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Crushed Limestone Waste as Supplementary Cementing Material for High Strength Concrete

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Abstract Use of greener materials and gaining popularity of environment friendly materials worldwide has led to newer research in utilizing waste materials produced from various human, agricultural and industrial activities for useful purposes. Agricultural wastes like rice straw and husk, industrial wastes like slag, fly ash, crushed stone, limestone waste and brick/ concrete waste from demolition of old structures are extensively being used in manufacturing concrete. This experimental study aimed at evaluating the properties of widely produced waste material from limestone processing industry with no beneficial usage i.e. crushed limestone waste as supplementary cementing material. For years a small percentage of limestone powder has been used in cement and masonry to improve workability and in concrete as fine filler however limited research has been carried out on high strength concretes with partial replacement of limestone crush as supplementary material. This study investigated the properties of high strength concrete made from Portland slag cement comprising 50% cement and 50% ground granulated blast furnace slag, natural aggregates and sand where crushed limestone waste was added to cement by replacing slag cement in the percentages of 10% and 20%. Wide ranging investigations covering most aspects of mechanical behavior and permeability were carried out for various mixes for compressive strengths of 60MPa and 80MPa. Compressive strengths of concrete specimen with partial replacement of 10% and 20% limestone waste were observed to be higher by about 4 to 12% than the control specimen. Flexural strengths were also observed to be higher by 12 – 13%. Higher elastic moduli and reduced permeability were observed along with better sulphates and acid resistance. Better strengths and improved durability of such high strength concretes containing up to 20% limestone waste make it a more acceptable material for major construction projects in addition to consuming this massively produced waste material for useful purposes along with reducing its disposal problems.

Keywords: *crushed limestone waste, sustainable construction, supplementary cementing material, high strength concrete, cement replacement material*

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1. Introduction

Use of environment friendly materials has gained huge popularity world-wide thereby resulting into greener practices. Sustainable and emerging green practices leading to environmentally friendly materials have led to use of many waste materials in manufacturing of cement and concrete Most waste materials produced from various human, agricultural and industrial activities are being investigated for useful purposes in addition to improving the environment worldwide. Agricultural wastes like rice straw and husk, industrial waste like slag, fly ash, stone/ limestone dust and brick/ concrete waste from demolition of old structures have been used in manufacturing concrete [1-12]. Ongoing research has led to newer chemicals and materials which have improved the quality of construction immensely. Concretes with improved strengths and durability characteristics are now readily available.

Huge amounts of limestone are quarried and used worldwide in construction and landscaping purposes. Large amount of waste is generated during cutting and sawing process of limestone which includes fragments, fine powder and slurry. 60% to 70% of the stone is believed to be wasted in this process, of which around 30% is believed to be fine powder [2]. Large amount of limestone waste generated from the processing has no useful utilization and is disposed off as waste, occasionally used for landfill purposes. Use of limestone waste as a binder and a supplementary cementing material for partial replacement of cement in concrete will certainly reduce the concrete costs and will hence result into cheaper construction. Improved strength and durability characteristics of concrete will certainly make it a popular material. Bulk use of this waste material can consume large quantities of this waste in construction industry, thereby reducing the burden on the environment. In the absence of any worthwhile research in this field, this study was undertaken to assess the properties of concretes produced by using crushed limestone waste as partial replacement of slag cement in concrete.

Presently, a maximum of up to 70% of slag is added to Portland cement though 50% slag is the usual amount added to Portland cement. Due to the primary issue associated with the use of slag cement in pavement construction being the reported loss of durability (salt scaling resistance) Federal Highways Agency vide its instruction FHWA-RD-97-148 - User Guidelines for Waste and By-product Materials in Pavement Construction restricts maximum of 25% blast furnace slag to be used with Portland cement. 2 to 3% lime is usually added to cement in the production stage to react with ettringite to form stable products during hydration. Large amounts of CO_2 are emitted during the production of cement estimated to be around 1 ton CO_2 per ton of clinker, if no precautions are taken to reduce these emissions. It is estimated that CO_2 emissions from cement manufacturing industry only account for about 7% of the total CO_2 industrial emissions in the world [1]. Use of supplementary cementitious materials (SCMs) like blast-furnace slag, fly ash and other waste materials like crushed limestone waste and rice husk ash etc. can reduce the quantities of Portland cement thereby reducing CO_2 emissions largely. The use of such SCMs also improve the performance concretes like better workability, low permeability, improved durability with better resistance to sulphates and chlorides as well as higher compressive and flexural strengths. Concrete industry is one of the largest users of materials worldwide. Use of such industrial and agricultural waste products in large quantities does reduce the cost of concrete and hence the overall costs of construction too.

The main composition of waste limestone powder is CaCO3 which does possess cementing properties hence can be used as cementitious material or a supplementary cementing material. European code EN 197-1:2000, allows up to 35% of limestone addition in Portland-limestone cement, or total of 35% of limestone plus other SCMs in composite cement [1]. While some of limestone is used up in stabilizing the ettringite formed during hydration of cement, some of it may act as filler or plasticizer in concrete to improve its mechanical properties [1]. Typically, slag cements have low early strengths and high long-term strengths. Addition of limestone powder in cement tends to improve its low early strength with some improvement in long term strength and durability [2].

2. Research Significance

This research investigates the possible use of crushed limestone waste as a supplementary cementing material to replace slag cement in concrete and study its characteristics. Improved strength and durability characteristics of such concrete can reduce the disposal problems of this waste produced worldwide in massive quantities along with providing a better product i.e. high strength concrete with improved strength and durability characteristics. Environment is hugely benefitted as a consequence of utilizing this waste for constructive purposes.

3. Mix Design

High strength concrete mixes were designed for concrete strengths of 60 & 80MPa based on the Design of Normal Concrete Mixes method of Department of Environment - Transport and Road Research Laboratory, London, UK [13]. The design graph for compressive strength versus w/c ratio is restricted up to maximum w/c ratio of 0.3 hence linear projection of compressive strength versus w/c ratio was considered beyond the limiting w/c ratio of 0.3. Characteristic strengths of 60 and 80MPa were selected for trial concrete mixes for concrete testing. These high strength concrete mixes were designed using ordinary Portland slag cement, crushed stone coarse aggregates (maximum 15mm diameter) and medium grade sand. Control mix contained 100% Portland slag cement while other two mixes comprised of 10% and 20% slag cement replaced with crushed limestone powder waste. Slag cement was thoroughly mixed with 10% and 20% replaced limestone powder in drum mixer for 2 minutes before using it for concrete. Crushed limestone waste used was 100% passing #50 sieves. Quantities of materials used in the concrete mixes are given in Table 1. Approximately 1-1/2% of superplasticizer with a maximum of 10 l/m^3 was used to maintain workability and slump in the range of 90 to 120mm for better compaction and specimen formation.

Table 1. Design of concrete mixes

Characteristic Strength MPa	W/C Ratio	Cement kg	SandKg	Waterkg	Aggregate kg	Super Plasticizer
60	0.35	460	510	161	1335	7 l/m^3
80	0.29	570	480	165	1260	10 l/m^3

Table 2. Details of Testing

Type of Test	Test Sample
Compressive strength/density	150mm cubes, 150mm diameter, 300mm long cylinders
Flexural strength	150x150x750mm beams
Stress/strain behavior	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.
Density	150mm cubes
Sulphate and Chloride resistance	150mm cubes. (Immersed in 5% H2SO4 and 5% HCl solutions for 90 days and measuring weight loss)

Note:- All specimen were cured in water at 20°C for 42 days before testing.

4. Testing of Concrete

Six specimens each from three different batches were used in all tests. All specimens were cured in water at 20°C for 42 days before testing. Table 2 gives the details of tests and specimen used for various tests.

5. Discussion of Test Results

The properties of the high strength concrete specimen are summarized in Table 3 and Table 4.

5.1. Compressive Strength

Compressive strength tests on cubes at 7, 28 and 42 days showed that the rate of development of strength of concrete specimen containing 10% and 20% slag cement replaced with crushed limestone waste was similar to normal slag cement concrete samples. The compressive strengths of high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste were higher by 2 to 3% than the control specimen. Specimen cured up to 42 days were tested as strength development of concrete with low w/c ratios spans over longer durations and specimen require excess of external water for hydration [14]. High strength concrete with 10% and 20% % slag cement replaced with crushed limestone waste both developed 80 to 82% of its 28day characteristic strength in 7 days like control mixes. Cylinder strengths of concrete with 10% and 20% % slag cement replaced with crushed limestone waste varied from 87 to 89% of cube strength similar to control mixes. Complete section of the test specimen failed explosively on reaching failure loads which is characteristic of high strength concretes [14]. Keeping in view the test safety and to prevent any damage due to such sudden failure of test specimen, a loading rate of 0.15 to 0.2 $N/mm^2/s$ was maintained which is slightly lower than 0.2 to 0.4 N/mm^2 specified by BS1881: Part 116:1983. Compressive strengths of test specimen are given in Table 3.

5.2. Flexural Strength

The flexural strength of high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste both were observed to be higher by 15 to 20% as compared to control specimen. Slightly higher compressive strengths with improved hydration and better packing due to addition of limestone results into higher flexural strengths of concrete with slag cement replaced with crushed limestone waste.

5.3. Stress/strain Behavior

The slopes of the stress/strain curve for high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste were seen to be similar to the curve for control specimen, typical for high strength concrete. Stress/strain curves were found to be linear up to the point of failure. Slightly higher static and dynamic moduli of elasticity were observed for high strength concretes with 10% and 20% slag cement replaced with crushed limestone waste. Idealized stress/strain curves for all specimen are given in Figure 1.

5.4. Static Modulus of Elasticity

Static Modulus of Elasticity for high strength concrete containing 10% and 20% slag cement replaced with crushed limestone waste were observed to be about 2 and 3% higher than the control specimen, respectively. Average values for Static Modulus of Elasticity varied from 38000 to 39760 MPa for high strength concrete with 20% slag cement replaced with crushed limestone waste as compared to 36340 to 37670 MPa for control mixes. Test results for Static Modulus of Elasticity are given in Table 4.

Table 3. Properties of concrete

W/C Ratio	Mixes	Cube Strength 7 Days MPa	Cube Strength 28 Days MPa	Cube Strength 42 Days MPa	Cylinder Strength MPa	Flexural Strength MPa
0.35	Control	49	61	64	54	7
	A	50	63	66	56	8.1
	B	52	64	67.6	58	9
0.29	Control	64	79	82	69	8
	A	66.4	83	84	72	9.3
	B	70	86	88	76	10

Note:-
Control – 100% Slag Cement
A – 10% Slag cement replaced with crushed limestone
B – 20% Slag cement replaced with crushed limestone.

Table 4. Properties of concrete

W/C Ratio	Mixes	ISAT $ml/m^2/s$	Elastic Modulus MPa	Dynamic Modulus MPa	Pulse Velocity km/s
0.35	Control	0.2	36340	51378	4.7
	A	0.18	37420	54145	5.0
	B	0.16	38951	56610	5.2
0.29	Control	0.19	37620	54563	4.8
	A	0.16	38897	57490	5.1
	B	0.15	39760	59194	5.3

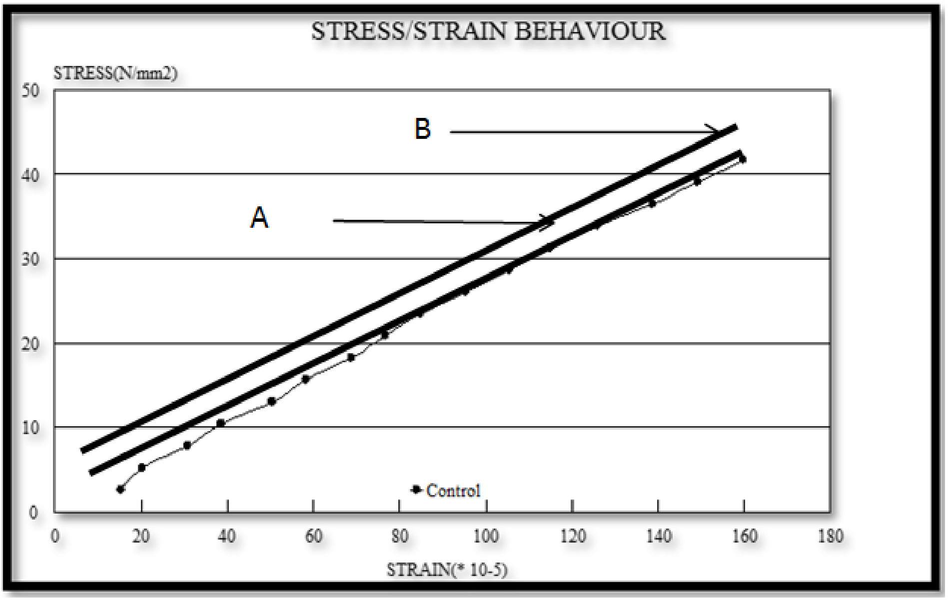

Figure 1. Idealized Stress – Strain Curves (Note: -Control – 100% Slag Cement, A – 10% Slag cement replaced with crushed limestone, B – 20% Slag cement replaced with crushed limestone)

5.5. Dynamic Modulus of Elasticity

Dynamic Modulus of Elasticity for concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5% and 10% higher than the control respectively. Results of testing for Dynamic Moduli of Elasticity of various specimen are given in Table 4.

5.6. Ultrasonic Pulse Velocity

Specimen containing 10% and 20% slag cement replaced with crushed limestone waste were observed to have pulse velocities of 5 and 5.2 km/s respectively as compared to average velocity of 4.8 km/s for control mixes. Hence ultrasonic pulse velocity in the case of concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5 to 10% higher than the control mixes. Higher pulse velocities are certainly due to better hydration, higher density and reduced voids in the high strength concretes containing partial replacement of slag cement with crushed limestone waste. Table 4 gives the test results for ultrasonic pulse velocities for different specimen

5.7. Density of Hardened Concrete

The average saturated and oven-dried densities for high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste were 2462 and 2452kg/m^3 respectively compared to control mixes which were 2440 and 2427kg/m^3, respectively. Hence the saturated and dry densities of concrete with 10% and 20% slag cement replaced with crushed limestone waste are about 1 to 1-1/2% higher respectively than the control mixes. Higher densities with 10% and 20% slag cement replaced with crushed limestone waste are due to better hydration, reduced voids and better packing of materials as compared to control mixes. Due to higher content of fines and cementitious material with low w/c ratios, the unhydrated cementitious material acts as filler too to densify the concrete, as the hydration process continues over longer duration.

5.8. Initial Surface Absorption (ISAT)

Initial surface absorption for concrete with 20% slag cement replaced with crushed limestone waste was observed to be lowest with around 20% lower whilst for concrete with 10% slag cement replaced with crushed limestone waste it was around 10% low as compared to the control. The values are compared with the guidelines given by the Concrete Society Technical Report # 31 [15]. Table 4 gives the values of initial surface absorption tests for various test specimen.

5.9. Sulphate and Chloride Resistance

Average weight loss of specimen due to submersion of specimen in HCL solution resulted in average weight loss of 4% for control specimen as compared to 2.6% and 2.1% for concrete with 10% and 20% slag cement replaced with crushed limestone waste respectively. Similarly, for Sulphate resistance testing of specimen by submersion of specimen in H_2SO_4 solution resulted in average weight loss of 3% for control mixes while 1.7% and 1.2% for specimen containing 10% and 20% slag cement replaced with crushed limestone waste respectively. Concrete with partial replacement of 10% and 20% slag cement replaced with crushed limestone waste is found to be twice better in acidic environment as well as in sulphates environment as compared to control mixes. Better chloride and sulphate resistance for concrete with 10% and 20% slag cement replaced with crushed limestone waste is mainly due to the better hydration, reduced permeability and higher densities of concrete with partial replacement of slag cement with crushed limestone.

5.10. Shrinkage

Shrinkage of 10% and 20% slag cement replaced with crushed limestone waste specimen was observed to be similar to control specimen. Shrinkage of specimen was observed over a 90-day period.

6. Conclusions

The performance of concrete with partial replacement of slag cement replaced with crushed limestone waste has proved to improve performance. Compressive strengths of 60 & 80MPa can be attained with up to 20% slag cement replaced with crushed limestone waste in normal concrete mixes with slag cement. Better packing, reduced voids, improved workability and better hydration due to fines dispersal in the mix resulted into better performance. 2% to 3% higher compressive strengths could be achieved with 10% and 20% slag cement replaced with crushed limestone waste as compared to control mix. Flexural strength of high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste are observed to be higher by 15 to 20% as compared to control specimen. The average Static Modulus of Elasticity for concrete specimen containing 10% and 20% slag cement replaced with crushed limestone waste was 2 to 3% higher than control mixes comprising slag cement. The average Dynamic Modulus of Elasticity for concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5% and 10% higher respectively as compared to control specimen. Ultrasonic Pulse Velocity in the case of concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5 to 10% higher than the control mixes. Saturated and dry densities of concrete with 10% and 20% slag cement replaced with crushed limestone waste are about 1% to 1-1/2% higher respectively than the control mixes. The performance of concrete with partial replacement of 10% and 20% slag cement replaced with crushed limestone waste was almost twice better in acidic environment and in sulphate environment as compared to control mixes. Shrinkage of specimen for all mixes was observed to be similar over a 90 days period.

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