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The mechanical properties of roller-compacted concrete blended with microsilica

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Abstract
This study aims to experimentally investigate the fresh and hardened state properties of roller-compacted concrete (RCC) blended with microsilica and study the functional relationship between concrete constituents and the curing ages. To measure the contribution of microsilica to the hardened state properties, microsilica was used to replace cement with ratios of 10%, 15%, and 20% at varying water to cement ratios of (0.35, 0.40, 0.45, 0.5). A control mix (0% micro-silica) content was prepared for each water-cement ratio, and these were used for comparison. A concrete mix design was carried out using ACI 211 standard code procedure for RCC.
A total of one hundred and forty-four cubes were tested to obtain the compressive strength, and the compressive strength was at the maximum value of 64.89 at a water-cement ratio of 0.35, and 15% replacement of cement with micro-silica.

Keywords — *Roller Compacted Concrete, Microsilica, water to cement ratios.*

I. INTRODUCTION

Roller-compacted concrete (RCC) is defined as a zero-slump concrete transported, placed, and compacted using equipment used in earth and rockfill operations. Roller compacted concrete (RCC) has similar basic ingredients as conventional concrete (Ouellet, 1998). However, RCC is slightly different from conventional concrete (CC). It is a drier mix-stiff enough to be compacted by vibratory rollers (Burns and Saucier, 1978).

RCC, if properly designed, does not require joints during construction. For the design of RCC, early strength of 40 N/mm^2 for cement content of 300 kg/m^3 and a w/c ratio of 0.35 has been achieved. In addition, RCC is less sensitive to cracking in relation to drying shrinkage.

The RCC is used in the design of low volume roads, ports, and dams. For instance, RCC pavement was used in Intermodal Yard Paving Projects at the Port of Tacoma, Washington.

Chorn et al. (2018) carried out a comparative study between the indirect tensile strengths of the RCC and those of the conventional concrete and developed relationship equations to evaluate the compressive and tensile strengths. However, a trivial linear regression analysis was used, yielding a low coefficient of determination.

II. LITERATURE REVIEW

Modarres and Hosseini (2014) examined rice husk ash's effects on original and recycled asphalt pavement material on the mechanical properties of roller-compacted concrete. Four design mixtures were used; concrete mix with an original aggregate of asphalt pavement, mixture with coarse recycled asphalt pavement plus fine original pavement, coarse original aggregate plus fine recycled asphalt pavement, and a mixture of total recycled asphalt pavement. The rice husk ashes were used as a partial replacement for cement in the production of the roller-compacted concrete with varying amounts of 3% and 5%. The mechanical properties were tested after curing for 7, 28, and 120 days with a fatigue test for only concrete cured for 120 days.

From the experiment, it was observed that the maximum dry density of the roller-compacted concrete was increased by the addition of recycled asphalt pavement than with the original asphalt pavement. The energy absorbency of the roller-compacted concrete was increased by the addition of recycled asphalt pavement. At 3% addition of rice husk ash (RHA), the concrete's flexibility was enhanced, but the increment of RHA content to 5% reduced the concrete's energy absorbency. Also, the compressive strength of RCC was increased by both fine and coarse aggregate recycled asphalt pavement with further increase in substitution of the Coarse aggregate content.

It was also observed that the roller-compacted concrete mixture with recycled asphalt pavement has lower fatigue life than the normal roller-compacted concrete. And it was also noted that the Coarse aggregate part's replacement was less detrimental than the fine aggregate content's replacement.

Karadelis and Lin (2015) examined the flexural strength and fiber efficiency of steel-fiber-reinforced, roller-compacted, polymer-modified concrete (SFR-RC-PMC). From the study, it was observed by the authors that higher flexural strengths were developed in steel-fiber-reinforced, roller-compacted, polymer-modified concrete than the conventional steel-fiber-reinforced concrete. Also, the fibers in SFR-RC-PMC showed higher efficiency than those in the conventional steel-fiber-reinforced concrete.

Rao *et al.* (2016) studied the effect of manufactured sand on the strength and abrasion resistance of Ground Granulated Blast Furnace Slag (GGBS) Roller Compacted Concrete (GRCC). GGBS was used as partial replacement of cement from 0% to 60% by volume with the mixes designed to have a flexural strength of 5 MPa following ACI 211.3R guidelines. Three design mixes of fine aggregates were used; 100% river sand, 100% manufactured sand, and 50% of each combination of river sand and manufactured sand. After curing the mixture for 3, 7, 28, and 90 days, compression, flexure, and surface abrasion resistance tests were conducted on mixtures.

Under early curing of 3 days, the concrete mixtures' strength for all aggregate combinations decreased on increasing addition of GGBS as replacement of cement from 0% to 60%. This was as a result of the poor pozzolanic reaction of GGBS at the early age of curing. But on the increase in the age of curing, to about 7 days of curing, the mixtures' strength increased to about 50% of the control mix. Also, the addition of manufactured sand increased the strength of GRCC.

It was observed that the abrasion resistance of RCC with GGBS depended on the strength of the concrete itself rather than the quantity of manufactured sand introduced into the mixture. However, it was discovered that the strength of roller-compacted concrete increased with increasing curing age.

Omran *et al.* (2017) carried out a field study on the production of roller-compacted concrete using glass powder. Glass powder was used as supplementary cementitious material by replacing about 20% of the cement content of the concrete mixture. This was used in the production of slab-on-ground Tricentris construction in Lachute-QC, Canada.

The study observed that the roller compacted concrete's compressive and flexural strengths were enhanced by replacing cement with glass powder. The durability properties such as resistance to freeze-thaw cycle and resistivity of RCC were improved by adding glass powder. This is because the volume of permeable voids and water permeability of roller-compacted concrete was reduced by dividing glass powder into the concrete.

It was concluded from the study that the improved mechanical and durability properties of roller-compacted concrete with glass would help the concrete to overcome bad weather conditions.

Lin *et al.* (2013) developed a mix design method for steel-fiber-reinforced and roller-compacted concrete and achieved high bond and strength and roller compatibility. In the study, the Modified Proctor compaction method and Modified Vebe method were examined in durability. Two mixes were proposed; the SBR and SBR-PVA hybrid polymer modified cement concrete mixes.

From the study, for optimal water content, the modified light compaction method was recommended for steel fiber reinforced, roller-compacted, polymer-modified, bond concrete overlays. Approximately 3% of air content was found for mixes with optimal water content determined by the modified proctor method.

III. MATERIALS AND METHODS

The following materials were used in the experimental design:

- Crushed granite (coarse aggregate) with a grade size of 10mm (conforming to EN 12620) was used.
- Fine aggregate (river sand) & conforming to EN 12620 was used
- Micro-silica made by Orisil
- Portland Limestone of grade 42.5 cement manufactured by Dangote cement conforming to NIS 444.
- Water conformed to EN1008 was used
- Superplasticizer dosage (SP): For developing a flowable self-compacting concrete, polycarboxylate ether (PCE) based superplasticizer was used. Based on the manufacturer's prescription, the dosage level should be between 1% to 1.3% of the total cementitious or powder content of superplasticizer conforming to EN 934-2 was used in this study. The sample preparation and tests were carried out in the structural laboratory of Rivers State University, Port Harcourt, Nigeria, and a comprehensive report on this study is obtainable in Onyegbadue et al. (2019)

IV. MIX PROCEDURE

The mix proportioning is in accordance with ACI 211.3R-02. The following procedures were adopted

- Portland Limestone cement was replaced with micro-silica at different percentages of 5%, 10%, 15%, and 20% by weight.
- Samples preparation and test method: The compressive strength test is in accordance with the guidelines of BS 123 90:3, 2009, using 150mm cubes. Each mixture was tested after 7, 14, and 28 days.
- The preparation of roller-compacted concrete met these two aspects;
- The mix design of RCC should meet the characteristics of dry concrete with low cement.
- RCC is generally constructed via the vibration compaction method.

A. Concrete Batching and Production of RCC.

The mixing of Roller compacted concrete was carried out in accordance with ACI 211.3R-02. The batching was carried out in accordance with the mix design obtained in Table 1. The mix was designed to give 30 MPa and above and slump less than 10 mm in accordance with the specification of ACI 211.3R-02. The presence of micro silica reduced the workability drastically; hence the presence of superplasticizer was adopted. The mixing of concrete was carried out by using a mechanical batching machine in the laboratory. The cement, sand, and micro-silica were first mixed for about two minutes, and then the addition of coarse aggregate, water, and superplasticizer followed, each having an average of two minutes interval. Proper care was taken to avoid balling and bleeding of the concrete

Table 1 Summary of the Mix Proportion

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W/C	Percentage replacement (microsilica)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Microsilica (kg/m^3)	Water (kg/m^3)	Superplasticizer (% of cement)
0.35	**0%**	**371.43**	**654.72**	**1159.20**	**0**	**140.4**	
	10%	**334.29**	**654.72**	**1159.20**	**37.14**	**140.4**	**1**
	15%	**315.71**	**654.72**	**1159.20**	**55.72**	**140.4**	**1**
	20%	**297.14**	**654.72**	**1159.20**	**74.29**	**140.4**	**1**
0.40	**0%**	**312.50**	**768.24**	**1159.20**	**0**	**135.9**	
	10%	**281.25**	**768.24**	**1159.20**	**31.25**	**135.9**	**1**
	15%	**265.63**	**768.24**	**1159.20**	**46.88**	**135.9**	**1**
	20%	**250.00**	**768.24**	**1159.20**	**62.50**	**135.9**	**1**
0.45	**0%**	**266.70**	**910.80**	**1159.20**	**0**	**132**	
	10%	**239.30**	**910.80**	**1159.20**	**26.70**	**132**	**1**
	15%	**226.69**	**910.80**	**1159.20**	**40.01**	**132**	**1**
	20%	**213.30**	**910.80**	**1159.20**	**53.40**	**132**	**1**
0.50	**0%**	**230.00**	**958.00**	**1159.20**	**0**	**127**	
	10%	**207.00**	**958.00**	**1159.20**	**23.00**	**127**	**1**
	15%	**195.50**	**958.00**	**1159.20**	**34.50**	**127**	**1**
	20%	**184.00**	**958.00**	**1159.20**	**46.00**	**127**	**1**

V. RESULTS AND DISCUSSION

Fresh state

A. Density of Concrete

Densities of the concrete for the different mixes appear in Table 2 show the average values of densities recorded for the different mixes at varying water-cement ratios and percentage volume replacement of cement with microsilica.

Table 2 Density Result for Samples

Water-cement ratio	% Replacement with Microsilica	Density (kg/m^3)		
		7 Days	**14 Days**	**28 Days**
0.35	0	2390	2410	2370
	10	2476	2510	2397
	15	2479	2430	2370
	20	2410	2439	2280
0.40	0	2430	2429	2430
	10	2419	2446	2570
	15	2499	2568	2427
	20	2360	2360	2360
0.45	0	2429	2400	2520

	10	2420	2469	2479
	15	2459	2509	2439
	20	2400	2499	2479
0.50	0	2499	2469	2479
	10	2331	2370	2360
	15	2419	2449	2399
	20	2549	2479	2490

Figure 1 shows that at early age curing, the peak density of 2549 kg/m^3 is observed at 20% replacement of cement with Microsilica and 0.50 water-cement ratio. This resulted from the introduction of more fine particles of cementitious materials, which led to a significant reduction in pore volume in the concrete, therefore, densified the concrete. It is pertinent to state that at 10% microsilica content, the lowest value of density was obtained, which is 2280 kg/m^3

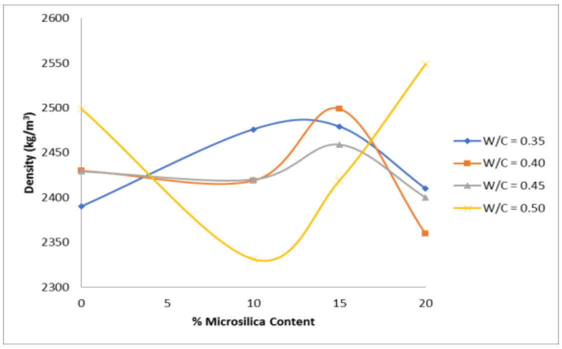

Figure 1 Density of Concrete after 7 Days Curing

Figure 2 shows the peak density of 2568 kg/m^3 at 15% Microsilica content and 0.40 water-cement ratio. This is due to lower water content and a high amount of cementitious material, which reduced the concrete's microstructural pores.

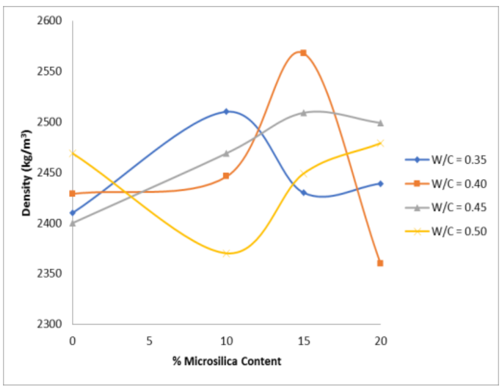

Figure 2 Density of Concrete after 14 Days Curing

Figure 3 shows the peak density of 2570 kg/m^3 is observed for 0.40 water-cement ratio and 10% replacement of cement with Microsilica. Figure 4.4 shows that at a lower water-cement ratio (at lower water content), the density of the concrete increases with the incorporation of microsilica and drops sharply beyond 10% Microsilica content

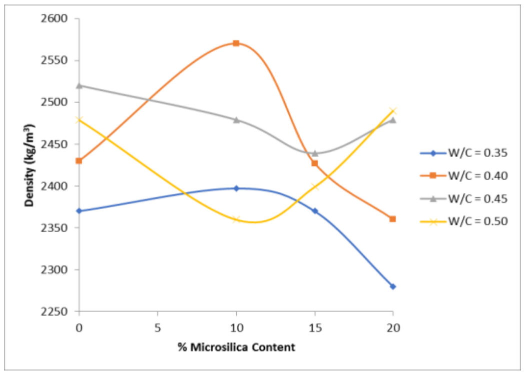

Figure 3 Density of Concrete after 14 Days Curing

B. Slump Flow

it is observed that the slump values range between 0 – 8mm for mixtures with partial replacement of microsilica, which satisfies the criteria for a zero slump concrete according to ACI 211.3R-02. We can also observe that the maximum slump was obtained at the control mix for each water-cement ratio. It is also observed that the presence of microsilica causes the mix to become drier.

Table 3 Slump values for various water-cement ratios of the fresh RCC.

Water-cement ratio	% Microsilica Content	Slump values (mm)
0.35	0	5
	10	0
	15	0
	20	0
0.40	0	8
	10	5
	15	0
	20	0
0.45	0	8
	10	5
	15	0
	20	0
0.50	0	8
	10	6
	15	0
	20	0

C. Compressive Strength

it is seen that the maximum compressive strength of 64.89MPa is recorded for the mixture with 15% incorporation of microsilica and 0.35 water-cement ratio. This is due to high cement content and low water content, making available more fine particles and binders to reduce the concrete's pores. From the result, it is observed that the compressive strength of the concrete increases on increasing amount microsilica and cement content. Also, at the same water-cement ratios and percentage incorporation of microsilica, the concrete's compressive strength increases as the curing age of the concrete.

Table 4 Compressive Strength Result

Water-cement ratio	% Replacement with Microsilica	Compressive Strength (MPa)		
		7 Days	14 Days	28 Days
0.35	0	34.96	43.55	44.15
	10	41.78	62.07	63.41
	15	53.33	59.55	64.89
	20	44.74	49.19	61.63
0.40	0	35.55	39.41	40.28
	10	42.96	45.18	45.92
	15	36.28	48.00	41.18
	20	36.44	39.41	45.63
0.45	0	30.37	35.41	33.78
	10	40.00	48.67	48.89
	15	31.70	40.89	43.41
	20	36.74	44.74	47.41
0.50	0	30.22	36.00	25.83
	10	36.30	39.18	29.02
	15	32.15	40.44	31.81
	20	34.74	37.44	27.82

Figure 4 shows the peak 7 days compressive strength of 53.33 MPa was observed for 0.35 water-cement ratio and 15% Microsilica content. The highest increment in strength with the incorporation of Microsilica is 52.55% at 0.35 water-cement ratio and 15% Microsilica content. Strength increment of 19.51% and 27.97% was observed for 10 and 20% incorporation of Microsilica. At 0.40 water-cement ratio, 20.84%, 2.05% and 2.5% increment were observed for 10, 15 and 20% incorporation of Microsilica respectively. At 0.45 water-cement ratio, strength increments of 31.7%, 4.38%, and 20.97% were observed to replace cement with Microsilica at 10%, 15%, and 20%, respectively. Also, at 0.50 water-cement ratio, -2.45%, 32.86% and 48.05% strength increment were observed for 10%, 15% and 20% Microsilica content respectively. Therefore, the most significant effect of Microsilica is observed for the water-cement ratio of 0.35.

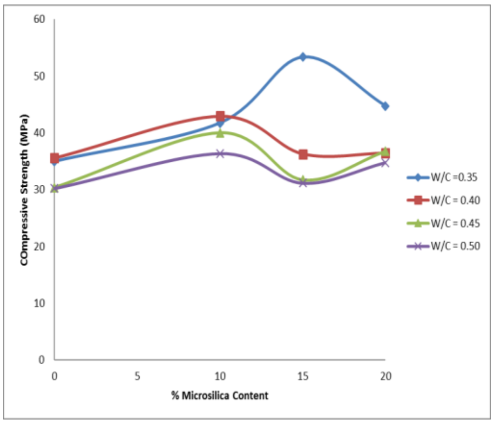

Figure 4 Compressive Strength for 7 days

Figure 5 shows that at 0.35 water-cement ratio, the highest increment of strength, 42.53%, is observed for 10% Microsilica content. Similarly, 36.74% and 12.95% increments were observed for 15% and 20% Microsilica content, respectively. At 0.40 water-cement ratio, increments of 14.64%, 21.79% and 0% were observed for 10%, 15% and 20% Microsilica content respectively. At 0.45 water-cement ratio, 37.45%, 15.48% and 26.35% were the increment of strength observed at 10%, 15% and 20% Microsilica content respectively. Similarly, at 0.50 water-cement ratio, -7.83%, 34.56% and 34.56% increment in strength were observed for 10%, 15% and 20% Microsilica content respectively. Hence, the most significant effect of Microsilica is observed for a 0.35 water-cement ratio.

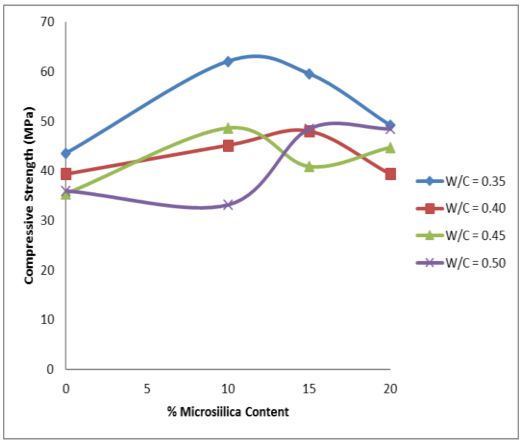

Figure 5 Compressive Strength for 14 days

Figure 5 shows that at 0.35 water-cement ratio, the highest increment of strength, 46.98%, is observed for 15% Microsilica content. Similarly, 43.62% and 39.59% increments were observed for 10% and 20% Microsilica content, respectively. At 0.40 water-cement ratio, increments of 14%, 2.23% and 13.28% were observed for 10%, 15% and 20% Microsilica content respectively. At 0.45 water-cement ratio, 44.73%, 28.51% and 40.34% were the increment of strength observed at 10%, 15% and 20% Microsilica content respectively. Similarly, at 0.50 water-cement ratio, 12.35%, 112.19% and 100.62% increment in strength were observed for 10%, 15% and 20% Microsilica content respectively. The most significant effect of Microsilica on strength is observed for the water-cement ratio of 0.50. From the results obtained and simulated above, the most significant effect of Microsilica is observed at a water-cement ratio of 0.35. That is to say, at higher cement content, the strength of the concrete improves greatly, especially at early ages.

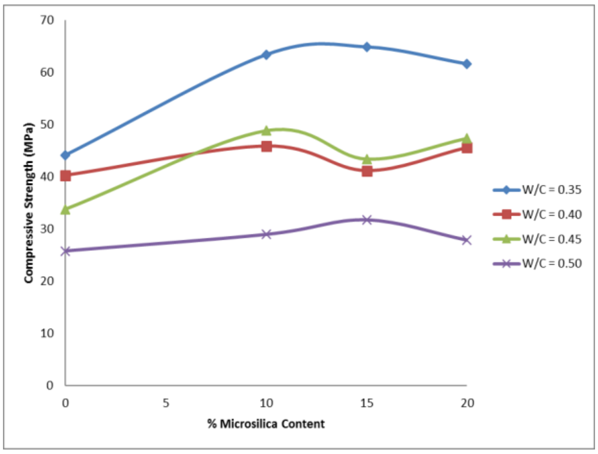

Figure 6 Compressive Strength for 28 days

VI. FINDINGS AND CONCLUSION

The aim of this research was to investigate the fresh and hardened state properties of zero-slump roller-compacted concrete incorporated with microsilica as a partial substitute for ordinary Portland cement. The compressive strength was measured at 7, 14, and 28 days of water curing. The following salient conclusion was drawn:

- The adopted mix design (ACI 211.3R-02) provided satisfactory results for fresh and hardened state zero-slump concrete. Hence, the mix design adopted can be applied for zero concrete slump structures.
- At 15% replacement of cement with microsilica and at 0.35 water-cement ratio, the maximum value for compressive strength at 28 days strength was 64.89MPa. For other water-cement ratios, the maximum strength was observed at 15% replacement of cement with microsilica. Therefore, the optimum percentage of microsilica as a partial substitute for cementitious material in the concrete mix is 15%

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