Influence of cement fineness on the performance of cement mortar

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ABSTRACT

This article investigates the influence of the fineness of cement on the properties of cement paste and mortar. The cement powder was prepared by grinding clinker obtained from a cement factory in Saraburi province, Thailand. Four different fineness levels were considered: standard cement (commonly available cement in the market), and cements passing through sieves of 325, 425, and 500 mesh. These were then mixed with gypsum at a ratio of 5% by weight (except standard cement) to form cement paste and mortar for testing various properties. The results indicate that finer cement particles result in increased specific surface area, faster reaction rate, and higher water demand for the reaction process. Moreover, the initial and final setting times of cement paste made from finer cement decrease. Conversely, the compressive strength of mortar made from finer cement increases. Additionally, early age development of strength (at 1 and 3 days) occurs more rapidly with mortars made from finer cement compared to the standard cement. These findings provide preliminary data for the development and improvement of cement quality to achieve desired properties in the future.

1. INTRODUCTION

Portland cement is a crucial component serving as a binder to integrate various aggregates in concrete. Due to its relatively low cost and favorable strength properties compared to other construction materials, it has gained widespread popularity and extensive usage in the construction industry. Consequently, there are numerous cement production plants distributed across almost every country globally. However, the production process of Portland cement is energy-intensive. Approximately 5% of the total energy consumption in the industrial sector is attributed to the production of Portland cement (World Energy Counc, 1995). Additionally, the process emits a significant amount of carbon dioxide (CO_2), accounting for roughly 5% of global CO_2 emissions (Worrell, *et al.*, 2001). The development of Portland cement with enhanced properties and efficiency is one of the avenues to reduce its usage in the construction industry. This reduction consequently mitigates energy consumption and CO_2 emissions associated with the

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Portland cement production process.

One significant property of Portland cement is its "fineness," which denotes the fineness of the cement particles and gypsum that have undergone the grinding process during production, or refers to the total surface area of Portland cement capable of hydrating reactions (Qureshi and Ahmed, 2011). Previous studies have indicated that the fineness of Portland cement influences several important properties of mortar and concrete. Portland cement with high fineness accelerates the hydration process, resulting in better early-age development of mortar and concrete compared to ordinary Portland cement. It can be demolded and gain strength faster (Ahmad and Qureshi, 2004). Portland cement with high fineness requires a higher water content to control its workability to be equivalent to ordinary Portland cement, which increases the risk of concrete shrinkage cracking (Neville, 1995). High-fineness Portland cement helps increase the density of concrete compared to using ordinary Portland cement (Chen and Kwan, 2012). Furthermore, it has been found that increasing the surface area of Portland cement by enhancing its fineness slightly affects the increase in the tensile strength of concrete (Bentz and Haecker, 1999). However, further research on the influence of cement fineness on various properties of mortar and concrete using cement from different sources is necessary because cement properties from different sources vary (Qureshi and Ahmed, 2011). Therefore, numerous researchers have studied various issues related to cement fineness (Li, *et al*., (2014); Ehikhuenmen, *et al*. (2019); Aghabaglou, *et al*. (2017); Moon, *et al*. (2017); Aydın, *et al*. (2009)).

This article examines the influence of cement fineness on the properties of cement paste and mortar. Cement powder was obtained by grinding cement clinker from a cement plant in Saraburi province, Thailand and sieving it through a specified sieve mesh. Gypsum was then added in a ratio of 5% by weight. The resulting mixture was used to produce cement paste and mortar for testing various properties, including the fineness of the cement powder, normal consistency, and setting time of the hydraulic cement. The development of compressive strength of the mortar was also investigated. The results of the study can serve as preliminary data for the development and improvement of cement quality to achieve desired properties in the future.

2. RESEARCH METHODOLOGY

2.1 Material used in this research

The materials used in producing cement paste and mortar samples in this research include cement clinker and gypsum. The details of the materials preparation are as follows:

<u>Cement clinker</u> is obtained from various raw materials such as calcium carbonate, limestone, marl, etc., which are finely ground and fired in a kiln at temperatures of around 1,500 degrees Celsius to form clinker. The cement clinker used in this study was obtained from a cement plant in Saraburi province. The clinker grinding process was conducted using a Los Angeles Abrasion Machine, followed by sieving to obtain the desired particle

size distribution. Fig. 1 illustrates the appearance of the clinker before and after grinding to achieve the desired fineness.

(a) Cement clinker before grinding (b) Cement powder after grinding

Fig. 1 Cement clinker before and after grinding to achieve the desired fineness.

Gypsum is a key ingredient in cement production, where it is added as a retarder to delay the setting of the cement and to facilitate the bonding of cement with other construction materials. The preparation process of gypsum involves grinding using a Los Angeles Abrasion Machine, similar to the preparation of cement powder. Subsequently, it is sieved to obtain the desired particle size. Fig. 2 illustrates the appearance of gypsum before and after grinding to achieve the desired fineness. In this study, the amount of gypsum added was controlled at 5% by weight of the cement.

(a) Gypsum before grinding (b) Gypsum after grinding

Fig. 2 Gypsum before and after grinding to achieve the desired fineness.

2.2 Details of specimen in this study

This study examines the influence of cement fineness on various properties of Portland cement and mortar. The study categorizes test samples into four types based on fineness:

Type 1: Samples produced from standard Portland cement available commercially in Thailand (General use Portland cement, rapid-hardening formulation). Samples in this group are denoted by the abbreviation 'STD'.

Type 2: Samples from high-fineness Portland cement passing through sieves of mesh sizes 325 and retained on mesh size 425. Samples in this group are denoted by the abbreviation 'C325'.

Type 3: Samples from high-fineness Portland cement passing through sieves of mesh sizes 425 and retained on mesh size 500. Samples in this group are denoted by the abbreviation 'C425'.

Type 4: Samples from high-fineness Portland cement passing through a sieve of mesh size 500. Samples in this group are denoted by the abbreviation 'C500'.

2.3 *Mixing ratios*

The cement paste mixing for the setting time determination followed ASTM C 191-08, (2021) 'Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needles' utilizes a water-to-cement ratio (W/C) that yields a normal consistency.

For mortar specimens, a water-to-cement ratio of 0.75 is employed to all specimens, as referenced from the flow rate test according to ASTM C230, (2023) 'Standard Specification for Flow Table for Use in Tests of Hydraulic Cement.' The flow rate is controlled to be 110 ± 5% of the specified rate. Additionally, the sand-to-cement ratio is maintained at 2.75.

2.4 Casting and curing of mortar

Fig. 3 illustrates the casting process and the casting of mortar. The casting procedure involves utilizing molds with dimensions of 50 x 50 x 50 mm. After casting, the specimens are placed in a temperature-controlled environment set at 23±2 degrees Celsius for a duration of 24 hours. Subsequently, the molds are removed, and the specimens are subjected to curing in water until the testing time.

Fig. 3 Mortar casting and samples after demolding.

2.5 Compressive strength testing

Compressive strength testing is conducted using mortar specimens measuring 50x50x50 mm, prepared for testing at ages of 1, 3, 7, 14 and 28 days. Three specimens are tested at each age. The reporting of test results is based on the average value of the three specimens. Testing is carried out in accordance with ASTM C109, (2016) 'Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.

3. STUDY RESULTS AND ANALYSIS

3.1 Cement fineness

The fineness of cement is tested using a Blaine air permeability apparatus according to ASTM C204, (2023) 'Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus'. The test results are presented in Table 1, indicating that as the cement fineness increases, the specific surface area also increases. Cement with fineness passing through sieves of mesh sizes 500, 425, 325, and standard cement have specific surface areas of 6,040, 4,910, 3,846, and 3,837 square centimeters per gram, respectively. Additionally, it can be observed that STD cement, which is commonly available in the market, and C325 cement have similar specific surface area values (not significantly different). This specific surface area affects the reaction rate, as finer particles result in a larger surface area and faster reaction rates.

Table 1. Specific surface area of cement with different fineness

Specimens	Specific surface areas (cm^2/g)
STD	3,837
C325	3,846
C425	4,910
C500	6,040

3.2 Normal consistency and setting time of Portland cement paste

The normal consistency and setting time of Portland cement paste were tested according to ASTM C187, (2023) 'Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste' and ASTM C191, (2021) 'Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle', respectively. Table 2 presents the quantity of water required to achieve normal consistency and the initial and final setting times of cement paste from samples with different fineness. It was observed that the water requirement for achieving normal consistency increased with the fineness of the cement. For instance, samples produced from commercial Portland cement in the market (STD), and cement passing through sieves of mesh sizes 325, 425, and 500, had water quantities for normal consistency of 27.0%, 27.5%, 30.5%, and 33.5%, respectively. This is attributed to the higher specific surface area of finely ground cement, which facilitates faster reaction rates and consequently necessitates more water for reaction.

The initial and final setting times of cement paste, as shown in Table 2 and Fig. 4, indicate that cement paste made from finer cement experienced shorter setting times.

For instance, the initial setting times for paste made from STD, C325, C425 and C500 specimens were 110, 100, 75, and 69 minutes, respectively. Similarly, the final setting times were 155, 145, 136, and 125 minutes, respectively.

Table 2. Water content for normal consistency and setting time of cement paste from cement samples with different fineness

Specimens	Water content (%)	Initial setting time (minutes)	Final setting time (minutes)
STD	27.0	110	155
C325	27.5	100	145
C425	30.5	75	136
C500	33.5	69	125

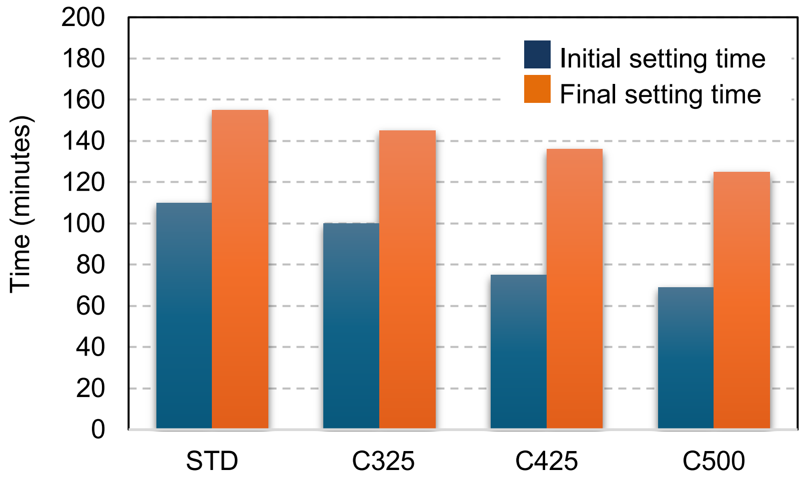

Fig. 4 Setting time of cement paste.

3.3 Compressive strength of mortar

The compressive strength testing of mortars made from Portland cement with different fineness was conducted using a water-to-cement ratio of 0.75 and a sand-to-cement ratio of 2.75. The specimens were aged for 1, 3, 7, 14, and 28 days, the test results shown in Table 3 and Fig. 5.

The study revealed that the compressive strength of the STD samples increased with increasing age. For specimens aged 1, 3, 7, 14, and 28 days, the compressive strengths were 127, 193, 234, 251, and 277 kilograms per square centimeter (kg/cm²), respectively.

The compressive strength of C325 samples also increased with age. For specimens aged 1, 3, 7, 14, and 28 days, the compressive strengths were 136, 197, 259, 261, and 292 kg/cm², respectively. When comparing the compressive strength development behavior with STD samples, it was found that C325 samples exhibited slightly higher compressive strengths, ranging approximately from 102-110% compared to STD samples.

Table 3. Compressive strength of mortar

Specimens	Compressive strength (kg/cm²) - (Percentage of compressive strength (%))				
	Ages of curing				
	1 day	3 days	7 days	14 days	28 days
STD	127 (100.0)	193 (100.0)	234 (100.0)	251 (100.0)	277 (100.0)
C325	136 (106.8)	197 (102.3)	259 (110.7)	261 (104.0)	292(105.4)
C425	155 (122.2)	260 (135.0)	283 (120.8)	292 (116.3)	324 (117.0)
C500	161 (127.1)	260 (135.1)	283 (120.8)	318 (126.7)	362 (130.7)

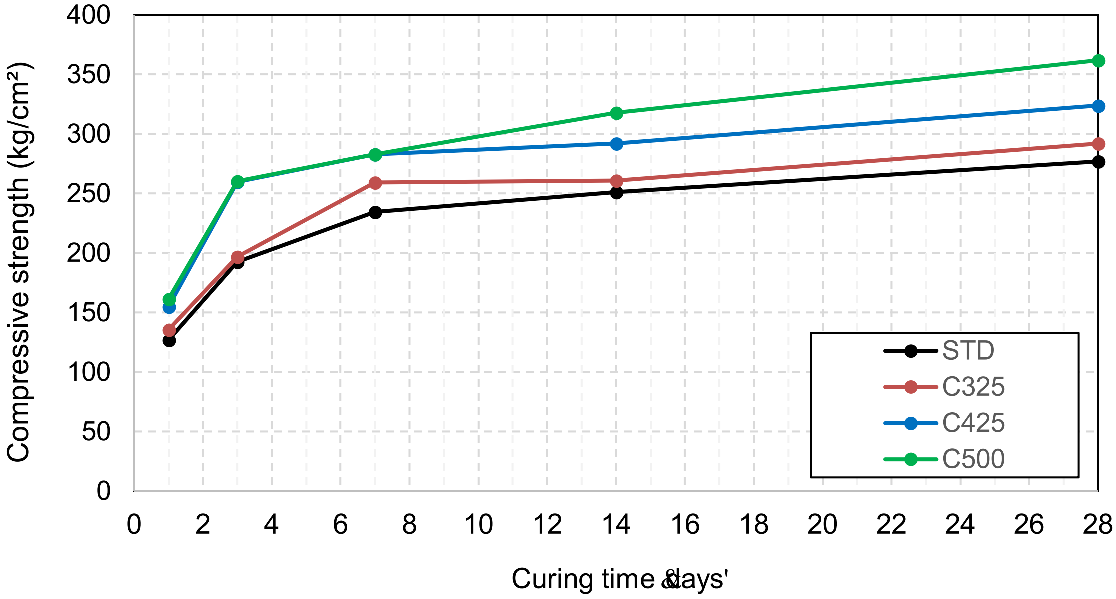

Fig. 5 Compressive strength of mortar specimens at different curing ages.

The compressive strength of C425 samples increased significantly with age. For specimens aged 1, 3, 7, 14, and 28 days, the compressive strengths were 155, 260, 283, 292, and 324 kg/cm², respectively. When comparing the compressive strength development behavior with STD samples, it was found that C425 samples had higher compressive strengths and exhibited rapid strength development, approximately 122, 135, 120, 116, and 117% compared to STD samples aged 1, 3, 7, 14, and 28 days, respectively.

The compressive strength of C500 samples also increased with age. For specimens aged 1, 3, 7, 14, and 28 days, the compressive strengths were 161, 260, 283, 318, and 362 kg/cm², respectively. The strength development behavior of this group was similar to that of C425 samples, with comparable strengths observed at 1, 3, and 7 days (early ages). However, at 14 and 28 days, C500 samples exhibited higher strength development compared to C425 samples. When comparing with STD samples, the compressive strength of C500 samples was approximately 127, 135, 121, 127, and 131% higher than STD samples aged 1, 3, 7, 14, and 28 days, respectively

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This article examines the influence of cement fineness on the properties of cement paste and mortar. Four different fineness grades of cement were considered: standard cement (commonly available cement in the market), and cement passing through sieves with mesh sizes of 325, 425, and 500. Cement pastes and mortars were prepared by blending the cement with gypsum at a ratio of 5% by weight, then tested to determine various properties.

The study found that increasing cement fineness resulted in higher specific surface areas and faster reaction rates. Specifically, the specific surface areas of standard cement and cement passing through sieves of 325, 425, and 500 were 3,837, 3,846, 4,910, and 6,040 square centimeters per gram, respectively.

The increased fineness of cement results in a higher demand for water in the hydration process. Upon considering the normal consistency values tested according to ASTM C187 standard, it was found that standard cements and cement with fineness passing through sieves No. 325, 425, and 500 require water quantities equivalent to 27.0, 27.5, 30.5, and 33.5 percent, respectively.

The initial and final setting times of cement paste made from finer cement decreased (became faster) compared to those made from coarser cement. For instance, the initial setting times of standard cement and cement passing through sieves of 325, 425, and 500 were 110, 100, 75, and 69 minutes, respectively, while the final setting times were 155, 145, 136, and 125 minutes, respectively.

The compressive strength of mortars made from finer cement was higher compared to those made from coarser cement. At 28 days of curing, mortars made from standard cement and cement passing through sieves of 325, 425, and 500 had compressive strengths of 277, 292, 324, and 362 kilograms per square centimeter, respectively, representing 100.0%, 105.4%, 117.0%, and 130.7% of the strength of mortars made from standard cement.

Furthermore, the compressive strength of mortars made from cement with higher fineness (C425 and C500) developed rapidly in the early stages (1 and 3 days of curing) compared to mortars made from standard cement. For instance, at 1 day of curing, the compressive strengths of C425 and C525 mortars were 122.2% and 127.1% of the strength of mortars made from standard cement, respectively. At 3 days of curing, the strengths were 135.0% and 135.1%, respectively.

4.2 Recommendations

This study employed the Los Angeles Abrasion Machine to grind cement clinkers and gypsum to achieve the desired fineness. However, the grinding process is time-consuming, limiting the quantity of cement prepared for testing. Consequently, concrete samples could not be tested due to the large volume of cement required. Therefore, future research should involve planning and adapting suitable grinding equipment to reduce grinding time and ensure an adequate supply of cement.

Furthermore, to comprehensively understand and improve the quality of cement appropriately, future studies should consider testing the chemical composition properties of cement from various sources. Additionally, other relevant properties should be tested, such as bleeding, the use of high-fineness cement with other additives, resistance to various conditions, and conducting tests on concrete samples produced from high-fineness cement.

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