Influence of Lauric acid on mechanical properties of Portland cement

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Abstract. In this research we focused on use of lauric acid as an admixture in cement. The main aim of this research is to scrutinize the outcomes of LA on different properties of cement i.e. normal consistency, setting time, compressive strength and the capillary absorption. As large amount of energy has been consumed during the grinding process of clinker therefore many researchers and investigators used fatty acids as a grinding aid to reduce this energy consumption. Herein, effect of LA as an admixture has been reported. Different proportion of LA i.e. 0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0% of dry weight of cement has been used as an admixture to know the properties of Portland cement. To test the compressive strength of Portland cement, total of 96 cubical specimens were prepared and tested for compression strength in UTM under curing stage of three, seven and twenty-eight days. Examined results showed that LA when used in appropriate amount extends the initial and final setting time of ordinary Portland cement. We noticed the decreasement in capillary absorption as amount of LA escalates. We have accomplished in upgrading the mechanical performance of cement, including the capillary absorption, the compressive strength and reducing the amount of mixing water used while modifying the setting time according to use requirements.

1. Introduction

The use of saturated and unsaturated fatty acid as a grinding aid is utilize in grinding of cement clinker to minimize the utilization of energy. Use of one of the saturated fatty acids i.e. LA as an admixture has been reported in the study. The unsaturated fatty acids like oleic acid, linoleic and reduces the compressive strength of the normal concrete while sunflower oil never been used as grading aids in cement industry[1]. The interrelationship between the saturated and the unsaturated fatty acids crystal clear that grinding the cement clinker together with 0.1% wt. Lauric and myristic acid offers the finer cement from that of same amount of sunflower oil[2]. Lauric acid-Myristic acid/expanded graphite composite phase change materials-based mortar plays a beneficial act in controlling temperature thereby hindered the temperature change in the model, by reducing heat value, a longer temperature
delay and a larger cooling extent[3]. Mortar incorporated with oils containing high dosage of monounsaturated fatty acids such as olive, peanut and rapeseed oil developed a drier interior over time and minimize the penetration of chlorides and water born aggressive, thus vegetable oils in significantly small amount (0.5-1.5 % of cement weight) can be used as water repellents for cement mortars[4]. Oleic acid and iminodiacetic acid when incorporated in cement exhausted the setting time and reduces the amount of water absorption however compressive strength has not been much influenced by adding these compound as an admixture in cement[5], [6]. Introduction of common saturated and unsaturated fatty acids like oleic acid, caprylic acids, linolenic acid, capric acids, lauric acid, linoleic acid, arachidonic acid etc also known as hydrophobizing agents improved the durability and aesthetic appearance of concrete by reducing water absorption and reduced rate of detrimental reactions, ingress of water born aggressive like chlorides etc[7]. Recently, many researchers used bacteria in concrete to enhance the durability and minimize the cracks[8]–[10]. Due to the presence of air occluded in fatty acid soap like Na oleate, it can be used as an additive in lime mortar for lowering water absorption, increasing rate of drying and resisting both frost cycles and salts crystallization[11]. Hydrophobic admixtures and water-related organic admixtures that consists of fatty acids like oleic acid, stearic acid, salts of calcium oleate, and esters such as butyloleate imparts a physical barrier to minimize the rate of penetration of corrosive agents in concrete[12], [13]. New bone cement having good mechanical properties and also antibacterial properties can be designed by incorporating fatty acids or triglyceride oils in acrylic bone cement[14]. Lower the chain length of fatty acids higher the increase in weight percentage of cement or vice versa. Fatty acids like acetic acid and propanoic acid reacts with all the calcium in the cement[15].

2. Materials required
This section deals with the detail of different materials used in the investigation. Different methodologies adopted to carry out the experiment and various test procedures performed has been briefly discussed. The whole discussion has been supplemented with disparate pictures to have a clear idea about the whole experimental work.

2.1. Lauric acid
Lauric acid also known as dodecanoic acid is a saturated fatty acid comes under the category of medium chain fatty acid having bright white powdery complexion as shown in figure 1. Lauric acid possess a faint odour of bay oil or any soap. Laurates is the term called for the salts and esters of lauric acid. It is used as an admixture in whole investigation and its other properties has been shown in the table 1. It is found to occur naturally in different plants, animal fats and oils (mainly coconut oil). It is a saturated fatty acid with 12 carbon atoms having molecular formula CH$_3$(CH$_2$)$_{10}$COOH[7]
Fig. 1 Lauric acid used in the investigation

| Properties       | Value                      |
|------------------|----------------------------|
| Formula          | C_{12}H_{24}O_{2}           |
| Molar mass       | 200.3178 g/mol             |
| Melting point    | 43.2 °C                    |
| Boiling point    | 298.9 °C                   |
| Density          | 880 kg/m³                  |
| Appearances      | White powder               |

Table 1. Properties of LA

2.2. Cement
The cement used in the investigation was Ordinary Portland Cement (OPC) of 43 grade conforming to standard IS: 8112 - 1989[16]. SG of cement was calculated by Le Chatelier’s Flask method as per IS 2720- Part3[17]. Its chemical and physical composition has been given in Table 2 as follows:

| Composition        | wt. % |
|--------------------|-------|
| CaO                | 65.5  |
| SiO₂               | 20.8  |
| Al₂O₃              | 5.4   |
| MgO                | 1.60  |
| Chlorides          | 2.4   |
| Alkalies           | 0.026 |
| Insoluble Residues| 2.3   |
| Sulphuric Anhydride| 2.5   |
| Fineness           | 340   |
| Specific gravity   | 3.17  |

Table 2. Chemical and physical composition of OPC

2.3. Fine aggregate
Locally available river sand as per IS: 383-2016 was adopted for the work[18]. The bulk density of sand is 2615 kg/m³. Normal sand of grading zone III was adopted for the experimental investigation. The properties of fine aggregate are shown in tabular form in Table 3.
| Properties       | Values |
|------------------|--------|
| Specific gravity | 2.61   |
| Fineness modulus | 3.12   |

Table 3. properties of fine aggregate

2.4. Water
Tap water having pH 7.23 and specific gravity 1.00 was used for experimental work. Its other properties have been given below in Table 3. All the below mentioned parameters has been examined and precisely tested in environmental engineering laboratory to get the accurate and precise results. Quality of water has found to be likely similar as given in IS 456-2000[19].

| Properties       | Values |
|------------------|--------|
| Ph               | 7.23   |
| TDS              | 1598   |
| Alkalinity as HCO3 | 470 mg/l |
| Chloride Ions    | 960 mg/l |
| Hardness         | 1496 mg/l |
| Specific gravity | 1.00   |

Table 4. Chemical parameter of Tap water

2.5. Cement mortar mix
For calculating compressive strength, mortar mix has been prepared with mix proportion of 1:3 (cement: sand) by weight. Mortar mix was prepared as per IS : 2250-1981[20]. Cement paste was prepared for computing normal consistency and setting time whereas mortar mix was designed for calculating compressive strength. Zone III sand was adopted for making mortar mix. Various proportion of LA has been taken as 0.25%, 0.50%, 0.75%, 1.0%, .25%, 1.5%, 1.75% & 2.0%.

3. Setting time
Setting time of cement is tested in order to check its deterioration due to storage. Vicat apparatus (as shown in figure2) conforming to IS: 5513-1976 was used for determining setting time of cement paste[21]. It is similar as recommended by IS: 4031 part 5[22]. It is further referred as initial setting time and final setting time. Initial setting time is referred as the time in which the square needle of size 1mm shows the penetration of 33 to 35 mm into the mould from the top. It is defined as the time that is measured from the instant when water is added into the cement up to the time it starts losing its plasticity. In order to perform this test, 500 grams of cement sample is taken and gauged with 0.85P (85% of the water required to prepare the cement paste of standard consistency is added in it) and the paste prepared is filled in the mould. Final setting time is referred as the time in which needle at the centre of annular ring is able to make the impression over the mould but annular collar fails to do so. It is referred as the time, which is measured from the instant, water is added into the cement up to the time, it completely loses its plasticity and attain sufficient firmness so as to resist definite pressure. Setting time of cement has been calculated for each percentage of LA in cement i.e. 0.25%, 0.50%,
0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0% of dry weight of cement. Initial and final setting time of acid incorporated cement has been calculated and results compared with that of ordinary Portland cement. All the tests were executed at a temperature range of 28 ± 2º C.

4. Compressive strength

Compressive strength test has been performed in order to check the compressive strength of the cement. In order to find out the compressive strength, mortar of cement and standard sand (Ennore sand) has been prepared in the proportion of 1:3. Water has been added in the mortar in the proportion of [(P/4)+3]% and the prepared paste was filled in the cubical mould of size 70.6mm, then properly compacted and immersed in water for curing. Total of 96 cubes were prepared and tested for compression strength in UTM at 3, 7 and 28 days (as shown in fig. 3). Compressive strength of mortar has been tested as per IS: 4031 - 1988 part 6 [23]. Twelve cubical specimens were prepared for each proportion of LA in cement. Different dosage of LA i.e. 0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75% and 2.0% by weight of dry cement have been taken for preparing mortar mix (as shown in fig. 3) in the experimental study. After 24 hours, cubes were demoulded and cured at stage of three, seven and 28 days for calculating compressive strength. Curing was done in water tank under standard condition (25±2ºC, 95% Relative humidity).
5. Capillary absorption

Capillary absorption test has been executed to know the durability of mortar. It somewhat dominates the strength of mortar. It is explained as proportion of water absorbed by different mortar specimen at a curing stage of 3, 7 and 28 days. Different factors such as material type, admixture composition, temperature and length of exposure influence the percentage of water absorption[24]. It is calculated by ratio of increase in weight of cement mortar to the surface area of cubical specimen. Water absorption of acid incorporated cement mortar has been expressed in gm/mm². The capillary absorption (CA) of cubical specimen at different percentages of LA and at different curing stage has been calculated by using the equation as given as follows.

\[ CA = \frac{(W_f - W_i)}{S} \]

CA: The capillary absorption (gm.mm⁻²);

\( W_f \): The mass of the specimen after curing period of 3 days, 7 days and 28 days, in grams;

\( W_i \): The mass of the specimen before curing period under the water in grams;

S: The area of the specimens in (mm²).
6. Results & Discussion

6.1. Setting time

Setting time has been calculated in minutes. Different proportion of LA i.e. 0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0% (by dry weight of portland cement) was incorporated in cement to know the properties of LA as an admixture. Initial setting & final setting time of cement has been computed by vicat apparatus. Initial and final setting time of cement incorporated with various proportion of LA has been shown in figure. in graphical form. Test results revealed that LA extended the setting time of ordinary Portland cement and this extension varies with the proportion of LA used in the cement. Mainly $C_3S$ and $C_3A$ are the basic component of cement that are responsible of hydration which are significantly delayed by using saturated and unsaturated fatty acid in cement. No linear relationship has been found between proportion of LA and variation of setting time. At 0.75% of LA, maximum initial and final setting of 147 minutes and 217 minutes respectively has been recorded as shown in figure 7.
6.2. Compressive strength

Influence of different dosage of LA on compressive strength of cement mortar are shown in fig. 8. According to Fig. 8, it has been observed that compressive strength at curing stage of 28 days was greatly affected by the proportion of LA while the 3 days compressive strength was faintly affected by it. The compressive strength at 28 days enhanced when the LA dosage increased up to 0.75% whereas it decreases beyond 0.75%. This is so happened may be because of the retarding effect of the LA. From figure, the higher setting time was achieved by the samples with 0.75% content of LA, hence the hydration process was slightly lengthened. Maximum compressive strength of cement mortar cube incorporated with LA achieved at its 0.75% dosage. Early day strength (3 days) of LA added cubical specimen was found to be lesser as compared to other cubical specimens.

6.3. Capillary absorption

Capillary absorption of different cubical specimen at three distinct curing stages i.e. 3, 7 and 28 days formulated by different percentage of addition of lauric acid has been shown in figure. 9. It can be concluded that capillary absorption of cubical mortar specimen is a function of proportion of LA. As it has been seen from the experimental investigation that by increasing the dosage of LA, capillary absorption of different cubical mortar specimen decreases. This decrease is explained by the fact that the molecule of the LA seems to increase the air content. By increasing the proportion of LA, water permeability within mortar specimen reduces. Reduction in capillary absorption of the mortars is influenced by the rate of the LA used in it. At 2.0% of LA, minimum amount of capillary absorption has been noticed. These effects are similar to the other authors, as well [7], [25].
After incorporating lauric acid as an admixture in cement, following conclusion can be made as:

- The setting time was regulated by the proportion of LA content in the cement. The initial setting and final setting time enhanced by enhancing LA content up to 0.75%. A retarding effect of about more than 1 h was reached with cement content up to 0.75%.
- At 0.75% of LA, initial and final setting time of ordinary Portland cement accelerates to 147 minutes and 217 minutes respectively which shows that LA can be used as a retarder in cement and construction industry when used in right proportion. This retarding effect is found to be useful in high temperatures to evade complications between mixing and placing.
- From literature study, it has been concluded that saturated fatty acids like LA creates a barrier around the cement particles that prevent the water molecules to reach the surface of unhydrated cement particles and enervate the bonds of CSH gel that slows down the hydration process. It is also economical and environmentally safe to use LA as a retarder in cement[2]
- The compressive strength has been influenced by enhancement of LA content in cement mortars. At each curing stage, the cement mortar cubes prepared with 0.75% LA content produced better result as compared with other proportion.
- Lauric acid used for resisting water in mortars even in very small amounts (0.25-2.0 % by dry weight of cement). Thus, hydrophobizing agents like LA causes lesser water absorption in cement mortar as it allows to water vapour out and makes the interior part drier that decreases the rate of detrimental reaction and thus increased the durability and aesthetic appearance of the cement mortar[7].

8. Future Scope
It is recommended to continue further research on use of LA as an admixture on microstructural analysis of cement and concrete. Further research should focus on effect of
LA on concrete properties like workability, flexural strength, split tensile strength, compressive strength, durability etc.

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