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Performance of Recycled Ceramic Waste as Aggregates in Asphalt Mixtures

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Abstract: Ceramic waste materials are abundantly available in Malaysia from the production of ceramic tiles. In general, ceramic materials seem to possess low thermal conductivity characteristics that could reduce pavement temperatures when used as aggregates in asphalt mixtures. A study was undertaken to look into the performance of crushed ceramics incorporated in asphalt mixtures to replace the conventional granite aggregates from sizes 5.0 mm down including the 75 micron filler. The replacement was done proportionally with 0%, 20%, 40%, 60%, 80% and 100% ceramic aggregates by weight of granite. Several mix designs with various percentages of ceramic aggregates were formulated to determine the marshal properties such as stability, flow, and resilient modulus. In addition, the potential of ceramic aggregates in reducing the asphalt pavement temperatures was also studied. The outcome of the study showed that the ceramic aggregates in the asphalt mixtures were able to improve the performance of the mixture up to 20% which means there is a great potential for the use of it in road construction. Besides that, the rate of heating (RoH) compacted samples subjected to various temperatures dropped significantly as compared with the control granite specimens. The fatigue performance of the compacted and temperature conditioned ceramic asphalt mixtures displayed an interesting trend in terms of strain resistance at elevated temperatures.

Key words: Ceramic waste aggregate, asphalt, stability, resilient modulus.

1. Introduction

The ceramic tile manufacturing in Malaysia increased several fold over the years and gave rise to some serious problems of dumping and management of the wastes. The rejected tiles of various types and sizes are normally sent to the landfills at a substantial cost. Such dumping activity is causing serious environmental problems. According to a survey carried out in 2012, tile factories in Malaysia generate more 5% of wastes amounting to thousands of metric tons of waste ceramics. The ceramic wastes not only occur in the manufacturing plant but also during the transportation to building sites, on the execution of several construction elements (facades and partition walls, roofs and precast joist slabs) and on subsequent works, such as opening of grooves.

Several studies had been carried out by several researchers over the years. Huang et al. [1] studied the effect of ceramic waste material from automotive manufacturing used as filler incorporated in Portland cement and Asphaltic concrete. The ceramic waste was pulverized to be used as natural sand substitute in concrete specimen and as filler in stone mastic asphalt (SMA). The slump and compressive strength tests were carried out on concrete specimens and dynamic shear rheometer (DSR) test was carried out on asphalt binders. Ratnasamy et al. [2] used ceramic tile waste as filler for asphalt mixture. A preliminary study was carried out by Ratnasamy et al. [3] with the initial investigation on the feasibility of utilizing ceramic waste in asphalt binder which focused on the physical and chemical analysis as well the composition of the material. The results were checked against the local road authority standard specification for compliance and further investigation was initiated to study the effect of ceramic tile waste as filler in asphalt mixtures. In addition, permanent deformation analysis, indirect tensile test, moisture induced damage, dynamic

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modulus strength and DSR test were also carried out. Most of the test results showed an improvement in rutting and fatigue performance. However, glazed ceramic tiles were not used in the study since the surface of ceramic tiles is glazed for sanitary ware industry [4].

2. Materials and Method

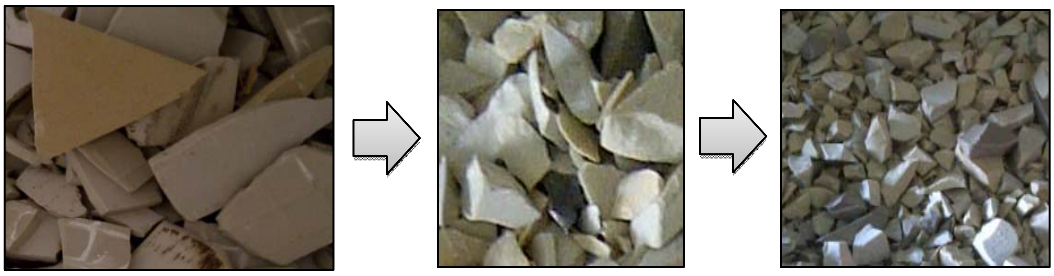
The ceramic waste materials were provided by one of the ceramic tile manufacturing companies in Malaysia for the study. The ceramic waste tiles were crushed into various sizes using an in-house portable crushing machine. The crushed aggregates were sieved over the selected gradation. The crushing produced a top aggregate size of 5 mm only since the tiles from the given source had an average thickness of 5-6 mm. As such, for the coarse aggregate fraction, granite aggregates were used in various proportions. The ceramic waste tile crushing process is as shown in Fig. 1 below.

The traditional granite aggregate was also used as the base aggregate in this study. Granite is widely used in paving on Malaysian roads. The crushed granite aggregates were provided by Kajang Quarry in Malaysia. The recycled waste ceramic was tested for its thermal conductivity with various matrixes of granite and ceramic blend.

The 80-100 penetration asphalt binder was selected for this study as it is traditionally used in many countries for road construction. The 80-100 penetration binder was tested for penetration, softening point and viscosity to comply with the local road authority requirements.

3. Sample Preparation and Asphalt Mixture Design

The experimental design matrix for the study covers six mix designs with the same blend of coarse aggregates as shown in Table 1 below. Samples made with 100% granite aggregates are taken as the control specimen which is named as G, and the samples named from 20 C to 100 C with an increment of 20% indicate the percentage of ceramic waste aggregate substituted in the combined aggregate matrix. The substitution of ceramic waste aggregates only involved aggregate sizes of 5 mm and below including the filler portion.



Raw ceramic waste from factory   Crushed ceramic waste   Crushed and graded

Fig. 1 Crushing and grading of ceramic waste tiles.

Table 1 Replacement of Ceramic Aggregatefor Asphalt Mixture Design.

Sieve size (mm)	G	20 C	40 C	60 C	80 C	100 C
14.00 10.00	100% granite	100% granite	100% granite	100% granite	100% granite	100% granite
5.00 3.35 1.18 0.425 0.150 0.075 Filler	100% granite	20% ceramic 80% granite	40% ceramic 60% granite	60% ceramic 40% granite	40% ceramic 20% granite	100% ceramic

The percentage indicated is calculated based on the total weight of aggregates for the selected gradation.

The mixtures were designed in accordance with Marshall procedure outlined in ASTM D 1559. A total of 90 specimens were prepared at the predetermined mixing and compacting temperatures using 50 blows per side. In this study, triplicate specimens were prepared to evaluate the effect of physical and thermal properties on the performance of ceramic modified asphalt mixture in terms of stiffness and stability. The Marshall samples were tested in accordance with ASTM D2726 for bulk specific gravity, ASTM D6927 for stability and flow test and ASTM D2041 for maximum theoretical specific gravity. The theoretical maximum density was determined through the rice method test. The optimum asphalt content for the 6 mixtures was determined using the Modified Asphalt Institute Method.

4. Results and Conclusion

Several tests were carried out to assess the performance of the ceramic aggregates in hot mix asphalt (HMA) such as resilient modulus, stability and flow, the Marshal Quotient (MQ), thermal conductivity of ceramic-granite aggregates and rate of heating (RoH) of ceramic modified asphalt mixture specimens. The MQ is a measure of the material resistance to shear stresses, permanent deformation and rutting. High MQ values indicate a mix with high stiffness and with a greater ability to spread the applied load and resistance to creep deformation. The optimum asphalt content (OAC) was determined to be 5.26%, 5.26%, 5.33%, 5.4%, 5.8% and 5.81% for G, 20 C, 40 C, 60 C, 80 C and 100 C respectively.

The crushed ceramic waste and granite aggregates were tested for compliance to the standards and checked with the Public Works Department's (PWD) requirement for HMA mixture. The physical properties for ceramic waste and granite aggregate are given in Table 2 below. From the results, it was found that the ceramic waste aggregates fulfilled all the minimum requirements.

An asphalt binder of 80/100 penetration grade was used for the mixture preparation. The results are in compliance with the road specification requirements. The summary of physical properties of the asphalt binder is as shown in Table 3 below.

Table 2 Physical properties of aggregates.

Properties	Standard	Result		PWD requirement
		Granite	Ceramic waste	
Los Angeles abrasion	ASTM C 131	20.12%	20.00%	Max 30%
Aggregate impact value	BS 812: Part 3	8.80%	4.30%	Max 15%
Specific gravity	ASTM C127	2.612	2.381	-
Water absorption	AASHTO T85	0.50%	1.04%	Max 2%
Flakiness index	ASTM D 4791, BS 812	6.12%	19.5%	Max 20%
Elongation index	ASTM D 4791, BS 812	0.07%	0%	Max 20%
Soundness test	ASTM C88	0.12%	0.08%	Max 12%

Table 3 Summary of physical properties of asphalt.

Type of test	Standard used	Results
Specific gravity at 25 °C, (g/cm^3)	ASTM D70	1.04
Penetration at 25 °C, (0.1 mm), 100 g, 5s	ASTM D5	82
Softening point (R & B) (°C)	ASTM D36	46.5
Viscosity at 135 °C, Pascal second (Pa·s)	ASTM D4402	0.353
Viscosity at 165 °C, Pascal second (Pa·s)	ASTM D4402	0.115

1 Pascal second (Pa·s) = 1,000 centipoise (cP).

A crushed coarse and fine aggregate with a maximum size of 14 mm was selected for a dense graded asphalt mixture. The gradation and the corresponding mix designations for HMA mixture together with PWD specification limits are shown in Fig. 2. Sieve analysis was carried out on a representative granite and ceramic waste. The dry sieve analysis was carried out in accordance with ASTM D546 and AASHTO T37.

The Marshall stability and flow results for all samples are as shown in Table 4 and Fig. 3 respectively. The measurement of Marshall stability is in kN whereas flow is in milliliter (mm).

It was observed that the stability values of all various ceramic-granite matrixes are well above the performance of the control sample. However, for the asphalt mixture

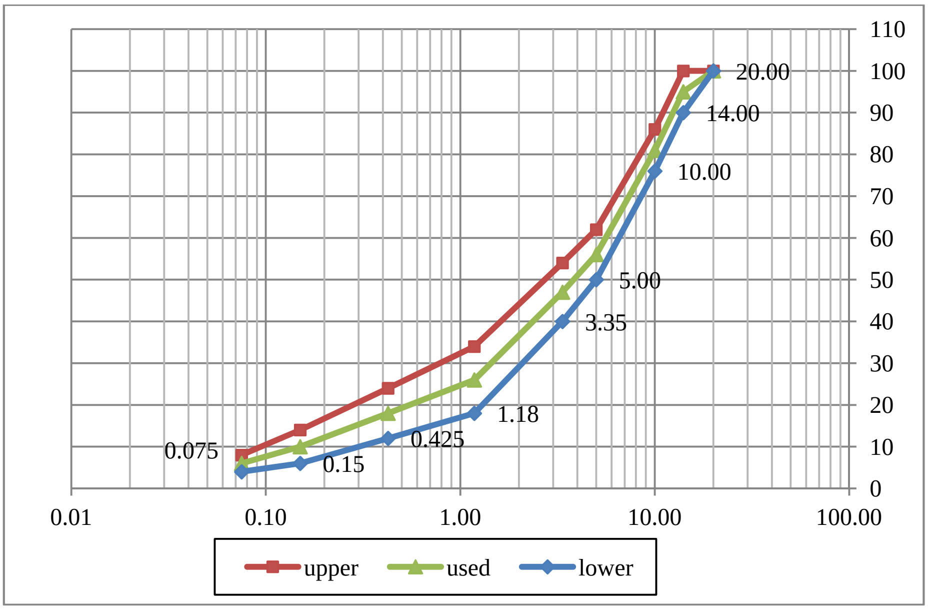


Fig. 2 Aggregate gradation for HMA mixture by JKR specification.

Table 4 Marshall stability and flow test results.

Mix type	GC	20 C	40 C	60 C	80 C	100 C
Marshall stability (kN)	10.55	13.15	12.37	11.9	10.5	9.72
Flow (mm)	3.9	3.32	3.41	4.19	3.76	3.44

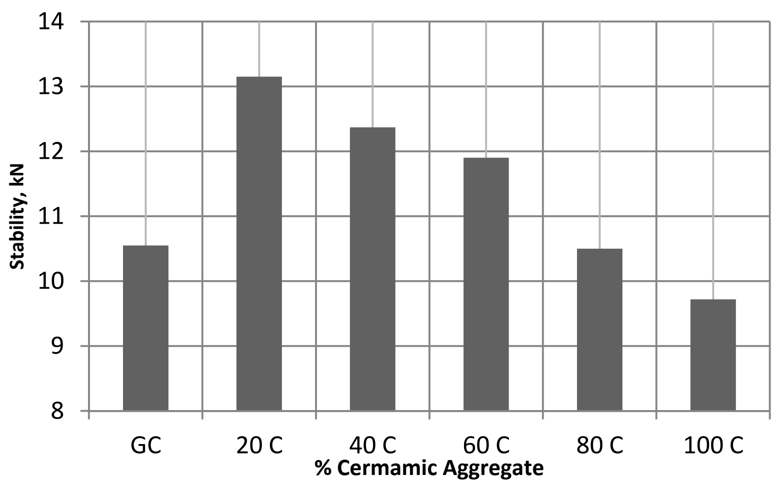


Fig. 3 Stability value for all types of samples.

with 100 percent ceramic aggregates displayed a slightly lower value as compared with the control sample. However, it is still above the minimum required stability value of 8 kN.

As the stability test was done together with the flow measurement, the ratio of stability to flow value (Marshall Quotient), MQ was calculated and presented as in Fig. 4 below.

MQ value shows an optimum at 20 C and still performed better up to 100 percent ceramic aggregates as compared with the control specimens.

As for the resilient modulus strength, it was observed that the asphalt mixture with 20 percent ceramic aggregates showed the highest value (an increment of 13.5%) whilst the 40 to 60 C showed a decreasing trend before an increase is seen from 80-100 C. The trend shows that the combination of ceramic and granite aggregates tends to increase the stiffness of the asphalt mixture. The resilient modulus values and comparison are shown in Table 5 and Fig. 5 respectively.

As highlighted before, the thermal properties of ceramic materials may be of importance when used in asphalt mixtures in terms of reduction of overall temperature of asphalt pavements. The thermal conductivity of the ceramic-granite aggregates with various proportions showed a remarkable reduction. This is shown in Fig. 6. This is an indication that ceramics when used as aggregates in asphalt mixtures may reduce the overall service temperatures of the asphalt layer.

Further to substantiate the above findings, the asphalt mixture specimens were made with varying proportions of ceramic aggregates and heated up in the oven. The rising temperatures of all specimens were measured at specified time intervals. It was observed that the RoH varied very much with varying proportions of ceramics in the mixture. It can be seen in Table 6 and Fig. 7 below that the RoH with respect to time is lower as the proportion of ceramics increases in the asphalt mixture. The maximum reduction in temperature is noticed at 120 minutes of exposure in the oven. The samples with 100 percent granite were 176 °C at its peak whilst samples with 100 percent ceramics measured 126 °C. There is a remarkable reduction in asphalt mixture temperature of 28.4%.

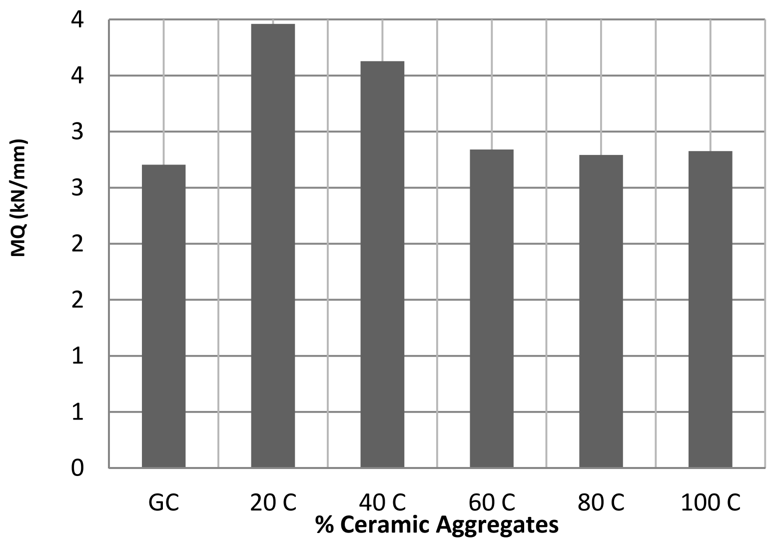


Fig. 4 MQ value for all types of samples.

Table 5 Resilient modulus test results.

Mix type	GC	20 C	40 C	60 C	80 C	100 C
RM	3,554.62	4,000	3,168	3,000	3,092	3,310

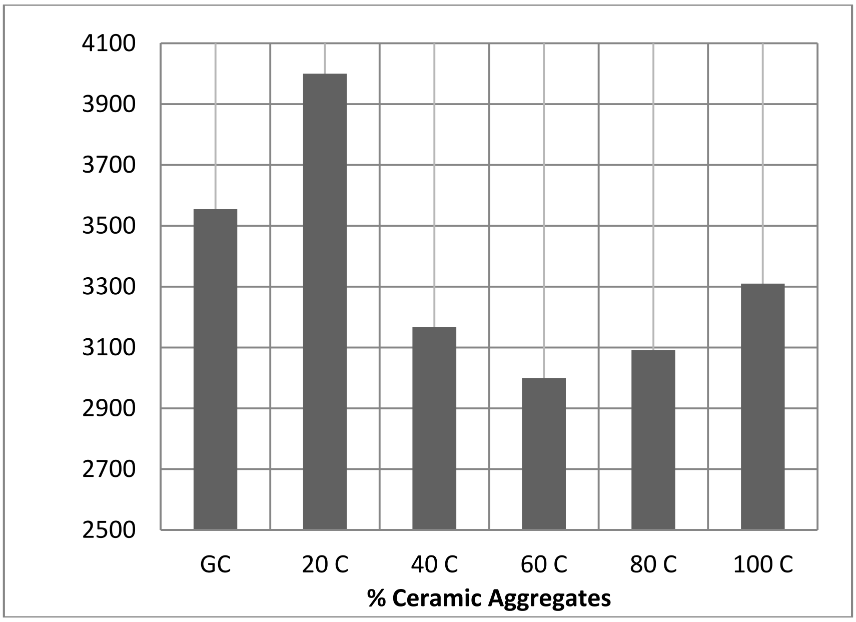


Fig. 5 Resilient modulus test results.

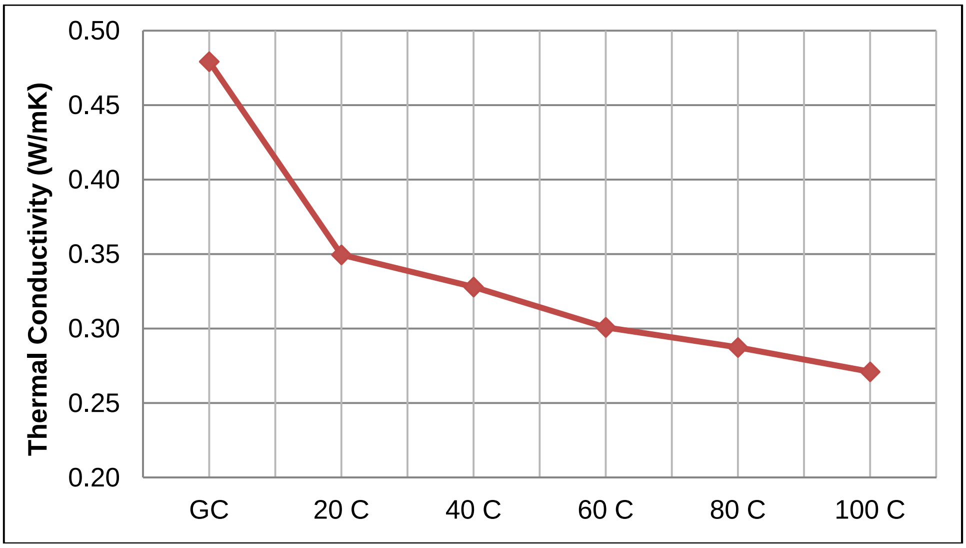


Fig. 6 Thermal conductivity values of granite-ceramic matrix at 35 °C, 45 °C and 55 °C.

Table 6 Thermal conductivity values of various ceramic-granite matrix.

Mix type	35 °C		45 °C		55 °C	
	Strain (%)	Thermal conductivity (W/mK)	Strain (%)	Thermal conductivity (W/mK)	Strain (%)	Thermal conductivity (W/mK)
GC	0.329	0.4610	0.346	0.4724	0.682	0.4772
20 C	0.418	0.3229	0.466	0.3238	0.749	0.3892
40 C	0.461	0.3077	0.625	0.3244	0.697	0.3342
60 C	0.423	0.2821	0.817	0.2634	0.891	0.3076
80 C	0.531	0.2713	1.246	0.2944	1.226	0.3152
100 C	0.605	0.2587	1.412	0.2767	1.235	0.2891

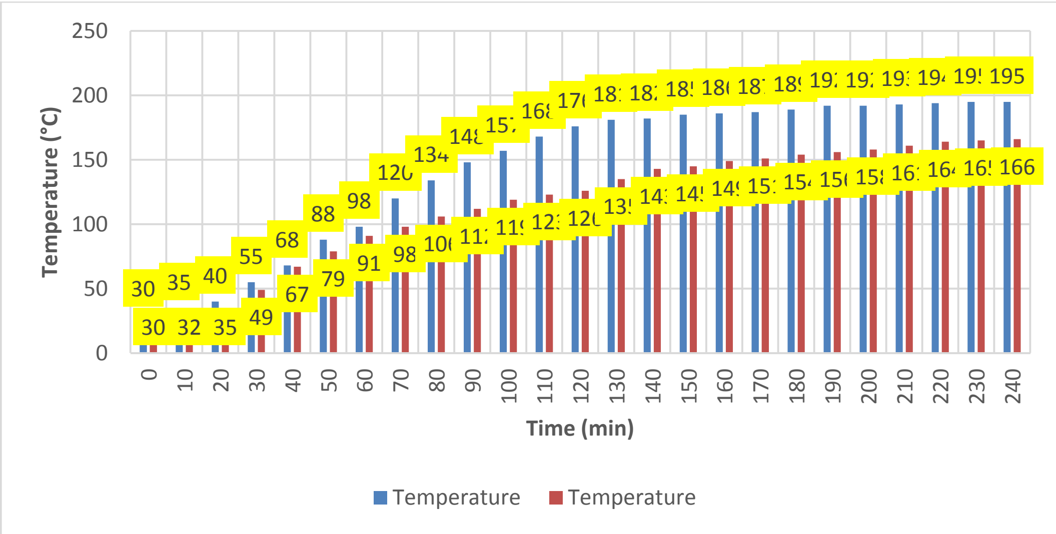


Fig. 7 **Rate of heating of various ceramic-granite matrix.**

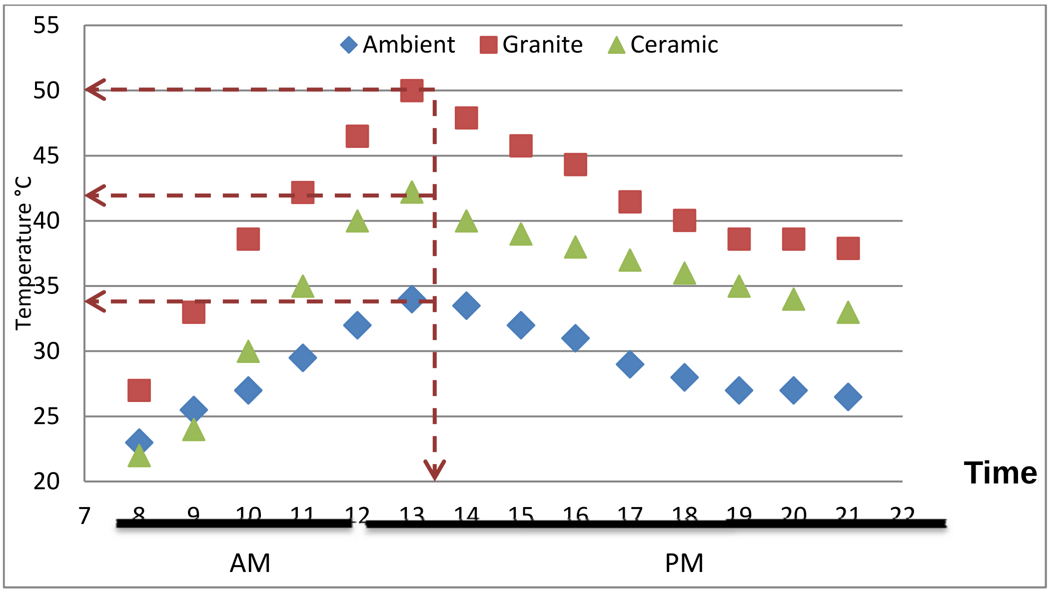


Fig. 8 **Rate of heating asphalt samples with various ceramic-granite matrix.**

Another two sets of compacted specimens with various ceramic-granite proportions were exposed to sunlight from 8 AM to 9 PM. It can be seen from Figs. 8 and 9 that the granite specimens showed a high temperature of about 50 °C at 1 PM as compared with ceramic which showed a temperature of around 42 °C. The temperature difference is approximately 19%. Fig. 9 showed a comparative assessment of 100% granite and 100% ceramic asphalt mixtures and it was observed that ceramic asphalt mixture samples' rate of heating is lower and takes a longer time to be heated up to 120 °C. One can imagine to what extent the asphalt binders in the road pavements can be saved from accelerated aging due to temperature reduction.

The asphalt mixture specimens were further subjected to permanent deformation test whereby the cumulative permanent strain levels were determined over a one hour test up to 3,600 cycles. It was observed that samples with higher ceramic contents displayed a higher permanent strain levels up to 45 °C and then the strain started to decrease when tested at elevated temperatures up to 65 °C. Table 7 and Fig. 10 below show the strain levels in three zones. There is a great potential to reduce the pavement service temperatures

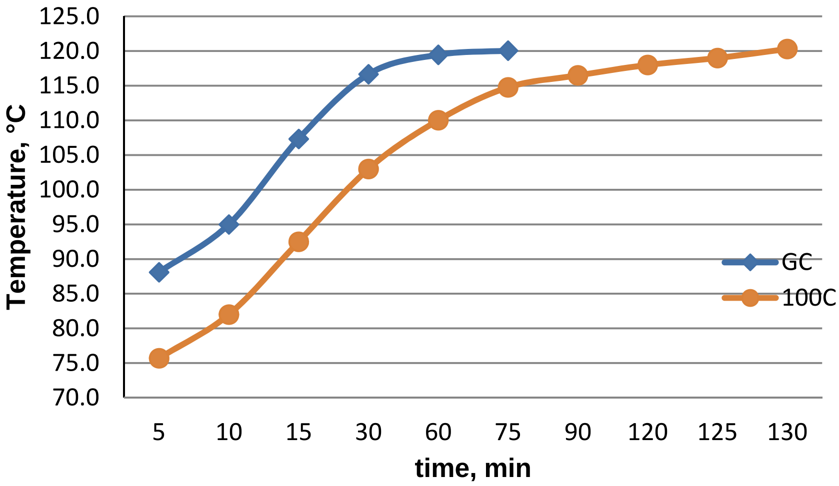


Fig. 9 Comparative assessment of samples with 100% granite and 100% ceramic.

Table 7 Temperature and time analysis of various ceramic-granite matrix.

Sample	Cumulative time (min)									
	5	10	15	30	60	75	90	120	125	130
GC	88.1	95.0	107.3	116.7	119.5	120.1				
20 C	88.0	91.0	107.0	112.3	117.1	119.9	120.4			
40 C	80.0	89.5	104.0	116.3	118.7	119.1	119.6	120.6		
60 C	80.0	89.0	102.7	114.0	116.1	118.1	119.6	120.3		
80 C	77.0	82.5	92.3	109.0	111.6	117.8	118.2	119.6	120	
100 C	75.7	82.0	92.5	103.0	110.0	114.8	116.5	118	119	120.3

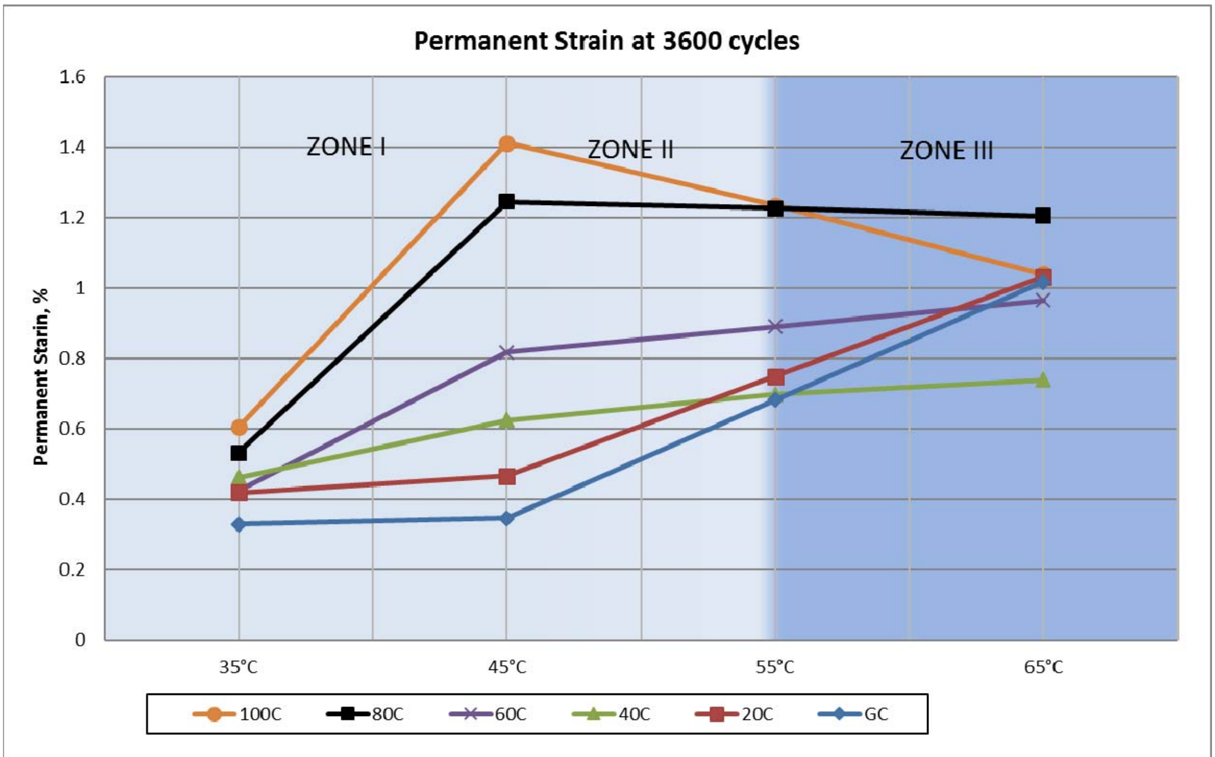


Fig. 10 Permanent strain levels of various ceramic-granite samples at different temperatures.

by using ceramic aggregates in asphalt layer construction. Reduced service temperatures may extend the overall pavement life.

5. Conclusion

Based on the study carried on ceramic as aggregates in asphalt mixtures, several observations were made.

The use of ceramic waste as aggregates in asphalt mixtures also showed that the mixture performance can be improved up to 80 percent ceramic waste. All of the ceramic blended mixtures showed a minimum stability of 9 kN which is above the minimum requirement of 8.0 kN. In addition, the resilient moduli results for all samples showed acceptable value and achieved more than 2,500 MPa as required by the road authorities.

Twenty percent (20%) ceramic waste blend showed the best performance amongst the rests. The study showed that ceramic waste aggregates have a potential to be used in the industry for pavement construction and can acquire the benefit in terms of environmental and cost efficiency.

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