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Enhancing Sustainability in Asphalt Concrete: Utilizing Ceramic Cake Waste and Performance Analysis

Asfalt Betonunda Sürdürülebilirliğin Artırılması: Seramik Kek Atığının Kullanımı ve Performans Analizi

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Abstract
The rapid growth of the global population has led to an increased demand for vehicles and industrial products, resulting in heightened production levels. Unfortunately, this surge in production inevitably generates significant amounts of waste, which, when not effectively managed, contributes to environmental pollution and poses challenges for waste storage. To address these pressing concerns, scientific research has been actively exploring ways to repurpose waste materials across various sectors to promote sustainability. This study delves into the innovative concept of incorporating ceramic cake waste (CCW) as an alternative aggregate material in the production of asphalt concrete -a key material in road construction. Our research explored the feasibility of incorporating CCW into asphalt concrete, typically consisting of aggregates and bitumen. We identified a pivotal threshold through rigorous testing and analysis: incorporating up to 20% CCW in asphalt concrete production aligns with industry standards. This approach not only aids in reducing environmental and visual pollution but also optimizes waste storage and resource utilization, ultimately contributing to a healthier environment and improved quality of life. In conclusion, our study takes a significant step towards promoting sustainability in the road construction sector. The findings provide a foundation for the further exploration and adoption of ceramic cake waste reuse in road construction, offering a promising solution and awareness to address the challenges posed by increasing waste generation and the imperative for sustainable development.

Keywords: Asphalt concrete, Ceramic cake, Waste recycling, Marshall design, Sustainable materials

Özet
Küresel nüfusun hızlı büyümesi, araçlara ve endüstriyel ürünlere olan talebin artmasına ve bunun sonucunda üretim seviyelerinin artmasına neden olmaktadır. Ne yazık ki, üretimdeki bu artış kaçınılmaz olarak önemli miktarda atık üretmektedir. Bu atıklar etkili bir şekilde yönetilmediğinde çevre kirliliğine sebep olmakta ve atık depolama konusunda zorluklara yol açmaktadır. Bu sorunları gidermek için sürdürülebilirliği teşvik etmek amacıyla çeşitli sektörlerde atık malzemeleri yeniden kullanmanın yolları bilimsel çalışmalarda aktif olarak araştırılmaktadır. Bu çalışmada, yol yapımında önemli bir malzeme olan asfalt betonu üretiminde seramik kek atığının (SKA) alternatif bir agrega malzemesi olarak kullanılmasına yönelik yenilikçi konsept incelenmektedir. Araştırmamız, SKA'nın, tipik olarak agrega ve bitümden oluşan asfalt betonuna dahil edilmesinin fizibilitesini sunmaktadır. Titiz test ve analizler sonucunda, asfalt betonu üretimine %20'ye kadar SKA'nın dahil edilmesi endüstri standartlarına uygun olduğu belirlenmiştir. Bu yaklaşım çevre ve görsel kirliliğin azaltılmasına yardımcı olurken, aynı zamanda atıkların depolanması ve uygun kullanılması ile daha sağlıklı bir çevreye ve yaşam kalitesinin iyileştirilmesine katkıda bulunmaktadır. Sonuç olarak, çalışmamız yol inşaatı sektöründe sürdürülebilirliğin teşvik edilmesi yönünde önemli bir adım atmaktadır. Bulgular, seramik kek atıklarının yol yapımında yeniden kullanılmasının daha fazla araştırılması ve benimsenmesi için temel oluşturmakta ve artan atık üretiminin yarattığı zorluklara ve sürdürülebilir kalkınma zorunluluğuna çözüm bulmak için umut verici bir çözüm ve farkındalık sunmaktadır.
Anahtar kelimeler: Asfalt betonu, Seramik keki, Atık geri dönüşümü, Marshall tasarımı, Sürdürülebilir malzemeler

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1. Introduction

Asphalt concrete pavements are the preferred choice in road networks due to their performance and ease of maintenance. This composite material primarily consists of aggregates and bitumen. Despite bitumen comprising only around 5% of asphalt concrete by proportion, it accounts for a substantial 80% to 90% of the total cost. In contrast, while aggregates constitute just 10-20% of the total cost, they make up approximately 95% of the composition of asphalt concrete. Even though the bitumen content in Hot Mix Asphalt (HMA) may be relatively low, it plays a pivotal role in determining overall coating performance [1-5].

On the other hand, the growth of industrial production has been accompanied by a relentless increase in waste generation, posing significant challenges to the environment. This surge in waste production has been driven by the global demand for products and services, resulting in higher levels of consumption and manufacturing. However, this intensified industrial activity has strained the availability of natural resources and the capacity of storage facilities. As a consequence, there has been a growing recognition of the urgent need to address the environmental repercussions of this burgeoning waste generation. The ever-mounting piles of waste have been associated with issues such as pollution, habitat degradation, and resource depletion. Additionally, the inadequacy of storage areas and the potential risks they pose to the environment have heightened concerns. In response to these pressing environmental concerns, a paradigm shift has occurred in research and industry practices. Waste management strategies have transitioned from conventional disposal methods to an emphasis on waste reduction, reuse, and recycling. This paradigm shift reflects a global commitment to sustainable practices that prioritize minimizing waste, conserving resources, and mitigating the environmental impact of waste disposal. This shift towards sustainable waste management practices has gained paramount importance across various sectors, including the construction industry and, notably, road construction. As a vital part of infrastructure development, the road construction sector has embraced the principles of sustainability, exploring innovative ways to incorporate recycled and repurposed materials into its processes. Research endeavors in this domain have not only sought to address waste challenges but have also aimed to optimize the performance and longevity of construction materials while minimizing their environmental footprint. [1-10].

Environmental waste materials find applications in asphalt concrete production, both in evaluating their potential in road construction and enhancing asphalt concrete's performance properties. These studies can be in the form of modified asphalt concrete mix [11-13] or modified bitumen [14-16]. The amount of material used in the mixture modification is higher than the bitumen modification. For this reason, environmental wastes can be evaluated at higher rates in the mixture modification of asphalt concrete. The amount of modifier used in bitumen modification is less. These additives can be used in the form of industrial production or as environmental waste [16, 17]. While industrial production materials tend to increase the production cost of asphalt concrete, the incorporation of environmental wastes generally reduces costs [3, 17-20].

For instance, Kara and Karacasu examined the effects of fully mixed ceramic waste on the mechanical behavior of HMA, revealing that as waste content increases, optimum bitumen content (OBC), voids in mineral aggregate (VMA), and void ratio (V) values increase, while Marshall Stability (MS), voids filled with asphalt or bitumen (VFA), and specific gravity (SG) values decrease [20].

This study investigates the feasibility of utilizing waste cake ceramics from ceramic factories in the Inonu region of Eskisehir, Turkey, in asphalt concrete production (Figure 1). The scope of this study encompasses a particular subset of waste materials generated within ceramic factories, which typically manifest in various forms, including waste generated from floors, walls, and ceramic cakes. It is essential to note that our investigation runs in parallel with three distinct master's studies, each specifically dedicated to exploring the utilization of one of these three aforementioned waste categories. The comprehensive exploration of these waste materials collectively forms a vital part of our commitment to sustainable practices within the ceramic industry. By sharing insights from this specific facet of our research, we aim to contribute valuable data and insights to the international literature, further enriching the body of knowledge on waste repurposing in construction.

Throughout our study, we systematically assessed the potential of ceramic cake waste (CCW) in asphalt concrete by replacing a portion of the aggregate material with CCW in varying proportions, including 10%, 20%, 30%, and 40% of the aggregate weight. These substitutions were made in accordance with the corresponding grain sizes of the aggregate. The results obtained from these experiments provide critical insights into the feasibility and performance implications of integrating CCW into asphalt concrete mixtures, shedding light on its potential as a sustainable and cost-effective construction material.

Figure 1. Ceramic waste materials

2. Material and Method

Prior to delving into the methodological aspects of our study, it is essential to thoroughly understand the properties of the materials used and the characteristics of the test samples. In Table 1, we provide a comprehensive overview of the properties of the bitumen employed in our experiments, highlighting key parameters that play a significant role in the performance of asphalt concrete. Table 2 offers the analysis of the properties of the limestone aggregates utilized in our research, shedding light on their essential attributes.

Table 1. Properties of the bitumen used in the study

Properties	Value	Standard
Penetration (25°C, 100 g)	64	ASTM D5
Softening point (°C)	48	ASTM D36/D36M-09
Ductility (25°C, 5 cm/min)	>100 cm	ASTM D113-07
Loss of Heating (%)	0.430	ASTM D6-95
Flash Point (°C)	314	ASTM D92-05a
Specific Gravity (g/cm^3)	1.026	ASTM D70-09e1
Viscosity (at 135°C, cP)	437.5	ASTM D4402-06
Viscosity (at 165°C, cP)	137.5	ASTM D4402-06

Table 2. Properties of the aggregates used in the study

Properties	Value	Standard
Apparent specific gravity (g/cm^3) of coarse aggregate (CA)	2.709	ASTM C127, C128
Specific gravity (g/cm^3) of coarse aggregate (CA)	2.695	ASTM C127, C128
Saturated surface dry gravity (g/cm^3) of coarse aggregate (CA)	2.691	ASTM C127, C128
Apparent specific gravity (g/cm^3) of fine aggregate (FA)	2.858	ASTM C127, C128
Specific gravity (g/cm^3) of fine aggregate (FA)	2.727	ASTM C127, C128
Saturated surface dry gravity (g/cm^3) of fine aggregate (FA)	2.688	ASTM C127, C128
Specific gravity (g/cm^3) of filler (MF)	2.783	ASTM C127, C128
Water Absorption (%)	0.380	ASTM C127, C128
Compacted Bulk Density (g/cm^3)	1.572	ASTM C 29
Loose Bulk Density (g/cm^3)	1.301	ASTM C 29
Los Angeles Abrasion Test (%)	16.200	ASTM C 131
Flatness Index (%)	16	ASTM D 4791
Freeze-Thaw Resistance (%)	4	ASTM C 88

The aggregate material was designed to meet the limits for Marshall Mix Design (MMD) for wearing course type 2 in the Republic of Turkey General Directorate of Highways Technical Specification (HTS) and Superpave Mix Design (SMD) [21, 22]. The design and sieve analysis of the aggregate is given in Table 3.

Table 3. The design and sieve analysis of aggregate

					MMD		SMD	
Aggregate Type	**Sieve No (in)**	**Sieve Size (mm)**	$X^{0.45}$	**Passing (%)**	**Lower Limit**	**Upper Limit**	**Lower Limit**	**Upper Limit**
CA	3/4"	19.000	3.76	**100**	*100*	*100*	*100*	*100*
CA	1/2"	12.500	3.12	**94**	*100*	*100*	*90*	*100*
CA	3/8"	9.500	2.75	**80**	*80*	*100*	-	-
CA	# 4	4.750	2.02	**49**	*55*	*72*	-	-
FA	# 8	2.360	1.47	**34**	-	-	*47.2*	*47.2*
FA	# 10	2.000	1.37	**31**	*36*	*53*	*36.8*	*42.4*
FA	# 16	1.180	1.08	**24**	-	-	*31.6*	*37.6*
FA	# 30	0.600	0.79	**18**	-	-	*23.5*	*27.5*
FA	# 40	0.425	0.68	**16**	*16*	*28*	*21.1*	*23.8*
FA	# 50	0.300	0.58	**14**	-	-	*18.7*	*18.7*
FA	# 80	0.180	0.46	**11**	*8*	*16*	-	-
FA	# 100	0.150	0.43	**10**	-	-	-	-
MF	# 200	0.075	0.31	**5.5**	*4*	*8*	-	-

CCW is a byproduct obtained through the filtration of production sludge, with residual moisture content ranging from approximately 28% to 32%. To meet the grain size requirements for asphalt concrete aggregate, we sieved the CCW waste material using a 1.18 mm sieve. Images of the samples can be found in Figure 2, while characteristics of CCW waste and XRF analysis results are detailed in Tables 4 and 5, respectively.

Figure 2. CCW samples

Table 4. Properties of the CCW used in the study

Properties	Value
Dry Strength (kg/cm3)	5.40
Cooked Size (mm)	89.95 x 179.85
Total Firing Shrinkage (%)	10.06
Baked Strength (kg/cm3)	464.50
Compacted Bulk Density (g/cm^3)	1.471
Loose Bulk Density (g/cm^3)	1.298
Water Absorption (%)	31.64
Black Core	NA
Color – L	54.45
Color – A	2.76
Color – B	10.09

Table 5. XRF analysis of CCW used in the study

Report Name	Result	Report Name	Result
L.O.I (%)	5.795	Na_2O	0.378
SrO (%)	0.021	SiO_2	63.510
ZrO_2 (%)	0.738	P_2O_5	0.132
NiO (%)	0.030	CuO	1.896
ZnO(%)	0.675	Al_2O_3	18.304
BaO (%)	0.171	SO_3	0.079
PbO (%)	0.014	TiO_2	0.661
Fe_2O_3 (%)	1.699	Cr_2O_3	0.024
CeO_2 (%)	0.155	K_2O	1.835
HfO_2 (%)	0.133	CaO	3.748

In our study, we employed the globally recognized MMD method for asphalt concrete [23-30]. We prepared a total of 105 asphalt concrete samples for our study, encompassing both control and ceramic cake waste (CCW)-containing specimens. Bitumen content in the samples ranged from 3.5% to 6.5%, with increments of 0.5%, resulting in 21 different ratios. For each ratio, we produced three samples. These specimens, totaling 105, consisted of 1150 grams of aggregate mixed with bitumen at a temperature of 160°C. Following the sample preparation, we subjected each specimen to 75 impacts on both surfaces using an automatic Marshall impact compactor, meeting EN 12697-30, 12697-10, 12697-12, ASTM D 1559, ASTM D 6926; AASHTO T245 standards. Subsequently, we measured specimen heights and subjected them to destructive testing. For this purpose, we utilized an Automatic Marshall Stability Test Machine, meeting EN 12697-34, 12697-23, 12967-12 (A), ASTM D1559, D5581, D6927; D6931; AASHTO T245, T283, EN 12697-44; NF P98-251-2 standards, to determine the Marshall Stability and flow values. Our analysis encompassed key parameters such as Marshall Stability (MS), flow (F), practical specific gravity (PSG), and void properties, including void ratio (V), voids in mineral aggregate (VMA), and voids filled with asphalt or bitumen (VFA). These measurements were instrumental in determining the optimum bitumen content (OBC) for each sample. It's important to highlight that every sample in our study adhered to the defined control standards specified in the Highways Technical Specification (HTS), as detailed in Table 6.

Table 6. MMD criteria outlined in the HTS

Experiment Name	Bitumen Content (BC) (%)	
Layer Type	*Binder*	*Wearing*
Unit Weight (g/cm^3)	Max.	Max.
MS (kg)	Min. 750	Min. 900
V (%)	4-6	3-5
VFA (%)	60-75	65-75
VMA (%)	Min. 13	Min. 14
F (mm)	2-4	2-4

3. Test Results and Evaluation

OBC graphs for both control and CCW-containing samples are presented in Figure 3. It's evident that OBC increases with the addition of CCW when compared to standard asphalt concrete samples. This emphasizes the need for a comparative assessment of the cost of waste material usage versus bitumen usage and the importance of conducting a feasibility study in this regard.

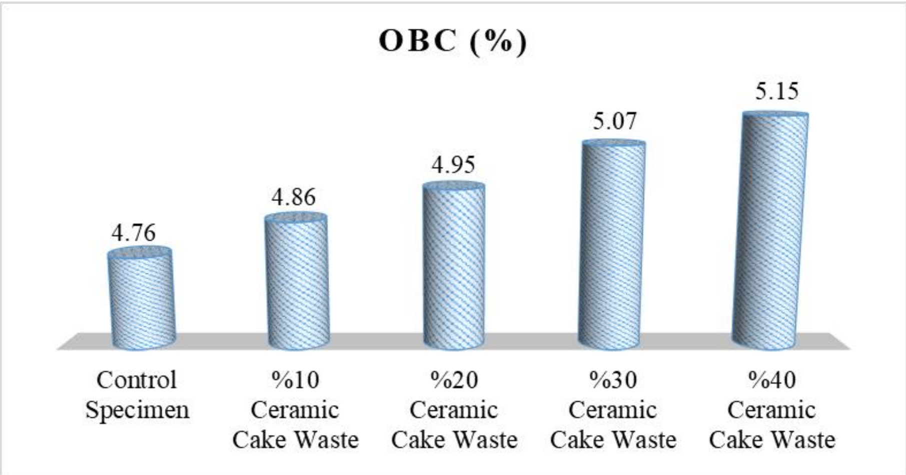

Figure 3. OBC values for each specimen type

The PSG values of CCW-containing samples are consistently lower than those of the control samples. This trend is directly linked to the increase in void ratio within the asphalt concrete as the CCW content rises, as illustrated in Figure 4. The porous nature of CCW contributes to this rise in void ratio, as demonstrated in Figure 5.

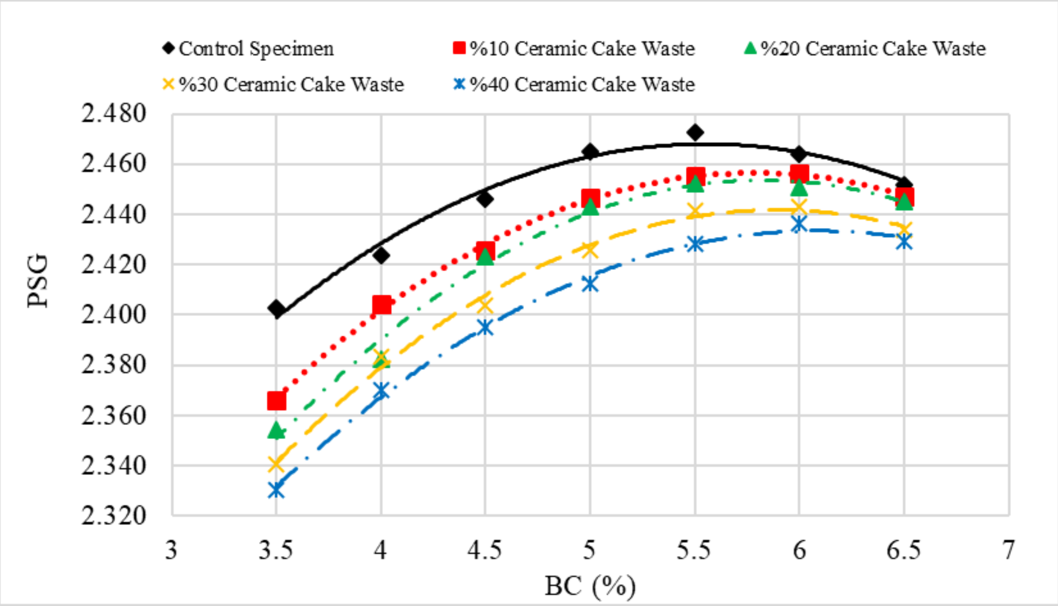

Figure 4. PSG and BC curves graph for each specimen type

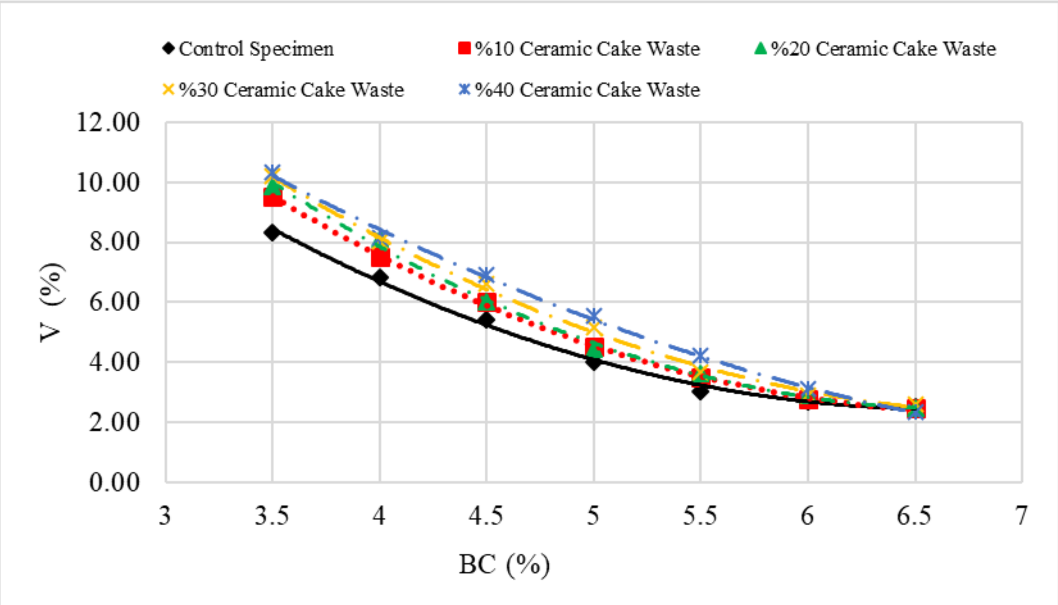

Figure 5. V and BC curves graph for each specimen type

As the BC increased, there was a corresponding increase in VFA. However, according to our experimental results, VFA values exhibited a decrease as the CCW ratio increased, as shown in Figure 6. Additionally, MS was lower in CCW-containing samples compared to control samples, indicating a decrease in stability associated with the increased void ratio due to the presence of CCW materials, as depicted in Figure 7.

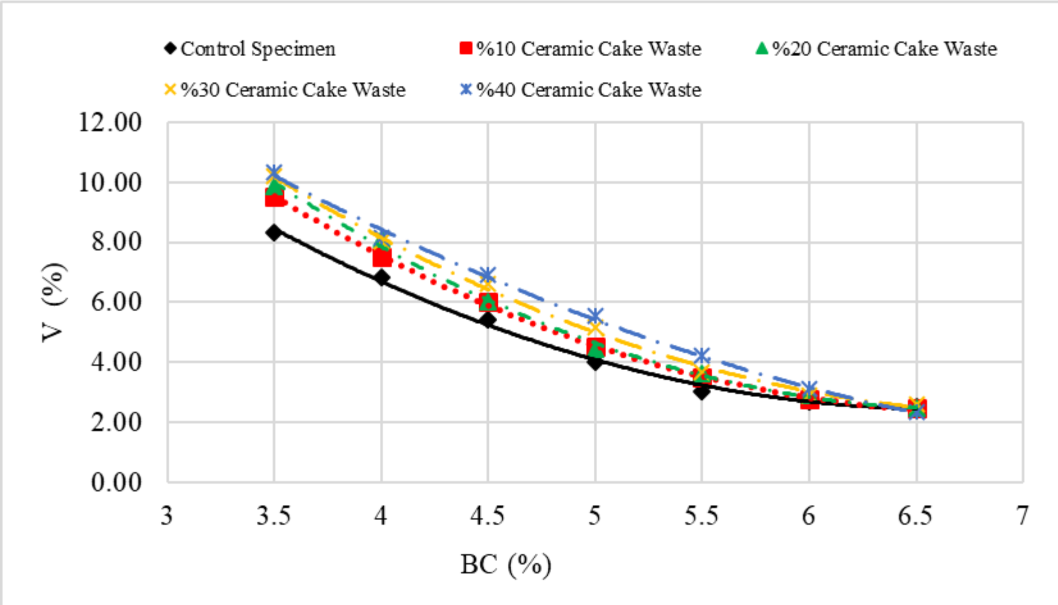

Figure 6. V and BC curves graph for each specimen type

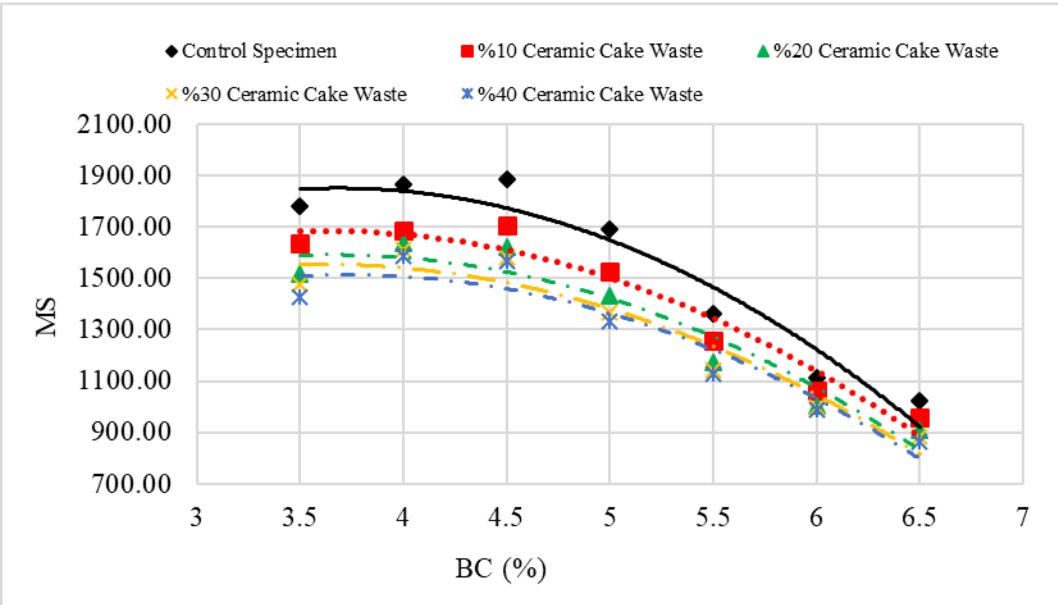

Figure 7. MS and BC curves graph for each specimen type

F values can vary due to sample manufacturing and grain distribution. In samples containing waste, F values are comparable to those of control samples, and all values fall within specification limits, as shown in Figure 8. Marshall Quotient (MQ), expressed as the ratio of MS to F (MS/F), serves as a stiffness indicator for the samples. Higher MQ values are preferred. However, CCW-containing samples exhibit lower MQ ratios than control samples, as illustrated in Figure 9. This trend in MQ correlates consistently with the MS results. Additionally, when examining VMA ratios in relation to BC, it's evident that all samples meet the lower specification limits (≥14%) for VMA, as depicted in Figure 10.

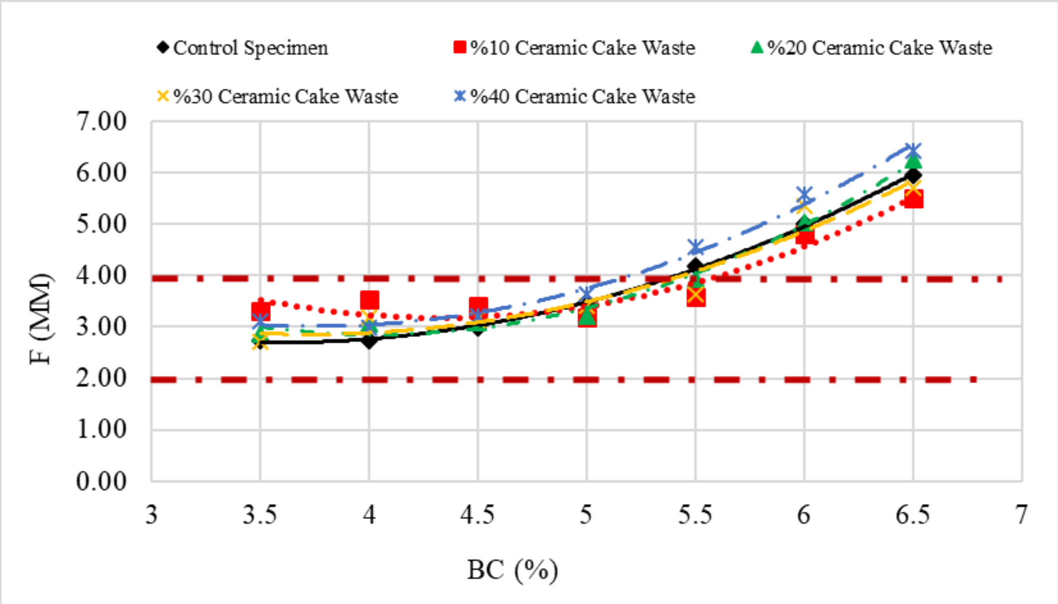

Figure 8. F and BC curves graph for each specimen type

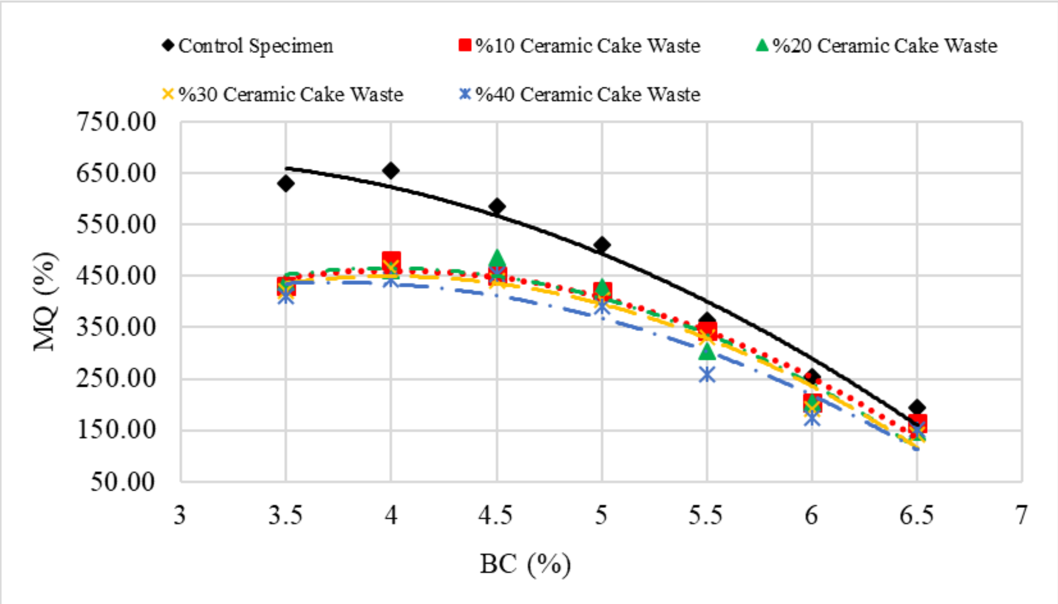

Figure 9. MQ and BC curves graph for each specimen type

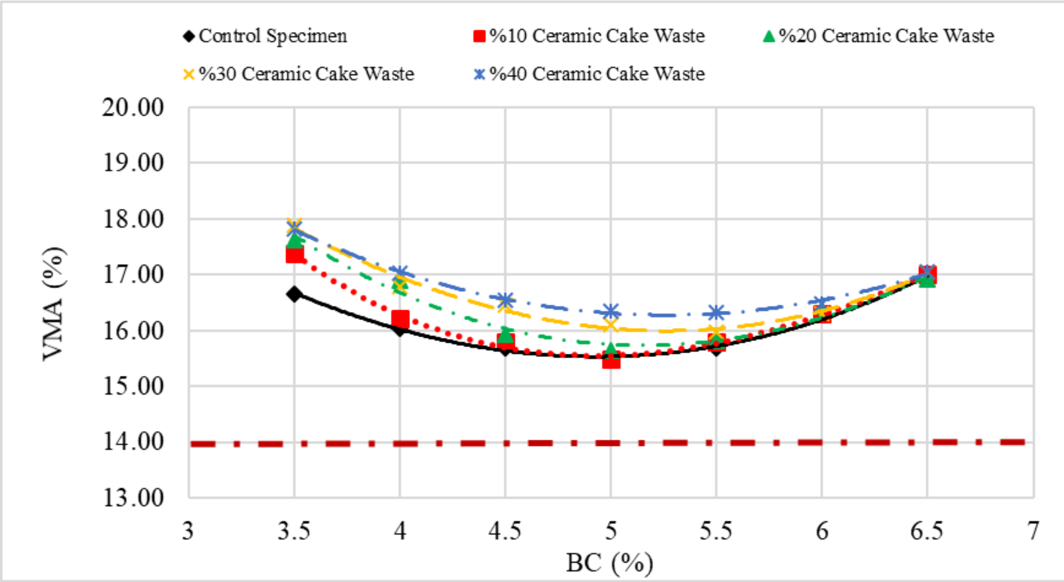

Figure 10. VMA and BC curves graph for each specimen type

In the field of incorporation of waste materials into asphalt concrete, our study extends and supports the findings of two previously conducted research studies. Our experimental results consistently corroborate the findings of these earlier studies. These research efforts have highlighted the benefits of integrating ceramic waste into asphalt mixtures, demonstrating that performance standards can be met by substituting recycled ceramic waste for up to 20% in the wearing course and 30% in the binder course [20, 31].

4. Conclusion

This comprehensive study delved into the feasibility of utilizing ceramic cake waste (CCW) materials in the production of asphalt concrete, a critical component of road construction. To gain a thorough understanding of the implications of CCW incorporation, we meticulously prepared and subjected a total of 105 asphalt concrete samples to an array of tests.

Our investigation unearthed several noteworthy trends that shed light on the impact of CCW on asphalt concrete properties. As the CCW content increased within the mixture, we observed corresponding increases in key parameters such as void ratio (V), voids in mineral aggregate (VMA), flow (F), and optimum bitumen content (OBC). Conversely, values for Marshall Stability (MS), practical specific gravity (PSG), voids filled with asphalt or bitumen (VFA), and Marshall Quotient (MQ) exhibited a consistent decrease with higher levels of CCW.

In particular, one of the most significant findings of our study is the identification of an optimal 20% CCW content for wearing course that aligns harmoniously with the Republic of Turkey General Directorate of Highways Technical Specification. This specific ratio not only meets the regulatory standards but also holds promise as a sustainable approach to road construction.

The broader significance of our research expands into the domains of environmental preservation and waste management. By promoting the reuse of ceramic cake waste in road construction, we effectively contribute to reducing both environmental and visual pollution. Simultaneously, our approach optimizes waste storage and maximizes resource utilization, underlining the importance of sustainable practices in modern infrastructure development.

In summation, our study underscores the potential for the responsible integration of ceramic cake waste in road construction, offering a compelling solution to the challenges posed by escalating waste generation and the imperative for sustainable development. These findings promote a greener, more sustainable future and a higher quality of life for the communities.

Future work in this field should focus on optimizing the CCW content within asphalt concrete, exploring the potential for variations beyond the 20% ratio. The potential applications of cake waste, especially those aimed at reducing OBC and enhancing MS through the use of various additives or waste combinations, warrant comprehensive examination. Apart from the Marshall Mix Design, it is advisable to consider investigations into Superpave Mix Design methodologies. Furthermore, conducting long-term performance assessments under diverse environmental conditions, rigorous environmental impact evaluations, and in-depth cost-benefit analyses are crucial steps. Expanding research to include alternative waste materials, exploring performance-enhancing additives, and establishing robust regulatory frameworks will propel the advancement of sustainable road construction practices. It is also important to engage with local communities and conduct comprehensive life cycle analyses to achieve a holistic assessment. Lastly, interdisciplinary research, integrating engineering, environmental science, economics, and policy studies, will furnish a comprehensive comprehension of the integration of waste materials into infrastructure projects, ultimately leading to more environmentally friendly and cost-effective road construction solutions.

5. Author Contribution Statement

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

6. Ethics Committee Approval and Conflict of Interest

"There is no conflict of interest with any person/institution in the prepared article"

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