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Assessment of hardened characteristics of raw fly ash blended self-compacting concrete☆

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Summary Fly ash is widely used as a supplementary cementitious material in concrete. Due to the implementation of new thermal power plants as a consequence of electricity demand, generation of fly ash is noticeably increased. In addition to pozzolana blended cement production, it is very imperative to use raw fly ash in concrete. Earlier research studies investigated the performance of processed fly ash in blended cement production as well as in concrete. In general, ground fly ash is used in blended cement production. A comprehensive study on the performance evaluation of raw fly ash in self-compacting concrete is not available in the existing literature. Moreover, utilization of raw fly ash in special concrete such as self-compacting concrete is essential to comprehend the performance of raw fly ash blended concrete compared to ordinary Portland concrete. Additionally, it will help to achieve maximum utilization of raw fly ash as a supplementary cementitious material rather than disposal as a waste, which eventually leads to several environmental issues. In the study, raw fly ash was collected and is directly used in development of self-compacting concrete. Two mixes were cast and hardened characteristics of blended concrete were investigated. Results from the study showed comparable performance with control concrete. Furthermore, significant reduction in chloride permeability was observed for raw fly ash blended concrete.

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Introduction

The massive generation of fly ash from thermal power plants and its disposal are most problematic concerns. The generation of fly ash is drastically increasing and it is estimated to reach about 225 million tonnes by 2017. On the other hand, utilization of fly ash is considerably limited to 60 million tones (IEA, 2013). The generation of fly ash is much higher than its consumption, which warrants an efficient management system for their disposal. In India, the problem of fly ash disposal will be critical due to the expansion of thermal power plants to meet the increasing demand of electricity. Fly ash is generally used for blended cement production after grinding to high fineness. Usage of raw fly ash and its performance evaluation in concrete is noticeably limited. In addition to ordinary concrete, raw fly can be used for special concrete such as self-compacting concrete (SCC) which helps to achieve low cost SCC, which eventually enable maximum utilization of raw fly ash instead of disposal. Besides the disposal issue, supplementary cementitious materials are commonly used in concrete owing to the enhancement of fresh and hardened characteristics of blended concrete. Those are the significant reduction in heat of hydration, strength gain as a result of pozzolanic reactions, lower permeability by virtue of pore refinement and superior performance against aggressive agents than ordinary Portland cement (OPC). Therefore, incorporation of blending materials facilitates to achieve durable and sustainable concrete for construction. In this study, raw fly ash blended SCC was developed and its performance was evaluated to examine its potential in concrete construction. Moreover, the utilization of raw fly ash in SCC helps to achieve economical concrete which in turn promotes its utilization in regular construction practices.

Materials and methods

Ordinary Portland cement (53 grade) conforming to Indian standard (IS 12269, 2008) and class F fly ash conforming to IS: 3812-2003 were used in this study. Raw fly ash was collected from a thermal plant in Tamil Nadu, India and directly used without further processing. Physical characteristics of raw fly ash were determined as per standard (IS 1727, 2004) and results are given in Table 1.

Initial and final setting times were determined for a blend of OPC and fly ash in the ratio of 0.8:0.2N as specified in the standard where N is ratio of specific gravity of any SCM to be tested to that of cement and testing procedure was adopted as per standard (IS 4031, 2005).

Compressive strength

From the previous research studies, the recommended binder content in SCC was found to be in the order of 450—600 kg/m^3 of concrete (Japan Concrete Society, 1999). In the study, self-compacting concrete mixes were designed with binder content of 450 kg/m^3. Moreover, two different levels of replacement with cement (30% and 40%) were adopted. To evaluate the influence of raw fly ash on compressive strength, the water content was fixed and each mix had the same water content of 195 l. The concrete specimens were cast and kept in laboratory condition for 24 hours. The specimens obtained then were demoulded and kept in controlled water curing until specified testing durations. The compressive strength was determined after 3, 7, 28, 56 and 91 days of curing as per standard.

Rapid chloride permeability test

The rapid chloride permeability test (RCPT) is a migration test used to find out resistivity of concrete against chloride ion ingress. The test was conducted as per standard (ASTM C1202, 2012) in which the chlorides migrate through the concrete under an applied voltage. The cylindrical specimens of dimension 100 mm diameter and 200 mm height were cast and cured as per standard for 28, 56 and 90 days for each mix. After particular curing duration, the specimen was coated with epoxy on the peripheral surface to avoid the leakage of chlorides from the sides of specimens during testing. Three specimens of 100 mm diameter and 50 mm thickness were prepared by slicing the cylinder using concrete cutter. The specimens thus obtained were saturated as per standard. The specimens were placed vertically in a desiccator to expose the surface of specimen and were subjected to dry vacuum for 180 minutes to expel air present in the pores. After dry vacuum, specimens were submerged in lime water for an additional 60 minutes and vacuum was continued during this period. In addition, the specimens were immersed in the lime water for an additional period of 18 ± 2 h without vacuum. After preconditioning, specimens were placed in RCPT migration cells and the cells were filled with 3.0% NaCl solution and 0.3 N NaOH solutions (anolyte) as specified in the standard. A constant potential of 60 ± 0.1 V was applied across the concrete to accelerate the chloride

Table 1 Physical and chemical characteristics of cement and raw fly ash.

Physical characteristics	OPC	Oxide composition	OPC	Raw fly ash
Specific gravity	3.12	Al_2O_3	6.56	22.12
Fineness (m^2/kg)	300	Fe_2O_3	4.23	9.027
Soundness, expansion (mm)	0.8	CaO	62.5	4.73
Consistency (%)	30%	MgO	1.77	1.86
Initial setting time (min)	190	SiO_2	21.09	57.27
Final setting time (min)	285	$K_2O + Na_2O$	0.82	1.17
Loss on ignition (%)	2.2%	SO_3	2.18	0.68

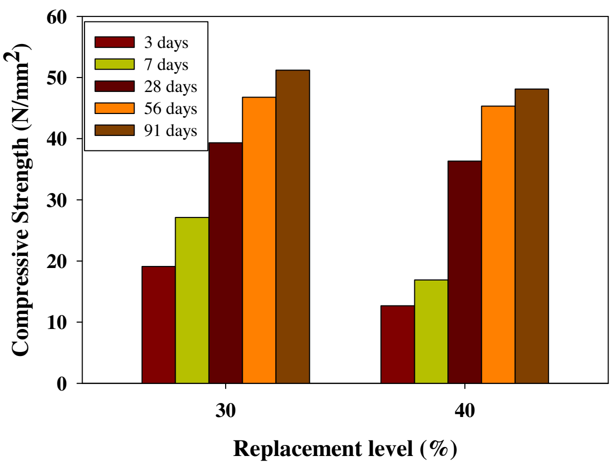

Figure 1 Compressive strength of blended concrete.

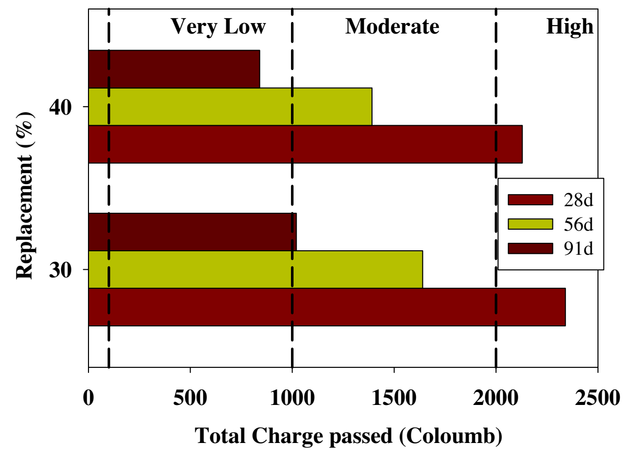

Figure 2 Observations from RCPT test.

ingress and current was measured at every 30 minutes intervals using multi-metre.

Results and discussion

As mentioned earlier, compressive strength was determined after specified curing duration and results are presented in Fig. 1. The compressive strength of concrete was found to be increased with curing duration. The study depicted considerable increase in compressive strength after 56 days of curing, which represents the pozzolanic performance of raw fly ash associated with additional CSH formation at later stages. On the other hand, reduction in compressive strength was observed for replacement level of 40% compared to 30% for the same curing duration. This may be due to the dilution effect of raw fly ash.

The chloride permeability of concrete was evaluated after 28, 56 and 91 days of controlled curing. Concrete with 30% of raw fly ash had high permeability as per standard classification (ASTM 1012, 2012). However, the permeability was found to be reduced to a greater extent after 91 days. It is a clear evidence for the improvement in the pore structure refinement due to the pozzolanic reactivity of fly ash.

Moreover, considerable reduction in permeability was observed for concrete with 40% raw fly ash than the 30% blended concrete as shown in Fig. 2. It is very imperative to note that substantial reduction in permeability of concrete was observed after 91 days of curing. Although the concrete with 40% replacement of raw fly ash falls under the category of high permeability of concrete after 28 days of curing, the same concrete had very low permeability after 91 days of curing. Moreover, the reduction in permeability was increased with replacement level due to additional pozzolanic reaction. Even though a marginal strength reduction was observed for 40% raw fly ash blended SCC concrete compared to 30% blended concrete, the enhancement in the pore structure was evidently observed in terms of permeability. From these observations, it is clear that raw fly ash can be used for SCC concrete without processing to achieve durable and low cost SCC concrete. The results obtained from the study, exhibits comparable performance of raw fly ash and it may promotes the bulk and effective utilization of raw fly ash in SCC to achieve durable and economical concrete.

Conclusion

The concrete with higher replacement level of raw fly ash had marginally lesser compressive strength compared to 30% raw fly ash blended SCC concrete. The pozzolanic performance of raw fly ash was evidently observed in terms of additional strength gain at later curing stages. The permeability of raw fly ash blended concrete is significantly reduced as results of pozzolanic reactivity of raw fly ash associated with pore refining process. In addition to marginal pozzolanic benefits, effective utilization of raw fly ash would help to elucidate disposal problems and subsequent environmental degradation.

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