Characteristics of Fresh Cement and Concrete Mixes made from Different Cement Brands in Ghana

Abstract

The reliance on inferior on cement products for the construction of housing projects and other civil engineering infrastructural facilities has led to a number of building and other structural failures in Ghana over the years. The manufacturing of concrete utilized in the building of various structural member, such as columns, beams, slabs, footings and wall, was negatively impacted by the use of low-quality cements, rendering them unable to sustain any loads placed on them. Another observation made from the cement used was the inadequate proportioning of the chemical compounds during the manufacturing process which has negatively affected the setting of the concrete contributing to poor performance of structural elements in buildings and other infrastructural projects. In this research, the impacts of the variations in chemical constituents including SiO_2, Al_2O_3, Fe_2O_3, Na_2O, K_2O, CaO, MgO, and SO_3 in the different brands on setting times of cement and workability of fresh concrete were examined. The Vicat apparatus and the slump apparatus set-ups were used to measure the setting time and concrete workability respectively. It was found that the majority of the chemical compounds of the various cement brands evaluated in this research provided appreciable setting time as well as typical and acceptable consistencies. Most cement brands showed initial and final setting times between 30 and 271-306 minutes for cements in the 32.5R class. The initial and final setting times generated by the test were likewise observed to fall within 30 minutes and between 172-263 minutes, respectively, in the 42.5R class of cements, where a similar pattern was also

observed. It was noted that for the same water-cement-ratio in all the concretes from the different brands of cement, good workability was obtained.

Key words: Concrete, Setting time, Workability, Compressive strength, Brands of cements.

1. Introduction

Concrete has been used globally over several decades for the construction of civil engineering projects and continue to be the ultimate building material for infrastructural development (Okumu *et al*., 2017). Since its application in civil and structural works, it has demonstrated durability and strength over time lasting for several decades. It is a sturdy substance that has a strong compressive strength but weak tensile strength. Though, it is a strong material with unique qualities yet there are deformities observed when used in structural applications. There is some evidence of cracks detected in the physical qualities of concrete when tensile stresses are applied. In general, cracks make structures more vulnerable to external effects, accelerate the ageing process and can immediately reduce the mechanical resistance of the structure. Therefore concrete must be produced with the requisite aggregates in order to serve the intended purpose so as to resist tensile stresses brought on by bending forces from applied loads that might potentially cause cracking and ultimately lead to the failure of structures (Masood Rafi and Murtaza, 2014). The development of cracks in concrete structures can largely be attributed to the poor setting time of concrete which makes them less durable to withstand stresses imposed on them (Mishra et al., 2022; Mohamad et al., 2022). As a result, many researchers have conducted investigations and observed that most chemical compositions of cement are not adequately proportioned to perform the requisite functions of cements (Akani et al., 2014); Akyem and Kankam, 2022a,b; Bhamere, 2016). The chemical compositions play vital role in the setting time and strength of both cement and concrete and insufficient quantity in the mix could lead the concrete to achieve poor strength. According to Oluyemisi *et al*. (2014), tricalcium silicate (C_3S) hydrates and hardens quickly, adding significantly to initial set and early strength, whereas tricalcium aluminate (C_3A) also hydrates, and hardens quickly, contributing to early strength of concrete. Testing for the setting time of concrete is frequently done to determine how well-developed the strength of fresh concrete is at typical temperatures. Contrarily, it was stated by Jaehyun and Taegyu (2019) that the SO_3 content should be less than 4% in accordance with European standard EN 197-1 (2000) because in cementitious systems, low SO_3 content cannot guarantee sufficient condensation delay, whereas high SO_3 content has a significant impact on the cement strength and dimensional stability. Additionally, it was found that a matrix with an ideal SO_3 composition guarantees maximal strength, little matrix shrinkage, and minimal matrix expansion in water. Patel and Mohanty (2016) conducted a comparative examination of the chemical and physical characteristics of a tiny cement plant and a large cement factory. The goal of their research was to examine the chemical and physical properties of cement and concrete. They revealed that cement setting time was inversely related to the lime saturation factor. They found that higher CaO produced higher lime saturation factor, which finally leads to considerably shortened setting time. Moreover, Arimanwa et al. (2016) found that the larger the total of ($CaO + SiO_2$) and (CaO/SiO_2) of a cement sample, the higher the compressive strength of concrete that can be made from it. They claimed that BS 12's (1996) restriction on the ratio of lime to silicon dioxide is intended to ensure that the amount of silicon dioxide is significantly less than that of lime so that the setting of concrete is not hampered. They also discovered that aluminum oxide (Al_2O_3) helps cement paste set quickly, with cement samples containing the most Al_2O_3 exhibiting the quickest initial setting of cement paste. Sulfur trioxide was also found to speed up cement paste's setting time and contributed to its soundness. In a similar investigation, Oduniyi et al, (2018) confirmed the finding that cements that contain greater contents of aluminum oxide (Al_2O_3) and sulfur trioxide (SO_3) set more quickly. Testing for setting times is frequently done to determine how quickly and at what temperature and humidity fresh concrete can become stiff enough to withstand certain regular conditions. A number of experimental research on the delay in concrete setting time have been undertaken over a long period of time to address the inadequacies that cause it. Tarun et al. (2002) examined the effects of fly ash and chemical admixtures on the setting times of cement paste and concrete and found that the source and quantity of fly ash had a substantial impact on both the initial and final setting times of concrete. Ten percent (10%) cement replacement had little to no impact on either the initial or final setting timeframes. The physical characteristics of a few chosen brands of Portland cements sold on the Libyan markets were compared in a study by Elbagermi et al, (2020). They examined the fineness, soundness, setting time, and compressive strength of cements produced by Libda, Al-Koms, Al-mergeb, and Al-borg factories in Libya, as well as several other foreign cements imported into the Libyan markets. Their research revealed that all of the evaluated cement brands' soundness values were below the 10 mm maximum permissible threshold. They also found that the fineness values for every brand examined are within the required specification limit (2500 cm^2/g). After all investigations, the author concluded that all of the cements could be used for standard construction work based on the findings of the compressive strength test. Adekunle (2013) studied the setting time of a few chosen cement brands utilized in Nigerian civil and building works. The cement brands including Dangote, Elephant, Burham, Diamond, and Purechem, were investigated. The authors aim was to ascertain whether the five standard brands of cement met the minimum requirements of setting. The results showed that all the five brands complied with the British Standard's standards for cement setting time. Burham Cement was found to develop quickest initial setting time of 100 minutes, and Dangote Cement had the slowest initial setting of 180minutes among the lot. There were just minimal differences between the main characteristics of the five brands (Adekunle, 2013). Onukwugha and Ibearugbulem (2016) also investigated the setting times of three A, B, and C-labeled cement brands that were chosen from Nigerian local markets. They found that the setting times of the three cement brands were different and that brand A’s final setting time of 355 minutes was the fastest.

The basic definition of the term "workability of concrete" is the ability of concrete to be handled, transported, placed, and compacted in position during the execution of building projects. The capacity of a fresh (plastic) concrete mix to fill the form or mould correctly with the desired work (vibration) and without compromising the quality of the concrete is known as workability (Sidharth and Rao, 2017). Concrete workability is a broad concept in concrete technology and a highly individualized phrase that refers to how quickly newly mixed concrete may be combined, set, solidified, and finished with the least amount of homogeneity loss (Sidhart and Rao, 2017). The amount of meaningful internal work required to generate complete compaction, uniformity, mobility, and compactibility, is what Bhattaral (2019) defined as "workability." When opposed to a lean mix of concrete that has the appropriate workability but uses very little water, a higher strength is obtained depending on the water cement ratio in the concrete mix (Gill and Kumar, 2015). The Slump Test, Compaction Factor Test, and Vee-Bee Consistometer Test are three empirical methods of study that can be used to conduct workability tests. Using air-entraining and water-reducing admixtures will make concrete easier to work with. Generally speaking, air-entraining raises the cement paste volume and enhances the fluidity of the concrete while lowering bleeding and segregation (Rawarkar and Ambadkar, 2018). Water-reducing admixtures spread out the cement's particles and make it easier to work with, which improves consistency and lessens segregation. Experimental research has been done to look into how cement's workability for construction has changed over a long period of time. The workability of concrete, as measured by slump, is a crucial component of the concrete mixture and is commonly understood to affect a concrete mix's consistency, flowability, compactibility, and harshness (Nhat-Duc and Anh-Duc, 2016). According to Nhat-Duc and Anh-Duc (2016), construction engineers should adopt an accurate workability prediction as a practical requirement through the selection of aggregate sizes, concrete mix ratios, and cement, Ede et al. (2017) employed the prediction of fresh and hardened concrete properties of typical concrete to find out that one of the primary causes of buildings collapsing in Nigeria is attributed to inadequate concrete production.

The workability test in cement and concrete technology have been used in a variety of other investigations. It offers a handy framework that enables an analyst to pick a suitable technique that might be applied to test the strength of cements. Largeau et al (2018) studied how iron powder (Fe_2O_3) affected the strength, workability, and porosity of binary blended concrete. The cone Abrams method was used to assess the new composite concrete's workability. They found that the porosity reduced by 21.88% and 26.77% at 1.5 mass percent and 2.5 mass percent, replacement respectively, although the workability of the fresh concrete mixtures decreased when the amount of iron powder content increased. Rangare and Khatri (2018) investigated flexural strength of concrete beams containing silica fumes and fly ash as admixtures and coir fibres. They found that when silica fume was added to concrete in addition to coir fiber, the flexural strength of the concrete performed better than when fly ash with coir fiber was used. Zhang *et al*, (2020), compared the workability of concrete using the minimal paste demand and the closest packing density. They used the mix design method (MDM) to design the workability of concrete containing three grades of stone. In their findings, the proportion of stone that corresponded to the smallest paste demand could satisfy the need for the packing density that was the closest to that proportion. Researchers found that while paste thickness and mortar thickness do not reach their respective extreme levels when workability achieves their maximum value, they do not reach their respective minimum values either. When assessing concrete workability, it is necessary to take into account the combined effect of the workability of paste and mortar respectively, in order to produce the concrete workability. Ajay and Girish (2015) concluded from their study on fresh concrete on workability that concrete's rheological qualities were what made it workable, overcoming the limitations of more conventional empirical tests like the slump test. The rheological characteristics of freshly-poured concrete are defined by Bingham parameters in terms of two physical variables, namely; yield stress and plastic viscosity. The workability of concrete has been the subject of numerous empirical studies over the years, but cutting-edge scientific research is still being undertaken utilizing a variety of techniques to make concrete workable for a variety of uses in civil and construction projects. For instance, Amziane et al, (2005) evaluated the workability of freshly mixed Portland cement concrete while it was still in the mixing truck by identifying key rheological parameters (plastic viscosity and yield stress). They investigated nine concrete mixtures with various yield stresses and plastic viscosities in a concrete mixing truck. The shear rate in the mixing truck was swept from high to low by altering the rotation speed of the drum, and the measurements taken using the truck were based on the conventional way of evaluating the flow behavior in a traditional fluid rheometer. Ahmed and Yehia (2022) provided a traditional technique evaluation of the workability and structuration rate of locally created 3D printed concrete. A cutting-edge building technique that has the potential to expand the construction sector is 3D printing of concrete. Igbal and Malhotral (2018) conducted studies to investigate the impact on the workability of self-compacted concrete when regular Portland cement was partially replaced by fly ash and brick dust in equal proportions. The key criteria used in the experimental testing to determine if self-compacting concrete was workable were the diverse materials that were readily available locally.

In order to use concrete efficiently for construction in Ghana, it is important to look at the effects of the different types of cement available on the market. For these reasons, previous works investigated the effects of chemical composition of concrete made from the cements (Akyen and Kankam, 2022a,b; Bediako and Amankwah, 2015). The aim of the project study was to look at the impact of a few specific brands of cement that are used for different types of infrastructure construction in Ghana on the properties of fresh cement paste and concrete.

2. Materials and Methods

2.1 Materials

The materials employed in this study included aggregates (coarse and fine), cement from six different brands namely, Ghacem, CIMAF, Dangote, Supacem, Diamond, and Sol. Cement brands such as Ghacem, Dangote, CIMAF, Diamond, Sol, and Supacem, however, come in several classes. For example, Class 32.5R, Class 42.5R, and Class 42.5N for Ghacem, and Class 32.5R, Class 42.5R Ultimate Plus, and Class 42.5R Smart Superior for the CIMAF brand, respectively. Class 32.5R and Class 42.5R cements brands available in both Supacem and Sol cements were used in the study, the same mix proportions and water-cement ratio were used in the mix for all the cement.

2.2 Experimental methods

2.2.1 Setting times test

2.2.1.1 Initial setting time of cement

The experiment was carried out in a controlled, temperature laboratory using Vicat equipment (fig 1) to measure the standard consistency, initial and final setting times of the cement paste. The cement pastes were placed in a metallic mould. An electronic scale was used to weigh a sample of 500g of cement. Potable water ranging from 25 to 35 percent of the cement weight was measured using a measuring jay. The water was added to the measured cement and combined until the cement paste gained standard consistency. The mould filled with cement paste was placed under a needle fitted to the Vicat apparatus for the test. The bottom of the needle was lowered such that it touched the top of cement paste filled in the mould. The locking pin was removed from the top and quickly the needle was released allowing it to penetrate the cement paste. At the initial stage, the needle penetrated and touched the bottom of the mould. The process was repeated quickly releasing the needle after every 5 minutes till the needle failed to penetrate the cement paste for about 5 mm measured from the bottom of the mould. The procedure was repeated until the needle when brought in contact with the test block and released failed to penetrate the test block beyond 5.0 ± 0.5 mm measured from the bottom of the mould. The period elapsing between the time when water was added to the cement and the time at which the needle failed to penetrate the test block to a point 5.0 ± 0.5 mm measured from the bottom of the mould was taken as the initial setting time.

2.2.1.2 Final setting time of cement

After the consistency of the paste was achieved, the reading from the Vicat apparatus was ensured that it was within 4mm to 8mm. The paste was then placed in a mould, leveled and placed in a container filled with water. At this stage, water was either added or reduced for the mix till the readings fall within 4mm to 8mm if the consistency did not fall within this range. The needle of the Vicat apparatus was replaced by a needle with an annular attachment. The cement was considered as finally set when upon applying the needle gently to the surface of the test block, it made an impression thereon while the attachment failed to do so. It was observed that the period elapsing between the time when water was added to the cement and the time at which the needle made an impression on the surface of test block while the attachment failed to make an impression was taken as the final setting time.

Figure 1: Vicat apparatus test setup for setting times

2.2.2 Workability of concrete

The slump test was used to determine the workability of concrete. The apparatus is a cone-shaped mold with a base diameter of 200 mm, a top diameter of 100 mm, and a height of 300 mm. The slump cone was well cleaned, lubricated, and then its larger base was set on a firm, flat surface once the concrete had been mixed. Three equal-volume layers of concrete were placed into the mold. Before filling in the subsequent layer, each layer was compacted with 25 strokes of a tamping rod. Excess concrete was removed and the top of the slump cone leveled after the third layer had been tamped down. The drooping cone mold was raised vertically upward and the change in height of the concrete was measured(fig 2). The slump was computed as the difference between the height of the slump cone and the height of the slumped concrete. The slump test was able to measure the workability of the concrete prepared from the various cement brands as appropriate water/cement ratio was used to give true slump of each concrete mix.

Figure 2: Laboratory investigation of workability test on concrete

3. Results and discussion

3.1 Initial and final setting times

The results of the initial and final setting times of the 32.5R and 42.5R brands of cements are presented in Tables 1 and 2 respectively. The chemical compositions of the cement brands obtained from an earlier study (Akyen and Kankam 2022a) have been summarized and presented in Table 3. The initial setting time for all the cement brands was found to be thirty (30) minutes irrespective of the brand and class and minor differences in their chemical components. However, appreciable differences were found in the final setting times of the various cements, for the 32.5R class of cements, the final setting time ranged from 254 minutes for DIAMOND brand to a maximum of 306 minutes for SOL cement. On the other hand, in the case of the 42.5R, the final setting time ranged from a minimum of 172 minutes for SOL to a maximum of 263 minutes for DANGOTE

Table1: Initial and Final Setting Times for 32.5R brands of cement

No	Cement	Class	Initial setting time (minutes)	Final setting time (minutes)	Interval (minutes)
1	CIMAF	32.5R	30	278	248
2	Diamond	32.5R	30	254	224
3	Ghacem	32.5R	30	271	241
4	Supacem	32.5R	30	295	265
5	Sol	32.5R	30	306	276

Table 2: Initial and Final Setting Times for 42.5R brands of cement

No	Cement	Class	Initial setting time (minutes)	Final setting time (minutes)	Interval (minutes)
1	CIMAF Smart	42.5R	30	257	227
2	CIMAF Ultimate	42.5R	30	247	217
3	Dangote	42.5R	30	263	233
4	Ghacem	42.5R	30	224	194
5	Sol	42.5R	30	172	142
6	Supacem	42.5R	30	246	216

The ratio of lime (calcium oxide) to silicon dioxide (SiO_2) of the 32.5R cements ranged from 1.44 for CIMAF to 2.53 for GHACEM as shown in Table 6. Foe cements with low lime to silicon-oxide ratio, that is on the high influence of silicon dioxide (CIMAF, SUPACEM and SOL) ranging from 1.44 to 1.82, the final setting time was relatively long (278 minutes to 306 minutes) compared to those within the ratio of 2.38 and 2.53 for DIAMOND and GHACEM. This confirms Arimanwa et al's (2016) interpretation of BS12 restriction on lime to silicon dioxide ratio. A similar trend is observed in the 42.5R brands in which the high content of lime in all brands (CaO) giving relatively high ratio of lime to silicon dioxide (SiO_2) in all cements reduced the effect of SiO_2 and resulted in an appropriately similar final setting times. The Al_2O_3 had no predictable influence on the setting times of the cement for 32.5R. Ghacem cement had the highest Al_2O_3 content of 5.80 percent while the highest value of 7.92 percent was registered by CIMAF (Akyen and Kankam, 2022a). On the other hand, for the 42.5R brands, the lowest and highest percentages were 3.78 and 5.38 for Dangote and CIMAF cements respectively. The trend of the AL_2O_3 levels of content again had no significant influence on the setting times. The results of the present investigation do not confirm the findings by Arimahwa et al. (2016) that Al_2O_3 helps cement paste set quickly.

Table 3: Chemical Compounds of 32.5R Brands of Cements (Akyen and Kankam, 2022a)

Chemical Compounds	Percentage (%)				
	Ghacem 32.5R	Diamond 32.5R	CIMAF 32.5R	Supacem 32.5R	Sol 32.5R
SiO_2	22.90	23.70	32.80	28.90	26.60
Fe_2O_3	4.55	2.34	4.45	4.52	7.68
CaO	58.00	56.40	47.20	51.10	48.50
Al_2O_3	5.80	6.99	7.92	7.49	7.45
MgO	3.34	5.90	2.07	2.94	2.85
SO_3	3.46	2.52	2.77	2.63	4.09
Na_2O	0.00	0.00	0.00	0.00	0.00
K_2O	0.61	0.584	1.52	1.12	0.899

Table 4: Chemical compounds of 42.5R Brands of Cements (Akyen and Kankam, 2022a)

Chemical Compounds	Percentage (%)					
	CIMAF Smart Superior 42.5R	CIMAF Ultimate Plus 42.5R	Dangote 42.5R	Ghacem 42.5R	Sol 42.5R	Supacem 42.5R
SiO_2	22.90	24.40	15.70	22.10	22.10	21.50

Fe_2O_3	3.59	3.77	3.49	4.04	5.18	4.17
CaO	60.90	59.20	70.10	61.10	59.80	61.50
Al_2O_3	5.09	5.38	3.78	5.20	5.18	5.36
MgO	2.05	2.37	1.08	3.25	1.78	3.22
SO_3	3.43	2.85	4.13	2.51	3.47	2.39
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	1.04	0.85	0.773	0.68	0.889	0.766

Table 5a: Combined Chemical Compounds of 32.5 Brands of Cements (Akyen and Kankam, 2022b)

Chemical Compounds	Percentage (%)				
	Ghacem 32.5R	Diamond 32.5R	CIMAF 32.5R	Supacem 32.5R	Sol 32.5R
$CaO + SiO_2 + Fe_2O_{3+} Al_2O_3$	91.25	89.43	92.42	92.0	90.26
$CaO + SiO_{2+} + Al_2O_3$	86.7	86.99	82.76	87.49	82.55
$CaO + SiO_2$	80.9	80.1	80.0	80.0	75.1

Table 5b: Combined Chemical analysis of 42.5R Brands of Cements (Akyen and Kankam, 2022b)

Chemical Compounds	Percentage (%)					
	CIMAF Smart Superior 42.5R	CIMAF Ultimate Plus 42.5R	Dangote 42.5R	Ghacem 42.5R	Sol 42.5R	Supacem 42.5R
$CaO+ SiO_2 + Fe_2O_3 + Al_2O_3$	92.48	92.75	93.07	92.44	92.26	92.53
$CaO+ SiO_2 + Al_2O_3$	88.89	88.98	89.58	88.40	87.08	88.36
$CaO + SiO_2$	83.8	83.6	85.8	83.2	81.9	83.0

Table 6: Ratio of lime (CaO) to silicon dioxide (SiO_2)

Brand 32.5R	GHACEM	DIAMOND	CIMAF	SUPACEM	SOL	
CaO/SiO_2	2.53	2.38	1.44	1.77	1.82	
Brand 42.5R	CIMAF SMART SUPERIOR	CIMAF ULTIMATE PLUS	DANGOTE	GHACEM	SOL	SUPACEM
CaO/SiO_2	2.66	2.46	4.46	2.76	2.70	2.86

Table 7: Slump test of brands of cement

No	Cement	Class	Slump value (mm)	Class	Slump value (mm)
1	Ghacem	32.5R	68	42.5R	50
2	Diamond	32.5R	60		
3	CIMAF	32.5R	60	42.5R Ultimate Plus	68
4	CIMAF			42.5R Smart Superior	70
5	Supacem	32.5R	65	42.5R	55
6	SOL	32.5R	65	42.5R	55
7	Dangote			42.5R	75

3.2 Workability of concrete

The results of slump test of concrete mixes from the different brands of cement are presented in Table 7. Most cement brands produced concrete of same mix proportion and water-cement-ratio with high slump range of 60 to 68mm. Diamond (32.5R) and CIMAF (32.5R) recorded 60 mm of slump, and Ghacem (32.5R) had a measured slump of 68 mm, while Sol (32.5R) and Supacem (32.5R) both recorded slump of 65 mm. The various cement brands tested in the investigation showed good workability. However, there was a small variation between the various cement brands employed in this study. The values of slump produced in cements belonging to class 42.5R brands ranged from 55 mm to 75 mm. When compared to the other brands, it was found that the Dangote (42.5R) brand had the largest slump, measuring 75 mm. Sol (42.5R) and Supacem (42.5R) recorded slump values of 55 mm, while CIMAF Ultimate Plus (42.5R) and CIMAF Smart Superior (42.5R) brands both had values of 68 mm and 70 mm. When tested in the laboratory, Ghacem (42.5R) brand showed the least amount of slump. The approximately similar values of slump development by concrete mixes using the different brands of cement indicate good consistency and workability properties and that no vast differences existed between them.

Conclusion

Factors including the water-to-cement ratio, chemical compositions, and humidity all affect how quickly concrete sets. If the specific concrete produced is exposed to the external ambient conditions, for a prolonged amount of time, the consistency of the concrete will deteriorate. The various cement brands that were evaluated in this study provided appreciable setting times as well as regular and acceptable consistencies. For the 32.5R class of cements, the initial and final setting times were observed to fall within the range of 30 minutes and 254-306 minutes, respectively. Most cement brands initial and final setting times fell between 30 minutes and 271-306 minutes. The 42.5R cement brands initial and final setting times fell within 30 minutes and 172 to 263 minutes, respectively. In terms of workability of the different cement brands using same mix proportions and w/c ratio, there were a few slight differences that did not matter to the general requirements of concrete workability.

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