

# **A Study of the Effects of Post-Combustion Ammonia Injection on Fly Ash Quality: Characterization of Ammonia Release from Concrete and Mortars Containing Fly Ash as a Pozzolanic Admixture**

Semi-Annual Technical Progress Report  
for the Period 10/12/01 to 04/11/02

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**U.S. DoE Cooperative Agreement Number:** DE-FC26-00NT40908

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## ABSTRACT

Work completed in this reporting period focused primarily on continuing measurements of the rate of ammonia loss from concrete, and the measurement of ammonia gas in the air above concrete and flowable fill immediately after placement. Concrete slabs were prepared to monitor the loss of ammonia during mixing, the concentration in the air-space above the slabs soon after placement, and the total quantity of ammonia evolved over a longer time period. Variables tested include temperature, ventilation rate, water:cementitious (W:C) ratio, and fly ash source. Short-term data indicate that for concrete placed in areas with poor air ventilation the fly ash  $\text{NH}_3$  concentration should not exceed about 90 to 145 mg/kg ash, depending on the water:cement ratio and the fly ash replacement rate, if a concentration of 10 ppm  $\text{NH}_3$  in the air is assumed to be the maximum acceptable level. Longer-term experiments showed that the ammonia loss rate is dependent on ammonia source (that is ammoniated ash vs. non-ammoniated ash with ammonia added to the water), and is also dependent on W:C ratio and temperature. Experiments were also conducted to study the loss of ammonia from fresh concrete during mixing. It was found that a high water:cementitious mix lost a greater percentage of ammonia than a low W:C mix, with a medium W:C mix losing an amount intermediate between these two. However, a larger batch size resulted in a smaller percentage of ammonia lost. The data suggest that a significant quantity of ammonia could be lost from Ready Mix concrete during transit, depending on the transit time, batch size, and mix proportions.

## EXECUTIVE SUMMARY

Work completed in this reporting period focused primarily on continuing measurements of the rate of ammonia loss from concrete, and the measurement of ammonia gas in the air above concrete and flowable fill immediately after placement. Mortar testing has been completed, and the remainder of these experiments are reported herein. In the previous reporting periods it was found that an increase in ventilation rate caused a significant increase in ammonia loss rate from mortar. Additional testing at a higher ventilation rate (reported herein) has confirmed the earlier data. However, it was also found that the volume of enclosed space above the mortar and concrete during the experiments had a substantial effect on ammonia loss rate: a greater volume caused more ammonia to diffuse from the materials than when a smaller headspace volume was used, even though the ventilation rate was kept constant. The reason for this is being investigated.

Concrete slabs (41 cm diameter, 11cm thick) were prepared to monitor the loss of ammonia during mixing, the concentration in the air-space above the slabs soon after placement, and the total quantity of ammonia evolved over a longer time period. Variables tested date include temperature, ventilation rate, water:cementitious (W:C) ratio, and fly ash source. The data indicate that for concrete placed in areas with poor air ventilation the fly ash  $\text{NH}_3$  concentration should not exceed 185 to 290 mg/kg, depending on the water and cement content, and the fly ash replacement rate, if the recommended OSHA exposure limit TWA of 25 ppm is not to be exceeded. A lower exposure limit is likely to be followed in practice, however, in order to minimize worker complaints. If this assumed to be half of the TWA, then the maximum concentration would be between 100 to 145 mg  $\text{NH}_3$ /kg fly ash. The presence of even a modicum of air ventilation would allow for a greater amount of  $\text{NH}_3$  to be present on the ash, perhaps as high as 250 mg  $\text{NH}_3$ /kg ash, again depending on the fly ash replacement rate, and cement and water content. Longer-term experiments showed that the ammonia loss rate is dependent on ammonia source (that is ammoniated ash vs. non-ammoniated ash with ammonia added to the water), and is also dependent on W:C ratio and temperature.

Experiments were also conducted to study the loss of ammonia from fresh concrete during mixing. These experiments were conducted using a 3.5 ft<sup>3</sup> concrete mixer that was modified to resemble a scaled-down concrete truck mixing drum. It was found that the high water:cementitious mix (or perhaps the cementitious content) lost a greater percentage of ammonia than the low W:C mix, with the medium W:C mix losing an amount intermediate between these two. After 40 minutes mixing a 20 liter batch of concrete lost 15, 25, and 35% of the initial ammonia content for the low, medium, and high W:C mixes, respectively. However, for a 40 liter batch (which was near maximum capacity) the high W:C mix lost only 12-14% of the initial ammonia amount. The data suggest that a significant quantity of ammonia could be lost from Ready Mix concrete during transit, depending on the transit time, batch size, and mix proportions.

## **EXPERIMENTAL**

### **A. Mortar and Concrete Preparation**

#### **A.1. Mortar**

Mortars were prepared and mixed using the materials and procedures described in Technical Progress Reports #1 and #2.

#### **A.2. Concrete**

Concrete studied in this project was prepared using Type I Portland cement (Quickcrete brand), graded sand, limestone aggregate, fly ash, and tap water. Slump was increased using Boral X20 mid-range water reducer, and air was entrained by addition of Boral Air 40. Concrete batch volumes of 0.02 m<sup>3</sup> were formulated following ACI 211.1-91 guidelines (ACI, 2000). Three water:cement + pozzolan (W:C) ratio mixes were designed and prepared in trial batches, and are presented in Table 1. Ammonia was introduced into the concrete by first dissolving ammonium sulfate in the mix water when non-ammoniated ash was used, and directly through the addition of ammoniated fly ash. The components were mixed for approximately 3 minutes in a 99 L (3.5 ft<sup>3</sup>) capacity mixer (Gilson Company), the opening of which was covered with a tight-fitting lid to prevent the escape of ammonia from the rotating mixing drum.

### **B. Long-Term Loss of Ammonia**

#### **B.1. Mortar**

The experimental design for measurement of ammonia loss from mortar is described in Technical Progress Report #1. During this reporting period, the effect of ventilation rate on the loss of ammonia from mortar was completed. Ventilation rates that would be applicable for residential buildings (ASHRAE, 1999) were proportioned to the cross-sectional area of the cylindrical mortar slabs as described for the mortar experiments in the aforementioned technical report.

#### **B.2. Concrete**

The experimental apparatus employed to complete the long-term experiments was described in Technical Progress Report #2, with a modification added during this period to obtain better temperature control of the concrete. This was accomplished by using a 41 cm (16 in.) diameter X 15 cm (6 in.) height polyethylene base, instead of a Sonotube section, to contain the concrete. This assembly was then immersed in a temperature-controlled water bath (13 cm deep) and was attached to the 213 cm (7 ft.) section of Sonotube (Figure 1).

### **C. Ammonia Concentration in the Air Above Fresh Concrete**

One of the major concerns regarding the use of ammoniated fly ash in concrete is the potential exposure of workers to high levels of ammonia. In this context, a key issue is the maximum concentration of ammonia allowable in fly ash, below which worker safety would not be jeopardized. Therefore, an experimental procedure was designed to address this issue. An 11 cm (4.3 in.) thick ammonia-laden concrete slab was placed into the Sonotube assembly described above. Ammonia concentration of the air within

the Sonotube was measured using GasTec ammonia detection tubes over the course of 1 - 2 days. Ventilation within the Sonotube was a variable, with rates of 0, 8.3, and 15.2 L/min (corresponding to air exchange every 0, 34, and 19 minutes, respectively). Furthermore, ammonia concentration, cementitious content, fly ash replacement rate, and water:cement ratio were varied during the tests.

#### **D. Ammonia Loss from Concrete During Mixing**

In order to realistically study the rate of ammonia loss during mixing our concrete mixer was modified to closer approximate the dimensions of a commercial concrete truck. Specifically, the end of our mixer was extended approximately 31 cm (12 in) by placing a polyethylene industrial funnel over the mixer opening. The end of the funnel was cut off such that a 15 cm (6 in.) diameter opening remained (Figure 2), and this section of funnel was temporarily sealed to the mixer using duct tape. The procedure commenced with charging the mixer with the ingredients and mixing at 22 RPM for two minutes with the end of the mixer capped to prevent ammonia loss. A sample of concrete (0.5 L) was taken, whereupon the cut-off funnel described above was attached to the mixer, and the mixing speed slowed to 4 RPM which is similar to a Ready Mix concrete truck in-transit to a job site. The concrete was mixed for 40 minutes, with samples taken at 10 minute intervals using a metal scoop.

Ammonia was measured in the concrete using an Orion ammonia-sensing gas electrode. The concrete was placed into a 1 L polyethylene bottle, capped, and agitated for 5 minutes. The solid cap was then replaced with a cap in which a 1.9 cm hole had been drilled and fitted with a rubber grommet. The ammonia electrode was inserted into the grommated hole such that the end of the electrode was above the concrete surface (Figure 3). The ammonia concentration of the water in the concrete was then obtained by comparing the voltage readout with those from standards. The experimental apparatus was checked for accuracy by preparing cement paste, mortar, and concrete (with ammonia added to the water at 122 mg  $\text{NH}_3/\text{L}$ ) within the polyethylene bottle, without any external mixing. The ingredients were shaken vigorously for 10 minutes, whereupon the ammonia was measured within the bottle. Results of this testing are shown in Table 2, and indicate that the technique provides an accurate measure of ammonia in the concrete and mortar, but inexplicably, overestimates the ammonia content of the paste only. However, for our purposes it is a useful method for ammonia measurement in concrete.

## **RESULTS AND DISCUSSION**

### ***A. Long-Term Ammonia Loss from Mortar***

#### ***A.1. Effect of Ventilation Rate***

As was discussed in Technical Report #2 previous research has shown that the loss rate to the atmosphere of gases that are reactive in water, such as  $\text{SO}_2$  and  $\text{NH}_3$ , is limited by the gas concentration in the air layer immediately overlying the seawater. Thus, for water with a high pH (i.e. 12), and a constant temperature and area:volume



ratio, the ammonia loss rate should be limited by the air ventilation rate over the water. Figure 4 depicts the complete data set that shows the effect of ventilation rate on ammonia loss from Low W:C mortar containing 486 mg  $\text{NH}_3$  per kg of fly ash, at 18°C. The data indicate that an increase in ventilation did indeed substantially increase the ammonia loss rate from mortar. Ventilation of the cylinder with 15 L/min of fresh air for four weeks caused a loss of 40% of the ammonia compared with only 15% in the case of the 1L/min ventilation. These data indicate that a well-ventilated space could substantially increase the loss of ammonia from mortar and, by inference, a concrete slab. However, it should be kept in mind that even the high ventilation rate of 15 L/min, where the air was being replaced every 4 seconds, represents a wind speed of only 0.067 miles/hr, which is significantly below wind speeds encountered outdoors even on a calm day. Therefore, extrapolation of these data to estimate the ammonia loss from mortar or concrete exposed outdoors prior to enclosure within a structure (i.e. a residential slab poured on-grade) is not warranted.

Over the course of these experiments it was discovered that reproducing outdoor exposure of mortar and concrete while at the same time monitoring the ammonia loss is very difficult in the laboratory. The main problem is that, unlike water, monitoring the ammonia loss from hardened concrete requires that all of the evolved ammonia be captured for measurement. Therefore, in order to replicate outdoor exposure conditions a very high ventilation rate would be required whilst still capturing all of the evolved ammonia in our trap flask. For example, to simulate a 1 mile per hour in the 15 cm X 30 cm cylinder with a 5.5 cm tall headspace would require a ventilation rate of 225 L/min through the cylinder. At this rate, configuring the experiment to trap all of the evolved ammonia would be extremely difficult. Therefore, the focus of our study has continued to be to simulate realistic indoor conditions.

## **B. Ammonia Loss from Concrete**

### ***B.1. Long-Term Loss Rate***

The loss of ammonia from concrete was studied over the course of 1 month with several variables tested. Four separate concrete mixes were proportioned to test the effects of water:cementitious (W:C) ratio and cementitious content. In addition to the three mixes listed in Table 1, an additional mix was prepared by adding water to the Low W:C mix to get a W:C = 0.50. The rationale for this was that it is very common for water to be added to Ready Mix concrete when it arrives on a job site, in order to increase the slump and make the concrete easier to work with (although it will lower the strength). Figure 5 shows the ammonia loss rate from the four different concrete mixes, expressed as a fraction of the initial  $\text{NH}_3$  concentration in the concrete. The data indicate that the W:C ratio has no significant effect on the fraction of  $\text{NH}_3$  remaining in the concrete after 1 month, which is approximately 65-70% of the initial amount. This result is somewhat unexpected when compared to the mortar data which showed that the High W:C ratio mortar lost ammonia at a greater rate than the Low W:C mortar, even when the data are expressed on a fractional loss basis. However, as was discussed in Technical Progress Report #1 the difference occurred primarily within the first 4 days, after which the loss rates were similar for the two mortars. This is probably related to the greater quantity of

bleed water that was observed for the High W:C mortar, which would bring ammonia towards the surface of the material. In comparison, even the High W:C (0.68) concrete mix did not exhibit nearly the degree of bleed observed for the High W:C mortar.

The source of ammoniated fly ash did not exhibit a noticeable effect on the long-term loss rate, as is shown in Figure 6 for Belews Creek and Conesville fly ash concrete (Medium W:C mix) ventilated at 8.3 L/min. The deviation in the Belews Creek data at the end of the experiment occurred because of a vacuum that developed within the Sonotube apparatus that was caused by a clogged inlet particulate filter: the rest of the data correspond well with the Conesville loss curve. However, concrete prepared with Bowen fly ash, with the  $\text{NH}_3$  introduced as  $(\text{NH}_4)_2\text{SO}_4$  in the water, exhibited a lower ammonia loss rate. Whether this is caused by the Bowen fly ash itself or is a function of the method of ammonia addition to the concrete will be the subject of additional experiments.

In a separate set of experiments another departure from the mortar data was observed: ventilation rate apparently exerts a negligible influence on long-term ammonia loss rate from concrete. Two experiments were conducted using the Medium W:C mix prepared using Conesville fly ash, with ventilation rates of 8.3 L/min and 15.2 L/min. As can be seen in Figure 7 these ventilation rates produced similar ammonia loss rates over the course of 1 month. It should be noted that ventilation rates of 8.3 and 15.2 L/min represent an exchange of the air within the Sonotube every 33 and 19 minutes, respectively. It appears that, under these ventilation conditions, the diffusion of ammonia from concrete is limited by diffusion through the concrete and not by the gas phase concentration of ammonia above the concrete, as is the case for water. Therefore, according to our data exposure of the concrete outdoors, with a high degree of ventilation, prior to enclosure within a structure would not necessarily result in an increased loss of the ammonia within the concrete compared with a slab placed indoors with a lower degree of ventilation. As is the case for other results, these will be checked prior to issuance of the Final Report for the project.

### ***B.2. Ammonia Concentration in the Air Above Fresh Concrete***

The accumulation of ammonia in the air within the Sonotubes after placement of concrete and without ventilation is shown graphically in Figures 8 - 10. During each of these experiments the ammonia increased to its maximum concentration within 2-3 hours, followed by a gradual decrease during the first 24 hours. Although there was no ventilation within the Sonotubes, and thus the ammonia should not have decreased within the assembly, they were not completely air-tight. Thus, some ammonia was able to slowly escape during the experiment. However, this was not deemed to be a problem for the long-term (i.e. 1 month duration) experiments since air was being pulled through the Sonotubes and therefore should keep any significant amount of ammonia from leaking out of the apparatus. In contrast to the experiments with no ventilation, venting the Sonotubes with 8.3 L/min fresh air resulted in a different profile for the ammonia-in-air concentration with time. As can be seen in Figures 11 and 12, the  $\text{NH}_3$  concentration in the air increased to its maximum within approximately 0.5 hrs,

whereupon it decreased rapidly. Similar results were observed when 15.2 L/min of fresh air were vented through the Sonotube (Figure 13).

The experiments were conducted for the three different W:C ratio concrete mixes, using both ammoniated and non-ammoniated (but with ammonia added to the water) fly ash, and with different  $\text{NH}_3$  concentrations. In addition, several experiments were conducted using ammoniated fly ash at a cement replacement of 30% instead of 20%. This had the effect of increasing the  $\text{NH}_3$  concentration in a different manner than adding more  $\text{NH}_3$  to the water or decreasing the W:C ratio. The maximum  $\text{NH}_3$  concentration in the air was then recorded for each experiment (generally after 3 hrs for the non-ventilated experiments, and 0.5 hours for the ventilated ones) and plotted versus the  $\text{NH}_3$  concentration of the fly ash (Figure 14). For non-ammoniated fly ashes, where ammonia was added to the water, the concentration is also expressed on an ash basis. The graph in Figure 14 reveals an obvious relationship between the  $\text{NH}_3$  concentration in the fly ash and the maximum concentration of  $\text{NH}_3$  in the air. There is, however, a significant degree of scatter in the data, particularly at high  $\text{NH}_3$  concentrations. Furthermore, there is very little difference between the ventilated and non-ventilated experiments. Although a part of the scatter can be attributed to experimental error, some of it is caused by reporting the  $\text{NH}_3$  concentrations on an ash basis. This occurs because expressing the  $\text{NH}_3$  concentrations in this way does not account for the different water contents, W:C ratio, and cement replacement rates that will change the total quantity of ammonia in a concrete mix. A more suitable method is therefore to express the  $\text{NH}_3$  concentration on a water basis, that is, in mg  $\text{NH}_3$ /L water. This is done in Figure 15, and it is evident that there is a clearer relationship between the variables, whilst the ventilated conditions also are shown to produce a lower maximum  $\text{NH}_3$  concentration in the air than the non-ventilated conditions.

An important aspect of the data in Figure 15 is that they provide the information needed to estimate the concentration of  $\text{NH}_3$  on fly ash that should not be exceeded in order to ensure worker safety. The data indicate that for concrete placed in areas with little to no air ventilation the  $\text{NH}_3$  concentration in the concrete should not exceed 110 mg/L if the recommended exposure limit TWA of 25 ppm is not to be exceeded. The maximum amount of  $\text{NH}_3$  on the fly ash will vary based on the concrete mix proportions and the cement replacement rate (with fly ash). The pertinent equation is then:

$$\text{NH}_{3\text{water}} = \frac{(\text{NH}_{3\text{ash}} * (\text{CWF} * \text{RPL}))}{\text{WF}}$$

Where  $\text{NH}_{3\text{ash}}$  is in mg/kg ( $\approx$ ppm), CWF = cement content, RPL = replacement rate, and WF = water content. For example, for our Low W:C mix with a 20% replacement of fly ash for cement the  $\text{NH}_3$  content in the ash should not exceed 244 mg/kg, whereas for the High W:C mix the maximum concentration is 373 mg/kg. However, 25 ppm  $\text{NH}_3$  in the air would produce a strong odor, thus a lower exposure limit is likely to be followed in practice in order to minimize worker complaints. If this assumed to be 10 ppm in the air, then the maximum concentration in the concrete is 50 mg  $\text{NH}_3$ /L water. Using the

same examples as above, the ammonia concentration in the fly ash should be no higher than 110 and 170 mg  $\text{NH}_3$ /kg ash for the Low and High W:C mixes, respectively.

Following the same procedures, it can be seen that placing concrete in a space with some ventilation present can raise the maximum  $\text{NH}_3$  concentration in the fly ash. For example, with ventilation that meets the ASHRAE minimum standards for a residential living space (approximately equivalent to our 8.3L/min rate) the  $\text{NH}_3$  content of the fly ash should be below 166 to 254 mg  $\text{NH}_3$ /kg ash for our Low and High W:C concretes, respectively, assuming a limit of 10 ppm  $\text{NH}_3$ -in-air. Interestingly, increasing the ventilation rate to 15.2 L/min (equivalent to a fresh air replacement every 19 minutes) did not have an effect on these calculated values (Figure 15). This result was unexpected, but does agree with the long-term ammonia loss data which showed that the loss rate was similar for concrete exposed to 8.3 and 15.2 L/min ventilation rates.

### ***B.3. Ammonia Loss During Mixing***

The loss of ammonia from concrete during mixing was accomplished as described in the Experimental section. The first set of tests examined the effects of batch size on the ammonia loss rate, based on the hypothesis that a larger batch would contain less free air space above the concrete within the mixer and would thus lose a smaller percentage of the initial ammonia content. Figure 16 presents the results of these tests and shows that batch size did indeed exert a pronounced effect on the ammonia loss rate during mixing. For the 20 L batch, the mixer was approximately  $\frac{1}{2}$  full whereas the 40 L batch was near the mixer capacity. As is seen in Figure 16, after 40 minutes of mixing the 20 L batch contained about 65% of the initial  $\text{NH}_3$  content, whereas the 40 L batch retained almost 90% of the initial amount. The implication of these data is that a full Ready-Mix concrete truck will retain a larger proportion of ammonia than if the truck is not filled to capacity.

Figure 17 presents the results of tests designed to investigate the effects of mix proportioning. For our three concrete mix designs, the Low W:C concrete lost proportionately less ammonia during mixing than the High W:C concrete, with the Medium W:C mix intermediate between the other two. Interpretation of these data at this time has not been completed because additional tests are needed to determine if these results are primarily a function of fly ash content (i.e. the quantity of  $\text{NH}_3$  present in the concrete), the quantity of total cementitious material, and/or the physical properties (e.g. slump) of the different concrete mixes. Therefore, additional mixing experiments will be performed prior to the project's completion.

**Table 1. Proportions of Concrete Mixes Used in this Study**

Property/Component	Low W:C Mix	Med W:C Mix	High W:C Mix
Cement (kg/m <sup>3</sup> )	354	245	203
Fly Ash (kg/m <sup>3</sup> )	88	61	51
Fine Aggregate (kg/m <sup>3</sup> )	792	862	873
Coarse Aggregate (kg/m <sup>3</sup> )	1000	1070	1090
Water (kg/m <sup>3</sup> )	195	168	173
Water:Cement + Fly Ash	0.44	0.55	0.68
Slump (mm, in.) no admixtures with admixtures <sup>1</sup>	76, 3 127, 5	-- 178, 7	76, 3 178, 7
Air Content (% , volume) <sup>2</sup>	5.5	6	6

<sup>1</sup> Low W:C mix = 3.25 ml X20/kg cement + fly ash, 3.25 ml Air 40/kg cement + fly ash  
High W:C mix = 0.65 ml Air 40/kg cement + fly ash

<sup>2</sup> Air content determined only for concrete mix containing the admixtures

**Table 2. Ammonia Concentration of Fresh Concrete Prepared in a Polyethylene Bottle**

Material	Actual NH <sub>3</sub> (mg/L H <sub>2</sub> O)	Measured NH <sub>3</sub> (mg/L H <sub>2</sub> O)
Paste <sup>1</sup>	122	134
Mortar <sup>2</sup>	122	120
Concrete <sup>3</sup>	122	120

<sup>1</sup> Cement, ash, water; <sup>2</sup> Cement, ash, sand, water; <sup>3</sup> Cement, ash, sand, gravel, water



Figure 1. Sonotube apparatus used to measure long-term ammonia loss from concrete.



Figure 2. 3.5 cu. ft. mixer modified to simulate a commercial Ready Mix truck mixing drum.



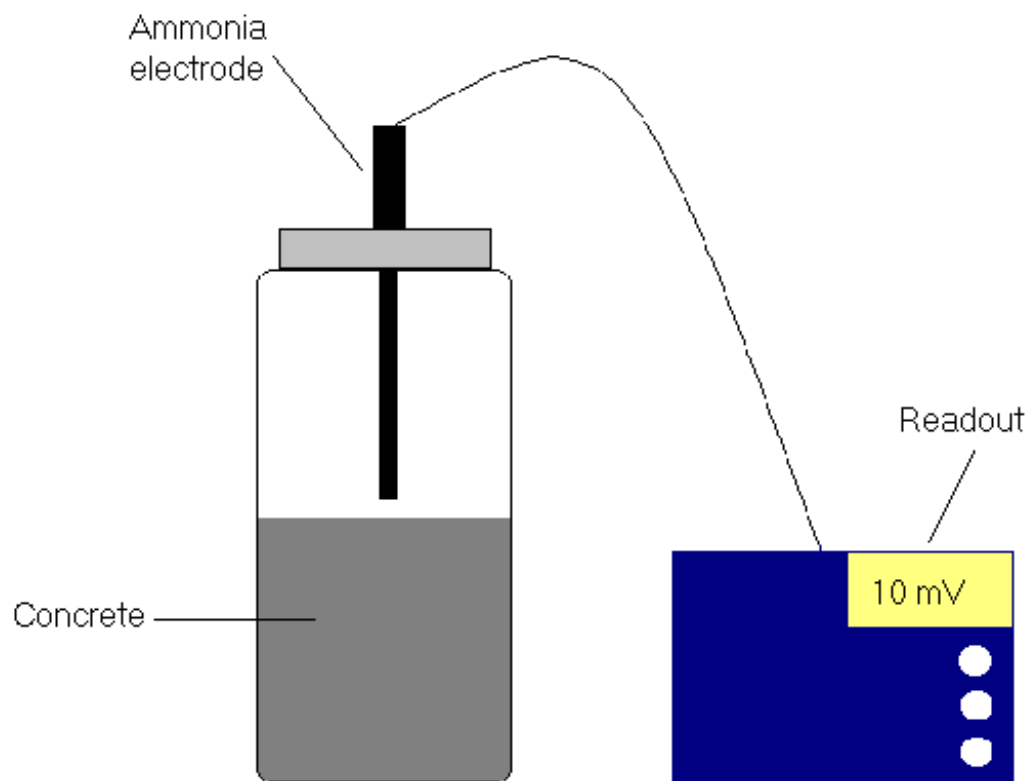


Figure 3. Experimental apparatus used to measure ammonia in wet concrete.



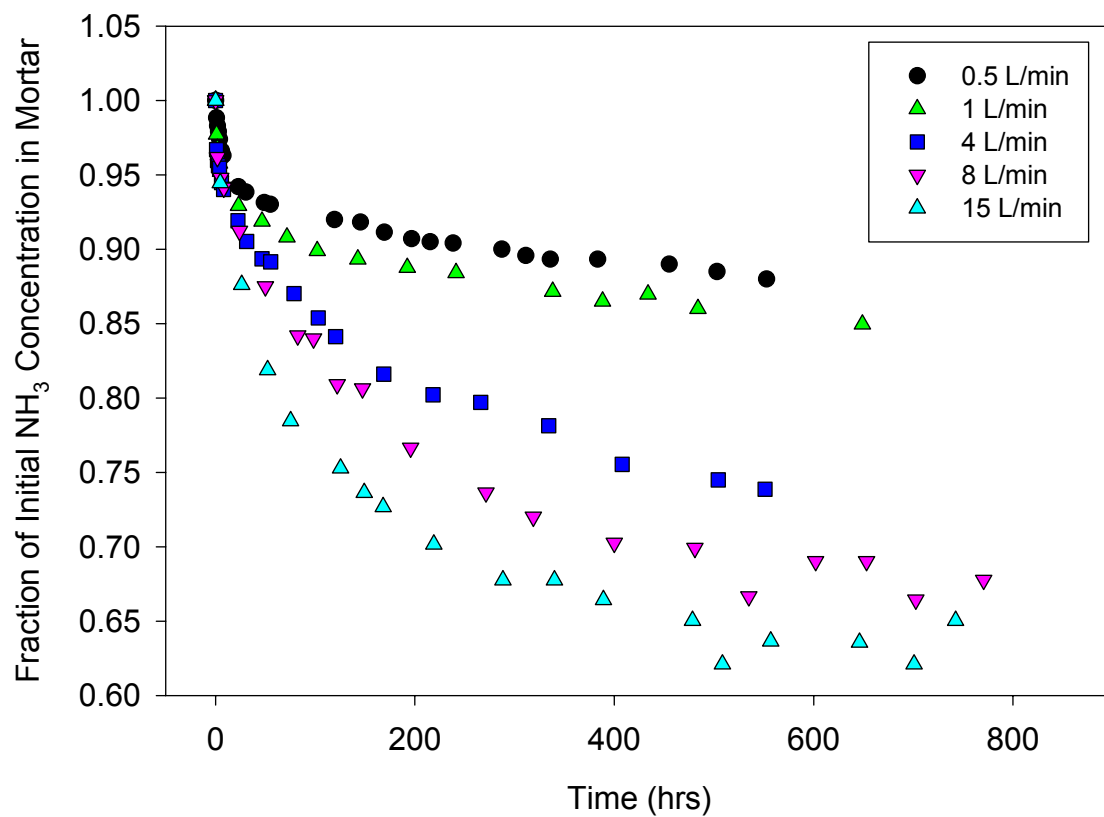


Figure 4. The effect of ventilation rate on the loss of ammonia from mortar. Low W:C mix, Bowen fly ash, 486 mg NH<sub>3</sub> added per kg ash, 18°C.

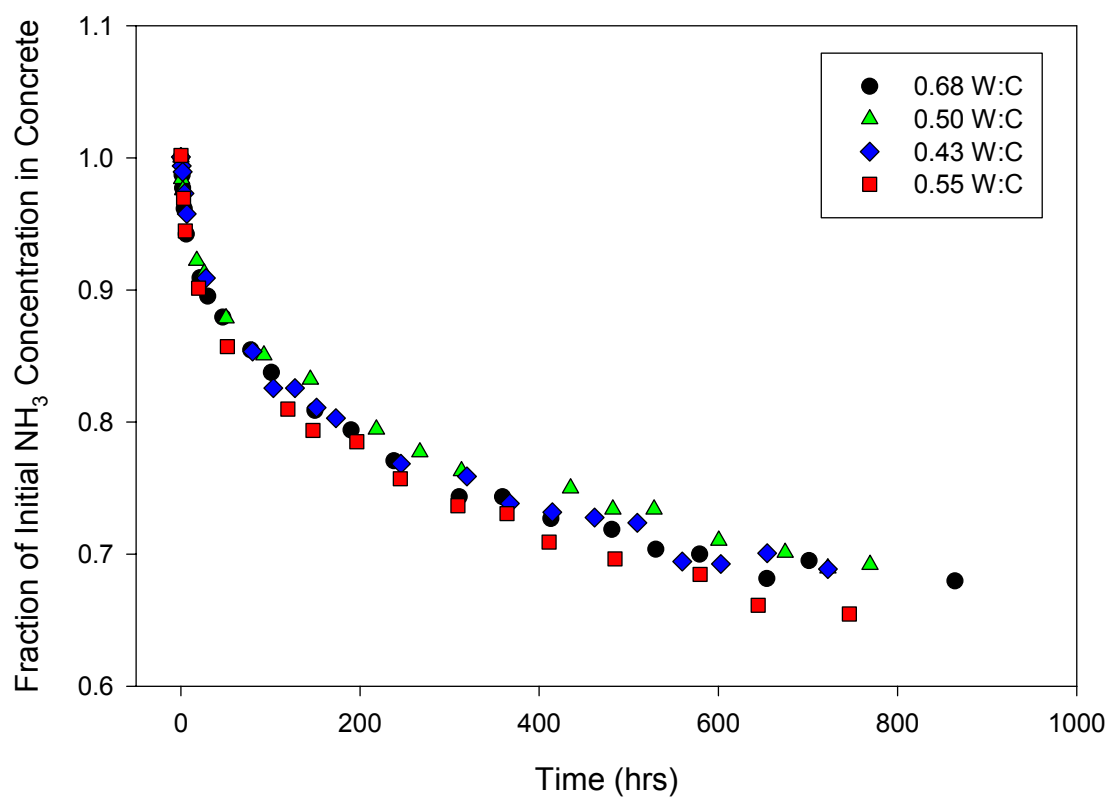


Figure 5. Long-term ammonia loss rate from four different concrete mixes. Bowen fly ash, 486 mg  $\text{NH}_3$  added per kg fly ash, 15°C, 8.3 L/min ventilation.

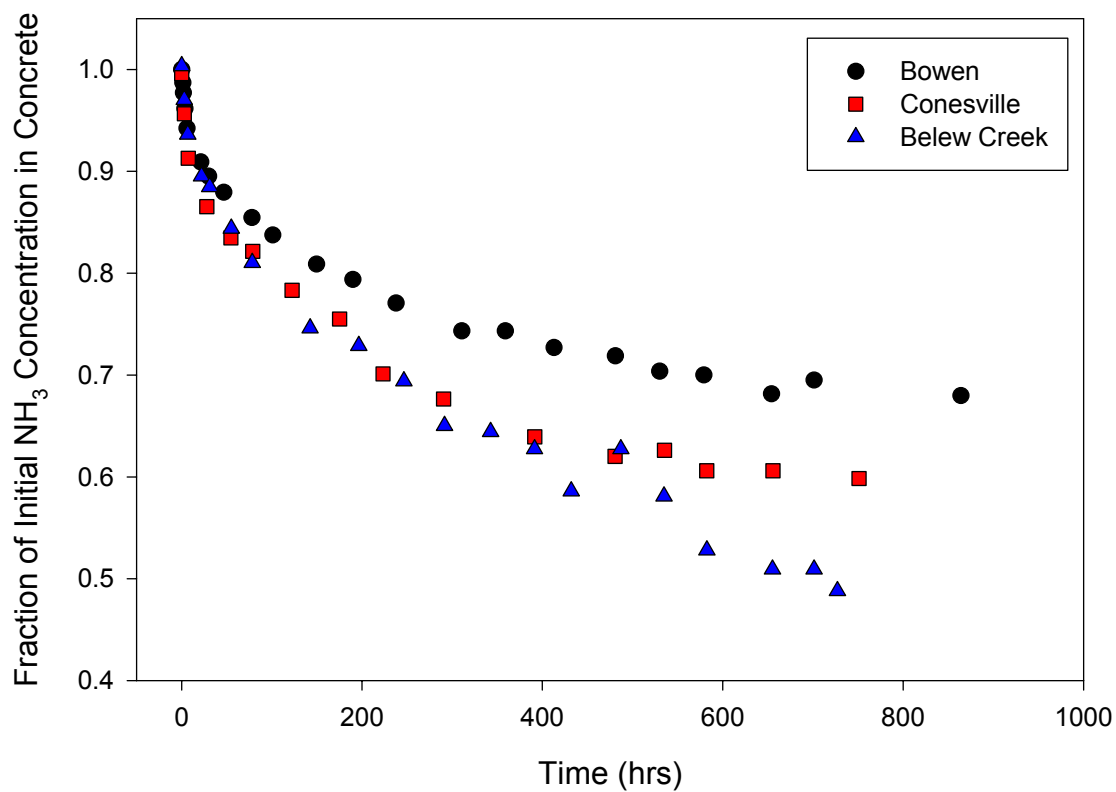


Figure 6. Long-term ammonia loss rate from concrete prepared using three different fly ashes. Conesville and Belew's Creek are ammoniated ashes, whereas the ammonia was added to the Bowen concrete at 400 mg  $\text{NH}_3$  per kg ash. Temperature = 15°C, 8.3 L/min ventilation rate.

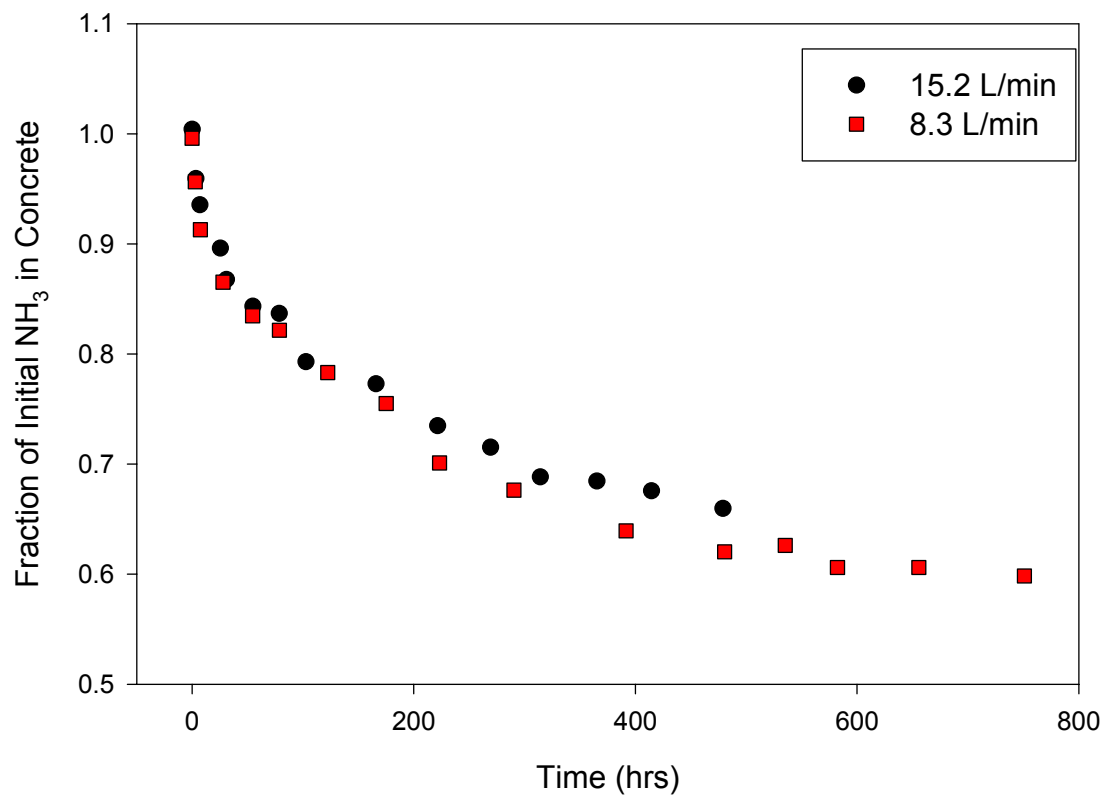


Figure 7. Long-term loss of ammonia from Medium W:C concrete prepared using Conesville fly ash, with two ventilation rates. Temperature = 15°C.

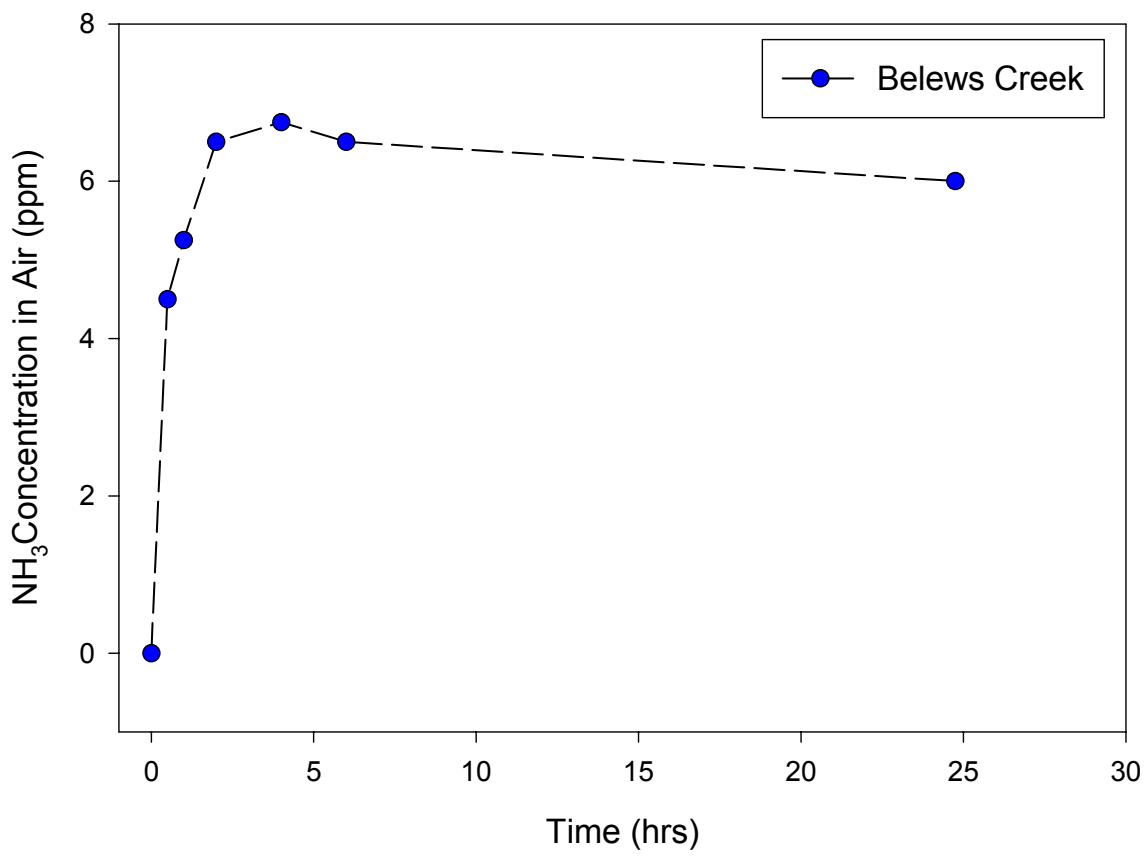


Figure 8. Ammonia in the air above High W:C concrete prepared using Belew's Creek fly ash, with no ventilation.

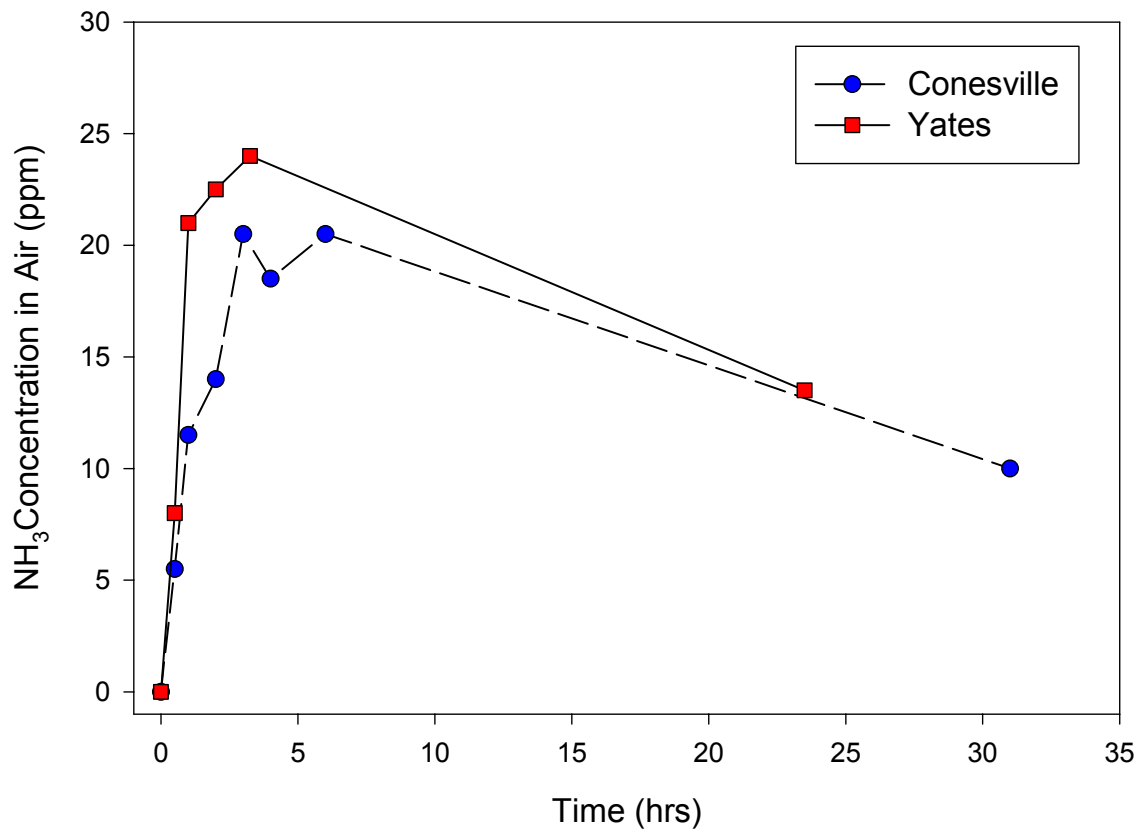


Figure 9. Ammonia in the air above High W:C concrete prepared using Conesville and Yates fly ash, with no ventilation.

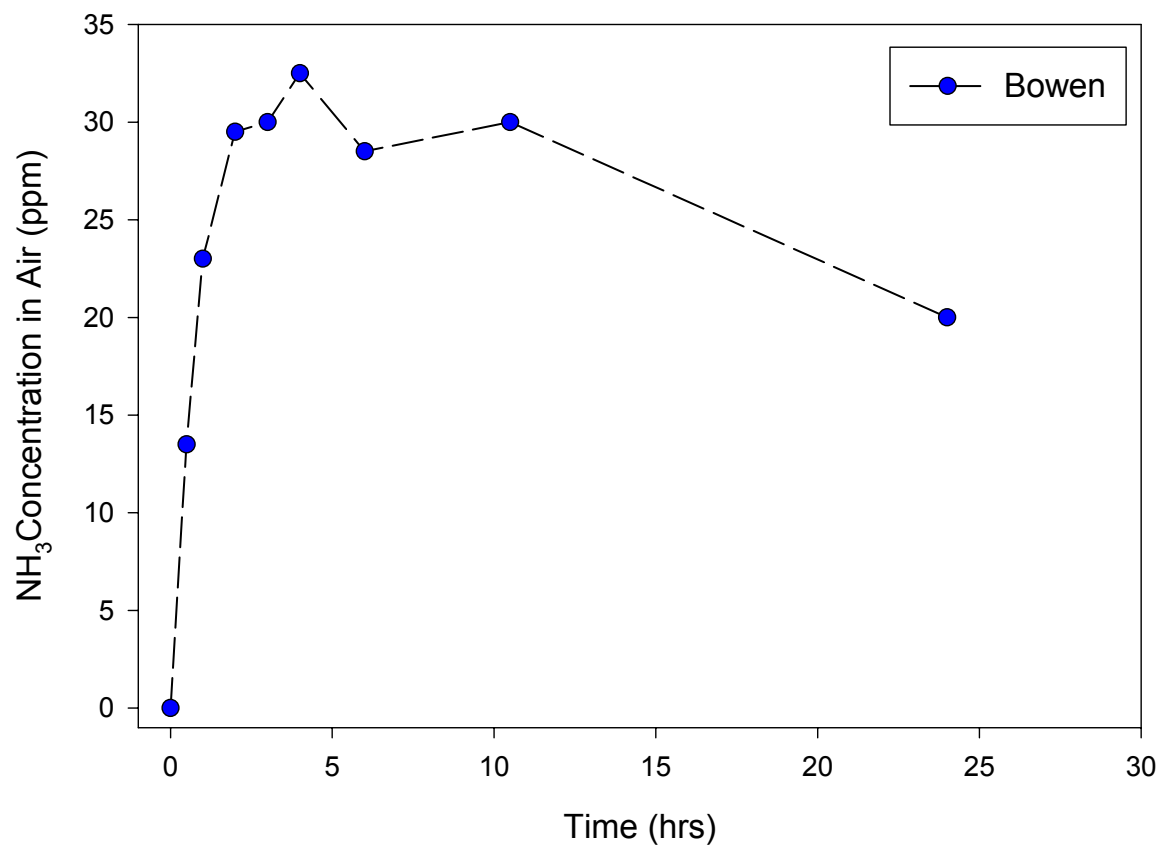


Figure 10. Ammonia in the air above High W:C concrete prepared using Bowen fly ash, with no ventilation.

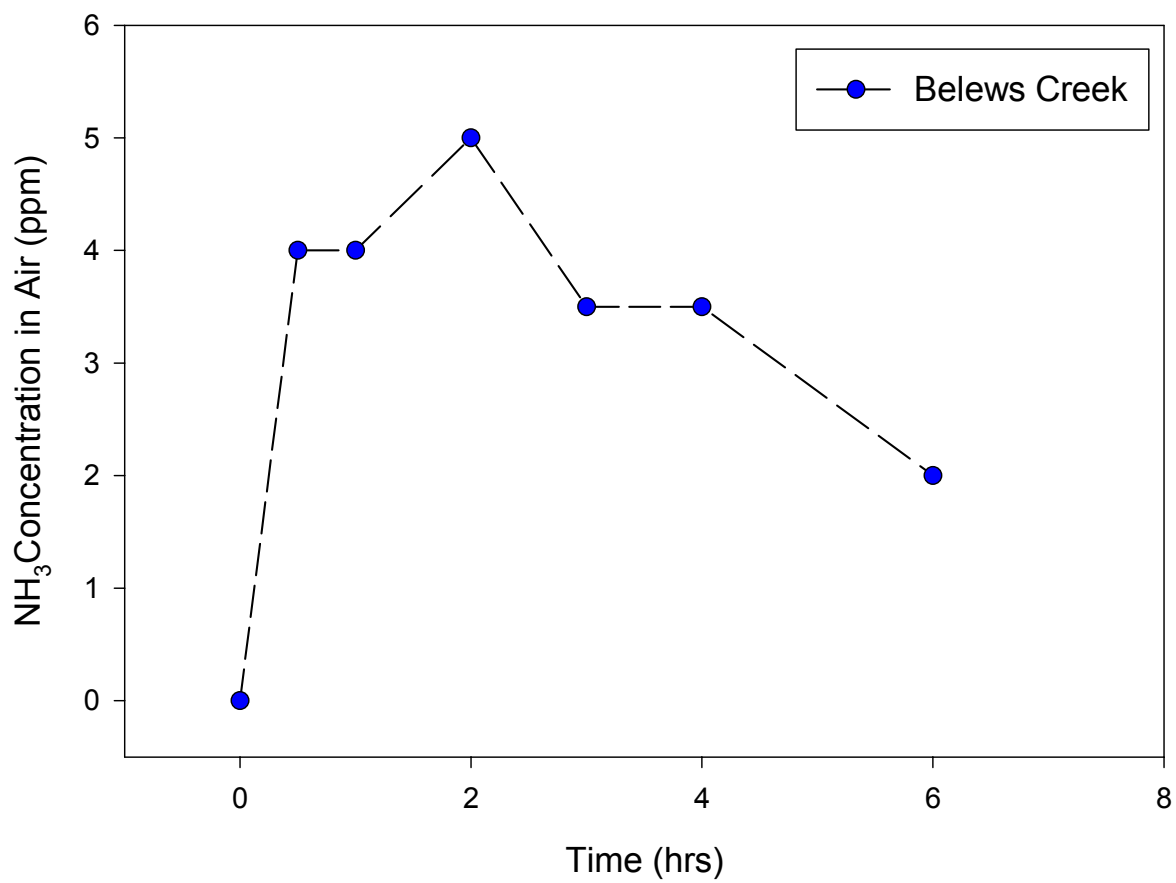


Figure 11. Ammonia in the air above Medium W:C concrete prepared using Belew's Creek fly ash, with 8.3 L/min ventilation.



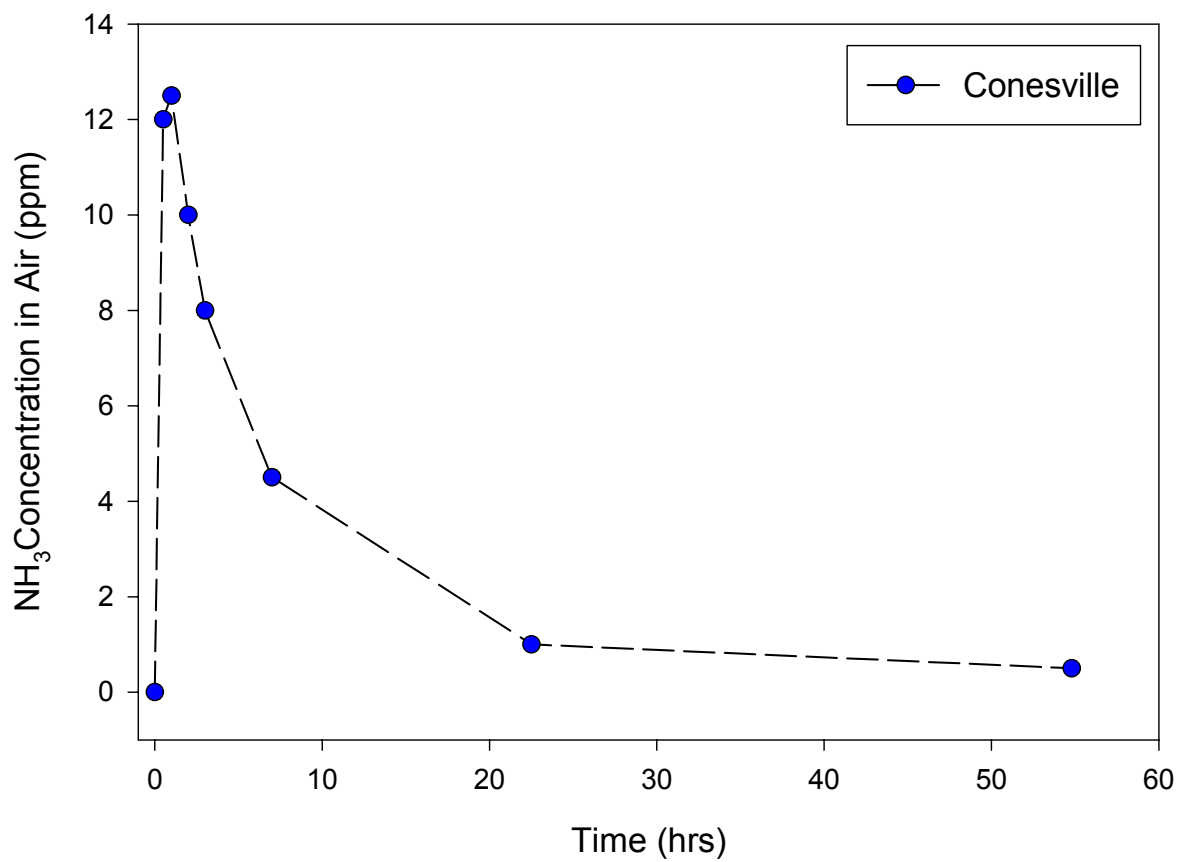


Figure 12. Ammonia in the air above High W:C concrete prepared using Conesville fly ash, with 8.3 L/min ventilation.

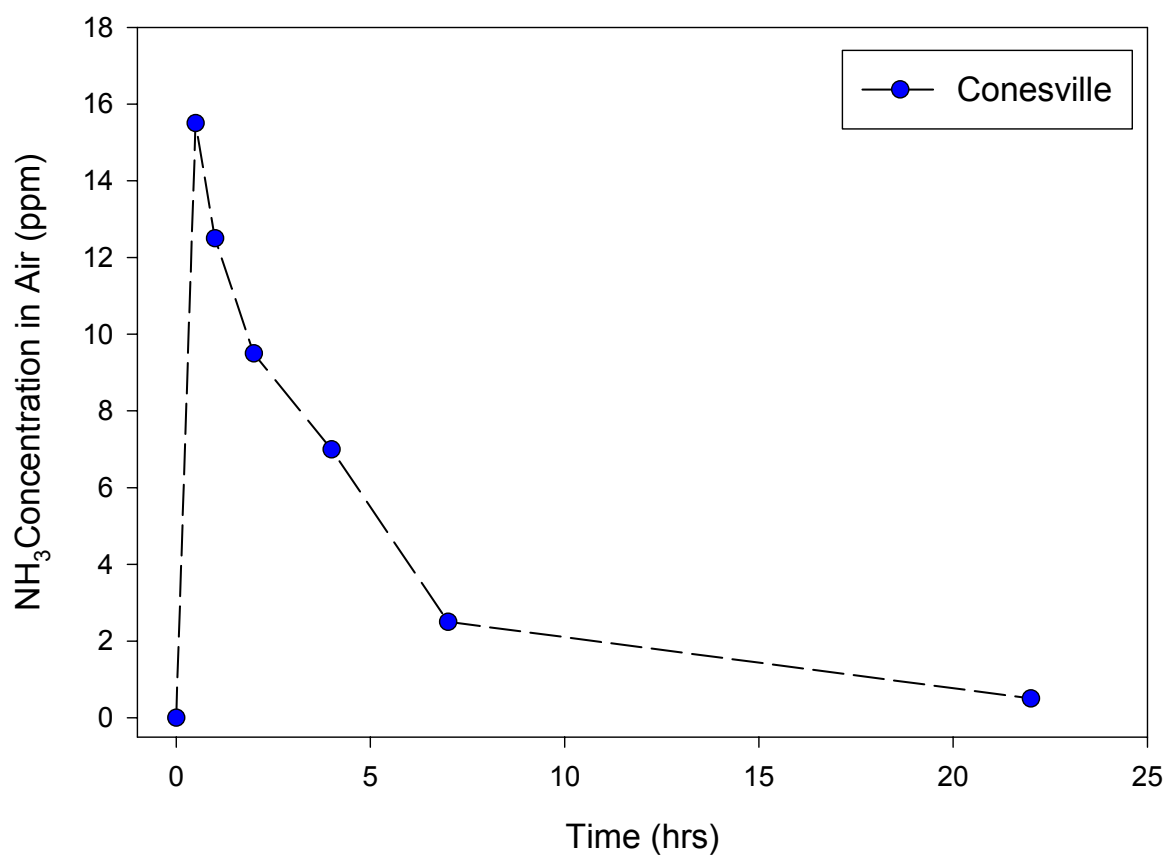


Figure 13. Ammonia in the air above Medium W:C concrete prepared using Conesville fly ash, with 15.2 L/min ventilation.

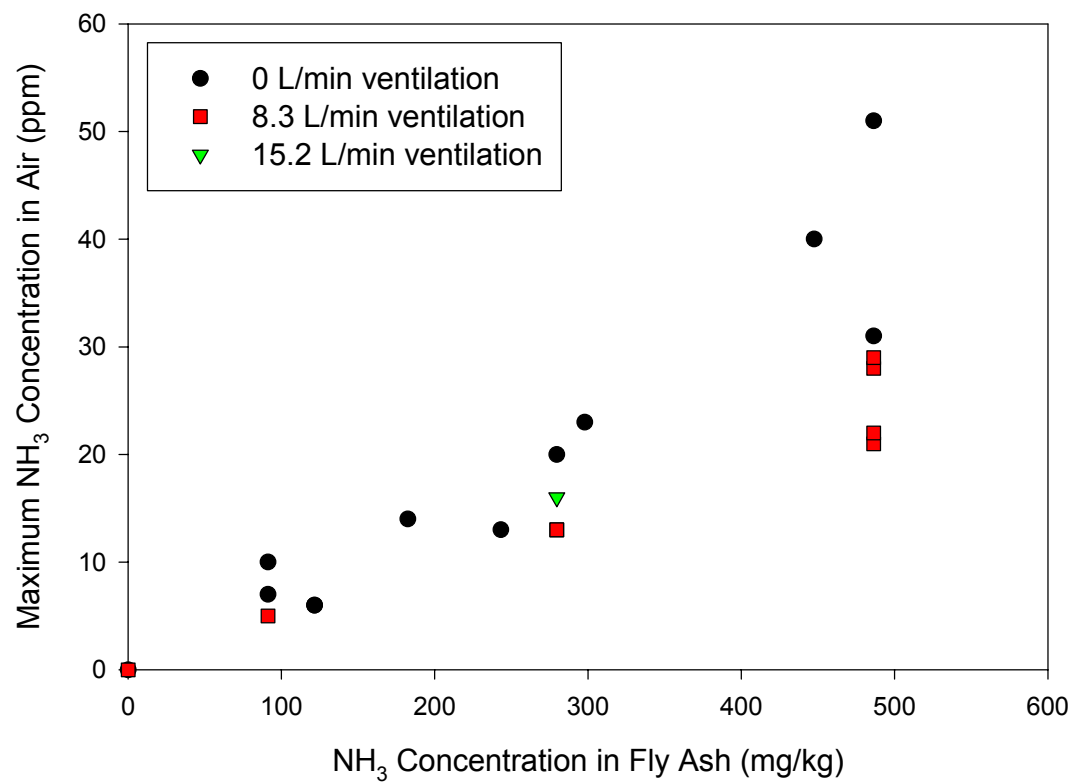


Figure 14. The maximum concentration of  $\text{NH}_3$  in the air above fresh concrete prepared with different fly ash  $\text{NH}_3$  concentrations.

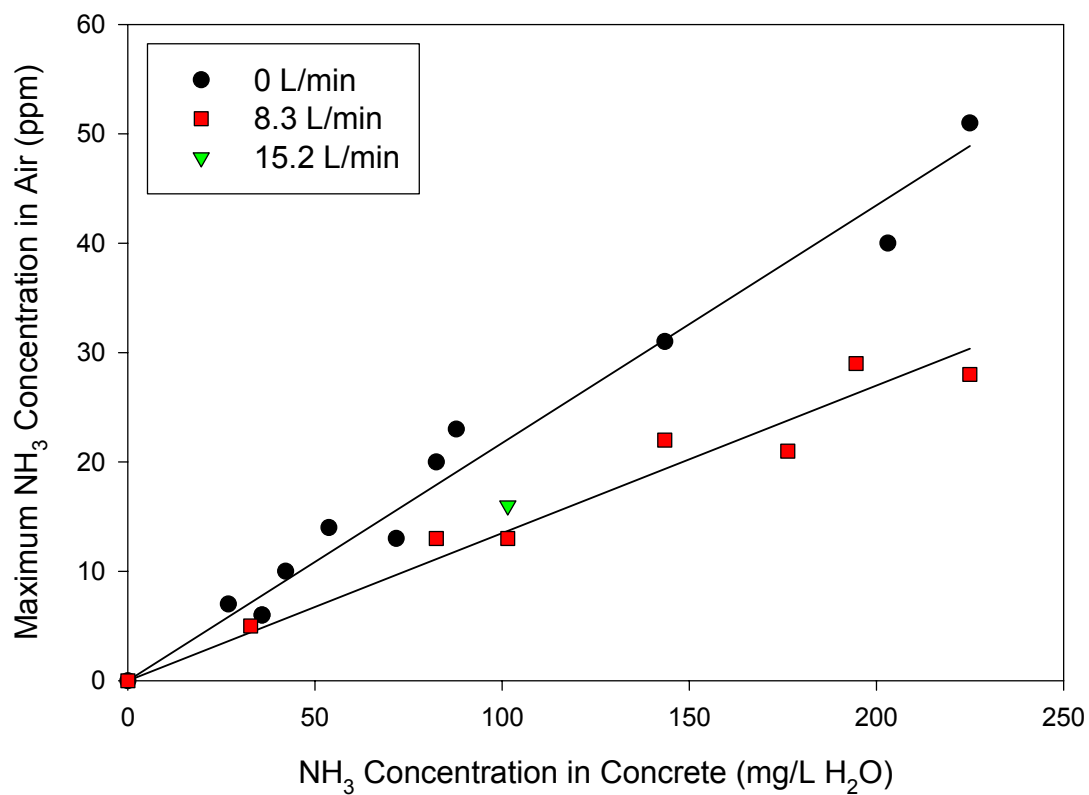


Figure 15. The maximum concentration of NH<sub>3</sub> in the air above fresh concrete prepared with different fly ash NH<sub>3</sub> concentrations, but expressed as the concentration of NH<sub>3</sub> in the mix water.

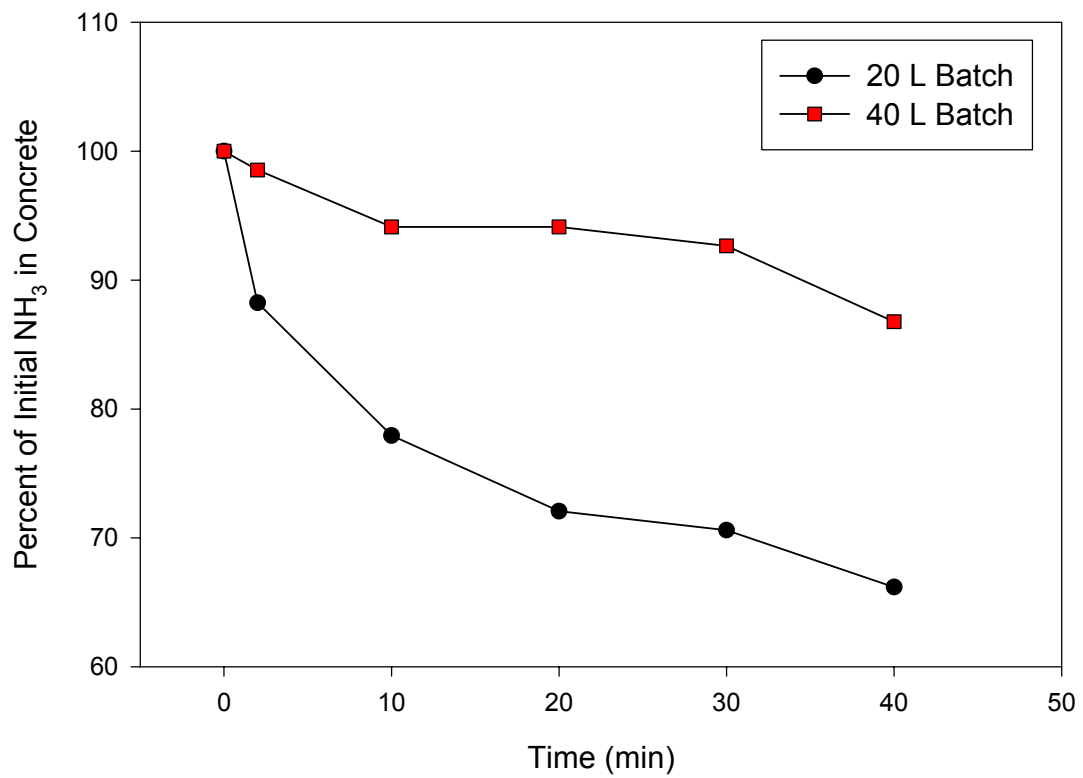


Figure 16. Ammonia loss during mixing for 20 liter and 40 liter batches of the High W:C concrete mix prepared using Conesville fly ash.

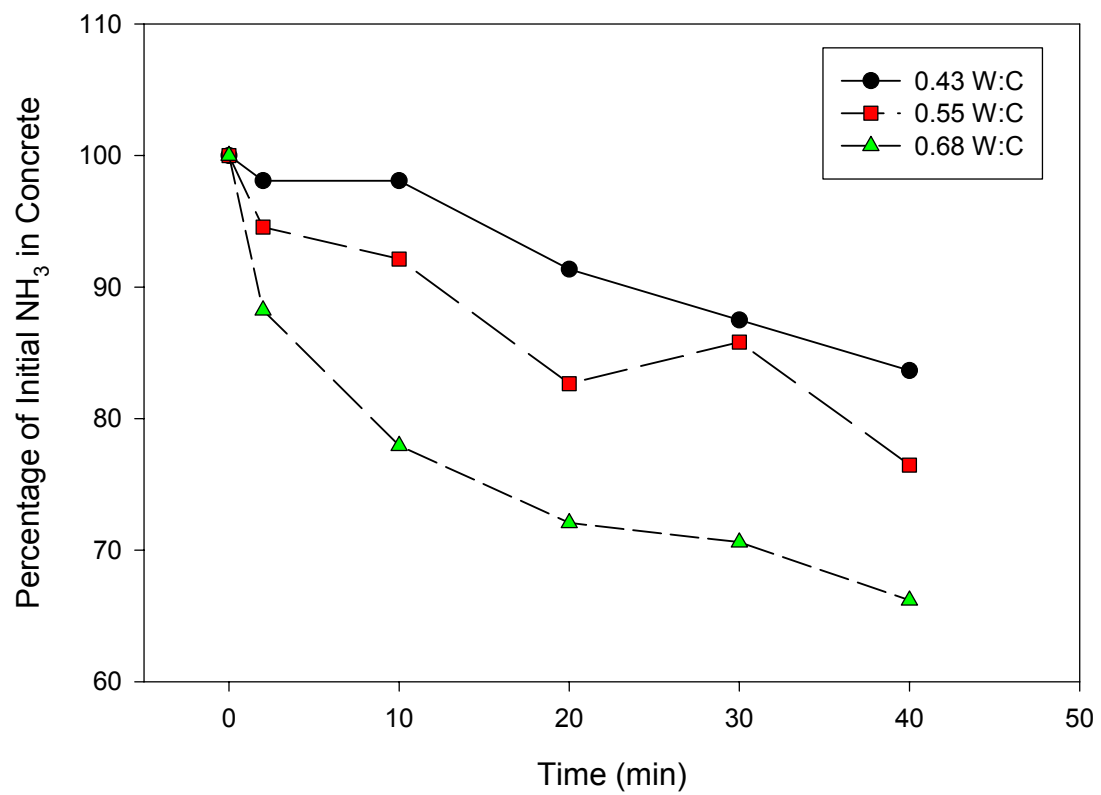


Figure 17. Ammonia loss during mixing for three concrete mixes, prepared using Conesville ash.