CYCLIC BEHAVIOUR OF SANDWICH CONCRETE BEAM UNDER FLEXURAL LOADING

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ABSTRACT

The theories relating to the structural analysis shown that the part of the concrete structural elements whose strength works maximally in resisting the bending force is in the compressive region. Therefore, it is inefficient if the core part of the concrete is made of the same type of concrete. The sandwich concrete consisting of different layers between the center (core) concrete and the surface (skin) layers became the basic idea in this study. With this sandwich concrete, we can streamline the design of structural elements made of concrete by using high strength concrete in the skin layer while the ordinary and lightweight concrete in the core layer. The core layer is made of lightweight concrete with the compressive strength of 30 MPa. It is sandwiched between two skin layers made of normal concrete with compressive strength 50 MPa. The connector is applied to connect different composite layers in order to transfer the longitudinal shear force in the beam. Moreover, the cyclic loading test was conducted on three kinds of beam specimen with dimensions of 2100 mm in length, 100 mm width and depth of 200 mm. Differences in the cyclic flexural behavior of sandwich beams with respect to the connector and compressive strength of the core layers were monitored in terms of cracking patterns, stiffness and strength degradation, energy dissipation and ductility. The obtained results showed that the cyclic load of the beam determined the degradation of stiffness and strength in every cyclic due to the slip at the lower load (pinching effect). The connector and the compressive strength of the center layer of the beam established the increasing of dissipation energy. Observation on the ductility of the flexural beams shows that ductility response of the beams is specified by the loading systems, the connector in the middle part of the concrete beams, and the compressive strength of the central layer concrete.

Keywords: cyclic, sandwich concrete, dissipation-energy, ductility.

INTRODUCTION

The sandwich beam consists of two thin, rigid and strong layers of solid material separated by a thick layer made of a low-density material, which has a lower stiffness and strength than the two other layers (Callister, 1997). The two thin layers are functioned as skin layers and the thick mid layer is known as a core (Figure 1). In accordance with the concrete material, it is efficient if the core part of the concrete is made of different type of concrete, since the theories relating to the structural analysis shown that the part of the concrete structural elements whose strength works maximally in resisting the bending force is in the compressive region.

This concept is being the basic idea to create the sandwich concrete consisting of different layers between the center (core) concrete and the surface (skin) layers. Proportionally, an efficient sandwich beam occurs when the core weight of the sandwich is approximately equal to the total weight of the skin layer. Sandwich structures combine the superiority of the materials used as its layers, the high-strength and stiffness of the skin layers and the low density of the concrete core layer (Jones, R.M, 1975). As it is known that the aggregate has the largest proportion in the concrete mix (Neville, A.M, 2000), replacing the conventional aggregate with artificial lightweight aggregate (ALWA), will reduce the total weight of the concrete and structure will become lighter as well. Although the lightweight concrete also has low stiffness as its weaknesses, it is suitable to be used as the core layer in the sandwich concrete beam. Hence, this combination will produce a strong and stiff yet lightweight sandwich concrete.

Using the sandwich concrete can streamline the design of structural elements made of concrete by using high-strength concrete in the outermost layer (skin) while the center (core) is filled with lightweight normal strength concrete. The core layer must be stiff enough under shear loading, such that when the sandwich structure bends the skin layers do not slide against each other and prevent the lost of the composite effect. Moreover, the core layer must be stiff enough such that the skin layers stay level under bending load to against the delamination (Van Straalen, 1998). Meanwhile, the connector is applied to connect different composite layers in order to transfer the longitudinal shear force in the beam. The combination of this high-strength concrete, lightweight concrete, and the connector among the layers will be assigned on how the behavior cyclic of this sandwich beam.

MATERIAL AND METHODS

This study is based on bending cyclic test of the sandwich concrete in a laboratory. The specimens used the following specifications: the skin layers are precast concrete (normal weight concrete (NWC)) with the depth of 6 cm and the core layer (lightweight concrete (LWC)) with the depth of 8 cm cast between the two concrete layers of precast age 4 days.

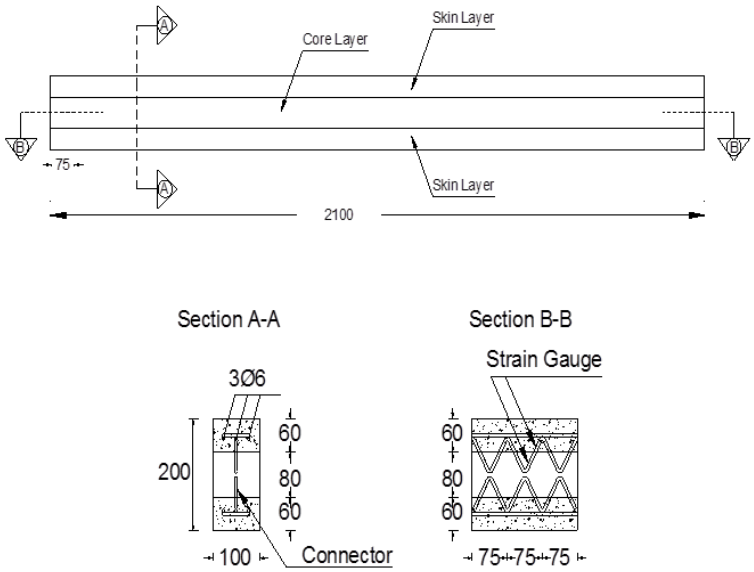
Figure 1: Sandwich Concrete Layers

A. Specimen Preparation

Basically, the sandwich beam is laminated of three layers concrete. Those layers consist of the top and bottom layers as the skin layers and the core layer in the middle. This laminated layer beam will produce a very complex mechanical behavior under external and other types of loading.

Figure 2 shows the dimension of the specimen which consists of 60 x 100 x 2100 mm in size for the surface layer, and 80 x 100 x 2100 in size for the core layer. The two surface layers concrete was made of the precast concrete. After 4 days the core layer in the middle of the part of the sandwich is an in-situ cast placed between the two surface layers. The number of longitudinal reinforcement bar for each beam is 3 with the diameter of 6 mm. Since the roughness effect is negligible, the inner surface of the precast concrete that will touch the core layer was not roughened.

Figure 2: The Sandwich Concrete Beam



B. Materials

The beams were constructed with the skin layer of high strength concrete for the normal weight with an average 28-day concrete compressive strength of 50 MPa and the core layer of normal strength concrete for the lightweight concrete with that of 30 MPa. The concrete compressive strength was based on the average values from tests performed on at least three 150x 300 mm cylinders from each concrete batch on the day of testing the beam under the standard rate of loading (0.25 MPa/s).

The mix design of normal weight high strength concrete was done in accordance with the guidelines specified by ACI 211.4R-93. While the lightweight normal strength concrete was batched based on ACI 211.2-91. The natural fine aggregates used were Galunggung sand collected from Galunggung mountain. The natural coarse aggregate with 9.8 mm of maximum size sourced from Banjaran, West Java. ASTM Type 1 Tiga Roda Portland cement and ASTM C618 class F fly ash with the density of 2.31 gr/cm^3 from PLTU Suralaya, West Java were used as the filler of the concrete. The chemical additive, namely, sikament NN from PT SIKA Nusa Pratama was applied as the superplasticizer in the normal weight high strength concrete. All the main ingredient of the normal weight high strength concrete was used in the lightweight normal strength aggregate. The different material was the lightweight aggregates, which are the artificial lighweight aggregate with 12.54 mm of maximum size from Cilacap, West Java.

The yield strength, f_y of 390 MPa was used as the longitudinal reinforcement bar and the connector bar as well. The mix proportions are given in Table 1.

Table 1: The Mix Proportions of Each Layer of Sandwich Comcrete Beam

Composition	Normal Weight Concrete (kg)	Lightweight Concrete (kg)
CEMENT	411.1	420.9
FLY ASH	72.6	
FINE AGGREGATE	574.3	564.9
NATURAL COARSE AGREGATE	964.8	-
LIGHWEIGHT COARSE AGGREGATE		552.5
WATER	213.6	226.5
SUPERPLASTISIZER	3.2	-
WATER CEMENT RATIO	0.4	0.5381

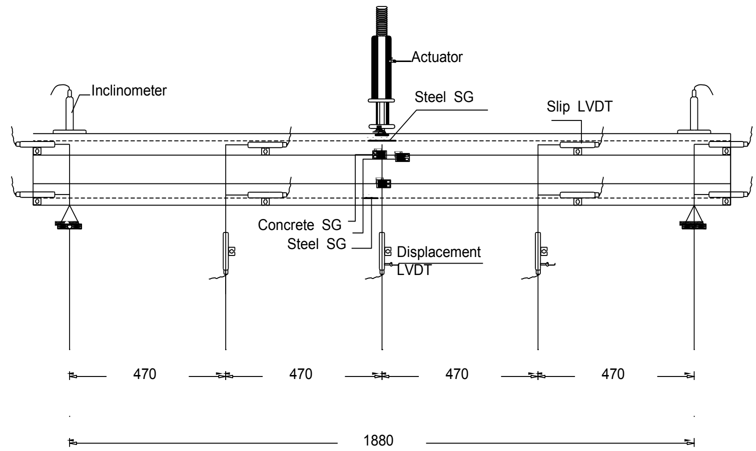
C. Instrumentation

The figure 3 showed the instruments which are used in the sandwiched beam testing in this study consist of:

a. Reinforcement bar and concrete strain measurement

b. Deflection measurement apparatus
c. Slippage measurement apparatus
d. Rotation measurement apparatus
e. Load Cell

Figure 3: The Position of The Measurement Apparatus in Sandwich Concrete Beam Testing



D. Beam Loading

Figure 4 shows the setting of sandwich concrete beam testing. Each of 28 days old beam specimens was tested by laying horizontally in a loading frame. The pin and roll supports were conducted at the ends of the beam as the simply supports. Moreover, the additional supports were applied for the cyclic testing. Cyclic loading was performed by using the loading history based on displacement control (Figure 5).

Figure 4: The Setting of Sandwich Concrete Beam Testing

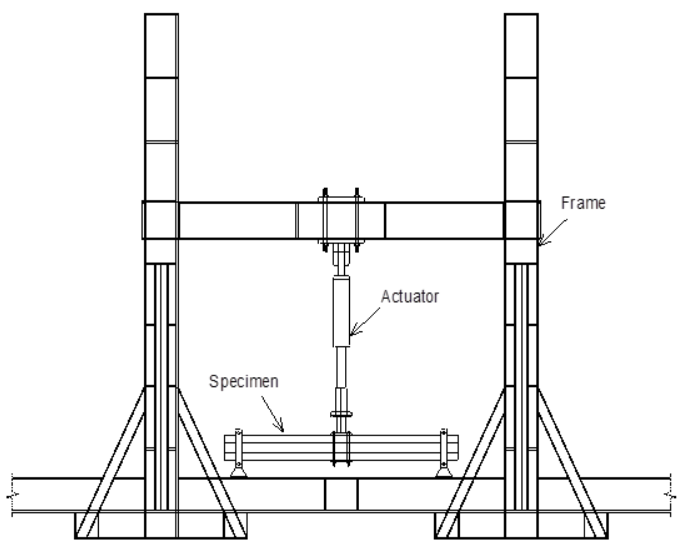
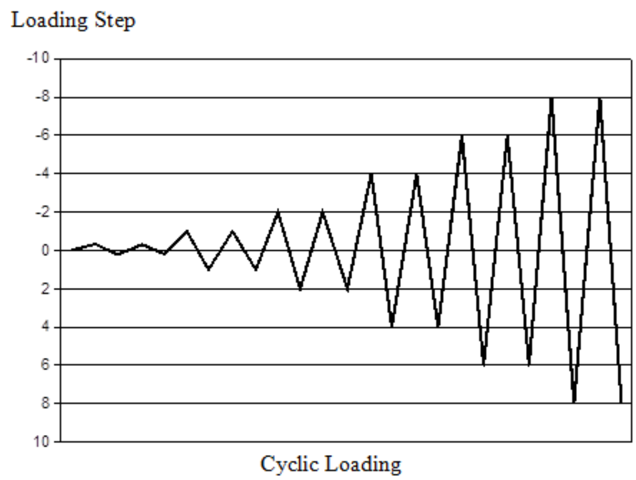


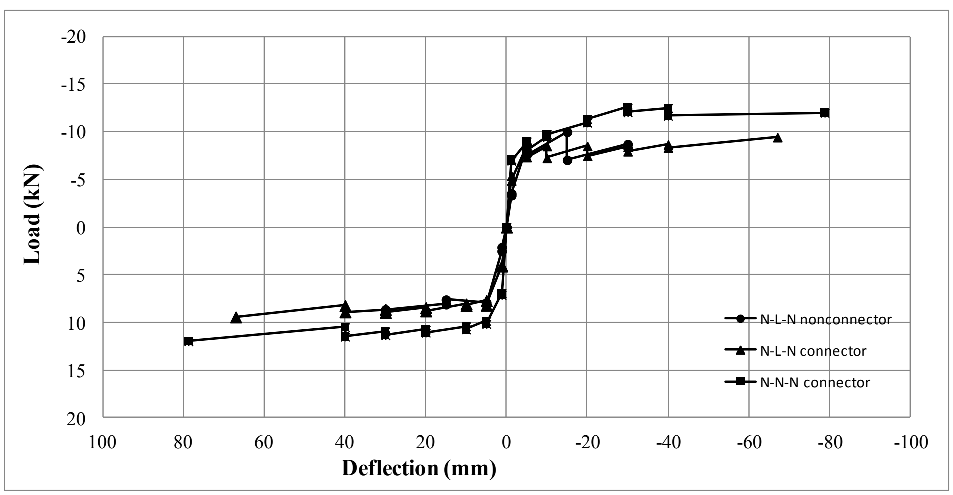
Figure 5: The Loading History of Cyclic Testing



RESULTS AND DISCUSSION

The flexural strength of the beam was computed in each loading stage referred to testing data. This Figure 6 presents the envelope curve of the hysteresis curve which shows the load versus deflection in the middle of the span beam. That each graph shows the comparison of the cyclic behavior of the specimens. The N-N-N reached the biggest maximum deflection among others before it collapsed. The bigger deflection the higher ductility of the specimen reached. Obviously, each specimen explains the stable condition until the ultimate deflection.

Figure 6: The Envelope Load Deflection Curves



A. Cracking Pattern

1. N-L-N Nonconnector Beam

Cyclic loading was applied on this N-L-N non-connector beam. Fine cracks began to appear in the center of the bottom surface the beam leading upward at the first cycle compression load. These cracks closed again when the load reversed to the pull, so it was visually invisible. Inversely, when the tensile load applied, the fine cracks was shown in the center span of the top surface of the beam. The bending moment that caused the initial cracks on the beams is 1.993 kNm in compression direction and 1.335 kNm in tension direction. In the second cycle of the loading step, other cracks occurred at the one-third of beam span. The bending moment that caused the longitudinal reinforcement to yield is

4.056 kNm in compressive direction and 3.784 kNm intention direction. At the later loading stage both on the tension and the tensile direction, the cracks were concentrated in the middle of the span and increased in width a perpendicular direction to the beam axis. In the second cycle of the 6th step of cyclic loading, the sloping cracks near the load point started on the top surface of the concrete. These crack was then wider and caused a buckling effect on the top surface layer. This flexural cracks was continued with the tilted cracks caused a shear collapse. The maximum bending moment that can be supported by the beams is 4.094 kNm in compressive direction and 4.056 kN.m in tension direction.

2. N-L-N connector Beam

In this N-L-N connector beam the behavior of crack pattern was identical with the N-L-N non connector. The bending moment that caused the initial cracks on the beams is 2.496 kNm in compressive direction and 1.922 kNm in tension direction while which that caused the longitudinal reinforcement to yield is 4.023 kNm in compressive direction and 3.854 kNm in tension direction. The propagation of crack pattern was started with the fine cracks at the first cycle of the first loading step and wider at the next step. The cracks were concentrated at the mid span of the beam. Those cracks continued as the flexural cracks until the beam reached the collapse patterned perpendicular to the beam axis. The maximum bending moment that can be carried by the beams is 4.315 kNm.

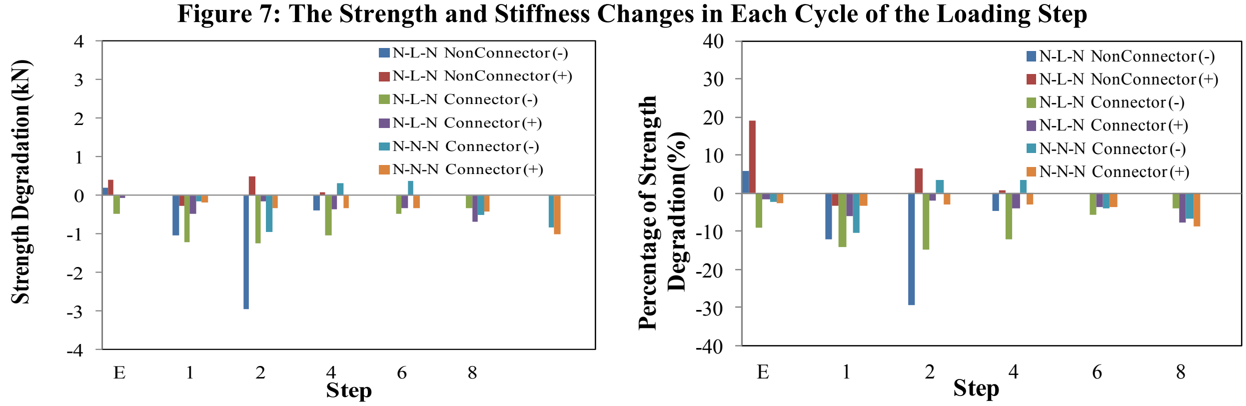
3. N-N-N connector Beam

At the first loading step, this N-N-N connector beam also shown the same behavior of crack pattern. The cracks were also concentrated at the middle of the span and continued to grow in width. The cracks that occurred the beam collapsed caused the top surface layer of the beam was broken. Those cracks patterned perpendicular to the beam axis are the flexural cracks. The bending moment that caused the initial cracks on the beams is 3.346 kNm in compressive direction and 3.346 kNm in tension direction. The bending moment that caused the longitudinal reinforcement to yield is 4.225 kNm in the compressive direction and 4.803 kNm in the tension direction. The maximum bending moment that can be generate by the beams is 5.635 kNm.

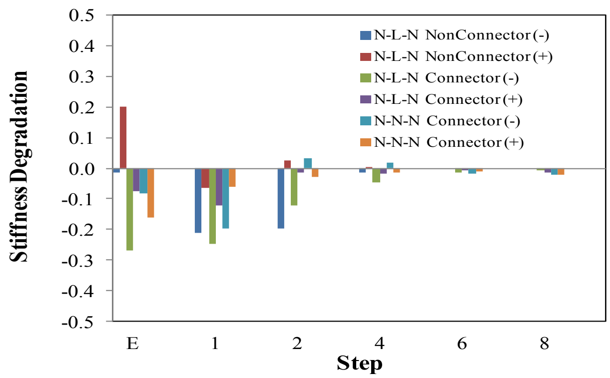
B. Stiffness and Strength Degradation

Each specimen was tested using a displacement control method. The number of steps used in the test based on the value of displacement which was increased sequentially. Each step of this test was applied in 2 cycles. Based on the test results seen that there was a change in the value of strength and stiffness between cycles at each loading step, as well as the changes in the strength and the stiffness values among loading steps. Figure 7 below shows the change in between the strength and the stiffness of each specimen.

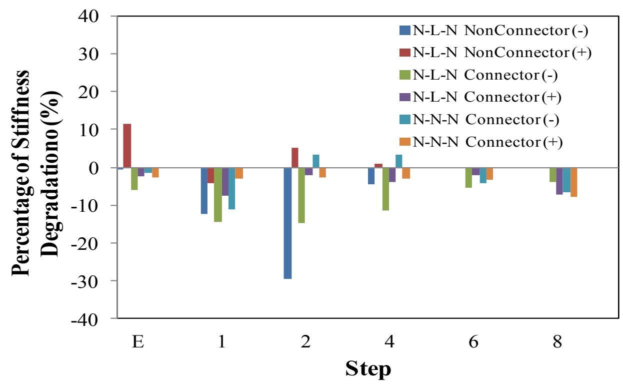
Figure 7: The Strength and Stiffness Changes in Each Cycle of the Loading Step



(a) (b)



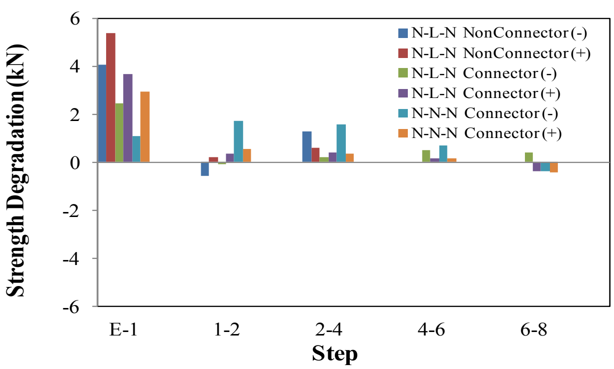
(c)



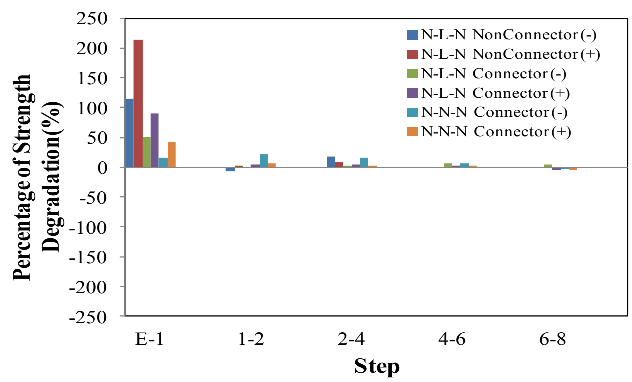
(d)

Figures 7 (a) and (b) shows the change of strength between two cycles in each step loading. It is described that the strengths which are tended to be a decline in each cycle are different. The percentage of decreasing between cycles is below 20% except for N-L-N Non-Connector specimen which reaches up to 29.43%. The use of the connector results in different strength change between cycles in each loading step. The beam with connector seems to be more stable than those without a connector. The same trend also occurs in the change of stiffness between two cycles in each step loading. Figures 7 (c) and (d) clearly explain that the stiffness change tends to be a decline with no more than 15%, except for N-L-N Non Connector specimen which reached up to 29.57%. The connector of the beam also resulted in the differences in stiffness changes between cycles in each loading step as can be seen from those graphs. The stiffness between cycles tends to be more stable at the higher load step, as seen from the smaller percentage of stiffness change.

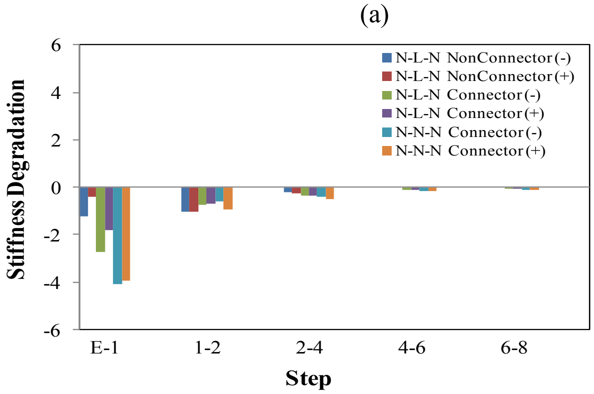
Figure 8: The Strength and Stiffness Changes in Each Loading Step



(a)



(b)



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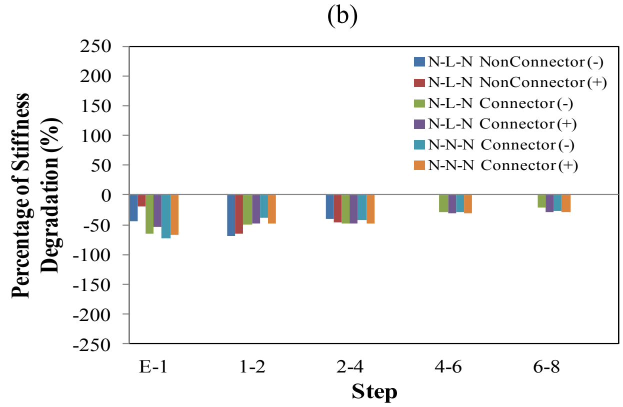


(d)

The strength changes among the loading steps are clearly shown in Figure 8 (a) and (b) A large increase in strength is imposed upon loading through the elastic condition with a relatively low strength value. At the next loading step, it becomes quite stable with a relatively small load burden. The strength begins to decline at the last step. The N-L-N Non Connector specimen only lasts up to the 4th loading step while other specimens are able to withstand up to a higher loading step with relatively stable conditions.

Otherwise, the stiffness value of the specimen is a degradation significantly as the loading passes through the elastic state. Figures 8 (c) and (d) show that at a higher step the decrease in stiffness continues with the value tends to decrease.

Based on all comparisons of strength and stiffness it can be concluded that the decrease of stiffness degradation occurs when the load is lower. This is caused by the slip condition experienced by the beam causing the pinching effect. While post peak loadr changes are relatively stable in all specimens.

C. Ductility

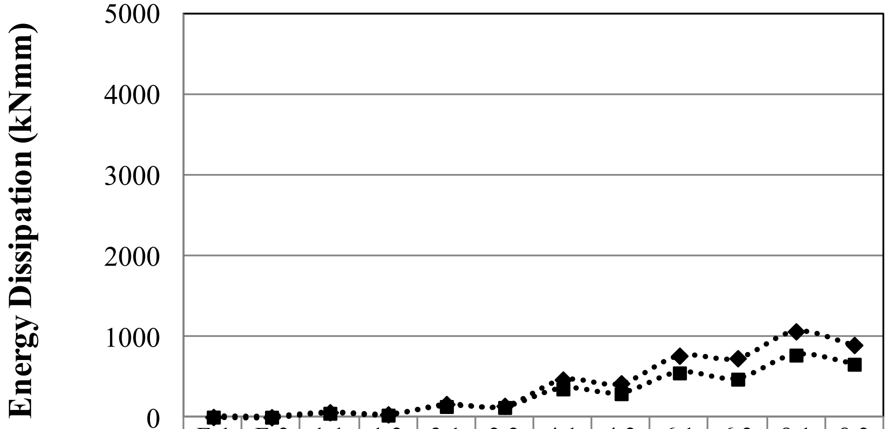
Based on the cyclic test, the ductility value can be determined by comparing the deflection occurring in the ultimate condition to that of at yield state. Table 2 shows the differences of the three beam specimens in this cyclic test. The N-N-N Connector specimen yields the highest ductility value of 15,578. The use of connector in the sandwich beam proved to affect the resulting ductility, seen from the results obtained that the ductility of the N-L-N Connector test specimen is higher than N-L-N Non connector.

Table 2: Ductility of the Beam

	Yield Condition					Ultimate Condition		
	Yield Load (kN)				Deflection (mm)	Ultimate Load (kN)	Deflection (mm)	Ductility
	P_{push}		P_{push}					
Specimen	I	II	I	II	$\square_y$	P_{push}	$\square_u$	$\square_u/\square_y$
N-L-N NON CONNECTOR	8.63	7.7	8.05	7.89	5	6.01	34	6.8
N-L-N CONNECTOR	5.31	4.89	4.09	4.03	5	9.43	67.09	13.418
N-N-N CONNECTOR	7.12	6.96	7.12	6.99	5	11.99	78.79	15.758

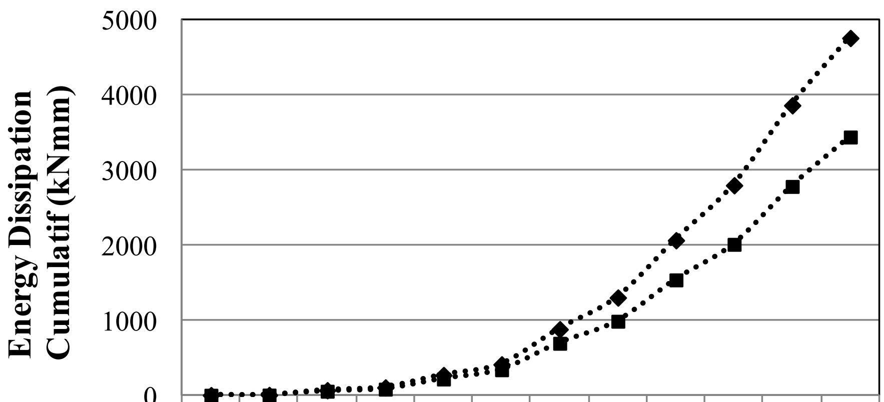
D. Energy Dissipation

Figure 9: Energy Dissipation in Each Cycle of The Cyclic Test



	E.1	E.2	1.1	1.2	2.1	2.2	4.1	4.2	6.1	6.2	8.1	8.2
N-L-N Connector	4	2	51	28	135	123	353	294	551	474	772	659
N-N-N Connector	5	2	63	37	165	143	468	422	764	733	1066	897

Figure 10: Cumulative Energy Dissipation of The Cyclic Test



	E.1	E.2	1.1	1.2	2.1	2.2	4.1	4.2	6.1	6.2	8.1	8.2
N-L-N Connector	4	6	57	85	220	343	696	990	1541	2015	2787	3445
N-N-N Connector	5	7	70	108	273	415	884	1306	2069	2802	3868	4765

The calculation of energy dissipation was determined on N-L-N connector beam and N-N-N connector beam based on cyclic test result. Figure 9 shows the time history of the energy dissipation response in each cycle to the boundary state. While Figure 10 presents the cumulative energy dissipation value to the ultimate state of the two beam specimens. The energy decline in the second cycle at each loading stage which is shown in Figure 9 is due to the degradation of the stiffness of the structure according to the one shown in Figure 7 (c) and (d). This is due to the slip condition of the pinching effect.

Figure 10 presents that the N-L-N connector beam produces higher energy dissipation. It is concluded that the combination of lightweight concrete materials used in the sandwich concrete layers results in more ductile behavior based on the ability of the beam to dissipate the energy.

CONCLUSION

a. The bonding between the two different concrete layers which is set by the connector heavily influenced the composite behavior of the beams. The beam with the connector leads the better cyclic behaviour.
b. The cyclic load of the beam determined the degradation of stiffness and strength in every cyclic due to the slip at the lower load (pinching effect).
c. The connector and the compressive strength of the center layer of the beam established the increasing of energy dissipation. The N-L-N Connector beam produced the higher energy dissipation.
d. The cyclic loading observation on the flexural beams shows that the ductility response is specified by the connector in the middle part of the concrete beams, and the compressive strength of the core layer of the concrete.

REFERENCES

ACI (1991). *Standard Practice for Selecting Proportions for Structural Lightweight Concrete* – ACI 211.2.91, ACI Manual of Concrete Practice Part 1, American Concrete Institute, Detroit.

ACI (1993). *Guide for Selecting Proportions for High Strength Concrete with Portland cement and Fly Ash* – ACI 211.4R-93, ACI Manual of Concrete Practise Part 1, American Concrete Institute, Detroit.

Callister, W.D. (1997). *Materials Science and Engineering – An Introduction*, John Wiley & Sons, Inc.

Corden, J. (1990). *Honeycomb Structure*, in Engineered Materials Handbook. ASTM Int., Ohio, pp: 721-728.

Jones, R. M. (1975). *Mechanics of Composite Materials*. McGraw-Hill.

Neville, A.M., 2000. Properties of Concrete. Prentice Hall.