International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-2 Issue-3, February 2013

Shrinkage Properties of HPC using Granite Powder as Fine Aggregate

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Abstract— ***Shrinkage is the time-dependant decrease in concrete volume compared with the original placement volume of concrete. Shrinkage potential of a high performance concrete is perhaps the most important consideration which affects the long-term strength and durability, and hence efforts are being made to reduce the shrinkage and shrinkage cracks. The main objective of this experimental work was to investigate the shrinkage properties of concrete made with granite powder as fine aggregate and partial replacement of cement with combination of admixtures. The granite powder, one of the byproducts in stone crushing process, not being used for any applications other than filling-up low lying areas was identified as a replacement material for river sand in concrete. Admixtures such as silica fume, fly ash, slag and superplasticiser have the inherent ability to contribute to continued strength development and very high durability. In the present work, concrete made with 25% of granite powder as a replacement of sand and with 10% of Fly ash, 10% of ground granulated blast-furnace slag, 7.5% of silica fume and 1% of superplasticiser as a replacement of cement were considered. The results indicated that concrete specimens produced with admixture and granite powder has lesser shrinkage parameters like maximum length of crack, minimum width of crack, total number of cracks as compared with conventional concrete specimens. The test results also indicated that the values of both plastic and drying shrinkage strains of concrete in the granite powder with admixture concrete specimens were greater than those of ordinary concrete specimens.***

Key words – HPC, Granite powder, admixtures, plastic shrinkage, drying shrinkage and crack.

I. INTRODUCTION

In the last few decades there has been rapid increase in the waste materials and by-products production due to the exponential growth rate of population, development of industry and technology, and the growth of consumerism. Natural resources are depleting worldwide while at the same time the generated wastes from the industry are increasing significantly (1). The non availability of sufficient quantity of Ordinary River sand (natural resource) for making cement concrete is affecting the growth of construction industry in many parts of the country. Therefore, the construction industries of developing countries are in stress to identify alternative materials to eliminate the demand of river sand. On the other hand the granite waste generated by the industry has accumulated over years. Only insignificant quantities have been utilized and the rest has been dumped unscrupulously resulting in environment problem. The reduction in waste generation by manufacturing value added products from the granite stone waste will boost up the economy of the granite stone industry. Granite powder is one of the materials that can be considered as a waste material which could have a promising forthcoming construction field as a replacement material of river sand. Substitution of alternate materials can result in changes in the performance characteristics that may be acceptable for high performance concrete.

High-Performance Concrete (HPC) has been introduced into the construction industry worldwide with the benefits of improved characteristics such as workability, durability, ease of placement, compaction, early age strength, long-term mechanical properties, permeability, toughness, volume stability and long life in severe environments. The main difference between conventional concrete and high performance concrete is essentially the use of chemical and mineral admixtures. The admixtures such as, silica fume, fly ash, slag, can be added to cement concrete as a partial replacement of cement along with superplasticiser as a water reducer to get the high performance. Use of these materials individually or in combination, with cement and proper dosage of superplasticiser improves the strength and durability of products. It is well recognized that the use of silica fume as a partial replacement for cement provides a significant increase in strength of concrete (2). Mineral admixtures such as fly ash and slag have the inherent ability to contribute to continued strength development and very high durability, the latter through pore refinement and reduced sorptivity. Use of chemical admixtures, usually superplasticiser reduces the water content, thereby reducing the porosity within the hydrated cement paste (3). The researcher (4) reported that the compressive strength of concrete incorporating the combination of fly ash and finely ground granulated blast furnace slag is higher than that of individual concrete. It has been reported that 25% granite powder as a replacement of river sand with 7.5% silica fume, 10% fly ash, 10% slag and 1% superplasticiser as a replacement of cement in concrete mixture is higher strength than that of conventional concrete (5, 6 and 7).

Based on the above observations, tests were conducted to study the shrinkage properties of concrete containing 25% granite powder as a replacement of river sand with 7.5% silica fume, 10% fly ash, 10% slag and 1% superplasticiser as a replacement of cement. The concrete mixture is further referred in this paper as GP25. Some of the typical property values of GP25 in comparison with conventional concrete are presented in Table 1. However study of shrinkage is of great importance to concrete engineers, especially when dealing with admixtures. Moreover high-performance concrete is relatively new material and therefore information on its shrinkage behavior is significant. Concrete mixture may undergo a volume

Manuscript received on February 13, 2013.

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reduction due to plastic shrinkage, drying shrinkage, carbonation and autogenously shrinkage. Plastic shrinkage and drying shrinkage are of great value owing to the application of high performance concrete (HPC) in construction. One of the major drawbacks of admixtures in HPC, particularly under change of climate conditions is the development of plastic and drying shrinkage cracks, particularly if the concrete is not inadequately cured. The effects of expansive additive and shrinkage reducing agent on the reduction of shrinkage show that Ultra HPC is experiencing very small drying shrinkage while extremely high autogenous shrinkage. In addition, the composition with 5% of expansive additive and 1% of shrinkage reducing agent is seen to reduce significantly the autogenous shrinkage (8).

Table 1: Properties of M60 Concrete (at 90 days of curing, 32°C water ponding and 0.35 w/c)

Concrete Mix	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Flexural strength (MPa)
CC	63	4.23	41	5.12
GP25	70	4.68	43	5.87

Plastic shrinkage cracks often appear within the first 3 hr to 36 hr after casting of large surface area concrete members (8). Moreover, plastic shrinkage is an inherent property of all concrete and is potentially one of the most severe problems facing the concrete industry. Plastic shrinkage cracks can severely compromise structural integrity and durability and the consequences are often not known until late in structures life (Kulkarni and Prakash, 2008). For this reason, concrete mixes should be proportioned such that minimal plastic shrinkage occurs. Plastic shrinkage cracking of concrete occurs within the first 3 hr to 36 hr after casting of large surface area concrete members (9) and before it attains any significant strength, it results in an unsightly and non uniform appearance on the concrete surface (1). Controlling the plastic shrinkage cracking may lead to increase mechanical properties and imaginative qualities of concrete structures. Plastic shrinkage cracks are caused by a rapid loss of water from the surface of concrete before it has set. The critical condition exists when the rate of evaporation of surface moisture exceeds the rate at which rising bleed water can replace it. If the concrete surface has started to set and has developed sufficient tensile strength to resists the tensile forces, cracks do not form, because cracking occurs if the tensile stresses are greater than tensile strength of the concrete. If the surface dries very rapidly, the concrete may still be plastic, and cracks do not develop at that time, but at the time plastic cracks will surely form as soon as the concrete stiffens a little more. Conditions that high evaporation rates from the concrete surface, and thereby increase the possibility of plastic shrinkage cracking, include, wind velocity in excess of 5 mph, low relative humidity and high ambient temperatures. Shrinkage and creep have a significant impact on the performance of concrete structures. They cause deflections and affect the stress distribution in reinforced concrete structure and within concrete elements. Plastic shrinkage cracks can lead to the development of larger cracks as drying shrinkage occurs. Controlling plastic shrinkage and drying shrinkage cracking in concrete is essential in the development of more durable and longer lasting structure (1). Consequently, development of crack, plastic shrinkage measurements were carried out for 24hrs after casting the specimens and drying shrinkage characteristics were performed at 32°C and 38°C curing temperatures with 0.35 water-to-binder (w/b) ratio for 1, 7, 14, 28, 56 and 90 days. Plastic and drying shrinkage of conventional concrete were also evaluated for comparison purposes.

II. MATERIALS USED

A. Cement

The cement used in this study was ordinary Portland cement (OPC) of 43-grade, purchased from one of the cement companies in Chennai. This cement is the most commonly used one in the construction in Chennai. It was dry, powdery and free of lumps. Stored the cement away from exterior walls, off damp floors, and stacked close together to reduce air circulation.

B. Silica fume

The silica fume used in this study was in powder form, purchased from ELCOM Pvt. Ltd. at Hyderabad, which contain 95% SiO_2, 0.39% CaO, 0.21% MgO, 0.11% K_2O, 0.15% Na_2O, 0.13% Al_2O_3), 40% Fe_2O_3. Condensed silica fume is considered (7.5% as a replacement of cement) as the most efficient microfiller for high performance concrete. Its two fold effects are reduction of w/c ratio and increase of strength of hardened concrete. .

C. Fly ash

Fly ash (Type F) from the Ennoor thermal power plant Chennai, India was used. 10% fly ash was considered in the present study as a replacement of cement. It is a fine, glass powder recovered from the gases of burning coal during the production of electricity. The major elemental constituents of fly ash are Si, Al, Fe, Ca, C, Mg, K, Na, S, Ti, P, and Mn.

D. Slag

Ground granulated blast furnace slag supplied by the Andhra Cements, Visakhapatnam India was used. In the present study, 10% slag was considered along with other admixtures as a replacement of cement. Components of slag include the oxides of silicon, aluminum, and magnesium as well as sulfur, which is always present. Slag also contains phosphorous, calcium ash, remnants of flux materials such as limestone, and remainders of chemical reactions between the metal and the furnace lining.

E. Superplasticiser

In order to improve the workability of high strength concrete a sulphonated naphthalene formaldehyde condensates based superplasticiser was used in this investigation. Superplasticiser was added 1% replacement of cement according to producer's prescription. With higher dosage some delay in hydration and hardening may occur together with apparent early setting of the fresh mix.

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F. Fine aggregates

In the present study, the concrete mixes were prepared using river sand and granite powder. Granite powder is obtained from the nearby crusher units in Chennai. Fineness modulus and specific gravity of the granite powder are 2.43 and 2.58 respectively. Locally available river sand was also adopted to prepare reference mix for comparison purpose. Its range is size from less than 0.25 mm to 6.3 mm. Fineness modulus and specific gravity of the sand are 2.33 and 2.63 respectively. Sieve analysis was carried out for the sand and granite powder at different sieve sizes and the results are presented in

Table II. It is shown that the amount of fine particles present in granite powder is considerably higher when compared to the river sand.

Table II:NSieve Analysis Results of Fine Aggregates

Sl.No	Sieve Size	Sand Percentage Passing	Granite Powder Percentage Passing
1	4.75mm	98	100
2	2.36mm	96	98
3	1.18mm	78	93
4	600µm	51	62
5	300µm	26	47
6	150µm	7	26

G. Coarse aggregates

Ordinary blue metal was used as a coarse aggregate in concrete. Sieve analysis of the course aggregates was done and percentages passing at different sieves are furnished in Table III.

Table III: Sieve Analysis Results of Coarse Aggregates

Sl.No	Sieve Size (mm)	Percentage Passing
1	25	100
2	20	98
3	16	87
4	12.5	64
5	10	26
6	6.3	03
7	4.75	00

H. Water

In general, water fit for drinking is suitable for mixing concrete. Impurities in the water may affect concrete, setting time, strength, shrinkage or promote corrosion of reinforcement. Hence locally available purified drinking water was used in the present work.

III. LABORATORY TESTING PROGRAM

A. Mixture proportions

The dosages of different admixtures used in the experimentation were based on the review of previous researchers. A minimum quantity of admixtures as a replacement of cement with 7.5% Silica fume (SF), 10% fly ash (FA), 10% slag and 1% superplasticiser (SP) for each concrete mixes except CC were considered in the present study. The mixes were designated in accordance with ACI mix design method (10, 11), and with ASTM C 596-89. Based on the literature survey, the mix proportions of the control mix M30 was considered. The details of mix proportions are given in Table IV.

Table IV Details of Concrete Mix

Mix Designation	Weight in kg per m^3 of concrete								
	Cement	Fly ash (10%)	Silica fume (7.5%)	Slag (10%)	Superplasticiser (1%)	Water	Coarse Aggregate	Fine Aggregate	
								Granite Powder	Sand
GP0	874	122	92	122	12	488	3666	0	1833
GP25	874	122	92	122	12	488	3666	460	1373
100	1222	-	-	-	-	488	3666		1833

B. Specimen preparation

The granite powder was collected from different crusher units and its properties were tested. The aggregates were soaked in part of the mixing water for about 5 minutes, prior to the start of the mixing operations. Coarse aggregate was placed in the drum first and batch water was increased to account for the adsorption of the aggregates during rotation. After mixing for 10 to 15 seconds, the fine aggregates with correct proportions was introduced and mixed in for the period of 15 to 20 seconds.

This was followed by the final 20% of the water and all the cement were added with fly ash, silica fume and slag, which were mixed in until a total mixing time of 60 seconds was achieved. The superplasticiser was added 30s after all the other materials during the mixing. The specimens were finished smooth after giving sufficient compaction both through table vibrator and hand compaction.

After 1 day the demoulded specimens were cured by water ponding at water temperature of 32°C (±2°C) and 38°C (±2°C) (different climates). Specimens were prepared with water to cementitious materials ratio of 0.35. Different batches were adopted for 1 day, 7 days, 14 days, 28 days 56 days and 90 days of ages to find drying shrinkage strains. The dimensions and the number of specimens used for the present study are listed in Table V.

Table V: Details of Test Specimens

Material Properties	Shape	Dimensions of the Specimens (cm)	No of Specimens
Crack Development	Slab	500 X 500 X 10	18
Plastic Shrinkage (1 day)	Slab	100 X 100 X 10	6
Drying Shrinkage (1, 7, 14, 28, 56 and 90 days)	Slab	100 X 100 X 10	36

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C. Testing procedure

After casting and finishing, the concrete specimens were covered with plastic sheets for 24hrs. Immediately after casting, the slab specimens were kept in open atmospheres at 32°C (±2°C) and 38°C (±2°C) along with the mould. The moment all the specimens were transferred to the open atmosphere the time was reckoned. During this time, plastic shrinkage measurements were conducted on the slab specimens. The concrete specimens were visually inspected to monitor and map cracks, if any. Plastic shrinkage measurements were conducted for 24hrs after casting while drying shrinkage measurements were conducted after the completion of the curing period. After 24hrs from the time of transferring the specimens to open atmospheres the plastic shrinkage parameters such as length of crack, width of crack, total number of cracks and total area of cracks were noted down on a plastic sheet.

For this purpose, a transparent plastic sheet was placed on a glass plate which in turn was kept on the surface of the concrete specimen and all the possible visible cracks (length, width and number) were drawn on the sheet. The minor cracks were drawn with a help of a magnifying lens. The widths of cracks were measured with the help of a hand microscope. Plastic shrinkage strain was measured by embedding aluminium strips (measuring 25 x 150 x 6 mm) to a depth of 100mm in the slab concrete specimens. The strips were placed at the mid-section of each of the four sides of the specimen. The movements of the strips was monitored using liner variable differential transducers (LVDTs) that were connected to a data acquisition system for a period of 24 hr. Shrinkage readings were recorded every 10min during the first 400min and every 30min thereafter. The drying shrinkage strain was measured after the completion of the curing. Strain readings were taken at 1, 7, 14, 28, 56 and 90 days of drying for 32°C (±2°C) and 38°C (±2°C) curing temperatures. This was done by embedding demec gauges on the surface of the specimens. Two pairs of demec gauges were fixed on each specimen. Drying shrinkage was measured by measuring the length between the demec gauges with the help of an extensometer.

IV. TEST RESULTAND DISCUSSION

1. Shrinkage parameters

The variation of shrinkage parameters like maximum length of crack, maximum width of crack and total no of cracks with various concrete mixes GP0, GP25 and CC are depicted in the form of bar chart form Fig.1 through Fig. 6.

A. Maximum length of crack

It has been observed from the Fig.1 and Fig.2 that the concrete produced from the combination of admixtures with granite powder concrete, GP25 show lesser maximum length of crack as compared to admixture concrete, GP0 and conventional concrete, CC both for 32°C (±2°C) and 38°C (±2°C) open atmospheres. The percentage decrease in maximum length of crack for the combination of admixtures with granite powder concrete is 14.44% and 16.67% respectively for 32°C and 38°C as compared to conventional concrete. The significant decrement in the length of crack is due to the characteristic of admixtures and granite powder combination. From the figures, it is also shown that the maximum length of cracks increased with the increase of open atmosphere temperatures for all the mixes. In case of GP25, the maximum length of crack is 6mm higher when atmosphere temperature is increased from 32°C to 38°C. This is due to the higher evaporation rate from the concrete surfaces.

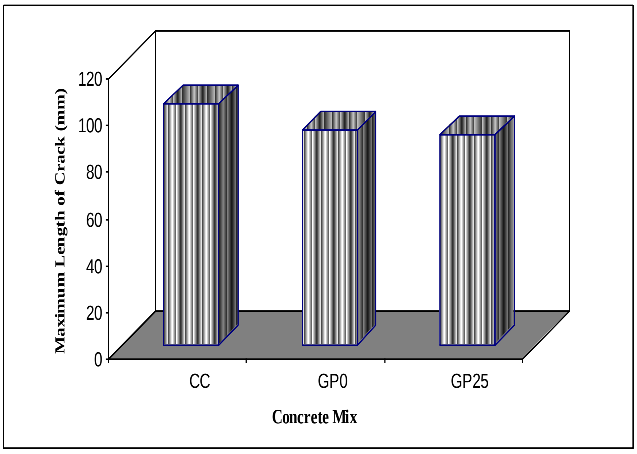

Fig. 1 Maximum Length of Crack at 24 hrs (32°C)

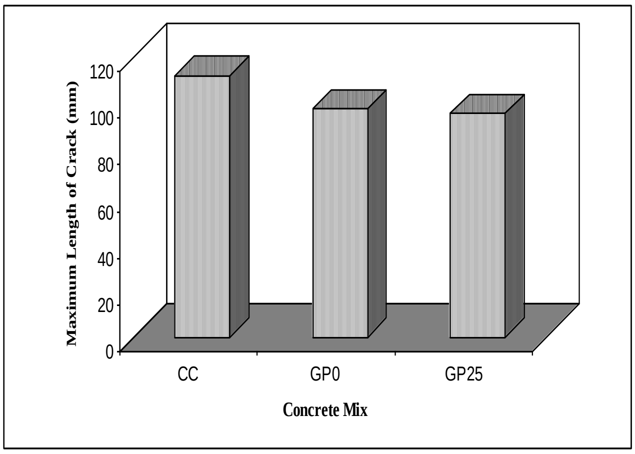

Fig. 2 Maximum Length of Crack at 24 hrs (38°C)

B. Maximum width of crack

It has been observed from Fig.3 and Fig.4 that the concrete produced from the combination of admixtures with granite powder concrete, GP25 show lesser maximum width of crack as compared to admixture concrete, GP0 and conventional concrete, CC both for 32°C (±2°C) and 38°C (±2°C) open atmospheres. The maximum decrement in width of crack of GP25 over CC is found to be 31.21% and 31.58% respectively for 32°C and 38°C due to its later start of set. The admixture concrete, GP0 exhibited slightly higher value of crack width than GP25.

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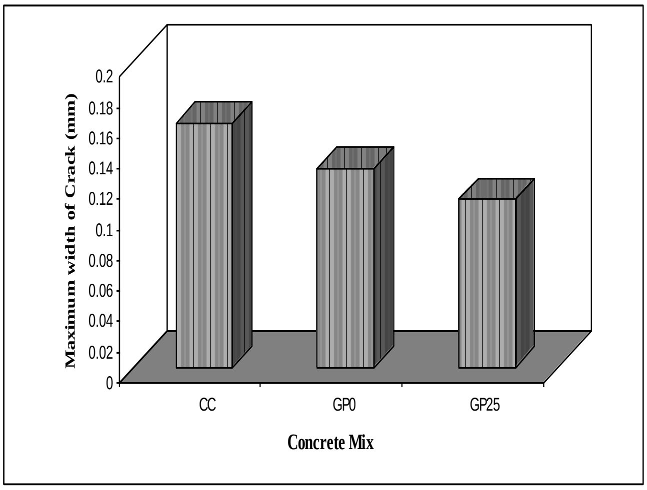

Fig. 3 Maximum Width of Crack at 24 hrs (32°C)

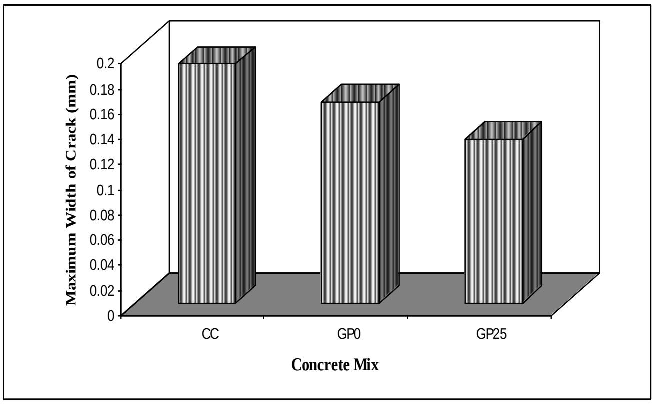

Fig. 4 Maximum Width of Crack at 24 hrs (38°C)

Similar to maximum length of crack the width of crack also increases with increase in open atmospheres temperatures. In case of GP25, the maximum width of crack is 18.2% higher when atmosphere temperature is increased from 32°C to 38°C. This is due to rapid loss of water from the concrete surfaces before it has set.

C. Total number of cracks

Total number of cracks is presented in the figures 5 and 6. It can seen from the Fig.5 and Fig.6 that the concrete produced from the combination of admixtures with granite powder concrete, GP25 show lesser number of cracks as compared to admixture concrete, GP0 and conventional concrete, CC both for 32°C (±2°C) and 38°C (±2°C) open atmospheres. The percentage decrease in maximum length of crack for the combination of admixtures with granite powder concrete is 13.7% and 13.75% respectively for 32°C and 38°C as compared to conventional concrete. This is due to the fact that the addition of combination of admixtures and granite powder in concrete. From the figures, it is also shown that the maximum length of cracks increased with the increase of open atmosphere temperatures for all the mixes as expected. Further, it is clear from the figures that admixture concrete show lesser number of cracks than conventional concrete. Thus it can be concluded that the combination of admixtures with granite powder can produce concrete of lower shrinkage parameters as compared to conventional concrete.

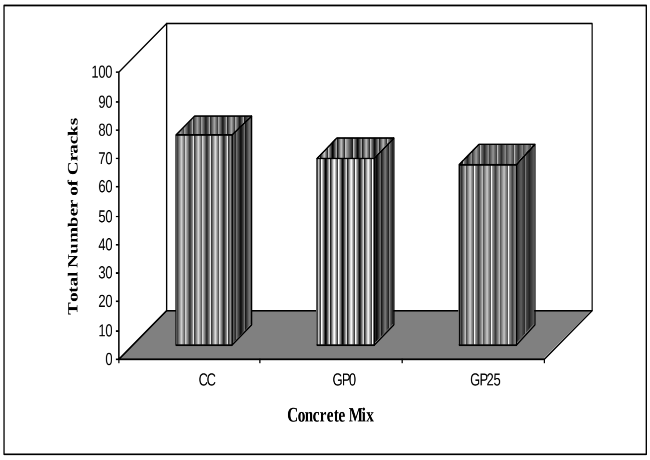

Fig. 5 Total Number of Cracks at 24 hrs (32°C)

2. Plastic shrinkage strain

Fig.7 and Fig.8 are a typical presentation of the plastic shrinkage strain of different concrete mixtures GP0, GP25 and CC in the large (1 x 1 m) specimen.

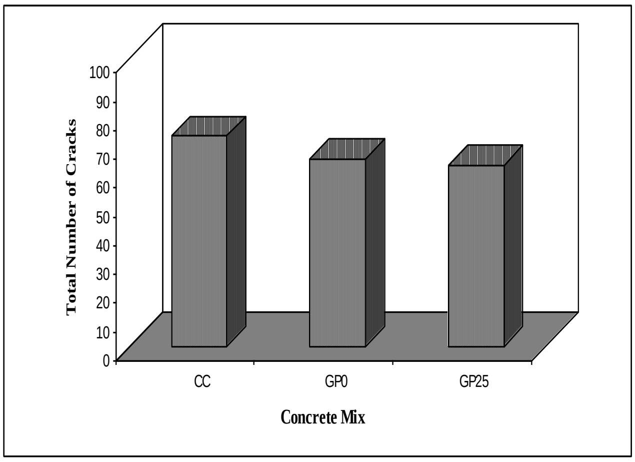

Fig. 6 Total Number of Cracks at 24 hrs (38°C)

The data presented in the figures indicate that the plastic shrinkage increased with the increase of period of exposure to the curing temperatures at 32°C and 38°C. It can be seen from the figures that the plastic shrinkage strain in the admixtures concrete (GP0 and GP25) specimens was more than that in the conventional concrete (CC). The increase in plastic shrinkage strain of GP25 up to about 900 min of casting is about 638 µm and 630 µm respectively for 32°C and 38°C curing temperatures. After about 900 min of casting, the plastic shrinkage strain in the conventional concrete (CC) specimens are 282 µm and 275 µm respectively for 32°C and 38°C curing temperatures.

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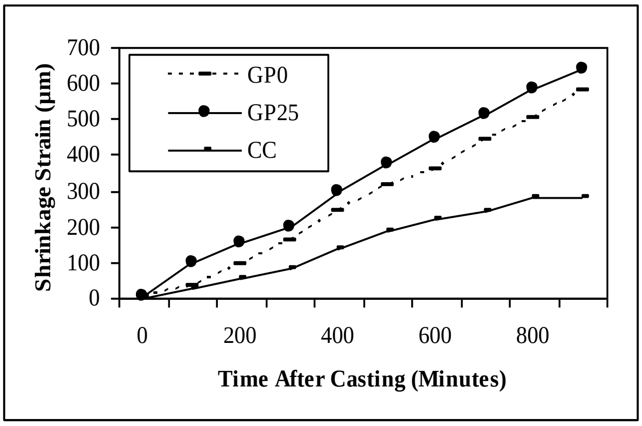

Fig. 7 Variation of Plastic Shrinkage in 1x1m with Days of Curing at 32°C Water Ponding

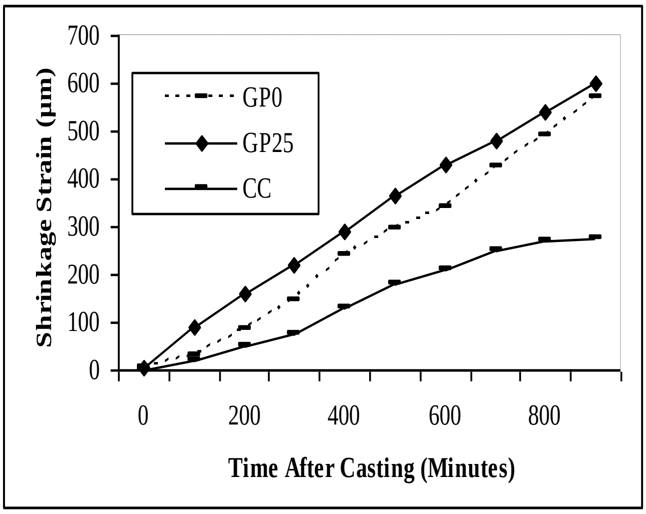

Fig. 8 Variation of Plastic Shrinkage in 1x1m with Days of Curing at 38°C Water Ponding

3. Drying Shrinkage Strain

The drying shrinkage measurements were taken after the completion of curing. Fig. 9 and Fig.10 depicts the drying shrinkage strain in the small (1 x 1 m) specimen of different concrete mixtures GP0, GP25 and CC cured by water ponding. As expected, the drying shrinkage strain increased with the period of exposure to the curing temperatures at 32°C and 38°C in all the concrete specimens. However, the drying shrinkage strain in the GP25 specimens was more than that in the CC specimens. The drying shrinkage strain after 90 days

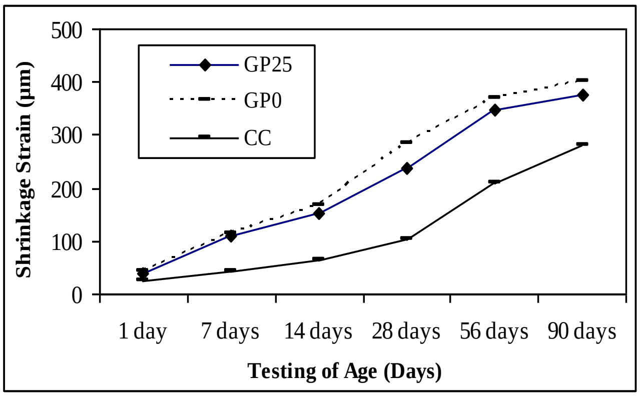

Fig. 9 Variation of Drying Shrinkage in 1x1m with Days of Curing at 32°C Water Ponding

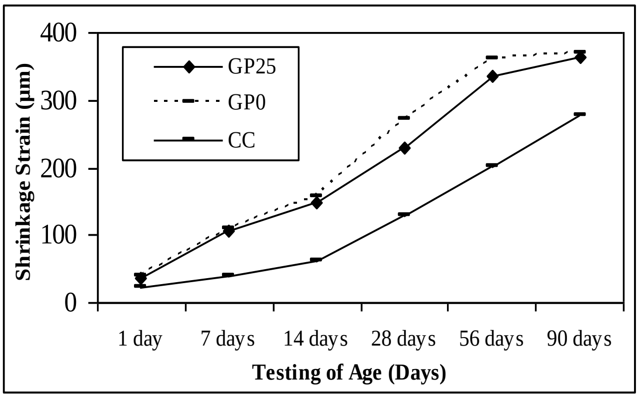

Fig. 10 Variation of Drying Shrinkage in 1x1m with Days of Curing at 38°C Water Ponding

of exposure to the curing temperatures at 32°C and 38°C was 280 μm and 276 μm respectively in the conventional concrete (CC) while it was 376 μm and 364 μm respectively in the granite powder concrete (GP25).

V. SUMMARY AND CONCLUSION

Experimental investigation on the high performance concrete made with granite powder as fine aggregate and partial replacement of cement with 7.5 % silica fume, 10% fly ash, 10% slag and 1% superplasticiser is conducted for finding the shrinkage parameters, and plastic and drying shrinkage strains at 32°C (±2°C) and 38°C (±2°C) for 1, 7, 14, 28, 56 and 90 days of curing for 0.35 water-cement ratio. The test results show clearly that granite powder as a partial sand replacement and partial replacement of cement with admixtures has beneficial effects of the shrinkage properties of high performance concrete. Of all the three mixtures considered, concrete with 25% of granite powder (GP25) was found to be superior to other mixtures for all operating conditions. Hence the following conclusions are made based on a comparison of GP25 with the conventional concrete, CC.

- The combination of admixtures with granite powder concrete, GP25 used in the experimentation do not have compatibility problems either with respect to the properties of concrete or produce a concrete with low shrinkage.
- The lower shrinkage parameters such as maximum length of crack, maximum width of crack, total no of cracks, total area of cracks can be obtained with combination of admixtures with granite powder concrete, GP25. This is follows by the combination of admixtures with sand, GP0. Thus it can be concluded that the combination of admixtures with granite powder can produce a concrete of lower shrinkage parameters as compared to conventional concrete.
- Plastic shrinkage strain in the GP25 specimens was more than that in the CC specimens. The plastic shrinkage strain in the GP25 specimens was on an average 60% more than that in the CC specimens.
- The drying shrinkage strains in the granite powder concrete specimens were more than those in the conventional concrete specimens both for 32°C (±2°C) and 38°C (±2°C) curing temperatures

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In general, the behavior of granite aggregate with admixtures in concrete possesses the higher properties like concrete made by river sand.

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