Influence of Bottom Ash and Limestone Powder on the Properties of Ternary Cement and Mortar

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ABSTRACT

The use of inorganic materials, also known as supplementary cementing materials, is a means of increasing production capacity and reducing the energy intensiveness in cement production. Supplementary cementing materials provide economical, ecological and technical benefits on blended cements. The influence of coal bottom ash and limestone on the properties of cement and mortar was investigated in the present work. Several ternary mixtures were prepared by intergrinding Portland cement clinker (C), coal bottom ash (BA) and limestone (L) in a laboratory ball mill at different percentages ranging from 0-40% cement replacement and their physical properties such as consistency, setting times, soundness, compressive and flexural strength were determined in accordance with IS:4031:1988. The results showed an increase in the setting times as bottom ash content increased. There was a reduction in the volume stability as limestone was increased relative to bottom ash. The blended mixtures gave a considerable drop in volume expansion compared to the control, i.e. sample without additives. However, two compositions, 70C-10L- 20BA and 80C-10L-10BA gave higher compressive strengths compared to the control sample at 28- 90 days.

(KEYWORDS: Bottom ash; Limestone; Ternary blend; Properties; Cement replacement)

INTRODUCTION

One of the major achievements of the cement and concrete industry over recent years is the increasing use of inorganic additives (www.1). Since the production of Portland cement clinker is an energy intensive process, the partial substitution of clinker by additives represents considerable energy savings (WBCSD, 2009). In a bid to attain sustainability in the cement industry, one of the alternative options is the use of mineral additives as partial replacement of clinker. It is generally agreed that, with proper selection of additives, mixture proportioning and curing technique, inorganic additives can greatly improve the durability of concrete (Naik *et al*., 2002). The combination of two or more kinds of inorganic materials has emerged as a superior choice over single additive to improve concrete properties (Pandey *et al.*, 2003).

Recently, the use of ternary cement blends in preference to binary cement blends was reported by Kaya (2010). Although the utilization of bottom ash either as a cement replacement material or a concrete mineral additive is not practiced on a large scale due to high unburned carbon content, it has high porous surface and possesses pozzolanic properties (Amanda, 2011). Coal is abundant in many parts of Nigeria and its use in the cement industry offers a life line as a result of the high cost of oil. The addition of limestone accelerates the hydration of C_3A and C_3S and provides better development of the microstructure (Tsivilius *et al*, 2002, Soroka *et al*., 1977).

This paper investigates the performance of ternary mixture incorporating limestone and coal bottom ash as partial replacement for clinker. The physical and mechanical properties such as compressive and flexural strength, water requirement for normal consistency, soundness and setting times were studied in this work.

MATERIALS

In this study, Portland cement clinker for Type I (CEM I-42.5R), class F coal bottom ash (BA) and limestone (L) were used for the preparation of blended cements. The Portland cement (C) and limestone were obtained from AshakaCem works, Gombe State, NE Nigeria, while coal bottom ash was obtained as residue from coal burning furnace at School of Environmental Technology, Abubakar Tafawa Balewa University, Bauchi, NE Nigeria. Coal bottom ash meets general requirement of ASTM class F and has a relatively low CaO content of 0.84%. The chemical composition of the starting materials is given in Table 1.

Table 1: Chemical composition of Portland cement, coal bottom ash and limestone

Component	Portland Cement %	Coal Bottom Ash %	Limestone %
SiO_2	19.239	68.853	10.273
Al_2O_3	5.776	24.157	3.56
Fe_2O_3	2.726	2.887	1.378
CaO	60.637	0.839	46.373
MgO	0.781	0.237	0.448
SO_3	2.118	0.048	0.321
K_2O	0.955	0.683	0.55
Na_2O	0.167	0.146	0.039
P_2O_5	0.171	0.124	0.126
Mn_2O_3	0.190	0.067	0.112
TiO_2	0.281	2.111	0.157
Cr2O3	0.033	-	-
Cl	0.007	-	-
SrO	0.011	-	-
$CaCO_3$	-	-	82.766
C_3S	51.896		
C_2S	15.985		
C_3A	10.698		
C_3AF	8.296		
Specific gravity	3.02	2.21	2.64
Density kg/m^3	2710	1389	2083
Specific surface area cm^2/g	3310	3553	4890

EXPERIMENTAL PROCEDURE

The mix composition of the blended samples are presented in Tables 2 and 3. Table 2 shows the details of six selected blending proportions and one control sample for compressive and flexural strengths, while Table 3 shows the experimental setup for consistency, soundness and setting times. The ingredients were homogenized with a standard blending machine for 15 minutes.

For the flexural and compressive strength tests, prismatic specimen of 40mm x 40mm x 160mm in size were produced using a water: cement: sand ratio of 1:2:6. The pastes were placed in a humidity chamber at 25°C for 24 h. They were demolded and cured in clean tap water for 2, 28, 60 and 90 days. The samples were demolded, broken into two by bending test and each half tested for compression strength, using the Toni Technik compression and bending machine. Other properties such as consistency, setting time, soundness were according IS 4031:1988.

Table 2: Mix compositions for compressive and flexural strength tests

Samples	Mixture ID /100g	OPC (g)	BA (g)	L (g)	Sand (g)	Distilled Water (ml)
1	60C-30L-10BA	270	45	135	1350	225
2	70C-20L-10BA	315	45	90	1350	225
3	80C-10L-10BA	360	45	45	1350	225
4	60C-20L-20BA	270	90	90	1350	225
5	70C-10L-20BA	315	90	45	1350	225
6	60C-10L-30BA	270	135	45	1350	225
7	Control 100C	450	-	-	1350	225

Table 3: Mix compositions for physical properties tests

S/No	Mixture ID wt.%	OPC CEM I 42.5R C wt. %	Limestone L wt. %	Coal Bottom Ash BA wt. %
1	60C-35L-5BA	60	35	5
2	65C-30L-5BA	65	30	5
3	70C-25L-5BA	70	25	5
4	75C-20L-5BA	75	20	5
5	80C-15L-5BA	80	15	5
6	85C-10L-5BA	85	10	5
7	90C-5L-5BA	90	5	5
8	60C-30L-10BA	60	30	10
9	65C-25L-10BA	65	25	10
10	70C-20L-10BA	70	20	10
11	75C-15L-10BA	75	15	10
12	80C-10L-10BA	80	10	10
13	85C-5L-10BA	85	5	10
14	60C-25L-15BA	60	25	15
15	65C-20L-15BA	65	20	15
16	70C-15L-15BA	70	15	15
17	60C-35L-15BA	75	10	15
18	60C-35L-15BA	80	5	15
19	60C-20L-20BA	60	20	20
20	60C-15L-20BA	65	15	20
21	60C-10L-20BA	70	10	20
22	60C-5L-20BA	75	5	20
23	60C-15L-25BA	60	15	25
24	60C-35L-25BA	65	10	25
25	60C-35L-25BA	70	5	25
26	60C-10L-30BA	60	10	30
27	60C-5L-30BA	65	5	30
28	60C-5L-35BA	60	5	35
29	100C	100	-	-

RESULTS AND DISCUSSION

Effect of Limestone and Bottom Ash on the Compressive and Flexural Strengths

Effect of Limestone at Constant Bottom Ash Content

Figure 1 shows the compressive strength as a function of limestone increment at constant bottom ash. An increase in the limestone at 10% constant bottom ash led to a decrease in the compressive strength. This trend can be attributed to dilution of the pozzolanic reaction (Heikal *et al.*, 2000). Also as the curing age increases from 2 days to 90 days, it was observed that the compressive strength increased which agrees with literature (Kaya, 2010).

In Figure 2, highlights the effect of limestone at constant bottom ash on the flexural strength. The results showed that the flexural strength decreased at 2, 28 and 60 days with an increase in limestone content at 10% constant bottom ash whereas for 90 days an increase was observed at 20% limestone followed by a drop at 30% limestone content.

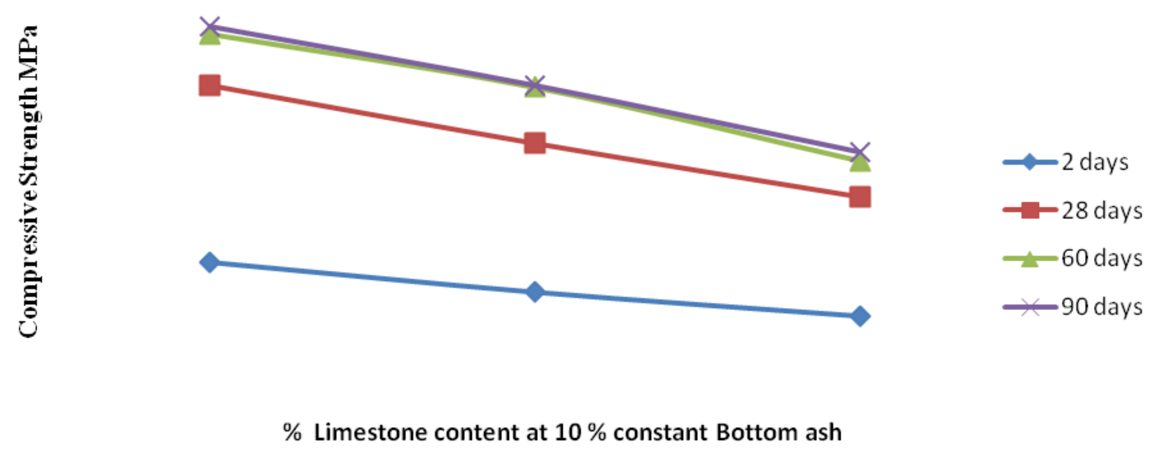

Fig. 1: Effect of Limestone at constant bottom ash content on compressive strength

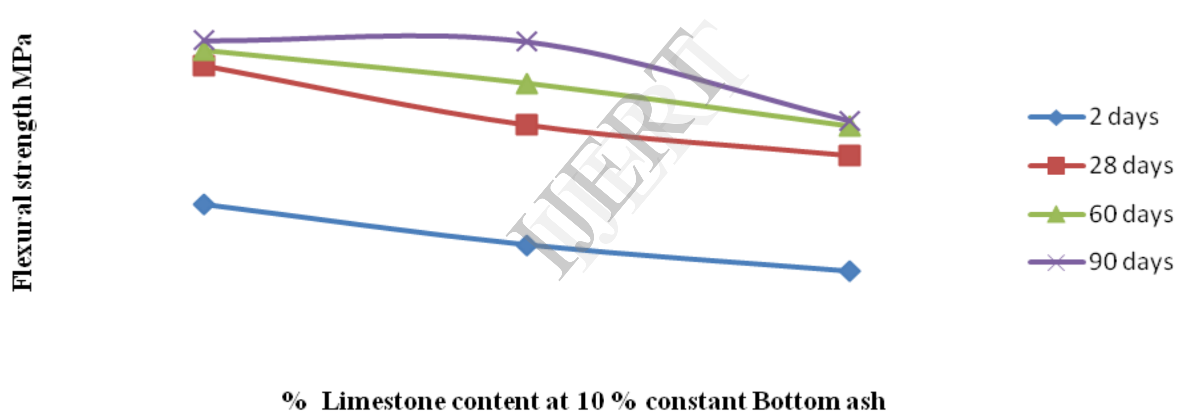

Fig. 2: Effect of Limestone at constant Bottom ash content on Flexural strength

Effect Of Bottom Ash at Constant Limestone Content

The compressive and flexural strengths of the blended samples cured for 2, 28, 60 and 90 days are presented in Figures 3 and 4. The compressive and flexural strengths decreased with increase in bottom ash content when the limestone content is held constant at 10 %, except for samples cured 60 and 90 days which experienced an increase at 20% bottom ash content followed by a decrease. Higher strengths were also obtained for bottom ash increment at constant limestone content as compared to limestone increment at constant bottom ash content. This is because of the availability of free silica present in bottom ash compared to limestone, thus formation of more hydrated products from pozzolanic activity.

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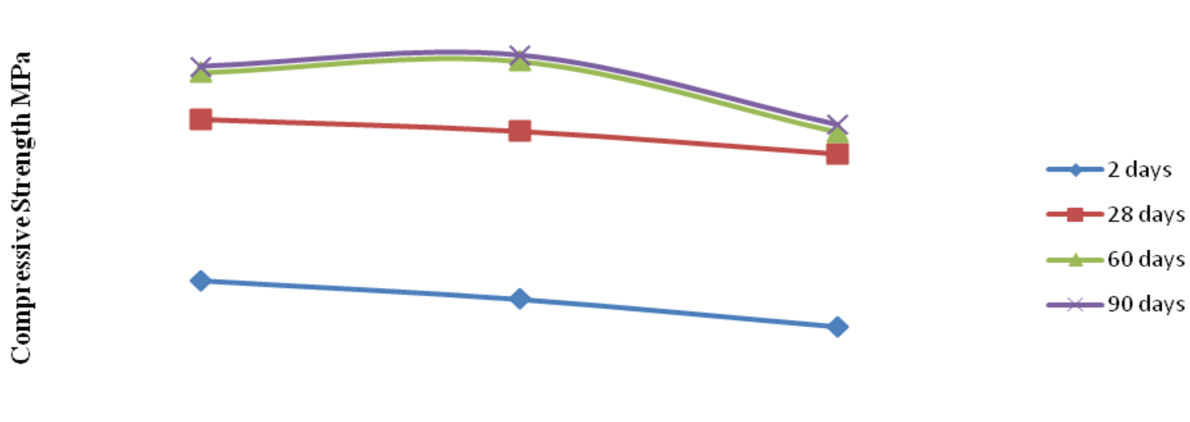
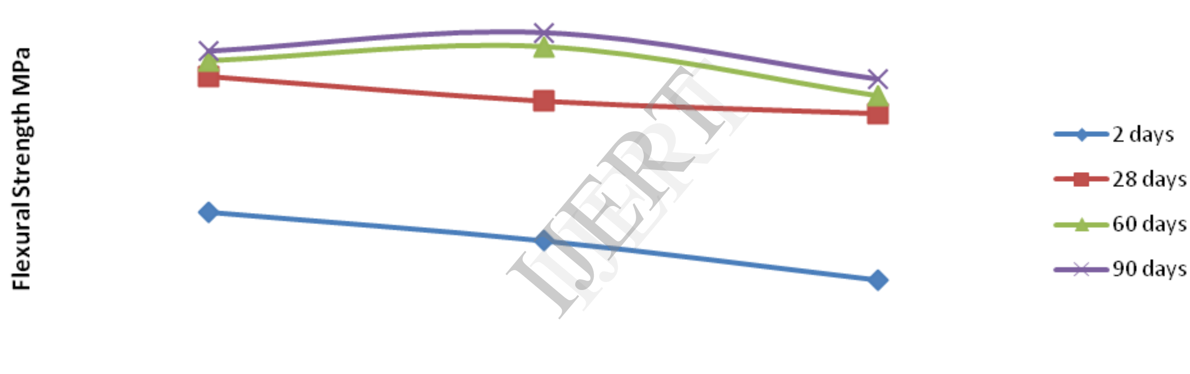


% Bottom ash at 10 % constant limestone

Fig. 3: Effect of Bottom ash at constant limestone content on Compressive strength



% Bottom ash content at 10 % constant Limestone

Fig. 4: Effect of Bottom ash at constant limestone content on Flexural strength

The compressive and flexural strengths of the hardened blended cement mortars and control are illustrated as a function of hydration ages in Figures 5 and 6. It is clear that the compressive and flexural strength increases with curing time for all hardened blended cement mortar.

Also for Figures 5 and 6, as cement replacement level was increased, the compressive and flexural strengths decreased at various curing ages. Similar trends were also observed when the quantity of either limestone or bottom ash were helded constant while other component were increased, resulting in a reduction in the compressive/ flexural strengths. This is due to the high unburnt carbon of the bottom ash (up to 1.5%) increase the water demand. The lower compressive/ flexural strength is experienced when there is higher water requirements and dilution of portland cement.

It was observed that after 28 days both 70C-10L-20BA and 80C-10L-10BA gave greater compressive strengths in comparison with the control. Whereas for flexural strength, after 28days 80C-10L-10BA gave a better flexural strength. At 60 days and beyond samples 70C-10L- 20BA, 70C-20L- 10BA and 80C-10L-10BA gave more satisfactory results compared to the control.

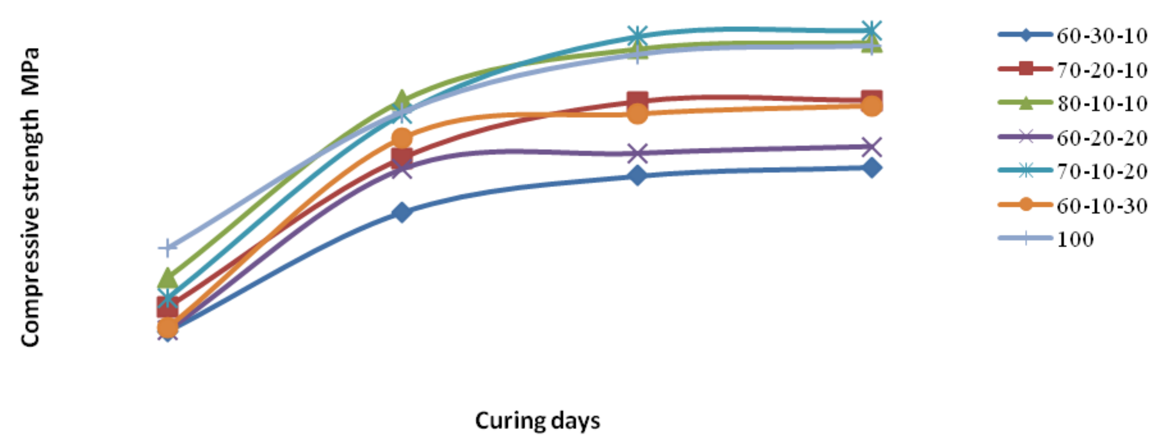


Fig. 5 :Compressive strength at different curing days

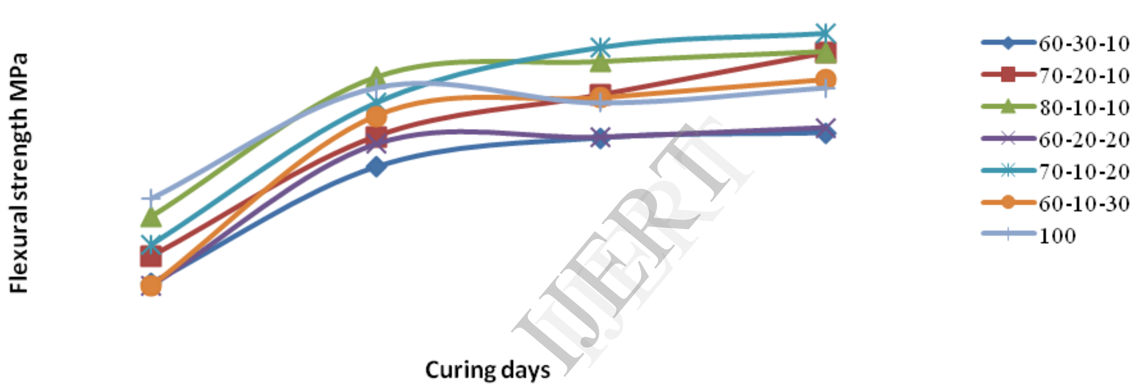


Fig. 6 : Flexural Strength at different curing ages

Effect of Bottom Ash and Limestone on Normal Consistency of Cement Blends

Effect of Bottom Ash At Constant Limestone Content

From Figure 7, the effect of bottom ash at constant limestone on the consistency of blended cement was observed. An increment in the water requirement for normal consistency at constant limestone from 5 - 20% as bottom ash content was increased. This trend agrees with Kaya, (2010) in which increment in bottom ash content from 10 to 40% by weight led to more water required for normal consistency. This can be attributed to the following reasons; high porosity levels and the unburnt carbon particle of bottom ash which could increase the water requirement for consistency.

The normal consistency for ordinary portland cement blended with bottom ash increment from 5-35% by weight at constant limestone content from 5-20% increased from 0.335 to 0.534. Figure 7 also showed that at constant limestone content the increment of bottom ash content experienced a considerable increment in the water requirement for normal consistency between 5 to 10 % compared to above 10% Bottom ash content. Ordinary Portland cement gave less water requirement for normal consistency of 0.32 compared to Blended cement samples.

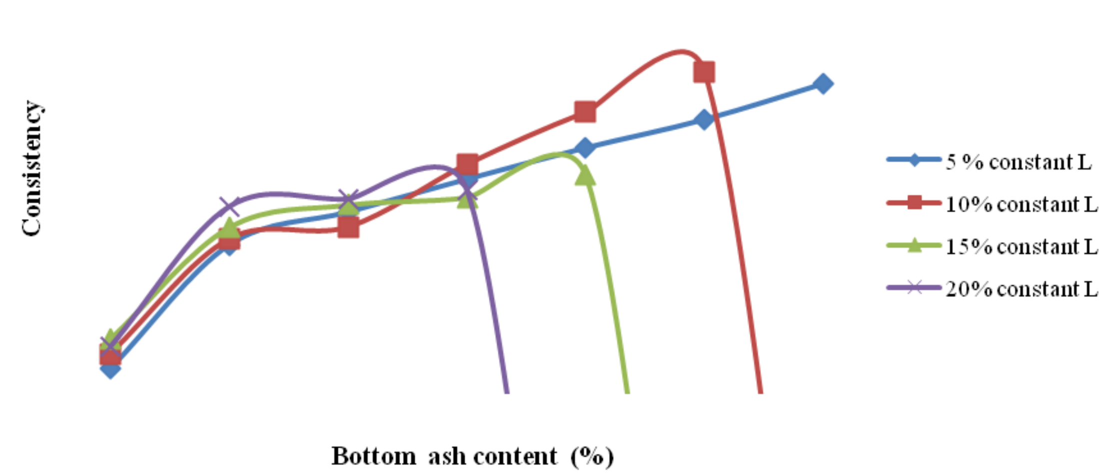


Fig.7: Effect of Bottom ash on Consistency of Blended cement

Effect of Limestone at Constant Bottom Ash Content

Tsivilius *et al* (2002) stated that an increase in limestone content cause a decrease in water demand but in Fig. 8, indicated at 5 and 10% constant bottom ash content, increment in limestone content led to an increase before a decrease. This can be attributed to the high porosity levels and the unburnt carbon particle of bottom ash thus resulting in high water demand initially but as the limestone content is increased a reduction in water demand was experienced. At 15 % constant bottom ash, while limestone content was increased resulted in an reduction in water demand followed by an increase in water demand. Whereas, for 20% constant bottom ash gave an increment in water demand followed by reductions. This could be as a result of interplay between the bottom ash (high porosity) and limestone effect (high specific surface area).

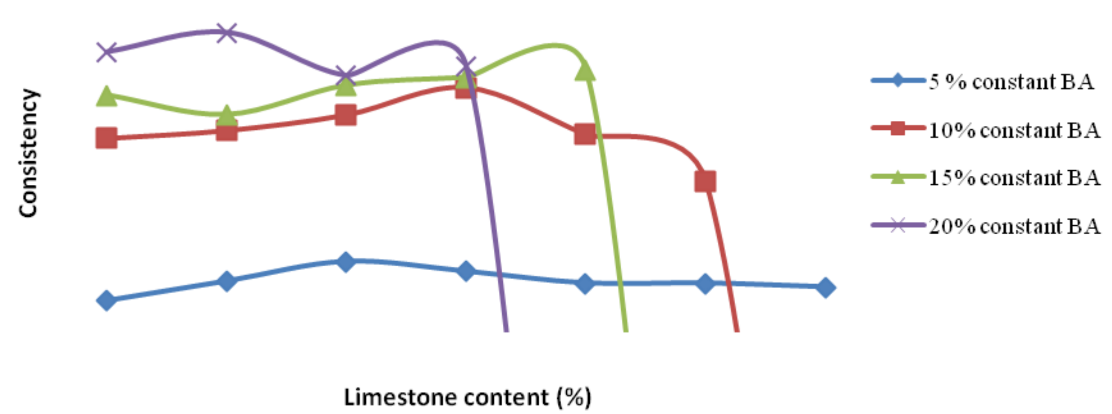


Fig. 8: Effect of Limestone on Consistency of Blended cement

Effect of Limestone and Bottom Ash on Soundness of Blended Cement

Effect of Limestone at Constant Bottom Ash Content

The results obtained on the effect of limestone on the soundness of blended cement sample are presented in Table 4. It was observed that an increment in limestone content at 5% constant bottom ash led to a decrease in volume stability an increase in volume expansion from 0.5 to 3.0mm in stepwise of 0.5mm. This can be attributed to the presence of free lime from limestone content in the cement blend. The volume expansion of blended cement samples results from the availability of free lime. Similar trends were observed at 10% and 15% constant bottom ash. The volume expansion increased from 0.5 -2.0 mm in stepwise of 0.5mm at 10% constant bottom ash, whereas for 15% constant bottom ash indicates a gradual increase in expansion from 1.0 to 2.0 mm in stepwise of 1.0 with limestone increment. There was no observable increase in volume expansion until limestone content reached 15%. From 5-15% constant bottom ash, it was observed that as bottom ash was increased the expansion ratio increased. For 20% constant bottom ash, changes in limestone content gave no significant effect on the volume expansion/ stability as it remained at 1mm.

The control sample gave a volume expansion of 3.0mm. All blended mixes fell within standards (< 10 mm for Le Chatelier apparatus). Blended cements gave better results compared to control samples (Kaya, 2010). It could be concluded that as the cement replacement increase with respect to limestone content, the volume expansion increase while the volume stability decrease due to the higher free lime value in the cement paste.

Table 4: Effect of Limestone on Soundness of Blended cement at constant Bottom ash

Limestone content %	5 % constant BA Expansion mm	10% constant BA Expansion mm	15% constant BA Expansion mm	20% constant BA Expansion mm
5	0.5	0.5	1	1
10	1	1	1	1
15	1	1	1	1
20	1.5	1.5	1	1
25	2	2	2	-
30	2.5	2	-	-
35	3	-	-	-

Effect of Bottom Ash on Soundness at constant Limestone Content

The soundness determined on the blended cement pastes are reported in Table 5. It was shown that bottom ash has little effect on soundness of the blended cement pastes compared to limestone. The volume expansion of the samples increased gradually from 0.5 to 2.0mm and 1.0 to 2.0mm respectively in stepwise of 0.5mm as bottom ash was increased at 5 and 10% constant limestone. At 15% constant limestone as bottom ash content was increased gave no significant effect on the volume expansion of 1.0mm as limestone content was held at 15%. Whereas at 20%, a gradually reduction in volume expansion from 1.5mm to 1.0mm in stepwise of 0.5mm was experienced when bottom ash content was increased as limestone content was held constant at 20%. This could be attributed to the low content of CaO in bottom ash, implying that less free lime available. Thus, indicating that bottom ash has little effect on the soundness of the blended cement paste.

It could be observed that limestone has a greater effect as compared with bottom ash due to the amount of available free lime presence in limestone. Le Chatelier soundness test only takes into account CaO. Volume stability of blended cements were better than that of portland cement due to the lower CaO content of the blended cements. There was a tendency for volume expansion to decrease when clinker replacement ratio was increased. All blended cements had less than 3mm expansion except 60OPC-35L-5BA. Hydration products has larger volume than that of free lime and finally gives rise to cracks in the concrete (Neville and Brooks, 2007). Thus, blended cements give advantageous volume expansion results due to lower free lime value in cementpaste.

Table 5: Effect of Bottom ash on Soundness of Blended cement at constant Limestone

Bottom ash content %	5% constant L Expansion mm	10% constant L Expansion mm	15% constant L Expansion mm	20% constant L Expansion mm
5	0.5	1	1	1.5
10	0.5	1	1	1.5
15	1	1	1	1
20	1	1	1	1
25	1.5	1.5	1	-
30	1.5	2	-	-
35	2	-	-	-

Effect of Limestone and Bottom Ash on Setting Times of Cement Blends

Effect of Limestone at Constant Bottom Ash Content

Figures 9 and 10 show the initial and final setting time plotted as a function of limestone content while bottom ash was kept constant respectively. Both figures indicated increment in initial and final settng time as limestone rose from 5 to 15% by weight at constant bottom ash content of 5%. This can be attributed to the reduction in the amount of ordinary portland cement resulting in the diminution in the amount of tricalcium silicate C_3S, since C_3S readily react with water, thus setting times of the paste increases. The initial setting time decreased between 20 -35% limestone increment while final setting time showed a reduction between 20-25%. This can be attributed to dilution effect resulting from depression of setting time due to reduced solubility of aluminate phase to produce carbonaluminate (Taylor, 1990) ,while at 30-35% limestone increment, the final setting time increased possibly due to presence of free lime provides nucleating sites for it growth thus increasing the rate of hydration.

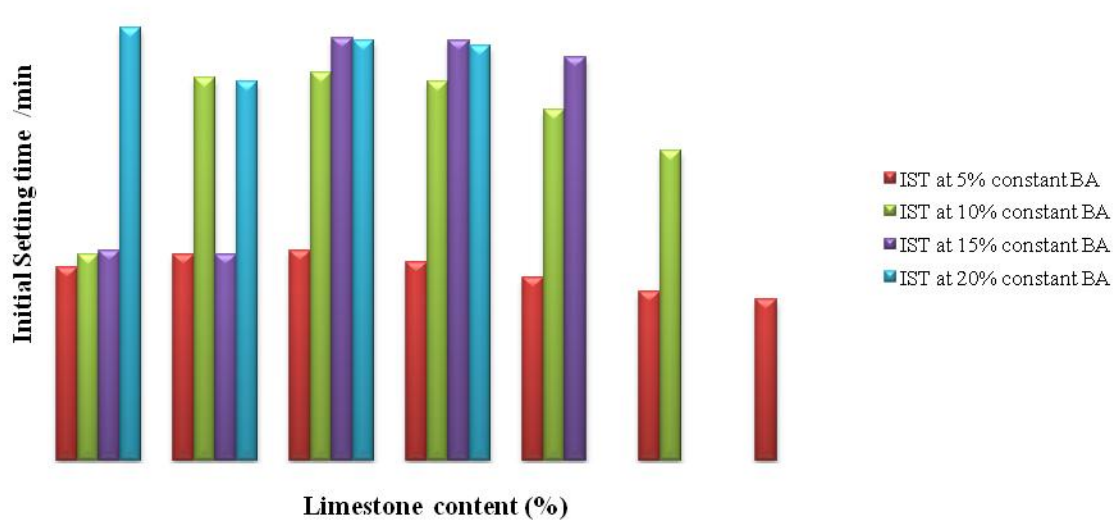


Fig. 9: Effect of limestone on Initial setting time of blended cements

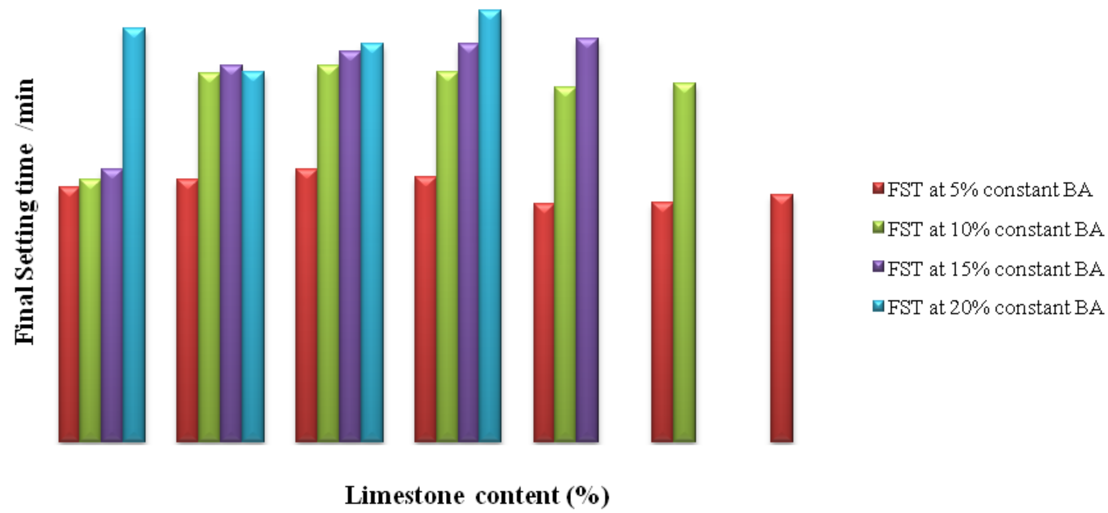


Fig. 10: Effect of Limestone on Final setting time of blended cements

Effect of Bottom Ash at Constant Limestone Content

Figures 11 and 12 show the effect of bottom ash at constant limestone content on the initial and final setting times of blended cement, respectively. The relation was directly proportional, i.e. as the bottom ash content was increased at constant limestone content, the initial and final setting times increased gradually. This can be attributed to the partial replacement of cement; resulting in diminution in the amount of C_3S, thus increasing the setting time.

The results presented in Figures 9 to 12 met the limit value given in ASTM C 595 (420min> Setting time >45min). As expected, the initial and final setting times of Ordinary Portland cement was shorter than the blended cement. The initial and final setting times of blended cement with limestone substitution as compared with Ordinary Portland cement retarded by 70 and 90 minutes, respectively.

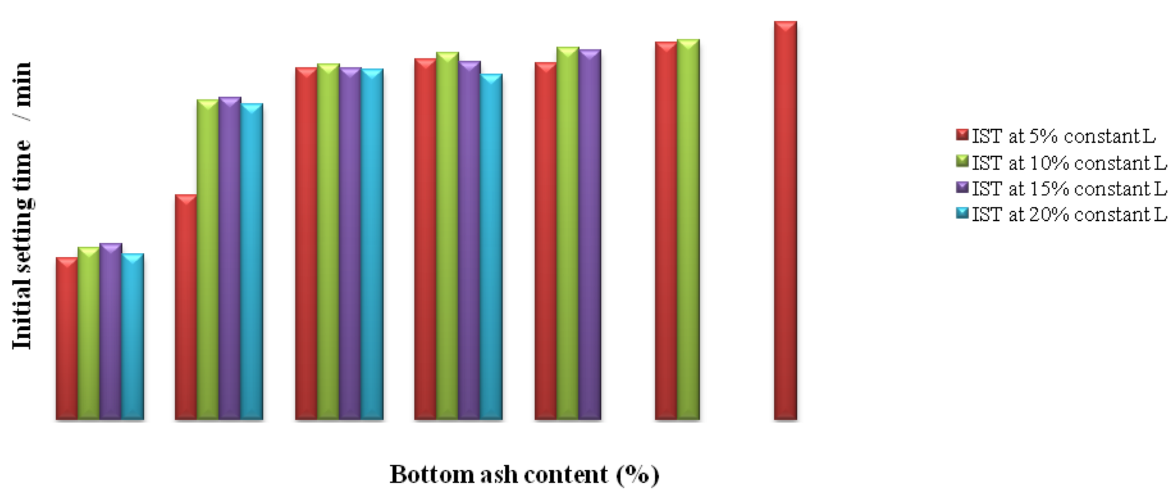


Fig. 11: Effect Bottom ash on Initial setting time of blended cements

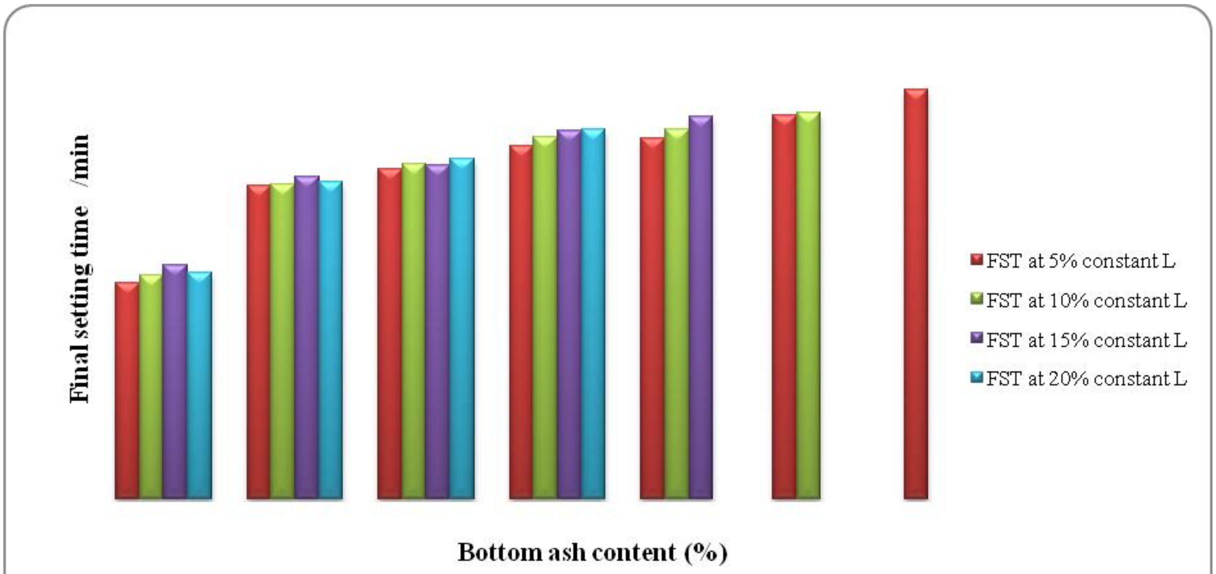


Fig. 12: Effect of Bottom ash on Final setting time of blended cements

CONCLUSION

From this research, both initial and final setting time of the ternary cement pastes decreased with an increasing of bottom ash content at constant limestone content. Whereas, limestone increments at constant bottom ash content caused changes in the setting times.

From the soundness test, an increase in limestone at constant bottom ash had a considerable effect on the volume instability of the ternary mixture compared to bottom ash increment while limestone was held constant. Moreover, this can be attributed to the availablity of free lime. Blended cement exhibited a more satisfactory soundness compared to Ordinary Portland cement.

For the ternary blends, the water requirement for normal consistency increased as the bottom ash content was increased at constant limestone content. Particularly, blended cement containing 10% Limestone L by weight with 10% and 20% bottom ash BA gave higher compressive strength at latter ages, i.e. beyond 28 days, than the control sample.

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