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EFFECT OF GLASS BEAD AND ZEOLITE IN CONCRETE UNDER HIGH TEMPERATURE

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Abstract

The paper presents the impact of high temperature on concrete with glass bead and zeolite in its mixture. It is desired to reduce the concrete surface temperature when it is exposed to high temperature. In this study, different range of proportions of glass beads (%10, %20, %30) and zeolite (%10, %30) were added into the C30/37 strength class concrete as a fine aggregate and Portland cement, respectively. Surface temperatures of concrete samples were measured when concrete was under about 3000°C flame for a short time. It was determined that, using glass bead and zeolite together in concrete reduces surface temperature significantly under high temperature. The study presented herein provides important results on regulating concrete mixture if there is any risk to be exposed to high temperature.

The study presented herein provides important results on regulating concrete mixture if there is any risk to be exposed to high temperature. The main research question is "Is it possible to reduce surface temperature of concrete when it is exposed to very high temperature by using glass bead and zeolite in concrete mixture".

10 different types of concrete mixtures were designed to study the effects of concrete and zeolite on compressive strength and surface temperatures of concrete.

It was determined that using glass bead as a fine aggregate and zeolite, significantly affects concrete surface temperature and temperature differences of both sides when concrete is exposed to very high temperature.

Using glass bead and zeolite in concrete for fire resistance hasn't been searched before. In this study it was determined that it is possible to get lower surface temperatures by using glass bead and zeolite in concrete mixture. The ideal proportion was %20 for glass bead and %30 for zeolite in the mixture to obtain lowest surface temperatures and meet the compressive strength requirements. These types of mixtures can also be examined for concrete pavements to get lower temperature gradients in summer and obtain less thermal cracking on concrete road.

Keywords: High Temperature; Glass Bead; Zeolite; Concrete.

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1. Introduction

Many cases of fires taking place in buildings, tunnels and drilling platform structures. During a fire, the temperature may reach up to 1100°C in buildings and even up to 1350°C in tunnels, leading to severe damage in concrete structure [1]. Concrete generally provides the best fire resistance properties of any building material [2]. This is due to its low thermal conductivity, high heat capacity and slower strength degradation with temperature. This slow rate of heat transfer and strength loss enables concrete to protect itself from fire damage. The behavior of a concrete structural member exposed to fire is dependent on thermal, mechanical and deformation properties of concrete. These properties vary as a function of temperature and depend on the composition characteristics of concrete. When concrete is heated under conditions of fire, significant temperature gradients are observed between the concrete surface and the deeper layers. The surface temperature becomes significantly higher than the inner parts. High temperature damages concrete structure and alterations of its physical, thermal and mechanical properties occur. The increase in temperature results in water evaporation, C-S-H gel dehydration, calcium hydroxide and calcium aluminates decomposition.

The incorporation of pulverized fly ash (PFA) and slag in Portland cement can generally remain the mechanical properties of concrete at a higher level after heating to high temperature up to 900°C and 1050°C, respectively [3]. Portland cement blended with PFA and slag also exhibits a high resistance to spalling at high temperatures [4-6]. Karakurt and Topcu [7] determined that thermal cracking did not occur in PFA and slag blending samples and that the degradation of C-S-H decreased compared to PC sample by using SEM analysis. Besides, the incorporation of slag significantly reduces the amount of portlandite in PC so that decreasing the degradation of porlandite at high temperatures [8]. As a result of these aspects, the total porosity and the average pore diameter of PCs blended PFA and slag are smaller than those of PC at high temperatures [9]. The higher resistance of PCs blended PFA and slag to high temperature can be explained by this result. Zeolite is a natural or synthetic hydrated aluminosilicate mineral of alkali and alkaline earth metal with an open three-dimensional crystal structure. Zeolite concrete is much less frequent subject of investigation as compared with fly ash, silica fume or ground granulated blast furnace slag as SCMs. The most significant effects of using zeolite as cement in concrete are reduction in expansion due to alkali-silica reaction, resistance to acid and sulfate attacks and pozzolanic consumption of calcium hydroxide component of Portland cement hydration in the paste. The performance of natural zeolite in mortar/concrete has been compared with performance of other pozzolanic materials [10, 11]. Poon et al. determined that the degree of reaction of natural zeolite in a paste with a higher percentage of replacement is lower than in a paste with a lower percentage of replacement [11]. Pancar [12] determined that using zeolite in concrete mixture reduces alkali-silika expansion. Chan and Ji noticed that pozzolanic reactivity of natural zeolite is between pulverized fuel ash and silica fume [13]. Kılınçarslan determined that using zeolite as Portland cement decreases the thermal conductivity of concrete [14].

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 SiO2 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 Lam et al. [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 and Zhu 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 [15]. Ready-mixed concrete made with glass pozzolan and/or glass sand shows increasing in strength development to 1 year, indicating a pozzolanic contribution from the fine glass particles [16, 17]. Lower concrete pavement surface temperatures were obtained by using glass bead in concrete mixture [18].

In recent years, the use of numerical methods for the calculation of the fire resistance of structural members is gaining acceptance because of their cheaper and time consuming properties [19]. In this study, different range of proportions of glass beads (%10, %20, %30) and zeolite (%10, %30) were added into the C30/37 strength class concrete samples as a fine aggregate and Portland cement, respectively. The mechanical properties of the mixtures and alkali-silica expansions were examined. The temperatures of top and bottom surfaces of these mixtures measured after heating the concrete under about 3000°C flame for a short time. Lower temperatures were obtained with the glass bead and zeolite as it was expected before testing. In this study, the ideal proportions for the glass bead and zeolite were determined when the concrete is exposed to high temperature.

2. Materials and Methods

In this study, glass beads which are used for road marking were used as a fine aggregate to reduce the surface temperature of concrete under high temperature. They have 1.6 gr/cm^3 of density. Thermal conductivity of glass beads used in this study was about 0.0014 W/mK. The chemical properties of the fine aggregate, glass bead, portland cement and zeolite, used in this study, to determine the ideal concrete mix design to reduce the impact of high temperature on concrete are in Table 1.

Table 1: Chemical properties of materials used in concrete mixture

Oxide	**Fine aggregate**	**Glass bead**	**Portlan Cement 42.5 R**	**Zeolite**
SiO2 (%)	2.59	69.80	22.55	68.81
Al2O3 (%)	1.09	1.45	7.12	14.17
CaO (%)	95.09	9.52	61	1.91
MgO (%)	-	4.20	3.56	1.10
Fe2O3 (%)	0.92	0.15	3.81	1.84
K2O (%)	0.17	0.72	0.12	3.40
Na2O (%)	-	13.85	-	-

Ten different types of mixtures were designed to study the effects of glass bead and natural zeolite on compressive strength and surface temperatures of concrete. One of these mixtures was a control mixture and three of the mixtures had 10%, 20%, 30% proportions of glass bead by total weight of aggregates. Six different mixtures with different proportions (10-30%) of zeolite for each glass bead proportions were also prepared. All coarse and fine aggregates were limestone in control mix design. Fine aggregates are more effective in thermal conductivity than coarse aggregates. Due to this reason, glass bead was used as a fine aggregate to obtain lower surface temperatures in this study. Aggregates used in this study were limestone and Portland cement 42.5 R was used in all mixtures. The mixtures were named using the type and percentage of glass bead and zeolite in the concrete mixtures. For example G10Z0 represents the concrete mixture that consists of %10 proportion of glass bead by total weight of aggregate and %0 proportion of zeolite in cement. Water/cement ratio was 0.50 in all blends. After all, ten different mixtures were heated by a flame, which was about 3000°C, from 10 cm distance for 15 seconds. Concrete samples with 3.5 cm in thick were prepared for all these mixtures. The heated top surface and unheated bottom surface temperatures were measured. The aim of this test was to get lower top surface temperatures and lower surface temperature differences. Mixture designs of concrete samples are in Table 2.

Table 2: Mixture designs of concrete samples

Mixtures	**Cement PC 42.5 (Kg)**	**Water (lt)**	**Glass bead (Kg)**	**Zeolite (Kg)**	**0-5 mm fine aggregate (Kg)**	**5-12 mm coarse aggregate (Kg)**	**13-22 coarse aggregate (Kg)**	**Admixture (gr)**
Standard Mixture	7.70	3.85	0	0	20.22	8.80	12.32	80
G10Z0	7.70	3.85	4.13	0	16.09	8.80	12.32	80
G10Z10	6.93	3.85	4.13	0.77	16.09	8.80	12.32	80
G10Z30	5.39	3.85	4.13	2.31	16.09	8.80	12.32	80
G20Z0	7.70	3.85	8.27	0	11.95	8.80	12.32	80
G20Z10	6.93	3.85	8.27	0.77	11.95	8.80	12.32	80
G20Z30	5.39	3.85	8.27	2.31	11.95	8.80	12.32	80
G30Z0	7.70	3.85	12.40	0	7.82	8.80	12.32	80
G30Z10	6.93	3.85	12.40	0.77	7.82	8.80	12.32	80
G30Z30	5.39	3.85	12.40	2.31	7.82	8.80	12.32	80

3. Results and Discussions

Compressive strengths of ten different types of mixtures at 28 days are in Figure 1. G30Z0, G30Z10 and G30Z30 mixtures didn't meet the compressive strength requirements of C30/37 strength class of concrete.

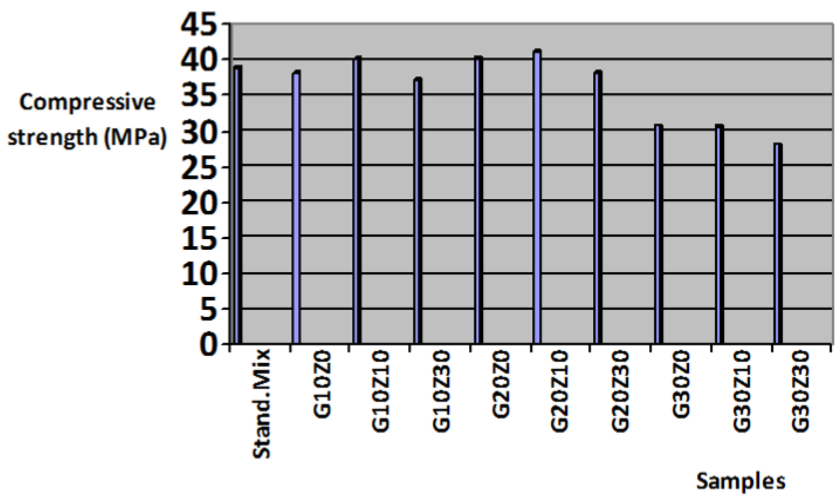

Figure 1: Compressive strengths of samples at 28 days

Table 3 represents the surface measurements of top and bottom surfaces of samples after heating by a flame. It was determined that using glass bead and zeolite, significantly affects concrete surface temperature and temperature differences of both sides. In this study glass beads used in the mixture with proportion of %10, 20, 30 reduced top surface temperature from 52.4°C to 38.3°C, 37°C and 36.2°C, respectively. The surface temperature difference decreased from 15.8°C to 3.0°C by using %30 proportion of glass bead. When zeolite (%30 by total weight of cement) was added into mixtures with glass beads (%10, 20, 30 by total weight of aggregate), the surface temperature differences decreased from 8.3°C to 5.8°C; 3.6°C to 3.1°C; 3.0°C to 2.9°C, respectively.

Table 3: Top and bottom surface temperatures after heating

Mixtures	**Top surface temperature (ºC)**	**Bottom surface temperature (ºC)**	**Surface temperature difference (ºC)**
Standard Mixture	52.4	36.6	15.8
G10Z0	38.3	30.0	8.3
G20Z0	37.0	33.4	3.6
G30Z0	36.2	33.2	3.0
G10Z10	38.0	31.1	6.9
G20Z10	36.6	33.3	3.3
G30Z10	36.0	33.3	2.7
G10Z30	37.5	31.7	5.8
G20Z30	36.5	33.4	3.1
G30Z30	36.2	33.3	2.9

After examining Table 3, it was determined that using glass bead in concrete reduces high surface temperature when the concrete is heated. Adding zeolite into mixture also helps to reduce the surface temperature. The proportion of zeolite effect on temperature reduction is more when the glass bead proportion in the mixture is less. Decreasing the difference between heated and unheated surface temperatures is desired conclusion for this study and it was obtained by using glass bead and zeolite in concrete mixture.

4. Conclusions & Recommendations

The first concern of this study was to obtain lower surface temperature after heating a concrete under a very high temperature. There are some methods in literature to evaluate the concrete response to high temperature. The easy, cheap and time consuming test will be better to compare different mixtures under high temperature. Due to this reason, an alternative method was used to determine the effects of using glass bead and zeolite on concrete surface temperature while heating process. Using glass bead and zeolite in concrete for fire resistance hasn't been searched before. It was obtained that concrete with glass bead and zeolite in its mixture is very effective under high temperature. Besides spalling, thermal cracks which occur by big surface temperature differences are also important problems for concretes. By the help of examining mechanical properties of concrete, it was determined that using %30 glass bead in concrete mixture is not suitable for compressive strength. Standard mixture heated surface temperature was measured as 52.4°C while heated surface temperature of G20Z30 measured was 36.5°C under the same condition. The top and bottom surface temperature difference was 15.8°C for standard mixture while this difference was 3.1°C for G20Z30 mixture under the same condition. Glass bead and zeolite are good alternatives in concrete mixture to mitigate high temperature effect on concrete. These types of mixtures can also be examined for concrete pavements to get lower temperature gradients in summer and obtain less thermal cracking on concrete road.

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