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FLEXURAL PERFORMANCE OF REINFORCED CONCRETE BEAMS MADE WITH LOCALLY SOURCED FLY ASH

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Abstract

The paper investigates the flexural performance of reinforced concrete beams in which fly ash from Vinh Tan power station was used to replace original Portland cement in the proportions of 0%, 10%, 20% and 40% by weight. Twelve reinforced concrete beams with the dimensions of 100×150 mm in cross section and 1000mm in length were cast and cured in water. These beams were flexurally tested under 4 points bending at 28 days, 56 days and 90 days. Load deflection curves, first cracking load, yielding of steel bars, ultimate load, and cracking pattern of the reinforced concrete beams are used to investigate the performance of the control and fly ash beams at 28 days, 56 days and 90 days. The results show that locally sourced fly ash does not affect the load and deflection curves. Fly ash reduced slightly the flexural strength of reinforced concrete beams at 90 days when 40% of fly ash was used to replaced Portland cement.

Keywords: fly ash; reinforced concrete beam; flexural performance; load; deflection.

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1. Introduction

Original Portland cement (OPC) is widely used as the cementitious material in conventional concrete. This causes many negative environmental impacts including CO_2 emission due to the OPC production process. Research has been conducting to find out the alternative cementitious to replace OPC and one of the potential material is fly ash [1, 2]. Standards covering supplementary cementitious material (SCM) [3] and general purpose and blended cements [4] recognises and specifies fly ash as a cement replacement for OPC. It enhances the performance of concrete including the workability, mix efficiency and durability [3, 4] and shrinkage [5, 6] for sustainable building construction development [7]. It has been using in blended cement for over 50 years in many construction works such as the Prudential Building in Chicago, Lednock Dam in the UK [8]. Fly ash can be used to replace fully or partly Portland cement but still maintains other criteria including engineering design aspects, constructional aspects and economic advantages [9]. Previous research showed that fly ash reduced the early strength of concrete but increased the long term strength depending on type and proportion of fly ash in the concrete mix [10]. Fly ash affects properties of both fresh concrete and hardened concrete including workability, mechanical strength, permeability and resistance to the penetration of chloride or sulfate resistance, etc.. depending not only on the proportion replacement and

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composition of fly ash, but also on the mix composition of concrete, curing environments. Therefore, there is not the best single replacement proportion for all applications [11].

The flexural strength of reinforced concrete (RC) beam depends on various factors including the tensile strength of the reinforcement, compressive strength of the concrete, tensile strength of concrete, steel reinforcement ratio, and the bond strength between steel and concrete. The tensile strength of concrete and the bond at steel/ concrete interface depend on the type of cementitious materials. There were many research carried out on structural performance of reinforced concrete members made with fly ash. For example, 50% of fly ash in India was used to replace the OPC and shows that the strength of such high volume of fly ash reinforced concrete beam is less at earlier days and gain more strength at later age in compared with the conventional reinforced concrete [12]. Other research also shows that 20% fly ash in India improves the flexural strength of reinforced concrete beams [13]. In addition, the 70% fly ash reinforced concrete beam has comparable flexuaral strength compared with the conventional reinforced concrete beam [14]. It can be summarised that the structural performance of fly ash beam depends partly on the source of fly ash and proportion of fly ash used to replace Portland cement. This paper investigated the long term performance of reinforced concrete beams in which locally sourced fly ash was used to replace original Portland cement at different proportions. The parameters were investigated as follows:

- Load deflection curves of the reinforced concrete beams.
- First cracking load, yielding of steel bars, ultimate load (failure of concrete).
- Cracking pattern of the reinforced concrete beams.

2. Experimental programme

2.1. Beam specimens

The test samples were under-reinforced concrete beams, each of 1000 mm in length with a rectangular cross-section of 150 mm in depth and 100 mm in width in accordance with some previous research [15, 16]. Each beam was reinforced by two 8 mm diameter mild steel bars, each with a total length of 960 mm (Fig. 1). For simplicity, shear reinforcement was not being used to eliminate the effect of shear reinforcement on the flexural performance of the beams. Externally mounted steel plates were mounted on each beam to prevent premature shear failure due to the absence of shear reinforcement in the beam when beam was tested as detailed in Section 2.4.

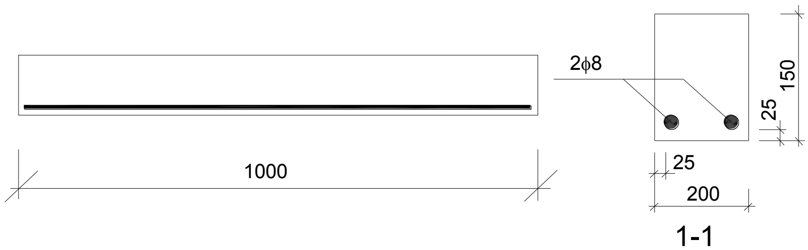


Figure 1. Details of beam specimens (all dimension in mm)

2.2. Sample groups

Twelve reinforced concrete beams dimension of 100×150 mm cross section and 1000mm length were divided into three groups as shown in Table 1. Each group consists of four beams in which fly ash was used to replace OPC in the proportions of 0% (control sample), 10%, 20% and 40% by weight. Three group beams were flexurally tested at 28, 56 and 90 days of curing in water respectively.

Table 1. Details of tests

Group	Beam ID	Dimensions (mm×mm×mm)	Steel bar	Concrete cover	Fly ash replacement (%)	Test age (days)
1	D1-28	100×150×1000	2ϕ8	25 mm	0	28
	D2-28	100×150×1000	2ϕ8	25 mm	10	28
	D3-28	100×150×1000	2ϕ8	25 mm	20	28
	D4-28	100×150×1000	2ϕ8	25 mm	40	28
2	D1-56	100×150×1000	2ϕ8	25 mm	0	56
	D2-56	100×150×1000	2ϕ8	25 mm	10	56
	D3-56	100×150×1000	2ϕ8	25 mm	20	56
	D4-56	100×150×1000	2ϕ8	25 mm	40	56
3	D1-90	100×150×1000	2ϕ8	25 mm	0	90
	D2-90	100×150×1000	2ϕ8	25 mm	10	90
	D3-90	100×150×1000	2ϕ8	25 mm	20	90
	D4-90	100×150×1000	2ϕ8	25 mm	40	90

2.3. Materials

Ordinary Portland cement (OPC) used was PCB40 manufactured by Song Gianh Company Ltd, Vietnam. Natural sand from Quang Nam, Vietnam was used as fine aggregate while the crushed limestone with a maximum nominal size of 20 mm from Da Nang, Vietnam was used as coarse aggregates. Grading curves of sand and coarse aggregates are presented in Figs. 2 and 3, respectively. The reinforcing steel bars were 8 mm diameter un-deformed reinforcing steels manufactured by Viet My Company, with a yield strength of 334 (N/mm^2) and ultimate strength of 430 (N/mm^2) determined by tensile strength test in the laboratory. PCB40 Song Gianh was used in this test meeting the requirement of TCVN 6260:2009 [17] (see Table 2).

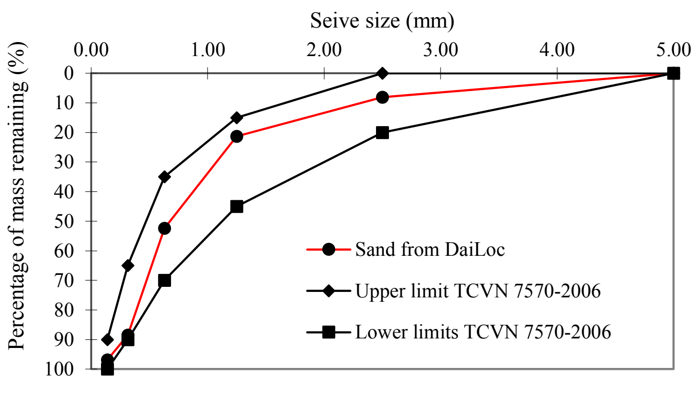


Figure 2. Grading curve for fine aggregate from Dai Loc - Quang Nam

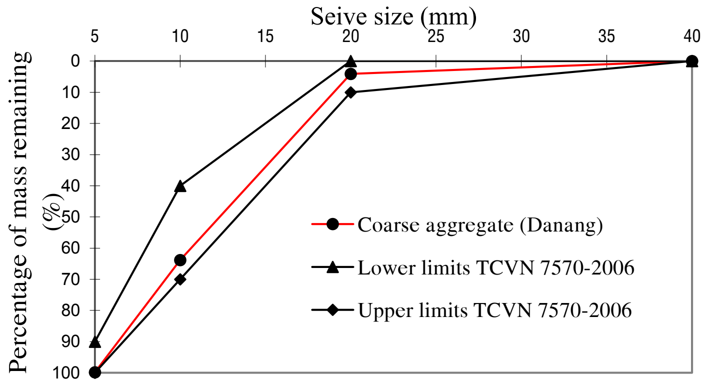


Figure 3. Grading curve for coarse aggregate from Da Nang

Table 2. Properties of Song Gianh PCB40

Properties	Unit	TCVN 6260:2009 [17]	Song Gianh PCB40
1. Compressive strength, MPa, not less than: - 3 days ± 45 min - 28 days ± 8 h	N/mm^2	≥ 18 ≥ 40	≥ 20 ≥ 44
2. Setting time - Initial, not less than - Finish, not less than	Minute	≥ 45 ≤ 375	≥ 100 ≤ 360
3. Fineness, determined by: - Remaining on seive size 0,09 mm - Blaine method	% cm^2/g	≤ 10 ≥ 2.800	≤ 4.0 ≥ 3.200
4. Soundness, tested in accordance with Le Chatelier method	mm	≤ 10	≤ 5.0
5. Anhydric sunphuric content (SO_3)	%	≤ 3.5	≤ 3.0
6. Soundness, tested in accordance with Autodave method	%	≤ 0.8	≤ 0.8

The concrete mix was designed to achieve an average 28-day cube strength of around 35 MPa in accordance with TCVN 3118:1993 [18]. The concrete proportions (by weight) for cementitious material, fine aggregates, coarse aggregates, water were 1: 2: 3: 0.45 in which cementitious material consist of OPC and fly ash. The compressive strength was determined by the mean values of three cube samples of 150×150×150 mm.

OPC was replaced by class F fly ash from Vinh Tan Power station, Binh Thuan, Vietnam. The chemical and physical properties of fly ash are given in Table 3. It was noted that all beams in the same group were cast carefully to ensure the same quality and strength.

Table 3. Chemical and physical properties of fly ash

Chemical composition	Vinh Tan fly ash
Fineness (%)	23.5
Loss on ignition (%)	5.9
Moisture (%)	0.04
SiO_2(%)	48.1
Fe_2O_3(%)	17.1
Al_2O_3 (%)	15.8
SO_3 (%)	0.15
CaO (%)	12.2
MgO (%)	2.18
ZnO (%)	0.01
MnO (%)	0.08
TiO_2 (%)	0.69
Na_2O (%)	0.93

2.4. Four point bending tests

All beams in groups 1, 2 and 3 were tested under flexure at age of 28, 56 and 90 days, respectively. The tests were carried out in accordance with BS EN 1992-1-1:2004 +A1:2014 [19]. Beams were tested under four point loading, supported at two points with two symmetrical loads applied at a distance of 300 mm. In order to prevent premature shear failure due to the absence of shear reinforcement in the beam, two externally mounted steel plates were mounted on each beam ensuring that the

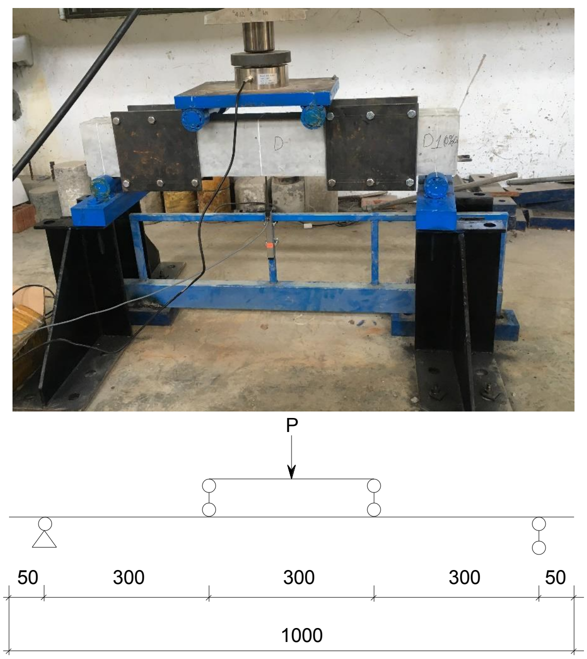


Figure 4. Four point bending test system

maximum flexural resistance of each beam was utilised. Loads were applied by means of a hydraulic actuator and a load cell with the maximum capacity of 300 kN, centered on a steel element which was simply supported on the two loading points of the beams. Beams were tested to failure and the loads at first cracking, yielding of steel bars and failure were recorded. The deflection at middle span was recorded by the linear variable displacement transducer (LVDT) at each incremental load. All data were recorded via the software installed in the computer (see Fig. 4).

3. Results and discussion

3.1. Workability of fresh concrete mixes

The workability of fresh concrete mixes was assessed using slump test which was conducted immediately after mixing and shown in Fig. 5. It can be seen that the slump increases with the increase of fly ash proportion in the mixes meaning that fly ash contributed to improve the workability of fresh concrete. This is agree well with previous research where the improving of workability is due to the differences between the spherical shape of the fly ash particles and angular shape of the cement particles, therefore the more fly ash used to replace OPC the better workability [10, 20].

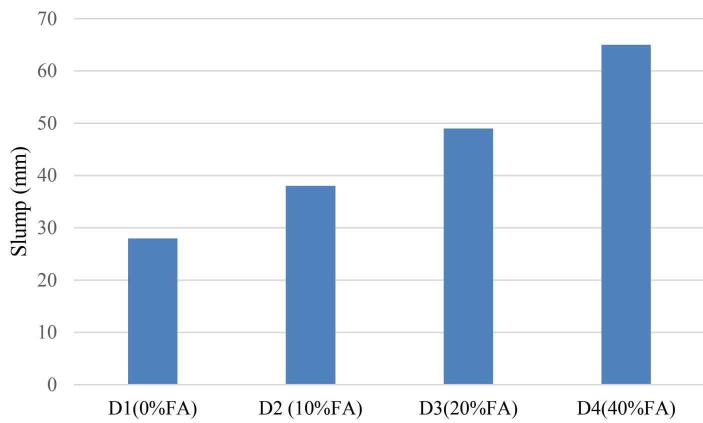


Figure 5. Slump of fresh concrete mixes

3.2. Compressive strength of hardened concrete

The compressive strengths of the control and fly ash concrete are given in Fig. 6. It can be seen that the compressive strengths of all mixes increase with ages. The 10% FA concrete achieved the higher compressive strength than that of the control at 56 days. In general, fly ash from Vinh Tan reduced the compressive strength even at 90 days, this does not agree well with the previous research on Pha Lai fly ash blend concrete as Pha Lai fly ash improved the compressive strength at later age [10]. However this agrees well with other research where the improvement of compressive strength of fly ash concrete at later age depends on the type of fly ash [21].

3.3. Flexural performance of reinforced concrete beams

Flexural performance of all group beams was assessed via the load deflection curves, the loads and deflections at first cracks, yielding of steel and failure of concrete as shown in Fig. 7. The load deflection curves of groups 1, 2 and 3 are presented in Figs. 8, 9 and 10, respectively. The summary of flexural performance of all beams is shown in Table 4.

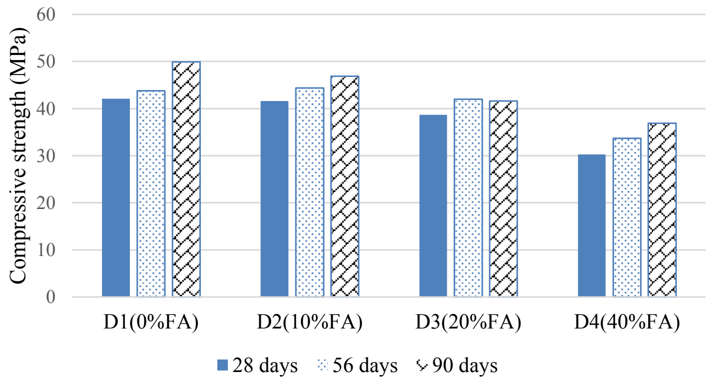


Figure 6. Compressive strengths of all concrete samples

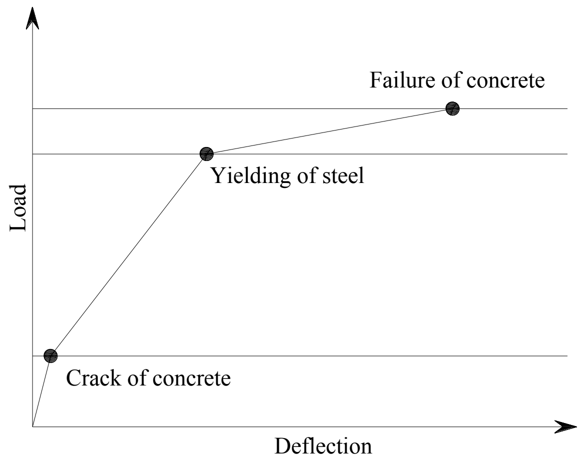


Figure 7. Typical load- deflection curve of reinforced concrete beam [15, 22]

a. Group 1

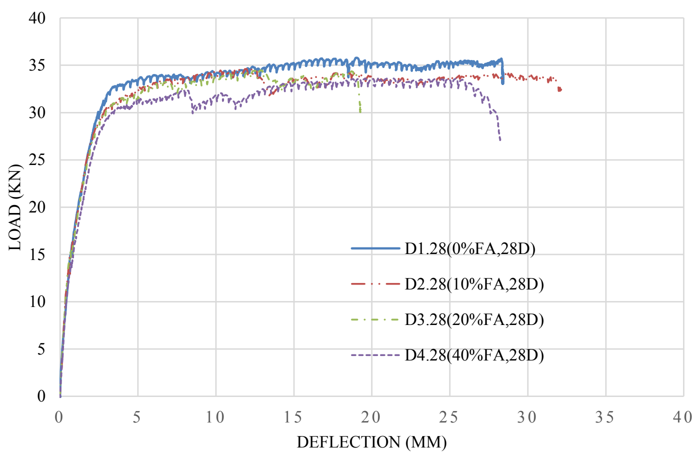


Figure 8. Load deflection curves of beams in group 1 (28 days)

Fig. 8 shows the load deflection curves of all 4 beams which are almost similar. So, it can be considered that the fly ash does not affect the load deflection curves shape of the reinforced concrete beams of group 1 tested at 28 days. From Fig. 8 and Table 4, it can be seen that the first cracking load of fly ash beams reduced in compared with the control beam without fly ash. The first cracking loads are 16.27 kN, 14.7 kN, 15.6 kN and 14.11 kN for beams D1-28 (0% FA), D2-28 (10% FA), D3-28 (20% FA) and D4-28 (40% FA) respectively representing the reduction of 9.6%, 4.1% and 13,2% for 10% FA, 20% FA and 40% FA, respectively. Within the range of this investigation, the first cracking load of 20% FA replacement beam (D3-28) is higher than that of 10%FA (D2-28) and 40%FA replacement (D4-28) beams.

Fig. 8 and Table 4 also show that the strengths of fly ash beams at yielding of steel bars reduced slightly in compared with the control beam without fly ash. At yielding of steel bars, the strength of the control beam is 32.93kN while the strengths of the fly ash beams are 32.27 kN, 31.6 kN and 30.07 kN for beams D2-28 (10%FA), D3-28 (20%FA) and D4-28 (40%FA) respectively representing the reduction in strengths of 2%, 4%, and 8.7% for 10% FA, 20% FA and 40% FA, respectively. In addition, fly ash reduced slightly the ultimate strengths of reinforced concrete beams at 28 days of curing in water. The ultimate strength of the control sample (0% FA) is 35.8kN while the ultimate strengths of the fly ash samples are 34.63 kN, 34.46 kN and 33.6kN presenting the reduction in ultimate strengths of 3.3%, 3.7% and 6.1% for 10% FA, 20% FA and 40% FA, respectively. This agrees with the reduction in compressive strength of concrete when fly ash was used to replace Portland cement.

Table 4. Summary of flexural performance of all beams

Group	Beam ID	Load at first cracking (kN)	Load at Yielding of steel (kN)	Ultimate load (kN)	Difference in ultimate load (%)	Deflection at first cracking (mm)	Deflection at yielding of steel Δy (mm)	Ultimate deflection Δu (mm)	Difference in ultimate deflection (%)	Failure mode
1	D1-28	16.27	32.93	35.80	-	0.8	3.87	28.43	-	Flexure
	D2-28	14.7	32.27	34.63	−3.3	0.64	3.71	32.8	15.4	Flexure
	D3-28	15.6	31.6	34.46	−3.7	0.84	3.31	19.26	−32.3	Flexure
	D4-28	14.11	30.07	33.6	−6.1	0.73	3.5	26	−8.5	Flexure
2	D1-56	16.43	30.6	37.48	-	0.60	2.2	20.1	-	Flexure
	D2-56	17.2	29.85	36.65	−2.2	0.71	2.42	16.98	−15.5	Flexure
	D3-56	15	29.3	36.43	−2.8	0.42	2.18	16.03	20.2	Flexure
	D4-56	15.6	29.2	35.65	−4.9	0.58	2.19	21.43	6.6	Flexure
3	D1-90	15.15	31.89	38.24	-	0.45	3.32	19.3	-	Flexure
	D2-90	16.6	31.18	36.28	−5.1	0.49	2.75	19.84	2.8	Flexure
	D3-90	15.5	30.73	35.91	−6.1	0.43	2.41	14.14	−2.7	Flexure
	D4-90	15.9	30.8	37.79	−1.2	0.62	3.3	36.8	9.1	Flexure

Fig. 8 and Table 4 show the deflections of all four beams at the first cracking, yielding of steel and failure. The deflections at the first cracking of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 0.8 mm, 0.64 mm, 0.84mm and 0.73mm respectively. There is a slight reduction in deflections of 10% FA and 40% FA but there is a slight increase in deflection of 20% FA. The deflections at the yielding of steel of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 3.87 mm, 3.71 mm, 3.31 mm and 3.5 mm respectively representing very small reductions in deflection of the fly ash beams in compared with the control beams without fly ash. The deflections at failure of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 28.43 mm; 32.8 mm, 19.26 mm and 26 mm, respectively. There is an increase in deflection of 15% for 10%FA whereas there are reductions in deflection of 32.8% and 8.5% for 20% FA and 40% FA respectively.

In conclusion for group 1 at 28 days, the fly ash does not affect the load deflection curves shape of the beams. The fly ash reduces slightly the first cracking load (within the range of 4.1% to 13.2%), the yielding steel loads (within the range of 2-8.7%), the ultimate loads (within the range of 3.3% to 6.1%). Within the range of this investigation, the deflections of fly ash beams reduced in compared with the control beam at first cracking and yielding of steel, but there was an increase in ultimate deflection (deflection at failure) for 10% FA beam.

b. Group 2

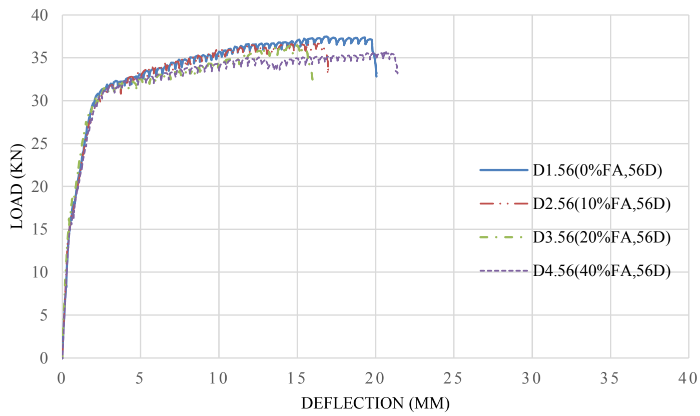


Figure 9. Load deflection curves of group 2 beams (56 days)

Fig. 9 shows the load deflection curves of all 4 beams which are greatly similar. So, similar to group 1 beams it can be considered that the fly ash does not affect the load deflection curve shapes of the reinforced concrete beams of group 2 tested at 56 days. From Fig. 9 and Table 4, it can be seen that the first cracking load of fly ash beams 20% FA and 40% FA reduced in compared with the control beam without fly ash while the first cracking load of 10% FA beam increased slightly. The first cracking loads are 16.43 kN, 17.2 kN, 15.0 kN and 15.6 kN for beams D1-56 (0% FA), D2-56 (10% FA), D3-56 (20% FA) and D4-56 (40% FA) respectively representing the reductions of 9.6%, 4.1% and 13.2% for 10% FA, 20% FA and 40% FA respectively. The first cracking load of 10% FA beam (D2-56) is higher than that of 20% FA (D2-56) and 40% FA (D4-56) beams.

Fig. 9 and Table 4 also show that at the yielding of steel bars, the strengths of fly ash beams reduced slightly in compared with the control beam without fly ash. At the yielding of steel bars, the strengths of the control beam is 30.6 kN while the strengths of the fly ash beams are 29.9 kN, 29.3 kN and 29.2 kN for beams D2-56 (10% FA), D3-56(20% FA) and D4-56 (40% FA), respectively representing the reduction in strengths of 2.3%, 4.2%, and 4.6% for 10% FA, 20% FA and 40% FA, respectively. Fig. 9 and Table 4 also present that the fly ash reduced slightly the ultimate strengths of reinforced concrete beams at 56 days of curing in water. The ultimate strength of the control sample (0% FA) is 37.48 kN while the ultimate strengths of the fly ash samples are 36.65 kN, 36.43 kN and 35.65 kN presenting the reductions in ultimate strengths of 2.2%, 2.8% and 4.9% for 10% FA, 20% FA and 40% FA. Similar to group 1, this agrees with the reduction in compressive strength of concrete when fly ash was used to replace Portland cement.

Fig. 9 and Table 4 show the deflections of all four beams at the first cracking, yielding of steel and failure. The deflections at the first cracking of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 0.6 mm, 0.71 mm, 0.42 mm and 0.58 mm respectively. There is a slight reduction in deflections of 20% FA and 40% FA but there is an slight increase in deflection of 10% FA. The deflections at the yielding of steel of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 2.2 mm, 2.42 mm, 2.18 mm and 2.19 mm respectively representing very small differences in deflections of the fly ash beams in compared with the control beams without fly ash. The deflections at failure of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 20.1 mm; 17 mm, 16.03 mm and 21.43 mm, respectively. There is an very small increase in deflection of 6.6% for 40% FA whereas there are reductions in deflection of 15.5% and 20.2% for 10% FA and 20% FA, respectively.

In conclusion for group 2 at 56 days, the fly ash does not affect the load deflection curves of the beams. Within the range of investigation, the fly ash reduces slightly the first cracking load for 20% FA and 40% FA, but increases for 10% FA. The fly ash reduces slightly the yielding strengths (within the range of 2.3% - 4.6%), the ultimate loads (within the range of 2.2% to 4.9%). There are small differences in deflections of fly ash beams and control beam at first cracking, yielding and failure.

c. Group 3

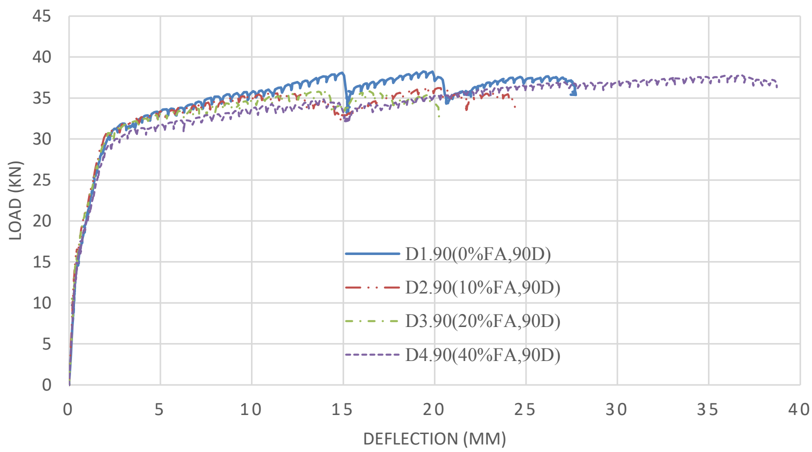


Figure 10. Load deflection curves of group 3 beams (90 days)

Fig. 10 shows the load deflection curves of all 4 beams which are almost similar, except for beam D4-90 where the ultimate deflection is far higher than that of other beams. So, it can be considered that the fly ash generally also does not affect the load deflection curves of the reinforced concrete beams of group 3 tested at 90 days. From Fig. 10 and Table 4, it can be seen that the first cracking loads of fly ash beams were a little bit higher than that of the control beam without fly ash. The first cracking loads are 15.15 kN, 16.6 kN, 15.5 kN and 15.9 kN for beams D1-90 (0% FA), D2-90 (10% FA), D3-90 (20% FA) and D4-90 (40% FA), respectively.

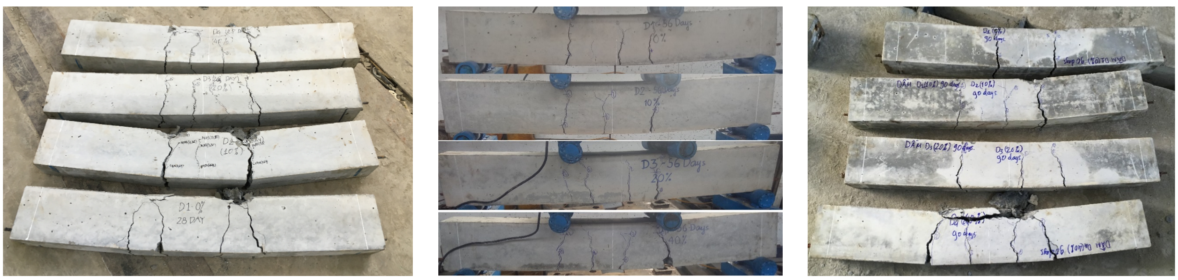
Fig. 10 and Table 4 also show that the strengths of fly ash beams at yielding of steel bars reduced slightly in compared with the control beam without fly ash. At yielding of steel bars, the strengths of the control beam (D1-90) is 31.89 kN while the strengths of the fly ash beams are 31.18 kN, 30.73 kN and 30.8 kN for beams D2-90 (10% FA), D3-90 (20% FA) and D4-90 (40% FA) respectively. Fig. 9 and Table 4 also present that the fly ash reduced slightly the ultimate strengths of reinforced concrete beams at 90 days of curing in water. The ultimate strength of the control sample (0% FA) is 38.24 kN while the ultimate strengths of the fly ash samples are 36.28 kN, 35.91 kN and 37.79 kN presenting the reduction in ultimate strengths of 5.1%, 6.1% and 1.2% for 10% FA, 20% FA and 40% FA.

Fig. 10 and Table 4 show the deflections of all four beams at the first cracking, yielding of steel and failure. The deflections at the first cracking of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 0.45 mm, 0.49 mm, 0.43 mm and 0.62 mm respectively. There is a slight reduction in deflection of 20%FA but there are slight increases in deflections of 10% FA and 40% FA. The deflections at the yielding of steel of the control beam (0% FA), 10% FA, 20% FA and 40% FA are 3.32 mm; 2.75 mm, 2.41 mm and 3.3 mm respectively representing very small reductions in deflections of the fly ash beams in compared with the control beams without fly ash. The deflections at failure of the control beam (0% FA), 10% FA, 20% FA and 40%FA are 19.3 mm, 19.84 mm, 14.14 mm and 36.8 mm respectively. There are increases in deflections of 2.8% and 9.1% for 10% FA and 40% FA respectively whereas there is a reduction in deflection of 2.7% for 20% FA.

In conclusion for group 3 at 90 days, the fly ash generally does not affect the load deflection curves of the beams. Within the range of investigation, the fly ash increase slightly the first cracking but reduces slightly the yielding steel loads and the ultimate loads (within the range of 1.2% to 6.1%). The fly ash does not affect much in deflections first cracking and yielding of steel, but there is an increase ultimate deflection (deflection at failure) for 40% FA beam showing more ductility of 40% FA beams than others.

3.4. Failure modes and cracking pattern

All beams of 3 groups were flexurally tested under four point bending. In terms of crack morphology and crack progression, the behaviour of the all beam groups 1, 2 and 3 was visually identical as shown in Fig. 11. The results show that all beams failed in flexure. It can be seen that the beams typical failed by first cracking of the concrete at the central underside of the beams (tensile strength area), and continued with the yield of the reinforcing steel bars (lower tensile reinforcement) to concrete crushing in the compressive zone, which is ductile mode of failure, normally called tension failure.



(a) Group 1 (28 days) (b) Group 2 (56 days) (c) Group 3 (90 days)

Figure 11. Failure modes and cracking pattern of beams

The crack patterns of all group beams are given in Fig. 11 which are almost similar for all beams. Crack progression in the beams began with the appearance of flexural cracks at the middle of the maximum moment region, followed by additional flexural cracks forming at the load points when the load was increased. Upon further increasing the applied load, the majority of the flexural cracks developed vertically.

4. Conclusions

Within the range of investigation, the main conclusions from the results reported in this paper are as follows:

- Locally sourced fly ash does not affect the load and deflection curves of RC beams. At 28, 56 and 90 days of age, the load deflection curves of all control and fly ash beams are almost similar.

- Fly ash reduces slightly the flexural loads of reinforced concrete beams when 40% was used to replace OPC. The ultimate strengths of 40% fly ash reinforced concrete beams reduced by 6.1%, 4.9% and 1.2% in compared with the control beams at 28 days, 56 days and 90 days respectively.

- Fly ash reduced slightly the strength of reinforced concrete beams at yielding of steel bars at 28 days, 56 days and 90 days.

- Failure modes and cracking patterns of all the control and fly ash beams are very similar at all test ages.

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