EFFECT OF LIMESTONE POWDER ON MECHANICAL PROPERTIES OF CEMENT COMPOSITE BOARD

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ABSTRACT

In order to enhance physical and mechanical properties of Cement Composite Board (CCB), various components in addition to cement are used in the manufacturing process. In this paper, the effect of limestone powder has been investigated as a cement substitute. Five mixtures were designed with different amounts of limestone powder; specimens were made and tested for flexural strength. In these mixes 0%, 5%, 10%, 15% and 20% limestone powder replaced the cement. The results showed that the 5% and 10% replacement of limestone powder led to maximum flexural strength of the cement composite board. The optimum mix in this investigation satisfies Class 1 classification of the BS EN 12467 standard.

KEYWORDS:

Cement Composite Board; Limestone powder; Natural cellulose fibres.

INTRODUCTION

Wood pulp fibres are unique reinforcing materials offering numerous advantages. They are non-hazardous, renewable, and readily available at relatively low cost compared to other commercially available fibres. As a result, pulp fibre–cement composites have found practical applications in recent decades in the commercial market (MacVicar, R. et al 1999). Research indicates that cellulose fibres have good potential for manufacturing of CCB with other synthetic fibres such as acrylic and PVA fibres (Ganjian, E. et al (2008; Coutts et al (2005); Bentur. (1990)).

Additives and admixtures are favoured in the construction industry as they allow a cementitious mix to exhibit properties that are otherwise unachievable without them.

The use of different types of chemical and mineral admixtures to increase flexural strength of CCB has attracted the interest of researchers. Admixtures are minerals or chemicals that can be added to a cementitious mix in order to vary its physical or mechanical properties. Properties such as colour, compactness and workability can be varied using admixtures. There are several types of additives which are more important than other additives; such as limestone powder, PFA, Bentonite and silica fume. This is because they are accessible, economical and have a vast effect on the cement composites depending on location and specific conditions. Some researchers (Babu and Prakash 1995) have found that the admixtures and additives can improve bonding between components of cement composite.

The additive that will be paid particular interest, for the purposes of this research, is limestone powder. Limestone powder, also known as limestone, calcium carbonate, precipitated calcium carbonate, ground / pulverized calcium carbonate, and Corinaldesi V et al (2003) claimed that the Blaine fineness of limestone powder is about 0.610 m^2/g and its absolute density was 2650 kg/m^3.

Portland cement is not cheap, and with the ever growing interest in formulating cheaper cementitious material, a hybrid filler cement compound was made - Portland limestone cement - which is widely used in the industry, containing 5% limestone. The ASTM C150 standard now permits up to 5% limestone to be blended into building materials (Bentz D.P 2006) but many regions in Europe commonly practice up to 20% limestone in many types of cement composite.

Limestone powder is predominantly a filler material and acts inertly. However Heikal Et al (2000) reported that limestone fillers improve the density of cement composites. This is achieved as the limestone particles has only physical reaction within the cement matrix and fill the voids and pores in the composite.

MATERIALS

The following materials are used in the mix to produce cement composite board in the Lab.

1. Ordinary Portland cement (CEM1 grade 52.5, BSEN 197-1).
2. Cardboard cellulose fibres.
3. Limestone powder with specific gravity of 2.5 measured by helium pycnometer, and the particle size distribution as shown in Figure 1, measured using a Malvern Mastersize 2000 laser analyser with an accuracy of ±1%.
4. Water.

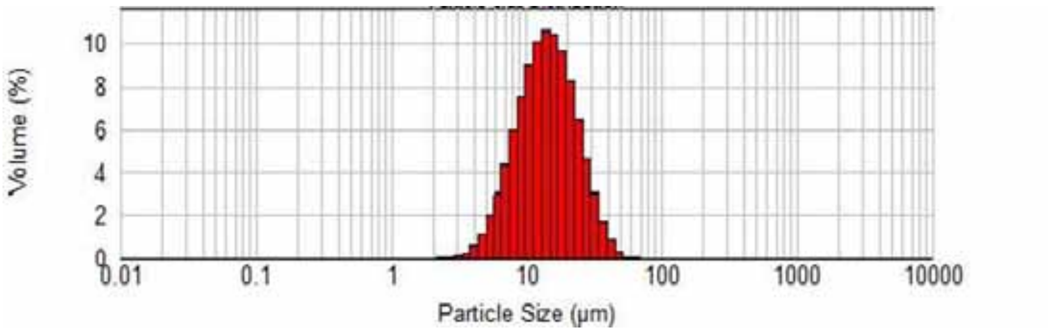

Figure 1 : Particle size distribution of the Limestone powder.

Materials Preparation

Cellulose fibres were obtained by shredding waste cardboards after being submerged in water for 72 hours (Fig 2). Then they were rinsed out and placed in a mixer with a wide blade at slow spin speed for about one hour. After that the pulp was mixed with narrow blade at fast spin speed. This processed pulp was then used as cellulose fibre in the cement composites made. (Fig 2a). After the above mention procedures, the average moisture content of the pulp was 76.58% being the percentage of weight of dry cellulose to weight of water plus cellulose.

Figure 2 a : Submerged cardboard pieces **Figure 2 b : Beating cellulose fibres in the lab**

After preparation of pulp cellulose fibres, they were beaten and refined in a twisting motion with pressure in a pestle and mortar (Fig. 2b), this twisting motion allowed the micro fibrils to unwind from the core stem to allow for suitable fibre fibrillation. The cellulose fibre solution was then mixed using an overhead propelling mixer for 2 minutes, this insured that the fibres did not clump together and that the fibres were uniformly distributed in the water. A propelling rate between 1700 and 2000 rpm was used.

After mixing all materials (cement, cellulose fibres and limestone powder) in the mixer, the slurry was then placed in a mould (Fig 3). A vacuum pump was then connected to the mould to pump out the excess water. After removing water and pressing the specimen with a 10 kg weight, the specimen was demoulded and put in a high humidity chamber.

Figure 3: System set-up for making the specimens

Table 1 shows the mix design. The mix codes were structured in the following manner: The abbreviation 'P' represents the pulp fibre and the abbreviation 'L' represents the limestone powder. The numbers after their respective abbreviations represent the percentage of that material used by weight of the cement content. For example P8-L15 denotes that there is an eight percent cellulose fibre and a fifteen percent limestone powder replacement by cement weight. If the percentage of cellulose content is expressed as a percentage of total materials, it becomes 7.41% i.e. 9.6 / (9.6+120).

Table 1: Mix design and proportions of the materials used.

Mix	Code	Limestone powder (gr)	Cement (gm)	Cellulose fibre(gr)	Water (gr)
1	P8	0	120	9.6	360
2	P8-L5	6	114	9.6	360
3	P8-L10	12	109.2	9.6	360
4	P8-L15	18	102	9.6	360
5	P8-L20	24	96	9.6	360

The specimens are then tested in flexure with the machine set to 8mm deflection limit. When the limit deflection is reached the machine, unloads the specimen. It is expected for the specimens to fail before an 8mm deflection is reached, and therefore a deflection beyond 8mm is not needed. A JJ Lloyds machine records all data including deflection and load. (See Figure 4).

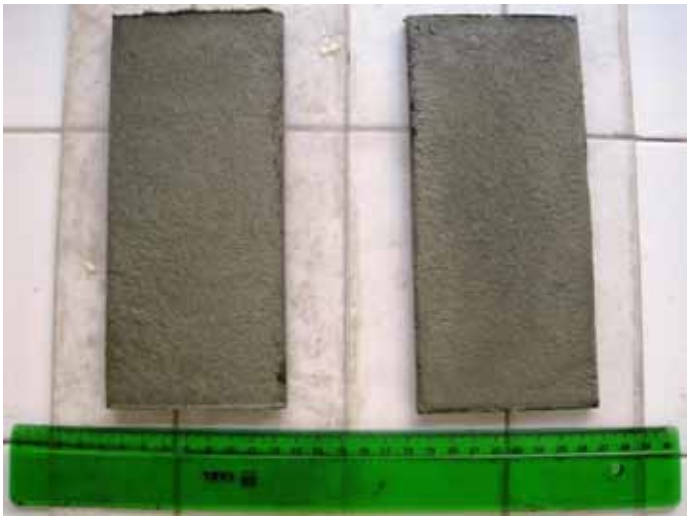

Figure 4: Some of the specimens produced in the laboratory

Six specimens were made from each mix and were cured at 95 % RH and 20 °C. Three were tested after 7 days of curing, and the remaining three after 21 days of curing. The typical dimensions of specimens were 80mm by 180mm and varied in depth between 6 and 8 mm (Fig 4. According to BS EN 12467, the condition for bending is 24 hours immersion in the water and doing the test immediately upon removal from the water.

TESTING

The specimens were tested in flexure. Also the densities of the specimens were measured.

Flexural Test

The specimen was placed into the flexural testing machine where it was simply supported (according to BS EN 12467:2004), where one support was fixed and the other free to move. It was also noted that the supports were rounded with a radius larger than 3mm but less than 25mm, which complies with BS EN 12467:2004 clause 7.3.2.2.1. Also according to BS EN 12467, the condition for bending test for categories A, B and c is 24 hours immersion in water and doing the test immediately upon removal from the water.

The test machine was set to a constant rate of loading (fulfils criteria 7.3.2.2.1 BS EN 12467:2004) and only allowed the specimen to deflect up to 8mm. All other criteria specified by BS EN 7.3.2.2.1 for flexural testing were fulfilled. The span for flexural strength was adjusted at 160 mm. (Fig 5).

In BS EN 12467:2004 flexural strength of CCB is called MOR which means 'the modulus of rupture' and is calculated using the following expression.

$$MOR = \frac{3Fl_s}{2be^2}$$

where:

F is the breaking load, in newtons;

l_S is the span between the axes of supports, in millimetres;

b is the width of the test piece, in millimetres;

e is the thickness, in millimetres:

Density Test

The way in which the densities of the specimens were determined was by using the water displacement method.

The dry weight of the specimen was measured using a top pan balance and recorded (Fig 6). The specimen was then placed on a cradle below the top pan balance (but attached) and then submerged underwater up to the same depth every time. The wet weight was then recorded.

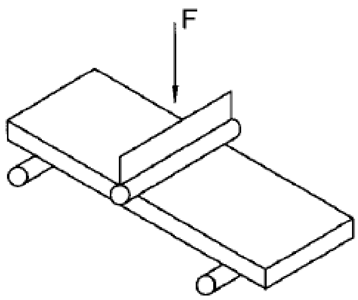

Figure 5: flexural strength test for CCB according to BS EN 12467:2004

Figure 6. System set-up for finding the density of CCB

The following expression was used in order to determine the density of the specimen;

Density= $W_{\text{in air}}/(W_{\text{in air}}-W_{\text{in water}})$

RESULTS AND ANALYSIS STATEMENT

The test results obtained from the experimental procedure includes the flexural behaviour of the cement composite boards (CCB), the thickness variation of the specimen and the density variations of the specimens.

This section will analyse the effects of increasing Limestone powder in 5%, 10%, 15% and 20% to mixes which contain 8% cellulose fibres. In this case the percentage of cellulose weight is 7.41% of total materials.

Effects of Curing Time on Flexural Behaviour

It is generally considered that cement products get stronger throughout their lifetime. This is due to the hydration reaction. Therefore it is expected that the specimens that are allowed to cure for 21 days perform significantly better than the 7 days cured specimens.

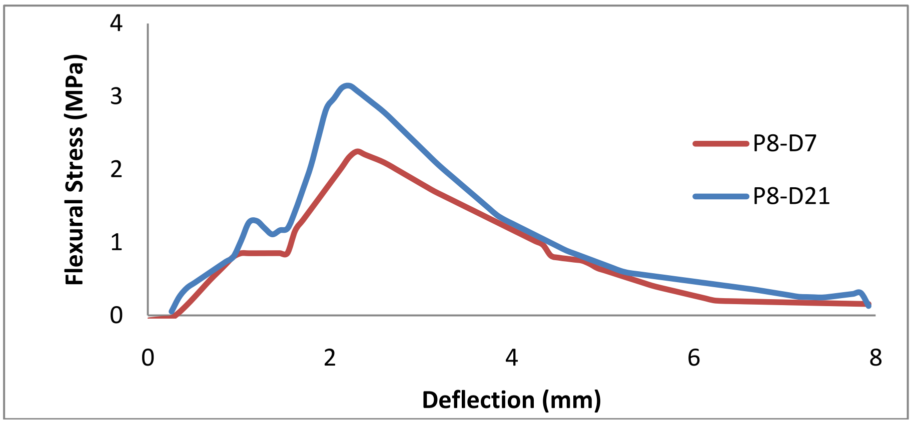

Figure 7 Flexural behaviour of CCB for 7 and 21 days of control specimens i.e. 8% pulp only

Figure 7 is the control specimen and shows that the 21 days cured specimen behaves as expected as it possesses a greater flexural strength. Both specimens also seem to fail at the same deflection. The curves represent the average of the results from three companion specimens.

The apparent discontinuity in stress development in this figure before the 2 mm deflection is due to the transfer of load from cement particles to fibres.

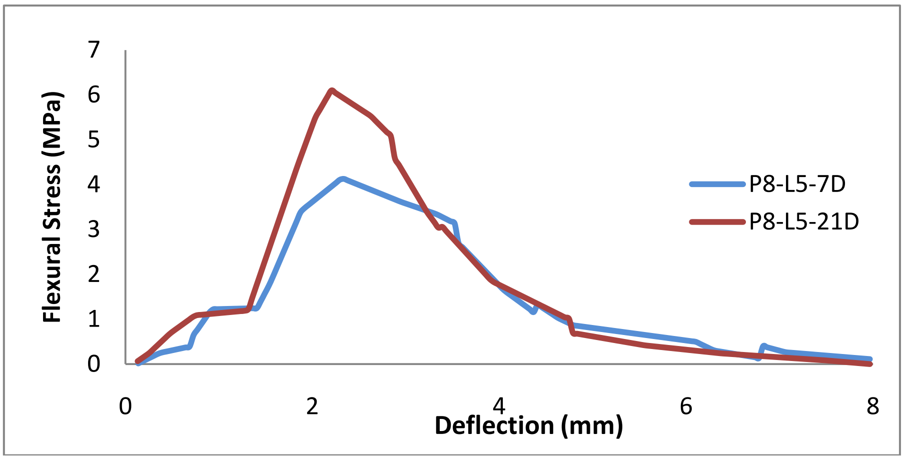

Figure 8: Flexural behaviour of CCB for 7 and 21 days specimens with 5% replacement of cement by limestone powder.

Figure 8 shows, as expected, the 21 day cured specimens fails at a larger flexural strength than the control (no limestone) specimens. However both formulations appear to have peaked at 2.5 mm deflection. It is also interesting to see that the 21 day specimens gradients are more than the 7 day specimens.

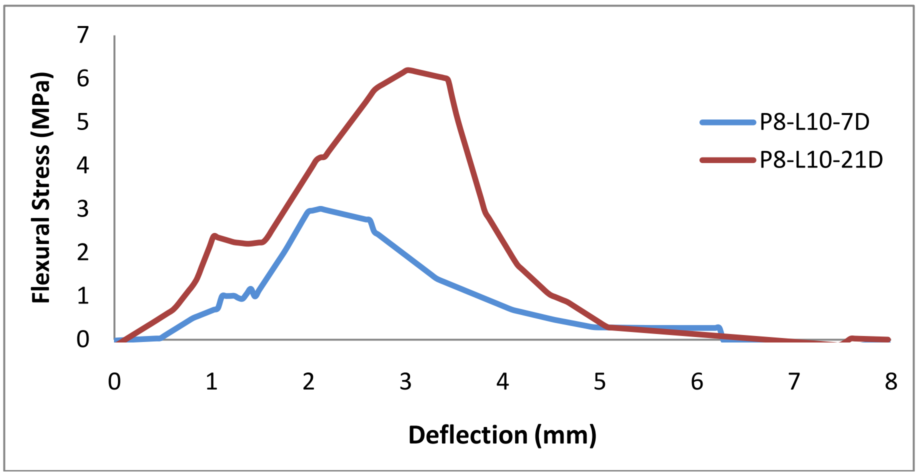

Figure 9 Flexural behaviour of CCB for 7 and 21 days specimens with 10% replacement of cement by limestone powder.

At 10% limestone replacement (Figure 9) the 21 day specimen fails at a larger flexural stress than the 7 day specimens. However opposed to Figure 8 this specimen allows for greater deflection before failing, approximately 3.5 mm as compared to its 8 day predecessor which fails at 2.3mm deflection. After failure occurs there is a steep curve which might suggest that the composite failed with little residual strain maybe suggesting a combination of fibre snapping and fibre pull out.

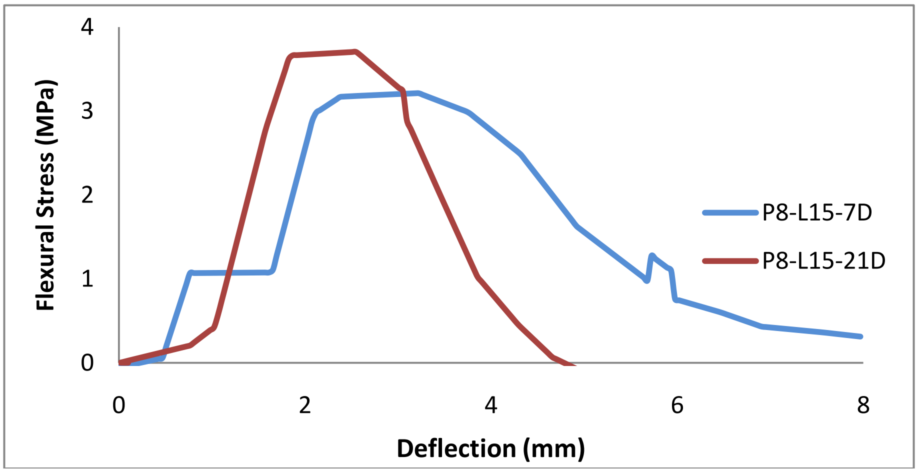

Figure 10 : Flexural behaviour of CCB for 7 and 21 days specimens with 15% replacement of cement by limestone powder.

The trend in figure 10 at 15% limestone replacement is a bit different from what is seen in the previous figures. Firstly the specimens both yield at much lower stress when compared to those in Figures 9 and 8 which could be due to the fact that too much limestone has replaced the cementitious material and is causing a weaker matrix to form. It can also be seen that the peaks of both curves are rounded which suggests a slow fibre pull out failure mechanism, as the composite seems to witness a better residual strain after yielding.

In Fig 11 with 20% limestone replacement the 21 day specimens seems to peak at a greater flexural strength than the 7 day specimens and both specimens fail at roughly the same deflection. The first slope in the graph might suggest the matrix is taking the stress induced on the composite, it then levels off suggesting there may be a transition of stress from the matrix to the reinforcement (i.e. fibres).

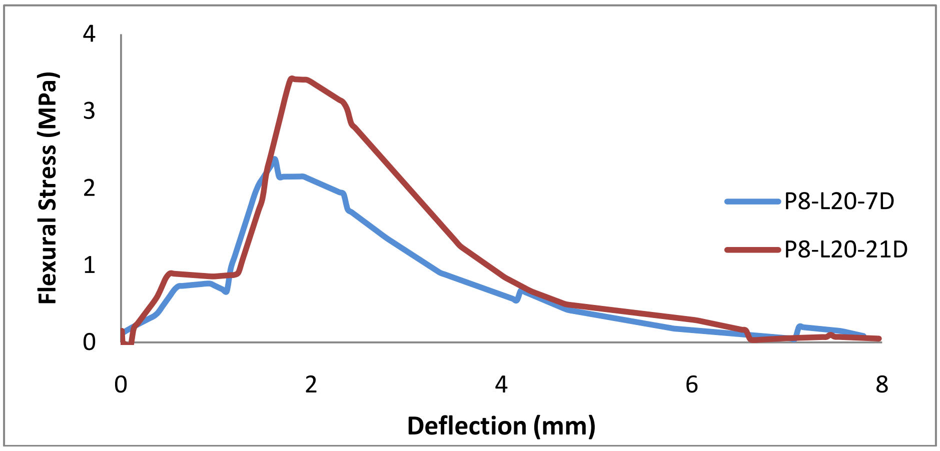

Figure 11 : Flexural behaviour of CCB for 7 and 21 days specimens with 20% replacement of cement by limestone powder.

The stiffness then increases between 1.1mm and 1.8 mm deflection compared to earlier part of the curve. This region may be where the reinforcing cellulose begins to take stress in the composite. The composite then fails due to fibre pull out as there is a relatively shallow gradient after failure instead of a sudden extreme decrease in the curve.

Effects of Varying Limestone Powder Content On The Flexural Behaviour

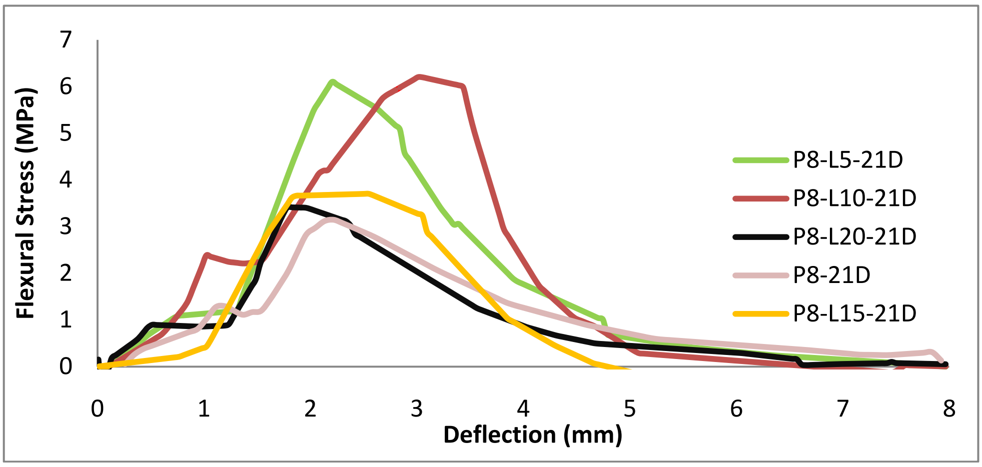

Figure 12 Flexural behaviour of CCB with varying limestone additives (21 days curing)

Figure 12 shows that an optimum value of 10% limestone admixture gives the highest flexural strength. It can also be seen that all the specimens including the control specimen fail between 1.8mm and 3mm.

Once the 10% optimum value (P8-L10) is exceeded it can be seen that the maximum flexural stress falls by about 40-50% of the corresponding optimum value (P8-L15 and P8-L20). This is because the limestone predominantly acts as inert material; it is a filler material. Once the 10% value is exceeded, the role of filling in voids in the matrix is fulfilled but now the cementitious material is effectively reduced and replaced by the inert limestone powder. This will weaken the matrix fibre interface and results in fibre pull out yielding a bell shaped curve suggesting there is not instantaneous failure but failure over time.

Also in specimen P8-L10 a higher flexural strength will allow the composite to keep on performing until failure stress is achieved where the composite fails completely. At this point an increase in deflection should occur without an increase in stress.

To conclude an optimum 10% limestone replacement inclusion was preferred as it gave the best result, and the results support the prediction that the CCB will witness better flexural properties and behaviour after 21 days of curing.

Effect of limestone powder on flexural strength

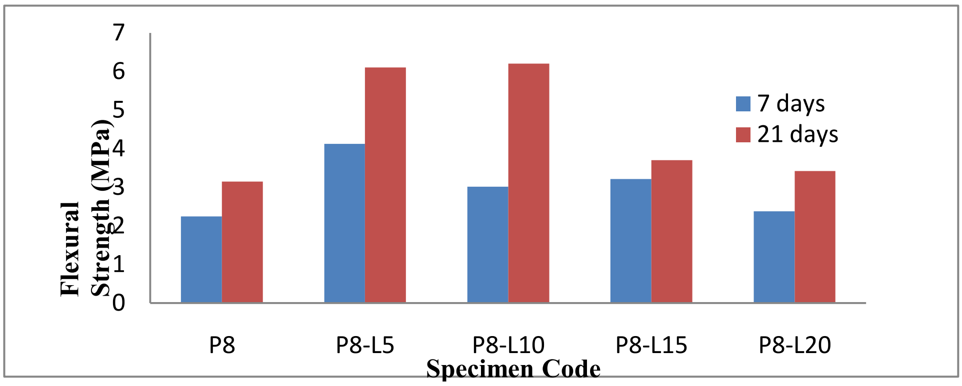

Figure 13. Flexural strength of specimens after 7 and 21 days of curing

Figure 13 compares maximum flexural strength for 7 and 21 days curing of CCB specimens. The flexural strength increases from 7 to 21 days in all specimens, due to cement hydration. The P8-L5 and P8-L10 specimen's MOR values meet class 1 classification of the BS EN 12467 standard.

There is an optimum value of limestone powder inclusion where after exceeding it, the CCB begins to weaken as the Limestone begins to replace the cementitious material rather than filling in the voids.

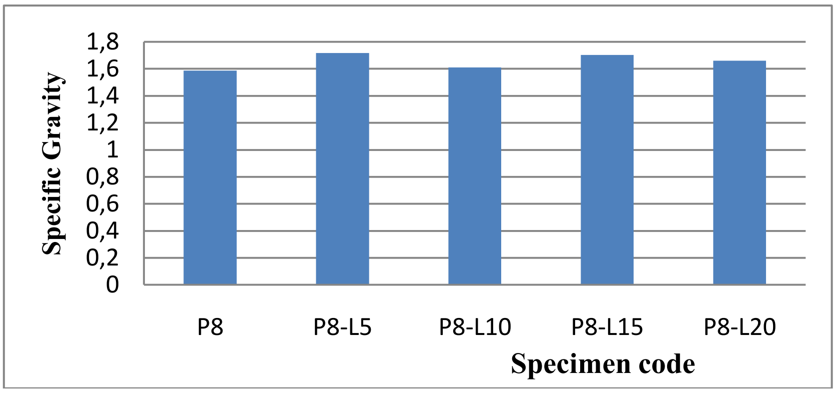

Figure 14 Density of specimens after 21 days of curing

As Figure 14 shows the density of the P8 control specimen apparently increases with the inclusion of limestone so that the highest density appears at P8-L5. Although the results are very close and can be due to experimental sensitivity ranges for relatively small specimens, but this can be in general due to the smaller particle sizes of limestone powder (less than 25 microns) is being enough to fill in the voids within the cement matrix (less than 75 microns) and not too much to start replacing the heavier cement particles.

It is also noteworthy that according to figure 12, the strongest specimen in flexure is the P8-L10, but was not the densest specimen. This proves that the strongest material does not have to be the densest.

CONCLUSION

After analysing the results the following conclusions are made;

- Limestone powder additives (up to 20 percent cement replacement) increases the flexural strength of CCB
- The most important effect of limestone powder in CCB is to act as a filler so that it can decrease the porosity of CCB thus increases the interface area of cementitious material with fibres
- Replacing smaller size limestone powder for cement in CCB has two effects: decreasing the cementitious material, leading to lowering of the flexural strength and decreasing the porosity of CCB, leading to increasing the flexural strength. So there is an optimum percentage for each type of CCB that can be obtained by experimental work
- The optimum percentage of cement replacement by limestone powder in CCBs with 8% cellulose fibre is about 5 - 10 percent by weight.
- Optimum limestone replacement causes the flexural strength of CCB to increase.

REFERENCES

Babu, K. G. Surya, P.P.V. (1995). Efficiency of silica fume in concrete. Cement and Concrete Research. 25 (6), pp 1273-1283.

Bentur, A. (1990). Fibre Reinforced Cementitious Composites: Elsevier Applied Science.

Bentz, D.P. (2006). Modelling the Influence of Limestone Filler on Cement Hydration Using CEMHYD3D. Cement and Concrete Composites. 28 (2), pp 124-129.

BS EN 12467. Fibre-cement flat sheets Product specification and test methods. British-Adopted European Standard 2007: ISBN: 0580450481.

Corinaldesi, V. Moriconi, G. (2003). Durable Fibre Reinforced Self-Compacting Concrete. Cement and Concrete Research. 34 (2), pp 249-254.

Coutts, R. S. P. (2005). A Review of Australian Research into Natural Fibre Cement Composites. Cement and Concrete Composites 27 (5), pp 518-526.

Ganjian, E, Khorami, M. and Sadeghi-pouya, H, (2008). Application of kraft and acrylic fibres to replace asbestos in composite cement sheets, 11th International Inorganic – Bonded Fiber Composites Conference, Madrid, Spain, pp 52-61.

Heikal, M. El-Didamony, H. Morsy, M.S. (2000). Limestone-Filled Pozzolanic Cements. Cement and Concrete Research. 30 (11), pp 1827-1834.

MacVicar, R. Matuana, L. (1999). Aging mechanisms in cellulose fiber reinforced cement composites, Cement and Concrete Composites 21(3), pp 189–196.

Mohr, B.J. Nanko, H. Kurtis, K.E.. (2004). Durabilty of Kraft Pulp Fibre-Cement Composites To Wet/Dry Cycling. Cement and Concrete Composites. 24 (7), pp 435-448.