum MQ values, 1.53 and 1.44 times that of the reference sample, were obtained for CEW and COW at 25% and 100% waste rates, respectively.

All in all, the current study's experimental findings suggest that using CEW and COW as filler material in HMA could be a more environmentally friendly alternative than using limestone.

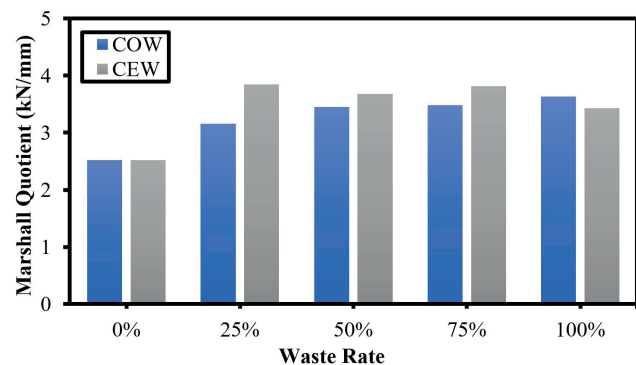


Fig. 11 Variation in MQ with different waste rate

Table 4 Some mechanical-physical data for the best performing COW-CEW ratios

	Reference	COW (100%)	CEW (50%)
Dp (g/cm ³)	2.25	2.29	2.29
MS (kN)	9.341	12.513	12.513
Va (%)	9.34	8.93	8.28
Vf (%)	55.93	57.46	59.31
VMA (%)	21.21	21.01	20.37
Flow (mm)	3.70	3.45	3.40

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