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Sustainable Construction – High-Performance Concrete Pavements using Blended Cements

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Abstract: This study aimed at evaluating the properties of high performance concrete pavements made from blended cements using agricultural wastes i.e. rice husk ash, Portland cement, natural aggregates and sand. Large quantities of agricultural wastes like rice husk are generated from rice processing units worldwide. Rice husk ash blended with Portland cement has proved to improve cement strength as well as durability however its use in high performance concrete pavements has not been investigated to-date. Keeping in view the typical problems of pavements mainly due to dynamic loading, larger exposed surfaces, use of deicing chemicals, effects of groundwater containing sulphates etc., wide ranging investigations covering most aspects of mechanical behavior, permeability and durability aspects including sulphate and chloride resistance and shrinkage were carried out for various mixes for compressive strengths of 60N/mm^2 and 80N/mm^2. Compressive strengths of concrete specimen with blended cements were observed to be higher by about 5 to 10% than the control specimen, higher values for concrete with 75% Portland cement blended with 25% rice husk ash whilst lower values correspond to concrete with 50% Portland cement blended with 50% rice husk ash. Similarly, higher flexural strength, improved moduli of elasticity, higher density, lower permeability, improved sulphate and chloride resistance and reduced shrinkage were observed. Better strengths and improved durability of such pavement concretes is likely to make it a more acceptable material for major road construction projects

***Keywords:** Agricultural wastes, Rice husk ash, Environmental friendly concrete, high performance concrete, sustainable construction, green concrete*

I. INTRODUCTION

Due to latest developments and research the quality of concrete has improved over the years and high performance/ strength concretes are being commonly used nowadays. Few investigations on rice husk ash have proved to improve strength/durability however its performance in concrete pavements has not been investigated to-date [1, 2, 3]. Resource crunch being a major hurdle towards development in the developing/under developed countries, search for cheaper alternates and better utilization of various waste materials have led to newer avenues. Several studies have been carried out to find better/ cheaper aggregates and cements [4,5,6]. Blending rice husk ash with cements and using it in high performance concrete pavements in major road construction projects is likely to reduce the material costs thereby aiding cheaper construction with added life due to improved durability. Bulk use of rice husk ashes in blending cements can consume large quantities of this agrowaste. In the absence of any research on such concrete pavements, this extensive study was undertaken to assess the performance of concrete pavements constructed from high performance concretes.

II. RESEARCH SIGNIFICANCE

The significance of this research is to investigate the possible use of an abundantly available agricultural waste product i.e. rice husk ash in road construction industry in high performance concrete pavements with improved characteristics thereby obtaining a better product along with solving its disposal.

III. CONCRETE MIXES USED FOR EXPERIMENTAL TESTING

Two concrete mixes for characteristic strengths of 60 and 80N/mm^2 were designed using ordinary Portland cement blended with 25% and 50% rice husk ash, crushed natural calcareous limestone aggregates (maximum 37.5mm diameter) and medium grade sand using a linear projection of compressive strength versus w/c ratio from Design of Normal Concrete Mixes method, beyond the limiting w/c ratio of 0.3 [7]. An initial estimate of density was made and later adjusted in the light of values obtained. Control mix containing 100% Portland cement was used. Table 1 gives the details of mixes. Up to 9 l/m^3 of superplasticizer was used to maintain high workability with slumps in the range of 90 to 120mm.

IV. EXPERIMENTAL TESTING REGIME

Testing regime followed is given below. Three sets of specimen from three different batches were used in all tests:-

Compressive strength/density	150mm cubes, 150mm diameter, 300mm long cylinders.
Flexural strength/Shrinkage	150x150x750mm beams.
Stress/strain behaviour	150mm diameter, 300mm long cylinders.
Static modulus of elasticity	150mm diameter, 300mm long cylinders.
Dynamic modulus of elasticity	150x150x750mm beams.
Ultrasonic pulse velocity	150mm cubes.
Initial surface absorption	150mm cubes.
Chloride Penetration	150mm cubes (Immersion in 5% NaCl solution for 60 days and measuring chloride penetration front.)
Sulphate and Chloride resistance	150mm cubes.

(Immersed in 5% H_2SO_4 and 5% HCl solutions for 90 days and measuring weight loss.)

All specimen were cured in water at 20^0 C for 42 days before testing.

V. EXPERIMENTAL TESTING RESULTS

Results obtained from testing of various test samples are summarized below and are also shown in Tables 2 to 3:-

A. Compressive strength.

Compressive strength tests on cubes at 7and 28 days showed that the rate of development of strength of concrete with blended cement containing 25% rice husk ash + 75% Portland cement as well as high performance concrete with blended cement containing 50% rice husk ash + 50% Portland cement concrete was similar to that for control specimen. The compressive strengths of high performance concrete with blended cement containing rice husk ash and Portland cement was about 10% higher for w/c ratio of 0.3 and about 5% higher for w/c ratio of 0.26, than the control specimen. It was observed that compressive strengths kept increasing, as it can be seen from 42 day compressive strength testing, since due to very low w/c ratios, water is required from external sources for hydration of cement which keeps progressing with time and strength continues increasing with continued hydration of cement [8]. High performance concrete with blended cement containing rice husk ash and Portland cement was observed to develop 80 to 85% of its 28-day characteristic strength in 7 days. The complete section of high performance concrete specimen including the aggregate and the paste, tends to reach failure simultaneously hence failure of cubes and cylinders tends to be sudden and explosive, typical of high strength concretes [8, 9]. Sudden failure is likely to cause damage or injury unless protective measures are taken. A loading rate of 0.15 to 0.2N/mm^2/s was observed to be safe enough as compared to 0.2 to 0.4N/mm^2 specified by BS1881: Part 116:1983.

B. Flexural strength.

From the values given in Table 3, it can be seen that the flexural strength of high performance concrete with blended cement containing 25% rice husk ash + 75% Portland cement and concrete with blended cement with 50% rice husk ash + 50% Portland cement are observed to be higher by 8 to 10% as compared to control specimen. It is also a consequence of higher compressive strength and increased density of concrete with blended cement containing rice husk ash. Increased flexural strengths are advantageous for concrete pavements since most loads applied are flexural in nature.

C. Stress/strain behavior.

Idealized stress/strain relationships in compression are shown in Figure 1. It was observed that the general form of the stress/strain characteristics of high performance concrete with blended cement containing 25% rice husk ash + 75% Portland cement and concrete with blended cement containing 50% rice husk ash + 50% Portland cement were similar to that for control specimen. All the curves were observed to be virtually linear up to the point of failure, except for the initial small portion, typical of high strength concretes. Higher moduli of elasticity were observed for high performance concretes with blended cements containing rice husk ash and Portland cement as compared to similar concrete with Portland cement which is advantageous for concrete pavements.

D. Static modulus of elasticity.

The average static modulus of elasticity for high performance concrete pavement with blended cement containing 25% rice husk ash + 75% Portland cement was observed to be about 7 to 8% higher than the control specimen. Similarly, concrete with blended cement containing 50% rice husk ash + 50% Portland cement was also observed to be 7 to 8% higher than the control. Static modulus of elasticity was observed to be around 38000 to 40000 N/mm^2 for high performance concrete with blended cement containing rice husk ash and Portland cement as compared to 36000 to 38000 N/mm^2 for high performance concretes containing Portland cement only.

E. Dynamic modulus of elasticity.

The average dynamic modulus of elasticity for concrete with blended cement containing 25% rice husk ash + 75% Portland cement was observed to be the highest being about 9% higher than the control as compared to concrete with blended cement with 50% rice husk ash + 50% Portland cement which was observed to be about 8% higher than the control specimen. Table 3 gives the values of dynamic moduli of elasticity of various specimen.

F. Ultrasonic pulse velocity.

The ultrasonic pulse velocities observed for different concretes are given in Table 3. Average pulse velocity across concrete with blended cement containing 25% rice husk ash + 75% Portland cement was observed to be highest i.e. 5.3 km/s whilst for concrete with blended cement with 50% rice husk ash + 50% Portland cement it is 5.2 km/s as compared to an average velocity of 4.8 km/s for control mixes. Hence ultrasonic pulse velocity in the case of concrete with blended cements containing rice husk ash and Portland cement was observed to be 10 to 12% higher than the control mixes. It is due to better quality, higher density and reduced voids in the high-performance concretes with blended cements containing mixture of rice husk ash and Portland cement as compared to the control mixes.

G. Density of hardened concrete.

The average saturated and oven-dried densities for high performance pavement concrete with blended cement containing rice husk ash + Portland cement were 2578 and 2449kg/m^3 respectively, as compared to control mixes which were 2480 and 2461kg/m^3, respectively. Hence the saturated and dry densities of concrete with blended cement containing rice husk ash and Portland cement are about 4% higher than the control mixes. It is due to better hydration and packing of finer materials in concrete with blended cement containing rice husk ash and Portland cement. In the presence of higher content of cementitious material and the low w/c ratios, most of the unhydrated cementitious material acts as filler to densify the concrete, whilst the hydration process continues over longer duration.

H. Initial surface absorption (ISAT).

Results of ISAT are given in Table 3. Initial surface absorption for concrete with blended cement containing 25% rice husk ash + 75% Portland cement was observed to be about 30% lower whilst for concrete with blended cement with 50% rice husk ash + 50% Portland cement was observed to be 25% lower as compared to the control. The values indicate very low permeability concretes according to the guidelines given by the Concrete Society Technical Report # 31 [4,6].

I. Sulphate and chloride resistance.

For HCL solution, the weight loss for control was 9% as compared to 4% for concrete with blended cement containing 25% replacement of cement with rice husk ash and 3% for concrete with blended cement containing 50% replacement of cement with rice husk ash.

Similarly, for H_2SO_4 solution, the weight loss for control was 6% as compared to 2% for 25% replacement of cement with rice husk ash, 1.4% for 50% replacement of cement with rice husk ash. The performance of concrete with blended cements was two to three times better in acidic environment and three to four times better in sulphate environment as compared to concrete with ordinary Portland cement control mixes. It is mainly due to extremely low permeability, negligible amounts of $Ca(OH)_2$ present in the products of hydration of blended cements and stable compounds formed due to secondary chemical actions by the silica content of the rice husk ashes.

J. Shrinkage.

Shrinkage was observed to be about 11% lesser for concrete with blended cement containing 25% replacement of cement with rice husk ash and concrete with blended cement containing 50% replacement of cement with rice husk ash as compared to control mixes, observed for a period of 90 days.

K. Chloride Penetration.

After keeping the specimen immersed in 5% NaCl solution for 60 days and splitting up the specimen, the penetration of chloride in concrete with blended cement containing 25% rice husk ash + 75% Portland cement was observed to be around 7mm for w/c ratio of 0.26 and about 1cm for w/c ratio of 0.3. Corresponding values for concrete with 50% rice husk ash + 50% Portland cement were observed to be 6mm for w/c ratio of 0.26 and 8mm for w/c ratio of 0.3. Penetration of chloride in control specimen was observed to be 12mm for w/c ratio of 0.26 and 14 to 15mm for w/c ratio of 0.3. Such depths are safe as the reinforcement in pavement concrete is given a minimum cover of at least 5cm on exposed soil.

VI. CONCLUSION

Mixes with blended cements containing 25 to 50% rice husk ashes can be designed for compressive strengths of 60N/mm^2, 80N/mm^2 and 100N/mm^2 like concrete with ordinary Portland cement. Concrete specimen with blended cements developed 5 to 10% higher compressive strengths, similarly higher flexural strength, 2 to 4% higher static moduli of elasticity with values up to 40000N/mm^2, higher values for dynamic moduli, about 10% higher pulse velocities, 4% higher density, very low permeability, reduced shrinkage and two to three times improved sulphate and acid resistance as compared to control specimen. Better strengths and improved durability of such high-performance concretes is likely to make it a more acceptable material for major construction projects. It will also help in consuming large volumes of agro-wastes like rice husk ash thereby reducing its disposal problems along with resulting into cheaper cements with stronger and durable characteristics.

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Table 1. Design of high performance concrete mixes.

Characteristic Strength N/mm^2	W/C Ratio	Cement + Ash kg	Sand kg	Water kg	Aggregate kg	Super Plasticizer
60	0.3	465	515	135	1335	7 l/m^3
80	0.26	565	490	135	1260	9.1 l/m^3

Table 2. Properties of high performance concrete.

W/C Ratio	Mixes	Cube Strength 7Days N/mm^2	Cube Strength 28Days N/mm^2	Cube Strength 42Days N/mm^2	Cylinder Strength N/mm^2	Flexural Strength N/mm^2
0.3	Control	54	63	66	53.5	6.4
	A	56	70	74	58	7.3
	B	53	58.5	72	56.5	7
0.26	Control	73	82	85	66	7.9
	A	74	86	88	74	9
	B	71	83	87	73	8.4

Control – 100% Portland cement
A – Blended cement with 25% rice husk ash+75%Portland cement
B – Blended cement with 50% rice husk ash+50%Portland cement

Table 3. Properties of high performance concrete.

W/C Ratio	Mixes	ISAT ml/m^2/s	Elastic Modulus N/mm^2	Dynamic Modulus N/mm^2	Pulse Velocity km/s
0.3	Control	0.18	36874	50783	4.9
	A	0.12	39365	56912	5.2
	B	0.14	38123	55426	5.1
0.26	Control	0.16	37487	54046	4.8
	A	0.10	40613	59021	5.4
	B	0.11	39874	58172	5.3

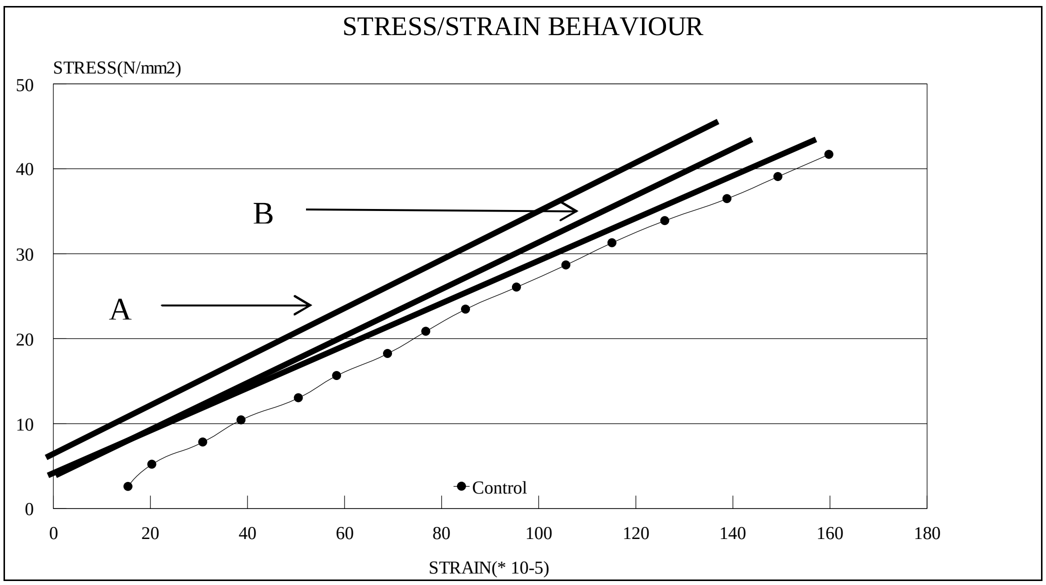

Figure 1. Idealized Stress – Strain Curves

A – Concrete with 25% rice husk ash.
B – Concrete with 50% rice husk ash.