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Optimum use of microsilica in high performance concrete

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***Abstract*—The results of an experimental research work on high performance concrete is presented in this paper. The percentage content of recycled aggregate was between 0% - 100% at 25% interval. Microsilica was incorporated within the range of 0% - 20% at 5% intervals. The 28-day target mean compressive cube strength and water-cement ratio la(w/c) were 63MPa and 0.39 respectively. The aim of this research was to determine the optimum addition of microsilica required to achieve better strength and durability in high performance recycled aggregate concrete. Compressive strength, tensile splitting strength, modulus of elasticity, and water permeability tests were conducted on hardened concrete samples respectively. The results show very significant improvement in mechanical properties respectively. The addition of 15% microsilica produced maximum performance results in terms of strength increase and durability. Further addition above 15% led to reduction in mechanical properties.**

***Keywords*—Microsilica, synthetic macro fibre, permeability, High performance concrete, recycled aggregate.**

I. Introduction

High performance concrete (HPC) by definition refers to concrete that is capable of satisfying special performance conditions which cannot be achieved with the use of conventional concrete. It also possess high strength, high durability, increased workability, high modulus of elasticity, and low permeability. [1] These characteristics are derived from the benefits of using microsilica which is a very fine and non-crystalline by-product of silicon or silicon alloys in the electric furnace and superplasticiser. The contribution of microsilica in concrete could either be physical (i.e. by acting as a micro filler to reduce the average size of pores present in cement paste in order to enhance concrete properties, often called "particle packing effect") or chemical (i.e. by acting as an efficient pozzolanic material which provide even distribution and higher volume of hydration products. Although the initial procurement of HPC is more than the cost of conventional concrete, this could be offset by long-term cost benefits which outweighed the higher economy of initial procurement. The incorporation of microsilica in concrete tends to shift the position of concrete from full heterogeneity to more homogeneity with a very significant improvement in terms of durability and strength. Porosity of the interfacial transition zone between aggregate and cement matrix in fresh concrete can be lowered with incorporation of microsilica which provides the required microstructure for a strong interfacial transition zone. [2, 3] Embedded reinforcement in concrete is protected by microsilica efficiently, with high resistance in critical environment by enhancing its durability. Most researchers discussed the use of microsilica as a partial replacement of cement but this research work considered addition of microsilica and it is intended to discover the optimum capacity required to achieve improved performance.

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II. Materials and Mix Design

A. *Materials*

The materials used in the experimental investigation are shown in Table 1.

TABLE 1. CONCRETE MATERIALS

Materials	**Type**
Cement	CEM II/B-V 32,5N (Portland - fly ash cement)
Synthetic macro fibre	54mm Forta Ferro, Virgin copolymer/polypropylene, Specific gravity of 0.91, tensile strength 570-660MPa
Microsilica	Elkem Microsilica Grade 940-U
Recycled coarse aggregate	Maximum size of 10mm, supplied by Coleman and company, Birmingham, UK
Superplasticiser Alphaflow 420	Modified synthetic Carboxylated polymer

B. *Mix Design*

Tables 2 – 6 shows details of six concrete mix series designed according to UK Building Research Establishment (BRE) method. Each series contained five concrete mixes. The 28-day characteristic cube strength, water/cement ratio and workability class were 50 MPa, 0.39 and high respectively. A total of 825 concrete samples at saturated surface dry (SSD) condition were investigated.

TABLE 2. CONCRETE MIX DETAILS –SERIES 1

Recycle Aggregate. (%)	0	25	50	75	100
Cement (kg/m³)	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Water (kg/m³)	230	230	230	230	230
Synthetic Macro Fibre kg/m³)	0	0	0	0	0
Microsilica (kg/m³) – 0%	0	0	0	0	0
Superplasticiser (kg/m³)	0	0	0	0	0

TABLE 3. CONCRETE MIX DETAILS –SERIES 2

Recycle Aggregate. (%)	0	25	50	75	100
Cement (kg/m³)	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Water (kg/m³)	230	230	230	230	230
Synthetic Macro Fibre (kg/m³)	1	1	1	1	1
Microsilica (kg/m³) – 5%	29.2	29.2	29.2	29.2	29.2
Superplasticiser (kg/m³)	0	2.33	2.33	4.66	4.66

TABLE 4. CONCRETE MIX DETAILS –SERIES 3

Recycle Aggregate. (%)	0	25	50	75	100
Cement (kg/m³)	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Water (kg/m³)	230	230	230	230	230
Synthetic Macro Fibre (kg/m³)	1	1	1	1	1
Microsilica (kg/m³) – 10%	58.3	58.3	58.3	58.3	58.3
Superplasticiser (kg/m³)	0	3.50	3.50	4.66	4.66

TABLE 5. CONCRETE MIX DETAILS –SERIES 4

Recycle Aggregate. (%)	0	25	50	75	100
Cement (kg/m³)	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Water (kg/m³)	230	230	230	230	230
Synthetic Macro Fibre (kg/m³)	1	1	1	1	1
Microsilica (kg/m³) – 15%	87.5	87.5	87.5	87.5	87.5
Superplasticiser (kg/m³)	0	4.66	4.66	5.83	5.83

TABLE 6. CONCRETE MIX DETAILS –SERIES 5

Recycle Aggregate. (%)	0	25	50	75	100
Cement (kg/m³)	583	583	583	583	583
Sand (kg/m³)	603	603	603	603	603
Gravel (kg/m³)	904	678	452	226	0
RCA. (kg/m³)	0	226	452	678	904
Water (kg/m³)	230	230	230	230	230
Synthetic Macro Fibre (kg/m³)	1	1	1	1	1
Microsilica (kg/m³) – 20%	116.6	116.6	116.6	116.6	116.6
Superplasticiser (kg/m³)	0	5.83	5.83	6.41	6.41

III. Tests

A. *Compressive Strength Test*

Concrete samples were subjected to uniaxial compression in order to determine the maximum stress on concrete cubes at failure using digital Avery-Denison compression testing machine at a constant loading rate of 2.4kN/s. The test was conducted on three standard 100x100x100mm concrete cubes at 28-day curing age respectively in accordance to [4].

B. *Tensile Splitting Strength Test*

This test was conducted on three standard hardened cylindrical concrete samples (100 mm diameter × 200 mm long) in accordance to [5]. The test was carried out using Denison testing machine in order to determine the indirect tensile strength of the concrete samples at 28-day curing age.

C. *Static Modulus of Elasticity*

Static Elastic Modulus test was conducted in accordance to [6] on hardened cylindrical concrete samples (100 mm diameter × 200 mm long). Three samples were prepared for each concrete mix in series 1 - 5 and tested to failure at 28-day curing age in order to determine the static modulus of elasticity in compression.

D. *Permeability Test (Autoclam)*

Permeability test was conducted in order to determine the water permeability index. Three standard 100×100×100mm cube samples were prepared for each concrete mix and tested using the Autoclam permeability test system. The test was conducted for 15 minutes and the cumulative volume of water into the concrete at different pressures was plotted against the square root of time between the 5^{th} and 15th minute. The gradient of the linear graph was taken as the permeability (sorptivity) index.

IV. Results and Discussion

A. *Compressive Strength Test*

Figure 1 illustrates the 28-day compressive cube strength results for each of the concrete mixes. It was observed that the compressive strength of concrete mix incorporating 15% microsilica produced the maximum strength compared to other mixes.

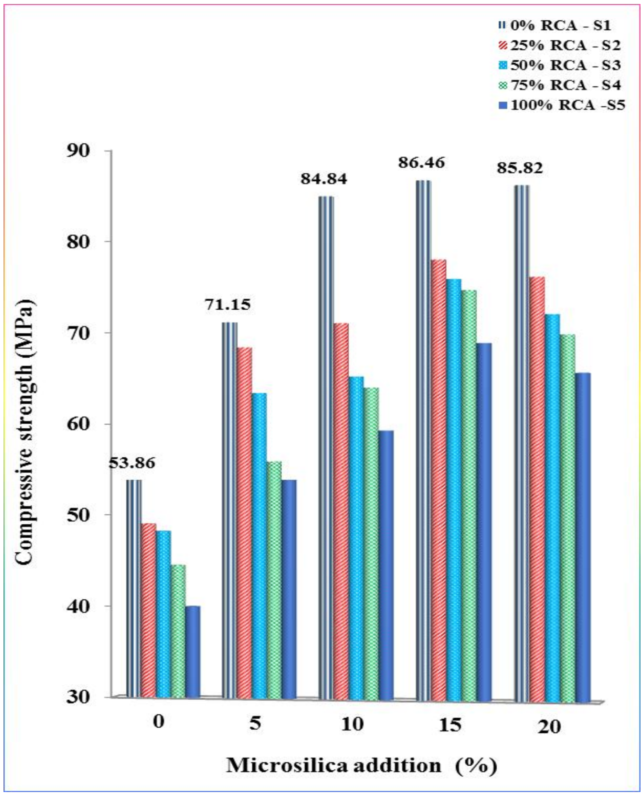

Figure 1. 28-day compressive strength

The relative strength increase with respect to control mix were 61%, 59%, 57%, 67%, and 72% respectively. These figures correspond to 0%, 25%, 50%, 75%, and 100% recycled aggregate content. Further addition up to 20% led to reduction in strength. This finding was corroborated by [7-9].

B. *Tensile Strength Test*

Results of average indirect tensile splitting strength test at 28-day curing age for series 1 – 5 concrete mix are illustrated in figure 2. Concrete mix in series 2 – 5 which incorporates microsilica produced better results. The maximum strength gain was observed in concrete mixes incorporating 15% microsilica. Microsilica improves the microstructure of the interfacial transition zone and increases the bond strength between the new cement paste and the recycled aggregate [10]. Similar results were reported by [11].

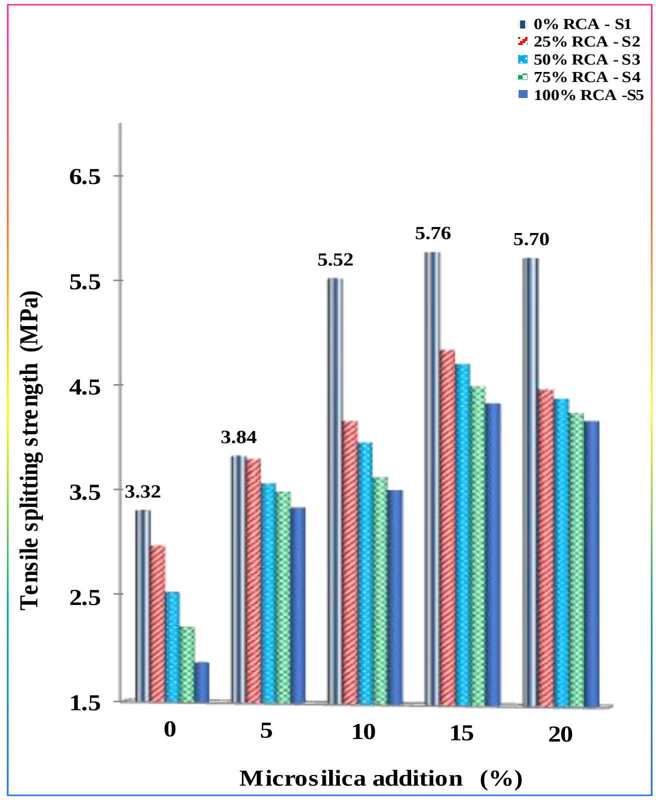

Figure 2. 28-day tensile splitting strength

C. *Static Modulus of Elasticity*

Results of static modulus of elasticity at 28-day curing age are illustrated in figure 3.

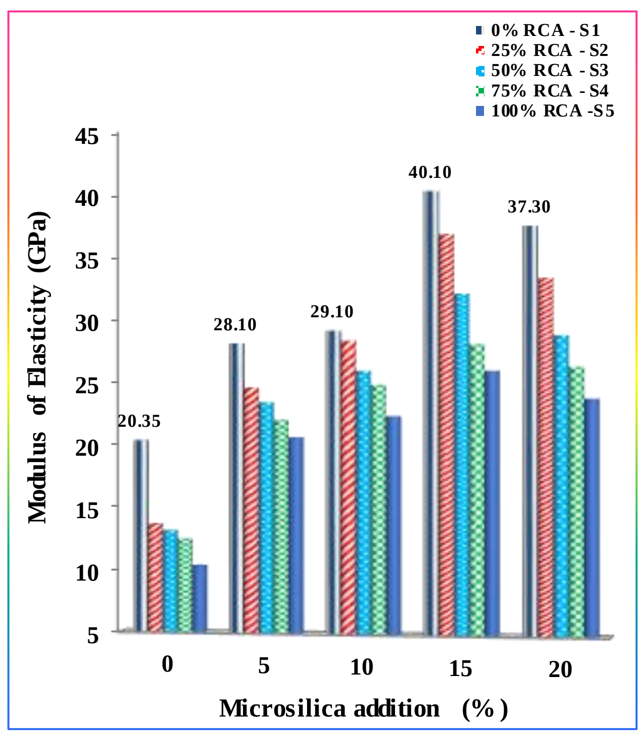

Figure 3. 28-day static modulus of elasticity

There were significant variations of about 50%, 54%, 60%, and 56% between control concrete at 100% recycled coarse aggregate content and other mixes incorporating 5%, 10%, 15%, and 20% microsilica respectively. The maximum static elastic modulus was observed in concrete mixes incorporating 15% microsilica. Higher elastic moduli similar to the findings were reported by [12, 13].

D. *Permeability Test (Autoclam)*

Table 7 represents the water permeability test results in each of the concrete mixes investigated. It was observed that the control mix produced the maximum permeability indices compared to others.

TABLE 7. 28-DAY WATER PERMEABILITY RESULTS

Mix Id	**Recycled Aggregate replacement (%)**				
	0	**25**	**50**	**75**	**100**
Permeability Index ($m^3x10^{-7}/\sqrt{min}$)					
Series 1	0.7	1.4	2.3	3.8	4.3
Series 2	0.3	0.5	0.6	0.6	0.7
Series 3	0.3	0.4	0.4	0.6	0.6
Series 4	0.3	0.3	0.4	0.5	0.6
Series 5	0.3	0.3	0.4	0.5	0.6

Concrete mix in series 2 - 5 incorporating microsilica produced the least permeability indices in comparison with reference mix. The best results of microsilica addition were observed in series 4 and 5 which incorporates 15% and 20% microsilica respectively. According to Table 8, Concrete society (2008) protective quality of concrete permeation indices, concrete mixes in series 2 - 5 fell under the category of very good protective quality of concrete from 0% to 100% recycled coarse aggregate content whereas the control concrete fell under very good to good category. This findings correlate with [14].

TABLE 8. PROTECTIVE QUALITY OF CONCRETE

Protective quality of concrete based on Clam permeation indices (Courtesy: The Concrete Society, 2008)				
Permeation Property	**Protective Property**			
	Very good	Good	Poor	Very poor
Clam Water Permeability ($m^3xE\text{-}7/\sqrt{min}$)	≤ 3.70	$> 3.70 \leq 9.40$	$> 9.40 \leq 13.8$	> 13.8

V. Conclusion

The main conclusions are as follows:

1) Addition of synthetic macro fibre has no significant effect on compressive strength;
2) The mechanical properties of concrete incorporating 15% microsilica were greatly improved in terms of relative strength increase and durability compared to others;
3) Further addition above 15% led to reduction in performance.

Acknowledgment

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"The optimum benefit of microsilica was derived at 15% addition, which produced the best results in terms of strength increase and durability compared to other mixes. Further addition beyond 15% led to reduction in strength."