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Optimizing Concrete Composition: Evaluating the Effects of Flaky Aggregates, Steel Slag, and Marble Powder on Performance

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Abstract

The characteristics of materials used in construction have a significant impact on the performance of the resulting concrete. Coarse and fine aggregates are crucial components in cement concrete, influencing its strength and workability. Research has shown that the type of aggregate used, whether coarse or fine, plays a critical role in these properties. In this study, we examine the combined effect of flaky aggregates and steel slag as partial replacements for coarse aggregates on concrete performance, with marble powder replacing sand. Flaky aggregates and steel slag were incorporated at 10%, 15%, 20%, 25%, and 30% of the coarse aggregate content. Two concrete mixes were prepared with sand-to-marble powder ratios of 1:1 and 1:0.5. The findings indicate that increasing the proportion of flaky aggregates reduces both the strength and workability of the concrete. Conversely, adding steel slag enhances concrete strength but decreases workability. Using both materials together boosts early strength but results in lower overall strength gains and reduced workability.

Keywords: Aggregate replacement, cement concrete, coarse aggregates, concrete performance, flaky aggregates

INTRODUCTION

Concrete is a blend of cement, coarse aggregates, fine aggregates, and water. Its versatility is its strength, as it can be tailored to withstand harsh conditions while adopting the most inspirational shapes. Scientists and engineers are continually pushing its boundaries by incorporating innovative admixtures and various waste alternative materials (WAMs) [1–5].

Historically, WAMs included naturally occurring materials like diatomaceous earth or volcanic ash, used by the Romans and Greeks to create engineering marvels such as aqueducts and the Coliseum. Today, most concrete mixtures include alternative cementitious materials (ACMs), primarily industrial by-products or waste materials.

Economically, for a given water-cement ratio, rounded aggregates are preferred over angular ones because flat particles negatively impact concrete's workability, cement requirements, strength, and durability. High contents of flaky aggregates result in lower-quality concrete [6–8].

The size and type of aggregates used, whether coarse or fine, are crucial as they significantly affect concrete's strength and workability. The texture of

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coarse aggregates is equally important. Some researchers oppose the use of round aggregates due to poor bonding with cement, while angular aggregates are favored in certain situations:

- Angular aggregates provide better interlocking, enhancing the performance of concrete used in roads and pavements.
- The rough surface of angular aggregates offers a greater surface area compared to smooth, rounded aggregates of the same quantity, resulting in stronger bonds.

The bond between cement paste and aggregates is influenced by various complex factors beyond physical and mechanical properties. Research has shown that smoother surfaces reduce contact area, leading to lower bonding strength compared to rough particles of the same size (Figure 1) [9–11].

Figure 1. Aggregates (coarse and fine).

OBJECTIVES

The study aims to evaluate the effects of replacing coarse aggregates with flaky aggregates and steel slag on concrete performance. It seeks to determine how varying proportions of these materials influence concrete strength and workability. Additionally, the study will assess the impact of incorporating marble powder as a partial replacement for sand in concrete mixes containing flaky aggregates and steel slag. By optimizing the sand-to-marble powder ratio in the mixes, the research aims to achieve the desired concrete properties. Furthermore, the study will analyze the combined effects of flaky aggregates and steel slag on early concrete strength development. Through comprehensive experimentation and analysis, the study aims to provide insights into improving concrete composition for enhanced performance in construction applications.

MATERIAL

Flaky Aggregates

Flaky aggregates are thin and flat particles that can negatively affect concrete’s properties. They reduce workability and require more cement, increasing costs. These aggregates also weaken the concrete's strength and durability, making it prone to breaking under load. Proper grading and blending with other aggregates can help mitigate these issues, but the use of flaky aggregates should be minimized to ensure high-quality concrete.

Marble Powder

During marble cutting, about 20% of the material becomes waste powder. The high global demand for natural sand in concrete, especially in rapidly developing countries, has led to supply shortages. Replacing some natural sand with marble powder is a cost-effective solution. Marble powder, a waste product, can enhance the properties of fresh and hardened concrete while addressing solid waste disposal issues.

Steel Slag

Steel slag, a by-product of steel manufacturing, consists of silicates and oxides. Annually, fifty million tons of LD slag are produced globally. For use in cement, its hydraulic properties and chemical composition are crucial, with higher alkalinity indicating better hydraulic properties. Studies show that steel slag can be used in construction if it has high crushing strength, climatic resistance, and wear strength. However, its free CaO and MgO content can cause volume instability, making it generally unsuitable for Portland cement concrete (Tables 1 and 2).

Table 1. Weight of ingredients (kg) in prepared concrete mixes.

S.N.	Concrete Mix	Cement	% Replacement of Coarse Aggregates	w/c Ratio	Fine Aggregates		Coarse Aggregates		
					Sand	*Marble Powder*	*Flaky*	*Steel Slag*	*Normal*
Sand/Marble Powder (1:1)									
1	Cx1	1	0%	0.45	0.81	0.81	0	0	3
2	Cx2	1	0%	0.5	0.81	0.81	0	0	3
3	Cx3	1	0%	0.55	0.81	0.81	0	0	3
4	Cx4	1	5%	0.45	0.81	0.81	0.17	0	3
5	Cx5	1	5%	0.5	0.81	0.81	0.17	0	3
6	Cx6	1	5%	0.55	0.81	0.81	0.17	0	3
7	Cx7	1	10%	0.45	0.81	0.81	0.34	0	3
8	Cx8	1	10%	0.5	0.81	0.81	0.34	0	3
9	Cx9	1	10%	0.55	0.81	0.81	0.34	0	3
10	Cx10	1	15%	0.45	0.81	0.81	0.51	0	3
11	Cx11	1	15%	0.5	0.81	0.81	0.51	0	3
12	Cx12	1	15%	0.55	0.81	0.81	0.51	0	3
13	Cx13	1	20%	0.45	0.81	0.81	0.68	0	3
14	Cx14	1	20%	0.5	0.81	0.81	0.68	0	3
15	Cx15	1	20%	0.55	0.81	0.81	0.68	0	3
16	Cx16	1	25%	0.45	0.81	0.81	0.85	0	3
17	Cx17	1	25%	0.5	0.81	0.81	0.85	0	3
18	Cx18	1	25%	0.55	0.81	0.81	0.85	0	3
19	Cx19	1	30%	0.45	0.81	0.81	1.02	0	2
20	Cx20	1	30%	0.5	0.81	0.81	1.02	0	2
21	Cx21	1	30%	0.55	0.81	0.81	1.02	0	2
22	Cx22	1	5%	0.45	0.81	0.81	0	0	3
23	Cx23	1	5%	0.5	0.81	0.81	0	0	3
24	Cx24	1	5%	0.55	0.81	0.81	0	0	3
25	Cx25	1	10%	0.45	0.81	0.81	0	0	3
26	Cx26	1	10%	0.5	0.81	0.81	0	0	3
27	Cx27	1	10%	0.55	0.81	0.81	0	0	3
28	Cx28	1	15%	0.45	0.81	0.81	0	1	3
29	Cx29	1	15%	0.5	0.81	0.81	0	1	3
30	Cx30	1	15%	0.55	0.81	0.81	0	1	3
31	Cx31	1	20%	0.45	0.81	0.81	0	1	3
32	Cx32	1	20%	0.5	0.81	0.81	0	1	3
33	Cx33	1	20%	0.55	0.81	0.81	0	1	3
34	Cx34	1	25%	0.45	0.81	0.81	0	1	3
35	Cx35	1	25%	0.5	0.81	0.81	0	1	3
36	Cx36	1	25%	0.55	0.81	0.81	0	1	3
37	Cx37	1	30%	0.45	0.81	0.81	0	1	2
38	Cx38	1	30%	0.5	0.81	0.81	0	1	2

S.N.	Concrete Mix	Cement	% Replacement of Coarse Aggregates	w/c Ratio	Fine Aggregates		Coarse Aggregates		
					Sand	***Marble Powder***	***Flaky***	***Steel Slag***	***Normal***
39	Cx39	1	30%	0.55	0.81	0.81	0	1	2
40	Cx40	1	5%	0.45	0.81	0.81	0.09	0	3
41	Cx41	1	5%	0.5	0.81	0.81	0.09	0	3
42	Cx42	1	5%	0.55	0.81	0.81	0.09	0	3
43	Cx43	1	10%	0.45	0.81	0.81	0.17	0	3
44	Cx44	1	10%	0.5	0.81	0.81	0.17	0	3
45	Cx45	1	10%	0.55	0.81	0.81	0.17	0	3
46	Cx46	1	15%	0.45	0.81	0.81	0.26	0	3
47	Cx47	1	15%	0.5	0.81	0.81	0.26	0	3
48	Cx48	1	15%	0.55	0.81	0.81	0.26	0	3
49	Cx49	1	20%	0.45	0.81	0.81	0.34	0	3
50	Cx50	1	20%	0.5	0.81	0.81	0.34	0	3
51	Cx51	1	20%	0.55	0.81	0.81	0.34	0	3
52	Cx52	1	25%	0.45	0.81	0.81	0.43	0	3
53	Cx53	1	25%	0.5	0.81	0.81	0.43	0	3
54	Cx54	1	25%	0.55	0.81	0.81	0.43	0	3
55	Cx55	1	30%	0.45	0.81	0.81	0.51	1	2
56	Cx56	1	30%	0.5	0.81	0.81	0.51	1	2
57	Cx57	1	30%	0.55	0.81	0.81	0.51	1	2
Sand/Marble Powder (1:0.5)									
58	Cy1	1	0%	0.45	1.08	0.54	0	0	3
59	Cy2	1	0%	0.5	1.08	0.54	0	0	3
60	Cy3	1	0%	0.55	1.08	0.54	0	0	3
61	Cy4	1	5%	0.45	1.08	0.54	0.17	0	3
62	Cy5	1	5%	0.5	1.08	0.54	0.17	0	3
63	Cy6	1	5%	0.55	1.08	0.54	0.17	0	3
64	Cy7	1	10%	0.45	1.08	0.54	0.34	0	3
65	Cy8	1	10%	0.5	1.08	0.54	0.34	0	3
66	Cy9	1	10%	0.55	1.08	0.54	0.34	0	3
67	Cy10	1	15%	0.45	1.08	0.54	0.51	0	3
68	Cy11	1	15%	0.5	1.08	0.54	0.51	0	3
69	Cy12	1	15%	0.55	1.08	0.54	0.51	0	3
70	Cy13	1	20%	0.45	1.08	0.54	0.68	0	3
71	Cy14	1	20%	0.5	1.08	0.54	0.68	0	3
72	Cy15	1	20%	0.55	1.08	0.54	0.68	0	3
73	Cy16	1	25%	0.45	1.08	0.54	0.85	0	3
74	Cy17	1	25%	0.5	1.08	0.54	0.85	0	3
75	Cy18	1	25%	0.55	1.08	0.54	0.85	0	3
76	Cy19	1	30%	0.45	1.08	0.54	1.02	0	2
77	Cy20	1	30%	0.5	1.08	0.54	1.02	0	2
78	Cy21	1	30%	0.55	1.08	0.54	1.02	0	2
79	Cy22	1	5%	0.45	1.08	0.54	0	0	3
80	Cy23	1	5%	0.5	1.08	0.54	0	0	3
81	Cy24	1	5%	0.55	1.08	0.54	0	0	3

S.N.	Concrete Mix	Cement	% Replacement of Coarse Aggregates	w/c Ratio	Fine Aggregates		Coarse Aggregates		
					Sand	*Marble Powder*	*Flaky*	*Steel Slag*	*Normal*
82	Cy25	1	10%	0.45	1.08	0.54	0	0	3
83	Cy26	1	10%	0.5	1.08	0.54	0	0	3
84	Cy27	1	10%	0.55	1.08	0.54	0	0	3
85	Cy28	1	15%	0.45	1.08	0.54	0	1	3
86	Cy29	1	15%	0.5	1.08	0.54	0	1	3
87	Cy30	1	15%	0.55	1.08	0.54	0	1	3
88	Cy31	1	20%	0.45	1.08	0.54	0	1	3
89	Cy32	1	20%	0.5	1.08	0.54	0	1	3
90	Cy33	1	20%	0.55	1.08	0.54	0	1	3
91	Cy34	1	25%	0.45	1.08	0.54	0	1	3
92	Cy35	1	25%	0.5	1.08	0.54	0	1	3
93	Cy36	1	25%	0.55	1.08	0.54	0	1	3
94	Cy37	1	30%	0.45	1.08	0.54	0	1	2
95	Cy38	1	30%	0.5	1.08	0.54	0	1	2
96	Cy39	1	30%	0.55	1.08	0.54	0	1	2
97	Cy40	1	5%	0.45	1.08	0.54	0.09	0	3
98	Cy41	1	5%	0.5	1.08	0.54	0.09	0	3
99	Cy42	1	5%	0.55	1.08	0.54	0.09	0	3
100	Cy43	1	10%	0.45	1.08	0.54	0.17	0	3
101	Cy44	1	10%	0.5	1.08	0.54	0.17	0	3
102	Cy45	1	10%	0.55	1.08	0.54	0.17	0	3
103	Cy46	1	15%	0.45	1.08	0.54	0.26	0	3
104	Cy47	1	15%	0.5	1.08	0.54	0.26	0	3
105	Cy48	1	15%	0.55	1.08	0.54	0.26	0	3
106	Cy49	1	20%	0.45	1.08	0.54	0.34	0	3
107	Cy50	1	20%	0.5	1.08	0.54	0.34	0	3
108	Cy51	1	20%	0.55	1.08	0.54	0.34	0	3
109	Cy52	1	25%	0.45	1.08	0.54	0.43	0	3
110	Cy53	1	25%	0.5	1.08	0.54	0.43	0	3
111	Cy54	1	25%	0.55	1.08	0.54	0.43	0	3
112	Cy55	1	30%	0.45	1.08	0.54	0.51	1	2
113	Cy56	1	30%	0.5	1.08	0.54	0.51	1	2
114	Cy57	1	30%	0.55	1.08	0.54	0.51	1	2

Table 2. Results of compressive strength and slump cone tests.

S.N.	Concrete Mix	Compressive Strength	Slump Value in (mm)
1	Cx1	19.2	97
2	Cx2	19. 4	95
3	Cx3	19.9	94
4	Cx4	18.6	93
5	Cx5	18.9	91
6	Cx6	19.4	88
7	Cx7	18.4	89
8	Cx8	18.7	87

S.N.	Concrete Mix	Compressive Strength	Slump Value in (mm)
9	Cx9	19.3	84
10	Cx10	18.1	86
11	Cx11	18.7	83
12	Cx12	19.1	82
13	Cx13	17.9	82
14	Cx14	18.3	80
15	Cx15	18.6	77
16	Cx16	17.6	79
17	Cx17	18.2	77
18	Cx18	18.5	74
19	Cx19	17.1	76
20	Cx20	17.8	73
21	Cx21	18	72
22	Cx22	19.6	92
23	Cx23	19.8	90
24	Cx24	20.3	89
25	Cx25	19.8	91
26	Cx26	20.1	88
27	Cx27	20.7	84
28	Cx28	19.9	86
29	Cx29	20.4	83
30	Cx30	20.8	81
31	Cx31	20.1	82
32	Cx32	20.7	77
33	Cx33	21.1	74
34	Cx34	20.3	80
35	Cx35	20.8	76
36	Cx36	21.3	74
37	Cx37	20.7	79
38	Cx38	21.2	75
39	Cx39	21.5	72
40	Cx40	19.2	91
41	Cx41	19.4	88
42	Cx42	19.7	87
43	Cx43	19.3	89
44	Cx44	19.6	87
45	Cx45	19.8	84
46	Cx46	19.5	85
47	Cx47	19.9	82
48	Cx48	20.2	80
49	Cx49	19.9	81
50	Cx50	20.3	77
51	Cx51	20.6	74
52	Cx52	20.1	80
53	Cx53	20.4	75
54	Cx54	20.7	72
55	Cx55	20.3	77

S.N.	Concrete Mix	Compressive Strength	Slump Value in (mm)
56	Cx56	20.8	73
57	Cx57	21.1	69
58	Cy1	19.1	99
59	Cy2	19.3	96
60	Cy3	19.8	94
61	Cy4	18.4	97
62	Cy5	18.6	93
63	Cy6	19.1	91
64	Cy7	18.1	92
65	Cy8	18.4	89
66	Cy9	19.1	87
67	Cy10	18.1	89
68	Cy11	18.5	87
69	Cy12	19.8	84
70	Cy13	17.8	85
71	Cy14	18.1	82
72	Cy15	18.2	79
73	Cy16	17.3	83
74	Cy17	18	79
75	Cy18	18.2	78
76	Cy19	17	81
77	Cy20	17.4	79
78	Cy21	17.8	76
79	Cy22	19.2	95
80	Cy23	19. 4	93
81	Cy24	20	90
82	Cy25	19.5	94
83	Cy26	19.8	91
84	Cy27	20.1	88
85	Cy28	19.4	89
86	Cy29	19.9	86
87	Cy30	20.2	85
88	Cy31	19.9	88
89	Cy32	20.3	85
90	Cy33	19.1	83
91	Cy34	19.4	83
92	Cy35	20.1	80
93	Cy36	20.4	78
94	Cy37	20.7	81
95	Cy38	20.9	79
96	Cy39	21.5	76
97	Cy40	19	93
98	Cy41	19.3	89
99	Cy42	19.5	87
100	Cy43	19.1	91
101	Cy44	19.4	88
102	Cy45	19.7	87

S.N.	Concrete Mix	Compressive Strength	Slump Value in (mm)
103	Cy46	19.3	88
104	Cy47	19.4	86
105	Cy48	19.8	83
106	Cy49	19.6	86
107	Cy50	20.1	83
108	Cy51	20.4	81
109	Cy52	19.8	84
110	Cy53	20.1	81
111	Cy54	20.3	79
112	Cy55	19.7	81
113	Cy56	20.1	79
114	Cy57	20.4	76

METHODOLOGY

Following is the methodology to be adopted for performing this study (Figure 2).

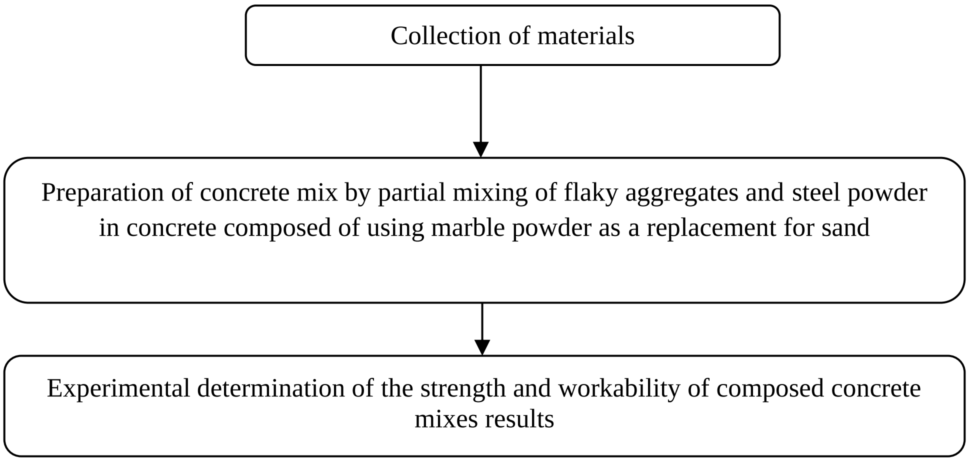

Figure 2. Methodology.

CONCLUSIONS

The compressive strength and slump values of various concrete mixes (Cx and Cy) were evaluated to assess their performance. It was observed that concrete mixes with different compositions exhibited varying compressive strengths and slump values. Generally, as the proportion of certain materials, such as flaky aggregates and steel slag, increased, the compressive strength of the concrete tended to increase, albeit with some fluctuations. Conversely, higher proportions of these materials often led to decreased workability, as evidenced by lower slump values.

Furthermore, the incorporation of marble powder as a partial replacement for sand in certain concrete mixes showed promising results. Concrete mixes containing marble powder exhibited comparable compressive strengths to those without, suggesting its potential as a sustainable alternative material in concrete production.

In conclusion, the study highlights the complex relationship between concrete composition and performance. While certain materials may enhance concrete strength, they can also adversely affect workability. However, careful adjustment of mix proportions, considering factors, such as, aggregate type and replacement ratios, can lead to the development of concrete mixes with optimized properties for specific applications. Further research and experimentation are warranted to explore the full potential of alternative materials in concrete production and to refine mix designs for enhanced performance and sustainability in the construction industry.

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