# Compaction of Rice Husk Ash Cement Concrete

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## ABSTRACT

The research work presents preliminary details of a laboratory study of roller compacted concrete (RCC) mixes containing different proportions of rice husk ash (RHA) with different water contents after up to 28 days of hydration process. This work also focuses on finding the optimum water content based on 28-day compressive strength for each mix types of RCC containing 0,30,50,70 and 100% RHA by weight.

Mechanical properties of RCC mixes such as compressive strength was examined. A reduction in compressive strength depends on the proportion of RHA present in the compacted concrete mixes. It was shown that RCC mixes containing RHA up to 50% can produce an acceptable compressive strength of about 45 MPa. The effect of compaction on concrete containing RHA also was investigated, and the results showed that at the same amount of cementitious material (50% RHA + 50% portland cement) RCC is much stronger than normal concrete.



## บทคัดย่อ

บทความนี้กล่าวถึงวิธีการผลิตคอนกรีตชนิดที่เรียกว่า Roller Compacted Concrete (RCC) ซึ่งเป็นคอนกรีตชนิดที่มีการเพิ่มแรงอัดเข้าไปในขณะทำการหล่อคอนกรีต โดยใช้อัตราส่วนผสมของขี้เถ้า-แกลบซีเมนต์และน้ำในอัตราส่วนต่าง ๆ และทำการบ่มคอนกรีตชนิดนี้จนมีอายุครบ 28 วัน แล้วทำการทดสอบหาค่ากำลังรับแรงอัดที่ 28 วัน นอกจากนี้บทความนี้ยังได้กล่าวถึงการหาปริมาณน้ำที่เหมาะสมในการผลิต RCC ที่ใช้ขี้เถ้าแกลบผสมเพื่อแทนที่ปริมาณซีเมนต์ใน RCC ในปริมาณ 0,30,50,70 และ 100 เปอร์เซนต์ ขี้เถ้าแกลบโดยน้ำหนัก โดยทำการทดสอบหาค่าส่วนผสมของน้ำที่ให้ค่ากำลังรับแรงอัดที่ 28 วันสูงสุด

จากการศึกษาคุณสมบัติทางกล เช่น ค่ากำลังรับแรงอัดที่ 28 วัน พบว่า RCC ที่มีส่วนผสมของขี้เถ้าแกลบเพิ่มขึ้น จะให้ค่ากำลังรับแรงอัดที่ 28 วันลดลง พบว่าเมื่อผสมขี้เถ้าแกลบใน RCC สูงถึง 50% แล้วจะให้ค่ากำลังรับแรงอัดที่ 28 วัน อยู่ในช่วงมาตรฐานที่ยอมรับได้ประมาณ 45 MPa นอกจากนี้ยังพบว่าแรงอัดก็มีอิทธิพลต่อความแข็งแรงของคอนกรีตเช่นกันโดยทำการเปรียบเทียบคอนกรีต 2 ชนิด ที่มีองค์ประกอบของส่วนผสมของปริมาณขี้เถ้าแกลบและซีเมนต์เหมือนกัน คอนกรีตที่หล่อโดยอาศัยแรงอัด (คอนกรีตชนิด RCC) จะมีความแข็งแรงมากกว่าคอนกรีตที่หล่อโดยวิธีธรรมดา (normal concrete)


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# INTRODUCTION

Due to its high silica content, rice husk ash (RHA) has been regarded as a cementitious material. RHA is also used to partially replace cement in making concrete to reduce heat of hydration as well as to improve some properties of concrete. However, the main reason for the use of RHA as partial replacement in cement concrete is that it lowers the cost of material in the finished concrete.

Roller compacted concrete (RCC) is a dry concrete material hauled and spread by earth moving equipment and compacted with vibratory rollers. It has properties equal to conventional unreinforced concrete. This concept involving the use of a relatively stiff (zero slump) concrete mixture compacted by vibratory compaction roller could conceivable permit a significant cost reduction. The cost reduction would result from a more optimal water-cement ratio from a strength stanpoint (that is RCC requires less cement to achieve the same strength compared to conventional concrete) and the elimination of the need of costly placement equipment. It also has demonstrated that the use of RCC can save time in construction.

As with other pozzolans, such as fly ash, the use of RHA can help in solving not only the shortage problem of cement in developing countries but also meets the demand for producing low cost materials such as RCC, especially for dam construction, which will be an appropriate technology for developing countries.

Since most of the investigations were carried out to study the properties of RCC containing fly ash. Hence, there is probably no information available on laboratory mix design of RCC utilizing cement-RHA blends as well as the physical and mechanical properties of the material such as strength parameters, optimum water-cementitious ratio, heat generation, permeability etc. Hence it is interesting to examine some properties of RCC in which RHA partially replaces portland cement in RCC mixes.

## OBJECTIVES

The objectives of this research work are to conduct a laboratory testing program to :

1. Examine the physical and mechanical properties of roller compacted concrete when portland cement is placed with RHA at different proportions.
2. Determine optimum water-cementitious ratio for mix design of roller compacted concrete with different proportions of RHA based on the maximum-28-day compressive strength.
3. Investigate the influence of compaction on RHA-Portland cement i.e. comparison between compacted and non-compacted RHA-Portland cement. (compare compacted concrete with normal concrete)

## SCOPE

In this research, the work started by mixing concrete specimens in 3 series of test. The first series includes RCC of different proportions of RHA and portland cement at different water contents (from very low to high). The second series was done by mixing RCC using lime and RHA (ratio 1:1) as cementitious material at different water contents and the third series was done by mixing normal concrete (no compaction) of 50% replacement of portland cement by RHA at different water contents. Then the optimum water contents for different types of mix proportions were determined based on maximum 28-day compressive strength (assuming that other mechanical properties of the concrete are related to compressive strength).

## TESTING PROCEDURE

### Compaction and Strength Tests

As basic mix proportioning for RCC the method recommended by ACI Committee 207 (ACI Committee 207, 1983) was employed and mixproportion for different types of cement replacement by RHA were calculated.

To investigate the effect of various water contents on the properties of the hardened RCC mixes e.g. compressive strength, different proportions of replacement of portland cement by RHA by weight (0%,30%, 50%,70% and 100% RHA, where 100% RHA means no portland cement in the mix, but it is mixed with lime in the ratio; lime : RHA = 1:1 since RHA, a highly reactive siliceous material reacts with calcium hydroxide to form calcium silicate hydrates in its hydration reaction.) were mixed at different water/cementitious material ratios. To examine the effect of compaction, normal concrete (making concrete without compaction) with 50% RHA portion at different water/cementitious material ratios was mixed and its properties were tested.

The five mix proportions used for density and compressive strength determination of RCC specimens and 50% RHA normal concrete specimens at different water contents are given in Table 1.

**Table 1.** Different RCC and Normal Concrete Mix Proportions

| Mix Type* | RHA:Cement | Gravel kg/m³ | Sand kg/m³ | RHA kg/m³ | Cement kg/m³ | Water kg/m³ |
|---|---|---|---|---|---|---|
| I | 0:100 | 1320 | 795 | 0 | 262 | 80, 90,103,110,117 |
| II | 30: 70 | 1320 | 795 | 76 | 176 | 95,105,115,125,135 |
| III | 50: 50 | 1320 | 795 | 123 | 123 | 100,110,120,130,140 |
| IV | 70: 30 | 1320 | 795 | 167 | 72 | 100,110,120,130,140 |
| V# | 100: 0 | 1320 | 795 | 230 | 0 | 125,135,145,155,165 |
| VI | 50: 50 | 1320 | 639 | 123 | 123 | 168 |
| | | 1320 | 586 | 123 | 123 | 188 |
| | | 1320 | 533 | 123 | 123 | 208 |
| | | 1320 | 480 | 123 | 123 | 228 |

* Mix type I to V are RCC mix proportions

* Mix type VI is normal concrete mix proportions

# 50% RHA + 50% Lime (RHA 115 kg/m³ + Lime 115 kg/m³)

Materials were mixed thoroughly and compacted in the moulds in three layers with the Kango vibrating hammer. Compressive strength tests were conducted at 28 days on all specimens. Since standard small cylindrical moulds (75 mm. x 150 mm.) were used to reduce the error in results due to the deviation of data obtained from compressive strength testing, 5 specimens were made (Naville, 1981) for each mix proportion and the results of the five were averaged.

## PRESENTATION OF THE RESULTS AND DISCUSSION

The results of the three series of tests for compressive strength and densities are shown in Table 2. and they are graphically described in Figure 1 through 6

**Table 2.** Compressive Strength and Densities of 6 Mix Types with Different Water Contents

| Mix Type* | RHA:Cement | Water content kg/m³ | Compressive Strength, MPa | Density kg/m³ |
|---|---|---|---|---|
| I | 0:100 | 80 | 53.87 | 2665.4 |
| | | 90 | 61.98 | 2723.8 |
| | | 103 | 69.17 | 2726.8 |
| | | 110 | 69.81 | 2718.2 |
| | | 117 | 59.47 | 2702.9 |
| II | 30: 70 | 95 | 45.78 | 2629.2 |
| | | 105 | 48.50 | 2676.2 |
| | | 115 | 51.27 | 2689.0 |
| | | 125 | 48.21 | 2706.4 |
| | | 135 | 46.02 | 2691.3 |

| Mix Type* | RHA:Cement | Water content kg/m³ | Compressive Strength, MPa | Density kg/m³ |
|---|---|---|---|---|
| III | 50: 50 | 100 | 38.65 | 2639.3 |
| | | 110 | 39.81 | 2660.6 |
| | | 120 | 44.97 | 2681.3 |
| | | 130 | 41.37 | 2673.1 |
| | | 140 | 39.70 | 2670.1 |
| IV | 70: 30 | 100 | 20.37 | 2495.5 |
| | | 110 | 22.01 | 2541.3 |
| | | 120 | 26.46 | 2597.7 |
| | | 130 | 27.16 | 2619.3 |
| | | 140 | 21.46 | 2605.0 |
| V | 100: 0 | 125 | 20.94 | 2555.6 |
| | | 135 | 16.95 | 2575.1 |
| | | 145 | 12.72 | 2556.6 |
| | | 155 | 12.13 | 2552.1 |
| | | 165 | 11.68 | 2543.4 |
| VI | 50: 50 | 168 | 16.61 | 2425.2 |
| | | 188 | 17.79 | 2530.2 |
| | | 208 | 13.51 | 2529.7 |
| | | 228 | 11.41 | 2500.9 |

* See explanation for each mix types in Table 1.

For all of the mix proportions, the 28 days compressive strength and the density were low at low water content, and both increase as water content increases up to certain water content values. With further increase in water content beyond these water content values, both decrease. It was noticed that the maximum points for both curves did not occur at the same water content value for all mix types. (see Fig.1 to 6).

The shape of the upper curve (strength curve) indicates that at the left hand side of the optimum water content, in spite of lower water/cement ratio, the water content is not sufficient for the hydration reaction to be completed and the voids in specimens increase with lower water content, and hence the strength is lower. The right hand side part of the curve is actually a demonstration of Abram's Law, which indicates the reduction in strength with increasing water content (or water/cement ratio at a given cement content). This obviously exhibits that Abram's Law is not valid for water/cement ratios (or water contents) lower than the optimum value.

The compaction or density curve (the lower curve) has the similar shape to the strength curve. For 100% portland cement mix the highest point of the density curve is located to the left hand side of the highest point of the strength curve, which is in agreement with the results of Rahimi (1987). However, the highest point of the density curve is located to the right hand side of the highest point of the strength curve for combined Portland cement and RHA mixes. A comparison of the strength and density curves shows that for a proper RCC mix design the strength curve should be used instead of a compaction curve. The concept of a compaction curve (Joshi and Natt, 1983) (normally used in soil mechanics) could be misleading in the design of RCC mixes. Considering the difference between the nature of shearing strength for soil which is related to the compactness of the grains and for concrete which is related to the hydration process of the cement, the difference between the two curves could be readily explained.

For RCCs containing RHA the water content for maximum density being higher than that for maximum strength needs more explanation. As the condition happened in high fly ash concrete (Haque et. al. 1986) during construction or compaction the loss of consistency with time has been observed with all the RCCs containing RHA especially for higher RHA proportions. In this RHA application, this can be because of the hollow skeletal structure of RHA (UNIDO, 1984) which absorbs water and RHA being finer than Portland cement (Kajorncheappunngam, 1990) which results in more specific surface area to absorb water. Hence, according to the loss of consistency more water is needed to obtain the highest compaction (i.e. highest density) than the amount of water just

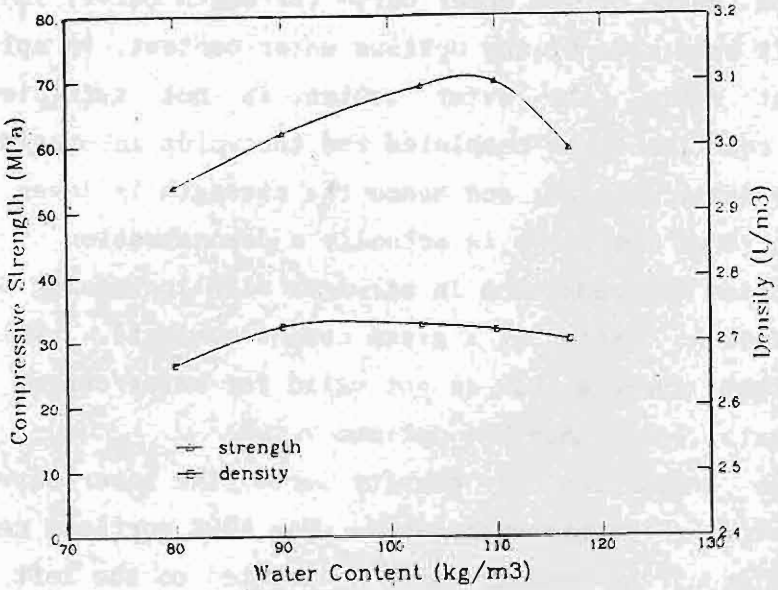


Fig. 1 Relationship between water content and 28 days compressive strength/ density for the RCC mix type I (0%RHA+100%Cement).

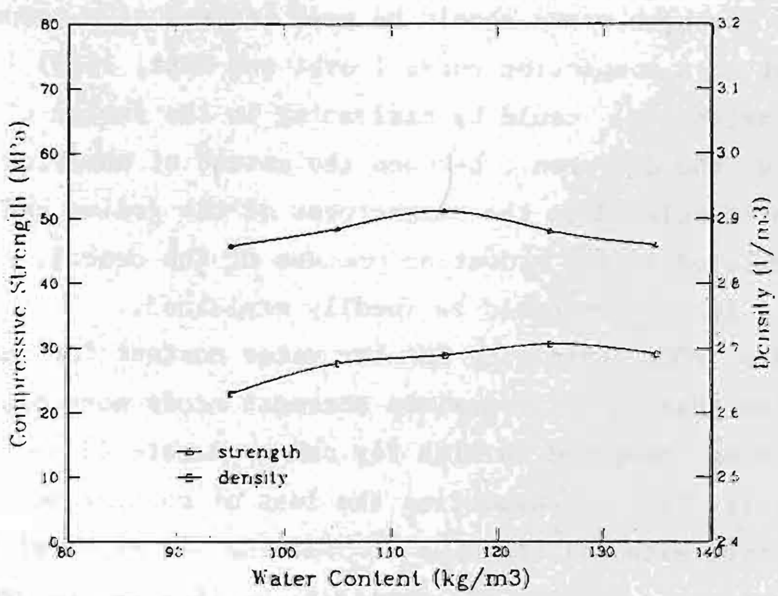


Fig. 2 Relationship between water content and 28 days compressive strength/ density for the RCC mix type II (30%RHA+70%Cement).

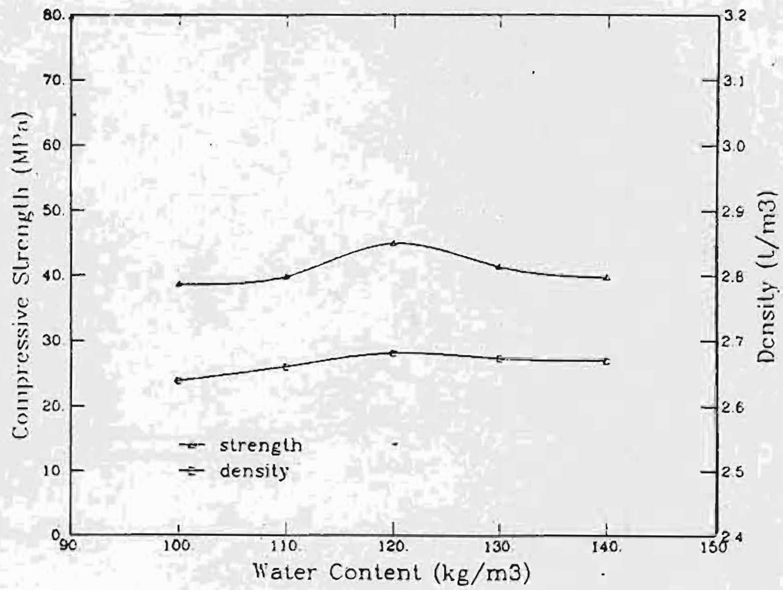


Fig. 3 Relationship between water content and 28 days compressive strength/ density for the RCC mix type III (50%RHA+50%Cement).

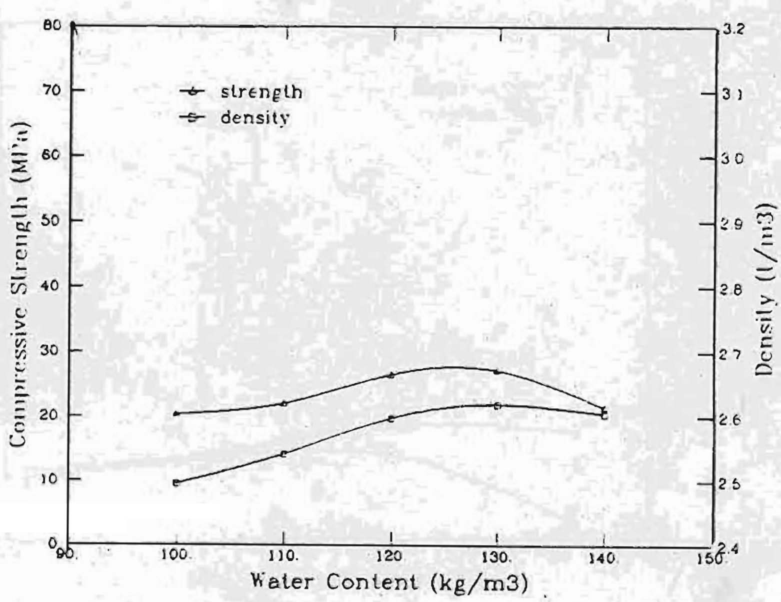


Fig. 4 Relationship between water content and 28 days compressive strength/ density for the RCC mix type IV (70%RHA+30%Cement).

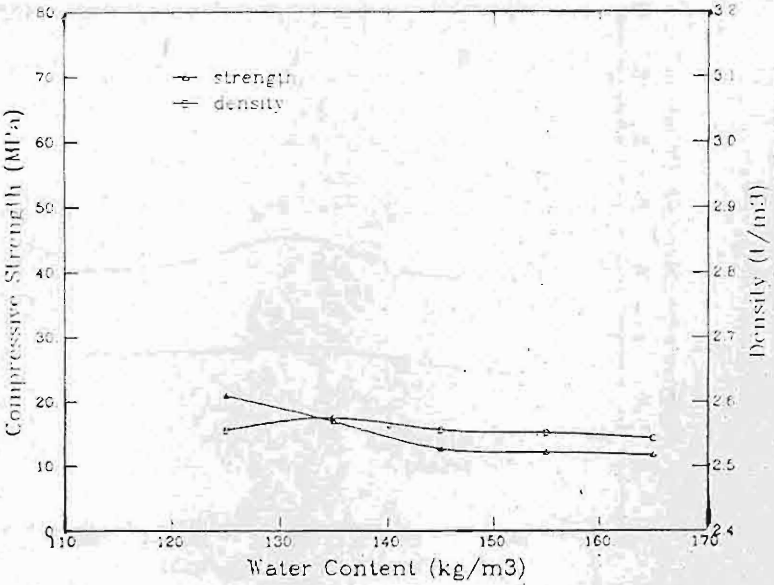


Fig. 5 Relationship between water content and 28 days compressive strength/ density for the RCC mix type V (50%RHA+50%Lime).

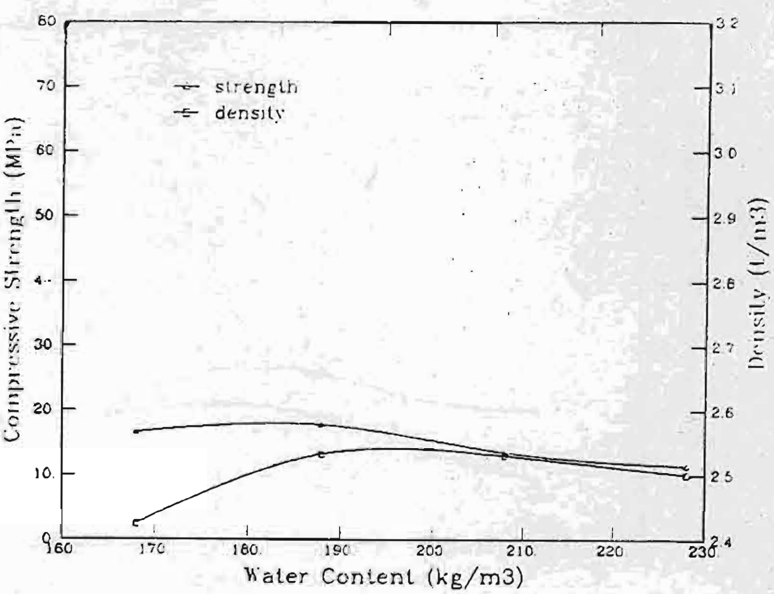


Fig. 6 Relationship between water content and 28 days compressive strength/ density for the normal concrete mix type VI (50%RHA+50%Cement).

sufficient for hydration reaction (i.e. for the highest strength). Therefore the highest point of the density curve is located to the right of the highest point of the strength curve in combined RHA and portland cement mixes.

In a difference from the RCCs containing fly ash (Haque et. al., 1986), the optimum water content based on compressive strength for RCCs containing RHA is increasing with the increase in proportion of RHA in the mix. This would be also explained by the structure of RHA and RHA being finer than the Portland cement. The Table 3, shows the optimum water contents for density and strength curves of the six mix types. The increase in the optimum water content has a negative effect on the compressive strength since the strength decrease with increase in water/cement ratio or water content.

**Table 3.** Optimum Water Contents Based on Maximum Strength and Density of 6 Mix Types

| Mix Type* | RHA:Cement | Optimum water content for | |
|---|---|---|---|
| | | Strength kg/m³ | Density kg/m³ |
| I | 0:100 | 108 | 94 |
| II | 30: 70 | 115 | 125 |
| III | 50: 50 | 120 | 122 |
| IV | 70: 30 | 126 | 130 |
| V | 100: 0 | 125 | 135 |
| VI | 50: 50 | 188 | 194 |

* See detail for each mix types in Table. 1

The reduction in density of RCC mixes containing RHA is due to a lower specific gravity of RHA compared to that of portland cement. However, the densities of these RCC mixes are still greater than that of normal concrete (Type VI) due to compaction and lower water content.

To investigate the effect of compaction in RCC mixes containing RHA, specimens of 50% RHA at different water contents without compaction (normal concrete) were made. The results are shown is Figure 6, which can be compared with Figure 3 of RCC at same cementitious material content. Since RCC possesses a very low water/Cementitious material ratio as compared to normal concrete with same cementitious material content, which requires a higher water content to get the required slump RCC is much stronger than normal concrete with the same cementitious material content. That shows the more optimal water-cement ratio of RCC from a strength standpoint. From this result, it can be anticipated that RCC will need less cementitious material than the normal concrete for the same strength. This can be explained as follows. For same strength, it can be assumed that both RCC and normal concrete need same water/cement ratio. For RCC very low water content per cubic meter is required because of its no slump condition. On the other hand the normal concrete needs much more water per cubic meter than RCC to obtain the required slump. Therefore RCC needs less cement per cubic meter than the normal concrete to satisfy that same water/cement ratio. Hence RCC needs less cementitious material than the normal concrete for the same strength. As a conclusion, the final result is a much lower unit cost per cubic meter of concrete placed compared to gravity dams or mass concrete constructed by conventional mass concrete techniques.

In Figure 7, the relation between the maximum compressive strength of mixes and percent replacement of Portland cement by RHA is shown. The strength reduction is mainly due to the substitution of RHA which has less cementitious reaction than portland cement. In addition, the increase in optimum water content of RHA mixes as compared to pure portland cement mixes contributes to lower strength due to the increase in water/cement ratio. Since concretes of a high strength (about 45 to 75 MPa) are not structurally required in most massive concrete applications, (Jones and Mass, 1980) the significant replacement of Portland cement by RHA could be employed mainly to lower the cost of materials in the finished concrete.

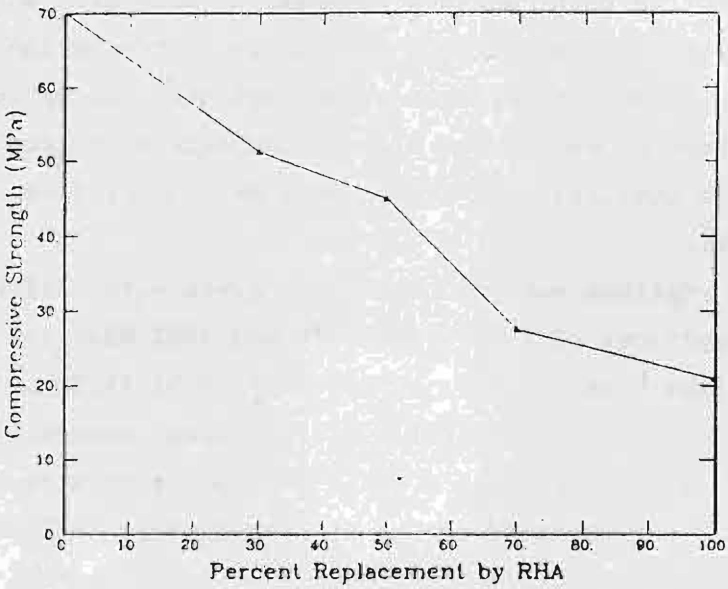


Fig. 7 Relationship between the maximum 28 days compressive strength and the percent replacement of Portland cement by RHA.

## CONCLUSIONS

Based on the results of the research work, the following conclusions are made.

1. For each mix type of specimens (mix types I to VI), there is an optimum water content which produces the maximum compressive strength. There is also another optimum water content producing the maximum density, which differs from the optimum water content for strength. If water content is changed to greater or less than these optimum values both compressive strength and density decrease.
2. For RCC with straight portland cement, the optimum water content for density is lower than the optimum water content for strength while the opposite is true for RCCs containing RHA. A comparison of these strength and density (curves) shows that for a proper RCC mix design the strength curve should be used instead of the compaction curve (density curve) to determine the optimum water content.

3. Based on both maximum compressive strength and maximum density, the higher the percentage of RHA in the RCC mixes the higher the optimum water content. The optimum water content producing the highest compressive strength for RCC mixes containing 0% RHA to 100% RHA varies from 108 to 126 kg/m$^3$.
4. At optimum water content, RCC mixes with different mix proportions of RHA (0,30,50,70 and 100% RHA) can produce a maximum compressive strength of 70,51,45,28 and 21 MPa respectively (see Fig.1-6) while normal concrete containing 50% RHA can produce a maximum compressive strength of 18 MPa. At the same amount of cementitious material roller compacted concrete is much stronger than normal concrete and this consequently results in less necessity for cementitious material in RCC than in normal concrete for the same strength.
5. Partial or the whole replacement of portland cement by RHA in RCCs results in a reduction in both compressive strength and density. However in RCC, portland cement could be replaced by RHA up to about 50% of total cementitious materials producing an acceptable compressive strength of about 45 MPa.
6. The significant replacement of portland cement with RHA can be employed mainly to lower a capital cost in the finished concrete. Therefore, utilization of RHA in RCC promises great economic potential, particularly in developing countries where rice husk is widely available and essentially a waste material.

# REFERENCES


ACI COMMITTEE 207 Mass concrete for dams and other massive structures. **ACI Journal** 67/4:273-309 (1970).

ACI COMMITTEE 207-Roller compacted concrete (ACI 207.5R-80), in **ACI Manual of Concrete Practice 1983 Part 1,** American Concrete Institute, ACI:207.5R1-22 (1983).

HAQUE, M.N. and WARD, M.A.-Marginal materials in roller compacted concrete for pavement construction. **ACI Journal** 83/4:674-679 (1986).

JONES, J.C. and MASS, G.R.-Use of roller compacted concrete in dam construction. **Geotechnical Problems and Practice of Dam Engineering Symp.** Bangkok, Thailand : 265-280 (1980).

JOSHI, R.C. and NATT, G.S.-Roller compacted high fly ash concrete (geocrete). **Fly Ash, Silica Fume, Slag & Other Mineral by Product in Concrete, V1.** American Concrete Institute. SP 79-18:347-367 (1983).

KAJORNCHEAPPUNNGAM, S.-**Research Project I ; Literature Review on Rice Husk Ash Cement,** Development Technologies Unit, The University of Melbourne : 75 pp. (1989).

KAJORNCHEAPPUNNGAM, S.-**Research Project II ; Compaction of Rice Husk Ash Cement Concrete,** Development Technologies Unit, The University of Melbourne : 46 pp. (1990).

NAVILLE, A.M.-**Properties of Concrete,** 3rd. ed., Longman Singapore Pb. Ltd., 779 pp. (1981).

RAHIMI, H.-**Research Project Laboratory Investigation on Concrete for Roller Compaction,** Dept. of Civil Engineering, The University of Melbourne ; 64 pp. (1987).

UNIDO,-**Rice Husk Ash Cement It's Development and Application,** Clarendon Printing, Kensington N.S.W. : 93 pp. (1984).