

MECHANICAL CHARACTERISTICS OF HARDENED CONCRETE WITH DIFFERENT TYPES OF CEMENT AND AGGREGATE AVAILABLE IN BANGLADESH

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ABSTRACT

This paper presents the results of an investigation into the influence of aggregate and binding material type on the mechanical properties of hardened concrete. Four different types of coarse aggregate (Brick Aggregate, Recycled Brick Aggregate, Black Stone and Shingles) and eight types of binding material have been used to perform this investigation. Aggregates were collected and prepared according to the grading requirements of ASTM C33-03. Several tests were performed for coarse aggregate, such as specific gravity, absorption capacity, unit weight, and abrasion resistance. Cylindrical concrete specimens were made with different W/C ratios and cement contents. A total of 42 other cases were considered for testing. The specimens were tested for UPV, compressive strength, stress-strain curve and Young's modulus at 28 days. The major objective of this study was to investigate the mechanical characteristics of concrete for different types of aggregate and binding materials. The study found that the UPV of concrete specimens made with brick aggregate and recycled brick aggregate was lower than that made with shingles and black stone. Black stone gave the best combination of high Young's modulus and high compressive strength to the concrete compared to others. Shingles gave the concrete the best combination of high UPV and high compressive strength compared to others. Young's modulus and compressive strength of concrete increased with a decrease in the w/c ratio for any type of aggregate and increased with an increase in cement content.

Keywords: Compressive strength, regression analysis, tensile strength, UPV, workability

INTRODUCTION

From an engineering perspective, strength performance is still the most significant characteristic of structural concrete. Research on the relationship between the mechanical properties of concrete and its composition has long been of interest [1]-[4]. The coarse aggregate, mortar, and interface properties all affect the concrete's strength. Different types of coarse aggregate with varying strength, mineralogy, shape, and texture may produce different concrete strengths for the same quality mortar. However, with the development of high-performance concrete, where the aggregate plays a more significant role, the limitations of the water/cement ratio (W/C) concept are becoming more evident [5].

The strength of the concrete may be increased by using a coarse aggregate with a higher strength and

appropriate textural and mineralogical properties [6]. Previous reports have examined the impact of certain coarse aggregate characteristics on high-strength concretes' strength and elastic properties [7]. Concrete properties can be directly impacted by aggregate strength, granulometry, grain shape, surface structure, and hazardous materials [8].

The strength of the mortar and the bond at the interface may be comparable to the strength of the coarse aggregate in high-strength concrete, which is typically manufactured with a W/C less than 0.4 [9]. Utilising the coarse aggregate particles' full strength potential might be feasible in this situation. Concurrently, as concrete's strength increases, so does its brittleness, thereby restricting its application. Therefore, employing

a coarse aggregate with reduced brittleness, increased strength, and the right texture and mineralogical properties could enhance the concrete's mechanical qualities [10].

Structures made of reinforced concrete must be able to tolerate extreme exposure in maritime environments and other similar settings. As a result, in addition to workability, the mixed design procedures need to be revised to include mechanical properties as the primary criterion [11]. Local porosity rises, and overall strength falls as the aggregate of larger sizes in the mix increases. Concrete's strength increases, pore structure improves, and the mix's average aggregate size is reduced [12]. The majority of the significant attributes of hardened concrete are associated with the quantity and nature of different kinds of pores in the concrete's aggregate and cement paste [13]. For instance, the quantity, type, and size of pores in concrete directly affect or control its engineering qualities, which include strength, durability, shrinkage, and permeability. While pore volume, size, and continuity impact concrete permeability, the overall volume of pores determines the material's strength and elasticity. Capillary voids smaller than 50 micrometres, known as micropores, are more closely associated with drying shrinkage and creep, while voids larger than 50 micrometres, known as macro pores, are thought to be harmful to strength and impermeability [14]. Due to their interactions with the components of concrete and the pore water, which can, directly and indirectly, change the integrity of concrete and cause structures to deteriorate, the movement of gases, liquids, and ions through concrete is crucial [15]. The primary causes of this deterioration in reinforced concrete are chemical attacks, freeze-thaw attacks, and reinforcement corrosion. Due to this kind of deterioration, the cost of repairing structures has increased recently [15]. So, durable concrete can be produced by resorting to mixes with a low average aggregate size.

The construction industry's high raw material consumption rates rank among the primary causes of pollution, environmental harm to the planet, and the depletion of natural and mineral resources. Thus, using recycled aggregate could be one of the significant steps toward building a sustainable structure [16]. The major difference between natural aggregate and recycled coarse aggregate (RCA) is the adhered mortar at the surface of the RCA. It is a porous material, exhibiting lower

bulk density and saturated surface dry density, 1290–1470 kg/m³ and 2310–2620 kg/m³ respectively [17]. The bulk density of lightweight aggregates and that of RCAs are similar. 10% more water is needed in the concrete when using RCA in place of natural coarse aggregate to produce the same slump. It is discovered that the concrete's compressive strength and RCA content are inversely correlated. However, this effect is minimal at a low replacement level of less than 20% [18]. Few researchers could suggest appropriate mix design techniques for the RCA. They seldom describe and analyse how well a particular mix design method works for the RCA. Majority of them have only displayed the experimental program's mix proportions for concrete mixtures. On the other hand, some researchers have suggested that when the RCA is designed using the conventional method, similar to regular concrete, it can achieve a higher target strength by making adjustments like lowering the water-cement ratio [19]. Nonetheless, the necessary quality for the concrete can be guaranteed by modifying the replacement ratio and estimating the quality decline by the relative quality values [20].

Different aggregates were used in the concrete mix with varying amounts of cement to achieve a balance that maximises the concrete's compressive strength, workability, and density. The major objective of the study was to achieve a balanced mix design of concrete that maximises the concrete's compressive strength, tensile strength and Young's modulus, as well as the workability and density of the concrete for different types of aggregate and binding materials.

MATERIALS AND METHODS

The properties of concrete can be changed with the change of aggregate type, water-cement ratio, sand-aggregate ratio and cement content. Compressive strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity (UPV), concrete workability, and air percentage were studied in our research. There were four types of coarse aggregate: brick aggregate, recycled brick aggregate, black stone and shingles. Each aggregate had 13 cases with the variation of binding materials (OPC, CEM Type II B-M, CEM Type II B-S, CEM Type II B-S (40% OPC – 60% Slag), 40% OPC – 60% Slag(CEM-III A), 80% OPC – 20% Slag (CEM II/A-S), 70% OPC – 30% Slag (CEM II/B-S),

30% OPC –70% Slag(CEM-IIIB), 15% OPC – 85% Slag (CEM-IIIC), W/C ratio (0.45, 0.50) and cement content (340 kg/m³, 400 kg/m³). A total of 42 cases were studied, and 546 specimens were made.

We used brick aggregate, recycled brick aggregate, black stone and shingles as coarse aggregate. We used Sylhet sand as fine aggregate, which is commonly used in our country for construction work. Coarse aggregates were collected from the local markets. For the ASTM requirements, various tests like specific gravity, unit weight test, absorption test, Los Angeles Abrasion test and sieve analysis were done for coarse aggregates. The Los Angeles abrasion test was done according to

ASTM C131, the specific gravity and absorption tests were performed according to ASTM C127, and the unit weight test was according to ASTM C29. Fine aggregates were collected from the local markets. For the ASTM requirements, various tests like specific gravity, unit weight test, absorption test, Los Angeles abrasion test and sieve analysis were done for fine aggregate. The Fineness Modulus test was done according to ASTM C136, specific gravity and absorption tests were done according to ASTM C127 and the unit weight test was done according to ASTM C29. The Fineness Modulus of Fine Aggregate was 2.58. Coarse aggregates used in this study are shown in Figure 1, and the overall results of aggregate testing are in Table 1.



a. Recycled brick aggregates



b. Brick aggregates



c. Shingles



d. Black stones

Figure 1 Coarse aggregates

Table 1 Overall results of materials testing

Type of Aggregate		Specific gravity	% Absorption	Unit weight (oven dry) kg/m ³	Unit weight (SSD) kg/m ³	% Wear
Fine Aggregate	Sand	2.46	3%	1528	1574	
Coarse Aggregate	Black stone	2.82	1.5%	1528	1551	14%
	Shingles	2.65	1.1%	1656	1674	27%
	Recycled aggregate	2.14	22.4%	825	1004	43%
	Brick chips	1.98	10.32%	892	1076	39.5%

For casting we used Ordinary Portland Cement (OPC), CEM Type II B-M, CEM Type II B-S, CEM Type II B-S(40% OPC – 60% Slag), 40% OPC – 60% Slag(CEM-III A), 80% OPC – 20% Slag(CEM II/A-S), 70% OPC – 30% Slag(CEM II/B-S), 30% OPC – 70% Slag(CEM-IIIB), 15% OPC – 85% Slag(CEM-IIIC). The cement content for each test procedure was weighted very carefully. The workability of the concrete was tested by taking the slump value and void test. Standard procedure was adopted from ASTM C143 during the slump test procedure. Percentage Air Entrancement was calculated following ASTM C231 & AASHTO T-152. The water we used in the concrete casting and for the curing of the concrete specimen was normal tap water with a unit weight of 1000 kg/m³.

The cylindrical mould was 4 inches in diameter and 8 inches in height. The cylinder was prepared very carefully. They were tightened, and the inside surface was polished with lubricant; grease was used for lubrication. Materials were weighted carefully as mix design and coarse aggregates were soaked for 24 hours before casting. Before casting, the aggregates were prepared for SSD conditions. ASTM C31 was followed as standard procedure for casting concrete specimens. We used a mixture machine to cast cylindrical specimens. Here, the mixing procedure differed slightly from the normal procedure followed in Bangladesh and compacted and scaled along the perimeter. Two layers compacted each specimen, and 25 blows per ASTM specification were given for compaction in each layer. After compaction, scaling and hammering were correctly done to avoid air voids and to get a smooth surface of the specimens. Specimens were covered for the first 24 hours with moist cloth and polythene to prevent water evaporation. After 24 hours, the specimens were de-moulded and placed in the water tub for final curing. After demolding, the concrete cylinders were completely immersed in water in the curing tub until the day of testing (28 days), according to ASTM C31. Different mix designs are shown in Table 2.

UPV test was done on the 28th day. UPV was measured on unloaded wet specimens using the Portable Ultrasonic Non-Destructive Digital Indicating Tester (PUNDIT) according to ASTM C597-02. The compressive strength of concrete was measured on the 28th day using a compressive strength testing machine according to ASTM C39. Before the destructive tests progressed,

Table 2 Mix Design

Case No.	Type of Cement	Type of Aggregate	W/C	s/a	Cement Content		
1	OPC	Brick Aggregate	0.45	0.44	340		
2			0.50				
3			0.45				
4			0.50				
5			0.45				
6		Black Stone	Recycled Brick Aggregate			0.50	
7						0.45	
8						0.50	
9						0.45	
10						0.50	
11			0.45				
12			0.50				
13			0.45				
14	0.50						
15	0.45						
16	0.50						
17	CEM Type II B-M	Brick Aggregate	0.45	400			
18			0.50				
19			0.45				
20			0.50				
21			0.45				
22		0.50					
23		0.45					
24		0.50					
25		CEM Type II B-SL	Brick Aggregate		0.45		
26					0.50		
27					0.45		
28					0.50		
29	0.45						
30	0.50						
31	0.45						
32	0.50						
33	40% OPC – 60% Slag(CEM-III A)		Brick Aggregate	0.45	400		
34				0.50			
35		0.45					
36		0.50					
37		0.45					
38		0.50					
39		80% OPC – 20% Slag(CEM II/A-S)	Black Stone	0.45			
40				70% OPC – 30% Slag(CEM II/B-S)		0.45	
41						30% OPC – 70% Slag(CEM-IIIB)	0.45
42							15% OPC – 85% Slag(CEM-IIIC)
	0.45						
	0.45						

capping was done properly to get a smooth surface for concentrated loading. The strain of concrete specimens was measured by a strain measurement setup of length 100 mm with two dial gauges. The stress of concrete at strain level 0.0005 was used to determine Young's modulus of concrete. The split tensile strength of concrete was tested on the 28th day, according to ASTM C496. The Universal Testing machine was used to perform this test. The failure surfaces of broken concrete specimens were also checked carefully after crushing the concrete cylinders to corroborate the findings of this investigation.

RESULTS AND DISCUSSION

This section discusses the results of various tests performed on concrete cylinders. The slump value, percentage air entrapped, compressive strength,

tensile strength, Young's modulus, UPV, and unit weight were calculated for each of the 42 mix designs. Finally, some relationships are proposed between the different mixing parameters and the materials used. These relationships can be used to measure the strength of concrete accurately. The various aspects of these relationships, as well as their level of accuracy, are discussed at the end of this chapter. Tables 3 to 6 display the overall results for slump value, percentage air entrapped, compressive strength, tensile strength, Young's modulus, UPV, and unit weight for all 42 mix designs.

Tables 3 to 6 show that compressive strength, tensile strength and Young's modulus were maximum for Case No. 11, where OPC was used as binder and black stone was used as coarse aggregate. Cement content was 400 kg/cu.m., w/c ratio was 0.45 and s/a ratio was 0.44.

Table 3 Results for OPC binder, cement content 340 kg/cu. m and s/a ratio 0.44

Case No	Type of aggregate	W/C	Slump value (mm)	% entrapped air	Compressive strength-28 days (MPa)	ft 28 days (MPa)	Young's Mod 28 days (MPa)	UPV (m/s)	Unit weight (kg/cu.m)
1	Brick Aggregate	0.45	2.50	2.20	28.7	2.8	19054	3826	2135
2	Brick Aggregate	0.50	7.70	2.20	28.2	2.6	14332	3756	2129
5	Recycled Brick Aggregate	0.45	1.00	2.40	26.2	2.7	21237	3945	2174
6	Recycled Brick Aggregate	0.50	5.75	1.90	24.1	2.4	16410	3940	2141
9	Black Stone	0.45	1.05	2.50	32.4	3.0	33733	4690	2419
10	Black Stone	0.50	16.80	2.10	27.4	2.6	28349	4673	2476
13	Shingles	0.45	3.50	2.45	30.3	2.9	29525	4509	2368
14	Shingles	0.50	18.90	1.95	28.6	2.6	25787	4489	2359

Table 4 Result for OPC binder, cement content 400 kg/cu.m and s/a ratio 0.44

Case No	Type of aggregate	W/C	Slump value (mm)	% entrapped air	Compressive strength-28 days (MPa)	ft 28 days (MPa)	Young's Mod 28 days (MPa)	UPV (m/s)	Unit weight (kg/cu.m)
3	Brick Aggregate	0.45	3.50	2.00	32.9	3.3	20273	3876	2140
4	Brick Aggregate	0.50	14.25	1.90	30.4	2.8	19382	3835	2135
7	Recycled Brick Aggregate	0.45	3.20	2.10	30.0	3.1	22086	3884	2154
8	Recycled Brick Aggregate	0.50	13.29	2.00	27.5	2.7	21351	3957	2176
11	Black Stone	0.45	7.30	1.70	35.1	3.5	37027	4709	2359
12	Black Stone	0.50	17.25	1.90	33.5	3.0	31749	4704	2385
15	Shingles	0.45	19.15	2.00	34.4	3.5	29762	4839	2380
16	Shingles	0.50	23.00	2.00	31.7	2.8	27231	4748	2362

Table 5 Result for CEM type-II BM binder, cement content 400 kg/cu.m and s/a ratio 0.44

Case No	Type of aggregate	W/C	Slump value (mm)	% entrapped air	Compressive strength-28 days (MPa)	ft 28 days (MPa)	Young's Mod 28 days (MPa)	UPV (m/s)	Unit weight (kg/cu.m)
17	Brick Aggregate	0.45	9.39	1.80	26.1	2.7	16743	3913	2111
18	Brick Aggregate	0.50	18.37	1.80	23.3	2.4	15970	3814	2104
19	Recycled Brick Aggregate	0.45	7.50	2.10	24.6	2.7	20401	3966	2156
20	Recycled Brick Aggregate	0.50	16.50	1.80	22.5	2.4	18727	3929	2143
21	Black Stone	0.45	15.00	1.50	30.2	3.0	30925	4829	2414
22	Black Stone	0.50	22.50	1.45	25.1	2.6	23519	4753	2409
23	Shingles	0.45	19.50	1.70	26.4	2.8	26249	4630	2366
24	Shingles	0.50	22.50	1.50	23.7	2.5	22645	4521	2353

Table 6 Result for cement content 400 kg/cu.m and s/a ratio 0.44

Case No	Type of cement	Type of aggregate	W/C	Slump value (mm)	% entrapped air	Compressive strength-28 days (MPa)	ft 28 days (MPa)	Young's Mod 28 days (MPa)	UPV (m/s)	Unit weight (kg/cu.m)
25	CEM Type II B-M-SL	Brick Aggregate	0.45	17.00	2.40	24.1	2.5	15462	3613	1949
26		Brick Aggregate	0.50	24.00	2.30	21.5	2.2	14747	3522	1943
27		Recycled Brick Aggregate	0.45	17.50	1.90	22.7	2.5	18839	3662	1991
28		Recycled Brick Aggregate	0.50	22.00	1.50	20.8	2.2	17294	3628	1979
29		Black Stone	0.45	16.50	2.10	27.9	2.8	28558	4459	2229
30		Black Stone	0.50	18.00	1.60	23.2	2.4	21719	4389	2225
31		Shingles	0.45	21.95	2.20	24.4	2.5	24240	4276	2185
32		Shingles	0.50	24.20	1.60	21.9	2.3	20911	4175	2173
33	40% OPC – 60% Slag(CEM-IIIA)	Brick Aggregate	0.45	22.80	2.20	25.4	2.6	16301	3810	2055
34		Brick Aggregate	0.50	23.50	2.00	22.7	2.3	15548	3713	2048
35		Recycled Brick Aggregate	0.45	9.50	2.20	24.0	2.6	19862	3861	2099
36		Recycled Brick Aggregate	0.50	20.00	2.10	22.0	2.3	18233	3825	2086
37		Black Stone	0.45	16.00	1.50	29.4	2.9	30109	4701	2350
38		Black Stone	0.50	21.50	1.50	24.4	2.5	22898	4627	2345
39	80% OPC – 20% Slag(CEM II/A-S)	Black Stone	0.45	18.25	1.80	30.7	3.1	31409	4904	2452
40	70% OPC – 30% Slag(CEM II/B-S)	Black Stone	0.45	15.75	1.60	30.0	3.0	30671	4789	2394
41	30% OPC – 70% Slag(CEM-IIIB)	Black Stone	0.45	20.25	1.50	28.8	2.9	29401	4591	2295
42	15% OPC – 85% Slag(CEM-IIIC)	Black Stone	0.45	10.00	1.60	27.4	2.7	28057	4381	2190

Compressive strength, tensile strength and Young's modulus were 35.1 MPa, 3.5 MPa and 37027 MPa, respectively. UPV and unit weight were found to be maximum in case no. 39, where 80% OPC – 20% Slag (CEM II/A-S) was used as binder, black stone was used as coarse aggregate, cement content was 400 kg/cu.m., w/c ratio was 0.45 and s/a ratio was 0.44. UPV and unit weight were 4904 m/s and 2452 kg/cu.m. respectively.

Split Tensile Strength: Tensile strength is one of concrete's basic and important properties. The

concrete is not usually expected to resist direct tension because of its low tensile strength and brittle nature [21]. However, determining the tensile strength of concrete is necessary to decide on the load at which the concrete members may crack. The cracking is a form of tension failure. Figure 2 shows the testing of split tensile strength done by UTM, and Figure 3 depicts the tensile strength of concrete made with various aggregates and binders for two types of w/c ratios.

Figure 3 shows that tensile strength increased with the decrease in the w/c ratio. For black stone, the tensile



Figure 2 Split tensile strength test by UTM

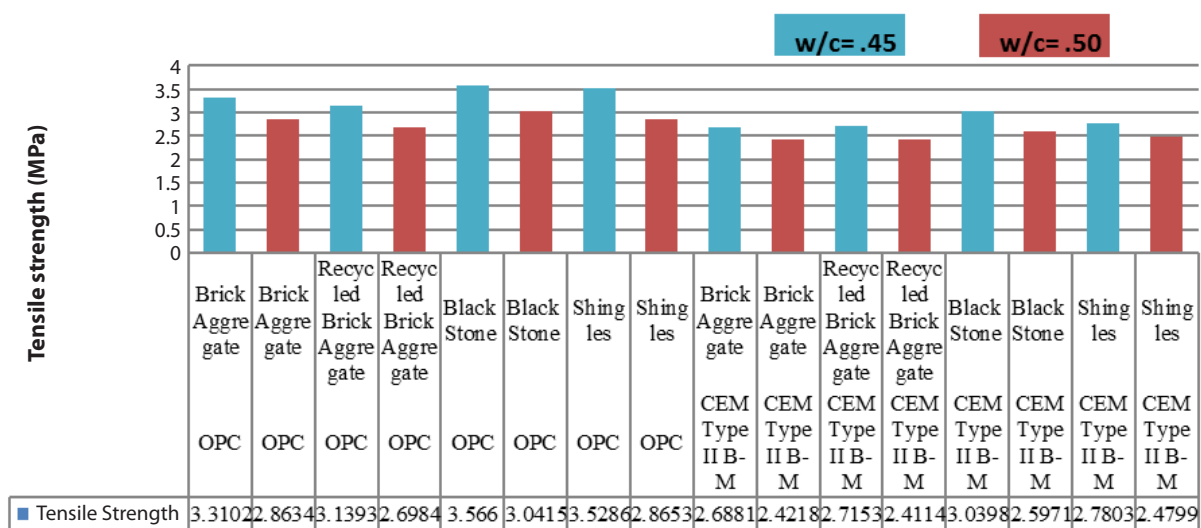


Figure 3 Split tensile strength for different types of aggregates and binders

strength was found to be maximum; for CEM type-II BM, the tensile strength was lower than that of OPC cement for all types of aggregate. Tensile strength also increased with the increase of cement content. However, for black stone, the tensile strength of concrete was consistently higher in all cases.

UPV: An ultrasonic pulse velocity test is an in-situ, non-destructive test to check the quality of concrete and natural rocks. In this test, the strength and quality of concrete are assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure. This test is conducted by passing an ultrasonic wave pulse through concrete to be tested and measuring the time the pulse takes to get through the structure. Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids.

Figure 4 shows the testing of the UPV of concrete, and Figure 5 shows the UPV of concrete using different aggregates and binders for two types of w/c ratios.

Figure 5 indicates that UPV increased as the w/c ratio decreased, with black stone and shingles having the highest UPV; for CEM type-II BM, UPV was almost the same compared to OPC cement for all types of aggregate. UPV increased with the increase in cement content. We achieved a higher UPV by using black stone and shingles as aggregates instead of brick and recycled brick.

Compressive Strength: The strength of hardened concrete measured by the compression test. The compression strength of concrete is a measure of the concrete's ability to resist loads which tend to compress it [22]. The compressive strength of concrete



Figure 4 UPV test of concrete specimen

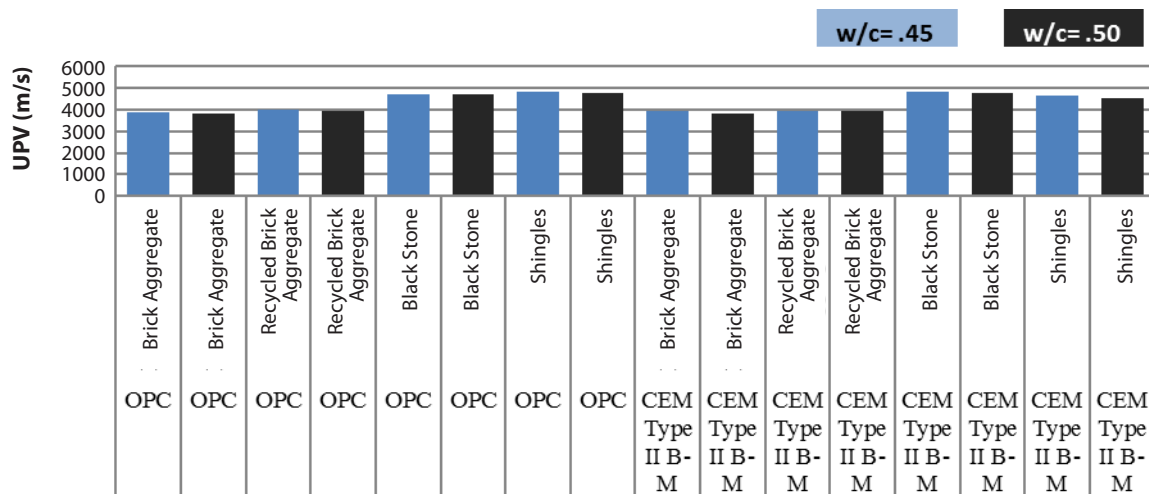


Figure 5 UPV for different types of aggregates and binders

depends on many factors, such as water-cement ratio, cement strength, quality of concrete material, quality control during concrete production, etc. Figure 6 shows the testing of the compressive strength of concrete specimens. The relationship between compressive

strength and w/c ratio for different aggregate types and binders with a cement content of 400 kg/m³ is shown in Figure 7. Figure 8 illustrates the relationship between compressive strength and cement content for different aggregate and OPC types.



Figure 6 Compressive strength testing of concrete specimen

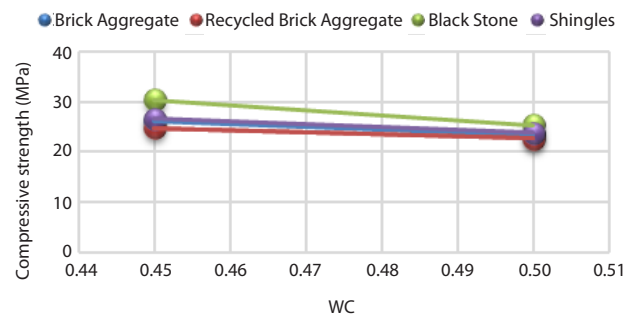
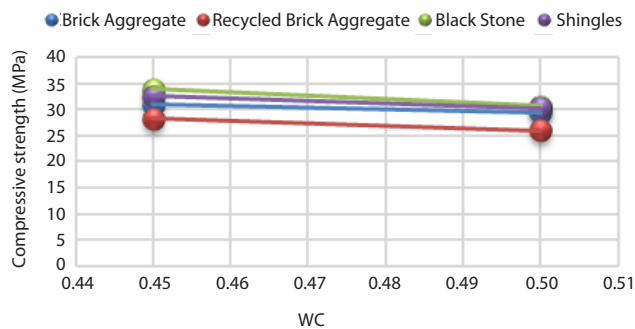


Figure 7 Compressive strength vs w/c for different aggregates

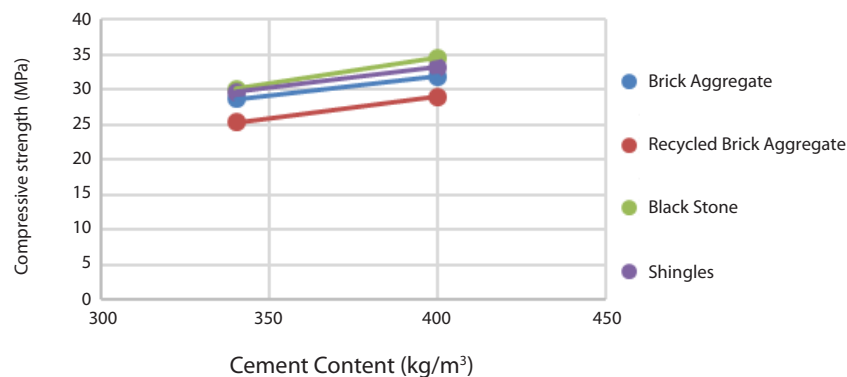


Figure 8 Compressive strength vs cement content for different aggregates

From Figure 7, it can be seen that compressive strength increased with a decrease in the w/c ratio and for black stone, the compressive strength was maximum for both OPC and CEM type-II BM. CEM type-II BM compressive strength was lower for all types of aggregate compared to OPC cement. From Figure 8, we can see that compressive strength also increased with the increase in cement content. However, for black stone, the compressive strength of concrete was always higher.

Young's Modulus: Young's modulus has been found for concrete specimens made with each aggregate tested to analyse their behaviour under applied stress. As Young's modulus indicates how elastic concrete is, thus it is very important to understand the behaviour of concrete made with a particular type of aggregate [23]. Figure 5 represents Young's modulus of concrete made using various aggregates and binders at two different w/c ratios.

Young's modulus increased as the w/c ratio decreased, as shown in Figure 9, and it reached its maximum for black stone. For CEM type-II BM, Young's modulus was less than OPC cement for all types of aggregate. Young's modulus increased with the increase in cement content. By using black stone, we got a higher Young's modulus than brick and recycled brick as aggregates for all cases.

Unit weight: The unit weight of concrete is primarily affected by the unit weight of the aggregate, which varies by geographical location and increases with concrete compressive strength depending on the added pozzolans. Variations in unit weights are mainly because of the greater specific gravity of one aggregate than the others. The highest variation in unit weight of similar concrete for aggregate to aggregate variation is observed in 28 days when the concrete tries to achieve almost 80%-85% of its strength, indicating most of the hydration is done within this time. Figure 6 illustrates the unit weight of concrete for two different types of w/c ratios using various aggregates and binders.

Figure 10 shows that unit weight increased with a decrease in the w/c ratio; for black stone, unit weight was the maximum, and for CEM type-II BM, unit weight was less than OPC cement for all types of aggregate. Unit weight almost remained the same with the increase in cement content. Using black stone gave us a higher unit weight than brick and recycled brick as aggregates for all cases.

Workability: Knowing how much concrete will be workable before casting is customary. As it often presents a problem during casting in congested areas like beam-column joints, a preliminary idea about the workability of concrete is necessary. The W/C ratio plays an important role, but aggregates have the most significant effect [24]. Figure 11 depicts

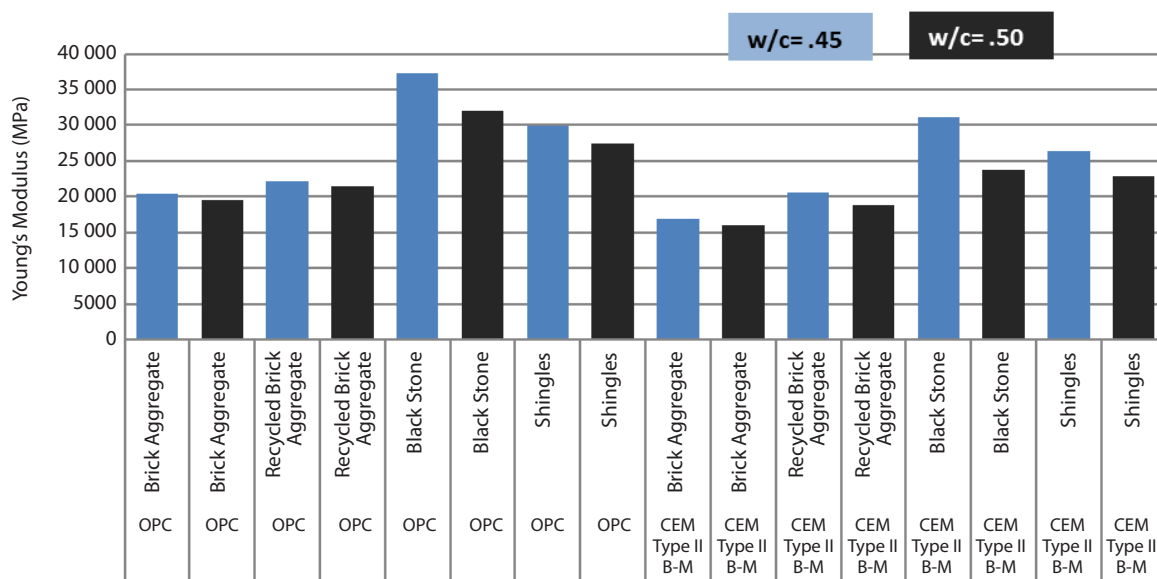


Figure 9 Young's Modulus for different aggregates and binders

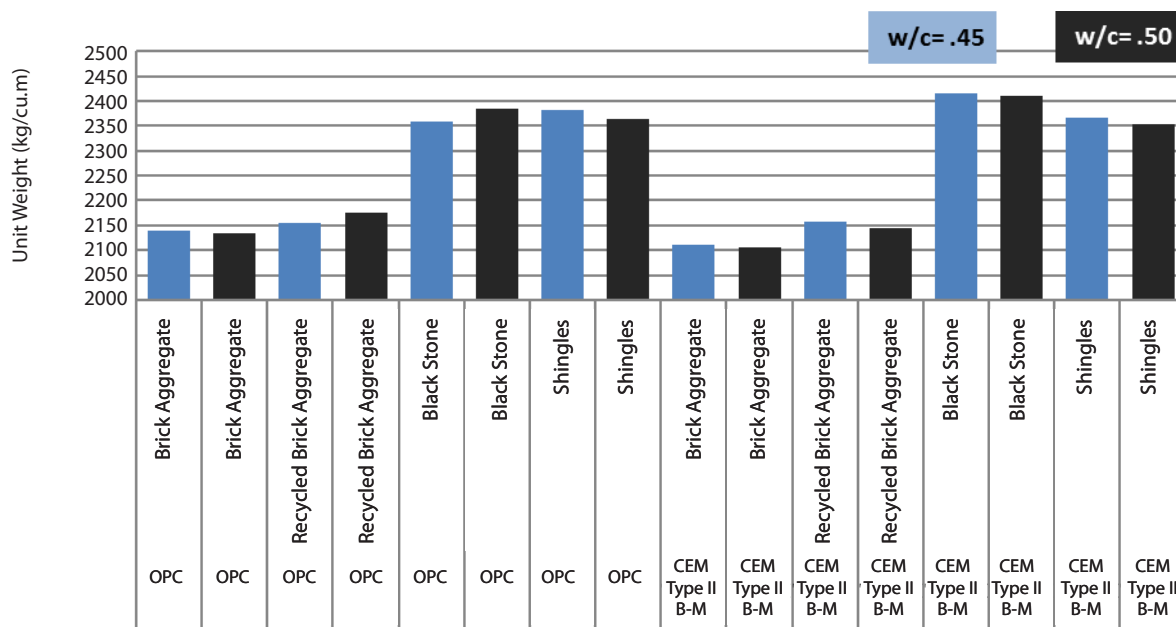


Figure 10 Unit weight for different aggregates and binders

the slump value of concrete made with various aggregates and binders for two types of w/c ratios.

using shingles, we got higher workability than brick and recycled brick as aggregates for all cases.

From Figure 11, we can see that workability increased with an increase in the w/c ratio and for shingles, workability was maximum. For CEM type-II BM, workability was found to be high compared to that of OPC cement for all types of aggregate. Workability increased with the increase in cement content. By

Air entrainment: The air-void system created by using air-entraining agents in concrete is also influenced by concrete materials and construction practice. Concrete materials such as cement, sand, aggregates, and other admixtures play an essential role in maintaining the air-void system in concrete. Fine aggregate serves

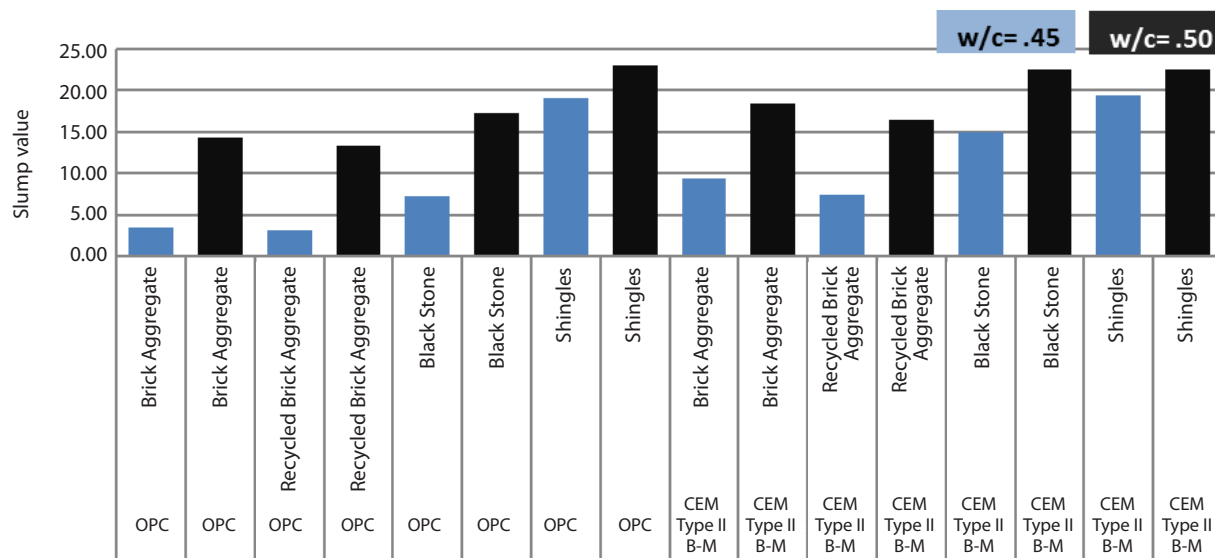


Figure 11 Slump value for different aggregates and binders

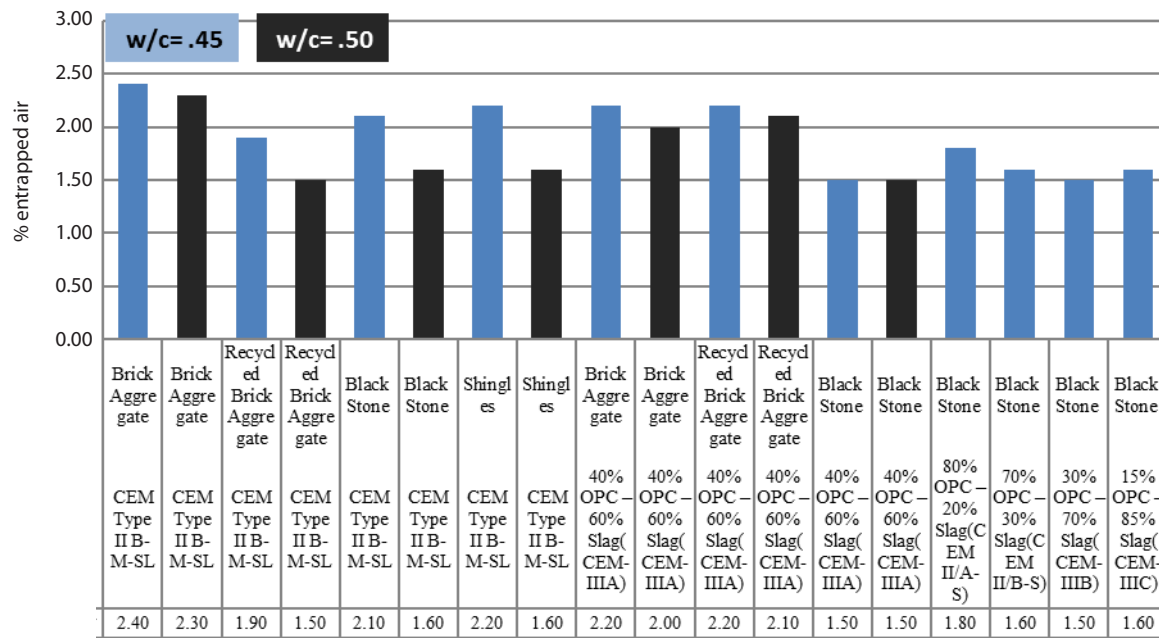


Figure 12 Percentage of air entrainment for different concrete mix

as a three-dimensional screen and traps the air; the more median sand there is in the total aggregate, the greater the air content of the concrete will be. Mineral admixtures such as fly ash and silica fume also affect the formation of void systems in concrete [25]. We can see the percentage of air entrained in concrete using different aggregates and OPC binder with cement content of 400 kg/m³ for two types of w/c ratio. The percentage of air entrainment decreases with the increase of w/c ratio, and for black stone, the maximum percentage of air entrainment. The percentage air entrainment of concrete with different binders and aggregates for two different w/c ratio types is shown in Figure 12.

From Figure 12, we can see that the percentage of air entrainment increased with a decrease in the w/c ratio, and for brick aggregate, the percentage of air entrainment was maximum for CEM type II BM, for CEM type-II BM percentage air entrainment was found to be high compared to OPC cement for brick aggregate. The percentage of air entrainment decreased with the increase in cement content.

Regression Analysis: The relationship between the compressive strength of concrete and the ultrasonic pulse response behaviour of concrete for different types of aggregate is illustrated in Figure 13. R2

indicates how close the data are to the fitted regression line. From all the graphs, we can see that we got a higher value of R2, which means that for shingles, the UPV vs compressive strength points are closer to a linear line than other aggregates. A higher UPV value indicates a higher elastic modulus, density and integrity of the concrete. A higher compressive strength value means higher resistance to compressive load. Both high values are expected for sound concrete. Shingle gave the concrete the best combination of high UPV and high compressive strength compared to others. For brick aggregate, we observed the worst case. Therefore, shingles have a higher significance.

Figure 14 depicts the relationship between the compressive strength of concrete and Young's modulus of concrete for various aggregates. R2 indicates how close the data is to the fitted regression line, while fc' represents the compressive strength of concrete. The graphs show that black stone has the highest R2 value, indicating that Young's modulus vs compressive strength points are closer to a linear line than other aggregates. A higher Young's modulus indicates that a material can better withstand changes in dimension when under tension or compression. A higher compressive strength value indicates greater resistance to compressive loads. Both high values are expected for sound concrete. Compared to other materials, black

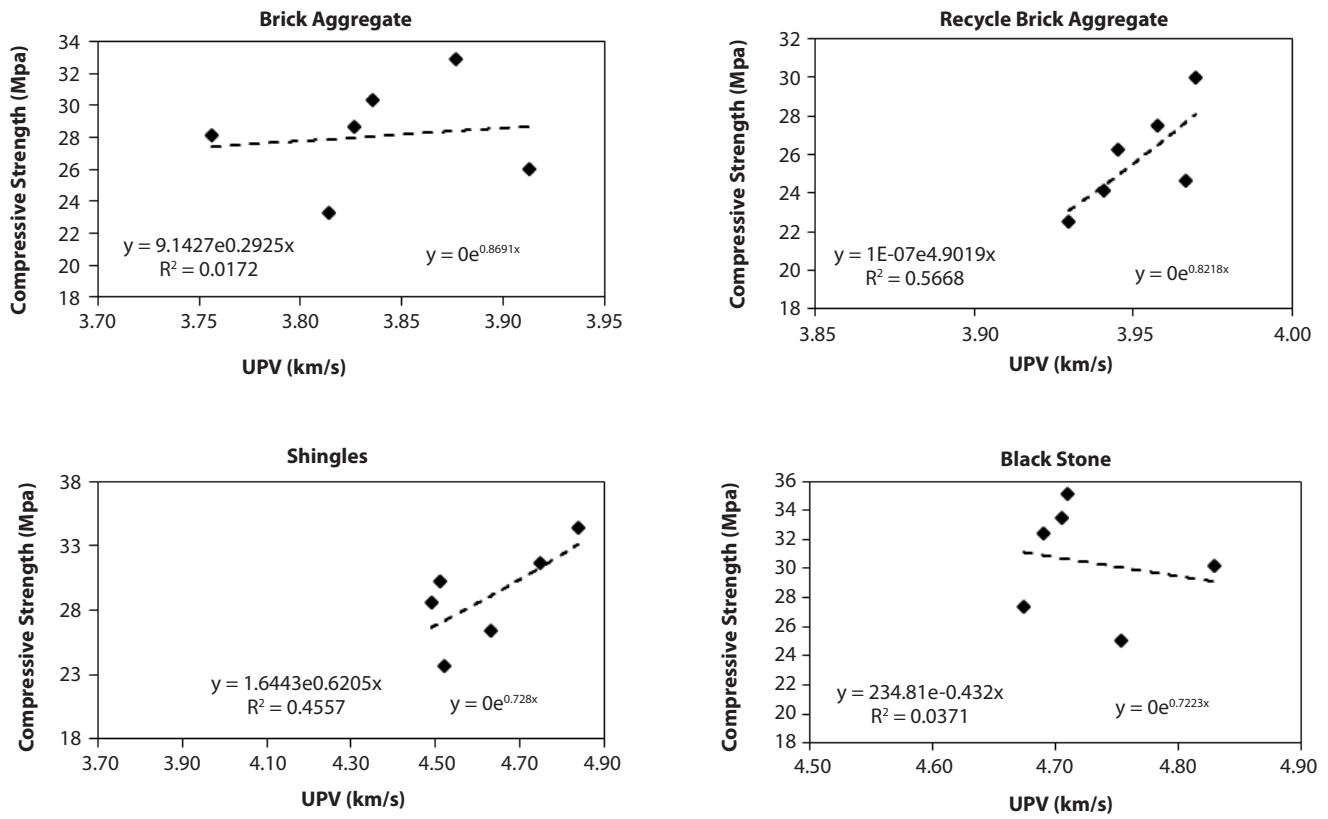


Figure 13 UPV vs Compressive Strength

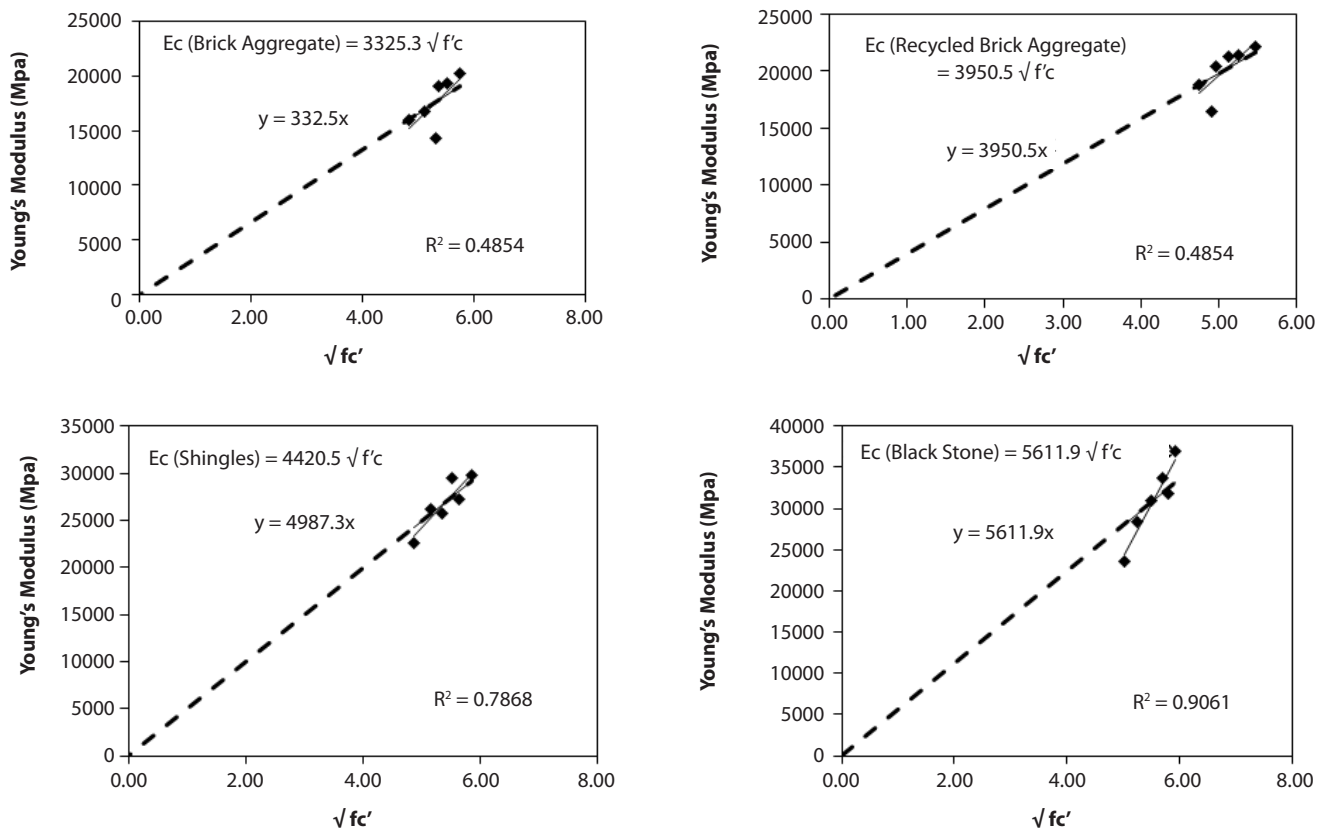


Figure 14 Young's modulus vs Compressive Strength

stone provided the best combination of high Young's modulus and compressive strength to the concrete. On the other hand, we saw the worst-case scenario with brick aggregate.

Figure 15 represents the relationship between the compressive and tensile strengths of concrete. R^2 indicates how close the data is to the fitted regression line, while f_c' represents the compressive strength of concrete. The graphs show that brick aggregate has a higher R^2 value, indicating that its tensile strength vs compressive strength points are closer to a linear line than other aggregates. A higher tensile strength suggests that a material is better able to withstand tension. A higher compressive strength value indicates greater resistance to compressive loads. Both high values are expected for sound concrete. Compared to other materials, brick aggregate provided the best combination of high tensile and compressive strength to concrete. For shingles, we saw the worst-case scenario.

Based on the results of this experimental investigation, the following conclusions are drawn:

1. The specific gravity of black stone was higher than that of shingles. So, we can say black stones are denser than shingles.
2. As the value of % wear of shingles was greater than that of black stone, it can be said that shingles are harder than black stone.
3. The abrasion value of recycled brick aggregate was the highest, which means it was the weakest of the aggregates investigated.
4. Slump value increased with an increase in the W/C ratio of the mix for any aggregate.
5. The percentage of air entrainment in concrete decreased with increased W/C ratio for any concrete. For brick aggregate, the percentage of air entrainment was maximum.
6. The UPV of a concrete specimen made with brick aggregate and recycled brick aggregate appeared

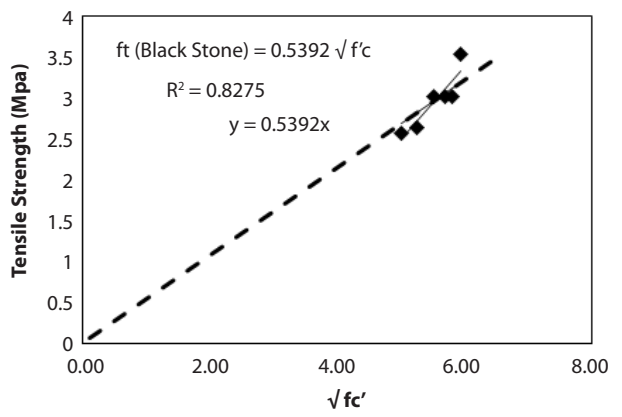
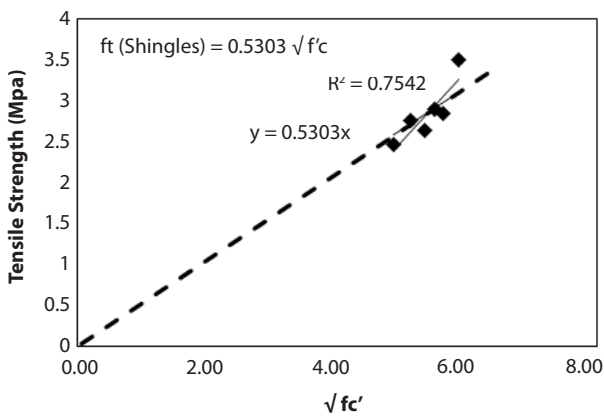
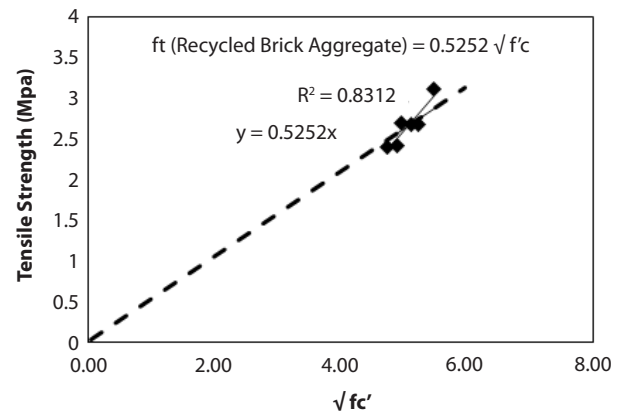
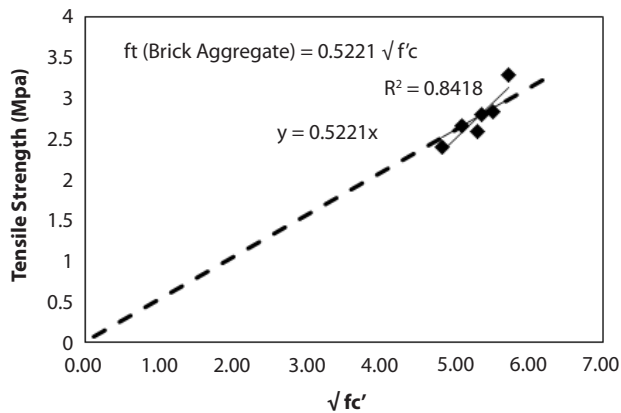


Figure 15 Tensile strength vs compressive strength

- lower than that of concrete made with shingles and black stone.
7. Split Tensile Strength was found to be higher for concrete made with OPC, and it increased with a decrease in the W/C ratio.
 8. Black stone gave the best combination of high Young's modulus and high compressive strength to the concrete compared to others.
 9. Shingle gave the concrete the best combination of high UPV and high compressive strength compared to others. For brick, we observed the worst-case scenario.
 10. Young's modulus and compressive strength of concrete increased with a decrease in the w/c ratio for any type of aggregate and increased with an increase in cement content.
 11. Unit weight increases with decreased w/c ratio, and for black stone, the unit weight is maximum; for CEM type-II BM, the unit weight was less than OPC cement for all types of aggregate. Unit weight almost remained the same with the increase in cement content.
 12. CO₂ emissions can be decreased by using alternative binders, such as fly ash, slag, or geopolymers. The results of this study show that binders such as CEM Type II B-M and CEM Type II B-S, which are a mixture of OPC cement and additives such as fly ash and slag, can produce concrete that has almost similar strength to concrete produced by OPC cement.
 13. Among the numerous natural resources required in significant quantities for concrete production are sand, gravel, and limestone. Over-extraction may lead to resource scarcity and environmental degradation. Recycled concrete aggregates are an alternative resource that can reduce the need for virgin materials. The study's findings demonstrate that concrete made with recycled aggregates can have sufficient strength for construction purposes.
 14. Compressive strength, tensile strength and Young's modulus were maximum for case no. 11, where OPC was used as a binder and black stone was used as coarse aggregate. Cement content was 400 kg/cu.m., w/c ratio was 0.45 and s/a ratio was 0.44. Compressive strength, tensile strength and Young's modulus were 35.1 MPa, 3.5 MPa and 37027 MPa, respectively.
 15. UPV and unit weight were found to be maximum in case no. 39, where 80% OPC – 20% Slag (CEM II/A-S) was used as binder, black stone was used as coarse aggregate, cement content was 400 kg/cu.m., w/c ratio was 0.45 and s/a ratio was 0.44. UPV and unit weight were 4904 m/s and 2452 kg/cu.m. respectively.

CONCLUSION

The primary goal of this study was to conduct a comparative analysis of the various parameters associated with the mechanical properties of concrete using different types of aggregates and binding materials. According to the study, the Ultrasonic Pulse Velocity (UPV) of concrete specimens made with brick aggregate and recycled brick aggregate was lower than that of shingles and black stone. Compared to other materials, black stone provided the best combination of high Young's modulus and compressive strength to the concrete. Shingles provided the best combination of high UPV and high compressive strength to the concrete compared to others. Concrete's Young's modulus and compressive strength increased as the w/c ratio decreased for any type of aggregate and increased with cement content. The most efficient specimen was where Ordinary Portland Cement (OPC) was used as a binder, black stone was used as coarse aggregate, cement content was 400 kg/cu.m., w/c ratio was 0.45 and s/a ratio was 0.44.

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