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An Experimental Investigation on Incorporation of Fine Aggregate with Glass Powder and Cement with Zeolite to Mitigate Urban Heat Island Effect

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ABSTRACT
An experimental study was done for replacement of glass powder and zeolite to evaluate the effect of urban heat island. All of the concrete sample mixtures carried out the intensified mortar bar test to evaluate the growth of the ASR. Perhaps this is partly related to a smaller glass particle size, the chemical characteristics of bottle as well as the participation of zeolite throughout concrete. Test specimens G20 Z10, GO Z10 and GI0 Z0, reached the power parameters. The G20 Z10 had the maximum resistance characteristics between them. These were found that intensity values with both the rising quantity of glass dust up to 20 per cent dose started to show a declining pattern. The replacing cement to zeolite powder research by up to 10 per cent indicates a tremendous pattern throughout strength properties. Decreased compressive tension, flexicurity and broken tensile strength may be due to reduced adhesion here between smoother surface of the glass particle as well as the cement. A G20 Z10 blend study revealed lower pavement surface temperature, which can also be considered a mitigating technique for urban heat islands.

***KEYWORDS:** ASR; urban heat island; zeolite; glass powder; pavement*

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INTRODUCTION

Urban Heat Island is one of the major environmental problems associated with the rapid increase in urbanization [1]. The concept of a considerable difference in temperature between the urban and rural areas surrounding the city can indeed be called the Urban Heat Island Effect (UHI) [2]. When urban areas begin to develop, landscapes and vegetation become buildings, pavements and other types of infrastructure. This urban area growth can lead to a UHI. Climate change could be one of the causes behind the rise in urban area temperatures [3]. Luke Howard provided first study and description of Urban Heat Island in 1810s [4]. Rising urban temperature will also increase energy consumption, pollution problems and human discomfort and health problems [5]. The buildings as well as the paved surfaces are significant contributors to the UHI. The paved surfaces comprise roads, sidewalks and parking spaces. They comprise a large part of metropolitan areas [6]. Due to their material properties and temperature sensitivity, the type and age of pavements also has an effect on UHI. The key factors influencing the pavement temperature are indeed the thermophysical properties of paving materials and environmental features. Thermophysical properties include thermal conductivity of pavements, volumetric heat capacity of pavements, thermal diffusivity of pavements, and reflectance or albedo of the pavement surface [7]. Pavement absorbs the sunlight and transforms it to thermal energy, which results in heating it up. By lowering the pavements surface temperature, urban area temperature can be reduced, which could improve the thermal conditions of urban area.

This condition of comfort could be achieved by replacing conventional materials to alternative materials, which will help in lowering pavement temperatures. The use of waste materials in civil engineering works is the strongest way of disposing of non-biodegradable waste materials [8,9]. Glass, being an inherently non-biodegradable material, the disposal of glass as landfill will generate many environmental problems. Glass can be successfully recycled to an degree of 100 % without impacting consistency [10]. Recycled glass is used worldwide in many building industries. A lot of foreign countries are currently using waste glass as an aggregate in highway construction [11]. Replacing fine aggregate by glass powder can be considered as a safer way of disposal and a means of reducing the urban heat island. This paper primarily focuses on rising surface temperature, which could help to mitigate the island 's urban heat. In concrete pavement the effect of different ratios of glass replacing the fine aggregate and zeolite replacing the cement was examined. For all test specimens the ASR expansion and strength tests were performed. Microstructural analysis has also been performed. Temperature of the pavement surface was measured to selected proportions. Concrete mixture was determined with lowest pavement temperature.

Methodology and experimental work

Various experiments were performed on fine aggregates, coarse aggregate, cement, glass powder, and zeolite. The M40 grade concrete mix design was performed as per IRC 44 2008. Then ASR expansion check (Accelerated Mortar Bar Method) in compliance with IS 2386 (Part 7) 1963 was performed in various proportions such as 0 %, 10 %, 20 % and 30%. Samples satisfying ASR expansion tests have been chosen for the strength tests. Samples of greater strength and lower strength were discovered from the strength checks. Microstructural analysis was performed on the strongest and weakest samples, with the help of Scanning Electron Microscope. The study aimed to identify the possible explanation for the reduction in power. Temperature evaluation was performed on such samples which met the strength requirements. Using an infrared thermometer and k-type thermocouple, top surface temperature, temperature at 75 mm depth, and low surface temperature was measured.

ASR Expansion Test

The extension of the Alkali Silica Reaction (ASR) into concrete arises when the alkalis in the cement react in the aggregate with free silica constituents. The products produced are expansive in nature, and will result in destructive effects of crack formation. Because the BaNs powder does have a higher amount of silica content, the expansion of the ASR can be estimated, since the size of the glass particles used in this analysis was less than 1.18 mm, the expansion of k could be smaller. Because the fineness of natural zeolite is greater, expansion of ASR could be reduced. ASR tests evaluating the ASR expansion were performed for all concrete mixtures in compliance with IS 2386 (Part 7):1963, Standard specimens of 25 x 25 x 250 mm scale were casted in an accelerated mortar bar process. The ratio of cement aggregates used was 1:2.25. This was air cured for 24 hours as well as the specimens were removed from the moulds afterwards. Sample were then submerged for another 24 hours in water, and their initial length has been noted. Then it was submerged for next 14 days in 1 N NAOH solution, and the final duration was again assessed. The expansion after 16 days of the calculated and after 16 days of casting it will be less than 0.10 %.

Table 1: Mix Design of Concrete Samples

Mixtures	Fine Aggregate (kg/m³)	Glass Powder (kg/m³)	Cement (kg/m³)	Zeolite (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)
Normal	680.50	0	425	0	1036.36	173.55
G0Z10	680.50	0	383.2	42.4	1036.36	173.55
G0Z20	680.50	0	342	84.5	1036.36	173.55
G0Z30	680.50	0	296.8	126.9	1036.36	173.55
G10Z0	612.50	69.02	424.5	0	1036.36	173.55
G10Z10	612.50	69.02	382.5	42.4	1036.36	173.55
G10Z20	612.50	69.02	341	84.9	1036.36	173.55
G10Z30	612.50	69.02	298	1276.9	1036.36	173.55
G20Z0	545.20	136.11	424.5	0	1036.36	173.55
G20Z10	545.20	136.11	382.4	43.1	1036.36	173.55
G20Z20	545.20	136.11	342	84.2	1036.36	173.55
G20Z30	545.20	136.11	298	127	1036.36	173.55
G30Z0	476.38	203.15	424.5	0	1036.36	173.55
G30Z10	476.38	203.15	382	43.1	1036.36	173.55
G30Z20	476.38	203.15	339	84.9	1036.36	173.55
G30Z30	476.38	203.15	296.8	126.4	1036.36	173.55

Compressive Strength Test

Concrete compressive strength can be defined as concrete's capacity to endure loads which tend to compress it. It was necessary to cast concrete test specimens with various percentages of fine aggregate replacement with glass powder and cement 7%, 10%, 20 % and 30% respectively. The default cube size had been 150 x 150 mm. These concrete mixes were prepared with 0.38 water cement ratio. It was then placed in three layers in mould and 35 numbers of blows were given. After the cube has been casted, it was air cure for 24 hours. It was demoulded after 24 hours, and water curing was provided. The examination was subsequently carried out, once the cube was extracted from the water. The 7th and 28th day compressive strength tests were conducted as per IS 516:2004 on compression testing unit. The rate of load had been at 140 kg / sq.cm / min till the specimen breaks. The compressive strength was determined by dividing the maximum load by the test specimen cross-sectional area.

Flexural strength Test

Concrete flexural strength is described as its capability to withstand bending failure. Concrete test specimens were prepared with the replacement of fine aggregate and cement with glass powder and zeolite at various proportions such as 0 % , 10%, 20 % and 30% respectively. The regular 100 x 100 x 500 mm shaped mould was used. The concrete mixes were prepared with 0.38 water-cement ratio. This was then put in three layers in the mould, and each layer got 35 blows. After the cube has been casted, it will treat with air for 24 hours. It was demoulded after 24 hours, and provided for water curing. The examination was subsequently carried out, once the cube was extracted from the water. The 7th and 28th day flexural strength tests were carried out as per IS 516:2004 in a flexural strength testing unit. The pressure has been continuously applied at a rate of 180 kg / min till the test specimen breaks. The ultimate load at which the specimen breaks is registered. The Formula used to calculate the flexural strength.

$$F_{cr} = \frac{Pl}{bd2}$$

Where, b= measured width of the specimen,
d = measured depth of the specimen
l= length of the span on which the specimen was supported
P = maximum load applied to the specimen.

Split Tensile Strength Test

Split tensile strength test is used to evaluate concrete tensile strength. Due of its brittle nature the concrete is fragile under stress. Pursuant to IS 5816:2004 this test is carried out. Concrete cylinder samples of standard size 300 x150 mm diameter was casted and the test performed on compression testing system on sample was split tensile strength tests on 7th and 28th day. The load was applied within a range of 1.2 to 24 N / mm2 / min at nominal rate and ultimate load is noted, the split tensile strength is determined using the formula.

$$F_{cr} = \frac{2P}{\pi ld}$$

Where, P=Load in Newton applied to the specimen
l=length of the specimen (in mm)
d= diameter of the specimen in mm

Temperature Assessment

Temperature evaluation for samples that have met the strength characteristics was conducted. For temperature evaluation the samples G20Z10, G0Z10 and GIOZ0 were taken. Concrete slabs of size 500 x 500 x 150 mm were casted to determine the temperature. Such samples have been kept under solar radiation, and temperatures were noted. The temperature at a depth of 75 mm, the bottom temperature and the top surface temperature were measured continuously with the interval of 1 hour for 12 hours. The temperature of the concrete samples was measured using infrared thermometer and thermocouple of k type.

Results and Discussion

ASR Expansion Test Results

In order to analyze the expansion of the ASR, an accelerated mortar bar test was performed on all samples in which fine aggregate and cement was partially substituted by glass powder and zeolite in different proportions such as 0 %, 10 %, 20 % and 30 % respectively. This was noted that all samples met the expansion limit for ASR as per IS 2386 (Part 7): 1963. See graph 5.1 for the test results. The use of glass powder smaller than 1 mm and the use of zeolite in concrete may have helped to limit concrete expansion of ASR. Glass chemical composition may also have helped to minimize expansion of the ASR.

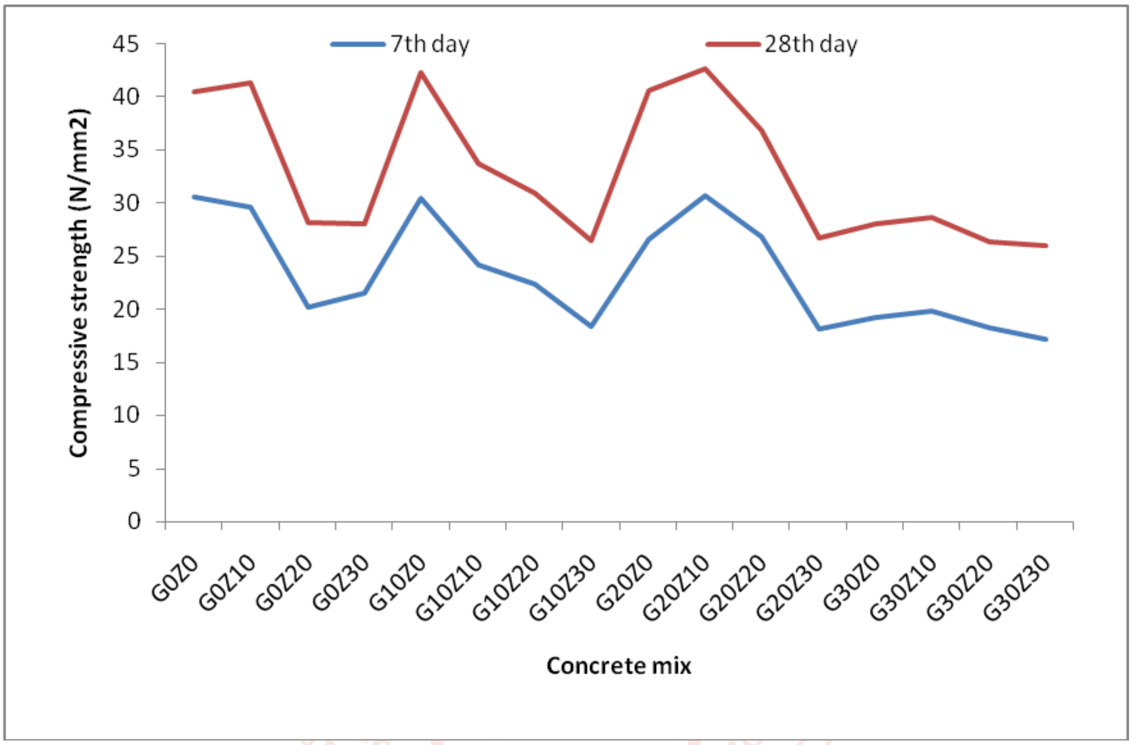
Strength Tests Results

Since the ASR expansion tests satisfied all the concrete samples, the strength tests were performed for each mix. For G20 Z0, G20 ZI0, GI0 Z0 and GO Z10 mixtures, compressive strength , flexural strength and split tensile strength have been found satisfactory. Among these, G20 Z10 showed highest strength characteristics. Concrete strength was found to be there in the decreasing trend when glass replacement has been more than 20%. It was also clear from this study that compressive, flexural, and split tensile strength of concrete reduces with the increasing percentage of glass powder and zeolite. Up to 10 % replacement of cement with zeolite powder showed an growing increase in strength values. Due to the weaker adhesion between the smooth surface of the glass particles and cement, there is decrease in compressive strength, flexural strength and split tensile strength with the rise in glass material.

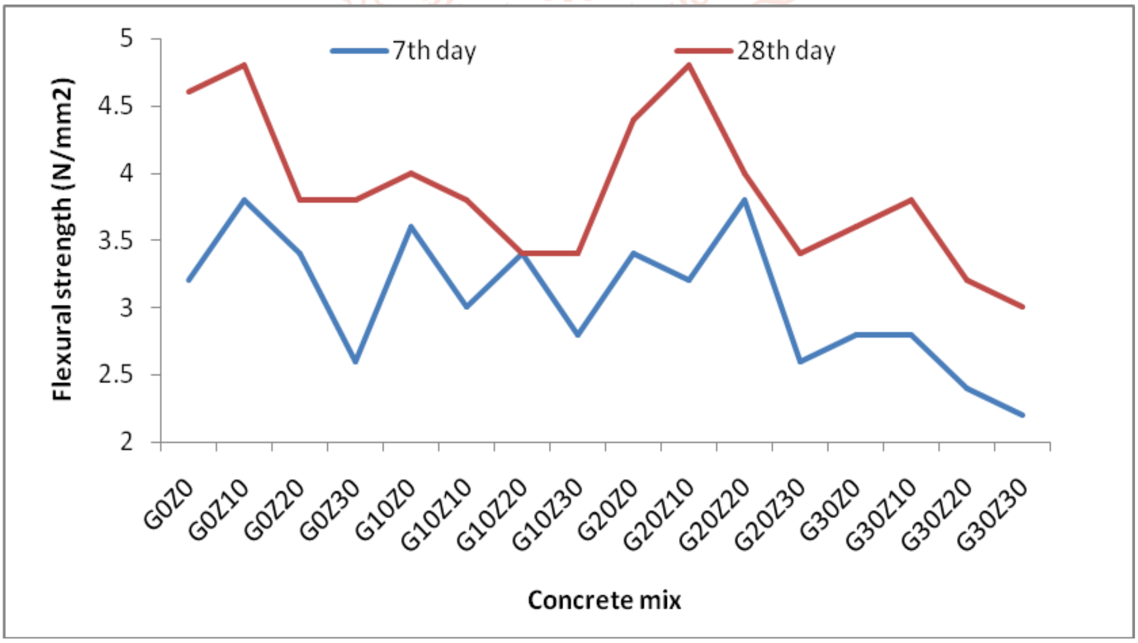
Table 2: Compressive strength test results

Concrete mixtures	Compressive strength(N/mm2)	
	7th day	28th day
G0Z0	30.6	40.42
G0Z10	29.522	41.255
G0Z20	20.22	28.21
G0Z30	21.566	28.024
G10Z0	30.466	42.236
G10Z10	24.22	33.655

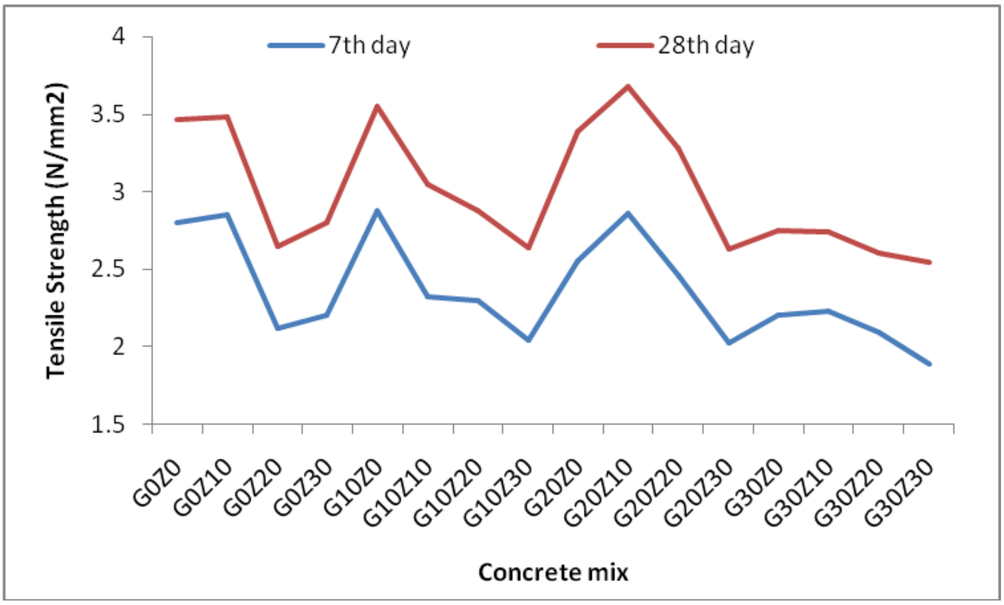
G10Z20	22.388	30.952
G10Z30	18.466	26.526
G20Z0	26.58	40.596
G20Z10	30.66	42.589
G20Z20	26.866	36.857
G20Z30	18.188	26.751
G30Z0	19.25	28.09
G30Z10	19.8	28.712
G30Z20	18.257	26.353
G30Z30	17.22	26.02



Graph 1: Outcomes of compressive strength of tested mix



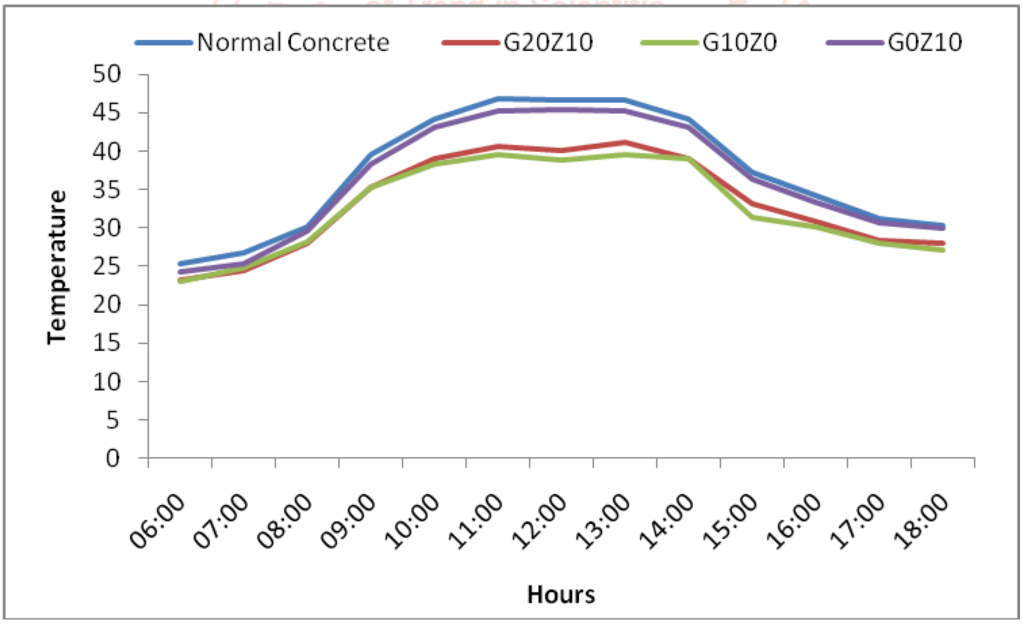
Graph 2: Concrete mix results of FS



Graph 3: Results of tensile strength of mix

Temperature Assessment

Temperature analysis for G20 Z10, G10 Z0 and GO Z10 was performed. Surface temperature variation, temperature variation at depth of 75 mm and bottom temperature variation for mixes was calculated and shown respectively in graphs 5.5, 5.6 and $.7. The surface temperature, temperature of the standard concrete mix at 75 mm depth and bottom surface temperature was reported to be greater than those of other mixes. This was clear that perhaps the G20 Z10 mix can reduce the pavement temperature effectively. The highest measured surface temperature on normal mix was at 1.00 pm and found to be 46.8 ° C. On the G20 ZI0 mix the maximum surface temperature was at 1.00 pm and found to be 41.3 ° C. The difference in temperature for regular concrete between the top and bottom surfaces was 9.7 ° C at 1.00pm. The G20 Z10 mix's top and bottom surface temperature difference was found to be 6.6 ° C at 1.00pm. Compared with the usual concrete mix, the maximum surface temperature reduction of the G10 Z0 and GO Z10 mixes was found to be 7.2 and 1.5 ° C respectively.



Graph 4: Temperature variations at top surface

Conclusions

The following conclusions are determined from such a current research:

1. All of the concrete sample mixtures carried out the intensified mortar bar test to evaluate the growth of the ASR. Perhaps this is partly related to a smaller glass particle size, the chemical characteristics of bottle as well as the participation of zeolite throughout concrete.
2. Test specimens G20 Z10, GO Z10 and GI0 Z0, reached the power parameters. The G20 Z10 had the maximum resistance characteristics between them. These were found that intensity values with both the rising quantity of glass dust up to 20 per cent dose started to show a declining pattern. The replacing cement to zeolite powder research by up to 10 per cent indicates a tremendous pattern throughout strength properties. Decreased compressive tension, flexicurity and broken tensile strength may be due to reduced adhesion here between smoother surface of the glass particle as well as the cement.
3. A G20 Z10 blend study revealed lower pavement surface temperature, which can also be considered a mitigating technique for urban heat islands.

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