INFLUENCE OF CEMENT TYPES ON COMPRESSIVE STRENGTH AND TEMPERATURE OF NORMAL GRADE CONCRETE

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Abstract

C20/25 concrete is known as normal strength concrete which has the cylinder and cube strength of 20 MPa and 25 MPa respectively, and it is a common concrete grade used in buildings and infrastructures. This study has investigated the workability, compressive strength and concrete temperature prepared by four types of local cement namely 42.5 N OPC, 52.5 N OPC, 32.5 N PLC and 32.5 R PFAC. XRD analysis were underwent to determine the composition phases of the four types of cement. Based on the slump, Vebe time and compacting factor tests, the results revealed that the concrete cast with 32.5 N PLC has the highest workability, followed by 32.5 R PFAC, 52.5 N OPC and lastly the 42.5 N OPC. In terms of compressive strength, 52.5 N OPC concrete has recorded the highest value of the compressive strengths at every curing ages of 7 days, 28 days, and 56 days, followed by 42.5 N OPC, 32.5 R PFAC, whereas 32.5 N PLC achieved the lowest compressive strength. Besides, the concrete temperature results showed that the concrete cast with 52.5 N OPC obtained the highest peak temperature, followed by 42.5 N OPC, 32.5 N PLC, and the 32.5 R PFAC obtained the lowest concrete temperature. The concrete temperature results were tally with the amount of heat of hydration calculated based on the composition phases percentage determined by XRD and Rietveld Refinement method. In short, the study provides an insight for the cements used in production of normal strength concrete to achieve designated strength and temperature control.

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1.0 INTRODUCTION

In construction industry, concrete has been used for a period of over 20 decades due to its lengthy stability and durability. From the other perspectives, concrete also provides great energy performance, adaptability, and ecologically favourable requirements (Mojtaba, Azin and Omidreza, 2013). The performance of concrete is influenced by numerous factors, including component materials, mix proportions, curing conditions, and environmental considerations. Among these, temperature is a crucial environmental factor affecting concrete behaviour. Variations in temperature can significantly impact the strength development, durability, and overall performance of concrete during its curing and service life. Concrete temperature is influenced not only by the ambient temperature but also by the cement content in the mix, which can be managed to control the temperature. Concrete construction in Malaysia faces significant challenges due to the country's tropical climate, characterised by high humidity and substantial temperature fluctuations. The curing temperature plays a crucial role in influencing the strength development and durability of the concrete. Excessive heat during curing might cause thermal cracking and deterioration in durability. It becomes feasible to regulate the curing process properly while managing the concrete temperature within acceptable ranges through studying the concrete temperature in relation to different cement types. Understanding the strength and thermal characteristics of concrete is essential to prevent issues such as thermal cracking during the curing process (Poudyal, Adhikari and Won, 2021).

The characteristics of Portland cement are determined by the fineness of grinding and the relative quantities of four major chemical components, which account for approximately 90% of the cement by weight (Hamad, 1995). Tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF) are the principal compounds of cement (Neville, 2011). When cement reacts with water, a chemical reaction, which is known as the heat of hydration is released by cement, thus altering the temperature of the concrete (Miguel and Rui, 2008). It is important to ensure there was no tremendous amount of heat liberated as negative repercussions such as thermal cracking and reduced long-term durability may occur. Besides that, various types of cement are associated with distinct heat of hydration properties, which have an immediate impact on the temperature of concrete (Mojtaba, Azin and Omidreza, 2013). In the case study on temperatures and stresses due to cement hydration on reinforced foundation by Miguel and Rui (2008), the authors stated that the temperature of the concrete must be considered throughout the curing process. Therefore, in order to effectively regulate the curing process and maintain the concrete temperature within the acceptable ranges, it is critical to familiarise with the liberation of heat for each type of cement.

In Malaysia, there are limited study on concrete temperature and hydration heat in normal grade concrete used in buildings and infrastructure work, this research aims to study the strength properties and concrete temperature of C20/25 concrete that was prepared by various types of cement in Malaysia, namely the CEM I 42.5 N OPC, CEM I 52.5 N OPC, CEM II / B-L 32.5 N PLC and 32.5 R PFA cement. The fresh properties were evaluated through the fresh properties tests namely slump test, Vebe test, and compacting factor test. For hardened properties, compressive strength test was performed on concrete cubes at curing ages of 7, 28, and 56 days, and on concrete cylinders at 28 days. Additionally, concrete temperature test was conducted to determine the peak temperature generated by each concrete mix, and calculation for total heat of cement hydration was performed, whereas the phase compositions namely C_3S, C_2S, C_3A and C_4AF were determined through XRD scanning, and phase quantification by Rietveld refinement method (Karen, Ruben and Barbara, 2016; Evans and Evans, 2021).

2.0 DETAILS EXPERIMENTAL

This section describes raw materials preparation, screening of trial mixes, adopted method for workability test of fresh concrete, compression test of concrete cubes and cylinders, measurement of concrete temperature, and phase composition determination and quantification of various types of cement.

2.1 Raw Materials Preparation

The raw materials used in this research including cements, fine aggregates, 10 mm and 20 mm coarse aggregates and tap water.

Two types of local Ordinary Portland Cements and two types of local composite Cements were used in the study namely Ordinary Portland Cement- CEM I 52.5 N, Ordinary Portland Cement- CEM I 42.5 N, Portland Limestone Cement – CEM II / B-L 32.5 N, and lastly the 32.5 R Pulverised Fly Ash (PFA) Cement. These cements were sieved through a 300μm sieve opening to eliminate lumps and stored in an air-tight container before usage to prevent interaction with the external moisture (Lim *et al.,* 2024).

This research utilises the quartz sand, 10 mm and 20 mm coarse aggregates to produce the normal weight concrete. Both fine coarse aggregates were washed with clean water to remove debris and impurities, thereafter, dried under the sun prior to usage (Lim *et al.,* 2024). The sieve analysis was conducted in accordance with ASTM C33/C33M (2018) and the particle size distribution results are shown in Figure 1. The fineness modulus of 7.11 and 2.05 were obtained for coarse and fine aggregates respectively.

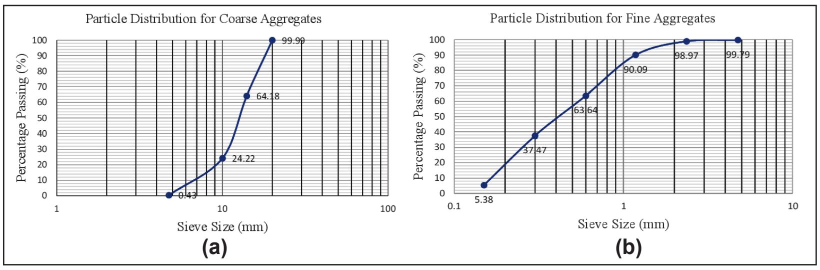

Figure 1: Particle size distribution of aggregates (a) Coarse aggregates; (b) Fine aggregates

Tap water that comply with the ASTM C1602/C1602M (2022) was used for the casting and curing process of the concrete.

2.2 Trial Mixes

Table 1 shows the mix proportions based on Design of Normal Concrete Mixes (2nd Edition) by Building Research Establishment (1997) for the trial mixes. The reference cement used for trial mixes was the 42.5 N local OPC. The water to cement ratio was adjusted from 0.63 to 0.72 to obtain cube compressive strength of 25 MPa. The concrete cubic specimens in trial mixes were prepared and underwent the compression test. Based on the compressive strength of trial mixes using 42.5N OPC depicted in Table 2, an optimal mix proportion of the reference cement has been selected for comparison study on concrete strength and temperature with those mixes prepared with different types of local cement.

Table 1: Mix Proportions for trial mixes based on $1m^3$ concrete volume

W/C Ratios	Mix Proportion (kg/m³)				
	Cement	Water	Aggregate		
			Fine	10mm	20mm
0.63	357.1	225	632.8	375	750.1
0.67	335.8	225	676.1	367.7	735.4
0.72*	312.5	225	721	360.5	721

**Optimal mix proportion based on compressive strength results in Table 2*

2.3 Workability Test

Slump test conducted in this study complied with the standard of ASTM C143/C143M (2018). First, a cone-shaped frustum with 300mm high was used as the mould for the slump test. The mould, with a 200mm-diameter base and a 100mm-diameter opening at the top, was placed on a flat, smooth, nonporous base plate. Fresh concrete was then poured into the mould in three layers, with each layer comprising approximately one-third of the mould's volume. Each layer was uniformly tamped with 25 strokes using the rounded end of a tamping rod. Excessive concrete was removed, and the top surface levelled with a trowel. The mould was then slowly and vertically removed, allowing the unsupported concrete to slump. The slump cone was placed next to the slumped concrete, and the tamping rod was laid across the top of the cone. The slump value was measured as the difference between the height of the slump cone and the center point of the concrete slump specimen.

Vebe test conducted in this study complied with the standard of BS EN 12350-3 (2019). The slump cone was placed into the cylindrical metal pot of the container for slump test. The procedure begun by rotating the consistometer, positioning the glass disc rider attached to the swivel arm on the surface of the unsupported concrete inside the container. The vibrating machine was then activated, causing the concrete to consolidate within the container. The vibration continued until the original conical shape of the fresh concrete transitioned into a cylindrical form. The transformation was completed after the glass disc rider had been fully submerged in the fresh concrete, indicating the end of the compaction process. The duration of this entire process was recorded as Vebe Time.

Compacting factor test, which adhered to the BS EN 12350-4 (2019) has been conducted to determine consistency of the mixes. Fresh concrete was placed into the upper hopper using a hand scoop until it was filled and levelled. The trapdoor at the bottom of the upper hopper was opened, allowing the concrete to flow into the lower hopper. Then, the trapdoor of the lower hopper was opened, permitting the concrete to descend into a cylinder placed below. Excessive concrete above the cylinder's top level was trimmed and leveled with a trowel. The partially compacted concrete obtained was weighed and recorded. The fully compacted concrete was obtained through layered compaction with standard tamping rod. The compacting factor was computed by Equation (1) below.

$$Compacting\ Factor = \frac{Partially\ Compacted\ Concrete}{Fully\ Compacted\ Concrete} \quad (1)$$

2.4 Compression Test

The compression test conducted is complied with the standard of BS EN 12390-3 (2019) for cubic sample and ASTM C39 (2021) for cylindrical sample. The concrete samples were water cured for 7, 28, and 56 days, and subsequently the compression test were performed. The results were taken as average of triplicate.

2.5 Concrete Temperature Measurement

This temperature test which complies with ASTM C1064 (2017) was conducted to monitor changes in concrete temperature over a specified period. The temperature of freshly mixed concrete in lab scaled 250 mm concealed square mould (0.0156 m^3) was measured with a digital probe thermometer inserted at center of the fresh concrete. The temperature readings were recorded at 15-minute intervals for the first 2 hours, at 30 minutes intervals for the third hour, and at 1-hour intervals for the subsequent hours until the temperature dropped from peak temperature. The hydration heat generated by the four main cement compounds was computed based on the values in J/g recommended by Neville and Brooks (2010), which C_3S is 502 J/g, C_2S is 260 J/g, C_3A is 867 J/g and C_4AF is 419 J/g. Equation (2) below shows the calculation of total hydration heat released by cement in kilo Joule (kJ).

$$\begin{aligned} Total\ Hydration\ Heat\ (kJ) &= Cement\ used (kg) \times cement\ compound\ \% \\ &\times \quad heat\ generated\ by\ cement\ compound\ in\ \frac{J}{g} \end{aligned} \quad (2)$$

2.6 Chemical Composition Determination

The X-Ray Diffraction (XRD) test has been adapted to analyse the phase compositions presented in the studied cements in accordance with ASTM C1365 (2018). Each cement powder was packed into a sample holder and placed in the path of an X-ray beam scanning. The cement powder sample was scanned at diffraction angle of $2^θ$ from 5 to 85 degrees for 40 minutes. XRD raw data was generated, and subsequently Rietveld refinement method in HighScore Plus Software was adopted to perform phase identification and phase quantification for four major chemical compounds namely C_3S, C_2S, C_3A, and C_4AF in the cement sample.

3.0 RESULTS AND DISCUSSION

This section shows results of trial mixes, workability of fresh concrete, compressive strength of concrete cubes and cylinders, C20/25 concrete peak temperature, and hydration heat generated by various types of cement in this study. The results were discussed and justified accordingly.

3.1 Compresive Strength of Trial Mixes

Trial mixes with different water to cement ratio were conducted to determine the optimal water to cement ratio to be used in actual mixes. Table 2 illustrates the 7-day and 28-day compressive strengths of concrete cubes from three trial mixes tabulated in Table 1. Based on the results, the water-to-cement ratio of 0.72 was treated as optimal ratio for this study, as it yielded an average 28-day cube strength of 25.72 MPa, aligning closely with the designated strength, and more economical compared with the other two mixes.

Table 2: Compressive strength of trial mixes

W/C Ratios	7 Days Strengths (MPa)				28 Days Strengths (MPa)			
	1	2	3	Average	1	2	3	Average
0.63	24.37	22.72	23.56	23.55	36.20	33.93	34.86	35.00
0.67	20.09	22.21	23.11	21.80	30.10	30.19	31.22	30.50
0.72	18.45	20.76	19.57	19.59	25.10	26.44	25.63	25.72

3.2 Workability

The slump test results in Table 3 reveal the slump values are ranged between 100 mm and 175 mm, confirming the exceptional workability of the concrete. It's worth noting that the concrete cast with 32.5 N PLC recorded the highest slump value, reaching 173 mm. The finding by Poudyal, Adhikari and Won (2021) stated that when compared with OPC concrete, higher slump value was achieved by PLC at same w/b ratio. In blended cement systems with higher packing density due to well distribution of Nano limestone powder particles, less water is trapped between the particles, making more water available to lubricate the particles, increasing the flow and workability of the fresh cement paste (Knop, Peled and Cohen, 2014). The Vebe time and compacting factor in Table 3 below further proven that the 32.5N PLC mix possesses the highest level of workability.

Based on Table 3, the 32.5 R PFAC mix is ranked as the second most workable concrete among the all mixes. The slump tests, vebe test, and compacting factor test yielded values of 140 mm, 5.59 seconds, and 0.9734, respectively. The findings align with the study by Nkomo, Masu and Nziu (2019), which concluded that incorporating fly ash into concrete positively affects its rheological properties and enhancing workability. Fly ash increases the paste volume, enhancing plasticity and cohesion. Moreover, the spherical shape of fly ash particles acts as a lubricant at the aggregate interface, reducing friction and improving workability. Generally, a higher fly ash volume fraction correlates with superior workability in the concrete mix. The spherical morphology of fly ash particles also facilitates easier handling, placement, and finishing of concrete, promoting smooth flow within the mixture and significantly enhancing workability (Nkomo, Masu and Nziu, 2019). The both 42.5 N OPC and 52.5 N OPC mixes exhibited lower slump values, longer Vebe time, and lower compacting factor values compared with that of 32.5 N PLC and 32.5 R PFAC mixes.

Table 3: Workability test results of C20/25 concrete cast with different types of cement

Cement Types	Slump Value (mm)			Vebe Time (s)			Compacting Factor		
	1	2	Average	1	2	Average	1	2	Average
42.5 N OPC	118	112	115	6.98	6.54	6.76	0.9676	0.9719	0.9698
52.5 N OPC	124	129	126.5	6.03	5.87	5.95	0.9726	0.9682	0.9704
32.5 N PLC	175	169	173	4.57	5.24	4.91	0.9774	0.9804	0.9789
32.5 R PFAC	136	144	140	5.81	5.37	5.59	0.9708	0.9759	0.9734

3.3 Density

There were two types of densities studied in this research, namely the fresh and hardened density. Based on Table 4, it is observed that 52.5 N OPC had the highest values for both fresh and hardened density, followed by 42.5 N OPC, 32.5 R PFAC, and finally 32.5 N PLC. Comparing 42.5 N OPC and 52.5 N OPC, the concrete cast with 52.5 N OPC recorded the highest fresh and hardened densities of 2283.16 kg/m³ and 2258.17 kg/m³, respectively. This could be due to the higher specific gravity of 52.5 N OPC compared to the PLC and PFAC as shown in Table 4. Besides, Table 5 shows that 52.5 N OPC has the highest chemical compounds which may lead to fast chemical reaction, thus contribute to slight increase of density.

For the concrete cast using 32.5 N PLC, the lowest fresh and hardened densities were recorded at 2254.02 kg/m³ and 2245.04 kg/m³, respectively. The inclusion of Nano size limestone particles with smaller average size and higher surface area compared to OPC suggesting higher packing density of blended cement systems (Knop, Peled and Cohen, 2014; Poudyal, Adhikari and Won, 2021). However, limestone particles are lighter than cement clinker particles, potentially leading to a lighter concrete mixture overall (Knop, Peled and Cohen, 2014). Table 4 shows that the 32.5 N PLC obtained lowest measured specific gravity at 2.57. On the other hand, the concrete cast with 32.5 R PFAC showed slightly higher fresh and hardened densities compared to 32.5 N PLC concrete, at 2256.20 kg/m³ and 2248.00 kg/m³, respectively. Adabu, Mohammed and Shafiq (2017) stated that specific gravity of local fly ash is 2.30 while that of local 42.5 N OPC is 3.15. Experimental results in Table 4 reveal that 32.5 R PFAC has smaller SG than that of both OPCs, which resulted in a lighter density concrete mixture compared to that of OPC concrete.

Table 4: Fresh and hardened densities of C20/25 concrete cast with different types of cement

Types of Cement	Fresh Density (kg/m³)	Hardened Density (kg/m³)	Specific Gravity (SG)*
42.5 N OPC	2265.68	2253.43	3.22
52.5 N OPC	2283.16	2258.17	3.09
32.5 N PLC	2254.02	2245.04	2.57
32.5 R PFAC	2256.20	2248.00	2.62

**Le Chatelier Flask method was adopted to measure specific gravity in accordance with ASTM C188 (2023), the values are the average of two measurements.*

3.4 Compressive Strength of Actual Mixes

The optimal water to cement ratio was determined as 0.72 based on the trial mixes results. In actual mixes, both concrete cubes and cylinders were cast and tested for compression test. As depicted in Figure 1, concrete cast with 52.5 N OPC cement exhibited the highest compressive strength across all curing periods, followed by mixes with 42.5 N OPC, 32.5 R PFA, and 32.5 N PLC, which demonstrated the lowest compressive strength throughout the curing periods. The use of a higher strength class of cement typically results in concrete cubes with greater compressive strength (Gupta, 2019). Therefore, the results for the compressive strength tests accurately reflected the trend.

Based on phase quantification results in Table 6, it is evident that the 52.5 N OPC contains a higher proportion of cement clinker compared to that of 42.5 N OPC. Since cement clinker contributes to concrete strength, thus higher cement clinker content in 52.5 N OPC resulted in greater compressive strength than that of 42.5 N OPC. On the other hand, the compressive strength of the concrete cast with 32.5 N PLC were the lowest. Although both PFAC and PLC have similar total cement clinker content as shown in Table 6, but 32.5 N PLC mix possesses the lowest C3S compound. Wang (2018) mentioned that the reactivity of limestone powder is much lower compared to cement and fly ash. Besides, pozzolanic behaviour of PFAC further contributed to medium to long term strength gain through pozzolanic activity, which proven by strength development shown in Figure 2.

Based on Figure 2, the increase in 7-day strengths to 28-day strengths for 42.5 N OPC, 52.5 N OPC, 32.5 N PLC, and 32.5 R PFAC mixes were 64.05%, 59.54%, 29.36%, and 50.59%, respectively. When fly ash was used as a partial replacement for cement in the studied concrete, it decreased the compressive strength at the ages of 7-day and 28-day compared to that of the OPC mixes, which is tally with the findings by Poudyal, Adhikari and Won (2021). However, fly ash's pozzolanic behaviour contribute positively to the concrete's long-term compressive strength. The strength development results in Figure 2 show that the 32.5 R PFA mix exhibited the most significant increment in compressive strength from ages of 28 days to 56 days. Specifically, the compressive strength of 32.5 R PFAC increased by 38.15%, rising from 17.98 MPa to 24.84 MPa during the period. On the other hand, the percentage increments of compressive strength from ages of 28 days to 56 days for 42.5 N OPC, 52.5 N OPC, and 32.5 N PLC mixes were 14.19%, 11.38%, and 14.79%, respectively, which are lower than the increment of 32.5 R PFAC mix.

According to the results depicted in Figure 3 above, the 28-day compressive strengths of the concrete cylinders possessed a similar pattern to that of the concrete cubes cast with the four types of cement. The strengths increased in ascending order from 32.5 N PLC, 32.5 R PFAC, 42.5 N OPC mixes, and finally, 52.5 N OPC mix. Among these, the concrete cylinders cast with 52.5 N OPC exhibited the highest 28-day compressive strength at 23.47 MPa, while those cast with 32.5 N PLC showed the lowest 28-day compressive strength at 11.78 MPa. Generally, the strengths of the concrete cylinders were 85 to 90 percent corresponded to that of concrete cubes as shown in Table 5 below.

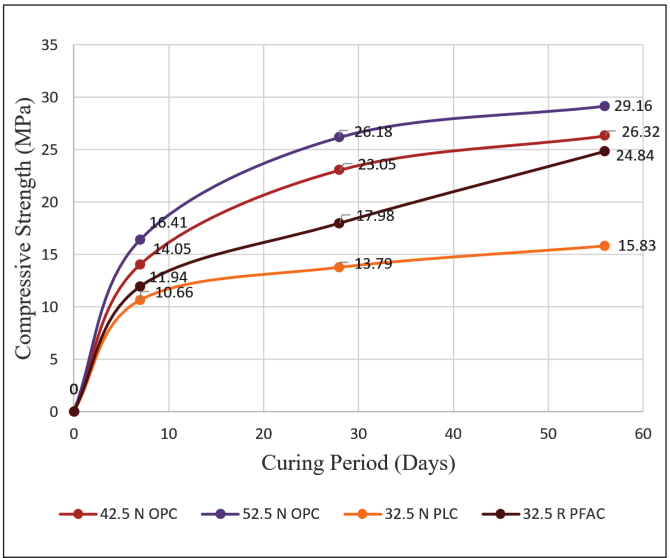

Figure 2: Compressive strength at 7, 28 and 56 days of concrete cubes cast with different cement

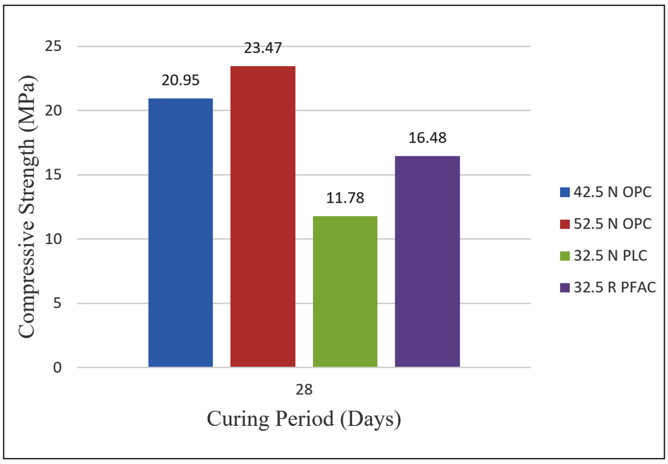

Figure 3: 28 days compressive strength of concrete cylinders cast with different types of cement

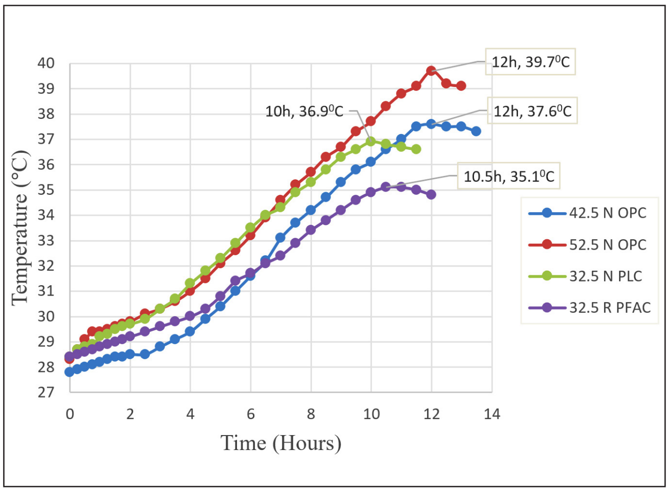

Figure 4: Temperature of concrete cast with different types of cement

3.5 Concrete Temperature

Based on optimal mix proportion shown in Table 1, at 0.72 w/c, cement used is 312.5 kg/m³. Thus, at 0.0156 m³ concrete volume, cement used in this study was 4.875 kg. It was evident that the concrete cast with 52.5 N OPC had reached the highest peak temperature of 39.7°C at 12 hours, and followed by 42.5 N OPC fresh mix reached its peak temperature of 37.6°C at 12 hours, 32.5 N PLC fresh mix reached 36.9°C at 10 hours, and lastly 32.5 R PFAC fresh mix obtained the lowest peak temperature of 35.1 °C at 10.5 hours. Based on Table 6, the increments of concrete temperature were recorded at 9.8°C, 11.4°C, 8.5°C and 6.7°C for 42.5 N OPC, 52.5 N OPC, 32.5 N PLC and 32.5 R PFAC fresh mixes respectively. Based on Table 7, it shows both ordinary Portland cement contain a greater proportion of tricalcium silicate (C_3S) and dicalcium silicate (C_2S) compared to both composite cements. The 52.5 N OPC possesses the highest amount of tricalcium aluminate (C_3A) and tricalcium silicate (C_3S), therefore accelerated the heat generation, leading to the highest peak temperature and highest temperature increment as shown in Figure 4 and Table 6 respectively. On the other hand, the PLC concrete recorded the 2nd lowest increment in temperature due to the lower C3S content compared to that of 42.5 N and 52.5 N OPCs. The incorporation of limestone powder has diluted the Portland cement clinker. Lastly, the fresh mix cast with 32.5 R PFAC recorded the lowest increment in temperature of 6.7°C due to the lowest C_3A and cement clinker content. A study by Nkomo, Masu and Nziu (2019) concluded that ground fly ash lowered the heat generated during hydration compared to pure cement.

Table 5: Comparison of cube strength and cylinder strength of C20/25 concrete cast with different types of cement

Types of Cement Mixture	28-Day Cube Strength (MPa)	28-Day Cylinder Strength (MPa)	Difference in MPa*	Cylinder Strength Corresponding to Cube Strength (%)
42.5 N OPC	23.05	20.95	2.10	90.89
52.5 N OPC	26.18	23.47	2.71	89.65
32.5 N PLC	13.79	11.78	2.01	85.42
32.5 R PFAC	17.98	16.48	1.50	91.66

**Compressive strength of concrete cube subtracts compressive strength of concrete cylinder*

As the proportion of fly ash in the concrete increased, there was a progressive reduction in heat release during hydration. Furthermore, the increased fly ash volume enlarged the surface area available for interaction, resulting in higher absorption of calcium ions. This increased absorption slowed down the accumulation of calcium ions in the early stages of hydration, thereby reducing the overall heat of hydration.

Table 6: Comparison of hydration temperature of C20/25 concrete cast with different types of cement

Types of Cement Mixture	Initial Concrete Temperature (°C)	Peak Concrete Temperature (°C)	Increment in Concrete Temperature (°C)	Increment in Percentage (%) *
42.5 N OPC	27.8	37.6	9.8	35.3
52.5 N OPC	28.3	39.7	11.4	40.3
32.5 N PLC	28.4	36.9	8.5	29.9
32.5 R PFAC	28.4	35.1	6.7	23.6

**Increment in °C corresponded to initial concrete temperature*

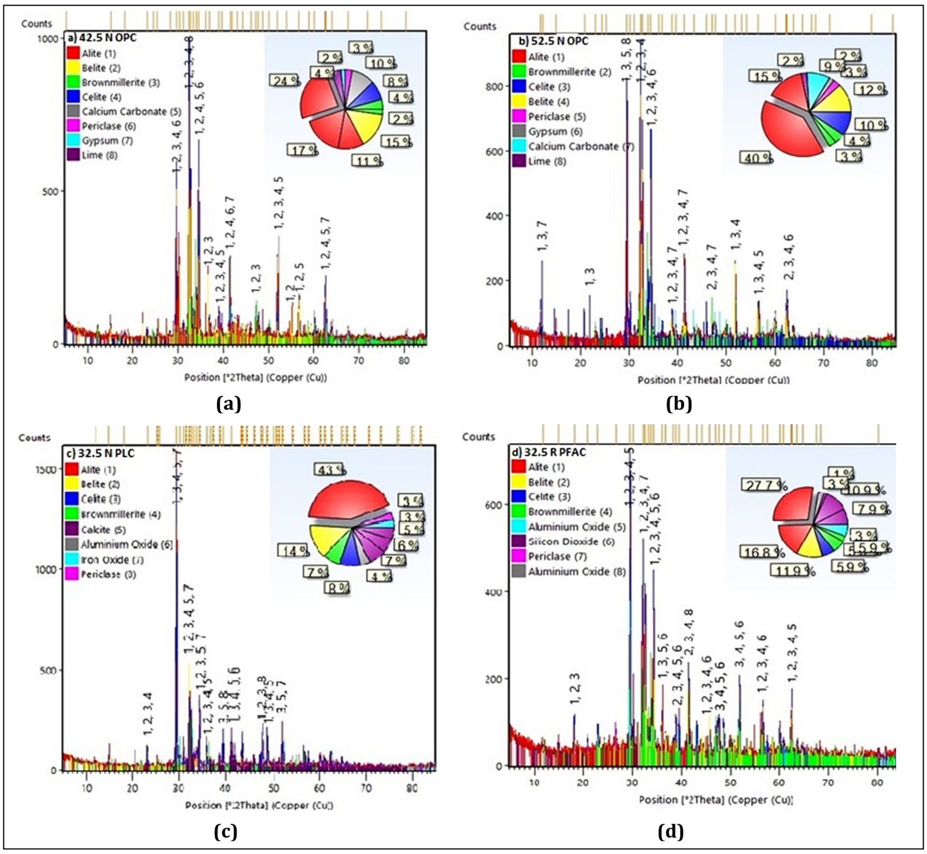

Figure 5: Phase composition of different types of cement powder. (a) 42.5 N OPC; (b) 52.5 N OPC;(c) 32.5 N PLC; (d) 32.5 R PFAC

3.6 Phase Quantification and Hydration Heat

XRD analysis was performed, and Rietveld refinement method has been adopted to determine the phase composition and quantification of respective cement powder as shown in Figure 5. The percentage of each chemical compound is crucial, as it was used to calculate the total heat of hydration generated by cements used in this study. The various types of cement used were assumed fully hydrated and the calculation of total hydration heat was computed using Equation 2 above, subsequently the results are presented in Table 7 below. Based on the results shown, the total heat of hydration for 52.5 N OPC is the highest, followed by 42.5 N OPC, 32.5 N PLC and lastly 32.5 R PFAC. The hydration heat results are tally with the respective peak temperature recorded in Figure 4 above.

4.0 CONCLUSION

Some conclusions can be drawn based on the study:

1. The incorporation of pulverised fly ash and limestone powder in concrete could increase workability of fresh concrete compared to that of the OPC mixes.
2. The incorporation of pulverised fly ash and limestone powder in concrete could slightly decrease fresh and hardened densities of concrete compared to that of the OPC mixes.
3. At the same mix proportion, compression test results revealed that 52.5 N OPC C20/25 mix exhibited the highest 28-day compressive strength among all cements, followed by 42.5 N OPC mix, 32.5 R PFA mix, and lastly 32.5 N PLC mix.
4. The compressive strength of the concrete cylinders from the studied mixes were 85 to 90 percent corresponded to that of concrete cubes.

Table 7: Chemical compounds and total heat of hydration of different types of cement

Types of Cement	C_3S Content (%)	C_2S Content (%)	C_3A Content (%)	C_4AF Content (%)	Total Cement Clinker (%)	Total Heat of Hydration (kJ)*
42.5 N OPC	52.0	15.0	8.0	6.0	81	1923.4
52.5 N OPC	55.0	12.0	14.0	11.9	92.9	2332.9
32.5 N PLC	43.0	14.0	8.0	7.0	72	1710.9
32.5 R PFAC	44.5	11.9	5.9	8.9	71.2	1671.0

**The calculated total heat of cement hydration is based on 0.0156 m^3 concrete volume, whereas 4.875 kg cement is used*

5. The incorporation of pulverised fly ash and limestone powder in concrete could reduce the peak temperature and temperature increment of concrete, whereas the dilution of principal compounds in the composite cements has reduced the total hydration heat generated by the cements.

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AUTHORS CONTRIBUTION

- **Siong Kang Lim and You Wai Kuan:** Conceptualisation, study design, and supervision.
- **Wai Mun Loke and Ze Long Lim:** Data collection, methodology, and formal analysis.
- **Ming Kun Yew and Jee Hock Lim:** Writing original draft preparation and literature review. ■

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