Development of High Performance Concrete Pavement Material: Recent Studies in India

by

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Abstract

Cement Concrete construction in today's developing countries is very common and the use of concrete is increasing day by day in many folds. Concrete is the most versatile material in today's world in the construction of buildings, bridges and roadwork etc. During the use of this high grade cement within last decade, pre-mature cracking was observed during construction in the western zone of the India as a result of the early setting coupled with high shrinkage cracks. These problems initiated this research to develop admixture presented herein. Rock Concrete Hardener (RCH) is a graded aggregate with metallic particles of chemically processed iron. It provides strength, durability and hard surface for the finished concrete. Metallic reaction of RCH in the mixture gives higher values in both compressive and flexural strengths as compared to the normal concrete and better performance. It is a specially designed component to produce high performance concrete economically with fly ash. As a result, the concrete thickness can be reduced for pavements, highways and other applications.

Introduction

Cement Concrete construction in today's developing, countries is very common and the use of concrete is increasing day by day in many folds. For the construction of building, bridges and roadwork etc. concrete is most versatile material in today's world. The consumption of cement per capital has become a barometer of the development of any country.

Present market in India is flooded by variety of cements such as 33, 43 and 53 grade. Present scenario in the major cement plants in India is that generally the cement is produced at 43 and 53 grades only. The use of these cements within last decade has indicated some problems in the west zone of the India due to pre-mature cracking of the RCC structure resulting from early setting coupled with high shrinkage cracks.

There has been recent research related to admixtures such as pozzolanic material (fly ash) and other additives to reduce the production cost of cement due to the price increase of fuel price. This further adds to the cost of all types of construction, where

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transportation is the major factor. Research reported here was carried out to overcome the above problems and to develop concrete to provide economical and durable structures.

Various properties of concrete have contributed to its development from the conventional normal concrete to the high strength concrete (HSC) and now to High Performance Concrete (HPC) and Self-consolidating Concrete (SCC). Its higher performance is due to the fact that it has become a high-tech engineered material. Its characteristics are developed for a particular application, environment and specifications.

Present study is based on the development of HPC for a large highway project, in which highway network will connect from North to South and East to West golden corridor of India. Due to the higher cost of concrete or "rigid pavement" compared to that of the bituminous or "flexible pavement", concrete pavement is not adopted in general in developing country like India. Concrete was chosen for the national importance of highways in view of its versatility and such pavements will be free of maintenance and from pot holes, a very common feature in very heavy monsoon season, which in turn involves large maintenance and repair cost by the related authority and even more importantly the great inconvenience to the traffic and a loss of high value fuel.

Rock Concrete Hardener (RCH)

The raw material is available as a by-product from metal industries, which is processed to manufacture RCH. It is produces under good quality control process and tested in well equipped laboratory. Rock concrete hardener (RCH) is a graded aggregate with metallic particles of chemically processed iron. It provides strength, durability and hard surface for the finished concrete. Metallic reaction of RCH in the mixture gives higher values in both compressive and flexural strengths as compared to the normal concrete and a better performance. RCH was specially designed to enhance the properties of high performance concrete (HPC), with particular emphasis on economy using fly ash, which is available in large quantities in India.

Various physical properties of RCH from standard tests were conducted to determine its characteristics. They are summarized below:

- Physical Appearance : Black / Brown Coarse particles
- Loss on ignition : <1.0%
- Fe_2O_3 : > 45 - 60%
- SiO_2 : <3.0 %
- Inorganic Chlorides : Absent
- Moisture : <1.0%
- Bulk Density : 2.37 g/cc

Initial testing was performed with the addition of 5-10% RCH as compared to cement in the concrete mix; these tests led to a substantial increase in the compressive and flexural strength. RCH dispersed well in concrete throughout the mass of the concrete to make the mix more cohesive and less prone to segregation. RCH was then used for designing the concrete mixture proportions various grades from M-20 to M-45 with a view to optimize the concrete for the above grades and to achieve HPC in line with the national standards for various properties of concrete.

RCH Concrete: The properties of RCH concrete in fresh and hardened states are influenced by the type of aggregates, its composition, volume fraction and material properties of RCH and its interfacial bond characteristics.

Fresh Concrete Properties: RCH concrete mixture is a practical one that enhances transporting, placing, workability, compacting and finishing, and ensures its uniform distribution. RCH is little heavier than other components due to metallic presence, but this does not affect the mixture and distribution in the matrix.

Properties of Hardened Concrete: RCH significantly delays and controls cracking in the composite concrete. These unstable cracks in concrete are transformed to slowly growing ones. RCH provides mix a ductile matrix and results behavior of components in a ductile fashion significantly different than normal concrete. This strengthening mechanism involves transfer of stress from the RCH matrix by interfacial shear or by interlocking between RCH particles. Properties of hardener in concrete are the result of a complex mechanism, which depends on the type of aggregates, combined gradation method of mixing placing etc. This mechanism of failure causes affects various properties of concrete significantly. These are ductility, toughness, tensile and flexural strengths, fatigue life, abrasion and impact resistance, shrinkage, durability and resistance against cavitation (without any order of importance).

Details Experimental Work

It was decided to undertake investigations to improve the tensile strength of concrete with respect to its compressive strength for a specific propose. This initial research over a year has shown many encouraging results in the laboratory as well as in the field, some of which has been presented here. These tests were made to investigate different properties of normal concrete as control mix and the other with RCH. The details are presented below followed by the test data and finally the effect of RCH in a quantitative form in a comparative manner with the "control" concrete.

Mixture Design of RCH Concrete: This section provides details of mix used. It must be noted that the "control" mix was tested first and then RCH was added as a % of cement content; however no attempt was made to reduce cement (by the same quantity as RCH). More research will be conducted to determine real cost effective way to use RCH on a better commercial basis. Typical M-20 mixture is shown here:

M-20 Grade Concrete

Aggregate/Cement ratio = 6.20, using L&T Brand 53 Grade Type I cement
Different brand cements were used as were available from the local source
Cement = 50 kg
W/CM ratio = 0.54 (or as indicated in the tables)
River sand of Zone III (FA) = 115kg
Aggregate (M-1; <10mm) = 45 kg; (M-2; <20mm) = 150 kg
Mix Proportions by weight are: C: FA: M-1: M-2 as 1.00: 2.30: 0.90: 3.00
In the case of RCH concrete, RCH is added in the % shown in tables below.

Table I Comparison of compressive strengths of Normal and RCH Concretes (M-40)

Mix	RCH Concrete details	W/CM Ratio	Compressive Strength		
			3 Days	7 Days	28 Days
			MPa	MPa	MPa
C	Normal Concrete as per IS 456-1978/2000	0.40	20.00	27.00	40.00
C1	5.0% RCH	0.40	30.56	41.56	55.56
C2	7.5% RCH	0.40	31.90	42.20	57.40
C3	10.0% RCH	0.40	36.70	47.30	60.45

All cements were Kamal Brand, Grade 43

Table - 2 Compressive strength results of Rock Concrete Hardener

Sr. No.	Mix	Rock Concrete Hardener (Percent)	Slump (mm)	Compressive Strength					
				3 Days		7 Days		28 Days	
				Mpa	Increases in strength	Mpa	Increases in strength	Mpa	Increases in strength
1	R1	Normal Concrete	80	16.8	-	21.5	-	25.8	-
2	R2	5.0 % Blended RCH	77	21.7	29.17 %	28.4	32.09 %	37.1	43.80 %
3	R3	7.5 % Blended RCH	75	25.3	50.60 %	30.2	40.47 %	38.6	50.77 %

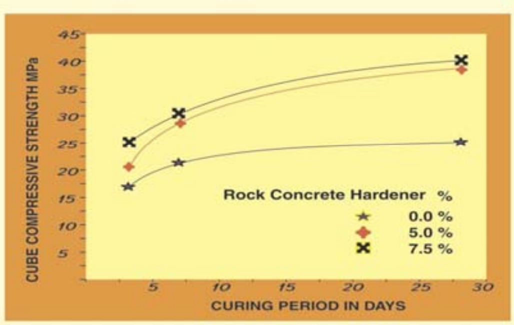

Fig. 1 Variation of Compressive strength with age of curing.

*** Test Results from Ahmedabad Engineering Research Institute, Ahmedabad**

Effects of concrete hardener on compressive strengths of concrete:

Increase in compressive strength is 20% to 50% with the addition of RCH in the range of 5 to 10%. However, there is substantial change in stress-strain response. This change is generally characterized by a noticeable increase in strain substantially higher toughness. This increased toughness is useful in preventing sudden explosive failure under static loading and in absorbing energy in dynamic loading. Typical increase in the compressive toughness index varies 150 to 300 percent. The toughness increases with the volume fraction of RCH. Matrix properties also have influence on the effectiveness of RCH in improving the compressive behavior of concrete. The improvements due to the RCH addition are relatively more significant at lower matrix compressive strength.

This change is generally characterized by a noticeable increase in the strain at peak load and significant increase in ductility and considerably higher toughness. This increase is useful in preventing sudden or explosive strain-type failure even under static loading and while absorbing energy in dynamic loading. The compressive strength increases with the increase in RCH.

Table 3 Flexural Strength results of with Rock Concrete Hardener

Sr. No.	Mix	Rock Concrete Hardener %	Flexural Strength					
			3 Days		7 Days		28 Days	
			Mpa	Increases in strength	Mpa	Increases in strength	Mpa	Increases in strength
1	R1	Normal Concrete	2.41	—	3.78	—	4.06	—
2	R2	5.0 % Blended RCH	3.19	32.63 %	5.10	55.76 %	6.87	72.56 %
3	R3	7.5 % Blended RCH	3.46	44.06 %	5.42	65.42 %	7.96	100.00 %
4	R4	10.0 % Blended RCH	3.97	64.83 %	6.29	91.90 %	9.15	130.10 %

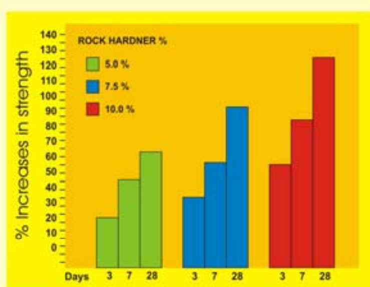

Figure 2 Percentage increases in flexural strength over normal concrete

*Test Results from Ahmedabad Engineering Research Institute, Ahmedabdad

Effect of RCH on Flexural Strength:

Significant difference in the behavior of plain and RCH is found in the flexural strength as shown in Figure 2 and Table 3. When the RCH concrete beams are loaded in flexural, two stages of behavior are observed in the load deflection curve. The behavior is more or less linear up to the first crack and then curve is significantly non-linear and reaches its peak and the ultimate strength or at the maximum sustainable load. A significance difference in the behavior of plain and RCH blended concrete is found in the flexural test, when the RCH blended concrete beams are loaded in flexure. Two distinct stages of behavior have been observed in the load deflection curve in Figure 3. The behavior is more or less linear up to the first crack and then the curve is significantly non-linear and reaches the peak at the ultimate strength or the maximum sustainable static load. Two factors that significantly influence the flexural test are the RCH type and its volume. Figure 3 presents the flexural load deflects curve for plain concrete beam and that for RCH blended concrete beam with 10% of RCH by weight of cement.

The RCH addition also demonstrated its property to arrest cracking. The cracks are prevented from propagating until the ultimate stress in the composite material is reached. The mode of failure results in simultaneous failure of the mortar matrix during the test. This indicates that the RCH particles contribute significantly to increase in bond between RCH particles and cement/sand (or mortar) matrix and its strength. This significance of good bond is indicated by the characteristic load deflection curves in Figure 3. These curves also indicate a ductile behavior and large energy absorption. The effect of RCH on the ultimate strength was significant and was evidenced in better pull-out performance, especially at large deformations and crack widths.

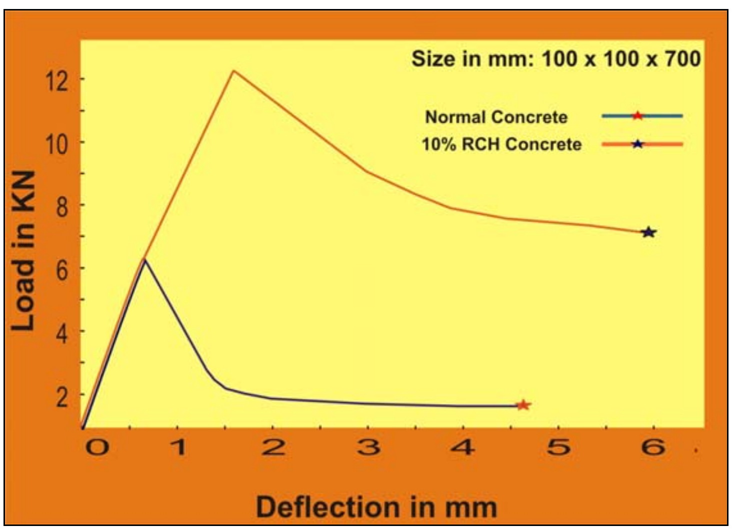

Fig.3 Load Deflection Curve for Static Loading at 28 Days

The volume of integrated RCH in the concrete significantly influences the flexural strength. This increase depends upon the volume for fraction of RCH which varies from 5 to 10% by weight of cement and the increase is more than 100% compared to the normal concrete at the different ages. The metallic bonding reaction of RCH may also cause this positive effect in the flexural strength.

Table 4 Comparison of flexural strength of normal and RCH concretes

Mix	Cement	Rock Concrete Hardener Percentage	W/C	Flexural Strength		
				3 Days	7 Days	28 Days
				MPa	MPa	MPa
C	-	Normal Concrete as per IS 456-1978/2000	-	2.50	3.40	4.43
C1	Kamal Brand 43 Grade	5.0% Blended with RCH	0.40	5.07	8.40	12.60
C2	Kamal Brand 43 Grade	7.5% Blended with RCH	0.40	5.76	7.83	12.12
C3	Sidhee Brand 43 Grade	10.0% Blended with RCH	0.40	7.27	10.40	13.80

* Test Results from Ahmedabad Engineering Research Institute, Ahmedabad

Table 5 Comparison of results of paver blocks with 10% RCH concrete (M-20)

Sr. No.	Description	Test Result	Recommendation As per I.S.1237-1980
1	Paver blocks		
	a) Abrasion Value	1.20 mm	<3..00 mm
	b) Water Absorption	2.5 %	<10.00 %
2.	Paver blocks		
	a) Abrasion Value	1.20 mm	<3..00 mm
	b) Flexural strength	49.70 kg/cm^2	> 30 kg/cm^2
	c) Water Absorption	0.79%	<10.00 %

I.S.1237-1980 is Indian Standard for cement concrete flooring tiles and pavers

Discussion of Results and other Properties of Concrete

Effects of RCH on workability: It was observed that addition of RCH in concrete mix caused reduction in water cementitious material ratio and capillary pores, thus improving impermeability in concrete. RCH in the mix lowered the surface tension of water to make cement particles hydrophilic to control the setting of concrete. It also reduced bleeding and easy placement of concrete with reduced porosity and finally resulting in a higher quality concrete surface. The workability is governed primarily by the unit water content of concrete and is relatively in sensitive to variation in cement and RCH content.

Effects of RCH on permeability: Permeability concept is more applicable to the saturated concrete but in actual practice most concretes have different degrees of saturation and therefore the concept of absorptive phenomenon is more relevant. Permeability of concrete is important due to possible indentation or even penetration while casting. Permeability of concrete has been verified in laboratory tests; the permeability was considerably reduced and the ingress of moisture of cylindrical cement concrete sample under split tensile test was less than 5mm from the external face. RCH concrete becomes a composite material with filler and concrete binder due to metallic bonding reaction in the mix. Permeability also affects the corrosion of steel in reinforcement and pre-stressed concrete. This is mainly influenced by the cover provided and the permeability. With RCH a fairly impermeable concrete is obtained by adopting a lower water cement ratio and by ensuring a thorough compaction of concrete.

Effects of RCH on Shrinkage: Uniform distribution of RCH throughout the mass of the concrete makes the concrete mix more cohesive and less prone to segregation. RCH reduces plastic shrinkage and increases impact resistance and improves tensile strength of concrete. It also decreases drying shrinkage. Large size of platforms have been paved with plain cement concrete using 10% of RCH (by weight of cement) at Agriculture Producers' Market building, Mahuva (India). Not even hair cracks were found until after the initial period of 3 months.

Resistance in thermal cracking: Thermal cracking is a major problem in mass concrete during the initial stage. In some cases where higher cement content is specified to get either higher grade of concrete or durability, the heat of hydration becomes an important factor. RCH concrete has relatively lower heat of hydration as compared to normal concrete. This greatly reduces the risk of cracking in mass concrete applications.

Protection from Sulphate attack: Deterioration of concrete on account of sulphate attack is mainly caused by the reaction of sulphate with C_3A present in cement, which produces ettringite and causes cracking and deterioration of concrete. RCH resists the sulphate attack due to reduced pore size and permeability and thus the attack from the ingress of harmful sulphate salts.

Reduction in Alkali Silica reaction (ASR): Some aggregates react with the alkali present in cement leading to expansion and therefore cracking to cause deterioration of concrete known as ASR. This reaction is more pronounced in structures in high humid environments; they include roads, bridge, piers, jetties, sea-wall and generally construction in the coastal region. The alkali content available for such reaction is reduced due to partial replacement of cement with RCH. As a result, the refined micro-structure of concrete helps reducing moisture influence to cause ASR from the decreased built-up internal stress.

Effect of RCH on Corrosion of steel: RCH is a non-corrosive material in both freezing and hot humid environment. Alkalinity in concrete is affected by the presence of moisture, oxygen, the chloride and the protective surrounding (matrix) and reduces effective coating of steel to cause its corrosion. Use of RCH causes sustained period of protection denser concrete matrix prevents ingress of chloride and others which are detrimental to concrete.

Cost-effectiveness: The planning for extended network of highways in India has been an impressive with majority of them being in concrete. This will enhance the use of concrete in pavements to be constructed in the coming years similar to those during the last decade. With higher strength properties, the initial cost will reduce the thickness of concrete pavements by adopting a rational design approach and the maintenance cost over its life span. RCH concrete could be important due to its higher compressive and flexural strengths along with the advantages in early stage. The concrete pavement currently designed for a 28 day flexural strength of 4-5 MPa; use of 5-10% RCH in the mix, flexural strength increases to as much as 10 MPa. RCH can be used for Pavements Quality Concrete (PQC) and Dense Lean Concrete (DLC).

Possible applications of RCH concrete:

- Concrete pavements, airport runways, taxiways, aircraft hanger etc.
- Industrial floors, railways platforms, bridges, ammunition storages, depots, parking decks & multiple basements.
- Tunnel / Canal lining, harbor, mine linings, domes etc.
- Heavy pedestrian floor traffic areas such as civil centers-sports arenas.
- Water dams, canals and other irrigation structures, sewage pipe & corrosion resistance structures
- Rock/slop stabilization, per cast products & pre-stress products.

Summary of advantages of RCH and Conclusions:

This investigation project was undertaken to demonstrate that concrete can be quite cost-effective. Following advantages of RCH concrete are found in this work.

- Increase in compressive and flexural strength of concrete as well as its long term strengths.
- Reduction in heat of hydration resulting in lesser drying shrinkage as well as plastic shrinkage and minimizing thermal cracking.
- Increase in durability and anti-crack strength.
- Reduction in permeability due to the concrete becoming denser and increase in durability and better resistance to freezing and thawing.
- Improvement in abrasion, impact and fatigue resistance along with increased anti-skid abrasion and resistance to chemicals.
- Better resistance to sulphate, alkaline soils and sea water attack with no chloride contents.
- Increase in the life of structures (pavements) and other applications.

- Ship yards, Jetties, Seawalls, Piers birth & Bridge deck overlays.
- Ready-mix concrete plant.

Research Significance and Conclusions

Rock Concrete Hardener (RCH) and such other materials like Ironite, Quarts & Silica material as metallic and non-metallic floor hardener have been used in the topping to obtain abrasion resistance for warehouses and industrials chemical plant floors. The experimental work was carried out at Ahmedabad Engineering Research Institute in Ahmedabad (India) to use RCH as concrete admixture to investigate its effect on strength parameters mainly flexural strength. These studies allow the use of RCH concrete in rigid pavements and runway applications, where design is based on the compressive and flexural strengths of concrete. Investigations conclude that the use of RCH enhances the flexural strength up to 200% compared to the normal concrete. Other applications such as dome structures, precast or prestressed concrete structures such as transmission poles, railway slippers, and spun pipes are also possible. Concrete made with RCH was recently awarded the first place in Concrete Cube Test Competition-2004 held by India Chapter of American Concrete Institute, Mumbai in Dec 2004.

References

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Appendix: Some Field Results with RCH Concrete

These results were provided by various manufacturers with their field tests. They manufacture different products, which include paver blocks, precast and prestressed concrete units. They are given to indicate the field applications and actual results.

1. RINA Cement Products, Mumbai, India
   (Interlocking Paver Block Grade M-40)

Mixture Design used:

Cement	: FA (Crushed sand)	: W/CM ratio
1	: 3.74 by weight	: 0.30
RCH	: 3% by weight of cement	

Compressive strengths of RCH concrete

a) 3 days : 28 to 32 MPa
b) 7 days : 43 to 48 MPa compared to 27 MPa as per IS: 456:2000
c) 28 days : 58 to 65 MPa compared to 40 MPa as per IS: 456:2000

2. Unitech Prefab Limited, Taloja, Mumbai, India
(Interlocking Paver Blocks, Grade M – 45)

Mix Design
Cement : FA (Crushed sand) : W/CM ratio
1 : 5.50 : 0.35
R C H : 5 % by Weight of Cement.

Compressive Strength
a) 7 days : 42.7 MPa compared to 30 MPa as per IS: 456:2000
b) 14 days : 55.3 MPa

3 N G. Patel & Company, Bhavnagar.
(Post-tensioned girders, Virendeel girders and electrical poles)

Results are for power Transmission line poles
Mix Design (Grade M-45)
Cement: FA (River Sand): Coarse Aggregate (6 to 20 mm)
1 : 2.40 : 2.64
RCH : 10 % by weight of cement

Results of compressive strength
a) 1 day : 16 MPa
b) 2 days : 24 MPa
c) 7 days : 46 MPa compared to 30 MPa as per IS: 456:2000

Additional Information**:** Without the addition of RCH in concrete mix poles were released after 72 hours and water curing periods was 28 days; after adding 10% of RCH in cement concrete mix, the same was done successfully in 48 hours with curing continued for 14 days. This did not show any adverse effect on the final product.

Comparison of compressive strength between Normal Concrete & RCH Concrete in pre-stressed Electrical pole (Grade M -45)

Days	As per manufactures result of normal concrete	After addition of RCH Concrete Results
1	12 MPa	16 MPa
2	16 MPa	24 MPa
7	32 MPa	46 MPa
28	46 MPa	59 MPa
Water Curing Time	28 Days	14 Days
Deflection Test500 at 25 cm	28 Days	14 Days