DEVELOPMENT OF ROLLER-COMPACTED CONCRETE PAVEMENT USING CLASS C FLY ASH

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ABSTRACT

This report explains the development of a roller-compacted concrete for constructing or renovating concrete pavement (RCCP), using lignite fly ash from Mae Moh. A method for proportioning the RCCP based on the ratio between paste volume and void content of total aggregate is proposed. The first field investigation was conducted on a 5x80m pavement section. Paving machine was not used in the first field test. It was found from the first field investigation that the compressive strength of the core specimens was 20% to 30% lower than the standard specimens. However, the core strength satisfied the required strength. The flexural strength of the cut-from-site specimens was also high enough to meet the requirement for road pavement of general use. According to the observed cracking pattern, the transverse joint could be extended to 15 m. The second test section with a dimension of 5x75m was investigated using a paving machine. It was found from the second field investigation that the compressive strength of the core specimens was 15% to 25% lower than the standard specimens. However, the core strength satisfied the required strength. No crack was observed in the second test section, since the transverse joints with an interval of 15m and depth of 5 cm was made. It was confirmed that smoother surface and nicer surface condition could be obtained when paving machine was used. It was also found that apart from using superplasticizer to adjust workability, the use of superplasticizer in high fly ash content RCCP was also effective in reducing the cementitious materials content or ratio between water and cementitious materials that gives rise to increase in early and long term strength of the RCCP.

1. INTRODUCTION

A large amount of lignite coal ash is produced and is awaited the effective application. Particularly in Southeast Asia, utilization of local coal ash is very limited resulting in accumulation of the coal ash as waste material. In Thailand, almost all of the lignite fly ash produced from the electricity generating plants is classified as ASTM Class C fly ash. The main objective of this study is to facilitate the use of this fly ash and introduce it into the construction industry.

Roller compacted concrete (here inafter called RCC) has been extensively utilized in dam construction for the last two decades. The use of roller compacted concrete for pavement (here inafter denoted RCCP) is relatively new when compared to the dam application. In North America, Europe and Japan, however, RCCP has been used for constructing pavement for a decade. It is recognized that RCCP has various advantages over the conventional method. Faster construction, earlier time to open to the traffic, less labor, lower overall cost and more enhanced durability than the conventional concrete have been confirmed worldwide. However, fly ash has rarely been used in RCCP even though it has almost always been mixed in RCC for constructing dams. The mix proportion method of RCCP seems to be diversified from country to country. This report describes the development of RCCP using lignite fly ash in Thailand together with a new concept for mix proportioning. Field investigations were conducted to confirm the applicability of the developed RCCP.

2. MATERIALS

The cement was Portland cement type 1. Fly ash was supplied from Mae Moh power generating plants. Materials used in this study and their properties are given in Table 1.

Table 1 Materials used in the study

Material	Specific gravity (g/cm^3)	Blaine fineness (cm^2/g)	Fineness modulus	Absorption (%)	Max. size (mm)	Void content (%)
Cement	3.15	3196	-	-	-	-
Fly ash	2.27	2467	-	-	-	-
Fine aggregate	2.61	-	3.40	0.88	-	36.62
Coarse aggregate	2.69	-	-	0.55	20	42.84

3. MIX PROPORTION

A new mix proportioning method was proposed based on the ratio of paste volume to void of total aggregate.

3.1 VOID RATIO OF AGGREGATES

Experimental works were conducted to obtain a void curve of binary mixtures with various ratios between coarse and fine aggregates. Fig. 1 shows the void curve of the binary mixtures using the fine and coarse aggregates from Lampang. The horizontal axis is the sand to total aggregate ratio by volume

$$s/a \quad = \quad V_s/(V_s+V_g) \qquad (1)$$

where V_s is the volume of fine aggregate and V_g is the volume of coarse aggregate.

Void ratio, v, is derived by

$$v \quad = \quad V_{va}/V_t \qquad (2)$$

where V_{va} is the volume of void in the aggregate assembly and V_t is the total aggregate volume which is equal to the volume of the container in which the aggregate is compacted. The volume of void can be calculated from

$$V_{va} \quad = \quad V_t-(V_s+V_g) \qquad (3)$$

where (V_s+V_g) is the total volume of aggregate compacted in the container.

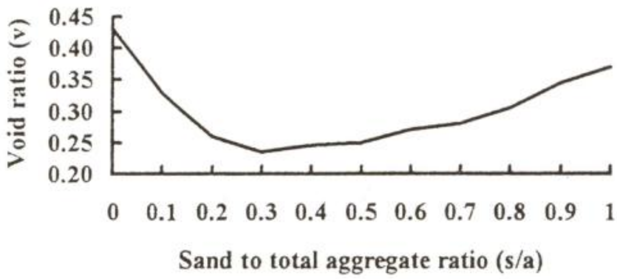

Fig.1: Relationship between void ratio and s/a

3.2 SELECTION OF MIX PROPORTION

The selection of mix proportion of RCCP in this study was conducted according to the following process:

1) Select optimum sand to total aggregate volume ratio s/a. To obtain minimum cementitious material content, optimum s/a is determined based on the value causing least void. However, the s/a of 50% was selected in this study in order to reduce segregation

during handling especially when paving machine can not be provided. As in Fig. 1, the void content at s/a equal to 50% is not much different from the minimum void content. It is noted here that if a paving machine is provided, it is advantageous to select the s/a giving minimum void content.

2) The volume of paste can be obtained from selecting value of ratio between paste volume and void content of total aggregate from the void curve. Let define this ratio as γ, then

$$\gamma = \frac{V_p}{V_{va}} \qquad (4)$$

where V_p is the volume of paste in a unit volume of RCCP and V_{va} is the volume of void in the densely compacted total aggregates with the selected s/a in a unit volume of aggregate assembly. The value of V_{va} can be derived directly from Fig. 1. The volume of paste, V_p, can be derived from

$$V_p = V_w + V_c + V_f \qquad (5)$$

where V_w, V_c and V_f are the volume of water, cement and fly ash, respectively, in the unit volume of RCCP mixture.

To minimize the paste volume, the value of γ can be selected slightly over unity. From the experience, γ can be chosen between 1 and 1.05. Therefore, up to this level, the aggregates and paste volumes are defined.

3) Select the mix proportion of the paste depending on required properties of RCCP, strength, workability and its retention period. The water to total cementitious material ratio by volume (W/(C+F)) and fly ash to cement ratio by volume (F/C) can be derived when knowing the required strength of RCCP. The relationship between strength and the two mentioned parameters (W/(C+F) and F/C) was derived approximately from the ACI 207.5R-89 established relationship between water to cementitious material ratio and fly ash to cement ratio for roller compacted concrete for dam given in Fig.2 [1].

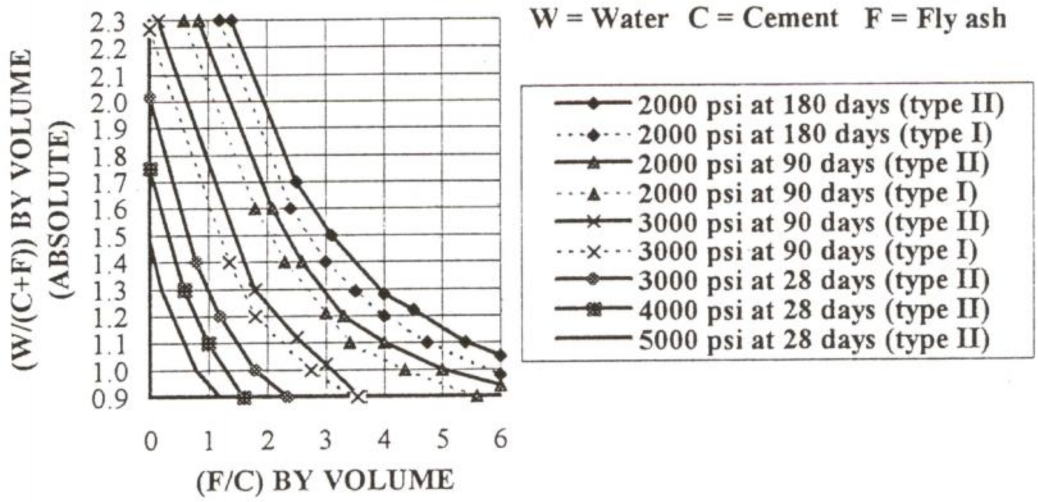

Fig. 2: Proportioning curves for equal strength concrete

4) To adjust workability, superplasticizer is recommended to be utilized. The workability of RCCP mixture with a constant water to cementitous material ratio by weight (W/P), usually measured by using Vibrating Consistency time (VC time), can be adjusted using superplasticizer. Increasing value of γ can also help improve workability and finishability.

From the above proposed method of mix proportioning of RCCP, the mix proportion in Table 2 was derived for being used in the field investigation. A relatively high fly ash replacement ratio of 0.51 was utilized. The developed RCCP mixture can then be classified into a high volume fly ash RCCP mixture.

Table 2: Mix proportion of RCCP used in the field investigation

W/P	s/a	Component (kg/m^3)					Water reducing agent (l/m^3)
		Cement	Fly ash	Water	Fine aggregate	Coarse aggregate	
0.32	0.5	180	185	116.8	960	988	0.5

4. CONSTRUCTION PROCEDURE AND FIELD INVESTIGATION

4.1 CONSTRUCTION PROCEDURE

The construction procedure can be seen in Fig. 3.

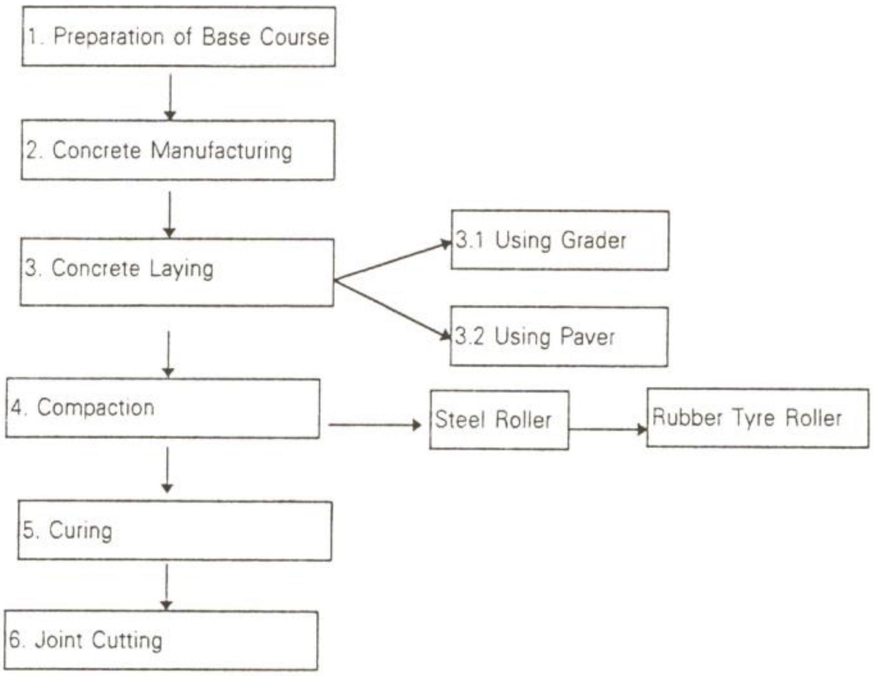

Fig. 3: RCCP Construction Steps

4.2 FIELD INVESTIGATION

Field investigation was conducted twice with the same mix proportion but different construction method. In the first investigation, grader was used to lay the RCC before roller compaction while paving machine was used in place of grader in the second investigation. It is known that the RCCP method can be efficiently constructed using paving machine, however, grader were used to test its applicability. Fig. 4 illustrates the plan view of the test section. Width of the test section was 5m. The target thickness of the pavement was 20cm. The length of tested pavement was 80m and 75m for the first and second investigations, respectively.

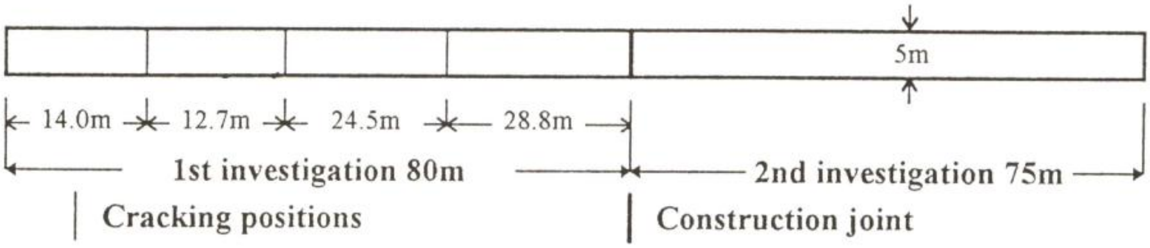

Fig. 4: Tested RCCP section showing construction joint and cracking positions

In the first field investigation, concrete was spread on the well compacted base course, then leveled with thickness of approximately 24cm using the grader. The steel roller was then applied to the leveled concrete with the following sequences; one round with vibration and two rounds without vibration. The steel-roller compacted RCCP was then compacted with a tyre roller to smoothen the surface. Transverse contraction joints were not arranged for the first investigation.

In the second field investigation of which the construction was executed about one month after the first investigation, the concrete was compacted into 2 layers due to the limitation on the maximum paving thickness of the paving machine. Each layer was approximately 11 cm in thickness. The bottom layer was compacted with 2 rounds of steel roller without vibration, being followed by rubber tyre roller until smooth surface was obtained. The vibration was not applied because the thickness of the pavement was only 10 cm in each layer. According to the observed crack spacing in the first investigation, crack inducing joints with an interval of 15m and depth of 5 cm were cut at 1 day after construction.

5. RESULTS OF FIELD INVESTIGATION

5.1 CONSTRUCTABILITY

The speed of construction achieved when using grader and paving machine is almost similar at about 12.5m/hr. It can be said that the speed of construction can be nearly doubled if the paving machine which can lay the RCC with the required thickness in one layer is used. Segregation of the coarse aggregate was not observed when paving machine was used. On the other hand, large efforts has to be exercised to control the segregation when grader was used. It was also confirmed that smoother surface and nicer surface condition could be obtained when paving machine was used. It seemed imperative to introduce an appropriate paver in order to get a satisfactory surface conditions without appreciable segregation of coarse aggregate. The value of vibrating consistency time (VC time varied from 17 to 25 seconds. It was found from the field test that RCCP with vibrating consistency time (VC time) of about 20 seconds was the most suitable in terms of constructability.

5.2 STRENGTH OF RCCP

The compressive and flexural strength of the standard cured and core specimens drilled from the test yard are summarized in Table 3 and 4 for the first and second investigation, respectively. Cored specimens were taken from the constructed pavement at a few days before the test ages described in Table 3 and 4. The standard cylinder specimens were taken from the fresh RCCP immediately after mixing. The compressive strength of standard and core specimens versus ages is plotted in Fig. 5 and Fig. 6.

Table 3: Strength results of RCCP in the first investigation (using grader)

Compressive strength (MPa)						Flexural Strength (MPa)	
Standard specimen				Core specimen		Standard specimen	Field test specimen
3 days	7 days	14 days	28 days	8 days	28 days	35 days	35 days
21.9	27.8	31.4	37.7	21.5	28.0	6.0	5.3

Table 4: Strength results of RCCP in the second investigation (using paver)

Compressive strength (MPa)						Flexural Strength (MPa)	
Standard specimen				Core specimen		Standard specimen	Field test specimen
4 days	7 days	14 days	29 days	7 days	29 days	27 days	27 days
29.4	30.6	35.0	37.6	26.7	28.5	-	6.6

It can be seen that the actual 7-day and 28-day compressive strength of the cored specimens were 22.7% and 25.7%, respectively, lower than those of the corresponding standard specimens in the case of using grader. In the case of using paver, the actual 7-day and 29-day compressive strength of the cored specimens were 12.8% and 24.2%, respectively, lower than those of the corresponding standard specimens. However, the strength of all core specimens satisfied the required strength. Aoyagi and Endo [2] also found that the reduction in actual compressive strength relative to the compressive strength of the standard specimens was approximately 30%.

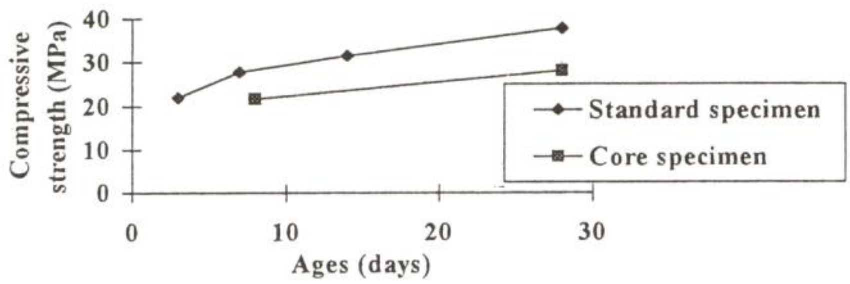

Fig. 5: Compressive strength of standard and core specimens in the case of using grader

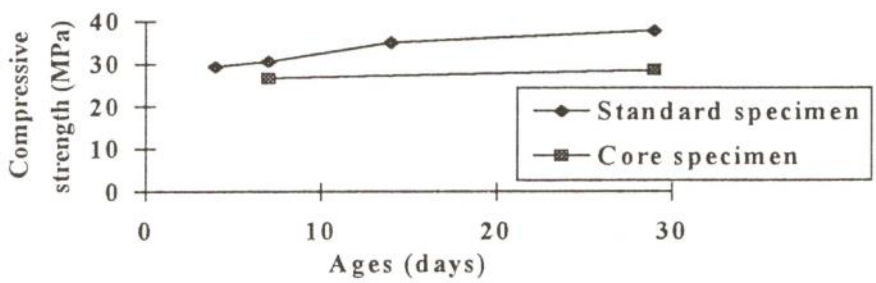

Fig. 6: Compressive strength of standard and core specimens in the case of using paver

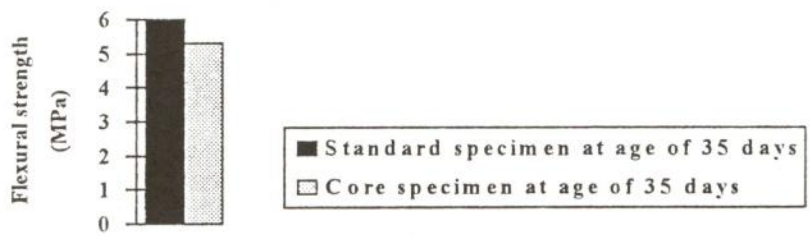

Fig. 7: Flexural strength of standard and core specimens

The flexural strength of standard and prism specimens extracted from the pavement at a location closed to that of the core compressive strength specimen also showed a satisfactory value (see Fig. 7). The flexural strength of all tested specimens was higher than that of conventional concrete which have the respectively equal compressive strength (see Fig. 8). This can be explained by the effect of shrinkage resistance of concrete containing high content of Mae-Moh fly ash. Sudsangiam T. [4] also found that, in comparison with concrete without fly ash, the flexural strength of specimens containing Mae-

Moh fly ash was lower in the case of submerged condition, but higher in the case of sealed condition where autogeneous shrinkage occurred.

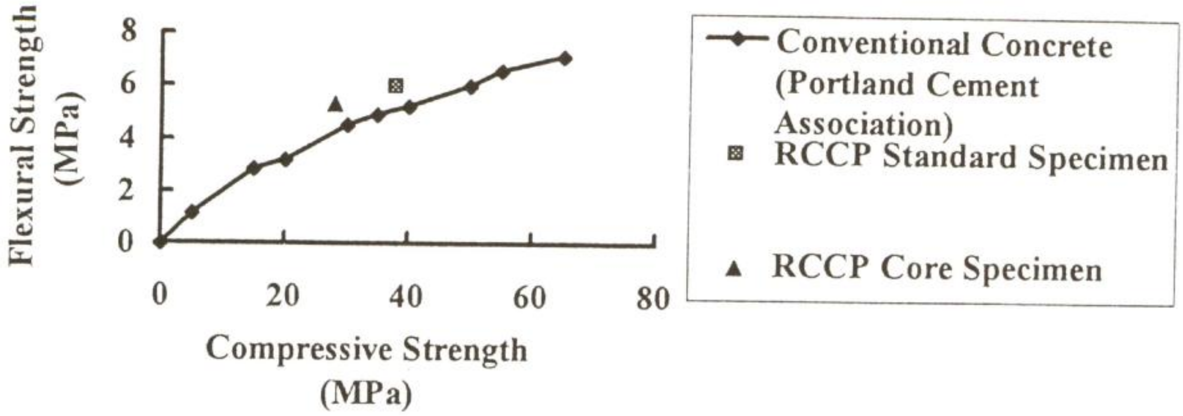

Fig. 8: Flexural strength of tested RCCP compared with conventional concrete versus compressive strength

The actual 28-day compressive strength of the tested RCCP specimens was in the range of proportioning curves for equal strength of RCC designed according to ACI 207.5R-89 (see Fig. 9). Therefore, the curves are useful in mix proportioning of RCCP with a view to the relationship between strength and two parameters namely water to cementitious materials ratio (W/(C+F)) and pozzolanic material to cement ratio (F/C).

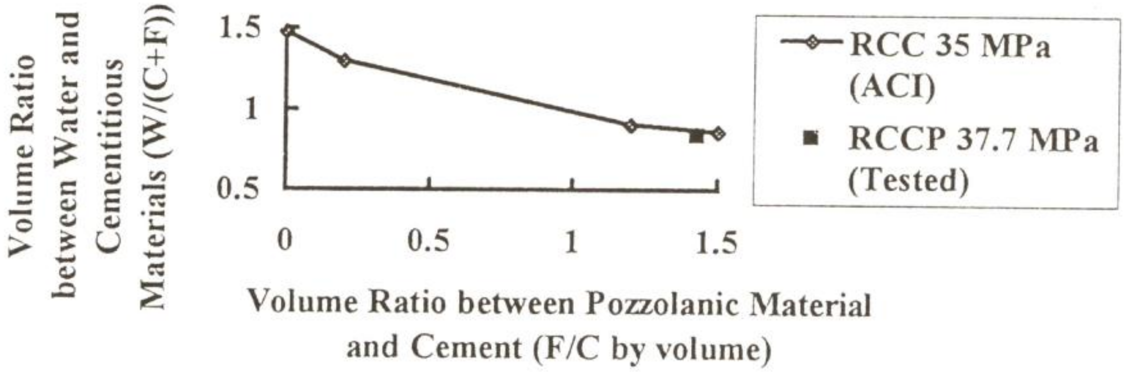

Fig. 9: Proportioning curves for equal strength of RCC according to ACI and tested results of RCCP

5.3 CRACKING PATTERN

Three transverse cracks were observed on the pavement constructed in the first field investigation. The distances between two adjacent cracks were measured to be 12.7m, 14m, 24.5m and 28.8m as in Fig. 4. The 12.7m and 28.8m intervals were measured from both ends of the first investigated pavement to the closest cracks. The average transverse crack spacing was therefore calculated to be 20m. From this results, joints can be cut at a substantially longer interval for pavement constructed with the tested RCCP than for the conventional concrete pavement that requires the joint interval ranging from 5m to 7.5m. Referring to the observed crack pattern, the spacing of transverse joints was decided to be 15m for the second field investigation. Thus no crack was noticed for the second field investigation. It can be concluded that the crack inducing joints with the interval of 15m are recommended for RCCP.

6. EFFECT OF SUPERPLASTICIZER ON RCCP PROPERTIES

The authors [3] investigated the effect of superplasticizer (SP) on required content of cementitious materials, workability and compressive strength of RCCP. The test results showed that for the same water to cementitious materials ratio by weight (W/P), the RCCP mixture with superplasticizer (SP) required lower content of cementitious materials than that of RCCP without superplasticizer (see Fig. 10). Similarly, for approximately equal cementitious materials content (P), the RCCP containing superplasticizer require less water content than RCCP without superplasticizer. However, even with smaller water content, the VC time of RCCP containing superplsaticizer is lower than that of RCCP without superplasticizer (see Fig. 11).

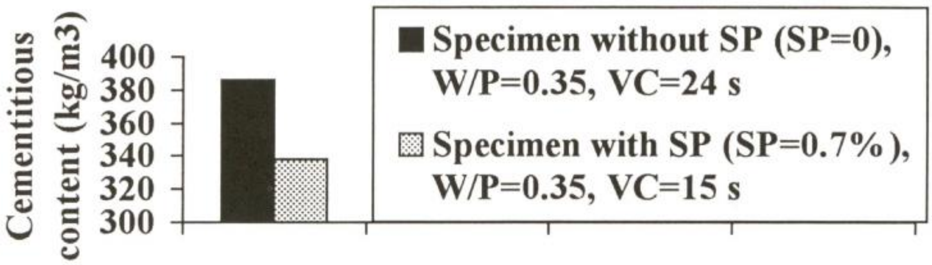

Fig. 10: Cementitious content of RCCP with and without superplasticizer

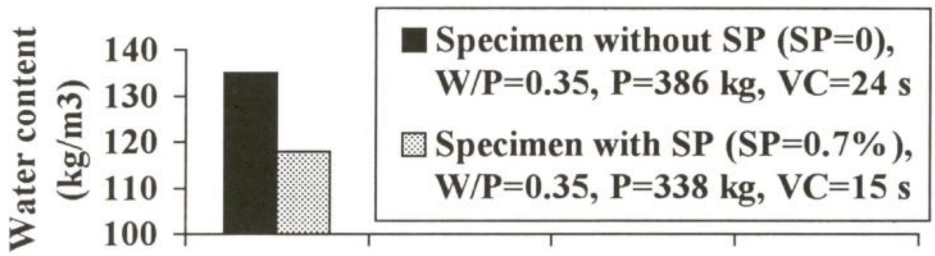

Fig. 11: Water content of RCCP with and without superplasticizer

The test results also confirmed that RCCP containing superplasticizer and high fly ash content follow the Abram's law on relation between compressive strength and water to cementitious materials ratio (W/P). It means that the lower value of W/P results in higher compressive strength of the RCCP (see Fig. 12). For the approximately equal cementitious materials content (P), the increases of 3-day, 7-day and 28-day compressive strength of RCCP containing superplasticizer were 23.7%, 26.5% and 18.5%, respectively, in comparison with that of RCCP without superplasticizer (see Fig. 13).

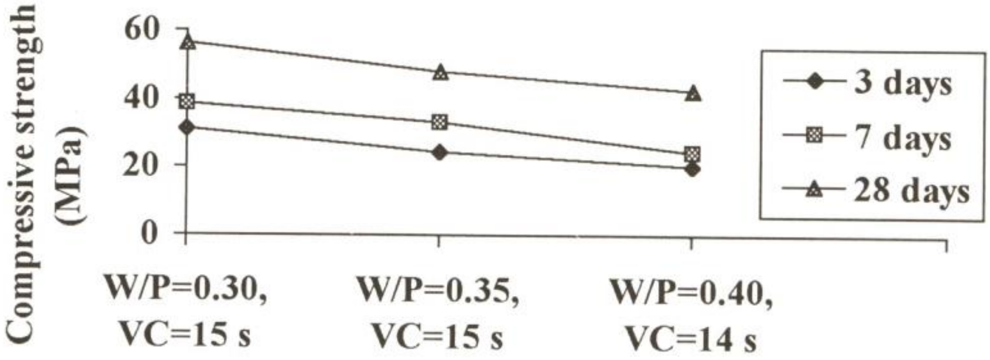

Fig. 12: Compressive strength of RCCP versus ratios between water and cementitious materials content

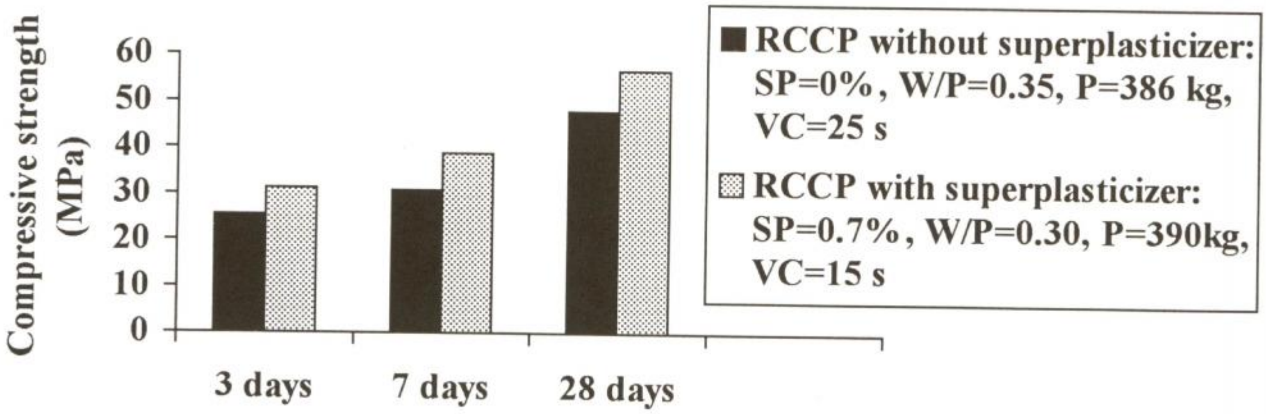

Fig. 13: Compressive strength of RCCP with and without superplasticizer

7. SUMMARY

The mix proportion of roller compacted concrete using Class C fly ash for pavement can be designed using a newly proposed proportioning method. Based on the results of field tests on RCCP, the developed RCCP using Class C fly ash is technologically efficient and economical for pavement construction. It can reduce construction time with satisfactory strength development of the concrete. The method can save labor because the compaction is effectively achieved by rollers, tedious works related to arranging tie bars as well as slip bars are eliminated, less joints are required. Total cost deemed definitely lower when compared to the conventional method.

Apart from using superplasticizer to adjust workability, the use of superplasticizer in high fly ash content RCCP was also effective in reducing the cementitious material content or ratio between water and cementitious materials that gives rise to increase in early and long term strength of the RCCP.

For complete evaluation of the RCCP using Class C fly ash, further studies are still needed in the area of strength prediction, abrasion resistance, durability and practical method for workability evaluation on the site.

8. REFERENCES

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