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Studi on The Efficiency Using Nature Materials in The Structural Elements of Reinforced Concrete Beam

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Abstract : *In general bending loads acting on structural elements of concrete beams are retained by the compression area on its pressured area while its drag area is being ignored. Therefore, it is reasonable if the concrete beam section on drag area is minimized with concrete mass reduction in tensile region by ignoring concrete tensile stress while receiving static loads or the area is filled with styrofoam concrete (styrocon). One effort to make efficient the concrete economic value is by reducing concrete and using styrocon thus natural material component such as sand mining, coarse aggregate, and cement and heavy construction becomes lighter. Styrofoam as waste can be used as filler to reduce the volume of concrete, especially for areas where the concrete section is not working mechanically. In an effort to study the flexural strength of concrete beams external reinforcement and composite Styrofoam filled, then a series of tests performed. Test material is in the form of blocks of 15 cm x 20 cm x 270 cm in dimension. Test material is consisted of concrete quality normal beam of 26.0 MPa with transverse reinforcement as a control of test material and the test material with external transverse reinforcement, as well as truss systems and Styrofoam filled composite. The normal-styrocon composite is beam with Styrofoam variation content. The beam is placed on 2 simple pedestal by 2 point loading method testing. The results indicated that normal concrete beam flexural strength is 36.7 kN, but the external transverse reinforcement beams decreased to 30.6 kN, but the external reinforcement beam truss system reinforcement is relatively equal to 35.8 kN. However, the beams with external reinforcement is susceptible to corrosion, fire resistant, and requires treatment. Therefore styrocon is used on the outer portion with styrofoam content of 30%, 40%, and 50% relatively having flexural strengths of 33.8 kN, 31.0 kN and 29.0 kN, respectively. It can be concluded that the use of normal-styrocon composite concrete beams can make efficient the use of natural materials of the concrete block and to reduce the weight construction as well as has environmental aspects by using the waste.*
***Keywords**: Flexural strength, Sandwich Concrete Beams, Styrocon, External Reinforcement,MonotonicLoading*

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INTRODUCTION

Concrete is still one of the most widely used material in the world and estimated that its annual global production is more than 2 billion meters cubic [1]. It is formed from a hardened mixture of cement, water, fine aggregate and coarse aggregate. As the main constituent of concrete materials, it is natural materials that decrease in number so that the study of natural materials that are used in the building structures optimum design is necessary to improve, especially in the bridge girder. Figure 1 indicates the implementation of the joint-roller placement on construction elements.

Of the various theories related to the analysis of structural elements concrete beams, it is noted that the part that its power is maximally worked in withstand bending style is the outer part only. Rose in the concrete which is compresed, while the tensile concrete which experiences strength is negligible [2]. Therefore it is not efficient when the unoptimally working concrete core parts is made from the same type of optimally working concrete.

Because of these inefficiency then aroses an opinion to make concrete that consists of several different layers [3]. Figure 2 indicates the concrete beam that consists of several different layers. With this, we can make the element design of beam structure made from concrete more effecient by using normal concrete in certain layers while the other part is filled with lightweight concrete styrocon using styrofoam.

Fig. 1: Applications for Simple beam

With the use of styrocon, the total weight of the concrete and the structure will be lighter automatically reducing the dimension of the structure, so that the optimal design can be achieved. But lightweight concrete has weakness such as lower stiffness and creep as well as greater shrinkage. Therefore this material tends to be placed in a position close to the neutral line or at the bottom. Through making efficient the concrete layer which worked in resist bending, theoretically, considered to the advantages and disadvantages of normal and lightweight concrete, it is expected the combination of two types of concretes to be composite, so that each type of concretes can overlap each shortage.

Styrofoam or expanded polystyrene is known as white foam which is usually used for packaging electronic items and often becomes garbage dumping. Figure 3 indicates an example of styrofoam. Polystyrene is produced from styrene (C6H5CH9CH2) that can not be decomposed by soil thus reduced the quality of land fertility, when it is burned, it produces carbon oxides (COX), which lead to global warming as well as the combustion becomes a liquid plastic leading to soil and water pollution. Therefore friendly environmental concrete technology is necessary by reusing the waste at the beam structural element for reducing the pollution. Thus the use of lightweight concrete styrocon in the core layer or under normal-light layered beam not only reduce the weight of construction but also has environmental aspects.

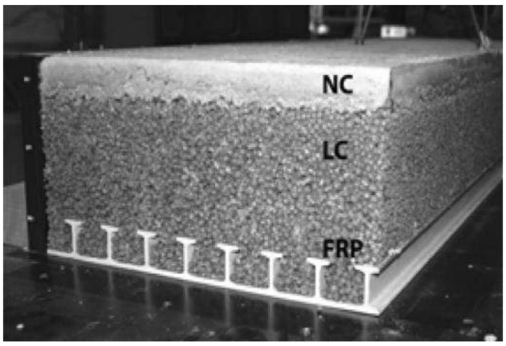

Fig. 2: Sandwich concrete beam section

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Fig. 3: Styrofoam

The use of styrofoam material in concrete by utilizing waste concrete can reduce construction costs, slow the onset of the heat of hydration, low the density of concrete, and reduce the earthquakes load which is smaller the works due to heavy reduced concrete structures [4,5]. That in the end the exploitation of natural materials such as sand, gravel, and cement for building materials can be reduced.

Motivation to investigate the performance of such normal concrete layered and lightweight beams is to design structural elements that utilize the most advantageous properties of two different concrete qualities in one section. Plated beams are used in applications which require high bending stiffness and strength which is combined by low weight [6,7].

Studies on the use of reinforcement frame system on structural elements have been conducted by several researchers such as Salmon et. al. [8] which uses steel trusses on the panel to reduce deflection shell. Deshpande et. al. [9] conducted experimental beam sandwich, which consists of a triangular truss core face-sheets, which have been printed with aluminum-silicon alloy and silicon in brass to get macroscopic effective stiffness and strength of face-sheets and tetrahedral core. Kocher et. al. [10] presents a theoretical approach to study several issues related to the design of sandwich structures with a polymer frame reinforced with hollow core using a simple analytical model that describes the contribution to the stability of the structure is hollow at the core. Liu et.al. [11] studied a multi-parameter optimization procedure on the panel ultralightweight truss-core sandwich. Configuration details and sizes for both facesheets and individual struts are in the optimized sandwich panels. The optimization improves the structural performance of each panel in the multiple loading case and minimizes the structural weight simultaneously. Kabir [12] developed a method to investigate the mechanical characteristics of the 3D sandwich wall panel in shear and flexural static load, in order to understand the structural components.

In general, the research is related to the utilization of waste styrofoam for use in beam structural elements for purposes of efficiency of use of natural materials in concrete construction and application of environmentally technological knowledge. Related to the studies, it is essential to expand the use of styrofoam to reuse the waste. To perform the styrofoam material application study for the natural material substitution, thus a series of analytical studies and experimental testing have been performed. This paper presents the study results that are related to the bending capacity of concrete beams using material coated with styrofoam.

Styrofoam or expanded polystyrene is known as a white foam which is usually used for packaging electronic items and often becomes garbage dumping. Figure 3 indicates an example of styrofoam. Polystyrene is produced from styrene (C6H5CH9CH2) that can not be decomposed by soil thus reduced the quality of land fertility, when burned, it produces carbon oxides (COX), which lead to global warming as well as the combustion becomes a liquid plastic that can lead to soil and water pollution. Therefore environmental friendly concrete technology is necessary by reusing the waste at the beam structural element for reducing the pollution. Thus the use of lightweight concrete styrocon in the core layer or under normal-light layered beam not only reduce the weight of construction but also has environmental aspects.

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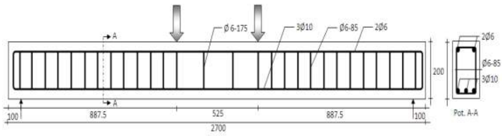
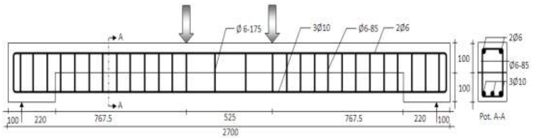
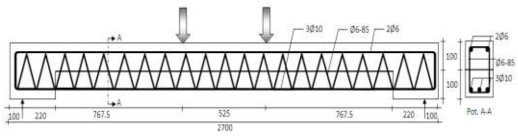
METHODS AND MATERIALS TESTING



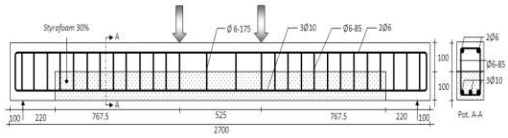
(a) Beams BN



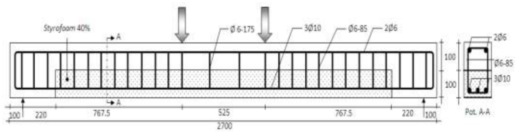
(b) Beams BTL



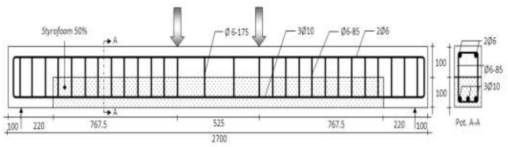
(c) Beams BTR



(d) Beams BSC30



(e) Beams BSC40



(f) Beams BSC50

Fig. 4:. Details of test materials

Figure 4. indicates the test material for each normal beam (BN), transversal external reinforcement beams (BTL), frame sysem external reinforcement beam (BTR), normal-styrocon beam with styrofoam content of 30% (BSC30), normal-styrocon beam with styrofoam content 40% (BSC40), and normal-styrocon beam with styrofoam content of 50% (BSC50). BN testing materials are intended as a control beam or as a comparison while BTL, BTR, BSC30, BSC40 and BSC50 as a competitor, which beams provide the strength and efficiency of natural materials Usages.

Table 1: Characteristics of concrete and reinforcing steel

Concrete		Steel	
Parameter	Value	Parameter	Value
Force of Compression	26.0 MPa	f_y	458.27 MPa
Force of Tension	3.0 MPa	f_{ymax}	442.32 MPa
Force of Flexural	3.81 MPa	ε_s	0.00253
Modulus of Elasticity	23219 MPa	E_s	209787 MPa

Table 2: Specifications expanded polystyrene / styrofoam

Spesifikasi	
Ukuran butiran *styrofoam*	3 mm – 5 mm
Berat jenis *styrofoam (Density)*	13 – 22 kg/m^3
Modulus Young's (E)	3000 – 3600 MPa
Kuat tarik *Styrofoam (Tensile strength)*	40 – 60 MPa
Specific heat styrofoam (c)	1,3 kJ/(kg.K)
Thermal conductivity Styrofoam (k)	0,08 W/(m.K)

All test materials are beams with 270 cm long dimensions, 15 cm wide beam, high beam and 20 cm in Figure 5. Reinforced concrete beams is planned to have reinforcement tensile reinforcement rods 20 cm 3 with a diameter of 6 mm shear reinforcement. To facilitate the assembly of reinforcement, then on the press side is also given reinforcement with diameter of 6 mm. Concrete materials is planned to have compressive strength 25 MPa. Casting process is performed according to the basic standards and concrete treatment process is peromed for 28 days as in Figure 7. To check the concrete properties press test and split test on cylinder test material are provided beside the material tensile

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strength test using a test beam. In detail the properties of concrete and steel reinforcement are presented in Table 1.
Tests are performed on BN beam above a simple span with burdening the beam by sentries on the 2 loading point is 525 mm.

Fig. 5: Test preparation materials and casting beams

Based on the theory of reinforced concrete flexural [13], the reinforcing melting point is marked by a change in beam stiffness significantly. Therefore beam is planned in reinforced weak condition (under reinforcement) then the stiffness changes will be caused by melting of reinforcement as illustrated in Figure 6.

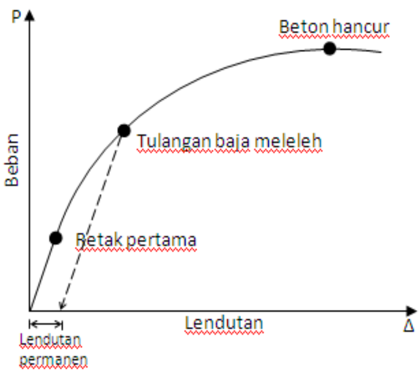

Fig. 6: Typical load-deflection relationship for under reinforced beams

Fig. 7: Curing specimen beams

From the styrofoam volume weight test results gained styrofoam volume weight value is 22.612 kg/m3 and loose factor value is 0.61. Where, styrofoam heavy volume is obtained from styrofoam solid weight ratio 354.8 g kg with the volume of solid styrofoam 15690.48 cm3. And factor scores derived from the comparison between the friable solid volume 15690.48 cm3 with volume loose 25636.73 cm3. Styrofoam base material characteristics are presented in Table 2.

Fig. 8: Beam loading method

The testing is performed by loading method as shown in Figure 8, normal reinforced concrete beams (BN). Beams were tested on a simple pedestal with 2500 mm distance. Imposition is given in the form of charging 2 points is 500 mm sentrically at midspan. Loading is performed in stages per 1 kN using a manual hydraulic jack. Deflection measurements is conducted by placing 3 pieces of the dial gauge on the center span and at the loading point. Dasn load dial readings is conducted on every 1 kN load increase. Observations is also made to the cracks that occurred. Than the appear

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cracks are skecthed. To observe the propagation of cracks, then 3 major cracks are selected to be analyzed.

ESTIMATED FLEXURAL **CAPACITY**

Figure 9. illustrates the basic assumption of strain, stress and the forces in the analysis of flexible capacities. The assumptions are based on weak reinforced cross-sectional condition (ρs <ρsb). Based on the theory of reinforced concrete flexural [13], it is also assumed that in this analysis occurs linear varying strain relationship in perfect cross section adhesiveness between the concrete and the reinforcing steel in the concrete strain ruined condition is 0.003. It is also assumed that the cross section of concrete compressive stress at ultimate capacity is rectangular and steel reinforcement behavior elasto-plastics.

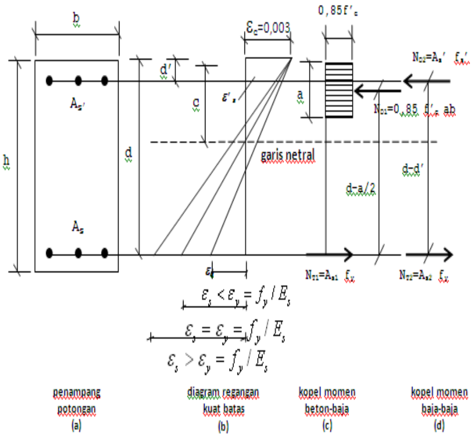

Fig. 9: Model of stress-strain

On a particular condition, beam can withstand loads that occur up to a maximum concrete compressive strain bending (ε'c) reaches 0.003 while the tensile stress tension reinforcement reaches melted tension f_y. If that happens, then the value of fs = f_y and named section reach equilibrium strain (balanced reinforced section).

Based on the assumptions outlined above, the test of strain, stress, and the forces that arise in cross-section beam that works to withstand the limit moment (Mu), the moment caused by the external load in the event of destruction can be tested. Flexural strength of concrete beams occurs due to ongoing mechanisms in stress-strain arising in the beam, in certain circumstances may be represented by the forces. Where ND is the resultant compressive force and a resultant compressive force in the area that is above the neutral line. While the NT is a resultant tensile force in the tensile strength and all gravitional forces that are planned for the area are below the neutral line. Resultant compressive force and the resultant tensile force in the direction parallel to the line of work, are equal but opposite to the distance z direction thus form duplexes in detainees moment, where the maximum value is referred to as flexural strength.

The inner obstruction moment will carry bending moments which is caused by the actual plan of external load. For planning purposes on the condition of the beam must be prepared in accordance with the loaded composition concrete beam dimensions and the amount of reinforcement area to resist the moment due to external loads. First was to determine the total resultant concrete force hit ND, and the location of the line of work force calculated to press the outer edge of the fiber, so that the distance z can be calculated. ND and NT values can be calculated by simplifying the curvilinear form of the stress distribution changed to a simpler equivalent form, by using the stress intensity value of the average order value and the resultant layout has not changed.

Based on rectangular shape, average press concrete intensity is determined 0.85 f'c and assumed to work in the press area and the amount of beam section width b and height a can be determined by the equation:

$$a = \beta_1 c \quad (1)$$

For bending collapse of underreinforced beam is marked by the melting of reinforcement while the stress

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that occurs in a small concrete (fc <fc '). Elastic limit where the value is fs = fy. So the moment that happened as the following equation:

$$M_y = f_y.A_s.jd \quad (2)$$

After the steel stress which occurs is equal to the stell melted stress then it is said that steel beam has undergone ductile bending. In case of beam bending ductile experiences deformation without the collapse of the tensile reinforcement.

From the balance force equation Cc + Cs = T, then:

$$A_s.f_y = 0,85f_c.b.a + A_s'.f_y \quad (3)$$

or

$$a = (A_s.f_y - A_s'.f_y)/(0,85f_c.b) \quad (4)$$

while to determine the ultimate moment:

$$M_u = 0,85.f_c.a.b(d-a/2) + A_s'.f_y(d-d') \quad (5)$$

Table 3 presents the estimation results for the ultimate moment of each test material using the material properties which are presented in Table 2. Moment of crack initiation is estimated using the elastic bending theory [13]. For the ultimate moment, estimates are carried out under conditions where press failure occurs on the concrete after a tap reinforcing steel melted using equation (5).

From Table 3 it can be seen that the estimation for ordinary reinforced beams (BN) has the ultimate load of 28.77 kN. reinforced beam is relative to the same outside, but in order to show an increase in system reinforcement. For normal-styrofoam composite beams indicated a better condition than the outer reinforced beams. So it can efficient the use of natural materials and utilize the waste back on the beam structural elements.

Table 3: Estimation of moment initial crack and moment ultimate

Kode	Retak Awal		Momen Ultimit		Rasio
Balok	M_{cr}(kN.m)	P_{cr}(kN)	M_u(kN.m)	P_u(kN)	(x/BN)
BN	4.28	7.54	14.77	28.77	1.00
BTL	1.21	2.00	12.51	28.77	1.00
BTR	2.82	4.50	14.84	28.90	1.00
BSC30	2.05	3.02	15.09	29.42	1.00
BSC40	1.56	2.01	15.09	29.42	1.02
BSC50	1.22	1.34	15.09	29.42	1.02

RESULTS AND DISCUSSION

Load and Deflection relationship

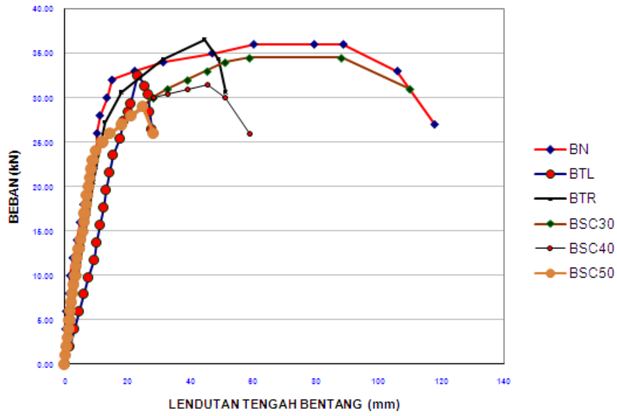

Figure 10. Load and deflection relationship

Table 4: Cracking load and ultimate load test results

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Code Beam	Theory P_{cr} (kN)	Theory P_u (kN)	Experimental P_{cr} (kN)	Experimental P_u (kN)	Ratio (x/BN) exp.	Exp/ Theory
BN(1)	7.54	28.77	8.00	37.50	1.00	1.303
BN(2)			8.00	36.00	1.00	1.251
BN(3)			8.00	36.50	1.00	1.269
BTL(1)	2.00	28.77	2.00	32.30	0.881	1.123
BTL(2)			2.00	31.50	0.859	1.095
BTL(3)			2.00	28.00	0.764	0.973
BTR(1)	4.50	28.90	4.00	36.60	0.998	1.266
BTR(2)			4.00	35.10	0.957	1.215
BTR(3)			4.00	35.60	0.971	1.232
BSC30(1)	3.02	29.42	4.00	34.00	0.927	1.156
BSC30(2)			4.00	33.00	0.900	1.122
BSC30(3)			4.00	34.50	0.941	1.173
BSC40(1)	2.01	29.42	3.00	30.50	0.832	1.037
BSC40(2)			3.00	31.00	0.845	1.054
BSC40(3)			3.00	31.50	0.859	1.071
BSC50(1)	1.34	29.42	2.00	29.00	0.791	0.986
BSC50(2)			2.00	29.00	0.791	0.986
BSC50(3)			2.00	29.00	0.791	0.986

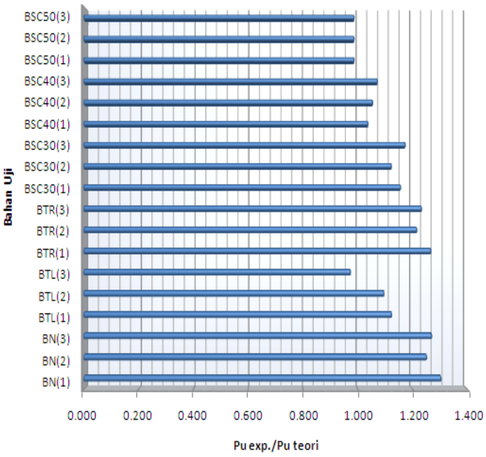
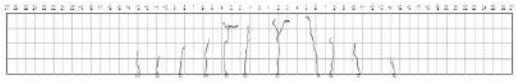


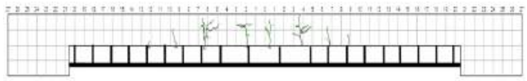
Fig. 11: Level of deviation between the test results with theoretical estimates

Figure 10 indicates the relationship between load and deflection of each the test material. On beam BN, early loading is a straight line that reveals the elastic behavior until the average load of 8 kN (working stage). In line with the increased load, the relationship of load and deflection are more gentle than before. This occurs until the load average of 32 kN (yielding stage). At the time steel melted which characterized by increasing large deflections without increasing a corresponding in the mean load, and the load deflection curve is much flatter than the previous. This occurs until the ultimate load average of 37 kN (collapse stage).

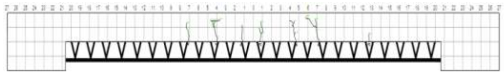
On beam BTL, ultimate response is lower than BN and relatively brittle. While on BTR with reinforcement frame system indicated an increase in ultimate load compared to BTL but still not ductile. BSC30 beam revealed a condition that is more ductile than the BN with the addition of styrofoam by 30% in the tensile concrete, so can efficient the use of natural materials and utilize the waste back on the beam structural elements. BSC40 and BSC50 beams, the capacity of each BSC is lower than 30.



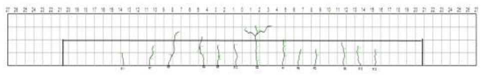
(a) Specimen BN



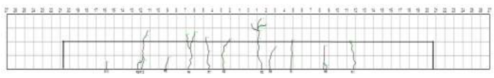
(b) Specimen BTL



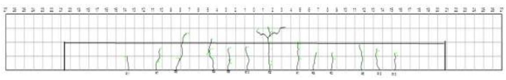
(c) Specimen BTR



(d) Specimen BSC30



(e) Material test BSC40



(f) Specimen BSC50

Fig. 12: Direction of crack propagation

Flexural Capacity

Table 4 presents a summary of the load at the time of the initial crack and the ultimate load of each normal beam (BN

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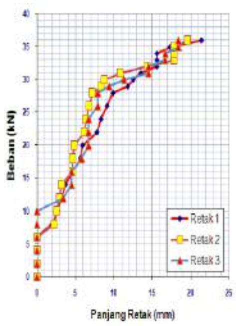
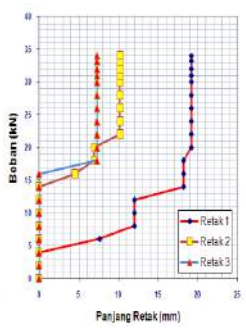
test material), outer reinforced beams (BLT test materials and BTR), and normal-styroco composite beam (test material BSC30, BSC40, and BSC40). In general for all the materials ultimate load test results of the test have quite good common ratio compared with theoretical estimates as shown in Figure 11, which indicates the level of deviation between the test results with theoretical estimates.

BSC50 beam ultimate load test results are achieved at the level of 29.0 kN load. When compared with the theoretical estimation using strain and stress assumptions described above, indicates good results with a ratio of 98.6% similarity. This indicates that the test substance BSC50 behavior as assumed in the theoretical estimation.

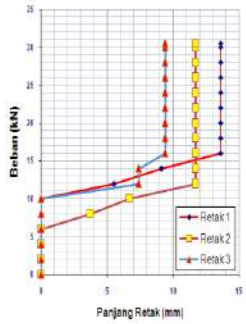
For BTL, test material has the lowest flexural capacity with another specimen of the test material and brittle BN behavior. BTR beam flexural capacity is closest to BN, but showed no ductile characteristics. BSC30 beam flexural capacity of the beam also approached BN and exhibited behavior that is more ductile materials such comparison test, which gives the efficiency of the use of natural materials, such as sand, gravel, and cement by 30% in the tension area. Besides reusing waste or garbage white cork wrap these electronic tools.

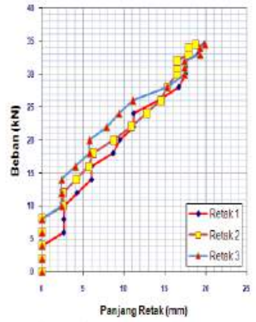
BSC40 and BSC50 test materials have a lower ultimate load. Thus provide less capacity than the pliable material BN test.



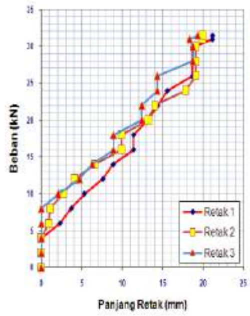


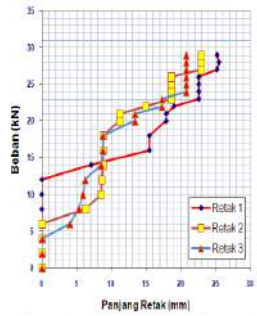
(a) Specimen BN (b) Specimen BTL





(c) Specimen BTR
(d) Specimen BSC30





(e) Specimen BSC40
(f) Specimen BSC50

Fig. 13: Crack propagation pattern


(a) Specimen BN (b) Specimen BTL


(c) Specimen BTR (d) Specimen BSC30

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(e) Specimen BSC40 (f) Specimen BSC50

Fig. 14: Collapse of the test material

Cracks and Failure Pattern

In general, the pattern of cracks as revealed in Figure 12 is a flexural cracks began to occur when the voltage exceeds the tensile strength of concrete material. The addition of the load will cause the spread of adhesiveness pointing up toward the neutral line of the beam as well as the new emergence.

Beam collapse at maximum load is characterized by widening cracks and melting of steel which is characterized by a large deflection to the beam that had destroyed the fiber tap. On reinforced concrete beams beragregat styrofoam, long cracks occur more slowly than the long cracks in reinforced concrete beams normal (BN).

Monitoring of the 3 crack propagation in each of the test material is presented in Figure 13. It seems that can be observed on the beam BN that cracks began to spread when the load is at the level of about 8 kN. Cracks continue to spread until they reached ultimate load beam. On the beam outside reinforced BTL and BTR can be observed by cracks began to spread after the load is at a slightly higher level than the initial crack load beam BN, but faster initial collapse because cracks have been in the compression area of the concrete beams.

Based on the pattern of cracks and crack propagation phenomena as shown in Figure 12 and Figure 13, it can be concluded that the agregate Styrofoam beam gives benefits and better conditions, the length of crack propagation patterns is not straight up, compared to the normal beam (BN) and outer reinforced beams (BTL and BTR), due to the additional expanded polistyerene styrocon have more elongation than normal concrete.

Figure 14 indicates the test material photos were damaged. All specimens indicated flexural collapse. But on BTR test materials with frame reinforcement system reveals deflection, but after the directly cracked press section concrete experiencing failure. In the normal beam (BN) damage is also occurred to the upper part of the concrete. While in the normal-concrete composite styrocon collapse reaches the Whitney quadrilateral high voltage block, caused by the styrofoam aggregate concrete tensile strength has better tensile strength than normal concrete.

CONCLUSION

Based on the testing and analysis, it can be drawn some conclusions as follows:

1. Relationships of load and deflection in the normal composite-concrete beams with the addition of 30% styrocon styrofoam exhibits quite well behavior on daktalitas displacement than normal concrete beams. Moreover, it can efficient the use of natural materials, such as sand, gravel, and cement by 30% on the cross-appeal and reduce the weight of construction and reuse of waste or trash waste of white wrapping cork electronic devices.
2. Flexural capacity of normal-styrocon composite concrete beams with addition of 30% styrofoam, has the ability to withstand the ultimate load of 34.5 kN, and the addition of expanded polistyerene material on tension area resulted styrocon has more elongation than normal concrete, so it has better flexibility as well.
3. The achieved test results indicated quite good results with the similarity ratio of 98.6% compared with the

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theoretical estimation, this indicates that the material test behaves as assumed in the theoretical estimation.

4. There is potential loss of adhesiveness between normal concrete layers and styrocon layers on composite concrete beams caused by the shift (sliding), chipped (bonding), wrinkles (wrinkling), and indentation (indentation) on the surface of the two layers.
5. Methods of strengthening the ability of adhesiveness between the two layers of composite concrete-styrocon normal need to develop to increase the strength and stability of the coated concrete beams.

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REFERENCES

1. Jacobsen, S. (2006). *Lecture Notes, BM3*. Trondheim: NTNU.
2. Nawy, E. G. (1998). *Reinforced Concrete A Fundamental Aproach*. Third Edition, Prentice-Hall, Inc.
3. Schaumann, E., Valle, T. and Keller, T. (2008). "Direct Load Transmission in Sandwich Slabs with Lightweight Concrete Core". *Journal of Tailor Made Concrete Structures-Walraven & Stoelhorst* (eds), Taylor & Francis Group, London, 849-855.
4. Satyarno. I. (2006). "Ligthweight Styrofoam Concrete for Lighter and More Wall Ductile". *Jurnal HAKI*, Yogyakarta.
5. Giri, I. B. D., Sudarsana, I. K., dan Tutarani, N. M. (2008). "Kuat Tekan dan Modulus Elastisitas Beton dengan Penambahan Styrofoam (Styrocon)". *Jurnal Ilmiah Teknik Sipil* Vol. 12, No. 1, Denpasar.
6. Skjølberg, O. G. and Hansson, A. (2010). "Hybrid Concrete Structures : Experimental Testing and Numerical Simulation of Structural Element". Department of Structural Engineering, Faculty of Engineering Science and Technology, NTNU - Norwegian University of Science and Technology.
7. Nes, L. G. and Overli, J. A. (2011). "Composite and Hybrids Investigation of Material Parameters and Structural Performance of a Concrete Sandwich Slab Element". *fib Symposium PRAQUE*, Session 5-6.
8. Salmon, D. C. and Einea A. (1995). "Partially Composites Sandwich Panel Deflections". *Journal of Structural Engineering*. ASCE, Vol. 121, No. 4, April, 778-783
9. Despandhe, V. S. and Fleck, N. A. (2001). "Collapse of Truss Core Sandwich Beams in 3-Point Bending". *International of Solid and Structures, Pergamon*, 38, 6275-6305.
10. Kocher, C., Watson, W., Gomez, M. and Birman, V. (2002). "Integrity of Sandwich Panels ands Beams with Truss-Reinforced Cores". *Journal of Aerospace Engineering*, ASCE, Vol. 15, No. 3, July, 111-117.
11. Liu, J. S. and Lu, T. J. (2004). "Multi-Objectif and Multi-Loading Optimization of Ultraweight Truss Material". *International Journal of Solids and Structures*, Elsevier, 41 (2004), 24 September 2004, 619-635.
12. Kabir, M. Z. 2005. "Structural Performance of 3-D Sandwich Panel Under Shear and Flexural Loading". *Journal of Scientica Iranica*, Vol. 12 No. 4, October 2005, 402-408.
13. Wight, J. K. and MacGregor, J. G. (2005). *Reinforced Concrete Mechanics and Design.* Sixth Edition, Pearson.

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a = Height Whitney rectangular stress block (mm)
A_s = Area of cross section of tensile steel reinforcement (mm^2)
A_s' = Area of cross section of compresion steel reinforcement (mm^2)
b = Width of beam (mm)
c = Distance to the outer edge of the neutral line (mm)
d = Effective reinforcement steel Height (mm)
d' = Concrete cover thickness (mm)
f'_c = Compressive strength of concrete (N/mm^2)
f_y = Yield force of steel reinforcement (N/mm^2)
h = High beam (mm)
I_{cr} = Moment of inertia of cracked reinforced concrete section (mm^4)
I_g = Moment inesia reinforced concrete section (mm^4)
M_n= Moment nominal section (N.mm)
M_u= Moment ultimate section (N.mm)
N_D= Resultant compressive force above the neutral line (N)
N_T = Resultant tensile force below the neutral line (N)
z = Distance resultant tensile force to the resultant compressive force (mm)
β_1 = Coefficient correction Whitney rectangular stress block height (mm)
ε_{cu} =Ultimate concrete strain press