Proceedings of the World Congress on New Technologies (NewTech 2015)
Barcelona, Spain – July 15 - 17, 2015
Paper No. 226

Use of Ceramic Wastes in Road Pavement Design

Çağdaş Kara, Murat Karacasu
Eskisehir Osmangazi University, Department of Civil Engineering
Odunpazari, Eskisehir, Turkey
ckara@ogu.edu.tr; muratk@ogu.edu.tr

Abstract **-**Environmental wastes caused by technological and industrial development are increasing, whereas natural resource and disposal areas for those wastes are decreasing day by day. So recycling and reuse of waste materials has become crucial in terms of protection of environment and economy.

Hot mix asphalt (HMA) which is used substantially in road construction, contains approximately 95% aggregate and 5% bitumen materials by weight. Because of high cost of aggregate, scientists focus on studies about using recycled waste in HMA nowadays. In Turkey tens of thousands of tons of ceramic wastes (CW) are disposed every month. One of the most effective ways to eliminate those CW and protect our environment is recycling them by using in HMA.

In this study, the effect of ceramic waste (CW) on performance of HMA's mechanical behavior was investigated. Bitumen and aggregate experiments were performed to determine mechanical properties of the materials which are used in HMA. Subsequently, in total 105 HMA specimens were prepared using the Marshall Mix Design Method. Marshall Stability (MS) & Flow Test was applied to specimens and MS and flow values recorded. For different bitumen and waste ratios, Marshall Parameters (practical specific gravity, voids of filled with asphalt cement, air void content etc…) were determined.

As a result, air void content (AVC), void of mineral aggregate (VMA) and optimum bitumen content (OBC) values increase with increasing the waste ratio. However, MS (Marshall Stability), voids of filled with asphalt cement (VFA) and practical specific gravity (PSG) values decrease with increasing the waste ratio. According to Turkish Highway Construction Specifications, it was concluded that waste ceramic aggregate could replace, for binder course up to 30% and wearing course up to 20% presenting sufficient mechanical conditions. Mixture which contains 30% CW was lighter (11%) than the conventional mixtures in equal volume. It means that trucks can carry HMA more than before. So in the context of the sustainable environment, using of recycled waste ceramic aggregates in HMA prevents pollution.

Keywords**:** waste, ceramic, asphalt, recycling

1. Introduction

HMA which is composed of bitumen and aggregate is used in road construction all over the world. HMA contains approximately %5 bitumen and %95 aggregate materials, by weight. Bitumen is obtained from the distillation of petroleum. Because of the reduction in natural resources like petroleum and high quality aggregate, the production cost of HMA is increasing day by day. On the other hand at the construction of base and sub-base courses under pavement, the usage of determined aggregate gradations due to natural subgrade increases the importance of aggregate. Day by day industrial waste reduction becomes priority for governments due to pollution and because of that the importance of waste material usage in road construction increases.

Some industrial wastes were tried for base and sub-base courses as landfill materials in some researches at literature (Koyuncu et al., 2004; Pamuk and Adalier, 2013). But in those researches, researchers generally tried to reduce the cost of bitumen and aggregate. It was seen in the research of recycled tire rubber usage in bitumen modification, recycled tire rubber in asphalt mixtures using dry process could improve the engineering properties of asphalt mixtures like resistance performance to the permanent deformation at high temperature and cracking at low temperature due to rubber content (Cao, 2007). In roofing polyester waste fibers usage in HMA research, the indirect tensile strength, void content, the asphalt content, the unit weight, and the Marshall Stability values in HMA samples were increased (Anurag et al., 2009). In the experimental research for the fatigue behavior of waste iron powder added asphalt concrete mixtures, waste iron powder usage in HMA were caused an increase tensile strength and increase in the ability of HMA's fatigue toleration under repeated loading (Arabani and Mirabdolazimi, 2011).

Some industrial wastes (ferrochromium slag, black carbon, marble powder, glass powder, ceramic…etc.) used as filler in HMA. Üstünkol researched using industrial waste material to modify HMA. Marble powder, fly ash, phosphogypsum and glass powder usage as filler were given suitable MS results according to Turkish Highway Construction Specifications (Ustunkol and Turabi).

Ceramic production in Bilecik-Eskisehir-Kütahya region makes 43.2% of total ceramic production in Turkey (Saatcioglu, 2010). Every year nearly 100,000 tons of ceramic waste (CW) is composed in this region. Using ceramic waste in HMA is an effective way to prevent environmental pollution. So instead of being an environmental pollution, CW aggregates can be used in pavement design for sustainable environment. There are few studies in the literature related using CW waste in concrete and HMA as aggregate, Torkittikul and Chaipanich analysed usability of ceramic waste and fly ash as fine aggregate in Portland cement concrete production. Due to results, the workability is reduced by ceramic waste addition in specimens. Also, the compressive strength in concrete with CW increased with increasing CW ratio (Torkittikul and Chaipanich, 2010). Pacheco et.al., researched the feasibility of ceramic waste usage in concrete as aggregates. Results identified that compressive strength values of concrete specimens were increased with increasing ceramic waste ratio. Results also showed that addition of ceramic aggregates provide better performance properties to HMA (Pacheco-Torgal and Jalali, 2010). Van de Ven at al. examined possibility of using ceramic waste from electrical insulators, plastic waste and household waste. From the results, it was shown that sintered household waste, plastic waste, ceramic waste can be used as coarse aggregate in HMA. Likewise with ceramic waste addition MS and Flow values increased comparing to control samples (Van de Ven et al., 2011). Silvestre et al. investigated the performance characteristics of the waste tile usage in HMA. It was found that the bitumen ratio, void content and plastic deformation values were increased with increasing WC. Additionally it was observed that mixtures with ceramic aggregates perform worse than the control mixtures concerning MS compressive strength and worse moisture susceptibility and up to 30% of natural aggregates can be replaced by recycled ceramic for binder course and wearing course according to Spanish Specifications (Silvestre et al., 2013a, b).

In this paper, The Marshall Design Method was used for HMA preparation. Different waste ceramic ratio were used as aggregate for preparation of HMA specimens. And the experimental results were compared with specification values.

2. Materials and Methods

In the study, CW aggregate obtained disposal area of Toprak Ceramic Factory in Eskişehir (Fig. 1.) and 50/70 penetration bitumen were used. CW aggregates prepared with jaw crusher due to Type II gradation in laboratory.

Fig. 1. A view from ceramic waste landfill site of TOPRAK Ceramic Factory in Eskisehir

In this study, the effect of ceramic waste (CW) on performance of HMA's mechanical behavior was investigated. Bitumen and aggregate experiments were performed to determine mechanical properties of the materials which are used in HMA. The mechanical properties belong to bitumen, natural and ceramic aggregates used in this study and specification values (Anonymous, 2013) are shown in Tables 1., 2.

Table. 1. Experimental results and specification limits related to aggregate.

Material's Properties	**Experimental Results**						Standards	Limits
	Natural Aggregate			Waste Ceramic				
	Filler	Fine	Coarse	Filler	Fine	Coarse		
Specific gravity (gr/cm3)	2,731	2,723	2,71	22,58	2,498	2,31	TS3526	—
Water absorbsion (%)	-	2,17	0,58	-	9,47	8,55	TS3526	< 2
Los Angeles wearing Test (%)	24,18			-	20,94		TS EN 1097-2	< 30
Freezing and thawing test (%)	4,05			-	3,302		ASTM C 131 TS 3694	< 10

Table. 2. Experimental results and specification limits related to bitumen.

Material's Properties	**Results**	**Standards**	**Limits**
Penetration (25ºC, 1/10 mm)	53,6	TS EN 1426	50-70
Softening point (ºC)	50	TS EN 1427	46-54
Ductility (25ºC 5cm/min)	>100	TS 119	-
Flash point (ºC)	322	TS EN ISO 2592	>230
Loss on heating (%)	0,42	TS 121	0.5
Specific gravity (gr/cm3)	1,035	TS 1013 EN ISO 3675	-

Subsequently, in total 105 HMA specimens were prepared using the Marshall Mix Design Method. As seen analysed test results, bitumen an aggregate used in mixtures were found to be suitable according to specification limits.

3. Experimental Study

In the experimental part of this study Marshall Test Method has been used. In the experiment of waste ceramic use in wearing course production, waste ceramic were added wıth &0, 10, 20, 30, 40 percentage by aggregate weight to five series of aggregate mixtures which were prepared up to Type II gradation (Fig 2). Then seven different percentage bitumen (3.5%, 4%, 4.5%, 5%, 5.5%, 6%, 6,5%, by weight) added to the mixtures and test specimens for Marshall Test has been fabricated.

Fig. 2. Aggregate prepared according to Type 2 wearing course

MS Test was applied to the specimens Marshall Strength and Flow values recorded. AVC , PSG, VFA, VMA and MQ values was calculated. After Marshall Stability & Flow Test was applied to the specimens, Flow and Marshall Strength values have been recorded and OBC values calculated for each CW ratio, respectively (Fig 3.)

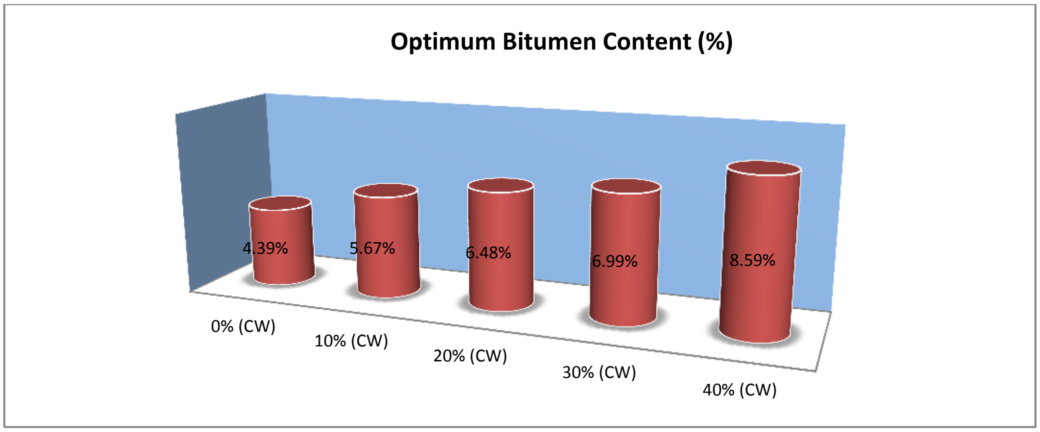

Fig. 3. Optimum Bitumen Content

Required limits for MS, AVC, VFA, Flow values according to GDH showed in Fig 3.

Table. 3. HMA design criteria for wearing course (GDH , General Directorate of Highways, 2013).

PROPERTIES	WEARING COURSE	
	MIN.	MAKS.
Marshall stability (kg)	900	—
Air void content (%)	3	5
Voids Of filled with asphalt Cement (%)	65	75
Flow (mm)	2	4

According to determined OBC, the other parameters were calculated for each WCA ratio respectively as shown in Table 4.

Table. 4. Calculated values corresponding to the OBC.

Waste ceramic content (%)	Optimum bitumen content (%)	Practical specific gravity (gr/cm3)	Marshall stability (kg)	Air void content (%)	Voids of filled with asphalt Cement (%)	Flow (mm)	Void of mineral aggregate (%)
0	4.39	2.44	1924.0	4.3	69.5	2.56	14.29
10	5.67	2.38	1685.6	4	75.7	2.42	16.56
20	6.48	2.31	1484.1	4.77	73.71	2.96	18.43
30	6.99	2.20	1545.5	5.98	68.9	2.98	20.6
40	8.59	2.12	1387.9	7.4	70.2	4.32	24.02

It was seen that OBC, AVC and VMA values increases by increasing waste ratio in HMA. However VFA and PSG values decreases by increasing waste ratio. However, according to results, for binder course up to 30%, for wearing course up to 20% of natural aggregates could be replaced by recycled ceramic aggregates because of demonstrating good mechanical characteristics in compliance with Turkish Highway Construction Specifications.

4. Conclusion

Ceramic is a material that has porous structure and high water absorption, so performance values getting better compared to control specimens with more bitumen and OBC values increased in the mixture, with increasing waste ceramic ratio. The highest MS values for % 0, 10, 20, 30, 40 waste ceramic ratios were 2121.4, 1716.42, 1549.74, 1562.45, 1429.39 kg's, respectively.

It was seen that up to 30% recycled ceramic waste in mixtures, were acceptable OBC according to economic bitumen limits. It was seen that, with increasing waste ceramic ratio in specimens, OBC, AVC, VMA, flow and specimens height values were increased and generally MS, PSG, VFA values were decreased. Accordingly these results, the CW spicemens, up to %30 CW addition for binder course, up to %20 CW addition for wearing course complied with the Turkish Highway Construction Specifications and can be used in HMA.

Also we examine that, specimen which contains 30% CW aggregate, by weight, was lighter (11%) than the conventional specimen in equal volume. It means that for equal loading limits, mixer trucks can carry HMA with CW material, more (11%) than conventional HMA. Because volume of HMA with CW material has 11% larger volume than conventional HMA. Due to this property, CW usage provides a reduction (11%) at transportation cost and gas emissions. Besides, thanks to the light HMA, the load which calculated from the pavement during the project planning for bridge and viaduct, will reduce. Thus the cost of building will reduce too. So, instead of being an environmental pollution, ceramic waste can be used as a construction material in HMA in the context of the sustainable environment.

References

Anonymous. (2013). General Directorate of Highways, Highway Construction Specifications. *General Directorate of Highways Press*, Ankara.

Anurag, K., Xiao, F., & Amirkhanian, S.N. (2009). Laboratory Investigation Of Indirect Tensile Strength Using Roofing Polyester Waste Fibers In Hot Mix Asphalt. *Construction And Building Materials*, 23, 2035-2040.

Arabani, M., & Mirabdolazimi, S.M. (2011). Experimental Investigation Of The Fatigue Behaviour Of Asphalt Concrete Mixtures Containing Waste Iron Powder. *Materials Science and Engineering: A*, 528, 3866-3870.

Cao, W. (2007). Study On Properties Of Recycled Tire Rubber Modified Asphalt Mixtures Using Dry Process. *Construction and Building Materials*, 21, 1011-1015.

Koyuncu, H., Guney, Y., Yilmaz, G., Koyuncu, S., & Bakis, R. (2004). Utilization Of Ceramic Wastes In The Construction Sector. *Key Engineering Materials*, 264, 2509-2512.

Pacheco-Torgal, F., & Jalali, S. (2010). Reusing Ceramic Wastes In Concrete. *Construction and Building Materials*, 24, 832-838.

Pamuk, A., & Adalier, K. (2013). On the Important Mechanical Properties of Rubber-Sand. *Advanced Materials Research*, 685, 8-14.

Saatcioglu, G. (2010). Türk Seramik Sanayi Raporu.

Silvestre, R., Medel, E., García, A., & Navas, J. (2013a). Using Ceramic Wastes From Tile Industry As A Partial Substitute Of Natural Aggregates In Hot Mix Asphalt Binder Courses. *Construction and Building Materials*, 45, 115-122.

Silvestre, R., Medel, E., García, A., & Navas, J. (2013b). Utilizing Recycled Ceramic Aggregates Obtained From Tile Industry In The Design Of Open Graded Wearing Course On Both Laboratory And In Situ Basis. *Materials & Design*, 50, 471-478.

Torkittikul, P., & Chaipanich, A. (2010). Utilization Of Ceramic Waste As Fine Aggregate Within Portland Cement And Fly Ash Concretes. *Cement and Concrete Composites*, 32, 440-449.
Ustunkol, F.N., & Turabi, A. Endüstriyel atıkların karayolu üstyapısında değerlendirilmesi.
Van de Ven, M., Molenaar, A., & Poot, M. (2011). Asphalt Mixtures With Waste Materials: Possibilities And Constraints. *Conference on Asphalt Pavements for Southern Africa [CAPSA11]*.