Determination of Normal Consistency and Setting time of Portland Cement According to ASTM Standards

Lab Report

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A report presented for

The Civil Engineering Materials of Construction Course

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April 21, 2024

Abstract

Following the guidelines laid forth by ASTM, this report details the processes and outcomes of evaluating the typical consistency and setting time of Portland cement. Finding the ideal water-to-cement ratio that gives the cement paste the right workability may be done with the use of the normal consistency test. The setting time test gives information on how the cement will behave in practical situations by measuring how long it takes for the cement to go from a liquid to a solid. In order to guarantee quality and conformity with industry requirements, the results of these tests direct the actual use of cement in building.

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1 Introduction

Many different kinds of concrete rely on cement as its structural backbone, making it an essential component in the building industry. It is crucial to conduct comprehensive evaluations of cement qualities using standardised testing since they determine the quality and durability of the concrete. Important factors influencing the working and hardening stages of concrete include cement's initial and final setting durations, which in turn influence workability and the timing of finishing activities.

The typical Vicat setting durations and consistency of Portland cement are determined in this lab report in accordance with ASTM standards. If cement is to be trusted in building projects, it must undergo such standardised testing. By delving into these characteristics, the paper seeks to clarify the impact of hydration on setting times and to demonstrate a connection between cement consistency and the water-cement ratio.

2 Summary

Following closely to ASTM C187 and C191 standards, this laboratory report details the results of determining the typical consistency and setting time of Portland cement. The goal of these tests is to confirm that the cement meets the quality criteria needed for building, according to the study. To determine the appropriate water-to-cement ratio for achieving the specified consistency, the Vicat apparatus was used. Results from the tests show that the cement in question has the right consistency and sets properly. With respect to the real-world applications of Portland cement in building, this study details the procedures, analyses, and consequences of the results.

The techniques that were followed included making many samples of cement paste with different amounts of water to cement in order to determine the optimal mixture that would achieve the desired consistency. Next, we timed the first set (when the cement paste stopped flowing) and the final set (when the cement formed entirely) to get the setting time. In order to guarantee precision and reproducibility, these tests were carried out in a controlled setting. This cement is suitable for building applications, according to the results of these trials, which also show that it follows all the required standards.

3 Theory

3.1 Definitions

Definition 1 (Cement Consistency and Setting Times). A sample of Portland cement is represented by C. The proportion of water mass needed for a Vicat plunger to reach a certain depth in a given amount of time is called the consistency of C, sometimes written as $\kappa(C)$. Specifically,

$$\kappa(C) = \frac{m_w}{m_c} \times 100\%;$$

where m_w is the mass of water and $m_c = 650$ g is the mass of cement.

Under controlled environmental conditions, the initial and final setting times of a Vicat needle are described as $t_{\text{initial}}(C)$ and $t_{\text{final}}(C)$ respectively. These times are necessary for the needle to penetrate 25 mm and less than 1 mm from the surface of moulded cement paste.

Proposition 2 (Determination of Consistency κ). For each $i \in \mathbb{N}$ in the series of experiments (E_i), prepare a different m_w^i of cement paste and observe the penetration depth d_i after 30 seconds to determine the exact $\kappa(C)$ that allows the Vicat plunger penetration to meet the ASTM C187 standard. Define m_w^* as the mass satisfying

$$w^* = \arg\min_{w \in W} \{|d_{w,30}(10) - 10| \leq 1\}$$

Then, $\kappa(C)$ is obtained from m_w^* as above.

Proposition 3 (Initial and Final Setting Times). Let $f : \mathbb{R}^+ \to \mathbb{R}^+$ be a function mapping the time since mixing t to the penetration depth $d(t)$ of the Vicat needle. The initial setting time $t_{\text{initial}}(C)$ is the smallest t such that

$$t^*_{\text{initial}} = \inf\{t > t_0 : d_{w^*}(t) \leq 25 \text{ mm}\}$$

$$t^*_{\text{final}} = \inf\{t > t^*_{\text{initial}} : d_{w^*}(t) < 1 \text{ mm}\}$$

4 Methods

4.1 Experimental Design

Portland cement's typical consistency and setting time were subjected to stringent evaluations via the use of standardised test procedures in the experimental methodology. The first step in conducting setting time tests was to establish the cement paste's consistency. Then, the crucial characteristics for evaluating cement's practical applications—its initial and ultimate setting times—were determined. The goal of the design was to create an environment that was as controlled as possible while yet being very similar to the actual thing.

4.2 Materials

Portland cement, a substance widely used in building, was selected as the main material for the trials. In order to obtain the necessary consistency, each batch of paste in the trials needed 650g of cement combined with different percentages of water. The consistency test was conducted using a Vicat apparatus that had a 10mm10mm diameter plunger rod and a 1mm1mm diameter needle, while the setting time test was conducted using standard laboratory equipment. A mixing bowl, trowels, gloves, and water were also necessary for the operations since they were the liquid for mixing the cement paste.

4.3 Experimental Settings

To reduce the impact of any confounding factors, all studies were carried out in well controlled environments. To mimic the usual weather conditions in temperate regions, the temperature was kept between 20°C and 27°C, and the relative humidity was kept below 50%. These parameters must be satisfied for the cement paste to mimic its real-world behaviour. To provide precise penetration readings, the Vicat instrument was calibrated in accordance with ASTM standards. The Vicat equipment was used to precisely monitor penetration depths while the cement paste consistency was modified via trial and error. The thorough documentation of each experiment allowed for the verification and replication of each step using the standardised methodology.

5 Procedures

5.1 Mixing the Pastes

First, fill the mixing bowl with all of the water that is specified for the procedure. Then, 650 g of cement is added to the water and left for 30 seconds to absorb before mixing begins, which is marked as the beginning time. The first step is to whisk the liquid slowly for 30 seconds at a speed of 140 revolutions per minute. This is temporarily stopped for fifteen seconds so that you may scrape the edges of the bowl and return any paste to the mix by hand. To get a uniform paste, scrape the ingredients and then beat it at a medium speed of 285 revolutions per minute for one minute.

5.2 Molding Test Specimen

The cement paste is mixed and then rapidly formed into a rough ball using gloved hands. To keep it approximately spherical, it is thrown between the hands six times. To avoid pressing the paste too much, the mould is filled to the brim by pressing this spherical into a conical ring. Slicing the surface at a little angle with a trowel creates a level surface without compressing the material, which allows for the removal of excess paste.

5.3 Consistency Determination

The typical consistency may be found by positioning the plunger rod, which has a diameter of 10 mm, such that it touches the surface of the paste. The next step in starting a measurement is to tighten the set-screw located at the zero point of the scale. The rod should be able to slide easily into the paste once you let go of it. During this test, the device must not vibrate in any way. When the rod enters within 30 seconds after 10 minutes, normal consistency is proven. To reach the correct consistency, the water content is adjusted using trial pastes. The quantity of water is varied, and new cement is used for each experiment to ensure accurate testing.

5.4 Time of Setting Determination

After the paste is made, it has to be kept in a damp cabinet for at least thirty minutes without being stirred. The next step in the measuring procedure is to position the 1 mm diameter needle so it touches the paste's surface. After that, the needle is released and allowed to enter the paste. The amount of cement that has been absorbed is noted at the beginning of the experiment, and further readings are taken every fifteen minutes for regular Portland Cement and every ten minutes for Rapid Hardening Cement. The initial setting time is defined as the moment the needle penetrates less than 25 mm, and the test continues until then. When the needle hole in the paste disappears completely, it's time to call it set.

6 Analysis

6.1 Normal Consistency Data

Table 1: Results from three trials of normal consistency tests for Portland Cement.

Trial	Amount of Water (ml)	Starting Time	Penetration (mm)
First Trial	170	9:02	7
Second Trial	185	9:24	12
Third Trial	178	9:45	9

6.2 Setting Time Data

Table 2: Setting time data showing penetration over time for the test initiated at 9:45.

Time	Penetration (mm)
10:15	40
10:30	40
10:45	38
11:00	35
11:15	28
11:30	20
11:45	12
12:00	3
12:15	0

Algorithm 1 Analysis of Normal Consistency and Setting Time for Portland Cement

Data Definitions:
$\text{data}_{\text{normal}} = \{\text{water amounts}, \text{start times}, \text{penetrations}\}$
$\text{data}_{\text{setting}} = \{\text{start time}, \text{time series}, \text{penetration series}\}$
function ANALYZENORMALCONSISTENCY(data)
    Initialize DataFrame from data
    Adjust water amount based on penetration to find *water_adjusted*
    Calculate average of *water_adjusted* for desired 10mm penetration
    return average water needed
end function
function PLOTSETTINGTIME(data)
    Initialize DataFrame from data
    Convert times to datetime and compute time since start in minutes
    Plot time versus penetration using matplotlib
    Mark the 25 mm threshold
    Display plot
end function
average_water ← ANALYZENORMALCONSISTENCY($\text{data}_{\text{normal}}$)
Output "Average water needed for 10 mm penetration: average_water ml"
PLOTSETTINGTIME($\text{data}_{\text{setting}}$)

7 Results

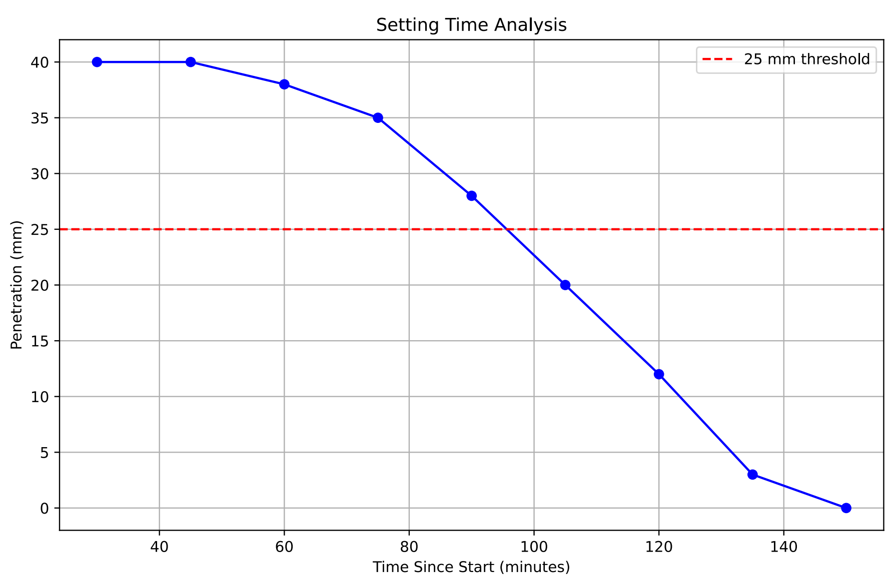

Figure 1: Plot of penetration depth versus time since start for Portland Cement; showing that the critical 25 mm threshold for initial setting time.

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Average water needed for 10 mm penetration:  198.27 ml
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Using the average water required for the consistency test and the formula provided in the theory section, we can get the water-to-cement ratio ($\kappa(C)$).

Given:

- $m_w = 198.27$ ml (mass of water)

- $m_c = 650$ g (mass of cement)

- The density of water is approximately 1 g/ml,

which simplifies calculations since the volume in milliliters of water roughly equals the mass in grams under standard conditions.

$$\kappa(C) = \frac{m_w}{m_c} \times 100\%;$$

Calculations. 1. Convert water volume to mass (assuming density is 1 g/ml):

$$m_w = 198.27 \text{ g};$$

2. Apply the formula for the water-to-cement ratio:

$$\kappa(C) = \frac{198.27 \text{ g}}{650 \text{ g}} \times 100\% = 30.5\%;$$

Therefore, 30.5% water to cement is the proportion that must be used to make this cement mixture reach the required consistency, with the Vicat plunger penetrating 10 mm. Accordingly, it is necessary to combine 30.5 percent water by weight of cement in order to make cement paste that meets the standards of these tests. As specified in ASTM C187 for setup time testing, this % serves as the foundation for the standard consistency level.

8 Discussion of Results

The typical consistency of the cement used in this research may be achieved with a water-to-cement ratio ($\kappa(C)$) of 30.5%, according to the experimental data. According to ASTM C187, this ratio is based on the amount of water needed (198.27 grammes) to dilute 650 grammes of cement to the necessary penetration depth (10 mm) when using the Vicat plunger. Two crucial qualities of cement used in construction—its workability and first setting time—are determined by the standard 30.5% water-to-cement ratio.

The Vicat test measures consistency, which is an important characterisation criterion for cement since it affects the cement's handling and performance in different uses. In this case, the Vicat plunger's penetration depth of 10 mm is designated as the typical consistency level, which provides information on the cement paste's flowability and, indirectly, its hydration kinetics.

If the water-to-cement ratio is too high, the concrete will be too porous to withstand the elements, and if it's too low, the mixture will be too dry, which might weaken the finished product. Thus, our experimentally-derived ratio indicates a happy medium between the two extremes, one that allows for sufficient setting durations and strength growth according to building requirements.

This experimental result also supports the conventional wisdom that water levels should be adjusted to satisfy certain consistency criteria; this, in turn, affects setting times, a crucial component of building activity scheduling. Cement hardening may be controlled more precisely with an understanding of the relationship between water content and setting properties, which impacts structural integrity and project efficiency.

9 Conclusion

To conclude, the fact that a 30.5% water-to-cement ratio for normal consistency has been established offers a solid foundation for future exploratory investigations that attempt to optimise cement mix designs for better performance in certain settings or under specific load circumstances. If we want cement-based products to be more versatile and effective, we need to study how different admixtures and environmental factors affect this key ratio.

10 Recommendations

The following suggestions for improving cement quality and use in building projects are made in light of the study's results:

1. *Standardization of Mixing Procedures.* In order to determine normal consistency, construction teams must follow rigidly to standardised mixing processes as described in ASTM C187. Cement paste qualities and performance may be reliably reproduced across batches and projects when the mixing procedure is consistent.

2. *Temperature and Humidity Considerations.* It is wise to keep an eye on and, if at all feasible, regulate the humidity and temperature levels while cement is being mixed and cured, because these factors affect the cement's setting time and consistency. Using this method, you may keep to your schedule and stay inside your goals.

3. *Use of Admixtures.* Learn more about how admixtures may change the cement paste's characteristics to meet your unique building needs. Modifying setting times, improving workability, and increasing durability, especially in harsh weather, are all possible with the help of additives.

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11 Appendix 1

Listing 1: Code 1

```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt


def analyze_normal_consistency(data):
    df = pd.DataFrame(data)
    desired_depth = 10
    df['water_adjusted'] = df['amount_of_water'] * (desired_depth / df['penetration'])
    average_water = df['water_adjusted'].mean()
    return average_water

def plot_setting_time(data):
    df = pd.DataFrame(data)
    df['time'] = '2024-04-01 ' + df['time']
    df['time_since_start'] = (pd.to_datetime(df['time'], format='%Y-%m-%d %H:%M') -
                              pd.to_datetime(data['starting_time'], format='%Y-%m-%d %H:%M')).dt.total_seconds() / 60

    plt.figure(figsize=(10, 6))
    plt.plot(df['time_since_start'], df['penetration'], marker='o', linestyle='-', color='blue')
    plt.title('Setting Time Analysis')
    plt.xlabel('Time Since Start (minutes)')
    plt.ylabel('Penetration (mm)')
    plt.grid(True)
    plt.axhline(y=25, color='r', linestyle='--', label='25 mm threshold')
    plt.legend()
    plt.show()
```

```python

normal_consistency_data = {
    'amount_of_water': [170, 185, 178],  # ml
    'starting_time': ['9:02', '9:24', '9:45'],
    'penetration': [7, 12, 9]  # mm
}

setting_time_data = {
    'starting_time': '2024-04-01 9:45',
    'time': ['10:15', '10:30', '10:45', '11:00', '11:15', '11:30'
        , '11:45', '12:00', '12:15'],
    'penetration': [40, 40, 38, 35, 28, 20, 12, 3, 0]
}

average_water_needed = analyze_normal_consistency(
   normal_consistency_data)
print(f"Average water needed for 10 mm penetration: {
   average_water_needed:.2f} ml")

plot_setting_time(setting_time_data)
```