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Analysis of Some Physical and Chemical Properties of Bad Cement Delivered to a Construction Site in Eldoret, Kenya

Clement Kiprotich Kiptum

Department of Civil and Structural Engineering, University of Eldoret, P.O. BOX 1125, Eldoret, Kenya

Abstract: Portland pozzolanic cement delivered to a construction site was having quick setting time and could not harden after 24 hours. Due to this problem a study on some physical and chemical properties of cement was done to determine the various components of cement. East African Standard procedures were used to determine properties. The results showed that only SO_3 and chloride were okay. The initial setting of five minutes was very quick and low when compared to the standard of around 75 minutes. Very high values of SiO_2 and insoluble residues, high values of Al_2O_3, Fe_2O_3, MgO and loss of ignition were observed and did not meet the standards. In addition, low compressive strength of 26.54 N/mm^2 was observed. Lime saturation factor and chemical modulus of 0.46 and 1.46, respectively were low compared to the standard. The quick setting time could be attributed to low CaO of 45.16%, and high values of Al_2O_3 and Fe_2O_3. The lack of hardening and compressive strength could be attributed to high values of Insoluble residues. Cement users are therefore requested to test their cement before using.

Keywords: Setting, pozzolanic, insoluble residues, East African Standards, compressive strength.

I. INTRODUCTION

In the recent past from 2011 to 2017, over 20 multi-storied houses have collapsed in Kenya because of various reasons resulting in loss of life and property. It was in this in mind that the Kenyan President launched an audit in January 2017. The reasons for collapsed buildings were poor quality of concrete, inadequate designs and other construction materials [1]. Poor quality concrete can be attributed to low quality cement among other issues like the quality of sand, water and aggregates.

Construction industry has been growing in Kenya and this can be shown through production and consumption of cement. Cement production in Kenya increased from 4.7 million tonnes in 2012 to 6.7 million tonnes in 2016. Cement consumption increased from 4.0 million tonnes to 6.3 million tonnes during the same period [2]. Surplus cement is normally exported to neighbouring countries in East Africa like Rwanda, Uganda and Tanzania among other countries. It is worth to note that the surplus cement decreased from 0.7 million tonnes to 0.3 million tonnes which means that cement consumption in Kenya is increasing faster than the cement production. This shows that a lot of construction work is going on in Kenya currently.

In Kenya most people do not test cement before using because they trust the companies that produce cement in Kenya. Some of the companies producing cement in Kenya include; National Cement, East African Portland cement, Bamburi cement Limited, Rai cement Limited, Savannah cement limited, Rhino cement, and Athi River mining limited. With the opening of clinker plant by National Cement in Kenya coupled with government agenda on infrastructure, means that more cement companies will be established in future.

The cement used in many construction sites in Kenya is Portland Pozzolana Cement (PPC). Pozzolana is a material that contains silica and alumina material that reacts with calcium hydroxide to form calcium silicates which have binding properties [3]. Pozzolanic material used includes volcanic ash from volcanic activities and fly ash among others. Fly ash is a by-product of coal when it is burnt during the production of electricity [4]. Portland cement clinker is made by burning raw materials that contain Calcium oxide, silicon dioxide and alumina. Alite (C_3S) which is a mineral in Portland cement is responsible for setting and early strength development due to presence of high calcium.

The cement produced has to be approved by Kenya Bureau of Standards (KEBS) with the diamond mark of quality stamped on each cement bag. KEBS have come up with standards which are normally used by companies to compare their results with. In this study, the results were compared with those specified in the East African Standard (EAS), the Kenyan standards as well as East African Standards are normally generated from the British Standards with some amendments here and there.

Cement companies normally test their cement before they dispatch to the market but sometimes complacency and lapse that happens in car manufacturing industries also happens in the cement manufacturing industries. If poor quality cement is used in construction it will result in bad concrete and its knock on effects on life and property can be disastrous. More often than not, people normally point fingers at the contractor and the engineers when a construction collapses not knowing that poor quality cement from factory can be the cause. This means that usage of bad cement can ruin people's careers and reputation. Tests done on cement can be broadly classified as chemical and physical properties. Chemical properties include: Insoluble residue, total Silica (SiO_2) , total Calcium Oxide (CaO), Alumina (Al_2O_3), Iron Oxide (Fe_2O_3), Magnesia (MgO), Chloride (Cl-), Sulphate (SO_3), Loss of Ignition. Physical properties of importance include, setting times and soundness tests. Soundness is a physical property of cement which determines the ability of cement paste to retain its volume after setting is completed. Setting is the stiffening of cement [5].

High Calcium Oxide (lime) content is associated with early strength. Low CaO, high alumina and high Iron Oxide result in quick setting which is undesirable. High SO_3 and Al_2O_3 aids quick setting. High magnesia and SO_3 affect soundness of cement. High amount of chloride result in corrosive nature of cement and thus it can affect the reinforcement used. Insoluble residue is non-cementing material that exists in Portland cement. It affects the compressive strength of cement. Insoluble residues are part of cement that does not dissolve in hydrochloric acid. High loss of ignition, can be attributed to pre-hydration caused by improper storage or prolonged storage. Hydration refers to the reaction between cement and water of any kind. Magnesia contributes to colour and hardening of cement [6].

In Eldoret Town, a developer bought some bags of cement to construct a house. While mixing the concrete, the concrete was setting within five minutes after leaving the concrete mixer and on placing the concrete on the bases for columns it was practically impossible to compact using the poker vibrator. Instead of the concrete hardening after 24 hours it turned to be wet and could be vibrated even after 72 hours despite the fact that vibration was impossible five minutes after mixing as pointed out earlier. This kind of experience had not been witnessed by all the people at the site. Therefore, this study aimed at testing the physical and chemical properties of the bad cement to ascertain what the problem was.

II. METHODOLOGY

The cement tested was specified as CEM IV/B (P) 32.5 N. CEM IV stands for Pozzolanic cement, B stands for medium proportion of clinker used, P stands for natural Pozzolana , 32.5 stands for strength after 28 days in N/mm^2 and N regards to normal early strength development. All parameters were tested following the procedures in East African Standards 148. Loss of Ignition (L.O.I) EAS 148-2 [7], sulphate (SO_3) EAS 148-2 [7], Insoluble Residue (I.R) EAS 148-2[7], Chloride (Cl^-) EAS 148-2 [7], Total Silicon Dioxide (SiO_2) EAS 148-2 [7], Aluminium Oxide (Al_2O_3) EAS 148-2[7], Iron Oxide (Fe_2O_3) EAS 148-2[7], Free Calcium Oxide (CaO) and Magnesia (MgO) were done in accordance to EAS 148-2 [7]. Chloride was done in accordance EN 196-21 [6]. Soundness was done following Le Chatelier Method and Initial setting time was determined in accordance with EAS 148-3 [8]. The compressive strength of cement was done in accordance to EAS 148-3 [8].

III. RESULTS AND DISCUSSION

From the results in Table 1, only SO_3 and chloride were okay. The initial setting of five minutes was very quick and low when compared to the standard of around 75 minutes. Very high values of SiO_2 and insoluble residues, high values of Al_2O_3, Fe_2O_3, MgO and loss of ignition were observed from the sample cement as shown in Table 1. In addition, low strength was observed. The quick setting time could be attributed to low CaO of 45.16%, and high values of Al_2O_3 and Fe_2O_3. The low strength observed could be attributed to very high values of insoluble residues and low values of CaO. Insoluble residue measures adulteration of cement coming from impurities in gypsum (calcium sulphate) and high values have been shown to reduce strength [9]. The high values of loss of ignition could be attributed to prehydration and it seems the cement had been stored for a long time.

Table 1 Percentages of parameters tested their comparison with those of EAS [7,8].

S/N	Parameter	Sample results	EAS	Remarks
1	Initial Setting	5	≥ 75 minutes	Very low
2	Soundness	0	10 mm	okay
3	SiO_2	30.85	21 %	Very high
4	Al_2O_3	6.76	≤ 6.0	High
5	Fe_2O_3	3.47	≤ 3.5 %	Okay but high
6	CaO	45.16	65%	Okay but less
7	MgO	2.28	≤ 2.0 %	high
8	SO_3	1.61	≤ 3.5 %	okay
9	I.R	24.30	≤ 5 %	Very high
10	L.O.I	5.05	≤ 5.0 %	high
11	Cl^-	0.018	≤ 0.1%	okay
12	Compressive strength after 28 days	26.54	≥ 32.5	Less

The chemical modulus that is the ratio of CaO to SiO_2 was found to be 1.46 as shown below

$$Chemical\ modulus = \frac{CaO}{SiO_2} = \frac{45.16}{30.85} = 1.46$$

The value of 1.46 should not be less than 2 according to BS 12 [10]. This meant that improper mixing was done during the manufacturing of cement.

$$The\ ratio\ of\ = \frac{(CaO + MgO)}{SiO_2} = \frac{45.16 + 2.28}{30.85} = 1.54$$

The value should not be less than 1 which is okay.

$$Lime\ saturation\ factor\ = \frac{(CaO - 0.7SO_3)}{2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3} = \frac{45.16 - 1.127}{86.38 + 8.112 + 2.2555} = \frac{44.033}{96.7475} = 0.46$$

Lime saturation factor (LSF) which is limited to 0.66-1.02 was found to be 0.46 which is low. The value should not be too high as it results in a lot of free lime, and should not be to low as it makes burning in the kiln very difficult. This supports the reason why the chemical modulus was less than 2 because burning was not done properly and hence wrong proportions of ingredients. The sum of CaO and SiO_2 was found to be 76.01 which was greater than 50% and hence satisfying the requirements in [10].

The results clearly showed that indeed bad cement was delivered to the developer. So it is the responsibility of developers or clients and building team comprising of the engineers and the contractor to be keen while using cement or any other building material. This is because if they use bad cement and incur losses they will have themselves to blame as the cement manufacturing companies will not be ready to compensate for any loss without a fight. The analogy of fresh milk gone sour can be applied to usage of cement since you cannot go back to the shop to ask for another packet of milk because the arguments that arises from there might not be favourable to you. Some cement manufacturers can hire lawyers to defend themselves in case a developer goes to court. Therefore, users of cement should not consider suing cement companies in case of losses as the ruling might go either way and paying for court damages in case one loses will be more costly. In the building industry, therefore, there is need for prevention of loss by testing the cement before use.

IV. CONCLUSION AND RECOMMENDATION

The quick setting of cement delivered to the site was due to low values of CaO and high values of Al_2O_3 and Fe_2O_3. The very high values of insoluble residues contributed to the non-binding nature of the cement. The mixing of the ingredients was not proportional and that is why majority of them were not meeting the standards. The cement had quick setting and of low strength therefore not good for construction works. It is recommended that each and every client should test the cement before using to avoid use of bad cement that can result to loss of life, property and reputation of the building team.

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