Journal of Sustainable Engineering: Proceedings Series 1(2) 2019
doi:10.35793/joseps.v1i2.30

Experimental investigation of the flexural ductility of singly reinforced concrete beam using normal and high strength concrete

Atur P. N. Siregar

Department of Civil Engineering, Faculty of Engineering, Tadulako University
Jl. Soekarno-Hatta Km 9, Tondo, Palu, Sulawesi Tengah, INDONESIA.

E-mail: atur_pns@yahoo.com

Abstract. This paper discusses and reports based on the experimental investigation of the flexural ductility of singly reinforced normal strength and high strength concrete beams. Compressive concrete strength of 40 and 95 MPa were employed to create singly reinforced normal strength and high strength concrete beams, respectively. Fourteen samples made of normal and high strength concrete were engaged to observe the flexural ductility behaviour of beams on the basis of four point bend testing. Analysis on the basis of the flexural cracking, ultimate failure and curvature ductility were carried out to derive the comparison of singly reinforced normal strength and high strength beams. The beams using high strength concrete revealed a higher ductility ratio than that of normal strength concrete, i.e. 4.50 for high strength concrete and 2.60 for normal strength concrete.

1. Introduction

Compressive strength of concrete below 50 MPa has been widely used in construction. Over the past 25 years, however, there has been increasing use of, and reliance on, high strength concrete (fc > 50 MPa) for the creation of ultra-high-rise buildings and long-span bridges [1]. The increase of compressive strength of concrete rises the degree of stiffness and as a consequence of the increased stiffness of concrete may induce the ductility of reinforced concrete (RC) structure. An ductile RC structure is of interest of engineer in designing a structure as it is an important aspect for safety intents of occupant. The ductility of RC structures which is the ability of sustaining deformation without a substantial reduction in the flexural capacity of the member [2] is dependent on the tensile reinforcement ratio, the amount of stirrup, and the strength of concrete [3]. A number of experiments has been conducted to observe the effect of the tensile reinforcement ratio, and the amount of stirrup on the concrete strength of less than 50 MPa [4, 5, 6] on the ductility of RC structure, but only a few experiments have been carried out on the concrete strength of greater than 50 MPa [7]. Since the compressive strength of concrete is a parameter influencing on the ductility of RC structure and there remains a lack of investigation on this area, the objective of this study is to investigate the effect of concrete strength on the flexural ductility of RC structure through singly reinforced concrete beam.

2. Determination of Flexural Ductility of RC Beam

An adequate measure of the ductility of a member subjected to flexure load is the ductility ratio (μ) of the ultimate curvature attainable without significant loss of strength (ϕ_u) to the curvature corresponding to the first yield of the tension reinforcement (ϕ_y), see Figure 1 [2, 7, 8]:

$$\boldsymbol{\mu} = \frac{\boldsymbol{\phi_u}}{\boldsymbol{\phi_y}} \tag{1}$$

By definition, the degree of the μ is essentially dependent on the yield strength of reinforcing bars and strength of concrete.

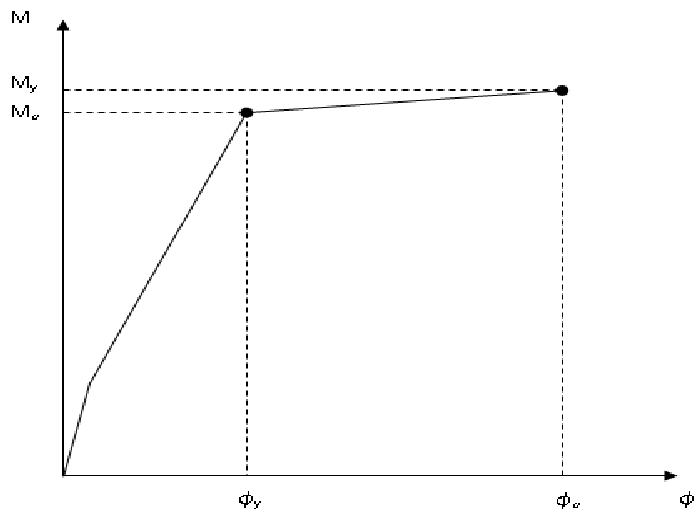

Figure 1. A tri-linear moment – curvature relationship [2]

3. Experiment

3. 1. Materials and Specimen Preparations

The coarse aggregate used in this study was a river gravel with the maximum and minimum particle size of 16 mm and 5 mm respectively. The sand fraction comprised a weathered river gravel of size ranging from 4 mm down to 0.30 mm. The Portland cement binder employed was a CEM Type I material, with a specific surface area of 338 m^2/kg, incorporating Pulverized Fuel Ash (PFA) complying with BS EN450-S category B. A slurry-based silica fume complying with BS EN 12363-1 was employed in some of the mixes. A poly-carboxylate polymer based super plasticiser was employed to allow adequate workability and ensure full compaction of the concrete. The proportions of each material used for the concrete mixes produced are shown in Table 1.

Table 1 Mix Proportion

Mix	w/b*	Unit weight (kg/m^3)					
		aggregate	cement	PFA	Silica fume	water	Super-plasticiser
C1	0.20	868.85	296.30	41.47	29.63	91.85	1.23
C2	0.55	868.85	367.40	-	-	110.21	0.81

*w/b = ratio of water to binder materials

It is well established that the workability of concrete has a profound effect on the ease of compaction of the fresh material and that incomplete compaction can adversely affect the properties of the resulting hardened concrete [9]. As a consequence it was decided to keep the workability for all the mixes used in this study constant, i.e. the slump value for all the mixes was 120 ± 20 mm. This was achieved by varying the quantity of super plasticiser in the mixes, see Table 1.

The compressive strength of the hardened concrete was determined by crushing at least nine 100 x 100 x 100 mm cubes following BS EN 12390: Part 3(2000) and slump test was determined by a standard slump following BS EN 2006: Part I (2003). The results are tabulated in Table 2.

The geometry of the beam specimen and the properties of reinforcing bars used in the experiment are shown in Figure 2. Fourteen beam specimens comprised of seven specimens using normal strength concrete and seven specimens using high strength concrete were employed in this study and all of the specimens were demoulded approximately 24 hours after casting and water cured at 22 ± 2 °C for 30 days prior to testing

Table 2 Slump value and compressive strength of hardened concrete

Mix	Slump			Compressive strength		
	mm	N*	S*	MPa	N	S
C1	115	3	6.3	94.8	9	2.6
C2	130	3	7.8	68.4	9	0.8

N= number of test specimens, S = Standard deviation of sample

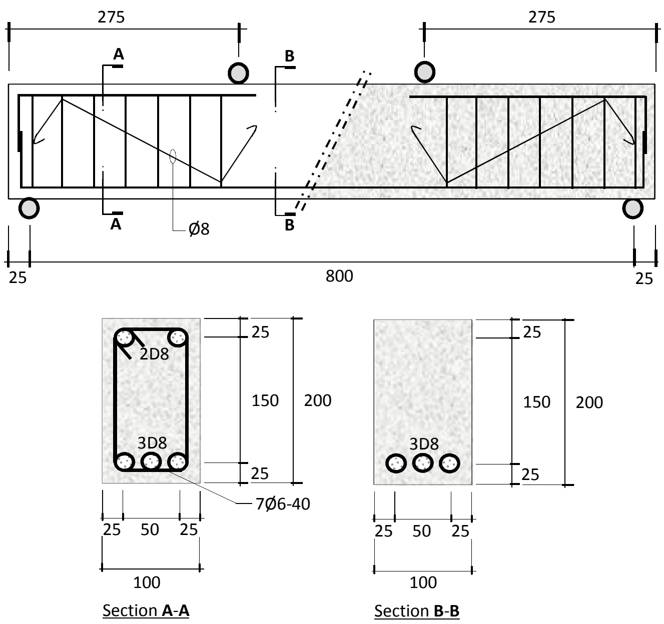

Figure 2. Dimension of beam and position of reinforcing bars

3. 2. Four-point Bend (FPB) Test Set up

The associated test arrangement of FPB as shown in Figure 3 was carried out using a servo-hydraulic closed-loop testing machine with a maximum capacity of 600 kN. A 10 kN capacity load cell was used to measure the applied load. The loading rate of all the specimens tested was controlled by applying a vertical displacement of 0.01 mm/s [10]. The vertical deflection of the beam was measured at the middle of RC beam where the critical deflection were occurred during the testing using a calibrated LVDT having a capacity and linearity of 7.5 mm and ± 0.0007 mm, respectively.

4. Results and Discussions

4. 1. Flexural Cracking and Ultimate Failure

Initial flexural cracking of RC beam appears during service loading while the principal stress exceeds the maximum tensile strength of concrete and the propagation of initial flexural cracking of concrete becoming apparent flexural cracks (Figure 4a and 5a) affects the flexural stiffness of RC beam which is reflected by the load-deflection curve as shown in Figure 6.

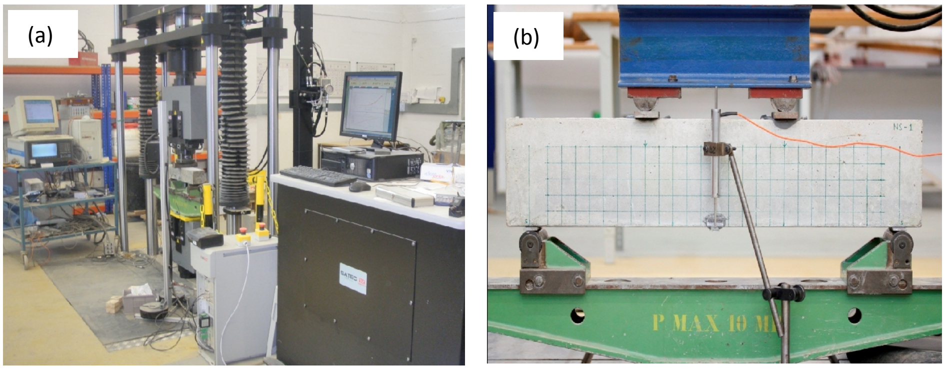

Figure 3. FPB test set up (a) a servo-hydraulic closed-loop testing machine with a maximum capacity of 600 kN, and (b) applied loading frame

The stiffness of RC beam begins to decline as the initial cracking of concrete is occurred. In reinforced normal strength concrete (RNSC) beam, the applied load (P_{cr}) of 25.03 kN causes the initial cracking of concrete at which the mid-span deflection of beam (δ_{cr}) is 0.31 mm. The flexural stiffness of beam represented by the degree of green-line slope (Figure 6) reduces following the propagation of cracks of concrete. Compared to the reinforced high strength concrete (RHSC) beam, the applied load of 27.66 kN which is higher by 10.51 % than of RNSC beam creates the initial cracking of concrete at which the mid-span deflection of beam is 0.25 mm (lower by 19.4% than that of RNSC beam). On the other hand ultimate failure of RC beam made of normal strength concrete gives a sign of compressive failure of concrete at the top fiber of beam section, but a distinct tendency of ultimate failure of high strength concrete in which concrete at top fiber of beam section does not sign a compressive failure.

Whilst the reinforcement of RC beam achieves the yield strength, the applied load (P_y) on both the RNSC and RHSC beams are relatively same, i.e. approximately 127.9 kN, but the mid-span deflection of beam (δ_y) are of 2.94 and 2.70 mm for RNSC and RHSC respectively. Those experimental facts indicate that the grade of ductility of RC beam is noticeably dependent on the reinforcing bars in terms of number and the yield strength of bars as pointed out by [2] and however the increase of concrete strength provides insignificant effect on the ductility of RC beam when the yield strength of reinforcing bars are not achieved.

4. 2. Ductility

Based on the curvature ductility of the RC beam, the μ which represents the degree of flexural ductility of RC beam as proposed by investigators [2, 5, 6, 7, 8], the RHSC beam provides a value of 4.5 whereas the NRSC beam gives a value of 2.60. It indicates that the compressive strength of concrete affects the flexural ductility of RC beam. Since this approach is to compare the response of RC beam on subjected load, the concrete strength which contributes significantly on the bond strength between reinforcing bars and concrete plays important role in influencing performance and behaviour of reinforced concrete structure by reducing the bond-slip effect of steel bars [11]. In reinforced concrete using ribbed bars, the transmitting stress depends on three phenomena [11, 12]: chemical adhesion between the cement and the steel, friction between concrete and steel, and mechanical interlocking of steel deformations and concrete. As a consequence of those mechanisms is to increase the ductility of RC beam.

Journal of Sustainable Engineering: Proceedings Series 1(2) 2019 doi:10.35793/joseps.v1i2.30

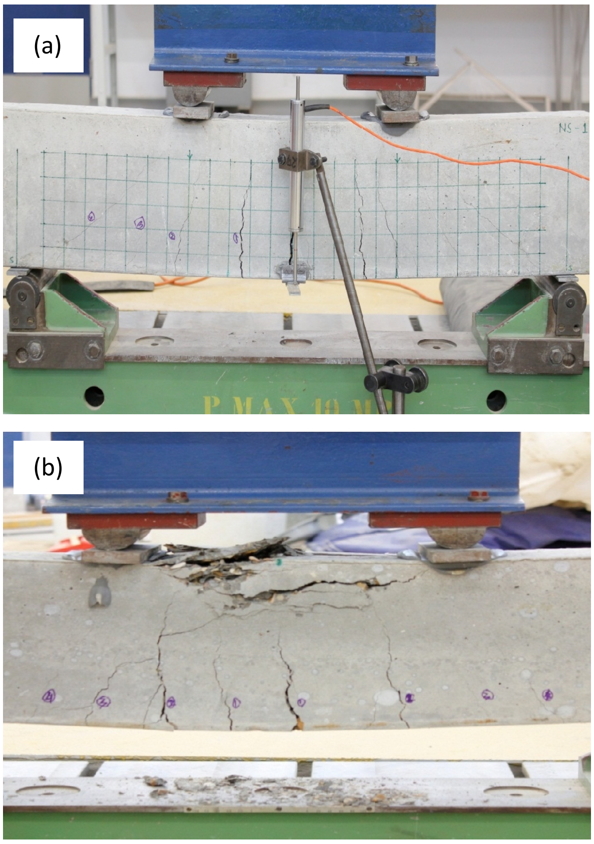

Figure 4. RNSC beam with typical (a) flexural cracking, and (b) ultimate failure

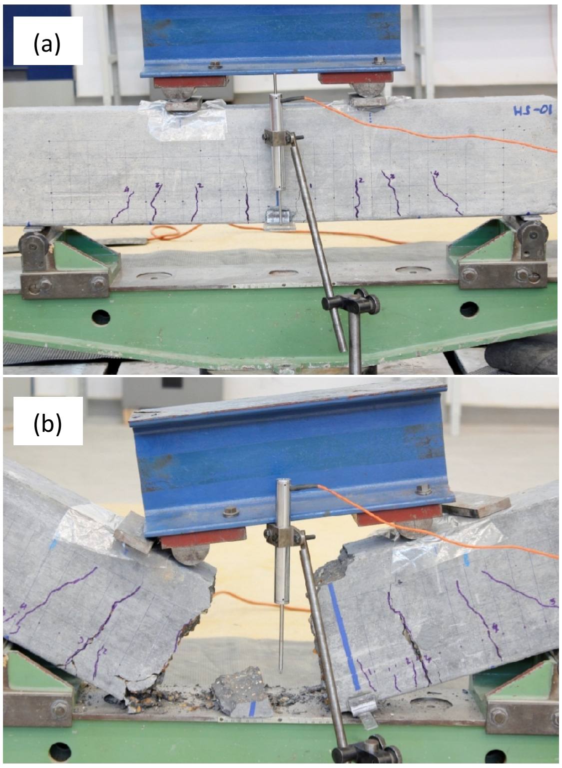

Figure 5. RHSC beam with typical (a) flexural cracking, and (b) ultimate failure

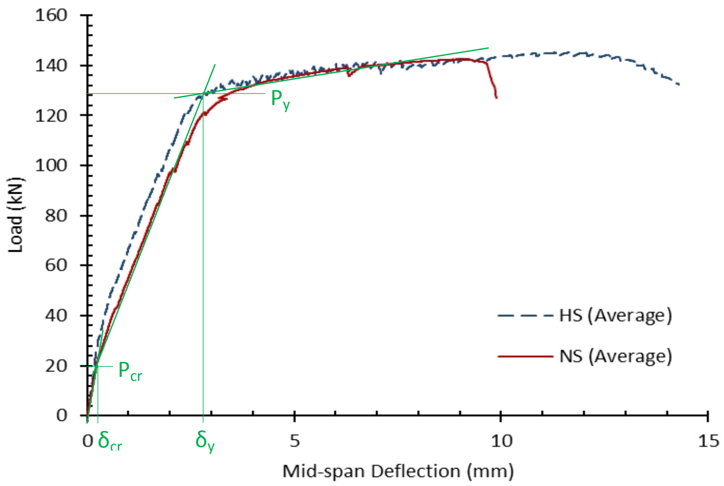

Figure 6. Total load against mid-span deflection curve of RNSC and RHSC beams

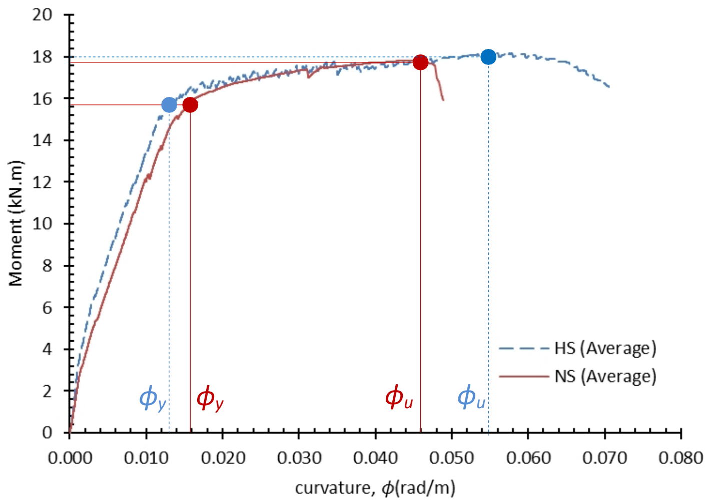

Figure 7. Moment-curvature curves of RNSC and RHSC beams

Figure 6 and 7 show that the diagram of high strength concrete tends to have a ’jig-saw’ curve after the first yielding of bar is achieved. The ’jig-saw’ curve indicates the fracture process of concrete is controlled by mechanical interlocking of steel deformations and concrete due to the type of bars used in the beam are ribbed steel bars. The ribbed of the steel bars effectively govern in resisting applied stress along the steel bars owing to a radial wedging action in concrete. The strength of concrete is then a significant factor influencing the wedging action. During the applied load subjects to the bending of beam, the steel bars are intended to be pulled out from the concrete. The wedging action of steel bars increase with the increasing of concrete strength. Consequently, the ductility ratio of RC beam inclines as the use of type of bars and concrete strength.

According to the current experimental results on ultimate failure of RC beams in terms of the flexural cracks and the spalling of concrete cover, albeit it is a qualitative analysis, the beams using high strength concrete tend to have a less series of distributed flexural cracks and spalling of concrete cover compared to the RNSC beam. The mechanical interlocking of steel deformations and concrete as aforementioned in the previous paragraph is dictated the ultimate failure behaviour of RC beams. The use of low strength of concrete is a reason of having a greater series of distributed flexural cracks due to the less tensile strength of concrete, and the bars tends to have a displacement slip rather than wedging action as a consequence that in the ultimate failure the RNSC beam the spalling of the concrete cover is not occurred. Hence, the diagram of RNSC beam after the reinforcement yielding provides relatively smooth curve compared to RHSC beam and the RNSC beam ends up with a series of greater distributed flexural cracks and none of concrete cover spalling.

5. Conclusions

As the main objective of this study is to investigate the influence of concrete strength on the flexural ductility of singly reinforced concrete beam, and on the basis of experimental investigation, some conclusions can be drawn:

1. The increase of compressive strength of concrete in RC beam tends to have an insignificant contribution on the flexural ductility of structure.
2. The effect of type of steel bars (ribbed steel bars) on the increase of flexural ductility of singly RHSC beam is greater than that of singly RNSC beam.
3. The ultimate failure of singly RNSC beam creates a higher number of cracks and none of spalling of concrete cover than that of singly RHSC beam.
   The ultimate failure of singly RNSC beam creates a higher number of cracks and none of spalling of concrete cover than that of singly RHSC beam.

Acknowledgement

The author would like to thank to The Higher Education Directorate General, Ministry of National Education, Republic of Indonesia for financial support, and also to University of Surrey for infrastructures, facilities and laboratories.

References

[1] American Concrete Institute 2010 *Report on High Strength Concrete* (ACI-363R-10 Farmington Hills, USA).
[2] Park R and Ruitong D 1988 Ductility of Doubly Reinforced Concrete Beam Section *ACI Structural Journal* **85** 217.
[3] Xie Y, Ahmad S, Yu T, Hino S and Chung W 1994 Shear Ductility of Reinforced Concrete Beams of Normal and High Strength Concrete *ACI Structural Journal* **91** 140.
[4] Noor M A 2004 Shear Ductility of Reinforced Concrete Beams of Normal and High Strength Concrete *BSRM seminar* 1.
[5] Prabir C B, Shylamoni P and Roshan A D 2004 Characterisation of Steel Reinforcement for RC Structures: An overview and related issues *The Indian Concrete Journal* 19-30.
[6] Chon M Z and Riva P M A 1991 Flexural Ductility of Structural Concrete Sections *PCI journal* 72.
[7] Arslan G and Cihanli E 2011 Curvature Ductility Prediction of Reinforced High-strength Concrete Beam Sections *Journal of Civil Engineering and Management* 16(4) 462.
[8] Pillai S U and Menon D 2007 *Reinforced Concrete Design* Tata McGraw-Hill Ltd 2nd edition Delhi India p.771.
[9] Neville A M 1995 *Properties of Concrete* Longman group Ltd 4th edition Essex UK p.182.
[10] Zhang X X, Ruiz G, Yu R C and Tarifa M 2009 Fracture behaviour of High Strength Concrete at Wide Range of Loading Rates *International Journal of Impact Engineering* 36(10-11) p.1204.
[11] Kwak H-G and Kim S-P 2001 Bond–slip Behaviour under Monotonic Uniaxial Loads *Engineering Structures* 23(3) p. 298.
[12] Mitchell D et al. 1992 *State-of-the-art Report on Bond Under Cyclic Loads* Reported by ACI Committee 408 ACI 408.2R-92 p. 1 in Weathersby J H 2003 Investigation of Bond Slip between Concrete and Steel Reinforcement under Dynamic Loading Conditions *PhD dissertation* Mississippi State University USA.