



## USE OF RECYCLED WALL CERAMIC WASTE IN BITUMINOUS MIXTURES

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### Abstract

Various types of recycled waste are used as constituent materials of bituminous mixtures with the aim of promoting environmental sustainability. The paper investigates the possibility of using ceramic wall waste as a partial replacement for coarse aggregate in bituminous mixtures of the asphalt concrete (AC) type. Bituminous mixtures containing 10%, 20%, 30% and 40% ceramic waste were tested for their physical and mechanical properties. Marshall Design and Static-Dynamic Creep Test methods were used in the experimental part. The results of the tests show that increasing the ceramic content reduces the creep stiffness and stability of the asphalt, while at the same time increasing the void content due to the porous structure of ceramic waste. A 20% ceramic content in the coarse aggregate of the bituminous mixture confirms optimal properties, achieving structural stability and resistance to deformations prescribed by the specifications of Turkish Highways. Therefore, the use of ceramic waste in an optimal ratio represents an effective and sustainable alternative to component materials for the construction of asphalt pavements. The use of previously laboratory-tested types and proportions of recycled wall ceramic waste encourages the practice of a circular economy and the conservation of natural aggregate resources, as well as the sustainability of development in road construction.

*Keywords: recycled waste, wall ceramic, bituminous mixtures, sustainable development*

### 1 Introduction

The increase in industrial production and the global population has led to a significant rise in waste generation. Limited landfill capacities have prompted research into reusing industrial waste in construction materials. The ceramic industry is a major waste source, especially in countries with developed tile manufacturing, such as Turkey. In line with sustainable development goals and the Paris Agreement, there is growing exploration of using such waste in road construction. Technical standards specify permissible percentages of recycled material in various layers of pavement structures [1-5]. In the tabular display in figure 2, the top ten countries in global ceramic tile production are reviewed, with descriptions and explanations of their positions. The ranking is based on long-term industry trends such as capacities, exports, domestic consumption, and technological level [6].



Figure 1 Ceramic wall waste – CWW

Table 1 Top ten countries in global ceramic tile production

Country	2018 [Sq.m Mill.]	2019 [Sq.m Mill.]	2020 [Sq.m Mill.]	2021 [Sq.m Mill.]	2022 [Sq.m Mill.]	% on 2022 world production	% var. 21/22
China	9,011	8,225	8,474	8,863	7,312	43.6	-17.5
India	2,011	2,223	2,318	2,550	2,300	13.7	-9.8
Brazil	872	909	840	1,049	927	5.5	-11.6
Vietnam	602	560	559	554	579	3.5	4.5
Spain	530	510	488	587	500	3.0	-14.8
Iran	383	398	449	458	480	2.9	4.8
Italy	416	401	344	435	431	2.6	-0.9
Indonesia	383	347	304	410	430	2.6	4.9
<b>Turkey</b>	<b>335</b>	<b>296</b>	<b>370</b>	<b>438</b>	<b>385</b>	<b>2.3</b>	<b>-12.1</b>
Egypt	300	300	285	340	380	2.3	11.8
Total	14,843	14,169	14,431	15,684	13,724	81.9	-12.5

Ceramic production in Turkey began in 1950, with the distribution of ceramic factories across regions as follows [7-10]:

- 49.82% region Eskisehir-Bilecik-Kutahya
- 28.61% region Izmir-Manisa-Usak-Aydin
- 14.61% provinces Canakkale
- 6.96% region Cankiri-Yozgat.

Ceramic wall waste (CWW) is generated in large quantities during the production of ceramic tiles and sanitary ware, including scrap, breakage, and defective products, as well as during building demolition and renovation. Due to its high durability, chemical inertness, and slow decomposition, ceramic materials occupy significant space in landfills and pose long-term environmental challenges. However, these materials possess favorable mechanical properties, such as high compressive strength and abrasion resistance, making them suitable for reuse as secondary raw materials in construction, especially in road building. In line with circular economy principles and sustainable development, increasing focus is placed on recycling and valorizing ceramic waste to reduce landfill dependency, conserve natural resources, and lower the environmental footprint of the construction sector [11].

## 2 Materials and testing methods

The aggregate used is a limestone material from the Eskişehir region. Bitumen with a penetration grade of 50/70, produced at Tüpraş refinery in Kırıkkale, served as the binder. Ceramic waste, collected from Seranit's manufacturing plant in İnönü, consisted of defective, broken, and process scrap wall tiles. These tiles were made from standard ceramic mass, including clay raw materials, quartz, feldspar, and minor amounts of carbonates and other minerals. After firing, the ceramic waste forms a compact, brittle, and chemically inert material suitable for crushing and secondary aggregate use. To determine the optimal bitumen content and basic asphalt mixture properties, the Marshall stability test was conducted following ASTM standards. The density and volumetric properties of the asphalt mixtures were measured according to ASTM D2726 and D3203. Resistance to permanent deformation was evaluated through static and dynamic creep tests based on ASTM D2990 and D4123. In Turkey, these standards are adopted as TS EN, ensuring full comparability of results.

### 2.1 Testing ceramic wall waste (CWW) as an additive to the aggregate

As a supplement to the aggregate in this study, ceramic wall waste (CWW) derived from the manufacturing process of ceramic wall tiles was used. This material includes defective products, breaks, and technological scrap, which, after crushing and granulometric processing, served as a secondary aggregate in asphalt mixtures. Due to its high compressive strength, wear resistance, and chemical inertness, CWW offers a sustainable alternative to natural aggregate, helping reduce industrial waste and conserve natural resources. Tests on the aggregate involved assessing basic physical, mechanical, and durability properties to determine its suitability for asphalt and road construction applications. Additional tests on the aggregate included the following:

- sieve analysis (TS/HRN EN 933-1)
- Los Angeles (L.A.) abrasion test (TS/HRN EN 1097-2)
- flakiness index test (TS/HRN EN 933-3)
- coarse aggregate specific gravity (TS/HRN EN 1097-6)
- fine aggregate specific gravity (TS/HRN EN 1097-6)
- filler aggregate specific gravity (TS/HRN EN 1097-7)
- bulk density test (TS/HRN EN 1097-3)
- freeze–thaw resistance test (TS/HRN EN 1367-1).

### 2.2 Bitumen testing

The examination of bitumen in this study included basic physical and rheological properties that determine its suitability for use in asphalt mixes and its behaviour under operational conditions:

- penetration test (TS/HRN EN 1426)
- softening point test (TS/HRN EN 1427)
- ductility test (TS/HRN EN 13589)
- flash point test (TS/HRN EN ISO 2592)
- loss on heating test (TS/HRN EN 12607-1)
- specific gravity test (TS/HRN EN 15326).

This testing ensures a complete understanding of bitumen properties necessary for proper asphalt mixture design and evaluation.

## 2.3 Testing asphalt mixture with CWW additive

The asphalt mixture testing, specifically asphalt concrete (AC) with CWW aggregate, included project, mechanical, and functional assessments to evaluate load-bearing capacity, durability, and adhesion properties. Tests conducted were:

- marshall shape analysis (TS/HRN EN 12697-34)
- static and dynamic creep tests (TS/HRN EN 12697-25, TS/HRN EN 12697-22)
- adhesion testing (TS/HRN EN 12272-3).

These evaluations provide a comprehensive understanding of the mixture's performance, including its strength, deformation resistance, and longevity during use.

### 2.3.1 Preparation of samples using Marshall design

The entire laboratory process for preparing and testing asphalt mixtures is outlined, from mixing to compaction and sample labelling:

- adding and homogenizing the mixture (TS/HRN EN 12697-1)
- mixing aggregates and bitumen (TS/HRN EN 12697-35)
- determining stability (TS/HRN EN 12697-30).

After removal from molds, samples are cooled and clearly labeled according to CWW content and test type. This sequence ensures controlled, repeatable sample preparation conditions, which are essential for reliable comparison of the effects of different ceramic wall waste (CWW) proportions on asphalt properties.

### 2.3.2. Static and dynamic creep testing

Static and dynamic creep tests were conducted to evaluate the resistance of asphalt mixtures to permanent deformation under long-term and cyclic loading conditions. These tests simulate real pavement conditions, particularly the occurrence of rutting (figure 3). For each asphalt mixture variant, three samples were prepared for static creep testing and three for dynamic creep testing. The mixtures contained varying proportions of ceramic wall waste (CWW): 10%, 20%, 30%, and 40% relative to the total aggregate content. Static creep testing analyzed deformation behavior under constant load over time, while dynamic creep testing assessed the accumulation of permanent deformation under cyclic loading, representative of traffic effects. The results enabled comparison of the influence of different CWW contents on the long-term stability of asphalt mixtures.



Figure 2 Laboratory device for static (left) and dynamic (right) testing of asphalt mixture creep

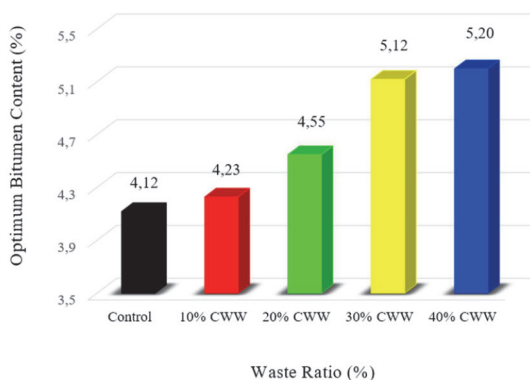
The following shows the criteria for asphalt mixture design based on bitumen ratio (%) for binder and wearing layers, as used in the Marshall test method (table 2).

**Table 2** Design criteria for asphalt mixtures

Design Criteria	Bitumen ratio [%]	
	Binder	Wearing course
Specific gravity (SG) [gr/cm <sup>3</sup> ]	Max	Max
Marshall stability (MS) [kg]	Min-750	Min-900
Void (V) [%]	4-6	3-5
Voids filled with asphalt (VFA) [%]	60-75	65-75
Voids of mineral aggregate (VMA) [%]	Min 13	Min 14
Flow (F) [mm]	2-4	2-4

For each test sample (figure 3), separate quadratic polynomial graphs were created for various asphalt mixture parameters: SG, MS, V, VFA, MQ, VMA, and F. These functions were used to determine the characteristic optimal bitumen content values for each parameter individually. The overall optimal bitumen content (OBC) was then calculated as the average of these values, ensuring a balanced assessment that meets stability, volumetric, and workability requirements of the asphalt mixture. The graphs compare Marshall's test results for control samples and samples with 10%, 20%, 30%, and 40% CWW additives. The optimal bitumen content is determined individually for each sample. The impact of ceramic wall waste (CWW) proportion on the optimal bitumen content (OBC) in asphalt mix is shown. Visible is that as the proportion of CWW increases, the required bitumen content gradually rises:

- reference (control) mixture without CWW shows the lowest OBC ( $\approx 4.12\%$ )
- adding 10% and 20% CWW causes a moderate increase in OBC
- at 30% and 40% CWW, a more significant rise in the optimal bitumen content is observed, reaching about 5.20%.



**Figure 3** Optimal bitumen content (OBC) depending on CWW share

### 3 Test results

The displayed results include properties of natural aggregate, ceramic wall waste (CWW), bituminous binder, and the behavior of asphalt mixes during creep testing, enabling comprehensive analysis of CWW's impact on the design and mechanical properties of asphalt mixtures.

#### 3.1 Results of natural aggregate and CWW task testing

Natural basic aggregate shows the following:

- high apparent and bulk density values ( $\approx 2.70\text{--}2.73\text{ g/cm}^3$ )
- very low water absorption ( $\approx 0.33\text{--}0.35\%$ )
- satisfactory wear resistance (Los Angeles  $\approx 24.5\%$ )
- favorable freeze-thaw resistance.

These indicators confirm that natural aggregate is a high-quality reference material for comparison with alternative aggregates. The CWW auxiliary unit of the generator is distinguished by:

- significantly lower density compared to natural aggregate
- extremely high water absorption ( $\approx 18\%$ ), due to porous microstructure
- comparable wear resistance (Los Angeles  $\approx 24.6\%$ )
- good resistance to freezing and thawing.

The results indicate that CWW is mechanically suitable as an aggregate but requires increased bituminous binder due to high absorption, directly affecting asphalt mixture design.

#### 3.2 Results of bitumen testing

Bitumen produced at Tüpraş refinery (İzmit, Turkey) shows:

- penetration of 64 (0.1 mm), characteristic of class 50/70
- softening point of  $48^\circ\text{C}$
- very good ductility ( $> 100\text{ cm}$ )
- low weight loss during heating (0.43%)
- high flash point ( $314^\circ\text{C}$ )
- appropriate viscosity values at  $135^\circ\text{C}$  and  $165^\circ\text{C}$ .

The obtained results confirm that the binder complies with road construction requirements and is suitable for mixes with increased proportions of alternative aggregate.

#### 3.3 Results of static creep testing

Based on the display of accumulated deformation (figure 4), control samples exhibit lower deformation values compared to samples containing ceramic wall waste. Creep testing indicates that the control asphalt mixture, without ceramic waste, shows the least permanent deformation, suggesting higher stiffness and resistance to long-term loading. Introducing ceramic wall waste into the mixture results in a gradual increase in accumulated deformation, with higher CWW content reducing the mixture's resistance to permanent deformation. The most significant creep was observed in the mixture with 40% CWW, indicating that high levels of ceramic waste substantially affect the deformation behavior of the asphalt mixture and may limit its use under higher traffic loads.

Based on the display of creep stiffness (figure 5), it is observed that creep stiffness decreases as the proportion of ceramic wall waste increases. Asphalt concrete samples with CWW additives reduce pavement creep under constant load.

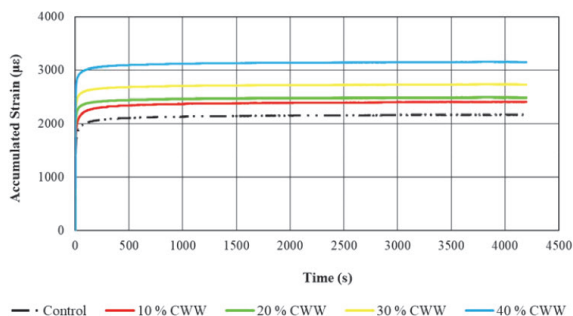


Figure 4 Accumulated stress - Time graphs

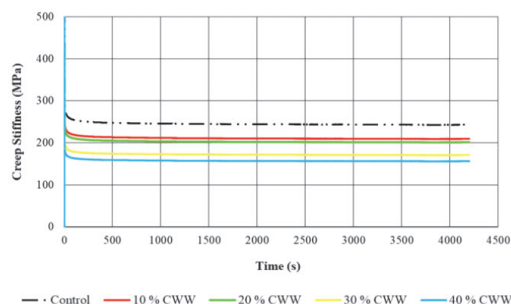


Figure 5 Creep Stiffness - Time graphs

The results of rutting stiffness tests indicate that the control mixture exhibits the highest resistance to permanent deformation, while increasing the CWW content gradually reduces stiffness. The lowest values are observed at 40% CWW. All mixtures show stabilization of stiffness after the initial loading phase. Moderate CWW levels, up to about 20%, maintain acceptable mechanical properties. An optimal CWW content of 20% offers a favorable balance between deformation resistance, cost-effectiveness, and environmental sustainability. Therefore, approximately 20% CWW can be considered the optimal compromise between sustainability and long-term asphalt mixture durability.

### 3.4 Analysis of Marshall project parameters based on the proportion of ceramic wall waste CWW

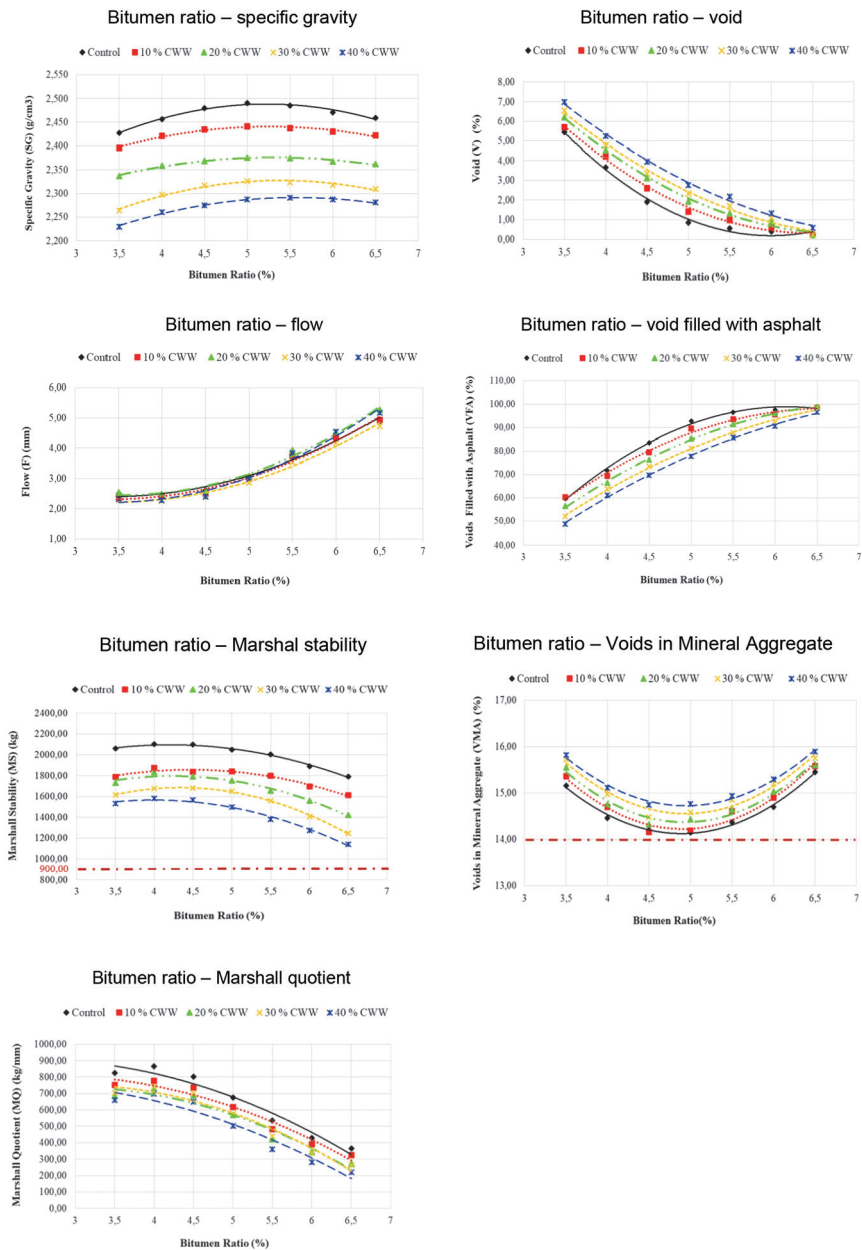


Figure 6 Analysis of Marshall parameters depending on the CWW share and bitumen content

### 3.5 Results of dynamic crawling testing

Accumulated deformation graph (figure 7) shows that the control mixture exhibits the slowest increase in deformation and the highest number of load cycles before a pronounced non-linear growth, indicating the best resistance to permanent deformation. As the proportion of CWW increases, there is an accelerated growth in accumulated deformation, with mixtures containing 30% and especially 40% CWW reaching significantly higher deformations at fewer cycles. This trend suggests reduced resistance to rutting at higher levels of ceramic waste. After 1,000 pulses, the accumulated deformation in samples modified with 10%, 20%, 30%, and 40% was greater than in control samples. Control samples demonstrated better performance in terms of deformation compared to samples containing wall ceramic waste. However, the performance values of samples with wall ceramic waste were also close to those of the control samples. Consequently, wall ceramic waste should not be used in amounts exceeding 20% as an additive. Additionally, the results aligned with Marshall design parameters.

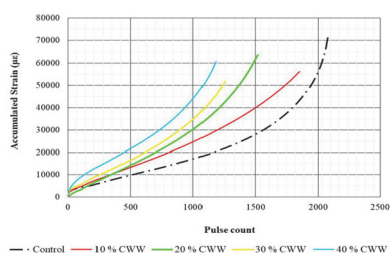


Figure 7 Accumulated stress - Number of impulses

The creep stiffness values (figure 8) decrease as the number of impulses increases. Testing the number of impulses and stiffness values concluded that creep stiffness in samples containing ceramic wall waste is not negatively affected. However, the highest stiffness values are observed in control samples. The stiffness graph during creep shows an opposite trend: all mixes exhibit a sharp decrease in stiffness initially, followed by a gradual slowdown. The control mix maintains the highest stiffness throughout testing, while increasing CWW content results in lower stiffness values. The lowest values are found in the 40% CWW mix, indicating a higher tendency for permanent deformation.

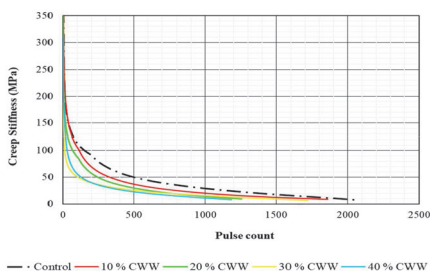


Figure 8 Creep Stiffness – Number of impulses

Overall, the results of dynamic crawling confirm that increasing the proportion of ceramic wall waste reduces stiffness and increases accumulated deformation of asphalt mixes. Moderate CWW levels (up to about 20%) still ensure acceptable behavior under cyclic loading, while higher levels significantly impair the mix's resistance to long-term traffic effects.

## 4 Conclusion

Analysis of technical, mechanical and economic indicators of asphalt mixtures with ceramic wall waste (CWW) showed that an increased proportion of CWW requires a higher proportion of bitumen due to a higher specific surface area, pronounced porosity and higher binder absorption compared to natural aggregate. This directly affects the volumetric properties of the asphalt mixture, but also the overall economics of asphalt production. The introduction of 10% CWW causes a negligible increase in costs, while at 20% CWW a moderate increase in total costs is recorded ( $\approx 4.86\%$ ), which is primarily a consequence of the higher proportion of bitumen, and not the price of the waste itself. At higher substitution proportions (30% and 40%), there is a sharp increase in costs due to the dominant influence of the price of bitumen, which means that the economic advantage of using waste is lost. From a technical point of view, mixtures with up to 20% CWW retain satisfactory mechanical and volumetric properties and acceptable resistance to permanent deformation, while at higher proportions a deterioration in stiffness and an increase in deformation are observed. In conclusion, a CWW content of approximately 20% represents an optimal limit that ensures a balance between technical acceptability, economic feasibility and environmental benefits, thus confirming the justification of its limited application in the asphalt industry.

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