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Original Article

Investigate the Effect of Ground Granulated Blast Slag on Self Compacting Concrete

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Abstract *- Ground Granulate Blast Slag (GGBS) is a very fine pozzolanic powder is by-product of the manufacturing of iron in a blast furnace. In this research, GGBS was used in self-compacting concrete (SCC) mixes as a partial cement replacement in various quantities mixed as a blended material with pure OPC. All the GGBS blended combinations were compared to a controlled mix, made with 100% pure OPC mix. This search investigates the properties of SCC as well as the effects of sustainability by testing the workability and the strength of concrete made with partial cement replacement GGBS. Some of the experiments were carried out such as: slump, workability, the compressive and tensile strength, air porosity, density and rheology. The strength values achieved were typical of structural capacity, specifically made for buildings, highway and railway bridges, something in the order of 40 MPa and above after curing 28 days. consequently, the materials used in the lab have resulted in sustainable forms of concrete with reduction of the cement.*

Keywords *- Ground Granulate Blast Slag; Self-Compacting Concrete; Workability; Viscosity; Compressive Strength; Tensile Strength.*

I. INTRODUCTION

Since 30 years ago Japanese Invented Self-compacting concrete SCC to improve the durability of concrete structures, overcome issues associated with the crowded reinforcement and hardly reachable spots (Goodier 2003, Brouwers and Radix 2005, Alyamaç and Ince 2009, Sfikas 2017). SCC is a type of concrete which used in a special cases such as: deep sections, heavily reinforced and narrow spaces by its own weight with consolidation without using any source of vibration, SCC maintaining its stability without bleeding and segregation (Brouwers and Radix 2005, Boukendakdji, Kadri et al. 2012, Sfikas 2017). Ground Granulate Blast Slag (GGBS) is manufactured of iron in a blast furnace at a temperature of 1500C. By melting iron ore, limestone and coke, two main products are manufactured; molten iron and molten slag. Adding GGBS to SCC have massive advantages to the properties of SCC such as improving durability, workability, strength with time and lower maintenance leading to long-term cost benefits and whole reduced life costing. The usage of GGBS adds massive technical benefits to the SSC mix (Boukendakdji, Kadri et al. 2012, Correia 2017, Vivek and Dhinakaran 2017). According to Hussein, (2019), the GGBS has both positive and negative effects on the SSC. Therefore, it is a necessity to determine and work on improving the disadvantages of GGBS.

The replacement of cement with different percentage 5%, 10%, 15%, 20% and 25% of Silica Fumes, enables analyzing and interpreting clear results of the performances incurred by this valuable replacement. SF effects on concrete by modifying hydration reaction in concrete and by micro-filler effect. Upon adding water to the Portland cement (Hassan, Lachemi et al. 2012), according to researches if cement is replaced by 10% -30% GGBS, it generally shows an increasing level of compressive strength. Any higher GGBS content has a worsening effect on the strength result. By changing the percentage of GGBS in the mixes, the structural properties of the concrete will change. By increasing GGBS, the workability will decrease, while on contrary compressive strength will increase after curing for 28 days (Babu and Kumar 2000).By adding higher percentages of GGBS, the SCC becomes denser, leading to lower air porosity. The splitting tensile strength will increase due to increase the percentages of GGBS at both 7 and 28 days. The results found that, the strength and durability of the concrete will increase remarkably as the percentage of GGBS increases up to 30% after then it exponentially starts reducing (BRE-guide)(Li and Yao 2001).

This research aims to study and investigate the fresh properties of SCC and carry out several experiments on the effects of sustainability by testing the workability, durability and strength of concrete made with partial cement replacement GGBS. These laboratory tests based on the British Stands and the BRE-guide specification. Some of the experiments that were carried out was slump and workability such as: V-funnel, L-box, Abraham cone, measuring slump flow, passing limit and filling limit. In addition to, the compressive strength, tensile strength, air porosity, density and rheology. The results of density were compared to the strength of the concrete, porosity was compared to the durability of concrete and rheology was compared to the workability and slump values of the concrete.

II. MATERIAL AND METHODS

A. Materials

The concrete mixture in this study was consisting of OPC class 52.5N BS EN 197-1 compliant. GGBS was used in various percentages as a partial cement replacement in all mixes, thereplacement percentage range between 10% and 30%. Coarse aggregate Uncrushed with size range from 10 to 20 mm maximum. fine aggregate sieve 600 µm. GGBF (BS EN 15167-1 compliant). In addition, to mitigate the chance of aggregate segregation and provide sufficient fluidity, super plasticizer and VMA will be used with a constant amount. V-MAR 10P which giving a creamy consistency, more cohesive and high workability to the concrete. The dose is 50 - 150 gms/m3, the normal average dose is 0.3% of cement weight.

B. Mix Design

The SCC mix proportions and laboratory tests was undertaken in accordance with the Built Research Establishment (BRE). GGBS was used in various percentages as a partial cement replacement in all mixes. In addition, to mitigate the chance of aggregate segregation and provide sufficient fluidity, super plasticizer and VMA will be used with a constant amount in all four mixes, as shown in Table1.

Table 1 The mix proportions used in all mixes according to BRE-guide (Hussein, 2019)

Mix no.	GGBS (%)	Cement (kg)	GGBS (Kg)	Fine Agg. (Kg)	Coarse Agg. (Kg)	Water (Kg)	Super plasticizer (mL)	V-MAR (g)
1	0%	11.3	0	17	21.5	4.3	94	3.5
2	10%	10.2	1.3	17	21.5	4.3	94	3.5
3	20%	9.0	2.3	17	21.5	4.3	94	3.5
4	30%	7.9	3.4	17	21.5	4.3	94	3.5

C. Preparing Mixes and Specimens

All of the materials mentioned before were prepared in the preferred quantities and poured in a 100L large concrete mixer. After that the mixer was turned on and visual observations was made in order to accurately add the necessary amount of water and cement insuring a workable mix. The moulds for the cubes and cylinders were placed in a poker table, cleaned of any precipitate and oiled to avoid sticking and ease of cleaning. The concrete was then poured into the moulds of cube and cylinder samples with the dimensions (100*100*100 mm) and (150*200mm) respectively. To ensure minimal air voids the poker was turned on sending small vibrations throughout the mix. Once that was done a small paper label was placed on top with my group name and the date on it. Dimensions of the cubes and cylinders were relative as expected with an imprecision of 1mm, which is standard since there is a tolerance about 1% (BS EN 12390-1: 2012). This can be a systematic error or a human error. Nevertheless, compression cracks of the cubes appeared as they were being crushed. The standard for cracks was used to check if the crack observed in the concrete was satisfactory or unsatisfactory cracks (BE EN 12390-3, 2009). The cubes had approximately an equal number of cracks as the cubes were failing, the cracks appeared around the circumference of the cubes which is considered to be satisfactory according to the British Standards: 12350-2, EN 12350-9, EN 12350-12, EN 12350-10. The author, however, still checked the soundness of the sample, the lack of segregation and the minimal amount of cracks due to shrinkage before testing. The results observed that, if the sample had little appearances of shrinkage and early thermal cracking then it would definitely last longer before testing till failure. After twenty-four hours, the samples were removed from their molded. For each mix a wet curing (18°C) and a dry curing (21°C) took place at both 7 and 28 days. For this investigation twelve cubes were to be cured in total for each mix; three to be dry cured (tested after 7days), three to be wet cured (tested after 7days), three to be dry cured (tested after 28days) and three to be wet cured (tested after 28days). The concrete Cylinders were left to wet cure and dry cured for 28 days; three were dry cured and three were wet cured.

III. RESULTS AND ANALYSIS

A. Slump Test

Slump test was used to evaluate the workability by the observing of the ability of the fresh concrete mix to flow. This test was carried out according to BS EN 12350-2 (EN BS 2009). Table 2 represents the slump test results and workability classification according to (EN 206-1:2000) (EN 2001).

Table 2. Slump test results and workability classification

Mix no.	Mix	Slump (mm)	Classification of workability
1	(Control mix)	265	S5
2	(10% GGBS)	265	S5
3	(20% GGBS)	255	S5
4	(30% GGBS)	275	S5

B. Slump Flow Test

The slump flow test is carried out according to BS EN 12350-8 (EN BS) to assess the flow ability and flow rate of the SSC mixes. The test produces a precise evaluation of the filling ability. The ability of the mix to flow according to its own weight without any constrain from boundaries. The results does not indicated of the ability of SCC through reinforcement without resulting a blockage, but does give some indication of the mixes resistance to segregation (Mishra 2010). Table 3 and Fig. 1 represents the test results.

Table 3. The Slump Flow Test Results

Mix No.	Mix	Diameter 1(mm)	Diameter 2 (mm)	Slump Flow (D1+D2)/2 (mm)
1	(Control mix)	530	500	515
2	(10% GGBS)	530	520	525
3	(20% GGBS)	470	472	471
4	(30% GGBS)	490	470	480

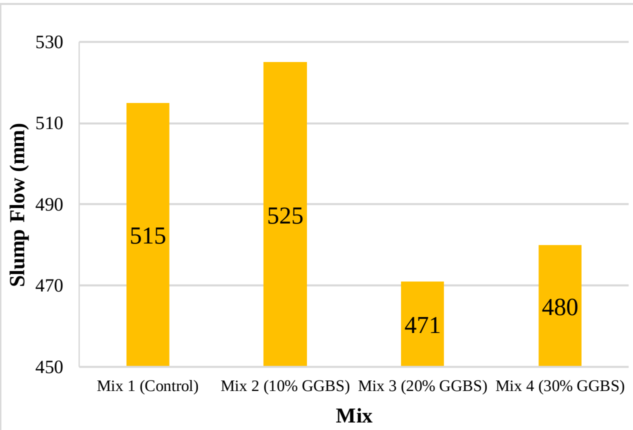

Fig. (1): Slump Flow Test Results

C. *Air* Porosity

Fig. 2 shows the Air porosity test results was carried out according to BS EN 12350-7 (EN 2012). As we can see from the pie chart Fig. 2, when the GGBS increases the air porosity percentage decreases, indicating a denser mix, thus a more durable and stronger mix. Air porosity, when it is at low levels, it ensures on a better serviceability, less corrosion of steel reinforcement and lower loss of passivity. This can reduce early thermal cracking, cracking due to shrinkage and cracking due to long-term creep. Therefore, GGBS concrete is far better than 100% pure OPC concrete in terms of compressive strength, tensile strength and durability (Limbachiya, Ganjian et al. 2016).

D. *V-Funnel Test*

The V-funnel test gave some promising results in proving what is expected. The flow time measured for every mix was increasing linearly as the GGBS content increased as shows in Fig. 3. This is because GGBS is highly water demanding, leading to a stiffer mix that takes longer time to pass the V-funnel.

E. *L-Box Test*

Fig. 4 represents the L-box test results. It is evident from studying the result of the experimental work, that the higher the GGBS content, the higher is the slump and the higher the passing ability.

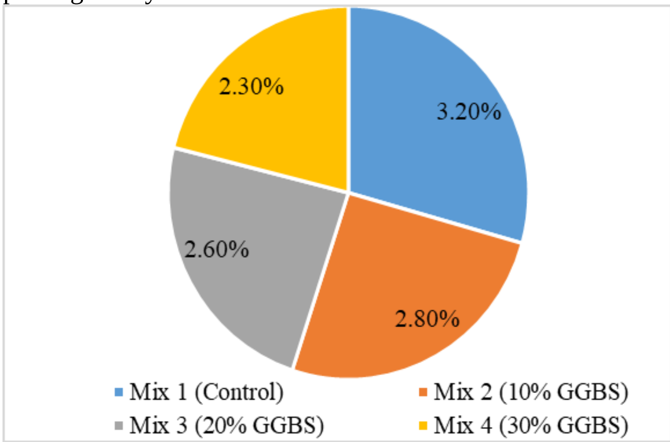

Fig. (2): Air porosity test results

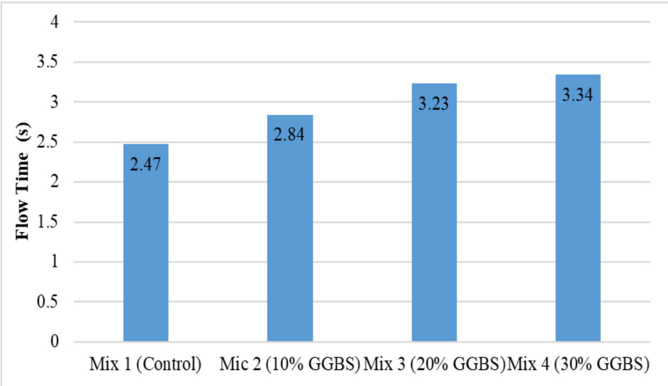

Fig. 3: The V-Funnel test results

F. *L-Box Test*

Fig. 4 represents the L-box test results. It is evident from studying the result of the experimental work, that the higher the GGBS content, the higher is the slump and the higher the passing ability. Even though, the viscosity was more accurately representing what is found in research and science and that the viscosity increases with the increase of GGBS. This is mainly because GGBS is very water demanding, but still the higher the cement content, the quicker the setting time of the concrete sample. This can affect the viscosity values.

G. *Rheology Test*

Generally, as the Torque value increases the plastic viscosity increases with respect to the GGBS content in every mix. Torque increases with the increase of GGBS content, indicating an increasingly more viscose mix. Furthermore, the mix at the beginning of the rheology experiment has a low viscosity, however, the level of viscosity and torque exerted increases as well. This is the case especially on the pure concrete mixes (controlled mixes), containing 100% cement content. This is because the pure OPC mix starts setting off immediately after the mixing is finished (Limbachiya, Ganjian et al. 2016). As the GGBS content increases the plastic viscosity increases as well and the slump value decreases, as shown in Figs. 5. This is because ashes are usually very water demanding (Neville 1995). Table 4 and Fig. 5 and 6 represents the rheology test results.

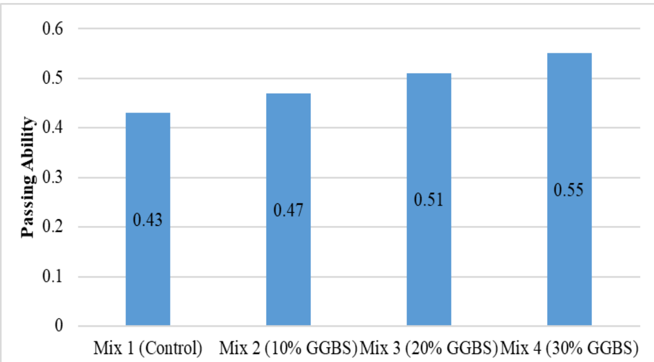

Fig. (4): The L- Box test results

Table 4. The Rheology test results

No.	Mix	Yield Stress (Pa)	Peak Torque (Nm)	Plastic viscosity (Pa.s)
1	(Control mix)	8.9	0.04	2.9
2	(10% GGBS)	464.2	2.36	3.2
3	(20% GGBS)	707.9	3.35	3.1
4	(30% GGBS)	437.4	2.24	4.6

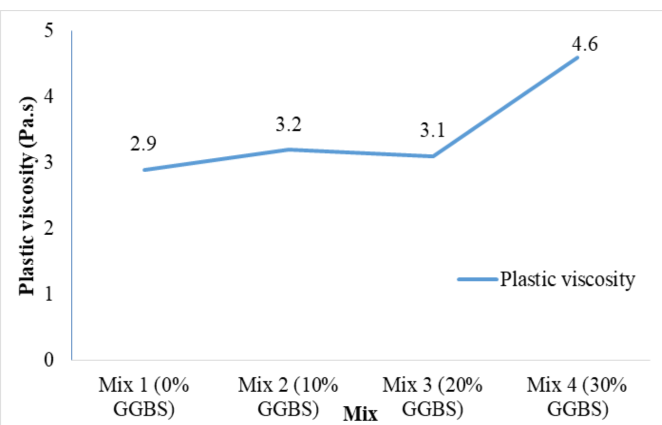

Fig. (5): Results of the Rheology test

H. Compressive Strength

The compressive strength was carried out according to BS EN 12390-3 (BSI 2009) results indicated that, the controlled mix (100% cement content) gave the highest results at 7 and 28 days as shown in Fig. 7. Which is correlating to science and industry. It is apparent from observing the results that as the GGBS increases the compressive strength at 7days decreases.However, because the setting time of the GGBS mixes is delayed in the first 7 days, hence giving lower compressive strength results.

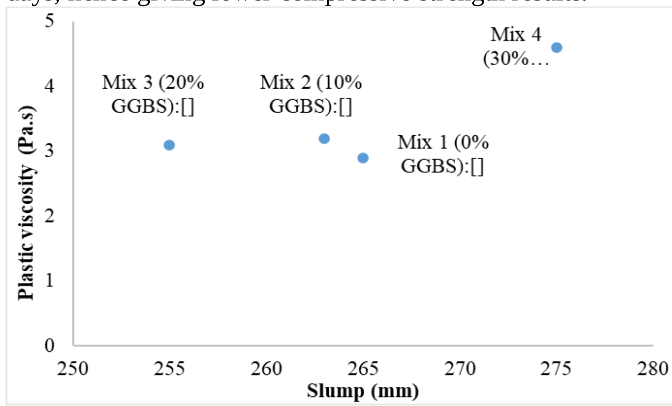

Fig. (6): Plastic viscosity (Pa.s) as a function of the Slump (mm)

This is rectified by the 28 days compressive strength where there is hardly any difference between the compressive strength results. Again, the compressive strength results of this project are correlating with science and research because the early setting time is delayed and the optimum at 28 days is equally achieved. The compressive strength at 28 days is indicative of reliable results because the wet cured in general and in all of the mixes is higher than the dry cured. This is as expected with research because the wet cured had better time to hydrate within the water of the curing tank. On the other hand, the optimum strength was for the 10% GGBS and all of the other mixes are more or less the same. Even though, w/c the water cement ratio was increased by visual observation to levels of almost 0.75, hence, increasing the slump, decreasing the torque and viscosity; it also gave strength values of around 40 MPa, which is quite promising. It was expecting such promising results of the crushing test to be for 0.5 w/c rather than 0.75 (Limbachiya, Ganjian et al. 2016). In all of the mixes both at 7 and 28 days the wet cured samples gave higher results than the dry cured samples. This is indicative of results from science and research. Table 5 and Fig. 7 represents the crushing test results. The compressive strength results were indicating a structural form of concrete, suitable for buildings and highway bridges, which is 40 MPa at 28 days on average.

I. Tensile Strength

The tensile strength of all the samples was carried out using the splitting tensile test. The samples were all a 150*200mm cylinders BS EN 12390-6 (EN 2009). The test was carried out only after 28 days of curing. This was to ensure that the optimum strength has been achieved. Both dry and wet cured samples were tested. The results again were very promising in the fact that the wet cured on average gave higher tensile strength and some of the highest tensile strength results were noted for the 30% GGBS content more than the others as shown in Fig. 8. Therefore, the author recommends an optimum value of 30% GGBS cement replacement is to be used in mixes intended for structural concrete purposes. Fig. 8 represents the tensile strength test results.

Table 5. The Compressive Strength test results BS EN 12390-4

Mix No.	Mix	Curing	Average Load (KN)		Average Stress (MPa)	
			7days curing	28 days curing	7 days curing	28 days curing
1	Control	Dry	300.3	349.1	13.4	31.3
		Wet	338.5	416.4	15.1	41.6
2	10% GGBS	Dry	274.8	369.3	12.2	36.9
		Wet	317.3	419.2	14.1	41.9
3	20% GGBS	Dry	253.6	342.5	11.4	34.3
		Wet	274.2	396.8	12.2	39.7
4	30% GGBS	Dry	229.1	322.9	10.2	32.3
		Wet	248.8	382.5	11.1	38.2

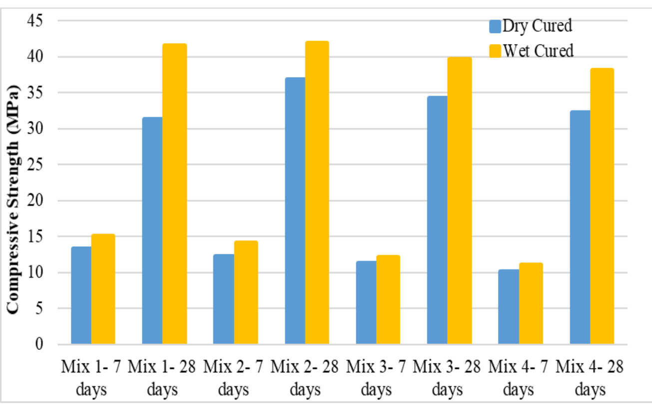

Fig. 7: Compressive strength results of 7 and 28 days dry cured cubes

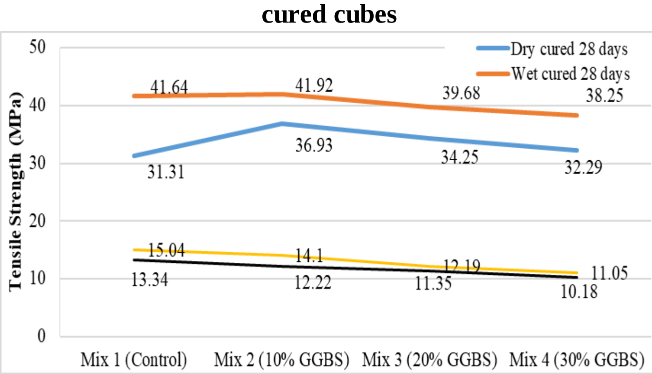

Fig. 8: Tensile strength of cylinders of dry and wet samples

J. Density

The density results are correlating with science as expected, the fresh density is higher than the seven-day dry density and the wet cured density is higher than the dry cured density both at 7 and 28 days as shown in Table 6. Furthermore, the concrete samples are denser as the GGBS content increases, this correlates nicely with the air porosity results, because the author noticed that the air porosity reduces with the increase of GGBS. Finally, mass, density and strength increases as the GGBS content increases. This is noted for GGBS content of a maximum 30%. Then the efficiency of GGBS decreases. Table 6 represents the density test results.

Table 6. Density of the mix

Mix No.	Mix	Fresh Density	Density Dry curing		Density Wet curing	
			7 days	28 days	7 days	28 days
1	(Control mix)	2265	2196	2198.5	2290.37	2276.7
2	(10% GGBS)	2305	2219.57	2218	2302.4	2294.3
3	(20% GGBS)	2359	2238.8	2160.4	2324.5	2327
4	(30% GGBS)	2240	2215.9	2201.8	2301.2	2265.5

CONCLUSIONS

Within this research project, the author has found some promising results across the board showing accuracy in the design mix and in the level of workmanship during lab work. All cubes and cylinder samples were sound and did not show any signs of bleeding or segregation. Even though the author for ease of handling the material and workability he had to increase the water content by visual inspection. This meant that instead of using w/c ratio = 0.5, the author used an average of w/c = 0.75. This gave appropriate results to slump and viscosity without undermining the compressive strength result. This alone gave remarkable results all round. The slump for the high GGBS content mixes (20-30%), did not exactly correlate with science and research. This is because, according to literature the higher the ash content, the lower the slump and the less workable the mix will be. This is because ashes in general are highly water demanding.

In terms of viscosity again the higher the slump, the lower the viscosity and the higher the ash content, the higher the viscosity. All this was noted by the author within his project. According to air porosity and density again, the results showed primarily that the higher the ash content, the denser the concrete and the lower air porosity percentage it has. Finally, for both compressive strength and tensile strength, using 30% GGBS replacement gave the best results and the optimum strength. In all the mixes, an average of 40N/mm2 and higher was achieved after 28 days. This is indicative of a use of concrete materials for highways bridges construction and of any concrete buildings construction. In all wet cured mixes, the tensile and compressive strength were both much higher than the dry cured concrete mixes. These results are exactly correlating to what is found in science and industry. Regarding the V-funnel and L-box results, both have should a consistency and correlation in results. They both indicated that the higher the GGBS content, the higher the time taken to pass. Both passing and filling ability increased linearly as the GGBS content increased.

This is as mentioned before that the ash is more water demanding. That is why, the rheology results too showed a higher viscosity for the mix as the ash content increased. Both for tensile and compressive strength, the results were in line with science and industry; strengths of structural capacity end use were achieved, between 25N/mm2 and 40N/mm2 and over. The cubes and cylinders made with 20% to 30% (wet cured), gave higher results. Indicating a higher efficiency and better use of materials. Regarding the density results, most samples tested showed a denser sample as the ash increased. This is because of the fineness of GGBS. It has a finer powder than cement.

Also, the wet cured were higher in density and mass than the dry cured. This again is in line with literature and science. According to science, research and industry, concrete made with partial cement replacement using GGBS specifically has several advantages. Such as, easier placing and compaction due to higher workability. Reduced permeability. High resistivity to sulphate attacks and chloride ingress, reducing the risk of reinforcement corrosion. Increased strength and durability. Minor early-age temperature rise, minimizing the risk of thermal cracking in huge pours. Achieving high effectivity in deep sections and long span members. More chemically stable. High resistance to ASR. Improved surface finish. Enhancement of Life cycle of concrete structures. Significant sustainability benefits, its production is also CO2 free.

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