

Bond strength properties of confined and unconfined coconut shell aggregate concrete by beam splice test.

Propiedades de resistencia de adherencia del concreto agregado de cáscara de coco confinado y no confinado mediante ensayo de empalme de vigas.

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ABSTRACT

This study investigates the bond strength properties of a green concrete produced by replacing the coarse aggregate by an agricultural by product, coconut shell (CS). The bond between steel reinforcement and coconut shell aggregate concrete was studied by using 60 numbers of beam splice specimens. Confined and unconfined beam splice specimens were used. The effects of rebar diameter of lap splice and types of aggregate were investigated. It was observed that the percentage reduction in bond stress for 16 mm rebar unconfined beam splice specimens for various percentage replacements of CS from 25% to 100%, lies in the range of 6-8% compared to 12 mm rebar specimens. Whereas, for confined beam splice specimens the range of percentage reduction is 6-10%. For unconfined and confined beam splice specimens, percentage reduction in bond stress for 25% to 100% replacement by CS for each 25% increment was approximately in the range of 2-3%, 20-23%, 31-34% and 47-48% respectively with respect to normal concrete for both 12mm and 16mm rebar specimens. The percentage increase in bond stress by confining the specimens for various percentage replacements of CS and different size rebar lies in the range of 52-58%.

Keywords: coconut shell aggregate concrete, bond strength of concrete, beam splice test.

RESUMEN

Este estudio investiga las propiedades de resistencia a la adherencia de un concreto verde producido al reemplazar el agregado grueso por un subproducto agrícola, la cáscara de coco (CS). La unión entre el refuerzo de acero y el hormigón agregado de cáscara de coco se estudió mediante el uso de 60 muestras de empalme de vigas. Se utilizaron muestras de empalme de vigas confinadas y no confinadas. Se investigaron los efectos del diámetro de la barra de refuerzo del empalme traslapado y los tipos de agregado. Se observó que el porcentaje de reducción en la tensión de unión para muestras de empalme de vigas no confinadas de varilla de 16 mm para varios reemplazos porcentuales de CS del 25% al 100%, se encuentra en el rango de 6-8% en comparación con las muestras de varilla de 12 mm. Considerando que, para muestras de empalme de vigas confinadas, el rango de reducción porcentual es del 6 al 10%. Para muestras de empalme de vigas confinadas y no confinadas, el porcentaje de reducción en la tensión de unión para el reemplazo del 25% al 100% por CS por cada incremento del 25% estuvo aproximadamente en el rango de 2-3%, 20-23%, 31-34% y 47- 48% respectivamente con respecto al hormigón normal para probetas de varilla de 12 mm y 16 mm. El aumento porcentual en la tensión de unión al confinar las muestras para varios reemplazos porcentuales de CS y varillas de refuerzo de diferentes tamaños se encuentra en el rango de 52-58%.

Palabras clave: hormigón agregado de cáscara de coco, resistencia de adherencia del hormigón, ensayo de empalme de vigas.

INTRODUCTION

Sustainable development is a challenge that civil engineers have an opportunity to address. It is necessary to look forward for sustainable constructions practises. Green materials which could be replenished and recycled can be used for producing sustainable concrete. Major volume of concrete constitutes the aggregates, such as coarse aggregate and fine aggregate. The continued extraction of natural aggregates is leading to its depletion and increased its cost (Saxena and Pofale, 2017; Luhar et al., 2019). Hence, it is necessary to find alternative building materials that can replace natural aggregates in producing concrete. One such alternate material is agricultural by-products.

Perfect bond between reinforcing bars and concrete is crucial for structural strength and serviceability performance. Adhesion between the reinforcing bar and concrete, frictional resistance and mechanical interlock between the reinforcing bar and concrete, quality and strength of concrete in compression and tension, mechanical anchorage effect of the end of reinforcing bars by its development length, hooks and

splicing, type of aggregates and its maximum size, surface geometry, rebar composition, diameter and spacing of reinforcement etc. are the various factors affecting the bond strength between the reinforcing bar and surrounding concrete (Gunasekaran et al., 2011). Many testing methods such as pull-out test, splice beam test, beam-end test and beam anchorage test etc. (Nadir and Sujatha, 2018a) have been developed to measure bond strength between reinforcing steel bars and concrete. Beam splice method is the full-scale method for bond strength of concrete (Turk and Yildirim, 2003; Turk et al., 2010; Türk et al., 2008).

Numerous research studies were found for the suitability of coconut shell as a construction material and used in concrete as fine aggregate replacement, coarse aggregate replacement, coconut fibre etc. (Kanojia and Jain, 2017; Kumar et al., 2019; Gunasekaran et al., 2013; Khan and Ali, 2018; Nadir and Sujatha, 2018b; Mathew et al., 2020). In this experimental study, the variables considered to investigate the bond strength between steel reinforcement and the surrounding coconut shell aggregate concrete were the effect of confinement, reinforcing bar diameter and percentage of coarse aggregate replacement with coconut shell. Beam splice specimens were used for conducting the study.

MATERIALS AND METHODS

Preparation of specimens: Total 60 beam splice specimens were cast and tested. Out of the 60 beams, 30 beam specimens were provided with 12 mm diameter tension reinforcement bars and 30 beams with 16mm diameter tension reinforcement bars. In each 30 beams, 15 beams were confined with transverse reinforcement bars and 15 were unconfined without transverse reinforcement. For confined beam specimens, transverse reinforcement was provided using stirrups of 6mm diameter bars. Five concrete mixes of 0%, 25%, 50%, 75% and 100% coarse aggregate replacement by coconut shells were considered for the study. 3 specimens were cast for each mix. Normal M25 concrete with 12 mm size coarse aggregate was prepared using the mix proportion 1: 1.47: 1.72 with water cement ratio 0.42. Fresh and hardened properties of CSAC were determined for 0, 25, 50, 75 and 100% replacement of CA by CS. The results of the study are shown in

Table 1. Beam splice specimens were prepared by splicing the tension reinforcement bars at the centre of the span. The splice length set for all the beam specimens was 300mm. This value of splice length was selected so as to develop a steel stress less than yield stress and to ensure splitting mode failure in all the beam specimens. Fig 1 shows the schematic diagram of unconfined beam splice specimen.

Table 1. Fresh and Hardened Properties of CSAC

Mix	Slump (mm)	Compressive strength (N/mm ²)	Split tensile strength (N/mm ²)	Flexural strength (N/mm ²)
CSAC 0	50	36.77	2.77	5.15
CSAC 25	44	33.33	2.69	5.08
CSAC 50	38	31.14	2.64	4.97
CSAC 75	30	28.27	2.58	4.89
CSAC 100	20	26.43	2.53	4.68

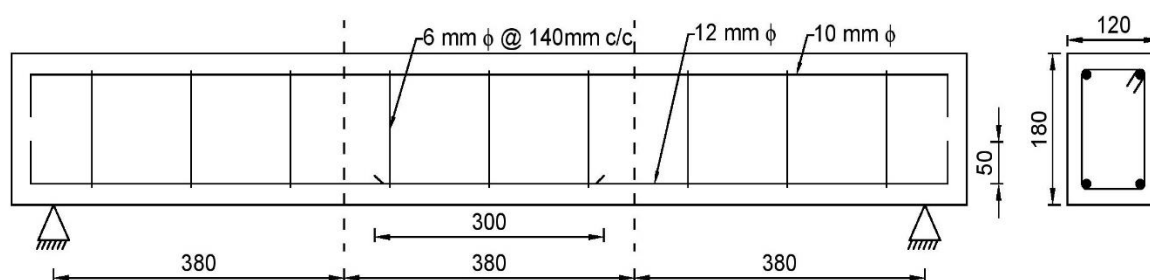


Fig 1. Schematic diagram of confined beam splice specimen

RESULTS AND DISCUSSION

The notations used for 12 mm rebar coconut shell aggregate concrete specimens are 12CSAC0, 12CSAC25, 12CSAC50, 12CSAC75 and 12CSAC100 indicating 0%, 25%, 50%, 75% and 100 % replacement of coarse aggregate by coconut shell. Similarly, 16mm diameter reinforced bar CSAC specimens are indicated by 16CSAC0, 16CSAC25, 16CSAC50, 16CSAC75 and 16CSAC100. For unconfined specimens the same notations were used with an additional letter U. Elastic cracked section analysis was used to measure the bond strength of the beam splice specimens using the following Eq. 1.

$$u_t = \frac{A_b f_s}{n d_b l_s} = \frac{f_s d_b}{4 l_s} \quad (1)$$

where u_t =bond strength (MPa), A_b =area of one bar, d_b =diameter of bar, l_s =splice length and f_s =stress in tensile steel. Elastic cracked section method was used to find the steel stress f_s and determined using Eq. 2 (Menon, 2009).

$$f_s = \frac{M_{max}}{A_{st} j d} \quad (2)$$

where M_{max} =maximum bending moment at bond failure, A_{st} =area of tensile steel, j =lever arm coefficient and d =effective depth of beam in mm.

The lever arm coefficient was determined by elastic analysis of a fully cracked transformed section method. The results of beam splice test were given in Table 2Table

2. Results of beam splice test.

Table 2. Results of beam splice test

Specimen notation	Ultimate load P _{max} (kN)	Maximum Mid span deflection (δ) (mm)	Stress in steel, f _s (MPa)	Bond strength, u _t (MPa)
12CSACU 0	54	3.1	345.89	5.19
12CSACU 25	52	3.55	333.89	5
12CSACU 50	42	4.01	270.15	4.05
12CSACU 75	37	4.5	238.58	3.57
12CSACU 100	28	4.9	180.86	2.71
16CSACU 0	64	4.01	237.88	4.76
16CSACU 25	62	4.10	231.12	4.62
16CSACU 50	50	4.7	186.76	3.73
16CSACU 75	44	4.4	164.84	3.29
16CSACU 100	33	4.95	123.88	2.48
12CSAC0	84	3.66	538.05	8.07
12CSAC25	81	3.9	520.11	7.8
12CSAC50	65	4.12	418.09	6.27
12CSAC75	56	4.66	361.09	5.41
12CSAC100	44	5.3	284.21	4.26
16CSAC0	99	2.18	367.98	7.36
16CSAC25	95	1.74	354.14	7.08
16CSAC50	78	2.3	291.36	5.83
16CSAC75	67	2.23	251	5.02
16CSAC100	51	2.33	191.45	3.83

It can be observed that the ultimate load decreases with increase in CS aggregate percentage. The specimens with larger bar diameter showed increase in ultimate load for corresponding mixes. Mid span deflections were found to be lesser for specimens with larger bar diameter. Percentage decrease in bond stress for 16 mm rebar unconfined specimens for various percentage replacements of CS lies in the range of 6-8% with respect to 12 mm rebar specimens. Whereas, for confined specimens the range becomes 6-10%. For unconfined and confined beam specimens, percentage reduction in bond

stress for 25% to 100% replacement by CS for each 25% increment was approximately in the range of 2-3%, 20-23%, 31-34% and 47-48% respectively with respect to normal concrete for 12mm and 16mm rebar specimens. The percentage increase in bond stress by confining the specimens for various percentage replacement and different size rebar in the present study lies in the range of 52-58%. The face-and-side split failure was observed as the mode of failure in all the beam specimens. The crack width of specimens with 12 mm diameter bar was higher than that of 16mm diameter bar specimens. Confinement makes the specimens stronger and hence a smaller number of cracks was developed. The crack patterns of the beam splice specimens with 12 mm diameter bar for different CSAC mixes are shown in Fig 2.

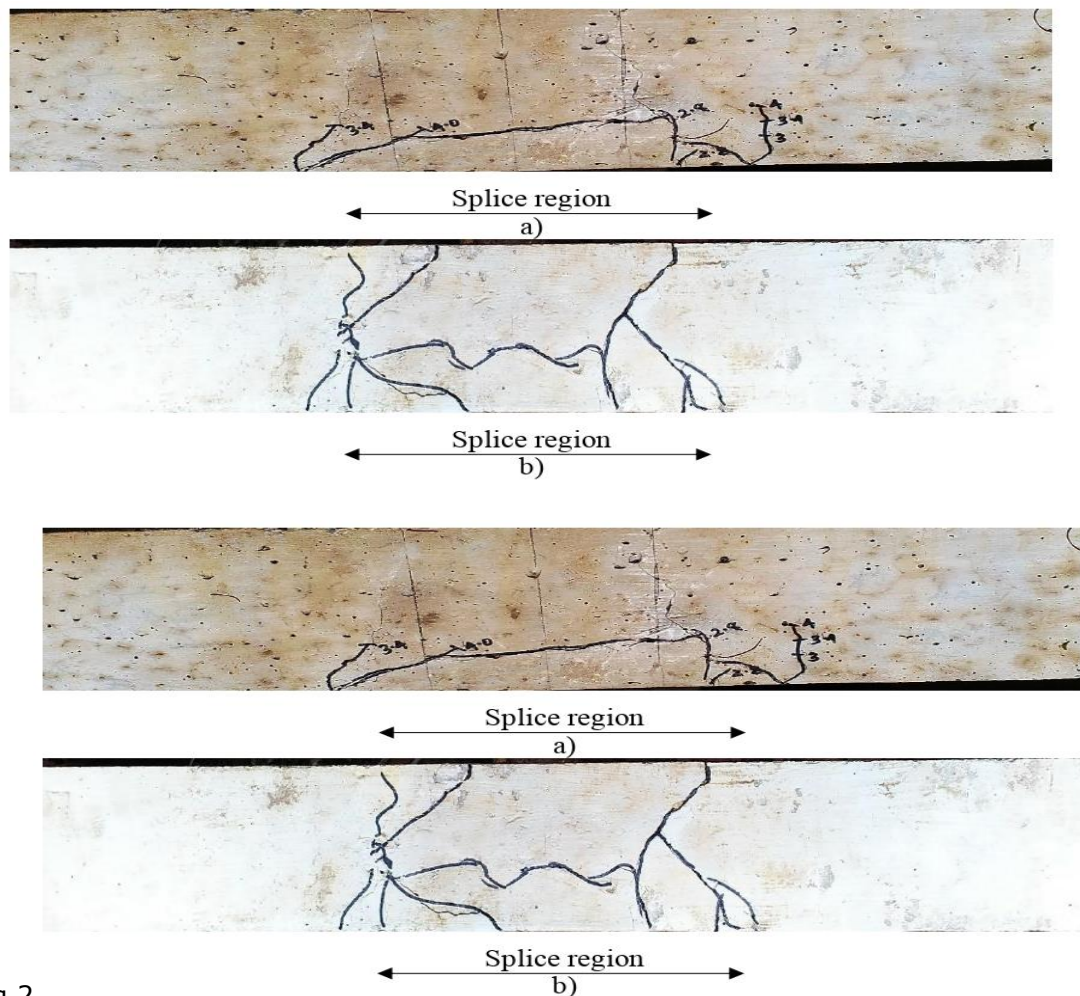


Fig 2

Fig 2. Crack patterns of 12CSACU0 beam splice specimens a) Side view of the beam b) Bottom view of the beam

The following conclusions were drawn from the present study. For unconfined beam splice specimens, percentage reduction in bond stress for 12CSAC25, 12CSAC50, 12CSAC75 and 12CSAC100 specimens was approximately 2%, 21%, 31% and 48% respectively with respect to normal concrete. For unconfined beam splice specimens, percentage reduction in bond stress for 16CSAC25, 16CSAC50, 16CSAC75 and 16CSAC100 specimens was approximately 3%, 22%, 31% and 48% with respect to normal concrete. For confined beam splice specimens, percentage reduction in bond stress for 12CSAC25, 12CSAC50, 12CSAC75 and 12CSAC100 specimens was approximately 3%, 23%, 34% and 48% respectively with respect to normal concrete. For confined beam splice specimens, percentage reduction in bond stress for 16CSAC25, 16CSAC50, 16CSAC75 and 16CSAC100 specimens was approximately 3%, 20%, 31% and 47% respectively with respect to normal concrete. Confinement increased the bond strength percentage in the range of 54-58 % for 12 mm and 16 mm rebar specimens. Bond strength slightly decreased with increase in bar diameter. For unconfined beam splice specimens, percentage reduction in bond stress for 16CSAC25, 16CSAC50, 16CSAC75 and 16CSAC100 specimens was approximately 6-8%. For confined specimens this range becomes 6-10%.

REFERENCES

- Gunasekaran, K., Annadurai, R., and Kumar, P.S. (2013). Plastic shrinkage and deflection characteristics of coconut shell concrete slab: *Construction and Building Materials*, Vol. 43, pp. 203–207, DOI: 10.1016/j.conbuildmat.2013.02.019.
- Gunasekaran, K., Kumar, P.S., and Lakshmiathy, M. (2011). Mechanical and bond properties of coconut shell concrete: *Construction and Building Materials*, Vol. 25, No. 1, pp. 92–98, DOI: 10.1016/j.conbuildmat.2010.06.053.
- Kanojia, A., and Jain, S.K. (2017). Performance of coconut shell as coarse aggregate in concrete: *Construction and Building Materials*, Vol. 140, pp. 150–156, DOI: 10.1016/j.conbuildmat.2017.02.066.
- Khan, M., and Ali, M. (2018). Effect of super plasticizer on the properties of medium strength concrete prepared with coconut fiber: *Construction and Building Materials*, Vol. 182, pp. 703–715, DOI: 10.1016/j.conbuildmat.2018.06.150.
- Kumar, V.R.P., Gunasekaran, K., and Shyamala, T. (2019). Characterization study on coconut shell concrete with partial replacement of cement by GGBS: *Journal of Building Engineering*, Vol. 26, No. March, p. 100830, DOI: 10.1016/j.job.2019.100830.
- Luhar, S., Cheng, T.W., and Luhar, I. (2019). Incorporation of natural waste from agricultural and aquacultural farming as supplementary materials with green

concrete: A review: Composites Part B: Engineering, Vol. 175, No. May, p. 107076,
DOI: 10.1016/j.compositesb.2019.107076.

Mathew, S.P., Nadir, Y., and Arif, M.M. (2020). Experimental study of thermal properties of concrete with partial replacement of coarse aggregate by coconut shell: Materials Today: Proceedings, Vol. 27, No. xxxx, pp. 415–420, DOI: 10.1016/j.matpr.2019.11.249.

Menon, D. (2009). Advanced Structural Analysis, Illustrated Ed. Alpha Science International.

Nadir, Y., and Sujatha, A. (2018a). Bond strength determination between coconut shell aggregate concrete and steel reinforcement by pull-out test: Asian Journal of Civil Engineering, Vol. 19, No. 6, pp. 713–723, DOI: 10.1007/s42107-018-0060-1.

Nadir, Y., and Sujatha, A. (2018b). Durability Properties of Coconut Shell Aggregate Concrete: KSCE Journal of Civil Engineering, Vol. 22, No. 5, pp. 1920–1926, DOI: 10.1007/s12205-017-0063-6.

Saxena, S., and Pofale, A.D. (2017). Effective Utilization of Fly Ash and Waste Gravel in Green Concrete by Replacing Natural Sand and Crushed Coarse Aggregate: Materials Today: Proceedings, Vol. 4, No. 9, pp. 9777–9783, DOI: 10.1016/j.matpr.2017.06.266.

Türk, K., Benli, A., and Calayir, Y. (2008). Bond strength of tension lap-splices in full scale self-compacting concrete beams: Turkish Journal of Engineering and Environmental Sciences, Vol. 32, No. 6, pp. 377–386, DOI: 10.3906/sag-1302-132.

Turk, K., Karatas, M., and Ulucan, Z.C. (2010). Effect of the use of different types and dosages of mineral additions on the bond strength of lap-spliced bars in self-compacting concrete: Materials and Structures/Materiaux et Constructions, Vol. 43, No. 4, pp. 557–570, DOI: 10.1617/s11527-009-9511-1.

Turk, K., and Yildirim, M.S. (2003). Bond strength of reinforcement in splices in beams: Structural Engineering and Mechanics, Vol. 16, No. 4, pp. 469–478, DOI: 10.12989/sem.2003.16.4.469.

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