Crushed ceramic wastes and its effect on strength and abrasion characteristics of roller compacted concrete pavement

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Abstract

The high rate of using ceramic and tile in building industry has led to the release of a high volumes of ceramic and tile wastes after the end of life of a building and the demolition process which has negative effects on environment. If these wastes could be used as an alternative for a portion of concrete's natural aggregates, its destructive effects will be reduced. In this study, wastes of the ceramic and tile factories located in central Iran are crushed and granularized within the range of regulations. Then, 15% and 30% of the aggregates weight in the pavement concrete mix is replaced with the wastes. The pavement concrete mix containing crushed ceramics undergoes the investigations of fracture mechanical behavior (compressive and flexural strength tests) in curing periods of 3, 7, and 14 days. The results show that 15% replacement will improve abrasive resistance; while, 30% replacement of these wastes has reduced the compressive and flexural strength of rolling concrete in different ages. The relationship between compressive strength and abrasion resistance of crushed ceramics were obtained using second-order nonlinear regression. The intersection of these two curves results replacing 18.95% of aggregates weight with crushed ceramics; that suggests the compressive strength and abrasion rate of 29.36 MPa and 2.10%, respectively.

Keywords: *ceramic and tile wastes, flexural strength, pavement,* roller-compacted concrete pavement*, fracture energy, abrasive resistance.*

Introduction

The increase in industrial wastes around the world, that arises many environmental problems and the need for producing new materials, has led to the utilization of factories wastes in recycled form. The roller-compacted concrete pavement (RCCP) is one of jointed plain concrete pavement (JPCP) types. Because of easy implementation and the lack of need for using steel, the RCCPs are used widely in most countries, including Iran. In the present research, concrete's mechanical behaviors, including compressive and flexural strength, have been investigated. Besides, evaluation of the void space in concretes produced with ceramic wastes is addressed. The ceramic wastes are used as different portions of natural aggregates to evaluate the mechanical strength of recycled concretes samples. These pavements have a more sensitive surface and higher possibility for damages and destructions than conventional and reinforced concrete pavements because of the curing type and low slump. According to ACI Committee 201, pavement concrete's abrasion resistance is the ability to resist abrasion and friction caused by contact of vehicle's wheels and slipping and abrasion of the pavement caused by other materials. In recent years, utilizing waste in concrete as an alternative for aggregate cement has obtained researchers attention and building industries. The use of ceramic wastes and fibers in producing concrete [1-3], and using powdered and crushed tiles as pozzolan in producing ready-mix concretes (RMCs) has been studied [4,5]. Also, using ceramic powder and waste bricks and nano-silica for producing high-strength concrete has been investigated [6-8]. Utilizing ceramic powder as a part of cement [9,10], studying the mechanical properties and durability of concretes containing methacholine [11], and investigating the effect of methacholine on the properties of high-strength concretes [12] have been addressed. A study has been performed on using ceramic and paper wastes to produce porous concrete. Different aggregates have been used in this study, and the void content, strength, and permeability were measured. The results indicate that this concrete's strength is lower, while its permeability is acceptable [13]. The 16 mix designs with 0, 10, 20, and 30% of fine-grained materials replaced with crushed ceramics, and 0, 5, 10 and 15% of cement replaced with ceramic powder were used to determine the effect of replacing aggregates with waste crushed ceramic and replacing cement with ceramic powder on the properties of the fresh and hardened concrete. In this study, the water to powder ratio of 0.4, 0.45, 0.5 and 0.55 were prepared. According to the analyses performed by the Taguchi method and from the tests results, it was found that adding crushed ceramics instead of aggregates is useful up to 20% of weight ratio; on the other hand, adding ceramic powder up to 10% ratio of weight is useful. Using both weight ratios mentioned earlier is recommended in terms of strength and economics [2].

An investigation has been done on the effect of using green Tuff of Shahindezh on the mechanical behavior of the roller-compact concretes. The compressive strength results at the ages of 7 and 28 days show that at 28 days, all of the studied mixtures have compressive strength is higher than 35 MPa. Besides, the ratio of fracture module to the square of compressive strength was calculated 0.7. The permeability results underwater pressure indicate that by reducing the water to cement ratio of 0.38 to 0.33, in equal Vee-Bee time, water permeability reduces from 14 to 10 mm. The very low permeability (5mm) of mixtures containing silica fume and pozzolanic cement indicates more dense microscale of the mixtures mentioned above [3]. Different works have been done worldwide on utilizing industrial and ceramic wastes in the RCCP and conventional concrete pavements [4-6]. The effect of granulation and content of rubber crumbs or recycled asphalt crumbs and cement on the stress intensity factor in modes I and II has been investigated in a paper about RCC beams containing rubber crumbs and recycled asphalt crumb. Sample's stress intensity factor results show that the RCC mix has a significant effect on its failure behavior. Besides, although the recycled material mix has increased the flexibility and toughness of samples, it will have a negative effect on the failure stress intensity factor of the samples and their bearing capacity [7].

The purpose of this research is to experimentally investigate the utilization of crushed ceramics in the RCC mix. To achieve this purpose, the crushed ceramics are used between the aggregates, and different contents of them are replaced in concrete instead of the required sand. The RCCP is a mixture of water and cement, which is relatively stiff and dry with a slump near zero. Compared with conventional concrete, the RCCP has higher density and durability, more execution speed, lower costs, and no rebar is needed. Of course, due to the numerous advantages of roller-compact concrete, it is used mostly for low-traffic areas, parking, roadsides, and highways.

Materials and methods

The tests that are performed, including the cubic sample's compressive strength at the ages of 3, 7, and 14 days, also the flexural strength of the concrete samples in these curing periods. Some other tests include water absorption (dry and fresh concrete) and elasticity module using the ultrasonic method. The proposed contents for replacing crushed ceramic are 15 and 30%, and they are available in three different granulations gradation. The granulation used in the concrete pavement is according to the ASTM mix design code [14]. Table 1 lists the stone materials ratio code according to the national regulations and previous specifications. The water to cement ratio and the cement to aggregates ratio used for producing the samples are 35% and 25%, respectively. Coding of the laboratory samples, after the letter "C", is the percentage of the waste ceramic content. To increase accuracy, three samples were made from each mixing design, If the Coefficient of Variation of the results data was more than 15%, the number of samples would increase.

Table 1: A mix ratio of components of a sample containing crushed ceramic (kg/m^3)

Sample code	***Water***	***Cement***	***Fine Aggregate***	***Coarse Aggregate***	***Crushed Ceramics***
C00	95	322	470	1010	**-**
C05	95	308	470	800	210
C10	95	295	470	700	310
C20	95	290	470	600	410
C30	95	281	470	500	510

To select appropriate materials (cement and aggregate), the stone materials were prepared from Barez concrete supplier. These materials are mainly mountainous and containing limestone. The specifications of these materials and their standards are presented in Table 2.

Table 2: Aggregates quality tests Results

Test Description	**Results**	**Test Standards**		**Max Allowable**
		ASTM	**AASHTO**	
Los Angeles Abrasion (%)	19	C131	T96	25
Max Water Absorption ،Coarse Aggregate (%)	2.2	C127	T85	2.5
Max Water Absorption ، Fine Aggregate(%)	2.4	C128	T84	2.5
Max Flakiness Index (%)	6	BS812		-
One Fractured Face Test (%)	92	D 5821	-	-
Two Fractured Face Test (%)	97	D 5821	-	-
Bulk Density (kg/m^3)	2020	C29	-	-
Porosity (%)	21.7	C830	-	-

The 15 cm cubic samples and the 10×10×35 cm flexural beam samples were used for compressive strength and flexural tests, respectively. The cylindrical samples with 5 cm diameter and 15cm length were used for the abrasion test according to the revolving abrasion test with the E-2045 standard [15]. The samples were cured for 14 days for the strength test. The reason for selecting this short period was the possibility of reopening a path. In the present study, for investigating abrasion resistance in concrete containing recycled crushed ceramics, 18 concrete samples were produced and tested. These samples were used to measure compressive, flexural, abrasion, and friction resistance. As shown in Table 1, due to the variability of the crushed ceramic content, the samples were coded. Some conventional samples (without crushed ceramics) were produced for comparison. The Portland cement type II prepared from Abadeh factory was the cement used in this study. The cement's specific surface is 2900 gr^2/cm (ASTM C204-16) [14], and its chemical components are shown in Table 3.

Table 3: Chemical and physical specifications of Portland cement type II

Physical Specification		**Blaine (cm^2/gr)**	**Vicat setting time (min)**			**Strength Test (kg/cm^2)**					
			Primary	**Secondary**		**2 Days**		**3 Days**	**7 Days**	**28 Days**	
Value		2900	150	200		160		200	310	400	
Chemical characteristics	LOI	Total Alkali	F.Co	Inr	Cl	SO_3	Al_2O_3	SiO_2	MgO	Fe_2O_3	CaO
Percent	1.2	0.7	1.1	0.65	0.03	1.8	4.5	21	2.5	3.6	63.4

Since aggregates compose approximately 75 to 85% of concrete volume, selecting aggregates in roller-compact concrete is essential. The regulations for aggregates assumed in the RCC are the same as those of conventional concrete. The maximum size of aggregate in the RCC has a considerable effect on the degree of density of thin layers, although, in thicker layers, this effect is negligible. In the pavement RCC, aggregates with size more than 25.4 mm are not recommended, because creating a relatively smooth surface for road pavement using coarse aggregates is difficult.

The crushed materials were prepared from the crushed ceramics of the Meybodtile factory. The large pieces of ceramics were completely crushed in the lab using a compaction hammer. First, the 2-inch sieve was used to separate and gradation the crushed ceramic to keep their specifications of one type and size. Then, a brand was used so that the ceramic wastes specifications remain constant during the research. The samples gradation is presented in Table 4, and specifications of aggregates obtained from ceramic wastes are listed in Table 5.

Table 4: Results of gradation test

Sieve number	Remaining on the sieve (gr)	Remaining on the sieve (%)	Passed through the sieve (%)	Cumulative Remaining (%)
12.5	0	0.00	100.00	0.00
9.5	94.7	4.74	95.26	4.74
6.35	875	43.82	51.43	48.57
#4	782	39.16	12.27	87.73
#8	183	9.17	3.11	96.89
#16	46	2.30	0.80	99.20
Sub-sieve	16	0.80	0.00	100.00
Sum	1996.7	99.835		

Table 5: Specifications of chemical compounds and physical specifications decompositions of tile

Detected element		Quantity (%)	
SiO_2		69	
Al_2O_3		18.5	
MgO		0.72	
P_2O_3		0.03	
TiO_2		0.73	
SO_3		0.06	
MnO		0.08	
CaO		1.5	
Na_2O		2.01	
K_2O		1.63	
Fe_2O_3		4.81	
LOI		0.5	
Properties	**Standard. No.**	**Dimension of broken waste tile**	
		Fine grained	Coarse-grained
Absorption of water	ASTM C642	7	5
Particle Shape	ASTM D 4791	-	cubic
Bulky density	ASTM C29	2.35 (gr/cm^3)	2.33 (gr/cm^3)
Coefficient of thermal conductivity	ASTM C177	1.04 (W/m.K)	

Since the roller-compact concrete is almost dry, a different method is used for producing RCC samples compared to conventional ones. In the sample compaction method, the RCC sample is placed in a mold and is compacted on a vibrating table under the effect of overhead and layer weights according to the ASTMC1176-13 standard [14]. In this method, the samples are compacted and prepared by compaction hammer blows in five layers according to the ASTMDISS7-12 standard [14]. Compacting using a compaction hammer gets closer to the real density; therefore, this method is selected in this research. The 15×15×15 cm samples and the 10×10×35 cm flexural beam samples were used to evaluate compressive and flexural strength. The compression tests were carried out in a 3000 kN hydraulic testing machine according to ASTM- C78 [14] .First, samples were placed in a mold for 24h and covered with plastic. Then, samples were extracted from mold and were maintained in water for 3, 7 and 14 days. Fabricated samples for this study are shown in Figure 1.

According to the British standard, the cubic samples have dimensions of 150mm, which are filled in three layers; each layer is compacted with a stick 25 times. Besides, as an alternative method, these concrete cubes can also be compacted by a vibrator. However, since the concrete samples were of RCC type, and their water content is less compared to other samples, the concrete mold was compacted 25 times per layer, so the creation of air cavities in concrete and honeycombing are prevented.

Figure 1: Variation of the samples tested in this study

In fact, the concrete cube samples test provides an overall idea of all concrete specifications. With this test, it can be recognized whether the concrete is good enough for our study. The concrete's compressive strength affecting different factors including water to cement ration, cement strength, concrete quality, quality control during the production and so on. This test is performed on the cubic-shaped pieces of concrete. Therefore, this is called a cube sample test, but it is also common to perform this test on the cylindrical pieces. Depending on the aggregates size used in concrete, the 15×15×15 cm or 10×10×10 cm samples are made. Given that in this test, the maximum nominal size of aggregate is 19mm, the cube samples with dimensions of 15 cm are used. Since strength depends on the loading rate, for hydraulic jacks, the sample must undergo the loading at a controlled rate between 0.15 to 0.35 MPa/sec; on the other hand, for mechanical jacks, the deformation rate must be limited to 1 mm/min. The loading continues until the failure point, which is the maximum loading the sample can bear. Then, the maximum loading and failure are reported.

The lack of crack is essential in maintaining and durability of concrete structures to maintain rebars and prevent steel rebar corrosion [16]. Since applying axial tensile to the concrete sample is difficult, the concrete tensile strength is determined indirectly using the flexural test and Brazilian test. Such methods predict the strengths higher than the real strength under axial tensile loading. In the flexural strength test, the maximum theoretical tensile was created in the lower axis of the studied beam, called modulus of rupture, used to design highways and airports pavement. This test is recommended by ASTM C 78 standard [14].

British pendulum number (BPN) is an index for pavement surface skid resistance to express friction resistance. The ASTME404 standard is used to calculate this type of resistance [14]. The 6.35×6.35×25.4 cm samples were used in this test, and the moving path length of the slider is 12.5cm, and the surface of the samples were cleaned and wetted. Figure 2 shows the British pendulum test.

Figure 2: Sample of concrete surface under British pendulum test

The aggregate abrasion value test, Dorry test, which gives a measure of the resistance of an aggregate to surface wear by abrasion [17], is performed according to Figure 3. This machine has a disc with a diameter of 60cm. The abrasive materials are inserted in three samples with a 7 – 900 gr/min rate and the test is performed according to EN1097-8 standards [15]. The aggregate abrasion value is the difference between the material surface's weight and its weight after the test in terms of its initial weight within the materials wear limit.

Figure 3: A view of concrete sample surface in Dorry test

Results and discussion

The variations of compressive strength in samples can be attributed to aggregates shape and strength in the concrete. Since ceramic wastes aggregates have fracture percentages, therefore they have low water absorption and high stiffness. It is observed that the compressive strength increases as the crushed ceramic content decrease. This increase continues until the waste materials content of 15%; then, by increasing the waste aggregates content and the lack of enough water to perform hydration reactions caused by tiles water absorption, the sample approvals are reduced. Figure 4 shows an example of strength variations. Lower energy is required for starting and growing cracks within the paste in the uniaxial tensile mode. The main factors for fracture in the concrete are rapid growth and the relation between the cracks system, including cracks in the transmission area and new cracks within the paste. The sample fracture has low fragility in compression mode than the flexural because more energy will be needed for creating and propagating cracks within the paste. Basically, for concretes with low to medium strength, it is agreed that in the uniaxial pressure test, new cracks do not occur in stresses less than 50% of fracture stress.

A stable system of cracks, called shear continuity cracks, exists near the coarse aggregates in this stage. New cracks are created in the paste for higher stresses, which rapidly increases as the stress has increased. The cracks exist in the paste, and the transition area (shear continuity crack) is finally connected and creates a fracture with an angle of 20 to 30 degrees respect to load direction. Given the existence of glaze in some crushed ceramics, and very low permeability of this side of crushed ceramic, the transition area is too weak, and most of the cracks are started in this area. As a result, the higher percentage of crushed ceramics are used, the number of shear continuity cracks increase and will have a higher effect on the sample's fracture.

According to the results obtained from tests, variations of compressive strength in the samples can be attributed to aggregates shape and strength in the concrete. Since the ceramic waste aggregates have some fractures, they have little water absorption and high stiffness. It is observed that with an increase in the crushed ceramic percentage, the compressive strength increases by up to 15%. With further increase in the waste aggregates content and due to the lack of enough water to perform hydration reactions caused by water absorption by tile, the samples approvals are reduced.

The main factors for fracture in the concrete are rapid growth and relation between the cracks system, which includes cracks available in the transmission area and new cracks within the paste. In compression mode, the sample fracture has low fragility than the flexural because more energy will be needed for creating and propagating cracks within the paste. Figure 5 shows how samples fracture as the loading is applied. Basically, for concretes with low to medium strength, it is agreed that in the uniaxial pressure test, new cracks do not occur in stresses less than 50% of fracture stress. A stable system of cracks, called shear continuity cracks, exists near the coarse aggregates in this stage. New cracks are created in the paste for higher stresses, which rapidly increases as the stress increases. The cracks exist in the paste and in the transition area (shear continuity crack) are finally connected and create a fracture with an angle of 20 to 30 degrees respect to load direction shown in Figure 6. Given the existence of glaze in some crushed ceramics, and very low permeability of this side of crushed ceramic, the transition area is too weak, and most of the cracks are started in this area. As a result, the higher percentage of crushed ceramics are used, the number of shear continuity cracks increase and will have a higher effect on the samples fracture.

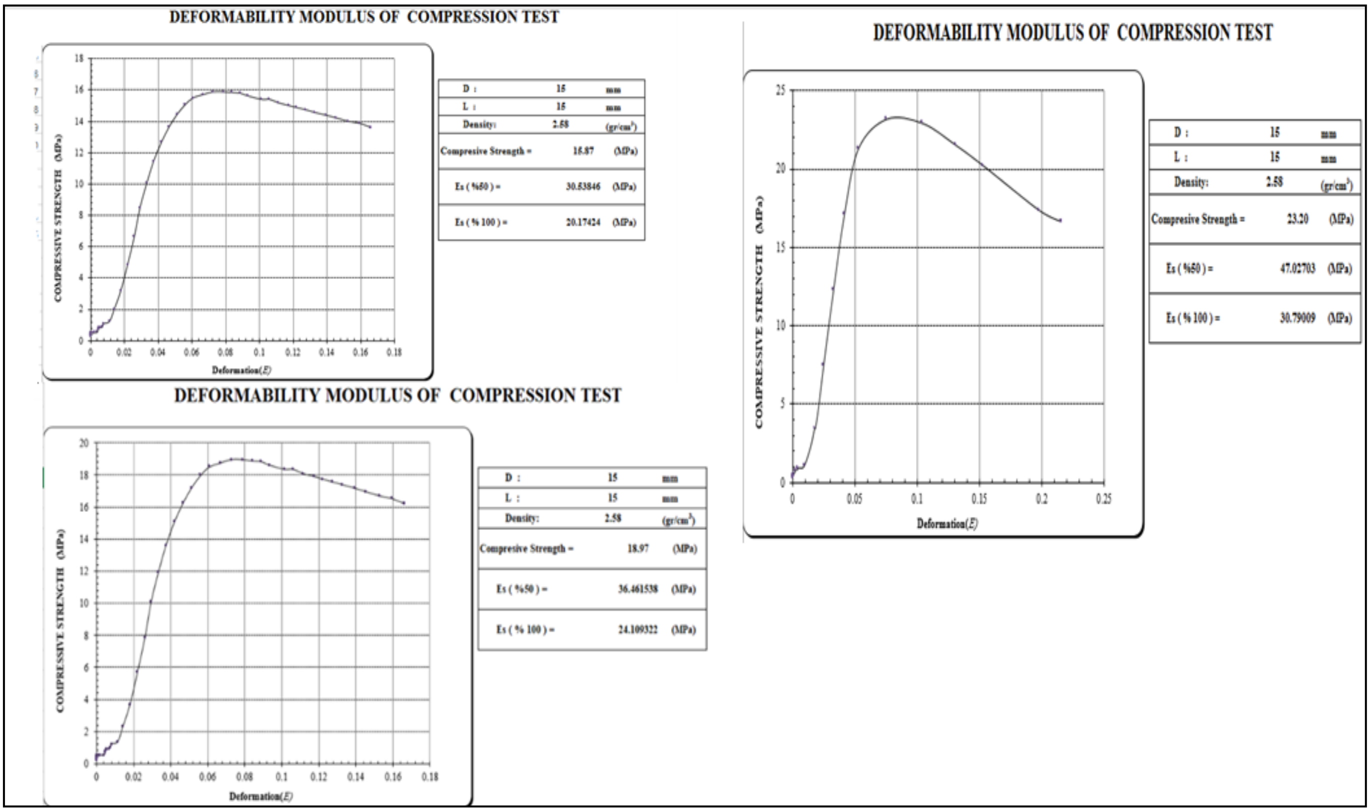

Figure 4: Deformation-stress variations plots

Figure 5: Images showing the cracks propagation in compressive samples

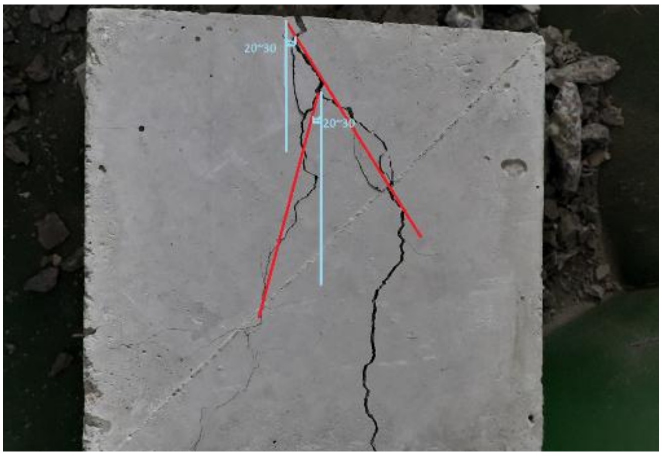

Figure 6: Cracks propagation angles in compressive samples

The flexural strength of samples is one of the parameters used in pavement design. Concrete pavements with higher flexural strength will have higher fatigue life and will crack later. This index is used in designing concrete pavements. Figure 7 shows the flexural strength of different mixtures in three different periods. As can be seen from the figure, the mixes containing crushed ceramic wastes have higher flexural strength. Besides, how the samples are fractured and the rupture at the time of applying load is shown in this figure.

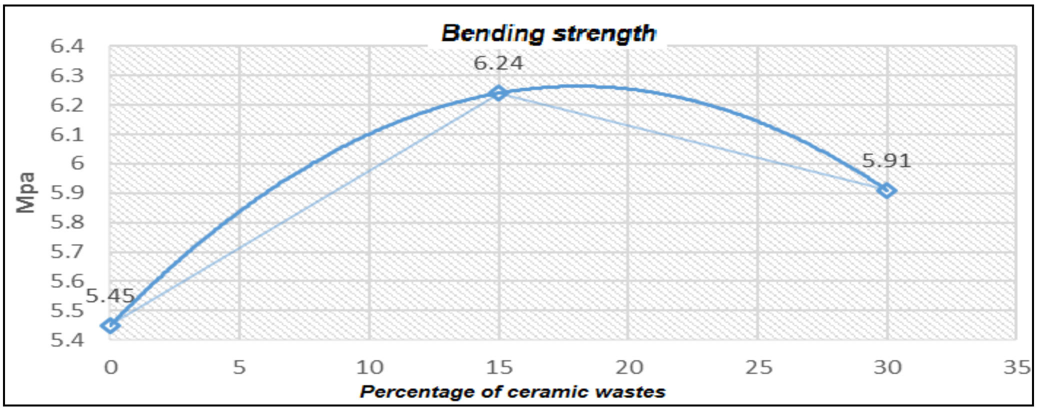

Figure 7: Flexural strength variation curve of samples containing different percentage of ceramic wastes

British pendulum number (BPN) is an index for pavement surface slip resistance to express friction resistance. To measure this resistance the same test condition for the samples was employed, as the previous ones. Figure 8 presents the abrasion results according to the usage of different percentages of ceramic wastes.

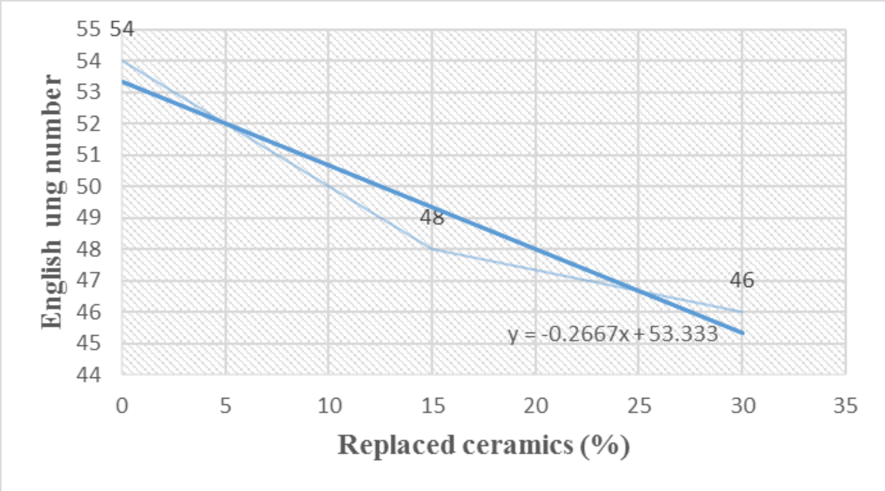

Figure 8: Friction test British pendulum number (BPN) results

In this study, the Dorry test was used to evaluate the abrasion resistance. The images of concrete samples surface before and after abrasion are shown in Figure 9. It is evident from this figure that when the crushed ceramics are used, the friction abrasion is reduced. By replacing 15% of ceramic in the samples, the surface friction rate has decreased which is due to the addition of aggregates with a smooth surface (in crushed ceramics). The sample with 30% of crushed ceramics has better abrasion resistance than the sample with 15% of crushed ceramics. This may be due to a strong bond of cement-crushed ceramic matrix and the higher stiffness of crushed ceramic against the abrasion; in tile and ceramic production industry, the product must have high abrasion resistance. Dorry test results are presented in Table 6 and Figure 10.

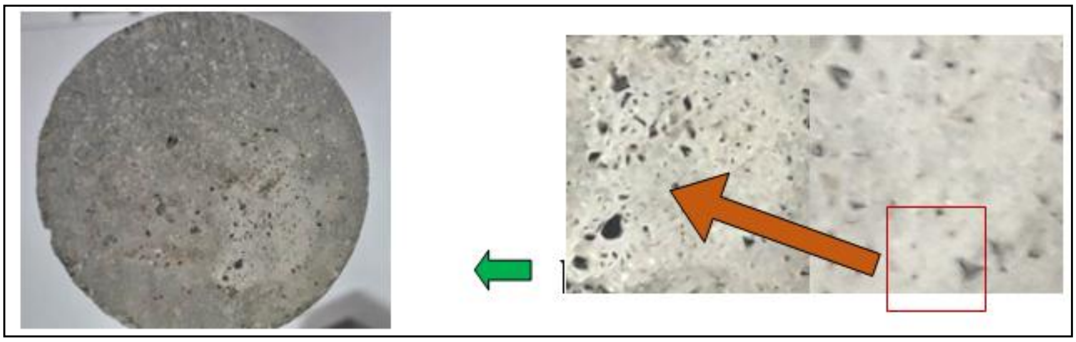

Figure 9: One concrete sample surface after abrasion test

Table 6: Dorry test results

Sample code	Weight before the test (gr)	Weight after the test (gr)	Weight Loss (%)
0%	241.3	234.4	2.86%
15%	291.2	284.8	2.20%
30%	195.5	191.6	1.99%

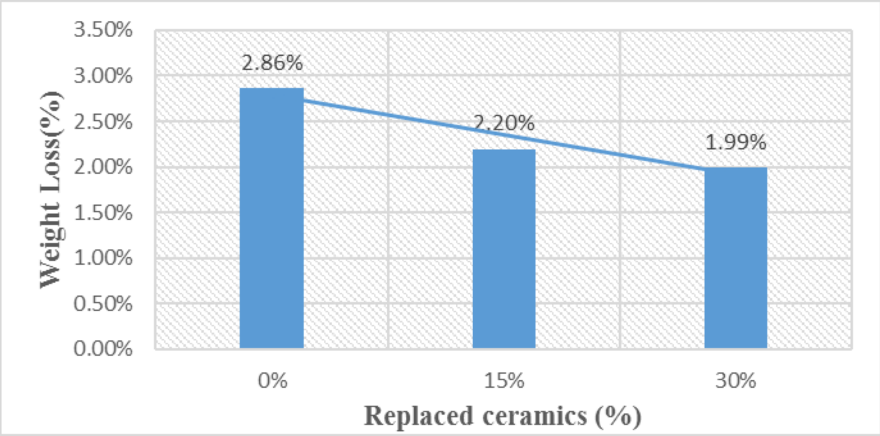

Figure 10: Weight loss variation of samples containing different percentages of ceramic wastes

Two indices, including compressive strength and abrasion resistance, were used to determine the optimal percentage of crushed ceramic. These indices are the main specifications of RCC samples. Figure 11 shows the optimal percentage of crushed ceramics. Since the two indices mentioned earlier have different measurement units, the standardized values in coordinate axes were used. Equation was used for standardization:

$$X_n = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}$$

where X_i, X_{min}, and X_{max} show the observed, minimum and maximum values of each variable, respectively.

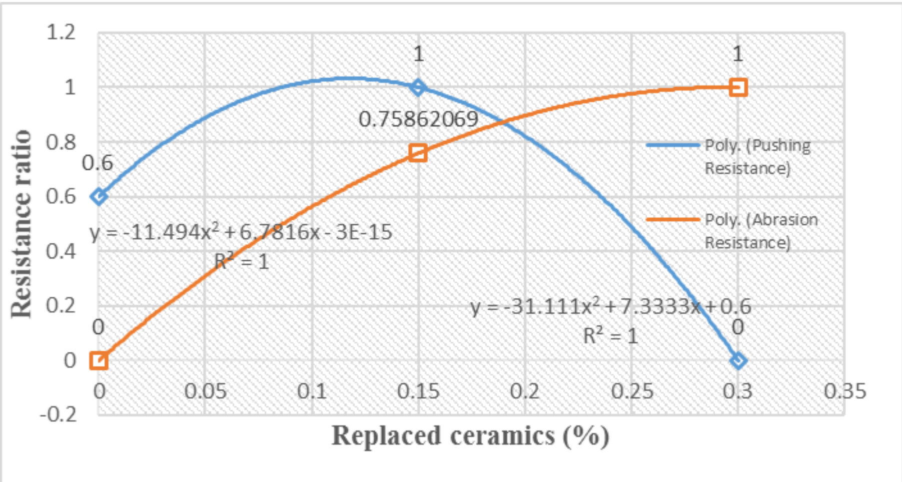

Figure 11: Plots for determining the optimal percentage of ceramic wastes

Other researchers confirm these findings and even point out, Concrete including waste ceramics(WC) decreases the renewed hardened density and density, and it reduces linearly with the increase in the ceramic content. The hardened properties of concrete usually decrease as the ceramic content incorporated is improved. Though, the compressive, flexural, indirect tensile strength (ITS), and elasticity modulus of WC concrete, which is slightly above reference concrete . WC concrete has more water absorption than RC. WC materials exhibit high abrasion resistance, freeze–thaw resistance, electrical resistance, and resistance to sulfate and nsulphuric attacks and environmental factors [18].

Conclusions

The need for managing industrial wastes is a way to preserve the environment in today's world. According to the tests performed on the ceramic wastes to determine the strength and abrasion of RCC, the following results are highlighted:

- With an increase in the contents of crushed ceramic wastes, the strength first increases. However, with the further addition of crushed ceramic (more than 15%), the compressive strength of RCC samples is decreased.
- Given the reduced costs, preserving the environment, waste management, and enhanced mechanical and abrasion resistance of RCC samples, using the crushed ceramic wastes in different conditions can be an action for sustainable development.
- The optimal percentage of crushed ceramic and the relationship between compressive strength and abrasion resistance were obtained using a second-order nonlinear regression. These two plot's intersection indicates that the optimal crushed ceramic percentage to be added to aggregates is 18.95%. At this point, the compressive strength and abrasion rates are 29.36 MPa and 2.10%, respectively.

List of symbols

BPN	*British Pendulum Number Test*
JPCP	*Jointed Plain Concrete Pavement*
RCCP	*Roller-Compacted Concrete Pavement*
RMC	*Ready-Mix Concretes*

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References

1. Farooq, M. A., & Mir, M. S. *Use of reclaimed asphalt pavement (RAP) in warm mix asphalt (WMA) pavements: a review*. Innovative Infrastructure Solutions,2017, 2(1), 1 – 9.
2. Hadavand, B., & Imaninasab, R.,*Assessing the influence of construction and demolition waste materials on workability and mechanical properties of concrete using statistical analysis*. Innovative Infrastructure Solutions,2019, 4(1), 29..
3. Klimek, B., Szulej, J. & Ogrodnik, P. *The effect of replacing sand with aggregate from sanitary ceramic waste on the durability of stucco mortars.* Clean Techn Environ Policy (2020). https://doi.org/10.1007/s10098-020-01932-w.
4. Shamsaei, M., Khafajeh, R., & Aghayan, I., *Laboratory evaluation of the mechanical properties of roller compacted concrete pavement containing ceramic and coal waste powders*. Clean Technologies and Environmental Policy,2019, 21(3), 707 – 716.
5. Vinod, B. R., Gopinath, R., Prasad, S., Kavitha, H. M., Mohta, M., & Ganapathy, A., *Analysis of E-Waste Ceramics as a Fine Aggregate for Rigid Pavements for Replacement of M-Sand and River Sand.* In Recent Developments in Waste Management, Springer, Singapore,2020, 385 – 396.
6. Lu, G., Liu, P., Wang, Y., Faßbender, S., Wang, D., & Oeser, M. , *Development of a sustainable pervious pavement material using recycled ceramic aggregate and bio-based polyurethane binder*. Journal of Cleaner Production,2019, 220, 1052 – 1060.

7. Ameli,R.,Parvareshkaran,A.Hashemi,K.,*Investigation of the results of 4-point flexural test of roller concrete mix beams (RCC) containing rubber chips and recycled asphalt chips*. Journal of Transportation,2019, 16 (2), 165 – 188.
8. Heidari, A., Tavakoli, S., & Tavakoli, D. , *Reusing Waste Ceramic and Waste Sanitary Ware in Concrete as Pozzolans with Nano-Silica and Metakaolin*. International Journal of Sustainable Construction Engineering and Technology,2019, *10*(1),1 – 10.
9. Awoyera, P. O., Akinmusuru, J. O., & Moncea, A., *Hydration mechanism and strength properties of recycled aggregate concrete made using ceramic blended cement*. Cogent Engineering, 2017, *4*(1), 1282667.
10. Kulovaná, T., Vejmelková, E., Keppert, M., Rovnaníková, P., Keršner, Z., & Černý, R. , *Mechanical, durability and hygrothermal properties of concrete produced using Portland cement‐ceramic powder blends*. Structural Concrete, 2016, *17*(1), 105 – 115.
11. Zhang, J., Yang, J., & Ying, Z. *Study on Mechanical Properties of Metakaolin-Based Concretes and Corrosion of Carbon Steel Reinforcement in 3.5% NaCl*. Int. J. Electrochem. Sci, 2016, *15*, 2883 – 2893.
12. Al-Alimi, S., Lajis, M. A., Shamsudin, S., Chan, B. L., Mohammed, Y., Al-Shaibani, N., & Wagiman, A. , *Development of Metal Matrix Composites and Related Forming Techniques by Direct Recycling of Light Metals: A Review*. International Journal of Integrated Engineering, 2016, *12*(1), 144 – 171.
13. Schackow, A., Effting, C., Barros, V. G., Gomes, I. R., da Costa Neto, V. S., & Delandréa, M. S., *Permeable concrete plates with wastes from the paper industry: Reduction of surface flow and possible applications*. Construction and Building Materials, 2020, 250, 118896.
14. Annual Book of ASTM Standards, *American Society for Testing and Materials standards manual, Section 4: Construction*, West Conshohocken, PA,USA, 2022.
15. European Standards European Committee for Standardization, EN 1097-8:2020; *Tests for mechanical and physical properties of aggregates Determination of the polished stone* value; European Committee for Standardization (CEN).2022. 1 – 38.
16. Chu, L., Guo, W., & Fwa, T. F., *Theoretical and practical engineering significance of British pendulum test*. International Journal of Pavement Engineering, 2020, 1 – 8.
17. Shetty, M. S., & Jain, A. K., *Concrete Technology,Theory and Practice*, 8E. S. Chand Publishing, 2018, p. 710.
18. Meena, R. V., Jain, J. K., Chouhan, H. S., & Beniwal, A. S. *Use of waste ceramics to produce sustainable concrete: A review*. Cleaner Materials, 2022(4), paper No.100085, 1 – 18.

Drcený keramický odpad a jeho vliv na pevnostní a obrusné vlastnosti válečkově válcovaných betonových vozovek

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Abstrakt

Vysoká míra používání keramiky a dlaždic ve stavebnictví vedla k uvolňování velkého množství keramických a dlaždicových odpadů po skončení životnosti budovy a demoličních procesech, což má negativní vliv na životní prostředí. Pokud by tyto odpady mohly být použity jako náhrada části přírodního kameniva do betonu, jeho destruktivní účinky se sníží. V této studii jsou odpady z továren na výrobu keramiky a dlaždic umístěných ve středním Íránu drceny a granulovány v rámci rozsahu předpisů. Poté je 15 % a 30 % hmotnosti kameniva ve směsi vozovkového betonu nahrazeno odpady.

Dlažební betonová směs obsahující drcenou keramiku je podrobena zkoumání lomově mechanického chování (zkoušky pevnosti v tlaku a ohybu) v dobách zrání 3, 7 a 14 dnů. Výsledky ukazují, že 15% náhrada zlepší pevnost při válcování; zatímco 30% náhrada těchto odpadů snížila pevnost v tlaku a ohybu válcovaného betonu v různém stáří. Vztah mezi pevností v tlaku a otěruvzdorností drcené keramiky byl získán pomocí nelineární regrese druhého řádu. Průnik těchto dvou křivek vede k nahrazení 18,95 % hmotnosti kameniva drcenou keramikou; což naznačuje pevnost v tlaku a rychlost otěru 29,36 MPa a 2,10 %, v tomto pořadí.

Klíčová slova: *keramické a dlaždicové odpady, pevnost v ohybu, vozovka, válečková zhutněná betonová dlažba, lomová energie, otěruvzdornost.*