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FACTORS AFFECTING MIX DESIGN OF CONCRETE

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Graphical abstract

Abstract

Concrete is a low-maintenance composite material that is primarily composed of cementitious material, water and gravel. It is often used construction material not only in Bangladesh but also across the world. The design of the concrete mix is a critical determinant of the qualities of the concrete. The fundamental ideas and comparative research of certain prominent concrete mix design methods from a qualitative perspective are presented in this work. Two types of concrete mix designs are used which are ACI 211.1-91 (2002) Standard and British Standard (1997) in this paper. Several factors have been determined in this study to choose between the ACI and British Standard. These approaches rely heavily on graphs, tables and bar charts with arbitrary values. The nominal maximum size of coarse aggregate, water to cement ratio (w/c), slump value and the % passing of fine aggregates are used here to change the amount of materials. Differentiating between these strategies allows for a better understanding of the impacts of variables. The ACI and British Standard have been used to compare how the w/c, fine aggregate to cement ratio (FA/C), total aggregate to cement ratio (TA/C) and fine aggregate to total aggregate ratio (FA/TA) are different for various strengths. The following study is expected to pave the path of concrete performance via extensive research on different suggested design factors.

Keywords: ACI Standard, British Standard, Concrete, Aggregate, Mix Design.

1.0 INTRODUCTION

Concrete is the prevalent and commonly utilized building material in Bangladesh. It is made out of cement as well as fine aggregate, coarse aggregate and water as needed. The cement and water are mixed to create a mixture that solidifies and links the aggregates Concrete is a versatile construction material that is used in a wide range of constructions. The factors for its significance are its fire resistance, tremendous strength, workability and durability (Bint Ashraf, 2012). One more significant feature is that concrete is created from nearby available resources, making it less expensive than other building substance. (Bint Ashraf, 2012). Mix design, also known as mix proportioning, is a process of identifying the cost-effective and feasible arrangement and percentage of accessible components to create concrete in an optimal manner that fulfills requirements under specified usage situations. As a result, the inherent characteristic of a mix design process is its attention to locally accessible substance. The appropriate qualities of concrete, which are the outcome of a competent concrete mix design strategy, are necessary behind the massive popularity of concrete. Concrete Mix Design refers to the procedure of picking appropriate concrete materials and calculating their relative quantities in order to make concrete with the specified strength, durability, and workability at the lowest possible cost. Several studies have previously been conducted in various nations to identify the optimal quantities of concrete materials. As a consequence, numerous nations, including the United States

(ACI 211), England (BS 812), Australia (AIS 3600), Europe (EN 206), India (IS 456), Malaysia (MS 523), and Japan (JIS), have developed their concrete mix design methodologies. However, there is an exception in the instance of Bangladesh (Bint Ashraf, 2012). A well-formulated concrete mix will guarantee that the completed construction is strong. It also improves ingredient efficiency by eliminating waste and extracting the most concrete from wet and dry components. It is worth mentioning that the ACI Standard of concrete mix design is widely utilized methodology in Bangladesh. The workability of concrete is affected by materials such as cement, sand, water and aggregate qualities such as size, grading, shape, mix design ratio and admixture application. Every process and material used in concrete mixing has a consequence on the workability of the concrete. Because aggregate covers roughly 70 to 80 % of the volume of concrete, it's logical that it has an impact on the material's varied qualities and attributes (Shetty and Jain, 2019). The quality of cement is critical for the construction of a proper concrete mix design and the manufacture of cement necessitates strict monitoring. Ordinary Portland (Type I) cement is a good basic cement that is frequently used (Neville and Brooks, 1987). The ACI Standard proposes a mixed design technique that considers the most cost-effective use of available ingredients to produce concrete with optimum workability, durability and strength. The design table, which includes the fundamental correlations between factors is important in identifying the best combination of the elements. The ACI mix proportioning Standard is appropriate for both normal and heavy weight concrete. On the other hand, the British Standard, is impacted by the water to cement ratio, needed strength, coarse aggregate and water content, among other factors. Bond strength is also affected by w/c ratio as lower w/c ratio results in higher compressive strength (Mahmud, M. S., et al., 2022). For concrete mix design employing different strength with a variety of factors are explored. Normally concrete is weak in tension and strong in compression on the other hand steel is strong in both tension and compression and the combined action of these two resists external loads. Proper bonding between these two ensures effective load transfer. Also, it is very important for characterization of crack pattern and anchorage capacity, splice length, and development length of the bars (Mim, N. Z., et al., 2021).

This research lead to the development of a concrete mix design that utilizes available and suitable materials. Changing various factors in both ACI and British Standard methods to observe how the concrete mix design responds. Several criteria have been worked out in this study between the ACI and British Standard. which have been distinguished in this manner.

2.0 METHODOLOGY

Materials used here in the study are cement, water, coarse and fine aggregate. The ACI Standard ensures that the workability of a mix with a specified maximum size of well-graded coarse aggregates is governed by the amount of water and entrapped air. The water content is picked from Table 4 of ACI Standard for non-air entrained concrete for a particular slump value and nominal maximum size of coarse aggregate. The w/c is obtained by the compressive strength at 28 days provided in Table 2 of ACI for non-air entrained concrete. The quantity of cement required is determined by the weight of the water and the w/c. According to this standard, the optimum coarse aggregate bulk volume to total concrete volume ratio is determined only by the maximum size of coarse aggregate and the fineness modulus of fine aggregate. Table 5 of the ACI standard specifies the volume of coarse aggregate per unit volume of concrete on an oven-dry rodded basis for various nominal maximum sizes of coarse aggregate and fineness modulus of fine aggregate. The dry mass of coarse aggregate is calculated by multiplying the value from table 5 by the aggregate's dry-rodded unit mass. The absolute volume of water, air, coarse aggregate and cement is deducted from unit volume of fresh concrete to determine the volume of fine aggregate. The weights of each component are approximated using the specific gravities once the volumes have been established. The volume of any ingredient in concrete is calculated by its weight & by its density. Although aggregate quantities are calculated using oven-dry unit weights, aggregate is typically batched using actual weight. As a result, any moisture in the aggregate will cause it to weigh more and stockpiled aggregates usually always include some moisture. The batched aggregate volumes will be wrong if this is not corrected. If the batched aggregate is not saturated, it will absorb or release water from the cement paste. The results in a total shift in the quantity of available water in the combination, which is adjusted by altering the content of mixing water supplied. However, the ultimate mix percentage should be determined via trial and error, with any necessary changes made for the field mix (Mishra, 2012; Santhosh R & Dr. Shivananda, 2017; Dixon et al., 1991).

The British Standard ensures that the water to cement ratio is influenced by cement strength class, coarse aggregate type and concrete compressive strength. Table 6 and figure 1 of the British Standard provide the w/c. Only two kinds of aggregates are identified in this method: uncrushed and crushed. According to table 3 of British Standard, the water content required to give a variable degree of workability characterized as slump is estimated for the two types of aggregates, crushed and uncrushed, with varying maximum sizes of coarse aggregates ranging from 10 to 40 mm. According to table 6, the 28-day strength of Ordinary Portland Cement (OPC) with crushed aggregate is 49 MPa. In figure 1, enter these values on the ordinate corresponding to a w/c of 0.5 and the w/c is calculated for the required strength. The quantity of cement required is governed by the weight of the water and the w/c. The total aggregate quantity is computed using this method by using the wet concrete density from the graph in this guideline. Wet density of concrete is determined by the specific gravity of the particles in the saturated surface dry state. If no further instruction is provided, the specific gravity for crushed aggregate should be 2.70 and 2.60 for uncrushed aggregate. From the figure 2 in this standard, the percentage of fine aggregate is determined as a percentage of total aggregate to achieve the desired consistency of the concrete mixture formed with the supplied fine aggregate grading, nominal maximum size of coarse aggregate, and free w/c. The percentages of fine and coarse aggregate in total aggregate content are used to compute the quantities of fine and coarse aggregates (Mishra, 2012; Santhosh R & Dr. Shivananda, 2017). According to table 1, relevant data are obtained for both the ACI and the British Standard for this research.

Table 1 Concrete Mix Design Parameters

	Parameters
ACI Method	Types of Aggregate= Crushed Stone Chips Fineness modulus of fine aggregate (Sand) = 2.4 Specific gravity of fine aggregate (SSD)= 2.65 Specific gravity of coarse aggregate (SSD)= 2.7 Type of Cement= Type-I (Ordinary Portland cement) Specific gravity of cement= 3.15 Absorption Capacity of coarse aggregate (SSD)= 1 % Absorption Capacity of fine aggregate (SSD)= 1.3 % Moisture Content of Coarse Aggregate= 0 % Moisture Content of Fine Aggregate= 3 % Dry rodded unit weight of coarse aggregate= 1600 kg/m^3($100lb/ft^3$)
BS method	Cement Strength Class=42.5 N Types of Aggregate= Crushed Stone Chips Specific Gravity of Coarse Aggregate= 2.7 Fine Aggregate passes 0.6 mm sieve

ACI Concrete Mix Design

Table 19.1: **Relation between water/cementitious material ratio and average compressive strength of concrete, accordording to ACI 211.1–91 (Reapproved 2002)**

Average compressive strength at 28 days, MPa (psi)	Effective water/cementitious material ratio, by mass	
	Non-air entrained concrete	Air entrained concrete
41.4 (6000)	0.41	–
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

Table 2 Relation between water/cementitious material ratio and average compressive strength of concrete, according to ACI 211.1-91

British method of Concrete Mix Design

Table 9.6: Approximate free-water (mixing water) kg/m^3 required for workability

MSA (mm)	Type	Slump 0-10 mm	Slump 10-30 mm	Slump 30-60 mm	Slump 60- 180 mm
10	Uncrushed	150	180	205	225
10	crushed	180	205	230	250
20	Uncrushed	135	160	180	195
20	crushed	170	190	210	225
40	Uncrushed	115	140	160	175
40	crushed	155	175	190	205

Table 3 Approximate free-water (mixing water) kg/m^3 required for workability (British Standard)

ACI Concrete Mix Design

Table 19.4: **Approximate requirements for mixing water and air content for different workabilities and nominal maximum sizes of aggregates according to ACI 211.1–91 (Reapproved 2002)**

Workability or air content	Water content, kg/m^3 (lb/yd^3) of concrete for indicated maximum aggregate size							
	10 mm (3/8 in.)	12.5 mm (1/2 in.)	20 mm (3/4 in.)	25 mm (1 in.)	40 mm (1½ in.)	50 mm (2 in.)	70 mm (3 in.)	150 mm (6 in.)
	Non-air-entrained concrete							
Slump:								
30–50 mm (1–2 in.)	205 (350)	200 (335)	185 (315)	180 (300)	160 (275)	155 (260)	145 (220)	125 (19
80–100 mm (3–4 in.)	225 (385)	215 (365)	200 (340)	195 (325)	175 (300)	170 (285)	160 (245)	140 (21
150–180 mm (6–7 in.)	240 (410)	230 (385)	210 (360)	205 (340)	185 (315)	180 (300)	170 (270)	–
Approximate entrapped air content, per cent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
Slump:								
30–50 mm (1–2 in.)	180 (305)	175 (295)	165 (280)	160 (270)	145 (250)	140 (240)	135 (205)	120 (1
80–100 mm (3–4 in.)	200 (340)	190 (325)	180 (305)	175 (295)	160 (275)	155 (265)	150 (225)	135 (2
150–180 mm (6–7 in.)	215 (365)	205 (345)	190 (325)	185 (310)	170 (290)	165 (280)	160 (260)	–
Recommended average total air content, per cent:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5*	1.0*
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5*	3.0*
Extreme exposure†	7.5	7.0	6.0	6.0	5.5	5.0	4.5*	4.0*

Table.4 Approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregate according to ACI 211.1-91 (Reapproved 2002)

ACI Concrete Mix Design

Table 19.9: **Dry bulk volume of coarse aggregate per unit volume of concrete as given by ACI 211.1–91 (Reapproved 2002)**

Maximum size of aggregate		Dry bulk volume of rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of:			
mm	in.	2.40	2.60	2.80	3.00
10	3/8	0.50	0.48	0.46	0.44
12.5	1/2	0.59	0.57	0.55	0.53
20	3/4	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
40	1½	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
70	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Table 5 Dry bulk volume of coarse aggregate per unit volume of concrete as given by ACI 211.1-91 (Reapproved 2002)

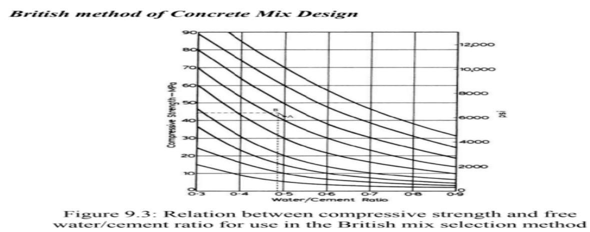

Figure 1 Relation between compressive strength and free water/cement ratio for use in British mix selection method

British method of Concrete Mix Design

Table 9.5: Approximate Compressive Strengths of Concretes Made with a Free Water/Cement Ratio of 0.5 According to the 1997 British Method

Cement Strength Class	Type of coarse aggregate	Compressive strength (MPa)			
		3 day	7 day	28 day	91 day
42.5	Uncrushed	22	30	42	49
42.5	crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
52.5	crushed	34	43	55	61

Table 6 Approximate compressive strength for concrete made with a free water/cement ratio of 0.5 according to the 1997 British Method

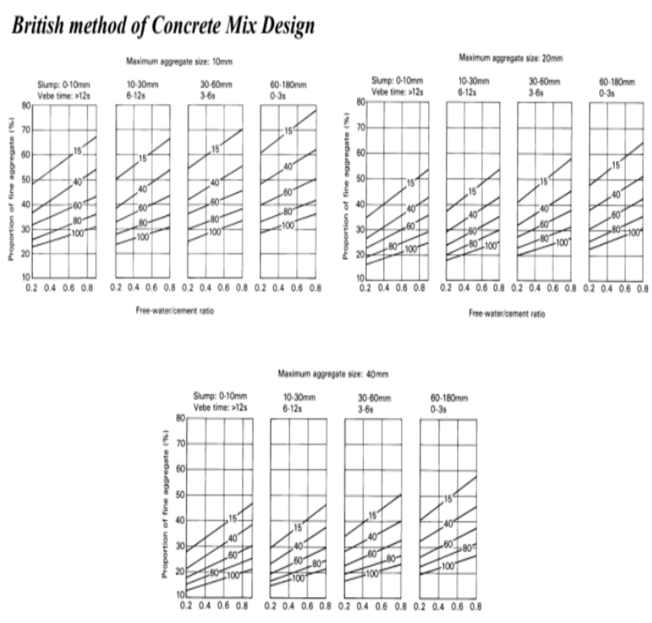

Figure 2 Graphs for British Standard of concrete mix design

3.0 ANALYSIS OF RESULT

The content of water, cement, fine and coarse aggregate are obtained by designing concrete mix in ACI and British Standard, by using the same data for 35MPa strength of concrete. The difference in the amount of materials between both ACI and British Standard is clearly observed due to factor change which is shown in the following tables.

In table 7, the fine aggregate with 40% passing is replaced by 60%, 80% passing and keeping slump, strength and nominal maximum size of coarse aggregate are same. According to our study, an excessive amount of fine aggregate weakens the structure, whether coarse aggregate strengthens it. In figure 3, % passing of fine aggregate is increasing. As a result, cement and water remain constant and the fine aggregate content steadily decreases, whereas coarse aggregate gradually increases, as shown in table 7. So, in accordance with the table, as % passing increases, gaining the strength of concrete.

In Table 8, the nominal maximum coarse aggregate size is changeable (10 mm, 20 mm, 40 mm), whereas all other components are set for the ACI and British Standard. The coarse aggregate size has been increased for a fixed strength (35Mpa) and slump (75mm). The w/c is fixed for all sizes of coarse aggregate, both ACI and British Standard. Again, for water, cement and fine aggregate content are decreasing, whereas coarse aggregate content is increasing for both standards. The paper on Concrete Mix Design Procedure Using Locally Available Materials (Bint Ashraf, 2012) also has similar findings. Table 8 is used to create a bar chart that reflects figure 4.

The higher the maximum size of aggregate for a given weight, the smaller the surface area of coarse aggregates and vice versa. Extra water is required to cover the particulates and give workability as the surface area increases. A smaller maximum size of coarse aggregate is needed, a greater volume of fine aggregate to protect particles and maintain the cohesiveness of the mixture of concrete (Berwal & Goel, 2017).

Table 7 Concrete Strength ~ 35 MPa [British Standard]

Material	For 40 % Passing	For 60 % Passing	For 80 % Passing
W/C ratio	0.62	0.62	0.62
Water (kg/m³)	225	225	225
Cement (kg/m³)	363	363	363
FA (kg/m³)	861	681	592
CA (kg/m³)	931	1112	1201

From figure 5, it is observed that, for 20 mm and 40 mm nominal maximum size of coarse aggregate is increasing coarse aggregate content with regard to 10 mm nominal maximum size of coarse aggregate. Again, figures 6, 7 and 8 shows that the contents of fine aggregate, cement and water in 20 mm and 40mm nominal maximum size coarse aggregate decreases with respect to 10mm nominal maximum size coarse aggregate. The rate of increasing CA content in the ACI method is higher than in the British Standard. Therefore, in terms of FA content, ACI has a lower decreasing percentage than British Standard. So, it means when the amount of CA 7content is increased, the FA content decreases. Thus, decreasing rate in the ACI Standard is greater than the British Standard for the percentage of decreasing cement quantity and water.

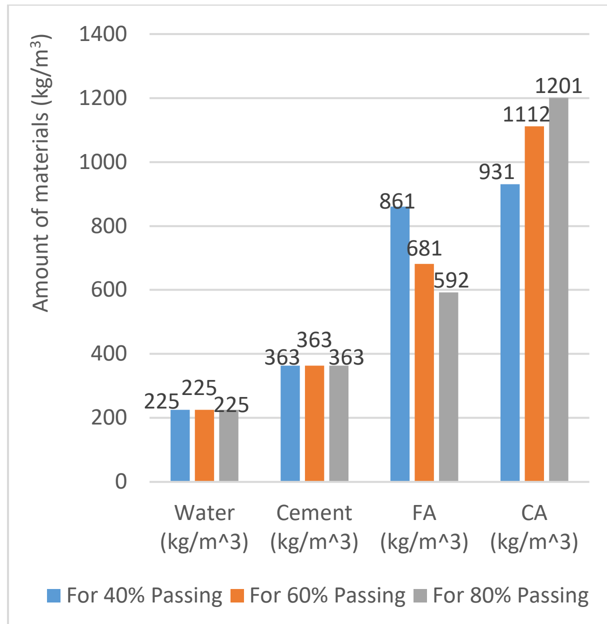

Figure3 % Passing Fine Aggregate in British Standard.

40mm down aggregate has a lower W/C than 20mm down aggregate. It means it has a higher strength for the same workability. Because it uses less water, it takes advantage of a larger maximum size of coarse aggregate to reduce cement use. An affordable mix for a particular strength is generated by increasing the cement to aggregate ratio and reducing the maximum possible size of aggregate. In general, the lower the W/C, the more cement is present. The most crucial criteria for maximum concrete strength and durability is a low water-to-cement ratio. (Chhachhia, 2021).

Table 8 Analysis of Concrete Strength ~ 35 MPa [Slump 75 mm]

	ACI Standard			**British Standard**			**The paper on Concrete Mix Design Procedure Using Locally Available Materials (Bint Ashraf, 2012)**	
Materials	For 10 mm nominal max aggregate size	For 20 mm nominal max aggregate size	For 40mm nominal max aggregate size	For 10 mm nominal max aggregate size	For 20 mm nominal max aggregate size	For 20 mm nominal max aggregate size	ACI method	BS method
							For 20 mm nominal max aggregate size	
W/C ratio	0.475	0.475	0.475	0.62	0.62	0.62	0.48	0.58
Water (kg/m³)	206	183	159	250	225	205	202	200
Cement (kg/m³)	481	425	375	403	363	331	420	345
FA (kg/m³)	789	676	664	798	677	637	700	583
CA (kg/m³)	809	1067	1214	900	1105	1237	1057	1082
TA (kg/m³)	1598	1743	1878	1698	1782	1874	1757	1665
TA/C	3.30	4.10	5.01	4.21	4.91	5.66	4.18	4.82
FA/C	1.64	1.59	1.80	1.98	1.87	1.92	1.67	1.69
FA/TA	0.50	0.40	0.35	0.47	0.38	0.34	0.40	0.35

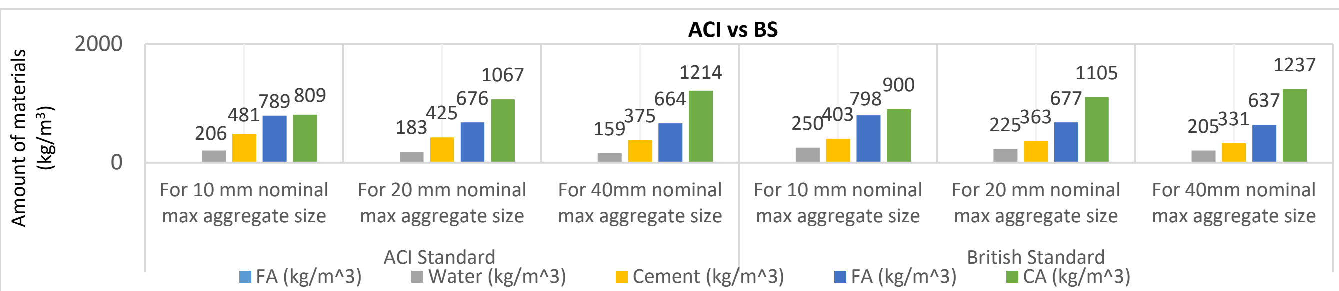

Figure 4 Uniform Slump Value with Different Aggregate Size

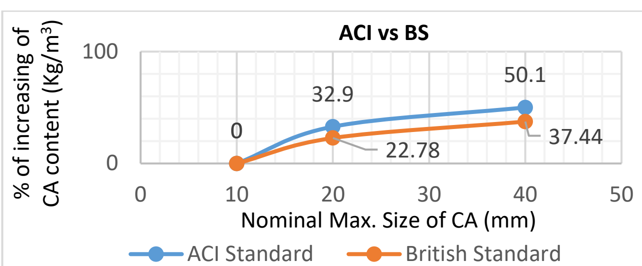

Figure 5 % of increase of CA content with different mix design standard

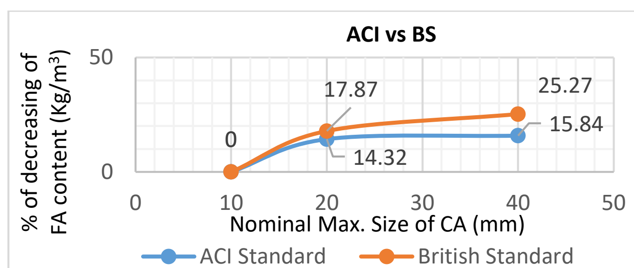

Figure 6 % of increase of FA content with different mix design standard

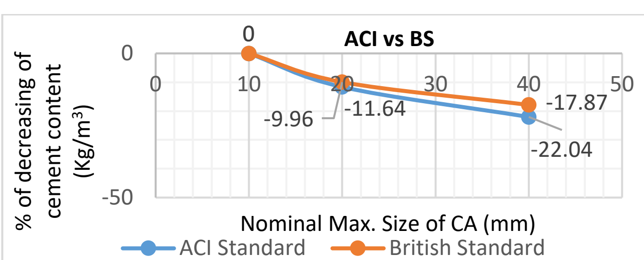

Figure 7 % of decrease of Cement content with different mix design standard

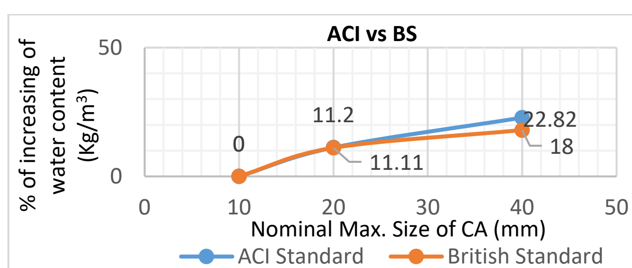

Figure 8 % of increase of Water content with different mix design standard

Table 9 ACI and BS Mix Design (35 MPa) For different slump value with same size (20mm) of aggregate.

	ACI Method			BS Method	
Material / Slump	For 50 mm	For 75 mm	For 150mm	For 50 mm	For 75 mm
W/C ratio	0.475	0.475	0.475	0.62	0.62
Water(kg/m³)	166	183	196	210	225
Cement(kg/m³)	394	425	450	339	363
FA (kg/³)	744	676	622	704	681
CA (kg/m³)	1068	1068	1068	1148	1112
Total Aggregate(kg/m³)	1812	1744	1690	1852	1793
Aggregate/Cement ratio	4.60	4.10	3.80	5.5	4.95

Workability falls as cement content (and consequently paste content) declines for a given water to cement ratio. This is especially noticeable in low water to cement combinations, which have lower water per unit paste concentration. Because mixtures with low paste content were stiff and had low workability, a high dose of water-reducing agent was required. This finding suggests that sufficient paste content is required to reach a particular level of workability (Yurdakul, 2010). If the aggregate to cement ratio is more, it means that aggregates are greater and cement is less and vice versa if it is less. The aggregate gives the concrete strength, whilst the cement works as an adhesive, binding all of the elements together. In table 9, the aggregate to cement ratio in British Standard is higher than in ACI Standard for the same workability. Thus, a rise in aggregate to cement ratio denotes a large amount of aggregate, indicating that it will provide strength to the concrete. In figure 9, the fine aggregate to cement ratios achieved utilizing various mix design standards, as shown in figure, do not show consistent fluctuation with varied aggregate sizes in general. When the nominal maximum size of coarse aggregate increases from 10 mm to 20 mm, the amount of fine aggregate in them is much less than the amount of fine aggregate found in 40mm nominal maximum aggregate size. So, the amount of coarse aggregate is higher at 40 mm nominal maximum size of coarse aggregate and the quantity of fine aggregate is less. As a result, FA/C begins to rise from 20 mm nominal maximum size of coarse aggregate.

The TA/C ratios determine the concrete's quality The overall aggregate to cement ratio should be lower for a good quality mix (Ahmed et al., 2016). The cement concentration in the mix must be sufficient to create adhesion and preserve workability for a suitable workable concrete. As a result, the aggregate to cement ratio is increased to enhance the performance of the concrete Workability improves as the aggregate to cement ratio decreases (Okah and Amos Elekima, 2018).

In figure 10, according to both the ACI and the British Standards, aggregate size increases as the overall aggregate to cement ratio increases. Because total aggregate to cement ratio in the British Standard is higher than in the ACI Standard, the British Standard is less workable than the ACI Standard. In figure 11, when the maximum size of coarse aggregates is smaller, the FA/TA ratios are greater. The FA/TA obtained using the ACI Standard are higher with higher workability conditions, but the FA/TA acquired using British Standard are lower with the same workability conditions. Figure 12 shows how the W/C affects concrete strength. The performance of a concrete mix decreases as the W/C rises and vice versa. As indicated in the graph, growing the water to cement ratio reduces the concrete's strength, whereas decreasing the W/C improves the concrete's strength. The elements of the cement mixture will separate if there is too much water in it. The mix containing an excessive amount of water will shrink further when the extra water disappears, resulting in interior fissures (especially at inner areas), which decrease the ultimate strength. Compared to ACI and British Standard, the value of the water to cement ratio is lower in ACI than British Standard. As a result, the concrete strength is found more in ACI than British Standard. In these graphs, water to cement ratio is lower for the highest strength (40 MPa). The strength vs. water to cement ratio plot indicates that when the concrete is vibrated, a lower W/C is employed to a better performance; however, a considerably larger water to cement ratio is necessary when the concrete is hand compacted or manually compacted. When the W/C is less than the practical limit, the performance of the concrete quickly decreases (Ahmed et al., 2016).

From the following figure 13, it is seen that the FA/C in the ACI Standard decreases first and then increases for nominal maximum size of coarse aggregate of 10 mm, 20 mm and 40 mm of 30 MPa strength of concrete. However, with the British Standard, the FA/C steadily drops for nominal maximum coarse aggregate sizes of 10mm, 20mm and 40mm. As a result, the difference between ACI and BS may be observed here. The graph with 30 MPa strength shows no consistent movement. ACI and British Standard have similarities for 35 MPa and 40 MPa where an optimal point (20mm nominal maximum coarse aggregate size) is determined after which the value of fine aggregate to cement rises. The closer the sand to cement ratio is to an even one-to-one, the stronger the concrete will be. However, if the ratio is shifted in the opposite direction, the resulting product will be significantly weaker. Higher cement content will be required for a flaky and elongated aggregate. They require more cement paste since they have a larger surface area for the same volume occupied. An angular aggregate, on the other hand, will need less cement to attain equal workability.

For ACI and British standards, three categories of strength (30 MPa, 35 MPa, and 40 MPa) have been selected in table 10. The differences between cement, fine aggregate (FA), coarse aggregate (CA), total aggregate (TA), FA/C, TA/C, and FA/TA for various strengths have been compared using the ACI and British Standards.

Table 10 Mix Design with different strength

For ACI Standard

	30MPa			35MPa			40Mpa		
	For 10 mm nominal max aggregate size	For 20 mm nominal max aggregate size	For 40mm nominal max aggregate size	For 10 mm nominal max aggregate size	For 20 mm nominal max aggregate size	For 40mm nominal max aggregate size	For 10 mm nominal max aggregate size	For 20 mm nominal max aggregate size	For 40mm nominal max aggregate size
Cement	431	381	336	481	425	375	539	476	420
FA	832	714	698	789	676	664	738	631	625
CA	809	1068	1214	809	1067	1214	809	1068	1213
TA	1641	1782	1912	1598	1743	1878	1547	1699	1838
TA/C	3.81	4.68	5.69	3.30	4.10	5.01	2.87	3.57	4.38
FA/C	1.93	1.87	2.08	1.64	1.59	1.80	1.37	1.33	1.49
FA/TA	0.51	0.40	0.37	0.50	0.39	0.35	0.48	0.37	0.34

For British Standard

	30 MPa			35 MPa			40 MPa		
	For 10 mm nominal max aggregat e size	For 20 mm nominal max aggregat e size	For 40mm nominal max aggregat e size	For 10 mm nominal max aggregat e size	For 20 mm nominal max aggregat e size	For 40mm nominal max aggregat e size	For 10 mm nominal max aggregat e size	For 20 mm nominal max aggregat e size	For 40mm nominal max aggregat e size
Cement	362	326	297	403	363	331	439	395	360
FA	834	746	668	798	677	637	764	665	609
CA	904	1073	1240	900	1105	1237	897	1085	1233
TA	1738	1819	1908	1698	1782	1874	1661	1750	1845
TA/C	4.80	5.58	6.42	4.21	4.91	5.66	3.78	4.43	5.13
FA/C	2.30	2.29	2.25	1.98	1.87	1.92	1.74	1.68	1.69
FA/TA	0.48	0.41	0.35	0.47	0.38	0.34	0.46	0.38	0.33

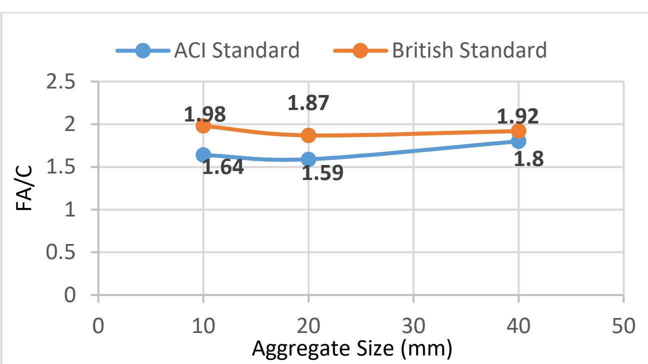

Figure 9 Fine aggregate to cement ratio obtained with different mix design standard.

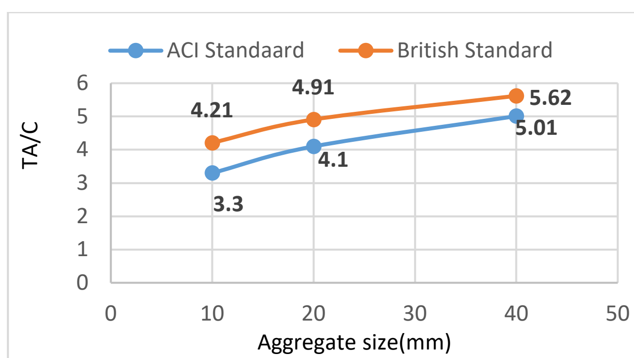

Figure 10 Total aggregate to cement ratio obtained with different mix design standard.

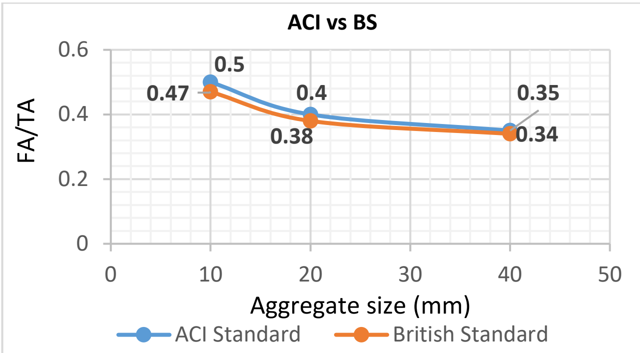

Figure 11 Fine aggregate to total aggregate ratio obtained with different mix design standard.

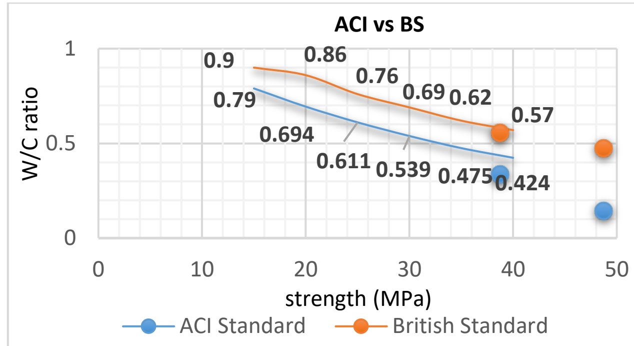

Figure 12 Water to cement ratio vs strength obtained with different standard.

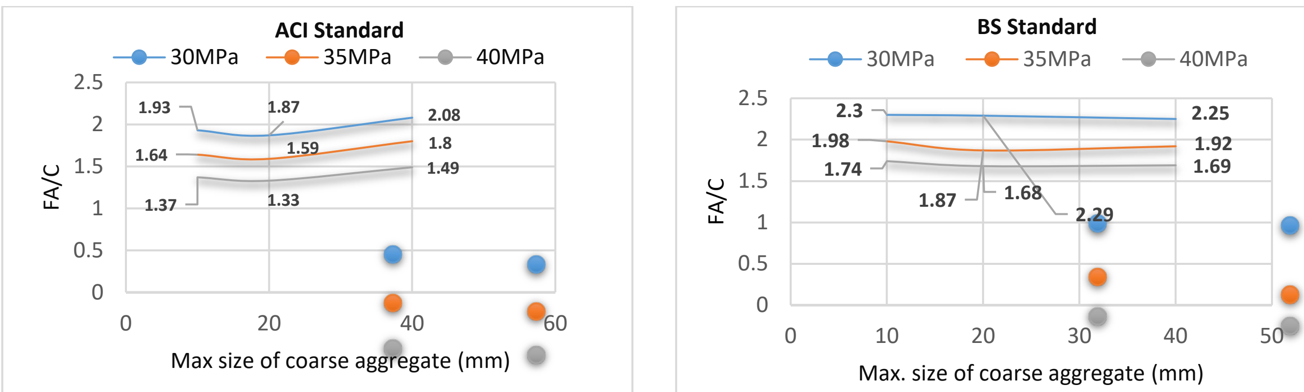

Figure 13 ACI vs BS for Fine aggregate to Cement ratio vs Max. size of coarse aggregate.

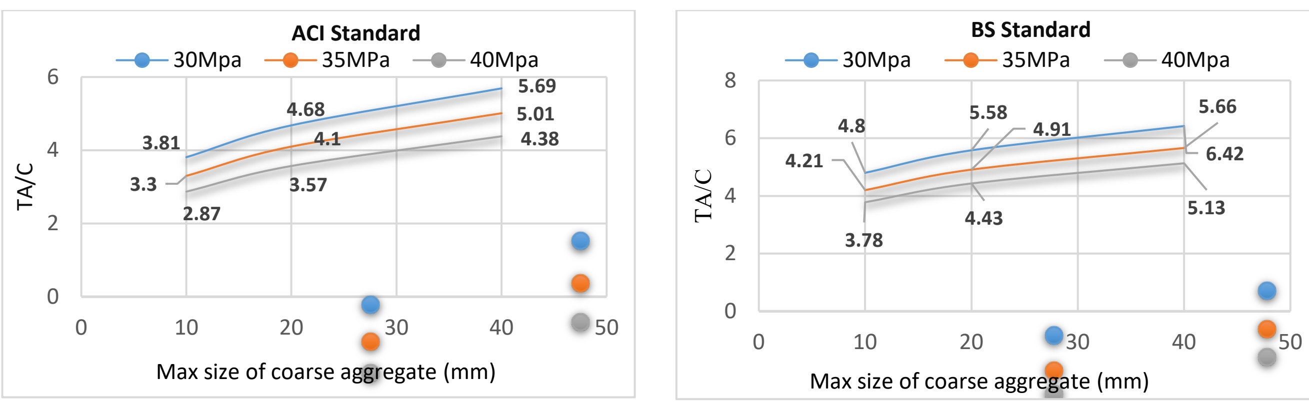

Figure 14 ACI vs BS for total aggregate and cement ratio vs max size of coarse aggregate

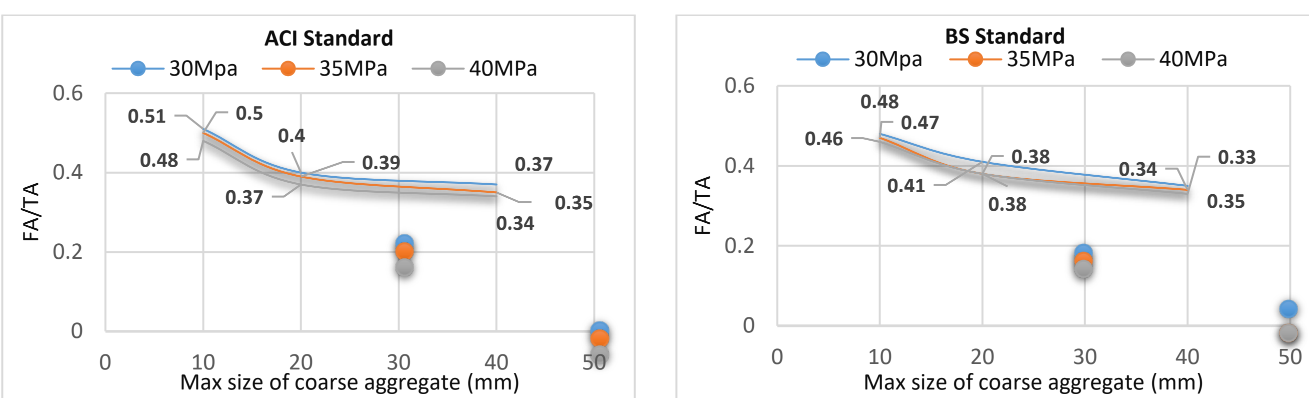

Figure 15 ACI Vs BS for fine aggregate and total aggregate ratio Vs Max. size of coarse aggregate

The aggregate to cement ratio is absolutely essential because it is utilized to produce optimal, workable and cohesive concrete from a set of locally accessible concrete materials. From figure 14, Strength decreases when the total aggregate to cement ratio increases in the ACI and British Standard and vice versa. In this case, M30 grade concrete has larger total aggregate to cement (TA/C) ratio than M35grade concrete. The higher the aggregate to cement ratio, the lighter the concrete mix since the cement concentration is lower. The quantity of total aggregate is steadily increased in the ACI Standard, whereas the value of cement decreases for nominal aggregate sizes of 10 mm, 20 mm and 40 mm. As a result, the total aggregate to cement ratio tends to grow. This is also clear in the case of the British Standard. For ACI and British Standard with a strength of 30 MPa, the greatest total aggregate to cement ratio is achievable. Maximum strength is available in concrete at 30 MPa, 35 MPa and 40 MPa for coarse aggregate sizes of 40 mm nominal maximum. When comparing the ACI and British Standard, it's clear that the British standard's total aggregate to cement ratio is higher than the ACI Standard. As a result, ACI has higher strength than British Standard. Concrete mixes are compacted with the help of aggregate materials. They also save cement and water while increasing concrete's mechanical strength, making them an important part of the construction and maintenance of rigid structures.

From figure 15, it is observable that the fine aggregate to total aggregate ratio gradually declines for 30 MPa, 35 MPa and 40 MPa under the ACI and British Standard, which are inversely proportional. For greater strength, the fine aggregate to total aggregate ratio should be lower. To enhance the fine aggregate to total aggregate ratio, increase the amount of fine aggregate while decreasing the amount of total aggregate. In order to reduce the fine aggregate to total aggregate ratio, the amount of fine aggregate must be reduced while the amount of total aggregate must be raised. Compactness and durability are increased in concrete with a greater fine aggregate to total aggregate ratio. As a result, having a greater fine aggregate to total aggregate number is beneficial. For coarse aggregate with nominal maximum sizes of 40 mm, 20 mm and 10 mm and strengths of 30 MPa 35 MPa and 40 MPa, the fine aggregate to total aggregate ratio steadily decreases. As a consequence, the 30 MPa strength has greater durability and compactness. Also, ACI has a higher FA/TA value than BS, hence ACI is superior than BS in terms of durability and compactness. Higher FA/TA indicates more fine particles to fill the pores (Lin, 2020). The impact of FA/TA (fine aggregate to total aggregate) on compressive strength was investigated and it was revealed that compressive strength increases as fine aggregate volume increases (Mohammed et al., 2017). An excessive amount of fine aggregate volume reduces the workability and performance of the concrete. Other studies have found that when the coarse aggregate concentration improves, the compressive strength of concrete increases until it reaches a critical volume (Ruiz 1966). These findings suggest that there may be an ideal fine aggregate to total aggregate ratio for achieving the greatest compressive strength of concrete. This ratio is also predicted to regulate the durability aspects of concrete such as carbonation and chloride intrusion (Uddin et al., 2020). The fine aggregate to total aggregate ratio is crucial when analyzing designing a concrete mix. The percentage of sand to coarse aggregate in total aggregate varies according to sand fineness. A fine sand minimizes the sand requirement percentage in the overall aggregate proportion. A coarse sand, on the other hand, will require a greater sand percentage in the overall aggregate proportion to produce a cohesive concrete mix.

4.0 CONCLUSION

Concrete mix design is influenced by a variety of aspects that must be addressed in order to get the optimum results, but they also exhibit distinct individual impacts for different standards.

- According to the findings, a constant slump value and fixed target strength combined with a variable of nominal maximum coarse aggregate size has no effect on the water to cement ratio. The w/c remains the same in both the ACI and British Standard. The amount of cement, water, fine aggregate decreases with increase of coarse aggregate.
- ACI and British Standard mix design (35 MPa) for different slump value(75mm) with same size of coarse aggregate (20 mm) found water and cement content are increasing whereas fine aggregate content is decreasing for both standard.
- When the aggregate to cement ratio is decreased, the workability increases because the amount of water compared to the total surface of solids increases.
- Additions in cement content per unit volume of concrete will also increase the water content per unit volume of concrete, enhancing the workability of concrete for a given water to cement ratio. Concrete's workability improves as its cement content rises, making it more appropriate for use in construction.
- To make the concrete mix design lighter, it is necessary to reduce the density of cement.
- The lower the density of cement, the higher the aggregate to cement ratio.
- The volume of fine aggregate must be reduced to enhance the workability and performance of concrete. As the British Standard has a lower fine aggregate to total aggregate ratio than the ACI Standard, it has more strength.
- The amount of total aggregate is less in ACI Standard than British Standard. So, British Standard for the concrete mix design is the most costly mix design method.

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