Comparison of Self Compacting Concrete (SSC) containing Fly Ash, Ground Granulate Blast Furnace Slag

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Abstract— *This research work includes the comparison of compressive strength of two different mineral admixtures namely Fly ash and blast furnace slag. It also comprises of comparison of workability of both the mineral admixtures. This is obtained by performing slump test, L box test, U box test and T50 test. The method adopted to perform the workability is by replacing 30%, 40% and 50% of Portland cement with the particular mineral admixture and then compared. The influence of these mineral admixtures on the properties of these mixtures is also investigated. The mix proportion is made as per the guidelines of European federation of contractors and producers for structure. The mixture comprises of Ordinary Portland cement (grade 43). Local rivers were used to obtain the sand lying under zone 2 was used. The specific gravity of the sand is kept 2.65 and that of cement 3.15. Coarse aggregates of nominal size of size 12.5mm conforming IS 383-1970 were used. The specific gravity of coarse aggregate being 2.77. The size of the coarse aggregate is to be checked in order to check that it does not cause a blocking effect in self compacting concrete. In case of self compacting concrete the ratio of coarse aggregate is much lower than that in case of ordinary Portland cement. Fine aggregate ratio in self compacting concrete is kept higher in comparison to Ordinary Portland cement so that flowing viscosity is high and the stability of the mixture is maintained and also bleeding is kept at bay and segregation of coarse material is also avoided (Boukendakdji et al., 2009). The specific gravity of the sand is kept 2.65 and that of cement 3.15 . Fly ash being industrial by product was obtained from Uttarakhand Power Corporation, Dehradun whereas Ground Granulate Blast Furnace Slag (GGBS) was obtained from local vendors for cheap prices.*

From this view point it can be incorporated that the cost of self compacting concrete can be considerably reduced by replacing Portland cement with industrial by-products and also reducing the amounts of chemical admixtures and hence their cost.

***Keywords:* Fly ash, Ground granulated blast furnace slag, Ordinary Portland cement, self compacting concrete.**

I. INTRODUCTION

Concrete is the most important and the most used construction material across the globe. Numerous efforts are being made at this very time also in order to modify and enhance the properties of concrete, be it its compressive strength, tensile and flexural strength, aesthetic looks, and compaction and consolidation properties. These decades of research can be classified into four stages. First came the conventional concrete that comprised of materials - water, cement, coarse aggregates, and fine granular aggregates. Then as the population grew, there grew a need of more infrastructure and with the advancements over the decades engineers created high compressive strength concrete (HCSC). In initial stages this was obtained by reducing the amount of water per cement ratio. In later years the fifth ingredient was discovered, they being chemical admixtures. They fall into these categories.

- Air entrainers
- Water reducers
- Set retarders

The main objective of these chemical admixtures was to enhance the properties of the concrete mixture in both the fresh state as well as hardened state. But in recent years mineral admixtures is the new addition in concrete technology which performs really well. With the addition of mineral admixtures to the concrete mixture Self Compacting Concrete is obtained which is cheap in cost and the same time does not compromise with the other properties of the concrete. Some common mineral admixtures used are.

- Rice husk ash
- Metakolin
- Silica fume
- Fly ash
- Blast furnace slag

Self compacting concrete (SCC) is a concrete which does not require any mechanical or dynamic vibrations in order to compact it. It flows under its own weight to achieve the desired compactness and placement even without bleeding and segregation. Self compaction concrete was first developed in Japan in late 1980s in order to tackle the problem of use of vibrators in congested reinforced constructions. But the only problem with the self compacting concrete is the cost as it amounts to large volumes of Portland cement and chemical admixtures to be manufactured and maintain the desired freshness and hardness. But to reduce the cost of the mixture. It has been proved economical due to number of reasons.

- Faster manufacturing
- Reduction in manpower on site
- Better surface finish
- Easy to place
- Improved durability
- Greater freedom in design
- Thin concrete sections
- Reduction in noise level
- Absence of vibrating machines
- Skilled labour for placement not required
- Safer working conditions

The way to achieve the desired freshness and performance of the SCC is the use of mineral admixtures such as silica fumes, ground granulated blast furnace slag, fly ash which is finely granulated and mixed into the concrete mixture. By the usage of mineral admixtures it reduces the amount of Portland cement. the cost will be automatically reduced if the admixtures used are industrial by products. They also tend to reduce the heat of hydration of the concrete mixture hence giving it a good performance as lower water content leads to higher durability in addition to better mechanical properties of the structure. With the use of mineral admixture the requirement for chemical adhesives is eliminated.

II. EXPERIMENTAL INVESTIGATION

2.1 Mix Proportion

In this study one control mix whereas six mixtures with different composition and different mineral admixtures were prepared and studied in order to study the behaviour of the self compacting concrete. The replacement of 30%, 40%, 50% of Portland cement with the respective mineral admixture is carried out. After several iterative calculations the water/cement ratio is kept 0.35(by weight). The total mass of the powder is kept 500 kg/m³. The weight of the coarse aggregate is kept 600 kg/m³. In the process of minimizing the water content for desired stability it can also result into low yield stress concrete with moderate viscosity. Therefore a strong amount of high water reducer is added to obtain a required deformability especially with binding materials being used very less (Brooks et al., 2000). In this case polycarboxylic ether (pH greater than 6) is used as it works just very well in low dosage also, plus it is better compared other bases in terms of effectiveness. Many efforts have been made in order to come up with a single way or a combination of methods to achieve the perfect way to obtain a self concreting mix which characterises all the workability aspects , so in order to get a perfect mix design one should always try different methods and consider their options *(Bonen et al., 2005).* The composition of the mineral admixtures being used and cement is given in the table.

TABLE 1
PROPERTIES OF PORTLAND CEMENT AND MINERAL ADMIXTURES.

Components (%)	Cement	Fly ash	Slag content (GGBS)
Chemical composition (%)			
SiO_2	20	40	10-19
Magnesium Oxide (MgO)	2.5	4	11
$Al2O_3$	4.85	26	1-3
Loss in ignition (LOI)	2.0	2.0	1.2
Fe_2O_3	0.6	6.0	22-30
Calcium Oxide (CaO)	62.56	15	40-52

2.2 Material Properties

In this research The Bureau of Indian Standards (IS) and American Society for Testing and Materials (ASTM) has been adopted to determine the properties of raw materials used in this research.

2.2.1 Cement

Ordinary Portland cement of grade 43 is used corresponding to IS- 8112(1989). The specific gravity of cement is 3.15

2.2.2 Chemical admixture

A polycarboxylate based water reducing admixture was used in the mixes apart from control mixes in order to prevent bleeding

2.2.3 Additive Mineral Admixtures

In this research two mineral admixtures have been used in order to replace the mass of Portland cement, they being Fly ash and Ground Granulated Blast Furnace Slag (GGBS). The chemical composition of both the admixtures is given in Table 1.

Fly ash being industrial by product was obtained from Uttarakhand Power Corporation, Dehradun whereas Ground Granulate Blast Furnace Slag (GGBS) was obtained from local vendors for as cheap as ₹ 4/ Kg.

The specific gravity of fly ash is kept at 2.12 and that of GGBS at 3.44 by weight.

2.2.4 Coarse Aggregate

Coarse aggregates of nominal size of size 12.5mm conforming IS 383-1970 were used. The specific gravity of coarse aggregate being 2.77.

2.2.5 Fine Aggregate

Local rivers were used to obtain the sand lying under zone 2 was used. The specific gravity of the sand is kept 2.65 in oven dry conditions.

2.2.6 Water

Ordinary tap water is used.

2.2.7 Curing

SCC tends to dry faster as compared to conventional concrete this is mainly due to absence of any bleed water at the surface. Therefore it is recommended to start initial curing as soon as practical to avoid shrinkage cracking.

2.2.8 Placing

Though it is quite easy to place SCC but there are certain recommendations that can be kept in mind while placing to minimise the risk of segregation:

- free fall vertical should not be more than 5 m
- the permissible distance of horizontal flow from the point of discharge should not be more than 10 m

Note: the advise is totally conservative as per the research, in suitable circumstances a contractor may demonstrate that the suggested limits can be maximised.

TABLE 2
SPECIFIC GRAVITY OF DIFFERENT COMPONENTS

Different components	Specific Gravity (g/cc)
Sand	2.65
Cement	3.15
Coarse Aggregate	2.77
Fly Ash	2.12
GGBS	3.44

III. METHODOLOGY

In this paper the compressive strength is evaluated by using the moulds of 150mm×150mm×150mm. 18 cube were tested and casted for each mixture of both fly ash, GGBS and then values of compressive strength is determined. Before studying the strength, the mixture is evaluated for its workability properties by performing tests Slump flow test, L box test, U-box test, V funnel test, T50 test.

3.1 Slump Test

The slump test is a mean of evaluating the consistency of the fresh concrete. It also determines the ability of self compacting concrete to deform under its own weight. It is also used indirectly to check the amount of water added to the mixture. It is also used to evaluate the flowing ability of the concrete with respect to spread diameter, or the horizontal free flow of the SCC under its own weight. On lifting the slump cone, filled from concrete the average diameter of the spread is measured. The results for slump test are given in the table. According to European codes the value of slump should lie in between 650mm-800mm (EFNARC, 2002).

3.2 T 50cm Test

This is the evaluation of filling ability of concrete mixture without any reinforcements. However it does not indicate the ability of the SCC to pass between reinforcements but it does give some indication of resistance to segregation. It is the evaluation of time taken by the slump to reach 50 cm of flow. T 50 test was performed during the slump test flow. Lower time indicates greater flow ability.

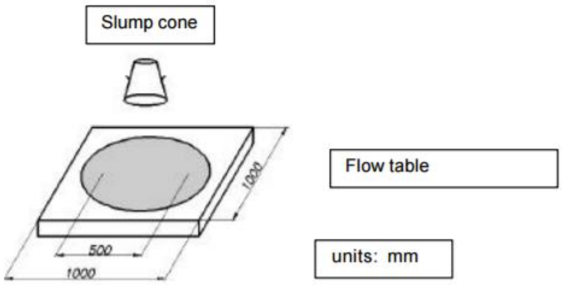

FIG 1. APPARATUS FOR BOTH (I) SLUMP TEST AND (II) T 50 TEST

3.3 L Box Test

It is a test used to assess the flow of the concrete and also the extent up to which it is subjected to blocking due to reinforcements. The apparatus consists of L shaped apparatus with a vertical section and a horizontal section. Both these sections are separated with a movable gate. In this process concrete mixture is poured in from the vertical portion of the apparatus, then suddenly the gates separating the sections is opened and the concrete mix is allowed to flow through to the horizontal section. When the flow is stopped the height of concrete at horizontal section is expressed as a proportion of that remaining in the vertical section (h2/h1). This test determines the passing ability of the concrete through the restricted bars. If flows as freely as water it will be completely horizontal at rest and therefore the ratio is unity. The minimum value of h2/h1 should be 0.8 (EFNARC, 2002).

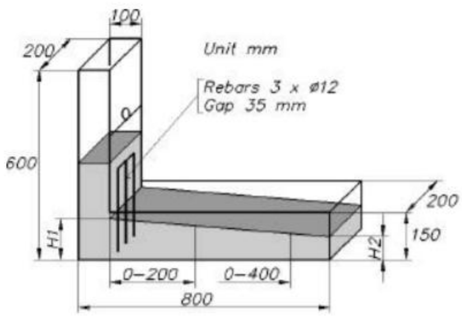

FIG 2. L BOX TEST APPARATUS

3.4 U Box Test

This test is used to determine the filling ability of self compacting concrete. The apparatus consists of U shaped apparatus divided into two compartments with a sliding gate comprising of reinforced bars with adequate spacing. The concrete mixture is poured from one of the compartments, and then after some time the sliding gate is slid causing the concrete mixture to flow into other compartment. Height in both the compartments is noted down as h2 and h1. If concrete is allowed to flow like water the concrete mix in both the compartments will be at same height, the difference in height between both the compartments (h2-h1) will be zero. The nearer the value of h2-h1 to 'zero' betters the flowing ability of the self compacting concrete. The maximum value of the height difference should be maximum 30mm (EFNARC, 2002).

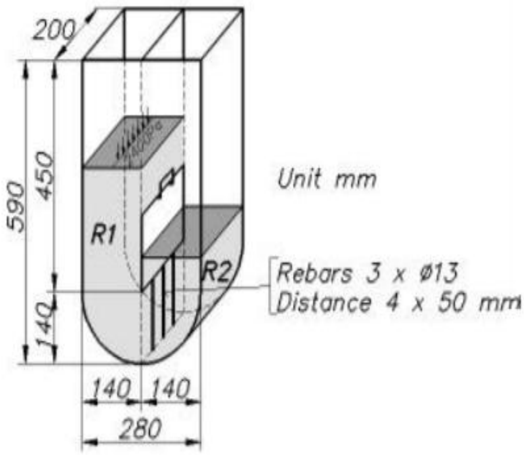

FIG 3. U BOX TEST APPARATUS

3.5 V Funnel Test

The described V Funnel test is used to determine the flow or filling ability of a SCC. The maximum size of aggregate used in mix design should be 20mm. The funnel is a inverted V shaped funnel which is filled with 12 litres of concrete mixture and the time taken for this concrete to flow through the apparatus is measured. Lower the time better the flowing ability of the concrete mixture. If the concrete exhibits segregation the flow time will increase considerably. The inverted shape expose any liability of the concrete to block is easily reflected. For example if there is a high flow time it can be associated with low deformability which is caused due to high paste viscosity, and with high inter particle friction. The maximum time that should be taken by any SCC mix is 10 sec (EFNARC, 2002).

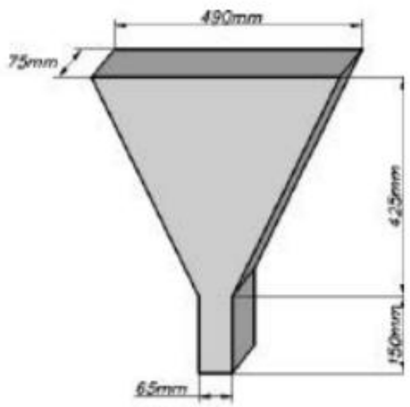

FIG 4. V FUNNEL TEST APPARATUS

IV. RESULTS AND DISCUSSIONS

In these paper properties of self compacting concrete is investigated by using industrial by products such as fly ash and GGBS at three different replacements rates for the cement. The study is done according to the European standards given for Indian conditions. In this paper fresh and hardened properties of a SCC produced by mixing of fly ash and GGBS were performed on fresh concrete, specifically workability tests and strength tests.

4.1 Fresh Properties

Slump test indicates the flowing ability of the concrete mixture under its own weight. All the self compacting mixtures containing fly ash or GGBS showed satisfactory results and the ranges were well within the permissible limits provided by EFNARC 600mm-690mm. This indicates good deformability of the mixtures. The slump flow values for all the self compacting mixtures are given in the table. The higher the value of slump flow it indicates the ability of concrete to fill or flow under its own weight. It is to be noted that as we replace higher amounts of GGBS the blast performance of slag slump increases up to 50%. Whenever cement is replaced by mineral admixture, a small amount of chemical admixture is needed in order to compensate for the water and improve the flow. In comparison to GGBS fly ash requires more amount of chemical admixture to maintain the same slump flow and shown good slump values. In comparison to GGBS fly ash had a more spherical geometry and a coarser particle surface, reducing the surface area. As the density of fly ash is lower in comparison to cement therefore when replaced fly ash causes higher volume of paste, which reduces the friction between the fine aggregates and paste interface, which further increases thee cohesiveness and plasticity, which leads to better workability.

Water/powder ratio is kept between 0.9 to 1.0 by volume depending upon the properties of the powder. With super plasticisers dosage is kept at 2.2%. For constant water/powder ratio and same content of super plasticisers it is observed that an optimum slump is observed at a replacement level of 30% and an increase up to 50% is observed.

In case of T50 test it is a measure of flowing ability of the concrete under no reinforcements. It can also be said as the secondary indication of flow ability. The lower the time the better the flowing ability. As the test is performed during the slump test itself it was influenced with a dosage of water and super plasticisers. It is observed that till 30% replacement the T50 time is reduced, but after replacing more percentage leads to increase in T50 time along with some bleeding and segregation. Various good relationships between T50 time and various mixtures of SCC are shown below. The values for T50 tests for all the self compacting mixtures are also reflected in the table 3 below.

V funnel test is a measure of self flowability and stability of self compacting concrete. The range under which the SCC is considered appropriate is 6-10 sec. We can notice that in both the cases when we increase the percentage of replacement the time decreases which shows the better flowability of the SCC. If the time increases it is sign of segregation or bleeding. In case of severe segregation coarser particles come in the middle part of the apparatus and the mortar and the paste on the outer periphery. All the values for the V Funnel test are given in the table 3 below.

L Box test is a test which assesses the flow of the concrete under the blocking of reinforcements. In here as explained before a blocking ratio h2/h1 is the determining criteria. If concrete flows like water the blocking ratio is unity, therefore the closer the value of the ratio to unity better will be its flowing ability. According to European standards the minimum value obtained should be at least 0.8. It is noticed that the values for SCC are more close to unity than a normal concrete, which shows its tremendous ability to flow under reinforcements. Here in all cases of mixture satisfactory results are obtained. All the values for the tests are given in the table below.

U Box test is used to measure the filling ability of SCC under blockage. It also is a measure of self compatibility of the SCC. In here also a blocking factor of h2-h1 plays a major role. If concrete flow like water in test it will be completely horizontal, hence h2-h1=0. So more the value is near to zero, it signifies better passing and filling ability of the concrete. According to European standards the range for appropriate SCC is set at 0-30mm. All the mixtures were well within the range. All the values for the test are given in the table 4.

TABLE 3
FRESH PROPERTIES OF SELF COMPACTING MIXTURES.

Mixture no	Water/powder	Slump (mm)	T50 (sec)	V funnel (sec)	L Box (h2/h1)	U Box (h2-h1) (mm)
Fly-ash 30%	0.35	660	6.1	10	0.9	26.5
Fly-ash 40%	0.35	675	6.6	9	0.93	26
Fly-ash 50%	0.35	680	7	9.15	0.95	25.7
Blast furnace slag-30%	0.35	680	5	10	0.9	26
Blast furnace slag-40%	0.35	685	5.5	8	0.95	25
Blast furnace slag-50%	0.35	690	6	7	1	24

TABLE 4
ACCEPTANCE CRITERIA FOR SELF COMPACTING CONCRETE.

Method	Unit	Typical ranges of values	
		Minimum	Maximum
Slump flow	Mm	650	800
T50cm	Sec	2	5
V funnel	Sec	6	12
L box	(h2/h1)	0.8	1.0
U box	(h2-h1) mm	0	30

4.2 Mechanical Properties

The compressive strength for all the mixture were taken at 7th and then 28th day. All the measures of compressive strength for each mixture of both the mineral admixture is given in the table below. It is observed when compared the control mix that on increasing the percentage of mineral admixture there is a reduction of strength for both fly ash, GGBS. This happens mainly due to fineness and packing. But on the final day it is noticed that the compressive strengths of both the mixtures of fly ash and GGBS achieved a good value in regard to the control mix. This mainly happens because on initial stages the pozzolanic reactions were not sufficient enough to increase the compressive strengths of both the self concrete mixtures. But in later stages it can be seen from the results that the compressive strength due to slower pozzolanic reactions increases.

TABLE 5
COMPRESSIVE STRENGTH OF FLY ASH AND BLAST FURNACE SLAG MIXES.

Water/ powder	Compressive strength (MPa)					
	Fly Ash			Blast Furnace Slag		
	Mixture no	7 days	28 days	Mixture no	7 days	28 days
0.35	Control	20	30	Control	20	30
0.35	Fly-ash 30%	29.16	37.18	Blast furnace slag- 30%	24.1	32.44
0.35	Fly-ash 40%	28.60	39.13	Blast furnace slag- 40%	21.4	31.8
0.35	Fly-ash 50%	28.73	41.42	Blast furnace slag- 50%	18.2	31.55

V. CONCLUSIONS

This paper focuses on the freshness as well as mechanical property of a self compacting mixture.

Some conclusions made out his research are:

1. All the mixes with both the mineral admixtures performed quite well in freshness tests. Out of the both Blast furnace slag had the best results.
2. With the use of mineral admixture the cost is considerably reduced due to no use of mechanical vibrators, plus viscosity modifying admixtures are also avoided.
3. It is observed that with a increase in replacement percentage of the mineral admixture the compressive strength is reduced considerably, so 30% replacement is considered the most optimum percentage of replacement.

4. It is observed that to determine the flowing ability of the self concrete mixture slump flow test is the most critical test out of all the tests.

5. Water by cement ratio is kept 0.35. The ratio underneath or beyond this value may cause segregation and develop blocking tendency in the self compacting concrete mixture.

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