Stress-strain response of high-volume fly ash self-compacting concrete (HVFA-SCC) under uniaxial loading and its effect on the reinforced HVFA-SCC nominal strength

Stefanus A Kristiawan, Sunarmasto, Agus S Budi and Desi CK

1. Introduction

- Sustainability has become the main issue in the development of various infrastructures and has become a major issue affecting the activities of concrete industries around the globe.
- In the development of concrete technology, sustainability may be achieved by optimizing concrete mix design, improving the durability of concrete, using materials with less impact to the environment, etc.
- Many of the new concrete structures already show a sign of decay (e.g. honeycomb) which impairs its durability. A solution has been found by Ozawa and Okamura for this case with the use of self-compacting concrete (SCC).
- SCC is a special type of concrete with the ability to flow and fill any recess within a formwork under its own weight without any aids of vibration.
- Fly ash is abundantly available as one of the coal combustion products in the coal-fired Power Plant. An inclusion of fly ash as partial cement substitution in SCC has been widely investigated. It has been shown that a very high inclusion of fly ash up to 70% replacement level is possible.

- One of such approaches is by the use of waste material such as fly ash to partially substitute cement. An inclusion of high volume fly ash (HVFA) is possible in the development of self-compacting concrete (SCC).
- For successful utilization of SCC incorporating high volume fly ash as structural element, there is a need to further identify the mechanical behavior of this concrete as a basis to develop an analysis of its structural behavior.
- In term of flexural behavior of RC beam element, the nominal strength of the beam made from conventional concrete is analyzed on several assumptions :

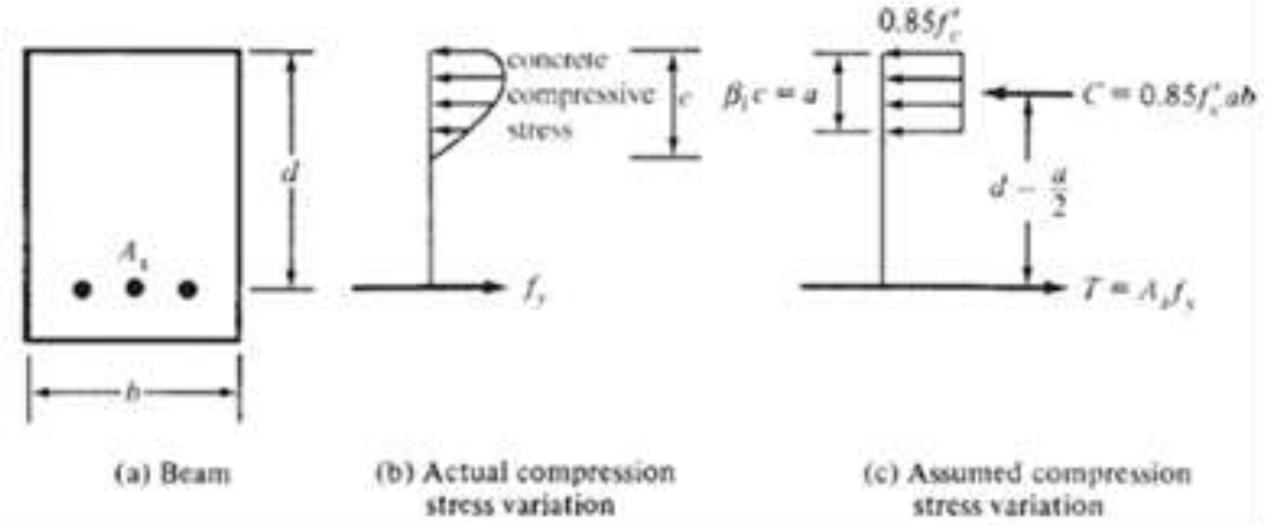


Fig. 1. Compression and tension couple at nominal moment

- The equality of the curved compression diagram of Fig. 1(b) and the rectangular diagram of Fig. 1(c) may not applicable for non-conventional concrete.

- The analysis of flexural strength of beam made from non-conventional concrete should be developed on the basis of the unique compression stress-strain diagram of that concrete.
- This paper aims to present the compression stress-strain diagram of SCC incorporating high volume fly ash and compared the behavior with that of conventional concrete and then analysis of nominal flexural strength of RC beam with SCC incorporating high volume fly ash is proposed and verified with the experimental results.

2. Materials

Table 1. The proportion of concrete mixtures (kg) as per 1 m3

Specimen ID	Cement	Fly ash	Coarse Aggregate	Fine Aggregate	Water	Superplasticizer
HVFA-SCC	294	442	703	578	211	7.3
NC	388	-	942	771	225	-

Fig. 2. Slump flow of HVFA-SCC of about 700 mm

Table 2. Chemical composition of fly ash (in %)

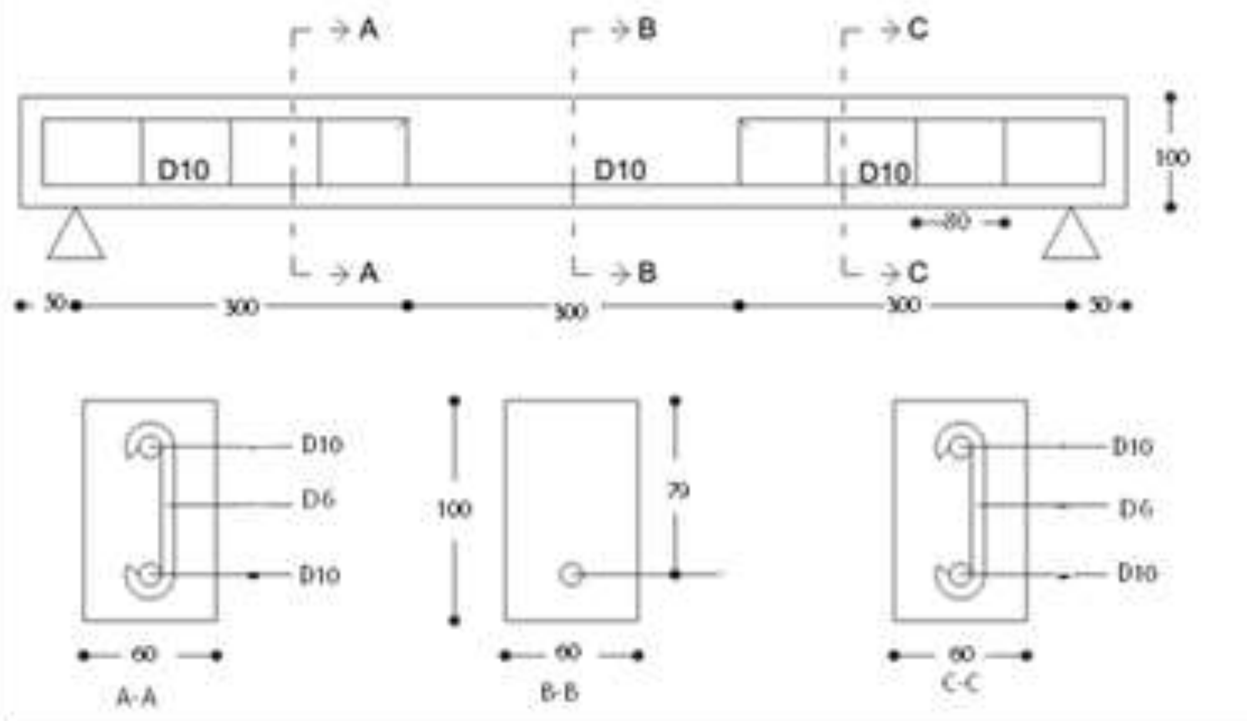
SiO2	Al2O3	Fe2O3	TiO2	CaO	MgO	K2O	Na2O	P2O5	SO3	MnO2
45.27	20.07	10.59	0.82	13.32	2.83	1.59	0.98	0.41	1	0.07

Table 3. Properties of aggregates

Aggregate	Absorption	Bulk specific gravity (SSD)	Fineness modulus
Fine	1%	2.66	2.98
Coarse	5.3%	2.51	5.69

3. Specimens

- Cylinders of 7.5x150 mm, for measurements of mechanical behaviors of the concretes under axial loading.
- Cylinders of 150x300 mm, for measurements of compressive strengths.
- Flexural strength of RC concretes beam specimens :



4. Testing

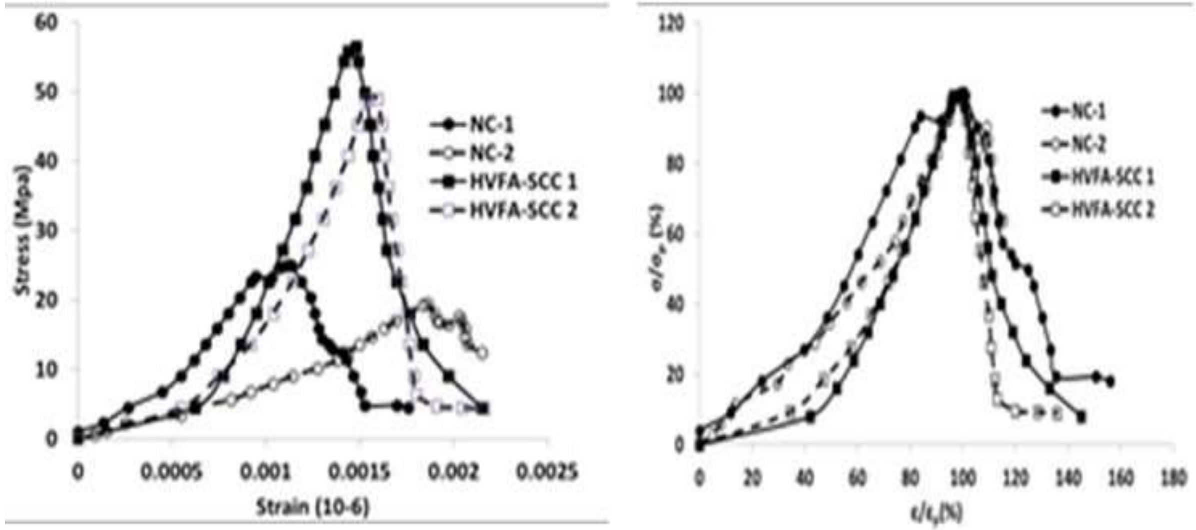
- The compressive strength and mechanical behavior of the concretes under axial loading were tested using Universal Testing Machine (UTM).
- Four points of loading were carried out to determine the flexural behavior of RC beams.

Fig. 4. Flexural strength test of RC beam

5. Results and discussion

- The average 28-day compressive strength of the NC and HVFA-SCC is 27.5 MPa and 52.84 MPa, respectively.

- The difference of actual stress-strain diagrams between NC and HVFA-SCC can be observed from Fig. 5(a)
- The HVFA-SCC tends to show a steeper curve either at the ascending or descending brand.



a. Actual stress-strain values

b. Normalized stress-strain values

Fig. 5. Compression stress-strain behavior of NC and HVFA-SCC

- The area under stress-strain diagrams between the two concretes is compared.
- The comparison should be made on the normalized stress-strain diagram as presented in Fig. 5(b).
- It is found that the average area under the normalized stress-strain curves of HVFA-SCC is about 64% of the corresponding NC.
- This value will be used to modify the equivalent rectangular compression diagram of Fig.1(c) for calculating the nominal flexural strength of HVFA- SCC.

Typical load-deflection behavior of reinforced HVFA-SCC beams under flexural loading is presented in Fig.6

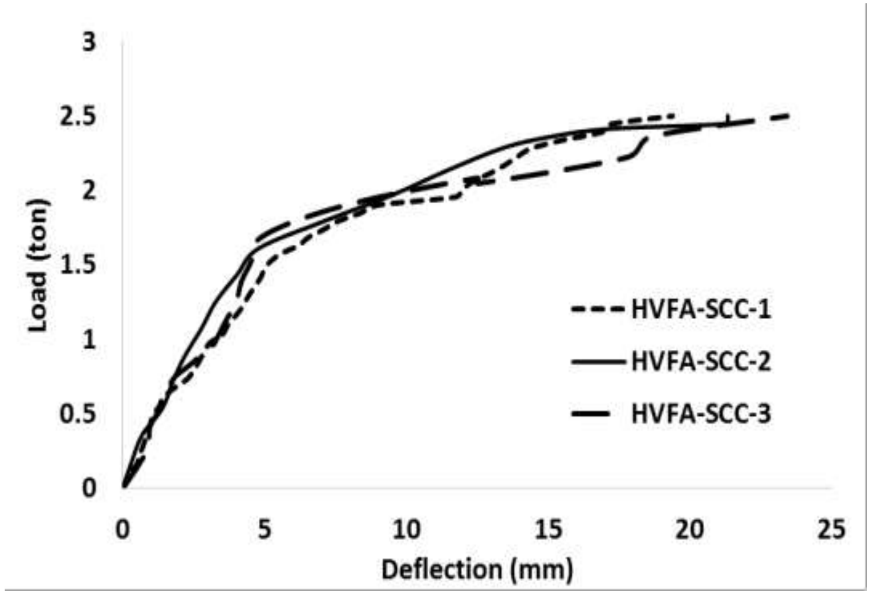


Fig. 6. Load-deflection behavior of reinforced HVFA-SCC beams under flexure

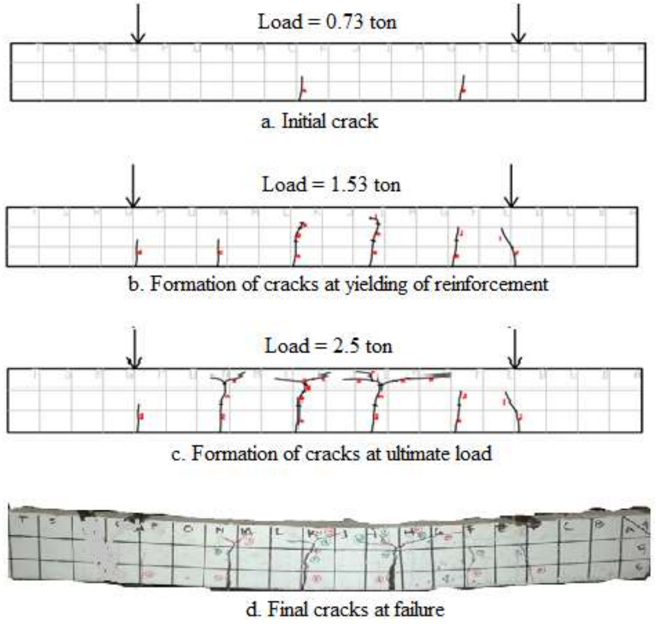


Fig. 7. Formation and propagation of cracks

- The nominal flexural strength of reinforced HVFA-SCC beam section could be computed using similar formula as that of NC beam (see Figure 1):

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) \quad \text{...} \; (1)$$

- However, for HVFA-SCC the value of *C* should be modified as follows:

$$C = (0.85 f_c' 0.64ab) \quad \text{...} \; (2)$$

- Equation (2) implies that the rectangular diagram of Fig. 1(c) is assumed to have a depth of 0.64 *a,* in order to give a comparable area to the area under the stress-strain diagram of the HVFA-SCC.
- Given the loading span, this nominal flexural strength is equivalent to a load of 2.37 ton which is close to the ultimate load determined experimentally.

6. Conclusions

- The compression stress-strain curve of HVFA-SCC is diverse to that of NC in which the average area under the curve represents 64% to that of NC.
- The equivalent rectangular compression stress for calculating the nominal flexural strength of reinforced HVFA-SCC section should be modified by a factor of 0.64.
- Based on this theoretical analysis, a close agreement exists between the predicted nominal flexural strength and the experimental result.

References

1. H. Okamura, K. Ozawa, Concr. Lib. JSCE. **25**, 107-120 (1995).
2. P. Dinakar, Mag. Concr. Res. **64**, 401-409 (2012)
3. J. Khatib, Constr. Build. Mater. **22**, 1963-1971 (2008)
4. S.A. Kristiawan, M.T.M. Aditya, *Proc. Eng.* **125**, 705-712 (2015)
5. S.A. Kristiawan, Wibowo., S. As'ad, B.S. Gan, D.P. Sitompul, *Advances in Civil, Architectural, Structural and Constructional Engineering*, 31-35.
6. S.A. Kristiawan, Sunarmasto, G.P. Tyas, *IOP Conf. Ser.: Mater. Sci. Eng.* **107**, 012029
7. R. Siddique, *Mater. Des.* **32**, 1501-1507 (2011)
8. Sunarmasto, S.A. Kristiawan, *Appl. Mech. Mater.***754-755**, 447-451 (2015)
9. J.C. McCormac, R.H. Brown, *Design of reinforced concrete (Ninth Edition)* (John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ, 2014)