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Reducing Thermal Cracks and Mitigating Heat Island by Using Glass Bead in Concrete Pavement

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Abstract: *It is desired to reduce pavement high surface temperature in summer to mitigate urban heat island (UHI) effect. High surface temperature also induces high possibility of thermal cracks. The prime aim of this study was to reduce concrete pavement surface temperature by using glass beads in concrete mixture. 10%, 20% and 30% proportions of glass beads were used for this purpose. Mechanical properties of samples were examined and the optimum proportion for glass beads was determined. It was detected that highest surface temperature was reduced 10ºC by using glass bead in concrete mixture. This treatment helps to mitigate heat island and reduce thermal cracks.*

Keywords: *Heat island, concrete pavement, thermal cracks, glass bead*

I. Introduction

Heat islands can be considered as surface and atmospheric heat islands [1, 2] and hot pavements contribute to the heat island effect. Surface heat islands can affect human thermal comfort and air quality. 70-80°C surface temperatures on pavements have been measured on hot summer days in Phoenix, Arizona [3]. As one major thermal characteristic, solar reflectivity or albedo (1-solar absorptivity) is an indicator of the reflecting power of a surface. It is dimensionless fraction and is measured on a scale from 0 to 1. Albedo of 0 means no reflecting power and albedo of 1 means perfect reflection [4]. Increasing the solar reflectivity of a pavement surface by using surfacing materials of light color or applying light color coating on dark surfacing materials can lower the pavement surface temperature [5-8]. Solar reflective materials can be identified as one of the most promising solutions to counteract urban heat island [9].

Temperature is one of the most important environmental factors for designing and predicting performance of Portland cement concrete (PCC) pavements. Temperature gradients throughout the slab thickness play a key role in calculating thermal stresses in PCC pavements, known as curling. It is necessary to increase the performance of PCC pavement by decreasing the curling stresses resulting from the fluctuation of temperature gradients. Richardson and Armaghani [10] and Shoukry and Fahmy [11], have determined that differential temperature was 10ºC through 225 mm concrete slab. Byrum and Hansen [12], used the differential temperature value as between 0.087 - 0.109 ºC/mm during the day time and between 0.044 - 0.065ºC/mm during the night time in their study. Kuo [13] recommend using loading at the center of the slab during the day time and loading at the edge of the slab at night time in analyzing of concrete pavement. Negative temperature gradient (night time) is not taking into account especially at concrete road design in Germany. This is because, negative gradient is less than positive gradient (day time) [14].

In this study, four different types of concrete mixtures with different proportions (% 0-10-20-30) of glass bead, which was used as a fine aggregate, were prepared. Compressive strength of concrete mixtures (% 0-10-20-30 glass bead by total weight of aggregate) were performed at 28 days in order to choose the ideal concrete mix design to obtain smaller surface temperature. 2 different types of concrete slabs with 1 m x 1 m x 25 cm dimensions were placed on base course layer. These slabs had different proportions of glass beads in their mix designs. The top and bottom surface temperatures of these two slabs were measured between 08:00-18:00 hours in summer on Black Sea Region of Turkey. It was observed how using glass in concrete mix design change the top surface temperatures of concrete slabs.

II. Glass In Concrete

It is known that, water absorption capacity of glass is almost zero and when it is used as an aggregate in concrete, it decreases the water absorption and drying shrinkage values which is a desired property for concrete [15]. Glass has a higher value of SiO_2 and it is observed whether alkali-silica reaction (ASR) expansion would be seen or not in concrete with glass in its mix design when there is enough moisture by [15]. It was observed that, if the proportion of the glass is lower than 25% weight of the aggregate in concrete, ASR expansions are in negligible level. Byars et al. [16] determined that, the reactivity of glass particles generally increases with particle size from around 1-2 mm. Glass particles below this size appear to reduce the propensity for ASR in larger glass particles. Ready-mixed concrete made with glass pozolan and/or glass sand shows increasing in strength development to 1 year, indicating a pozzolanic contribution from the fine glass particles.

In this study, glass beads which are used for road marking and have density of 1.6 gr/cm³ are shown on Figure 1. They were used as a fine aggregate to reduce the surface temperature of concrete slab. The properties of portland cement (PC 42.5) used in this study are shown in Table 1. Sphericity of glass beads was more than %70. Sieve analysis of glass beads used in concrete mix design is in Table 2. The density of the sand used as a fine aggregate was 2.63 gr/cm³.

Fig.1: Glass beads used as a fine aggregate

Table 1: Chemical properties of cement

Properties	Cement (PC 42.5)
SiO_2 (%)	20.81
Al_2O_3 (%)	5.41
CaO (%)	62.3
MgO (%)	0.97
Fe_2O_3 (%)	3.72
$Na_2O + K_2O$ (%)	0.43
SO_3 (%)	3.07
Density (gr/cm³)	3.17

Table 2: Sieve analysis of glass beads

Sieve Size in (mm)	Percentage passing by weight (%)
0.850	99.8
0.710	95.2
0.600	79.0
0.425	47.3
0.300	20.0
0.180	3.7

Standard 15 cm x15 cm x 15 cm cube C30/37 strength class concrete specimens were prepared for the testing program. Glass beads replaced with 10-20-30% weight of the total aggregate and compressive strength of concrete mixtures were performed at the end of 28 days in order to choose the maximum glass proportion which provides necessary compressive strength in the evaluated type of concrete. The mix designs of concrete samples are in Table 3 and the compressive strengths of these samples according to proportion of glass beads in their mixtures are in Table 4.

Table 3: C30/37 strength class concrete mix design

Strength Class C30/37	Cement PC 42.5 (Kg)	Water (Kg)	Glass Bead (Kg)	0/4 fine aggregate (Kg)	7/15 coarse aggregate (Kg)	15/25 coarse aggregate (Kg)	Addmix. (gr)
%0 Glass bead	1.50	0.87	0	4.874	2.343	2.164	18
%10 Glass bead	1.50	0.87	0.798	3.562	2.343	2.164	18
%20 Glass bead	1.50	0.87	1.597	2.250	2.343	2.164	18
%30 Glass bead	1.50	0.87	2.395	0.937	2.343	2.164	18

Table 4: Compressive strengths of concrete samples at 28 days

Strength Class	Glass Bead Proportion (%)	Compressive Strength (MPa)
C30/37	0	48.06
C30/37	10	42.48
C30/37	20	39.65
C30/37	30	35.57

The minimum compressive strength should be at least 37 MPa at the end of 28 days and %30 proportions of glass beads did not provide this value. %20 proportions of glass beads by weight of the total aggregate provided the minimum compressive strength of the C30/37 strength class concrete.

III. Temperature Measurements In Pcc Pavements

In this part of the study, two different type of concrete, C30/37 strength class without any glass bead and with glass bead (%20 by weight of total aggregate) were placed on a base course layer (25 cm thick crushed limestone). %20 proportion of glass bead was in acceptable limit for compressive strength test. The dimensions of these two slabs were 1 m x 1 m and 25 cm thick. In order to monitor the daily variations of temperature profiles, temperature sensors were installed in the middle of the top and bottom of the slabs. Temperatures were measured between 08:00-18:00 hours. Positive gradient is more important than negative gradient in concrete road design.

Figure 2 shows the temperature of top and bottom surface of standard C30/37 concrete slab between 08:00-18:00 hours. The highest top surface temperature was at 14:00 with a value of 49.7°C. The biggest temperature difference on top of the slab was 23.3°C during the testing time. The biggest temperature difference between top and bottom of the slab was at 14:00 with a value of 14°C. It is interesting to know that the top and bottom temperatures were same in the morning and evening indicating $\Delta T = 0$.

Figure 3 shows the temperature of top surface of concrete slab (%20 glass beads in its mixture) between 08:00-18:00 hours. The highest top surface temperature was at 14:00 with a value of 40.7°C. The biggest temperature difference on top of the slab was 19.3°C during the testing time. The biggest temperature difference between top and bottom of the slab was at 14:00 with a value of 5.0°C.

Figure 4 shows the temperature differences of top surface layers of standard C30/37 strength class concrete slab and the concrete slab which has %20 glass beads in its mix design. The biggest temperature difference was at 14:00 and the top surface temperature of standard concrete slab was 9.0°C more than the other slab's top surface temperature at that time.

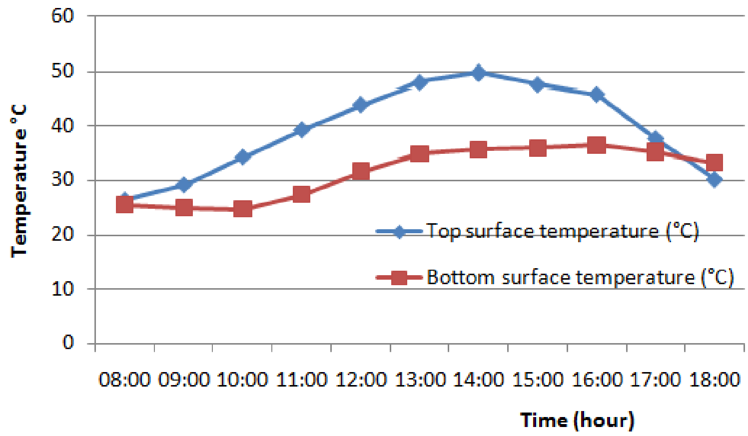

Fig.2: Top and bottom surface temperature of C30/37 strength class concrete (0% glass bead)

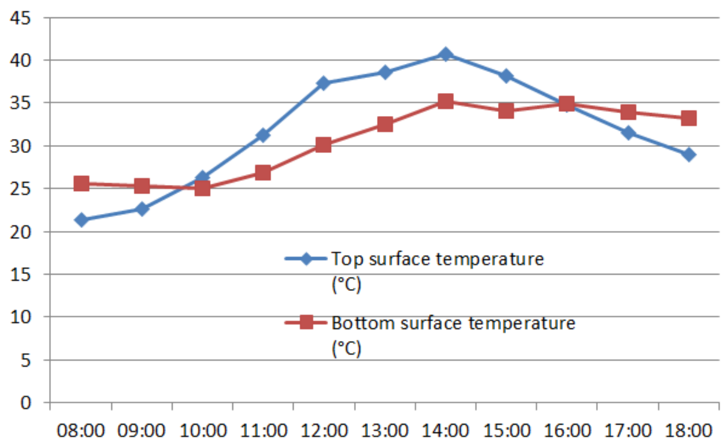

Fig.3: Top and bottom surface temperature of C30/37 strength class concrete (20% glass bead)

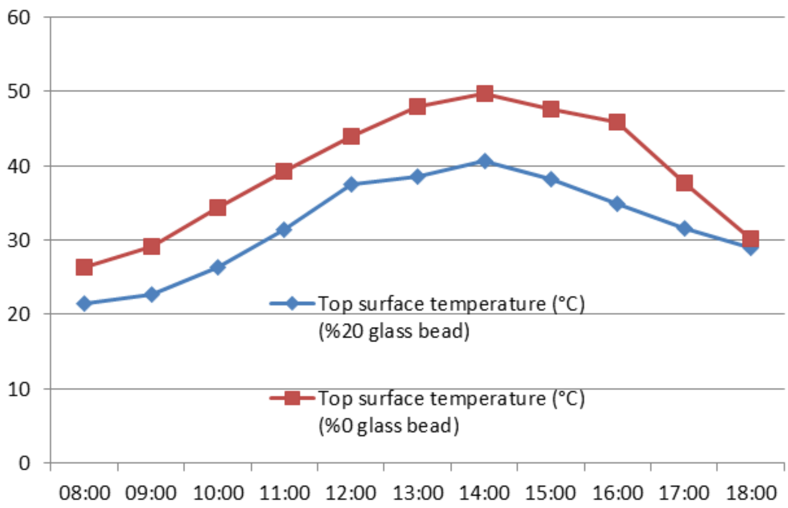

Fig.4: Top surface temperature of C30/37 strength class concretes with 0% and 20% glass bead in their mix designs

The reflection coefficient or albedo was not measured by a device in this study. However based on visual observation of the radiation reflection an albedo value of 0.5 was estimated. Albedo value can vary between 0.4 to 0.8 for white portland cement concretes. The estimated 0.5 value may increase over the years once the concrete pavement opens to traffic and tires start to wear the surface where later the glass beads may dominate the surface. The glass beads are used for good night vision on roads especially at nights. Instead of scattering light, glass beads turn the light around and send it back in the direction of the source. The glass bead's Refractive Index (RI) is an important physical parameter. The higher the RI of the bead and the fewer impurities in the glass material, the more light is reflected. Beads used in this study had RI of 1.5.

IV. Conclusion

Higher surface temperature differences induce a high possibility of thermal cracks in concrete slab. It is desired to reduce pavement high surface temperature in summer to mitigate UHI effect. In this study, different proportions (10%, 20% and 30%) of glass beads in concrete mixture were used to reduce concrete pavement surface temperature. Glass bead, which is %20 by weight of the total aggregate in concrete, was suitable to get enough compressive strength for C30/37 strength class concrete. After measuring surface temperature of two different concrete mix designs (%0-20 glass bead by total weight of aggregate) during the day in summer, it was obtained that, using glass beads reduced top surface temperature of concrete. The biggest surface temperature was at 14:00 and the top surface temperature of standard concrete slab was 9°C more than the other slab's top surface temperature at that time. The biggest temperature difference between top and bottom of the slab was at 14:00 with a value of 14°C and 5.0°C for concrete with %0 glass beads and %20 glass beads in its mixture respectively. It was noticed that using glass bead in concrete road mixture design may reduce the surface temperature in summer and mitigate heat island while reducing temperature gradients.

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