# *Influence Of Cement Kiln Dust As Partial Replacement On Some Properties Of Ordinary And White Portland Cement*

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## Abstract

Cement Kiln Dust (CKD) is produced as a solid waste with large quantities during manufacturing of Portland cement clinker. The possibility of utilizing CKD as partial replacement for Ordinary Portland Cement (OPC) and White Portland Cement (WPC) produced in factories of the Iraqi cement state company has been examined in this study to fulfil the environmental and economical aims. Different percentages of CKD were blended with OPC and WPC mixes. The results show that the amount of water for normal consistency were increased with about 39 % and 31 % for OPC and WPC blended with 25 % CKD. The setting time (initial and final) decreases with increasing percent of CKD added. Compressive strength decreases slightly with increasing CKD content up to 10 %. For 7- day curing time, it decreases 7 % and 9 % for OPC and WPC mixes, respectively. As percent of added CKD increases to more than 10 %, the compressive strength and other parameters where affected significantly. Overall results proved that OPC and WPC blended with up to 10 % CKD are admissible for passing relevant specification requirements.

**Keywords : Cement kiln dust (CKD), Ordinary Portland cement (OPC), Wight Portland cement (WPC), Setting time, Compressive strength.**

# أثر التعويض الجزئي للإسمنت بغبار الأفران على بعض خواص الإسمنت البورتلاندي الاعتيادي والأبيض

**الخلاصة**

ينتج غبار الأفران بكميات كبيرة كناتج عرضي لصناعة الإسمنت ويصنف كنفايات صلبة. ولغرض الاستفادة من هذه المخلفات تم اختبار إمكانية الاستفادة منه لتعويض جزء من الإسمنت البورتلاندي الاعتيادي والأبيض والذي ينتج في معامل الشركة العامة للإسمنت العراقية بهدف تحقيق مردود بيئي واقتصادي معاً. في هذه الدراسة تم خلط غبار الأفران مع الإسمنت الاعتيادي مرة ومع الإسمنت الأبيض مرة أخرى ليحل محلهما بنسب مئوية مختلفة. أظهرت النتائج أن كمية الماء المطلوبة تزداد بزيادة نسبة الغبار المضافة حيث تزداد بنسبة 39 % و 31 % لنسبة خلط غبار 25 % للإسمنت الاعتيادي والأبيض على التوالي، كما أن زمن التجمد الابتدائي والنهائي يتناقص مع زيادة نسبة الغبار المضافة. لوحظ أيضا أن قوة الانضغاط تتناقص قليلا مع ازدياد نسبة خلط الغبار لحد 10 % حيث تنخفض بنسبة 7 % و 9 % لخلطات الإسمنت الاعتيادي والأبيض على التوالي عند الفحص بعمر 7 أيام . حينما يزداد محتوى الخلطات من غبار الأفران لأكثر من 10 % يلاحظ انخفاض القوة بشكل مؤثر إضافة إلى تأثر المعايير الأخرى.

عموماً، النتائج تثبت أن تعويض الإسمنت الاعتيادي والإسمنت الأبيض لحد نسبة 10 % من غبار أفران الإسمنت يعطي نتائج مقبولة في حال المطابقة للمواصفات المعتمدة.

**الكلمات الدالة : اسمنت غبار الأفران ، الاسمنت الاعتيادي البورتلاندي، زمن التجمد ، قوة الانضغاط .**

**Nomenclatures**

BS = British Standard.
CKD = Cement Kiln Dust.
I.O.S. = Iraqi Organization of Standards.
L.O.I = Loss on Ignition .
OPC = Ordinary Portland cement.
WPC = White Portland cement.

## Introduction

Cement manufacturing is an important industry in the Iraq and throughout the world. As with most large manufacturing industries, by-product materials are generated. These industry by-product and waste materials must be managed responsibly to insure a clean and safe environment. Cement kiln dust (CKD) is a significant by-product material of the cement manufacturing process [1].

CKD is created in the kiln during the production of cement clinker. The dust is a particular mixture of partially calcined and non-reacted raw feed, clinker dust and ash, enriched with alkali sulfates and other volatiles. These materials are captured by the exhaust gases and collected in particular matter control devices such as cyclones, bag houses and electrostatic precipitators. The bulk of this dust is land filled with a significant environmental impact and financial loss to the local cement industry in terms of the value of raw materials, processing, and energy consumption during preprocessing, dust collection and disposal [2].

Investigation of CKD management practices at Iraqi cement factories have shown limited options. Most plants employ the CKD land-disposal alternative. CKD accumulates as irregular piles and accumulation usually near the plants; most of these piles are unlined and uncovered [3]. Over the past several years dramatic advances have been achieved in the world in the management and use of CKD, thus reducing its dependency on land fill disposal [1].

In the construction industry, CKD is used for various engineering purposes such as filler and activating agent for rubber compounds, brick industry, sand stabilizer and mineral filler in asphalt pavements. However, the use of CKD in one or more of these purposes may be a better solution than land filling while avoiding the associated costs and liabilities [1].

The present work aim is to investigate the partial replacement of cement with different amounts of CKD. The effects on physical-chemical properties and compressive strength of Mixes of Ordinary Portland Cement (OPC) with CKD and White Portland Cement (WPC) with CKD are investigated in this study.

## Blended Cement Kiln Dust and Cements

The utilization of CKD as partial replacement of cement or aggregates in concrete mixes or as an additive in different blends of cement mortars has been investigated by many researchers in the last few years. It has been reported that such utilization produces various technical, economical and environmental benefits.

A series of reports on the addition of CKD to Portland cement, along with fly ash and blast furnace slag, has been published with variable results [7].

Cements blended with CKD alone reportedly had reduced strength, setting time and workability. The strength loss was attributed to the presence of high alkalis in the dust. The addition of fly ash with CKD lowered the alkalis contents and resulted in improved strength. Those results also demonstrated that particular ratios of alkalis, chlorides and sulfates are important for better performance of cement blends [4].

Ravindrarajah reported that kiln dust could be used in masonry and concrete blocks without loss of strength or workability. His study showed that up to 15 % of the Portland cement could be replaced with CKD. If higher percentages of dust were used the setting was retarded, workability was reduced and water demand was increased [5].

Daugherty and Funnell have also evaluated the use of CKD by grinding and blending this dust with Portland cement. Their data showed no evidence of adverse effects on blend's setting time, soundness or shrinkage with up to 10 % CKD addition. However, the strength results varied, most likely attributed to the changing dust composition [6].

El-Didamony et al. studied the role of CKD in some blend cement pastes. These researchers found that adding CKD to blends of ordinary Portland cement, blast furnace slag cement, or sulfate resistant cement beyond specific upper limits to each of the blends adversely affected the physical and mechanical properties of these blended cement pastes [7].

Shoaib et al. studied the effect of CKD as partial replacement for Portland cement on the mechanical behavior of concrete. Results of compressive strength for the concrete specimens showed that for (10-20) % of CKD replacement, the compressive strength was slightly reduced. The authors have also reported that the direct mixing of CKD in concrete is more effective than the recycling of CKD with cement raw materials, which form a non-favored clinker phase during the firing in cement kilns [8].

Abo-El-Enein has studied the mechanical properties of blended cements using by-pass dust. The initial and final setting times of cement pastes were decreased due to the high free lime content in the CKD. Blended cements with up to 15 % kiln dust had increased compressive strength and accelerated hydration. Compressive strength decreased when more than 15 % of the Portland cement was replaced with CKD [9].

El-Sayed et al. have investigated the effect of CKD on the compressive strength of cement pastes and on the corrosion behavior of embedded reinforcement. They reported that substitution up to 15 % by weight of cement by CKD produced no adverse effect on the cement paste strength or on the reinforcement passivity [10].

Al-Husseini studied the feasibility of using CKD in concrete and mortar mixes as partial replacement for cement or sand. The results indicated that increasing the percentages of cement partial replacement by CKD leads to decreasing the compressive strength of concrete and mortar. Up to 10 % of cement replacement by CKD, the strength of concrete and mortar reaches about 91 and 95 percent of the control strengths, respectively [11].

Al-Harthy investigated the use of CKD as a substitute for Portland cement at different proportions in concrete and mortar samples. They also concluded that substitution of cement with CKD does not produce negative effects on strength properties of these samples when CKD was added at proper low ratios [4].

## Materials and Methods

In this study two groups of experiments were conducted to study the effect of using CKD as partial replacement of cement in pastes. In the first group CKD was added to OPC, while in the second group CKD was added to WPC.

OPC, WPC and CKD used in the experimental work of this study were produced locally by the Iraqi cement state company. The chemical analysis, Blain surface area and bulk density of the investigated materials are shown in table (1). The mix compositions of the investigated mixes are shown in table (2). Each dry mix was homogenized for five minutes in a laboratory steel mixer to assure complete homogeneity. In each group a set of experiments were carried out to determine the following:

Normal consistency of cement pastes with different mix composition of OPC and WPC with CKD, according to ASTM Specifications (C-187). The results are shown in table (3).

Initial and final times of setting for mixes composition by the Vicat needle were tested, according to ASTM specification (C191-77).The test results are reported as shown in table (3).

Compressive strength of cement mortar mixes with different ratios of CKD is indicated in table (2), according to ASTM specifications
(C109-77). The mortar was prepared by mixing one part of (cement + CKD) and three parts of sand. The results are shown in table (4).

Soundness of the mixes composition (Table 2) by autoclave test was made according to ASTM specifications (C151-77). This test refers to the ability of hardened cement paste to retain its volume after setting without delayed destructive expansion. The change in specimen length through the time in the autoclave is measured and reported as a percentage as shown in table (5).

The results of free lime and sulfate content of mixes, according to ASTM specifications (C114-77), are shown in table (6) and table (7), respectively.

## Results and Discussion

### *Normal Consistency and Setting Time (Initial and Final)*

Increasing the ratio of waste materials (CKD) replacement added to each mixes of OPC and WPC in the cement paste were significantly increased the amount of water required to produce a neat blend of normal consistency. The water for normal consistency to cement ratio (W/C) are plotted as a function of CKD content in figure (1) for OPC and WPC mixes. As concluded in table (3), the amount of water for normal consistency increased by about 39 % and 31 % for OPC and WPC respectively, when mixed with 25 % CKD. This may be attributed to high amounts of alkalis, sulfates, lime and volatile salts that require more water.

As shown in figure (1) for OPC mixes and WPC mixes, the setting time (initial and final) of cement mix pastes were decreased with increasing CKD addition. The initial setting time decreased from 140 minutes to 97 minutes and from 137 minutes to 105 minutes with increasing CKD added from 0 % to 25 % for each OPC and WPC mixes, respectively. In the same context, the final setting time decreased from 220 minutes to 155 minutes and from 216 minutes to 170 minutes for OPC and WPC mixes, respectively. This is also due to the high amounts of lime and alkalis in CKD which accelerate the hydration process, leading to fast setting. Worthy to mention that the high content of $SO_3$ in CKD which increases the $SO_3$ content of OPC and WPC mixes with increasing percent of CKD added (as shown in table 6). This has no affect on the setting time because it is presents in the anhydrite form.

***Free Lime Content***

As shown in figure (2), the percent of free lime increases with increasing amount of CKD added to mixes of both OPC and WPC due to the high percentage free lime in CKD. It is difficult to specify a quantitative limit for the free lime because the adverse effect depends not only on its content, but also on its particle size and distribution in the cement. The cement standards, including British Standard BS.12 do not specify a maximum free lime content but rather specify the soundness of the cement as measured by its expansion [12]. The relevant test prescribed in Iraqi Organization of Standards (I.O.S) 5/1984 is autoclave test and the upper permitted limit of expansion should not exceed 0.8 % [13].

The quantity of free lime increases with increasing amount of CKD added to pastes for both OPC and WPC due to the high percentage free lime in CKD. For the same percentage of CKD addition, the quantity of free lime increased with curing time in all the cement mix pastes as shown in figure (3) and (4) for OPC and WPC, respectively. This is due to the continuous hydration of the main cement phases which liberate free lime in addition to the amount leached from CKD. Excessive amounts of free lime (CaO) may cause an expansion in cement pastes. The expansion due to reaction of free lime with water to form $Ca(OH)_2$ has about twice the volume of the CaO from which it was formed [14]. The typical expansion test places a small sample of cement paste into an autoclave (a high pressure steam vessel). Results of autoclave expansion tests show that expansions were increased with increasing percentage of dust added to cement for both OPC and WPC mixes. In this process, it is predicted that increasing in dust percentage brings the increased of alkaline expansion. Anyhow CKD, due to having semi calcinations materials including free lime (and MgO), causes expansion of samples. As shown in table (5) increasing the percentage of CKD additive up to 15 % raises the value of expansion near to upper permitted limit for OPC and WPC mixes according to I.O.S. 5 / 1984. Thus, using 10 % CKD is a suitable proposal in case of passing relevant tests.

***Compressive Strength***

Figures (5) and (6) show the behavior of compressive strength with curing time of the hardened cement mortar-specimens containing OPC or WPC, respectively. Although the compressive strength increases with curing time for all hardened cement mortars, however, the compressive strength decreased with increasing CKD content. This reduction is attributed to the reduction in the cement content and an increase in free lime content in CKD. The higher amount of $Ca(OH)_2$ weakened the hardened matrix [12]. The porosity also increases due to the sulfate content of the CKD where increasing percentage of CKD addition increases $SO_3$ content in cement mixes paste as shown in table (6). Compressive strength decreases slightly with increasing CKD content up to 10 % (for 7 days curing time and cement without CKD additive). It decreased by 7 % and 9 % of its original value for OPC and WPC mixes, respectively. As the CKD content increases to 15 % the compressive strength decrease was 13 % and 18 % of its original value for the same curing time for OPC and WPC, respectively. So, the change in compressive strength for OPC and WPC mixed with up to 10 % CKD is acceptable and conformed with I.O.S 5/1984.

## Conclusions

From the above results, it can be concluded that:

- Addition of CKD increases the water for normal consistency of OPC and WPC pastes, whereas the setting time decreases.
- Addition of CKD increases the free lime content of OPC and WPC paste, and it increases with curing time for the same percentage of CKD addition.
- Substitution of OPC and WPC with CKD up to 10 % has no significant effect on the compressive strength of hardened cement mortar.
- Increasing CKD content more than 10 % adversely affects the compressive strength and other important parameters of test concerning cement quality such as expansion (autoclave test), free lime content, $SO_3$ content.
- The admissible value of CKD additive ranges up to 10% in case of passing relevant tests.

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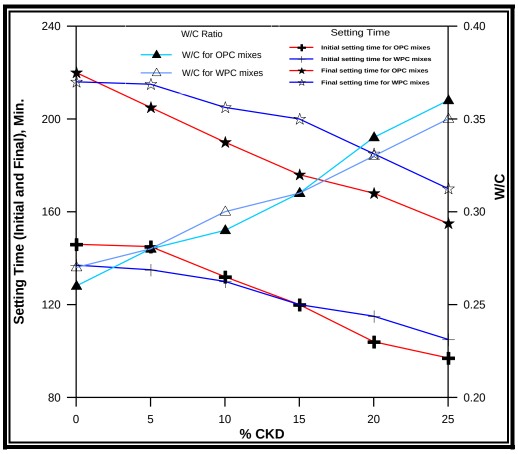


**Figure (1): Setting time and W/C ratio of OPC and WPC pastes with different percentage of CKD.**

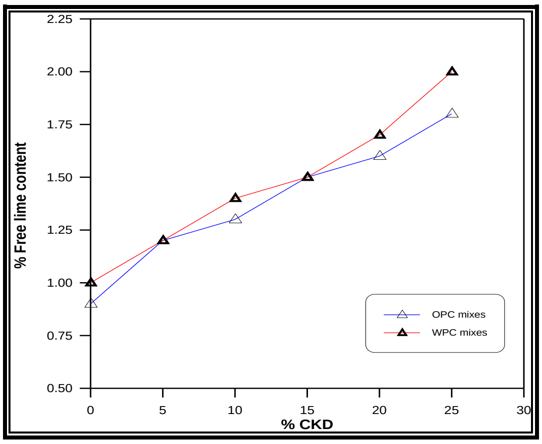


**Figure (2): Free lime content of OPC and WPC mixed with different quantities of CKD.**

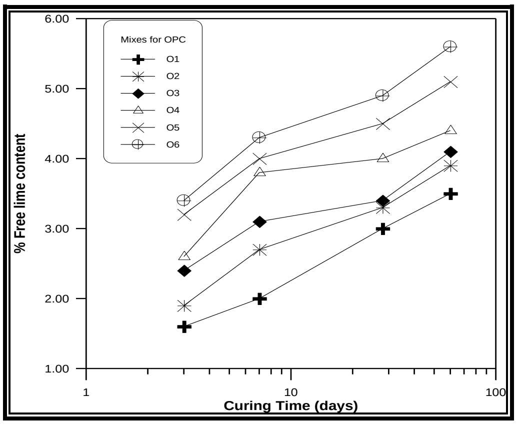


**Figure (3): Variation of free lime content with curing time for OPC mixed with different quantities of CKD.**

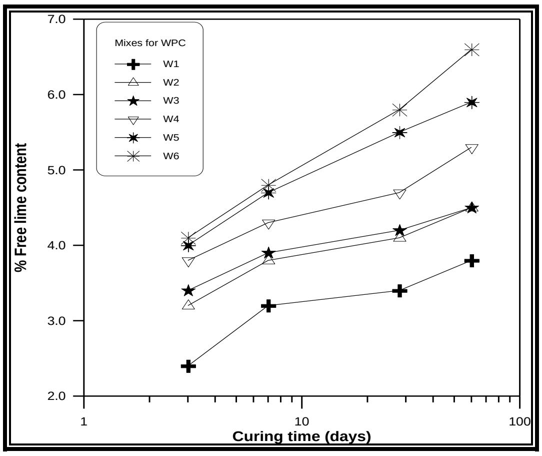


**Figure (4): Variation of free lime content with curing time for WPC mixed with different quantities of CKD.**

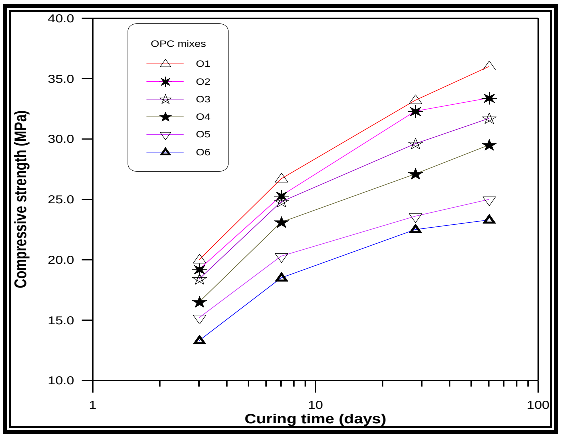


**Figure (5): Compressive strength of OPC mortars mixed with different value of CKD as a function of curing time.**

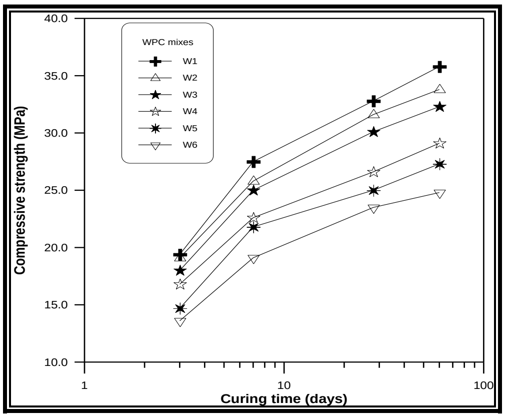


**Figure (6): Compressive strength of WPC mortars mixed with different value of CKD as a function of curing time.**

**Table (1): Chemical analysis of OPC, WPC, CKD**

| Constituent | OPC | WPC | CKD |
|---|---|---|---|
| **CaO** | 63.1 | 65.8 | 47.4 |
| **$SiO_2$** | 21.4 | 23.2 | 15.7 |
| **$Al_2O_3$** | 5.1 | 4.9 | 4.3 |
| **$Fe_2O_3$** | 2.9 | 0.4 | 0.3 |
| **MgO** | 2.0 | 1.7 | 1.4 |
| **$K_2O$** | 0.2 | 0.4 | 0.8 |
| **$Na_2O$** | 0.2 | 0.3 | 0.9 |
| **$SO_3$** | 2.3 | 2.4 | 6.1 |
| **FL*** | 0.9 | 1.1 | 3.5 |
| **L.O.I.**** | 1.9 | 2.2 | 19.4 |
| **Blain ($gm/cm^2$)** | 3200 | 3300 | 3000 |
| **Bulk Density (gm/l)** | 1200 | 1250 | 850 |

* FL : Free Lime
** L.O.I.: Loss On Ignition

**Table (2): Mix composition of the investigated specimens**

| Mix No. | Compositions, % | | Mix No. | Compositions, % | |
|---|---|---|---|---|---|
| | OPC | CKD | | WPC | CKD |
| **O1** | 100 | 0 | W1 | 100 | 0 |
| **O2** | 95 | 5 | W2 | 95 | 5 |
| **O3** | 90 | 10 | W3 | 90 | 10 |
| **O4** | 85 | 15 | W4 | 85 | 15 |
| **O5** | 80 | 20 | W5 | 80 | 20 |
| **O6** | 75 | 25 | W6 | 75 | 25 |

**Table (3): Water of normal consistency and setting time (initial and final) of mixes of cement pastes.**

| Mix No. | Water of consistency (ml) | W/C Ratio | Setting time (Min.) | | Mix No. | Water of consistency (ml) | W/C Ratio | Setting time (Min.) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | initial | final | | | | initial | final |
| **O1** | 104 | 0.26 | 146 | 220 | W1 | 107 | 0.27 | 137 | 216 |
| **O2** | 110 | 0.28 | 143 | 205 | W2 | 113 | 0.28 | 135 | 215 |
| **O3** | 116 | 0.29 | 132 | 190 | W3 | 118 | 0.30 | 130 | 205 |
| **O4** | 125 | 0.31 | 120 | 176 | W4 | 123 | 0.31 | 120 | 200 |
| **O5** | 137 | 0.34 | 104 | 168 | W5 | 130 | 0.33 | 115 | 185 |
| **O6** | 145 | 0.36 | 96 | 155 | W6 | 141 | 0.35 | 105 | 170 |

**Table (4): Compressive strength of OPC and WPC mixes (MPa).**

| Mix. No. | Curing Time | | | |
|---|---|---|---|---|
| | 3 days | 7 days | 28 days | 60 days |
| **O1** | 20.0 | 26.7 | 33.2 | 35.9 |
| **O2** | 19.3 | 25.3 | 32.4 | 33.5 |
| **O3** | 18.4 | 24.8 | 29.6 | 31.6 |
| **O4** | 16.5 | 23.1 | 27.1 | 29.5 |
| **O5** | 15.2 | 20.3 | 23.5 | 25.0 |
| **O6** | 13.3 | 18.5 | 22.5 | 23.3 |
| | | | | |
| **W1** | 19.4 | 27.5 | 32.8 | 36.0 |
| **W2** | 19.1 | 25.8 | 31.6 | 33.8 |
| **W3** | 18.0 | 25.0 | 30.1 | 32.3 |
| **W4** | 16.8 | 22.6 | 26.6 | 29.1 |
| **W5** | 14.7 | 21.8 | 25.0 | 27.3 |
| **W6** | 13.6 | 19.1 | 23.5 | 24.7 |

**Table (5): Results of autoclave expansion tests of investigated mixes.**

| Mix No. | Autoclave expansion % | Mix No. | Autoclave expansion % |
|---|---|---|---|
| **O1** | 0.23 | W1 | 0.25 |
| **O2** | 0.38 | W2 | 0.39 |
| **O3** | 0.54 | W3 | 0.61 |
| **O4** | 0.78 | W4 | 0.80 |
| **O5** | 0.97 | W5 | 1.05 |
| **O6** | 1.08 | W6 | 1.22 |

**Table (6): Free lime content of cement paste mixes*.**

| Mix No. | Curing time | | | | |
|---|---|---|---|---|---|
| | **Before curing** | **After 3 days** | **After 7 days** | **After 28 days** | **After 60 days** |
| **O1** | 0.9 | 1.6 | 2 | 3.1 | 3.5 |
| **O2** | 1.2 | 1.9 | 2.7 | 3.3 | 3.9 |
| **O3** | 1.3 | 2.4 | 3.1 | 3.4 | 4.1 |
| **O4** | 1.5 | 2.6 | 3.8 | 4.0 | 4.4 |
| **O5** | 1.6 | 3.2 | 4.0 | 4.5 | 5.1 |
| **O6** | 1.8 | 3.4 | 4.3 | 4.9 | 5.6 |
| | | | | | |
| **W1** | 1.0 | 2.4 | 3.2 | 3.4 | 3.9 |
| **W2** | 1.2 | 3.2 | 3.8 | 4.1 | 4.5 |
| **W3** | 1.4 | 3.4 | 3.9 | 4.2 | 4.5 |
| **W4** | 1.5 | 3.8 | 4.3 | 4.7 | 5.3 |
| **W5** | 1.7 | 4.0 | 4.7 | 5.4 | 5.9 |
| **W6** | 2.0 | 4.1 | 4.8 | 5.8 | 6.5 |

*The allowable limit of free lime according to IOS/5/84 is 5% for both OPC and WPC.

**Table (7): $SO_3$ Content of OPC and WPC mixes.**

| Mix No. | % $SO_3$ Content* | Mix No. | % $SO_3$ Content |
|---|---|---|---|
| **O1** | 2.3 | W1 | 2.4 |
| **O2** | 2.5 | W2 | 2.7 |
| **O3** | 2.6 | W3 | 2.8 |
| **O4** | 2.8 | W4 | 3.1 |
| **O5** | 3.1 | W5 | 3.3 |
| **O6** | 3.4 | W6 | 3.5 |

*The allowable $SO_3$ content according to BS/12 or IOS/5/84 is 1.5% for both OPC and WPC.