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Sustainable Construction—High Performance Concrete Containing Limestone Dust as Filler

Tahir Kibriya[1]*, Leena Tahir[2]

[1]Senior Consulting Engineer, Black & Veatch, Toronto, Canada (ex Faculty/Head of Civil Engineering Department, NUST, Risalpur, Pakistan)
[2]MSc Structural Engineering, City University, London, UK
Email *t_kibriya@yahoo.com

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Abstract

Massive amounts of limestone waste are produced by the stone processing industry worldwide. Generally, it is believed that 60% to 70% of the stone is wasted in processing in the form of fragments, powder and slurry out of which around 30% is in the form of fine powder [1]. This waste has no beneficial usage and poses environmental hazards. Use of this waste product in the construction industry can largely reduce the amount of waste to be disposed off by the local municipalities in addition to reducing large burden on the environment. Some basic research on use of limestone dust as cement/ concrete filler has been carried out in the recent past but high strength/ high performance concretes have not been investigated yet [2] [3]. The concrete industry is among the largest consumer of raw materials worldwide and has been investigated for use of various types of waste materials like crushed brick, rice husk and straw ash as either aggregates for concrete or as partial cement substitutes. Use of limestone dust as filler material in concrete can consume a huge amount of this waste material which has to be disposed off otherwise, creating large burden on the environment. This experimental study aimed at evaluating the properties of high performance concretes made from Portland cement, natural aggregates and sand. Limestone dust was added by replacing sand 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 60 N/mm^2, 80 N/mm^2 and 100 N/mm^2. Compressive strengths of concrete specimen with partial replacement of sand with 10% and 20% limestone dust as filler material for 60 N/mm^2, 80 N/mm^2 and 100 N/mm^2 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 sulphate and acid resistance. Better strengths and improved durability of such high-performance concretes make it a more acceptable material for major construction projects.

Keywords

Limestone Dust, Filler, Sustainable Construction, Construction Waste, High Strength Concrete, Cement Filler

1. Introduction

The quality of concrete has improved tremendously over the recent years due to ongoing research on newer materials and chemicals. High performance concretes with improved strengths and durability are readily available in the markets. Scarcity of natural aggregates and cement manufacturing raw materials has led to exploration of cheaper alternatives worldwide. Furthermore, sustainable and emerging green practices leading to environmentally friendly materials have led to use of many waste materials in manufacturing of cement and concrete. These have led to newer avenues especially in the developing/under developed countries where resource crunch is a major hurdle towards development. A number of studies have been carried out to find better/cheaper aggregates and cements along with better usage of waste materials in construction [4]-[11].

Massive amounts of limestone and marble are quarried and used worldwide for various purposes. Marble is a refined form of limestone and dolomite formed by their metamorphism. During cutting and sawing process of limestone, huge amounts of fragments, fine powder and slurry are generated as waste product. Generally, it is believed that 60% to 70% of the stone is wasted in this process in the form of fragments, powder and slurry out of which around 30% is in the form of fine powder [1]. Large quantities of limestone processing waste worldwide poses disposal problems since it has no beneficial usage. Use of limestone dust waste in production of concretes for major construction projects will certainly reduce the costs and will hence result into cheaper construction and improved durability. Bulk use of this waste material can consume large quantities in construction industry, thereby reducing the burden on the environment in addition to producing environment friendly concrete. In the absence of any worthwhile research in this field, this study was undertaken to assess the properties of concretes produced by using limestone dust as partial fines replacement.

2. Research Significance

The significance of this research is to investigate the possible use of an abundantly available waste product in construction industry thereby solving its disposal problems along with possibility of obtaining a better product *i.e.* high performance concrete with improved characteristics. Environment is benefitted as a consequence.

3. Mix Design

Mix design for three high strength concrete mixes was carried out based on

Table 1. Design of concrete mixes.

Characteristic Strength N/mm^2	W/C Ratio	Cement kg	Sand kg	Water kg	Aggregate kg	Super Plasticizer
60	0.3	460	511	135	1330	7.4 l/m^3
80	0.24	570	479	135	1265	9.8 l/m^3
100	0.2	690	440	135	1151	15.3 l/m^3

Design of Normal Concrete Mixes method of Department of Environment—Transport and Road Research Laboratory, London, UK [12]. Linear projection of compressive strength versus w/c ratio from Design of Normal Concrete Mixes method was considered beyond the limiting w/c ratio of 0.3. Characteristic strengths selected for the trial concrete mixes were 60, 80 and 100 N/mm^2. These mixes were designed using ordinary Portland cement, crushed limestone coarse aggregates (maximum 37.5 mm diameter) and medium grade sand partially replaced with 10% and 20% limestone dust. Control mix contained 100% medium sand. Limestone dust used was 100% passing #100 sieves. An initial estimate of density was made and later adjusted in the light of values actually obtained by the mix design method. The details of the quantities of materials used in the mixes are given in Table 1. Around 1% of super plasticizer with a maximum of 15.1 l/m^3 was used to maintain workability and slump in the range of 90 to 120 mm.

4. Testing of Concrete

Three specimens each from three different batches were used in all tests. Tests and specimen used for different tests were as follows:

Compressive strength/density	Cubes-150 mm, Cylinders-150 mm diameter, 300 mm long.
Flexural strength	Beams—150 × 150 × 750 mm long.
Stress/strain behavior	Cylinders—150 mm diameter, 300 mm long.
Static modulus of elasticity	Cylinders—150 mm diameter, 300 mm long.
Dynamic modulus of elasticity	Beams—150 × 150 × 750 mm long.
Ultrasonic pulse velocity	Cubes—150 mm.
Initial surface absorption	Cubes—150 mm.
Sulphate and Chloride resistance	Cubes—150 mm. (Immersed in 5% H_2SO_4 and 5% HCl solutions for 90 days and measuring weight loss)

All specimens were cured in water at 20˚C for 28 days before testing.

5. Discussion of Test Results

The properties of the high-performance concretes produced are summarized in Table 2 and Table 3.

5.1. Compressive Strength

Compressive strength tests on cubes at 7 & 28 days showed that the rate of

Table 2. Properties of concrete.

W/C Ratio	Mixes	Cube Strength 7 Days N/mm²	Cube Strength 28 Days N/mm²	Cylinder Strength N/mm²	Flexural Strength N/mm²
	Control	51	63	53.5	6.4
0.3	A	54	68	56	7.3
	B	56	71	59	8
	Control	73	82	66	7.9
0.24	A	74	84	74	9
	B	76	87	76	10.8
	Control	92	103	86	9.8
0.2	A	91	105	88	11
	B	94	107	90	11.9

Control—100% Medium Sand; A—10% Sand replaced with limestone dust; B—20% Sand replaced with limestone dust.

Table 3. Properties of concrete.

W/C Ratio	Mixes	ISAT ml/m²/s	Elastic Modulus N/mm²	Dynamic Modulus N/mm²	Pulse Velocity km/s
	Control	0.22	36,870	51,378	4.7
0.3	A	0.18	37,220	54,145	5.0
	B	0.17	38,395	56,610	5.2
	Control	0.20	37,200	54,563	4.8
0.24	A	0.16	38,750	57,490	5.1
	B	0.15	39,460	59,194	5.3
	Control	0.17	38,220	56,684	4.8
0.2	A	0.14	39,080	57,690	5.2
	B	0.13	40,620	57,954	5.4

development of strength of concrete specimen containing 10% and 20% sand replaced with limestone dust was similar to normal concrete samples. The compressive strengths of high performance concrete with 10% and 20% sand replaced with limestone dust was higher than the control specimen varying between 4% to 12% with higher range for 20% sand replacement with limestone dust. Since low w/c ratios require lot of external water for hydration, it was observed that the compressive strengths of test samples kept increasing with time [13]. High performance concrete with 10% and 20% sand replaced with limestone dust both developed 80% to 85% of its 28 day characteristic strength in 7 days like normal concretes. During the testing, it was observed that the complete section of high performance concrete specimen tends to fail suddenly and explosively which is typical of high strength concretes [13]. Protective measures must be taken to prevent any damage due to such sudden failure of test specimen. To maintain safety from the explosive failure of high strength concrete specimen, a lower loading rate of 0.15 to 0.2 N/mm^2/s was maintained during the testing as compared to 0.2 to 0.4 N/mm^2 specified by BS1881:Part 116:1983. Table 2 gives the compressive strengths of the samples as well as the control specimen.

5.2. Flexural Strength

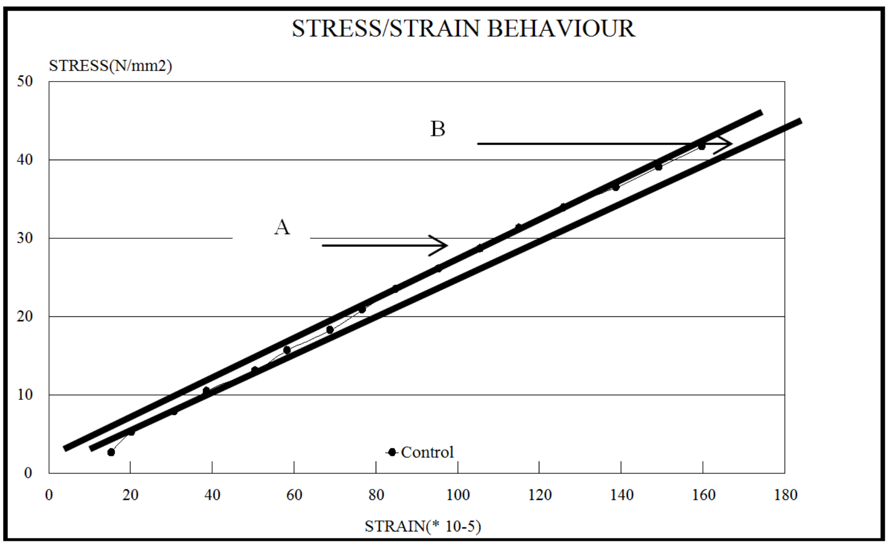
The flexural strength of high performance concrete with 10% sand replaced with limestone dust as well as specimen containing 20% sand replaced with limestone dust both were observed to be higher by 12% to 13% as compared to control specimen. Higher flexural strengths are certainly a consequence of higher compressive strength and increased density of concrete with 10% and 20% sand replaced with limestone dust as compared to the control mixes as shown in Table 2.

5.3. Stress/Strain Behavior

It was observed that the general slope of the stress/strain curve for high performance concrete with 10% sand replaced with limestone dust as well as specimen containing 20% sand replaced with limestone dust both were similar to the curve for control specimen. All the curves were observed to be virtually linear up to the point of failure which is typical of high strength concretes. Higher static and dynamic moduli of elasticity were observed for high strength concretes with 10% sand replaced with limestone dust as well as specimen containing 20% sand replaced with limestone dust both. Values for static and dynamic moduli are given in Table 3 while idealized stress/strain relationships for all samples are shown in Figure 1.

5.4. Static Modulus of Elasticity

Values for Static Modulus of Elasticity for high strength concrete with specimen containing 20% sand replaced with limestone dust was observed to be about 4 to



Control—100% Medium Sand; A—10% Sand replaced with limestone dust; B—20% Sand replaced with limestone dust.

Figure 1. Idealized Stress—Strain Curves.

5% higher than the control specimen. For concrete with 10% sand replaced with limestone dust, the Static Modulus of Elasticity was observed to be 2% to 3% higher than the control specimen. Average values for Static Modulus of Elasticity was observed to be vary from 38,000 to 40,000 N/mm^2 for high strength concrete with 20% sand replaced with limestone dust as compared to 36,800 to 38,000 N/mm^2 for high strength concretes containing 100% medium sand. The Values for Static Modulus of Elasticity are given in Table 3.

5.5. Dynamic Modulus of Elasticity

Dynamic Modulus of Elasticity for concrete with 20% sand replaced with limestone dust was observed to be 4% higher than the control as compared to concrete with 10% sand replaced with limestone dust which was observed to be about 2% higher than the control specimen. Table 3 gives the values of Dynamic Moduli of Elasticity of various specimen.

5.6. Ultrasonic Pulse Velocity

Average pulse velocity across concrete with specimen containing 10% and 20% sand replaced with limestone dust was observed to be 5.2 and 5.4 km/s respectively as compared to an average velocity of around 4.8 km/s for control mixes. Hence ultrasonic pulse velocity in the case of concrete with 10% and 20% sand replaced with limestone dust was observed to be 10% to 12% higher than the control mixes. Higher pulse velocities are certainly due to better quality, higher density and reduced voids in the high strength concretes containing partial replacement of limestone dust with sand, as compared to the control mixes. The ultrasonic pulse velocities observed for different concretes are given in Table 3.

5.7. Density of Hardened Concrete

The average saturated and oven-dried densities for high strength concrete with 10% and 20% sand replaced with limestone dust were 2580 and 2490 kg/m^3 respectively, as compared to control mixes which were 2488 and 2461 kg/m^3, respectively. Hence the saturated and dry densities of concrete with 10% and 20% sand replaced with limestone dust are about 4% & 2% higher respectively than the control mixes. Higher densities for concrete with 10% and 20% sand replaced with limestone dust are due to better packing of materials in concrete with sand replaced with fine limestone dust. In the presence of higher content of fines and cementitious material and low w/c ratios, most of the unhydrated cementitious material too acts as filler to densify the concrete, whilst the hydration process continues over longer duration.

5.8. Initial Surface Absorption (ISAT)

Initial surface absorption for concrete with 20% sand replaced with limestone dust was observed to be lowest with around 22% lower whilst for concrete with 10% sand replaced with limestone dust it was around 19% low as compared to the control. The values are compared with the guidelines given by the Concrete

Society Technical Report # 31 [14]. Results of ISAT are given in Table 3.

5.9. Sulphate and Chloride Resistance

For chloride resistance, submersion of specimen in HCL solution resulted in average weight loss of 7% for control specimen as compared to 3.6% and 3.2% for concrete with 10% and 20% sand replaced with limestone dust respectively. For sulphate resistance, submersion of specimen in H_2SO_4 solution resulted in average weight loss for control specimen as 6% as compared to 2.7% and 2% for specimen containing 10% and 20% sand replaced with limestone dust respectively. Hence, the performance of concrete with partial replacement of sand with limestone dust was almost twice better in acidic environment and slightly over twice better in sulphate environment as compared to concrete with ordinary Portland cement control mixes. Better chloride and sulphate resistance for concrete with 10% and 20% sand replaced with limestone dust is mainly due to the reduced permeability and higher densities of concrete with partial replacement of sand with limestone dust.

5.10. Shrinkage

Shrinkage of all specimen was observed to be similar. No appreciable difference in shrinkage of specimen cast from concrete with partial replacement of sand with limestone dust and control mixes were observed for 90 days.

6. Conclusion

The performance of concrete with partial replacement of sand with limestone dust proved to be satisfactory with improved performance. Compressive strengths of 60/80/100 N/mm^2 can be attained with up to 20% sand replaced with limestone dust in normal concrete mixes. Better packing, reduced voids, improved workability and better hydration due to fines dispersal in the mix resulted into better performance. 4% to 12% higher compressive strengths could be achieved with 10% and 20% sand replaced with limestone dust in normal concrete with higher range for 20% sand replacement with limestone dust. Flexural strength of high performance concrete with 10% and 20% sand replaced with limestone dust is observed to be higher by 12% to 13% as compared to control specimen. The average static modulus of elasticity for concrete specimen containing 20% sand replaced with limestone dust was observed to be about 4% to 5% higher than the control specimen while for concrete with 10% sand replaced with limestone dust, it was observed to be 2% to 3% higher than the control. The average dynamic modulus of elasticity for concrete with 20% sand replaced with limestone dust was observed to be 4% higher than the control as compared to concrete with 10% sand replaced with limestone dust which was observed to be about 2% higher. Ultrasonic pulse velocity in the case of concrete with 10% & 20% sand replaced with limestone dust was observed to be 10% to 12% higher than the control mixes. Saturated and dry densities of concrete with 10% & 20% sand replaced with limestone dust are about 4% & 2% higher respectively than the control mixes. The performance of concrete with partial replacement of sand with limestone dust was almost twice better in acidic environment and slightly over twice better in sulphate environment as compared to concrete with ordinary Portland cement control mixes. There is no appreciable difference in shrinkage of specimen cast from concrete with partial replacement of sand with limestone dust and control mixes were observed for 90 days.

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