THE PERFORMANCE OF PRETENSIONED PRESTRESSED CONCRETE BEAMS MADE WITH LIGHTWEIGHT CONCRETE

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ABSTRACT

A study on the behaviour of prestressed concrete beams made from clinker aggregate has been carried out at the Faculty of Civil Engineering, UTM. In this paper, the performance of prestressed lightweight concrete beam under two point load is discussed and comparisons are made with normal weight prestressed concrete beam. The clinker is incorporated into the concrete as a direct replacement for both fine and coarse aggregates at 100% replacement level. The use of clinker lightweight concrete was found to save the amount of the total dead load up to 18.8%. The test results show that lightweight concrete using clinker exhibit an almost similar pattern in cracking behaviour and failure modes. The test results show that the prestressed lightweight concrete beams can resist loading up to 90% of the normal prestressed concrete beams. The study also shows that clinker lightweight concrete exhibit good performance and is suitable to be used in prestressed concrete beam.

Keywords: *palm oil clinker lightweight concrete, lightweight aggregate, prestressed concrete beam, mix design, cracking, failure*

INTRODUCTION

Malaysia is one of the premier manufacturers of palm oil. Every palm oil mill produces a waste by-product, known as clinker. Clinker was found to be suitable to replace normal gravel aggregate in concrete mixture [1]. Concrete mixture containing clinker as aggregates can be classified as lightweight aggregate concrete due to its lower density. The British Standard, BS 8110 : Part 2 : 1985 classified lightweight concrete as concrete having density of 2000 kg/m^3 or less [2]. According to RILEM's functional classification of lightweight concrete, structural lightweight concrete is defined as having oven dry-density of less than 2000 kg/m^3 and compressive strength more than 15 N/mm^2 [3].

In the United States and Europe, lightweight aggregate concrete has been used as construction material, replacing the normal dense aggregate since in the late nineteenth century [4]. It has been used in structural concrete for many years and in many cases purely due to economic considerations. The most obvious characteristics of lightweight aggregate concrete is of course its density which is always considerably less than normal concrete [4]. For the same crushing strength, the density of concrete made with such lightweight aggregate can be as much as one-third lower than that of normal concrete made with sand and gravel or crushed rock aggregates [5].

Clinker has been used as an aggregate in concrete mixture, replacing the normal dense aggregate in Britain for more than 90 years and it is still an important aggregate in terms of quantity used. In the United States, clinker has also been used for about as long as in Britain, and it is still widely employed in spite of the large output and wide range of other alternative aggregates [4]. In Malaysia, the development of using palm oil clinker as lightweight aggregate in construction industry, especially in structural application started about 30 years ago [1].

Research on structural behaviour of reinforced concrete beams using palm oil clinker as fine and coarse aggregate replacing the normal weight aggregate has been carried out by Rezuwan [1]. In term of structural behavior, the researcher found that the lightweight concrete beams show a comparable behaviour in cracking, ultimate load and only a slight different in deflection. It was also found that lightweight concrete using palm oil clinker satisfies the code provisions for structural lightweight concrete. It was also deduced that the palm oil clinker does not pose any adverse effect on the strength development of the lightweight concrete.

The aggregates produced from clinker are lightweight, porous and irregular in shape, and consequently have low values of bulk density and specific gravity. The pore structure of such aggregates is complex, and this together with their absorption characteristics and relative density have been investigated and reported by the authors [6]. Regarding to the point that lightweight concrete is very economic especially for long span structure [7], investigation is carried out to study the performance of clinker concrete mixture towards prestressed concrete beams. This paper reports on the result of static load test on prestressed lightweight concrete beams made from clinker as fine and coarse aggregate in the concrete mix. The results are compared to the normal weight prestressed concrete beam having similar section and under similar loading system.

EXPERIMENTAL WORKS

Details of Tests

A total of four prestressed concrete beam specimens were tested. Two beams were casted using clinker lightweight concrete and another two beams using normal weight concrete. The type of beam specimens are pretensioned prestressed concrete beam. All beams were casted without the provision of web reinforcement. Both types of concrete were designed to achieve target strength of 40N/mm^2 at service and 30 N/mm^2 at transfer, which was the minimum required strength for pre-tensioned prestressed structure [2]. Details of the beam specimens are shown in Figure 1.

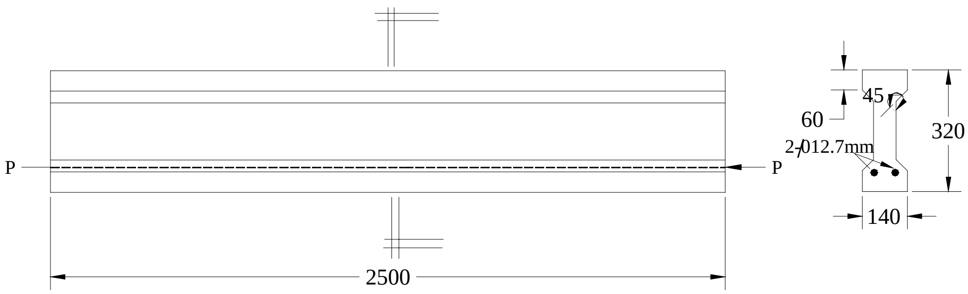

Figure 1: Details of beam specimens

Materials

Two concrete mixes, one is normal weight concrete (NWC) and the other is lightweight concrete (LWC) were prepared. The normal weight concrete used sand and gravel as fine and coarse aggregate while the lightweight concrete used crushed clinker as fine and coarse aggregate. Both concrete mixes were proportioned according to Building Research Establishment [8]. Since clinker is an industrial waste, several tests have been carried out in order to obtain some basic properties of these lightweight aggregates. The test results were then checked with appropriate standards to ensure the suitability of clinker aggregate to be used in lightweight concrete mixture. Table 2 shows the basic properties of clinker aggregate in the form of fine and coarse aggregate. The coarse clinker aggregates had a maximum size of 10 mm and satisfied the BS 3797 grading limit.

Table 2: Basic Properties of Clinker Lightweight Aggregate

Properties of Clinker Aggregate	Fine Aggregate	Coarse Aggregate
Specific Gravity (Oven-dry)	-	1.73

Bulk Density (kg/m^3)	1080	827
Gradation (Sieve Analysis)	Satisfied the grading limit	BS 3797: 1990
Water absorption (%)	7.5	3.0
Loss-on-ignition (%)	0.45	-

The strands used in this study were from Grade 270 with nominal diameter of 12.7 mm and were manufactured to meet the standard requirement as prescribed in ASTM 416 [9]. The characteristic strength of these strands (obtained from direct tensile test) is 1860 N/mm^2. Two numbers of strands were fixed in each beam, as shown in Figure 1.

Lightweight Concrete Mix Design

The lightweight concrete mix using clinker as fine and coarse aggregate was designed in accordance with the Building Research Establishment with some considerations given to the variations in design necessity such as aggregate bulk density and water absorption [8]. Casting, curing and testing the specimens were carried out in accordance with the requirements of the British Standard. The composition of the constituent materials and the saturated surface dry density for both normal weight mix and lightweight mix were tabulated in Table 3.

Table 3: Constituent Material Composition for NWC and LWC

Type of mixes	**NWC**	**LWC**
Free-water / cement ratio	0.47	0.44
Free-water content (kg/m^3)	188.33	205
Cement content (kg/m^3)	401	512.5
Fine aggregate content (kg/m^3)	778.7	487.2
Coarse aggregate content (kg/m^3)	1032.3	645.8
Saturated surface dry density (kg/m^3)	1.950	2.400

According to the design mix calculation, it was found that in order to produce a design strength of 40 N/mm^2 for NWC and LWC, total cementitious materials required were 401 and 512.5 kg/m^3 respectively. On the contrary, the saving in total aggregate content in LWC mix design was quite significant, where, in this research, it was found that about 37% of total aggregate content could be saved in LWC**.**

All concrete batches were designed for cohesive and workable mix. The fresh unit weight of LWC is 1950 kg/m^3 compared to NWC which is 2370 kg/^{3}, which the difference is about 18 %. This result was in good agreement with that obtained by Bender (1980), who found that 20% - 30% of the total dead load could be reduced by replacing the normal weight concrete with lightweight concrete [7]. The hardened concrete properties of all specimens were made and tested using standard mould based on British Standard.

Casting of Beams and Testing

All beam specimens were casted in formworks that were located in a prestressing bed with force capacity of 1000 kN. Prior to casting, the strands were first fixed and tensioned by using TITAN 20 hydraulic jack. The LWC and NWC specimens were cast separately. Compaction was carried out using a poker vibrator. The beams were covered with polythene sheeting and were left for two days before removing the formworks. All beam specimens were cured using wet hessian in the laboratory. All beams were detensioned after achieving the transfer strength at age of 7 days.

Altogether, four numbers of prestressed concrete beams were casted. All prestressed concrete beams were tested after a curing period of 28 days. Two-point load tests were carried out on normal weight and lightweight specimens. The full set-up for the two point loading test of both types of prestressed concrete beams is shown in Figure 2. The load was applied using ENERPAC hydraulic jack with load capacity of 200 tons. The loads were applied at an interval of 5 kN. During the test, data on mid-span deflection and strains in concrete were automatically measured at every load stages using Kyowa data acquisition system, together with the control software, UCS-25AS.

Figure 2: Two Point Load Test on Prestressed Lightweight Concrete Beam

EXPERIMENTAL RESULTS AND DISCUSSIONS

Basic Properties of Lightweight Concrete

The results of LWC and NWC properties in term of cube compressive strength, flexural tensile strength, indirect tensile strength and static modulus of elasticity were tabulated in Table 4. The mean cube strength for LWC is 44.1 N/mm^2 compared to 46.1 N/mm^2 of the NWC. It was found that the strength of lightweight concrete is only slightly lower than the strength attained by the normal weight concrete.

For flexural and splitting tensile strength, the tests were performed in accordance to BS 1881: Part 116 and 117. The mean moduli of rupture obtained for LWC and NWC are 6.1 N/mm^2 and 6.4 N/mm^2 respectively. The splitting tensile strengths obtained for LWC and NWC are 3.17 N/mm^2 and 3.31 N/mm^2 respectively. Based on these results, it shows that the tensile strength of lightweight concrete is slightly lower than the tensile strength of normal weight concrete.

The mean secant moduli for LWC and NWC are 22 kN/mm^2 and 30 kN/mm^2 respectively. The value of the LWC was about 0.73 times of the normal weight, concrete. This value is in close agreement with the research result obtained by the Cement and Concrete Association [10] on lightweight aggregate, in which case, the elastic modulus of LWC is approximately 0.5 to 0.75 times the value for NWC.

Table 4: Basic Material Properties of NWC and LWC

	NWC		**LWC**	
	Weight (kg)	**Strength**	**Weight (kg)**	**Strength**
Compressive Cube Strength (N/mm2) (100 x 100 x 100 mm)	2.39	46.1	1.98	44.4
Flexural Tensile Strength (N/mm2) (100 x 100 x 500 mm)	11.8	6.43	10.9	6.09
Splitting Tensile Strength (N/mm2) (150 dia. X 300 mm)	12.2	3.31	11.1	3.17
Elastic Modulus (kN/mm2) (150 dia. X 300 mm)	12.2	30	11	22

Cracking Behaviour

During testing, it is found that, in all beam specimens, cracks tend to appear earlier in lightweight beam specimens. This indicates that the lightweight beams have a lower cracking load compared to the normal weight beams. This phenomenon may be explained by the lower tensile strength properties of lightweight concrete, as indicated in the investigation of basic material properties.

Comparing the pattern of crack line between the normal weight and lightweight specimens, it shows that for lightweight specimens, the crack line propagated smoothly and almost linear during the load increment. This is due to the softer and weaker properties of lightweight aggregate. On contrast, for normal weight specimens which have stronger aggregate, the crack lines always propagated in a form of jagged line and take an appreciable time to develop. In normal practice, tension failure generally occurs due to the breakdown of the bond between the surface of aggregate and the matrix [4].

Load-Deflection

The typical load-deflection curves for lightweight and normal weight prestressed concrete beam specimens (after averaged) are shown in Figure 3. The maximum load achieved for both LWC and NWC specimens are 110 kN and 103 kN with maximum deflection about 6.1 mm and 4.6 mm respectively. Based on these results it is found that the ultimate load for LWC beams is almost similar to those of NWC beams. The different in load carrying capacity for LWC beams is only 6.4%. It was also found that LWC beams tend to have higher deflection at lower failure load compared to the NWC specimens about 32%. This phenomenon is well agreed with the fact that material with lower elasticity modulus would deform more than the stiffer material [11].

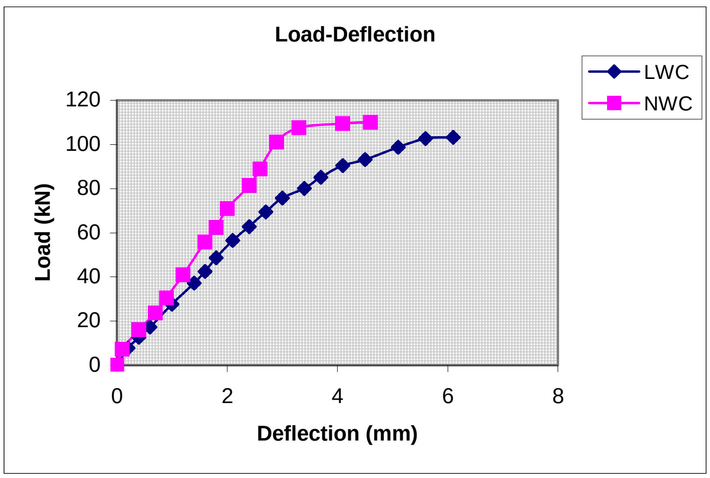

Figure 3: Load-Deflection for NWC and LWC beams

Failure Mode

All beam specimens were failed in shear mode, with almost similar value of maximum strength. The LWC specimens exhibit a very similar pattern of failure mode with the NWC specimens. The combination of several web-shear cracks, which formed with only small increase in load, have developed a larger crack width and thus effectively crushed the web part and the bottom flange of both specimens. For both specimens, the inclination of the failure cracks is about 20° to 30°.

This type of failure is known as web compression failure or web-distress failure, which usually occurred at the region of combined stresses. According to Khachaturian [12], failures in this region (combined stresses region) are brittle and often violent. He also said that this type failure behaviour is peculiar to prestressed concrete beams with thin web and with higher prestress. The propagation of these inclined cracks is accompanied by an increase in the inclined tensile stresses, which is not effectively taken by the prestressing strands because for straight tendon, the prestressing strands is not placed in a way that perpendicular to the inclined cracks, as in the case of pure flexure.

Variation of Strain on Concrete

Variation of strain on concrete surface over the depth for normal weight and lightweight beam specimens are shown in Figure 4. Generally, for both beams, the strain reading at each location tends to increase with the increment of load. In all cases, the strain readings above the neutral axis represent strain in compression while those below represent strain in tension.

From Figure 4 (a) and 4 (b), they show that the maximum strains measured at the top of NWC-OR and LWC-OR specimens are –1241με and –1435 με respectively while at bottom fibre, the maximum strain gained are about 1004 με and 1088 με. Comparing these values, it is noted that strain values for lightweight specimen always greater than the normal weight specimen. This observation is well demonstrated the point that material with lower elasticity modulus deforms more and thus produced higher strain value.

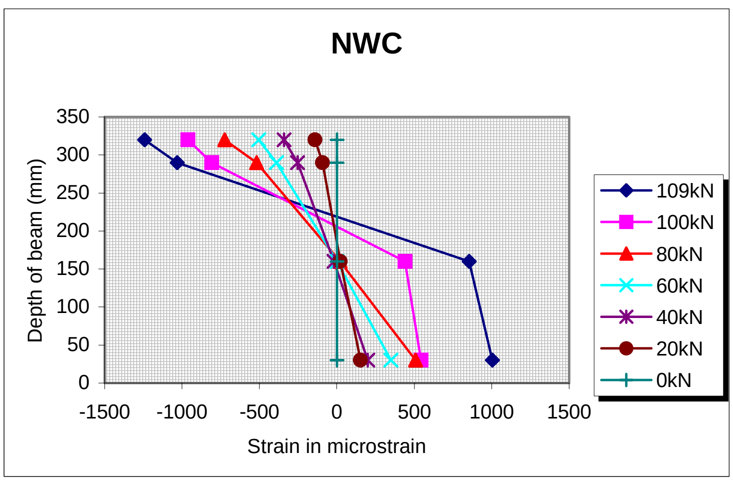

Figure 4(a): Variation of Strain on Concrete on NWC beams

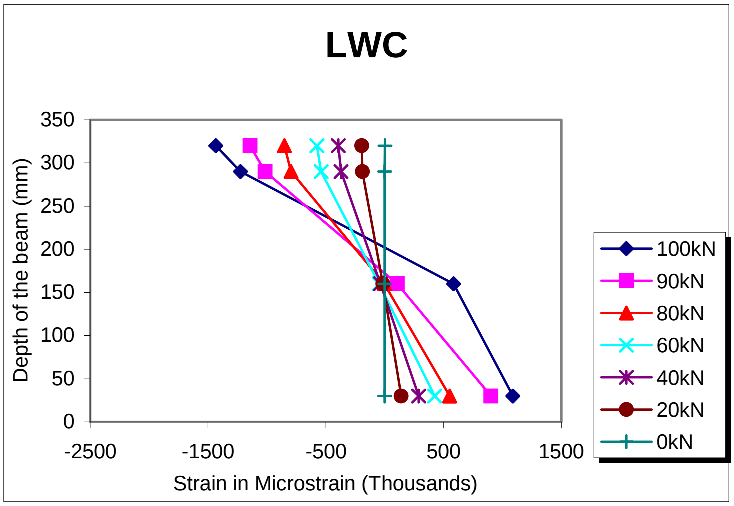

Figure 4(b): Variation of Strain on Concrete on LWC beams

CONCLUSIONS

Based on the experiment results, the following conclusions may be drawn:

1) Clinker lightweight aggregate, in a form of fine and coarse, could produce workable and cohesive lightweight concrete mix with a density of 1950 kg/m^3, thus saving about 18.8 % of the total dead weight.
2) In comparing the constituent materials of NWC and LWC, it was found that LWC requires 14% more total cementitious contents than the corresponding NWC. On the contrary, lightweight mixture provides economic used of aggregate where about 37% of total aggregate content were saved for the same strength of LWC and NWC.
3) The results from basic material properties of LWC show that the compressive and tensile strength of LWC is lower than the NWC, but the different is small, which is around 3.6% to 4.6%.
4) The value of elastic modulus of clinker lightweight concrete can be accepted as specified by Cement and Concrete Association.
5) The static load test shows that the ultimate load capacity for prestressed lightweight concrete beam specimens is only 6.4% lower than the normal weight specimens.
6) The deflection of prestressed lightweight concrete beams was slightly greater than the normal specimens. This was as expected due to the lower elasticity modulus value.
7) The cracking behaviour of LWC beam specimens show an almost similar pattern with those of NWC specimens, except at slightly lower load capacity.
8) The failure mode of both LWC and NWC beams show a very similar result, where all beam specimens failed in shear manner.

9) The strain readings on lightweight concrete specimens always give a higher value compared to the strain readings in normal weight specimens, due to the fact that lower elasticity modulus deforms more and thus produced higher strain.

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