Fracture Energy of Geopolymer Concrete

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ABSTRACT

Use of fly ash based geopolymer as an alternative binder can help reduce CO_2 emission of concrete. Effect of the geopolymer binder on fracture energy of concrete (GPC) has been investigated by testing both geopolymer and ordinary portland cement (OPC) concrete notched beams in accordance with the recommendations of RILEM TC 50 – FMC. The fracture failures of the GPC specimens were more brittle with relatively smooth fracture planes as compared to the OPC concrete specimens. Fracture energy of geopolymer concrete tends to be higher than OPC concrete for high compressive strengths.

Key words: Brittleness, fly ash, fracture, geopolymer concrete.

1. INTRODUCTION

The global demand of cement is continuously increasing for construction of infrastructures to maintain the continuous growth and accommodate the needs of the increasing population. OPC has been traditionally used as the binder in concrete. About one tonne of carbon dioxide is emitted into the atmosphere in the production process of one tonne of cement. This makes a significant contribution to the global green house gas emission. Therefore, development of alternative binders utilising industrial by-products will be helpful to reduce the environmental impact of the construction industry. Geopolymer is an emerging alternative binder for concrete. A base material that is rich in Silicon (Si) and Aluminum (Al) is reacted by an alkaline solution to produce the geopolymer binder. Source materials such as fly ash (Hardjito et al. 2004; Fernandez-Jimenez et al., 2006), metakaolin (Davidovits, 1994) and blast furnace slag (Bakharev et al., 1999) can be used to make geopolymer. The product of the reaction binds the aggregates together in geopolymer concrete. The coal-fired power stations generate substantial amount of fly ash as a by-product, which can be efficiently used in geopolymer concrete (GPC) to help reduce the carbon footprint of concrete.

The results of recent studies (Rangan, 2006; Sarker 2009, 2011) have shown the potential use of heat-cured fly ash based geopolymer concrete as a construction material. To use in structural applications, it is necessary to study various properties of geopolymer concrete. The previous research on fly ash-based geopolymer concrete studied the short-term and long-term properties. It was shown that heat-cured geopolymer concrete possesses high compressive strength, undergoes low drying shrinkage and creep, and shows good resistance to sulfate and acid attacks. Geopolymer concrete showed higher bond strength with reinforcing steel as compared to OPC concrete (Sarker, 2011). Geopolymer concrete beams and columns showed similar behavior to that of OPC concrete members (Sumajouw et al. 2005; Sarker 2009). Therefore, heat-cured geopolymer concrete is considered as an ideal material for precast concrete members.

The parameter fracture energy is used to describe the formation and propagation of cracks in a material. The crack path through a composite material such as concrete is dependent on the mechanical interaction between the aggregates and the binder matrix. Fracture energy of a composite material depends on the deviation of the crack path from an idealized crack plane (Wittmann, 2002; Sabir et al. 1997). Since the binder in geopolymer concrete is different from that in OPC concrete, the effect of the interaction between the aggregates and the alternative binder needs to be investigated. Thus, it is necessary to determine the fracture properties of geopolymer concrete to understand its resistance to cracking. In this study, the fracture energies of heat cured fly ash based geopolymer concrete specimens were determined from three-point bending test of notched beams. Fracture energies of OPC concrete specimens were also determined to compare with those of geopolymer concrete specimens of similar compressive strengths and containing the same aggregates.

2. EXPERIMENTAL WORK

OPC and GPC notched beam specimens were cast and tested for three-point bending. The fracture energy values were calculated from the load deflection diagrams of the test specimens.
General purpose Portland cement was used for OPC concrete. Commercially available fine grade low-calcium Class F fly ash was used to make geopolymer concrete. The percentage of the fly ash passing through a 45 μ sieve was 75%. The main components of the fly ash were SiO_2 : 50.5%, Al_2O_3 : 26.6%, Fe_2O_3 : 13.8% and CaO : 2.13%, and loss on ignition was 0.6%. The alkaline liquids for geopolymer concrete were sodium hydroxide and sodium silicate solutions. Sodium hydroxide pellets were dissolved in water to make 14M solution. The sodium silicate solution had a chemical composition of 9.1% Na_2O, 28.9% SiO_2, and 62% water by mass. The coarse aggregates were 7 and 10 mm nominal size crushed stone. The sand used was river sand. Tap water was used in mixing the concretes. The mixture proportions of OPC and geopolymer concrete are given in Table 1. These mixture proportions were obtained by carrying out trial mixes before the actual mixing. Slump of the OPC concrete varied between 75 to 120 mm and that of the geopolymer concrete varied from 185 to 220 mm. No extra water was used in the GPC mixtures GPC1 and GPC2. The OPC specimens were cured by immersing in water for 28 days and the GPC specimens were heat cured at 60 ^{0}C for 24 hours.

Table 1- Mixture Proportions of Concrete (kg / m^3)

Mixture	Cement	Fly ash	Water	Sodium hydroxide	Sodium silicate	Sand	Coarse aggregate	
							7mm	10mm
OPC1	310	-	152	-	-	870	341	682
OPC2	345	-	163	-	-	900	320	620
OPC3	375	-	180	-	-	815	355	711
OPC4	420	-	190	-	-	830	360	648
GPC1	-	408	-	68	103	647	647	554
GPC2	-	408	-	62	93	647	647	554
GPC3	-	408	4	62	93	647	647	554

The fracture test specimens were 100 mm × 100 mm section and 600 mm long with a 25 mm deep notch in the middle of the beam. Accompanying 100 mm × 200 mm cylinders were cast for compressive strength tests. Three-point bending tests of three specimens from each mix were performed in deflection controlled mode using an Instron Servo Control machine. The loads and corresponding mid-span deflections of the beams were recorded and plotted to calculate the area under the load-deflection curve. The fracture energy (G_F) was then calculated by using equation 1 (RILEM TC 50 – FMC, 1985).

$$G_F = {(W_0 + mg\delta_0)}/{A_{lig}} \qquad (1)$$

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A_{lig} is the area of the li

3. TEST RESUL

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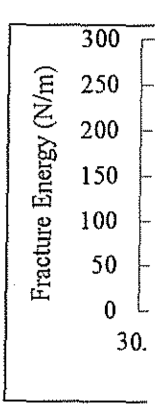

Figure 1 – Fracture en

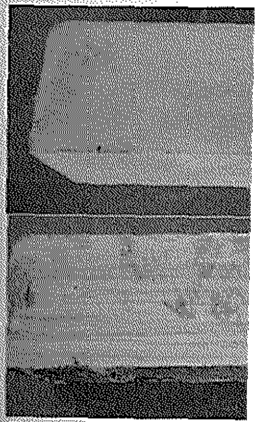

Figure 2- Typical frac

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Where, W_0 is the area under the load-deflection curve, m is the mass of the beam between the supports, g is the acceleration due to gravity, δ_0 is the deflection at final failure of the beam and A_{lig} is the area of the ligament.

3. TEST RESULTS AND DISCUSSIONS

The mean 28-day compressive strengths of the Mixes OPC 1, 2, 3 and 4 were 31, 36, ~~41~~ 43 and ~~48~~ 51 MPa respectively. The mean compressive strengths of the mixes GPC 1, 2 and 3 at the time of testing were 3~~4~~6, ~~50~~ 48 and 32 MPa respectively. The fracture energy of the OPC and GPC specimens are plotted against the compressive strength in Fig. 1. It can be seen from the plot that fracture energy increased with the compressive strength in both types of concrete. It is seen from the trend lines that the fracture energy of GPC tends to be higher than that of OPC concrete for compressive strengths above about 35 MPa. The fracture energies calculated by the equation of CEB-FIB (1990), which is based on the compressive strength and maximum aggregate size, is also plotted in Fig. 1. It is seen that the fracture energies of both OPC and GPC specimens are higher than those calculated by the CEB-FIP (1990) equation.

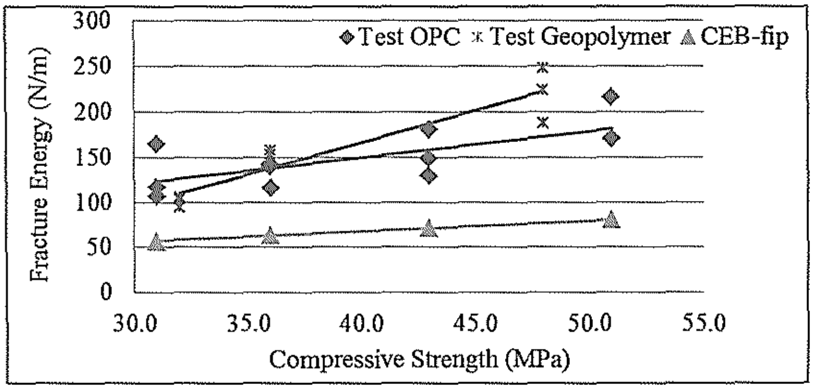

Figure 1 – Fracture energy of OPC and geopolymer concrete

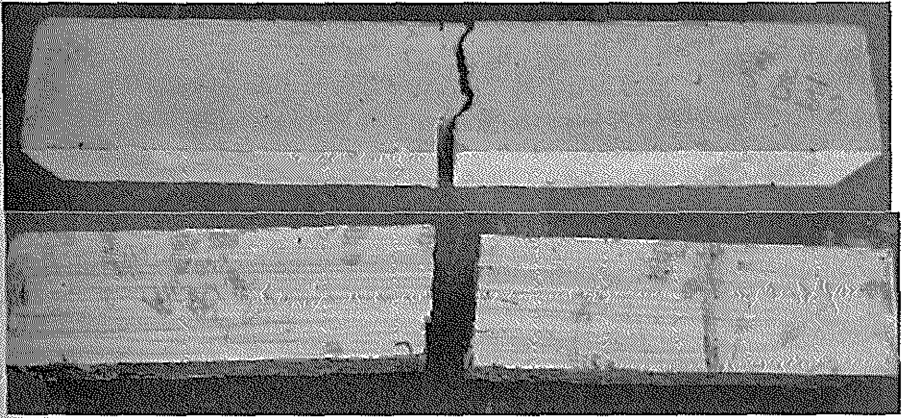

Figure 2- Typical fracture planes of OPC (top) and GPC concrete (bottom)

Generally, the GPC specimens failed in a more brittle manner than the OPC specimens. Typical fracture failure planes of OPC and GPC specimens are shown in Fig. 2. It can be seen that the fracture planes in the OPC specimens were tortuous whereas those of the GPC specimens were relatively smooth. The fracture planes in the OPC specimens passed around the aggregates and those in the GPC specimens passed through the aggregates. The reason for the fracture planes passing through the aggregates in GPC is believed to be the higher bond strength of geopolymer with aggregates than the OPC binder. This is consistent with the previous study (Sarker, 2011) where GPC showed higher bond strength with reinforcing steel than OPC concrete.

4. CONCLUSIONS

Geopolymer concrete tends to show higher fracture energy than OPC concrete at relatively high compressive strengths. The fracture energy of both GPC and OPC concrete can be conservatively predicted by the CEB-FIP equation. The fracture planes in GPC are relatively smooth as compared to tortous fracture planes in OPC concrete. The failure of GPC is more brittle than OPC concrete. The smooth fracture planes in GPC is believed to be because of higher bond strength of the geopolymer binder with aggregates than that of the OPC binder.

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Multiphase Hydrat
Blast-Furnace Slag

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ABSTRACT

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Keywords: Blended ce

1. MODELING

1.1. Stoichiometric

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