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Aluminum Dust Recycled as Aerating Agent for the Production of Autoclaved Aerated Concrete

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ABSTRACT

Aluminum dust is a by-product of aluminum dross recycling industry. There is some metallic aluminum in aluminum dust from composition analysis. In this paper, aluminum dust is used as aerating agent to replace metallic aluminum powder for the production of autoclaved aerated concrete (AAC). The results showed that aluminum dust can successfully replace aluminum powder in AAC production and the gas generation capacity of aluminum dust is around one sixteenth of that of aluminum powder. However, the incorporation of aluminum dust into AAC paste can make a fast yield stress gain to the AAC paste. Therefore, comparing with aluminum powder AAC, aluminum dust AAC has smaller pore size, lower porosity, higher density and higher compressive strength. Furthermore, the porosity of aluminum dust AAC cannot be further increased by increasing aluminum dust dosage because higher aluminum dust dosage leads to a faster yield stress gain. In general, this paper revealed a viable way to recycle aluminum dust in AAC production rather than direct landfill, but further study to optimize the property of aluminum dust AAC needs to be done in future.

INTRODUCTION

Aluminum dross is the by-product generated from the aluminum smelting industry. Aluminum dross can be mechanically recycled to separate the residual aluminum metal from the aluminum oxide. The recycled metallic aluminum is cast into ingot for resale. Figure 1 shows the flow chart of aluminum dross recycling process. As can be seen, another by-product, aluminum dust, is generated from the aluminum dross recycling process.

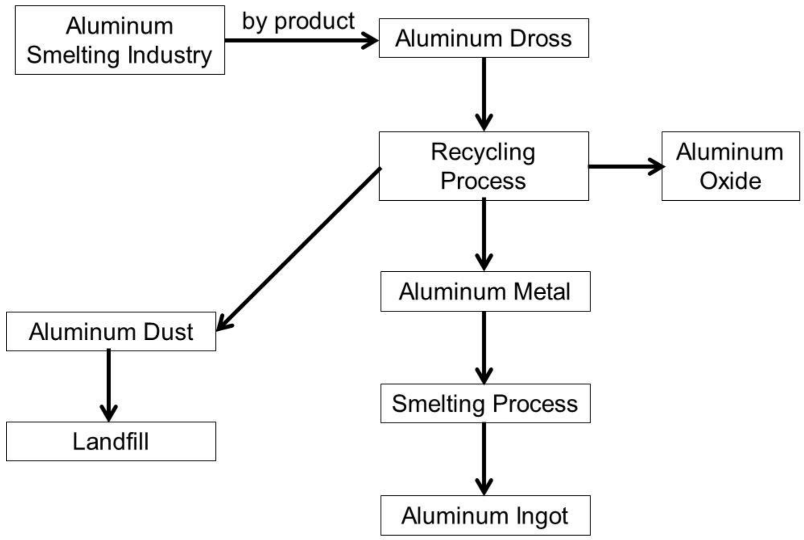

Figure1. Flow Chart of Aluminum Dross Recycling Process

As aluminum dust has low metallic aluminum content, it is not economically attractive to further extract aluminum metal from the dust. Therefore, aluminum dust is often considered as waste and disposed of by landfill. Aluminum dust may cause serious explosion [Eckhoff 2003; Myers and Timothy 2008; Ebadat et al 2007] and is regarded as hazardous waste. The cost of hazardous waste landfill is several times higher than that of non-hazardous waste landfill [Stephen 2003], which can greatly offset the profit made from aluminum dross recycling. It is of great interest to utilize aluminum dust and deviate it from landfill.

Aerated concrete is a lightweight material in which a uniform cellular structure of air voids distributed throughout a matrix of cement paste of mortar. With extremely low density (500 kg/m3) and thermal conductivity (0.1 W/m-K), aerated concrete is an idea material for thermal insulation and sound-proofing. Aerated concrete can be used for floors, trench fills, roof insulation and other insulating purposes, as well as to make masonry units. The introduction of gas in aerated concrete is achieved usually by the inclusion of finely divided aluminum powder. The aluminum reacts with the soluble alkalis in the cement slurry to generate small bubbles of hydrogen. Typical mix proportion and cost structure of autoclaved aerated concrete can be found in paper [Song et al 2015], and it can be found that aluminum powder, while only occupies a small portion/dosage in the mix design, represents about 10% of the total material cost of aerated concrete. In this paper, aluminum dust is used as gas forming agent to replace costly aluminum powder for the production of aerated concrete.

EXPERIMENTAL PROGRAM

Materials. Aluminum dust was collected from a factory which recycles aluminum dross to produce aluminum ingot. Figure 2 shows the XRD pattern of aluminum dust. It was found the main crystals in aluminum dust are metallic aluminum and aluminum oxide. Further XRD quantitative analysis shows the mass ratio of metallic aluminum to aluminum oxide is 1 to 3. The existence of metallic aluminum provides the basis to utilize aluminum dust as aerating agent in aerated concrete production.

To prepare AAC samples, Type I Portland cement, silicon sand, lime, and gypsum are used in this study. Commercial aluminum powder with 99.9% in purity and an average particle size of 45□m is used as aerating agent for traditional AAC (control sample) preparation. Tap water was used throughout AAC preparation.

To study the H2 gas generation property from Al dust, saturated calcium hydroxide solution was prepared from calcium hydroxide powder and distilled water.

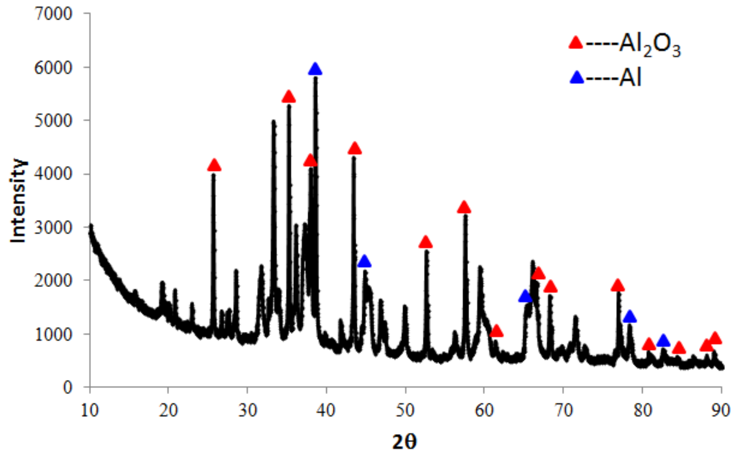

Figure 2. XRD Pattern of Aluminum Dust

Hydrogen gas generation from aluminum dust. A gas over liquid system was developed to study H2 gas generation from Al dust. In this system, 1 g Al dust powder reacted with 100 ml saturated calcium hydroxide solution under 60 oC and H2 gas could be generated based on the following equation:

2Al + 2OH- + 6H2O → 2Al(OH)4- + 3H2 (1)

The generated H_2 gas displaced the liquid in gas collection container. By measuring the volume of displaced liquid, the volume of generated H_2 gas can be known. The volume of H_2 gas generation from 1 g aluminum powder is also produced in this way for comparison. The reaction would finish when no more H_2 gas was generated, and the volume of total H_2 is V_{total}, so the reaction extent can be calculated from the following equation:

Reaction extent = (V_t/V_{total}) x 100% (2)

Where V_t is the volume of H_2 gas generated at time t.

AAC preparation. To study Al dust as aerating agent, total six mixes were prepared. Table 1 summarizes the mix proportions of six mixes. As can be seen, there are three mixes for Al powder AAC and Al dust AAC respectively. For Al powder AAC, Al powder dosage has three levels, i.e. 0.3g, 0.5g and 0.7g. To achieve the same amount of metallic aluminum for aluminum dust AAC, the amount of Al dust used is 15.6 times that of the mass of Al powder in the corresponding level of Al powder AAC. This was determined by H2 gas generation experiments as discussed in RESULTS part which shows Al dust contains 1/15.6 metallic aluminum. To maintain the same water to solid ratio for all the pastes, the amount of silicon sand used for Al dust AAC was reduced accordingly based on the amount of Al dust added.

Table 1. Mixture Composition (By Mass) of Al powder AACs and Al dust AACs

Mix	Silica (g)	Gypsum (g)	Cement (g)	Lime (g)	Al powder (g)	Al dust (g)	Water (g)
Al powder-AAC-1	64	3	16	17	0.3	0	60
Al dust-AAC-1	59.32	3	16	17	0	4.68	60
Al powder-AAC-2	64	3	16	17	0.5	0	60
Al dust-AAC-2	56.2	3	16	17	0	7.8	60
Al powder-AAC-3	64	3	16	17	0.7	0	60
Al dust-AAC-3	53.08	3	16	17	0	10.92	60

To prepare AAC specimens, the mixing procedures followed: a) Dry mixed silica sand and gypsum; b) Added two-thirds of the total amount of water and mixed for 1 minute; c) Added Portland cement and continued to mix for 1 minute; d) Added lime and one-third of the total amount of water, and then mixed for 1 minute; e) Added the gas generating agent (Al powder or dust) and mixed under high-speed for 15 s. Immediately after mixing, the paste was poured into 5 cm x 5 cm x 5 cm cubic mould. The moulds were then kept in environmental chamber and pre-cured under 60ºC and 98 rh% for 6 hours. After pre-curing, the specimens were de-moulded and autoclaved in a high pressure autoclave under 210oC and 2 MPa for 18 hours. Afterwards, the specimens were taken out from autoclave and cut into cubes by saw-cutting and the excessive material at the casting surface due to aerating and rising of the fresh mixture was removed to ensure a flat surface.

Testing. Density was calculated by measuring the dry weight and volume of each specimen. To determine its dry weight, the specimen was oven-dried at 105 ± 2 °C for 8 h. Compression test was conducted using the 50 mm cube. The loading rate was 50 KN/min and only peak load was recorded. Three samples were tested for both density and compressive strength test and the average value as well as the stand deviation were reported for each test. The specimens are also cut to get the cross section, which could be observed under a Nikon light microscope. The void ratio (porosity) of each sample can be obtained by image analysis from Nikon software.

To interpret the effect of aluminum dust addition on AAC, propertes of AAC paste in fresh state need to be tested. The fresh state means AAC pre-curing stage, i.e. the period when AAC paste was kept in environmental chamber under 60oC and 98 rh%. The fresh property tests include yield stress and rising height test. For yield stress test, a mini conical mould was used. The specifications of the conical mould were according to ASTM C230/C230M standard. The test procedures were referred to the research paper [Melo et al 2014]. Yield stress was calculated with the following equation:

$$\text{Yield stress} = (\text{mass of paste}) / (2*\pi*\text{square of average radius}) \quad (3)$$

To measure the rising height of AAC paste, once the mixing procedure finished, 40ml of AAC paste was poured into a 100 ml measuring cylinder and then the measuring cylinder was kept in environmental chamber under 60oC and 98 rh%. The height of the paste was recorded from the calibration of measuring cylinder every 5 minutes until no further height increase at all.

RESULTS

Hydrogen gas generation from Al dust. Figure 3 shows H_2 gas generation from Al powder and Al dust with saturated calcium hydroxide solution under 60°C as a function of reaction time. As can be seen, 583 ml H_2 gas can be generated per gram of Al powder, while only 37.2 ml H_2 gas was generated per gram of Al dust. Therefore, in term of the H_2 gas generation capacity, 1 g Al powder equals 15.6 g Al dust. From the reaction extent curve in Figure 3, Al dust has similar reaction extent development curve with Al powder during the reaction period, which means regarding H_2 gas generation properties, 15.6 g Al dust has no difference with 1 g Al powder. This provides the basis that the amount of Al dust used in Al dust AAC is 15.6 times amount of Al powder used in Al powder AAC.

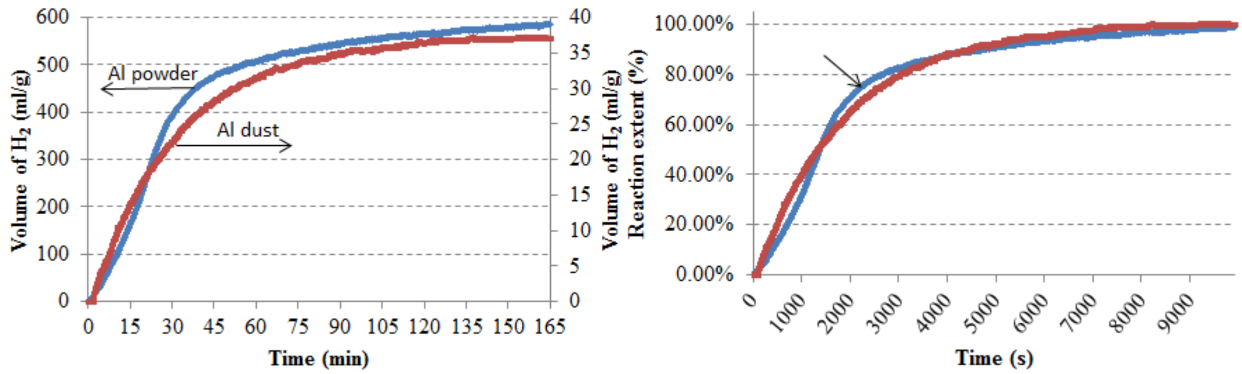

Figure 3. Volume of H_2 gas generation (left) and reaction extent (right) from Al powder and Al dust as a function of reaction time

Density and void ratio. Figure 4 shows dry density and void ratio of Al powder AAC and Al dust AAC of three metallic aluminum dosage levels. As can be seen, at the same metallic Al dosage level, Al dust AAC has higher dry density and lower void ratio than Al powder AAC. With metallic Al dosage increased from 0.3% to 0.7%, the density of Al powder AAC decreased and its void ratio increased. However, Al dust AAC shows completely different performance. Its dry density has no much difference and the void ratio keeps almost the same within the three metallic aluminum dosage levels. Figure 5 shows that dry density and void ratio have linear correlation, which means void ratio is the key factor to determine density for both Al powder AAC and Al dust AAC.

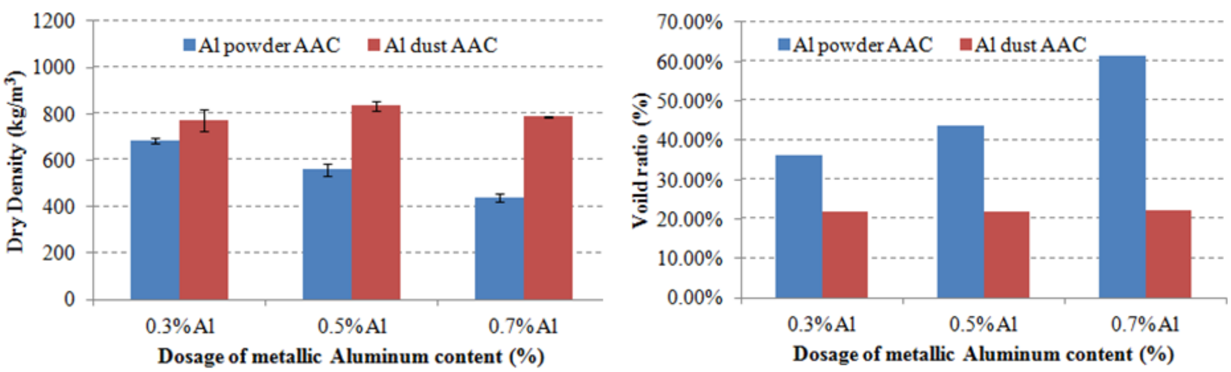

Figure 4. Dry density (left) and void ratio (right) of Al powder AAC and Al dust AAC of three metallic aluminum dosage levels (0.3%, 0.5% and 0.7%)

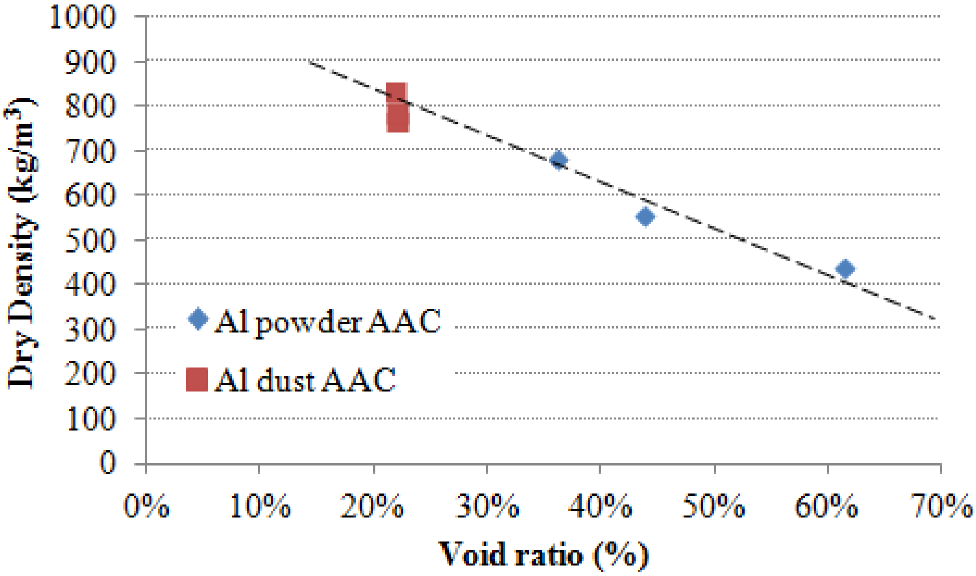

Figure 5. Correlation between dry density and void ratio

Compressive strength. Figure 6 shows the compressive strength of Al powder AAC and Al dust AAC of three metallic aluminum dosage levels. As can be seen, Al dust AAC has higher compressive strength than Al powder AAC. Further correlation analysis between compressive strength and void ratio / dry density as shown in Figure 7 implies compressive strength has high correlation with void ratio / dry density. The higher compressive strength of Al dust AAC is due to its lower void ratio and higher dry density.

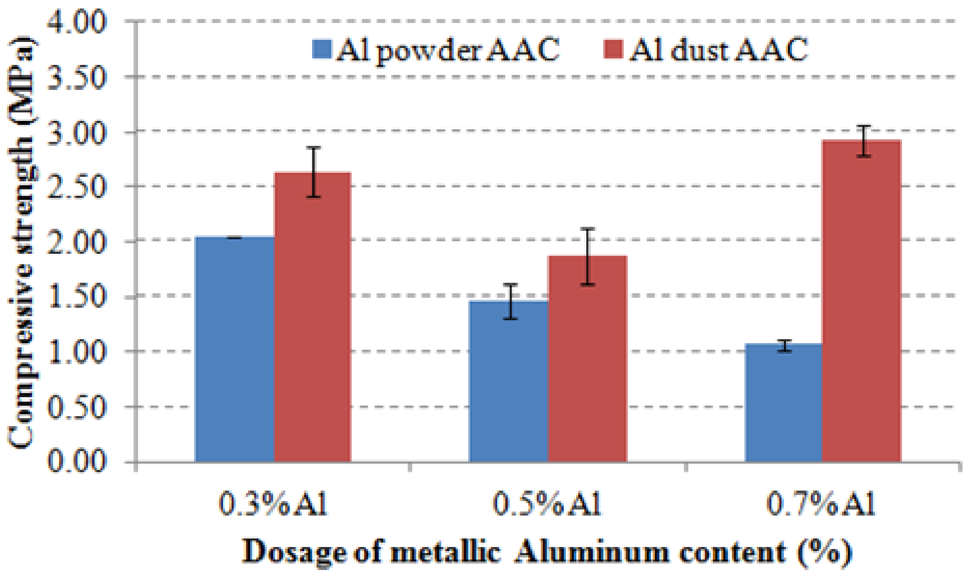

Figure 6. Compressive strength of Al powder AAC and Al dust AAC under three Al dosages

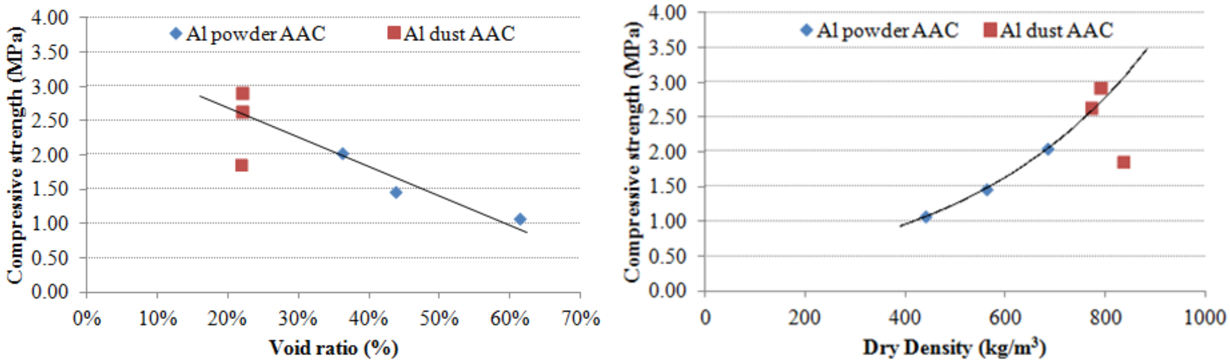

Figure 7. Correlation between compressive strength and void ratio (left) / dry density (right)

DISCUSSIONS

Based on the above results, no matter what kind of aerating agent used in AAC, void ratio is always the key factor to determine AAC density and compressive strength. In term of Al dust AAC, there are two questions which need to be clarified:

1. Why Al dust AAC has lower void ratio than Al powder AAC considering they contain the same amount of metallic aluminum?

2. Why is the void ratio of Al dust AAC not able to be increased by increasing Al dust content?

To answer the two questions, the effects of Al dust addition on the fresh properties of AAC paste need to be evaluated. Figure 8 shows the correlation between void ratio and rising height. As can be seen, void ratio has high correlation with rising height. The lower void ratio in Al dust AAC is due to its lower rising height. From Figure 9, which shows the rising height development with time for Al powder AAC and Al dust AAC with 0.3% metallic aluminum, Al dust AAC has no further rising after 23 mins, while Al powder AAC continues to rise after 23 mins.

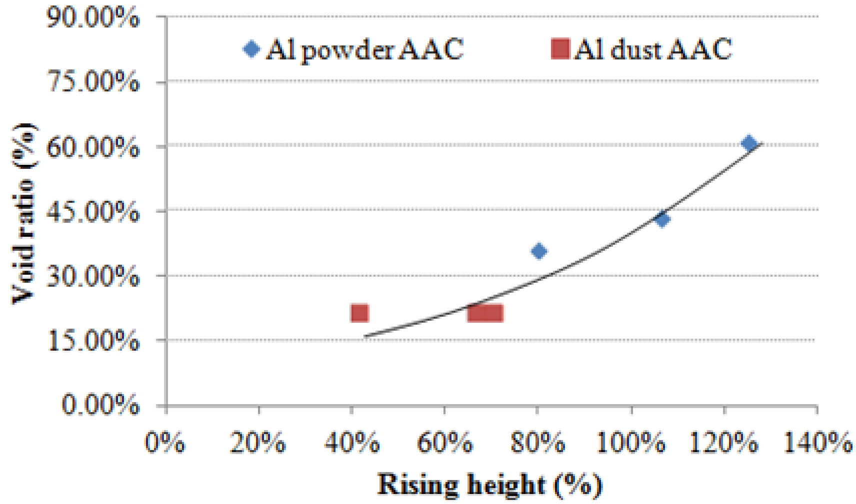

Figure 8. Correlation between void ratio and rising height

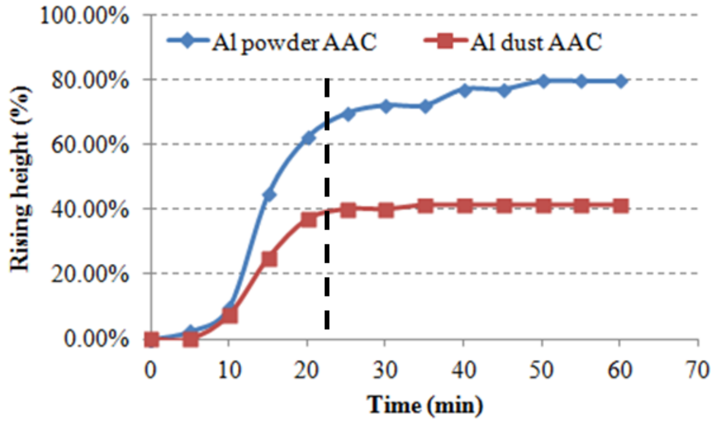

Figure 9. Rising height development with time for Al powder AAC and Al dust AAC with 0.3% metallic aluminum content

Figure 10 shows the yield stress of Al powder AAC and Al dust dosage AAC with 0.3% metallic aluminum content. Generally, yield stress increases with time increases for both samples, and both samples achieved the same maximum yield stress. The yield stress curves can further be split into two stages. The first stage is before 23 mins. At this stage Al dust AAC has faster yield stress gain which results in higher yield stress than Al powder AAC. From the research paper [Melo et al 2014], higher yield stress results in smaller void size. So the rising height of Al dust AAC at first stage is lower than Al powder AAC. At the time of 23 mins, the corresponding yield stress is 230 Pa for Al dust AAC. This is the threshold yield stress for rising as after that Al dust AAC paste is not able to further rise shown in Figure 9. However, the yield stress for Al powder AAC is only 120 Pa at 23 mins, which is much lower than threshold value. So the Al powder AAC paste continues to rise until 38 mins, at which time the yield stress of Al powder AAC paste achieved the threshold value 230 Pa. Therefore, the second stage is from 23 mins to 38 mins, during which Al dust AAC paste stop rising while Al powder AAC continues to rise. Take into consideration of stage one and two, totally Al dust AAC has lower rising height than Al powder AAC, which results in the lower void ration of Al dust AAC. The higher yield stress gain in Al dust AAC is perhaps due to the high aluminum oxide content in Al dust, which absorbs much water when reacts with alkali as showed in the following equation:

$$Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2Al(OH)_4^- \quad (4)$$

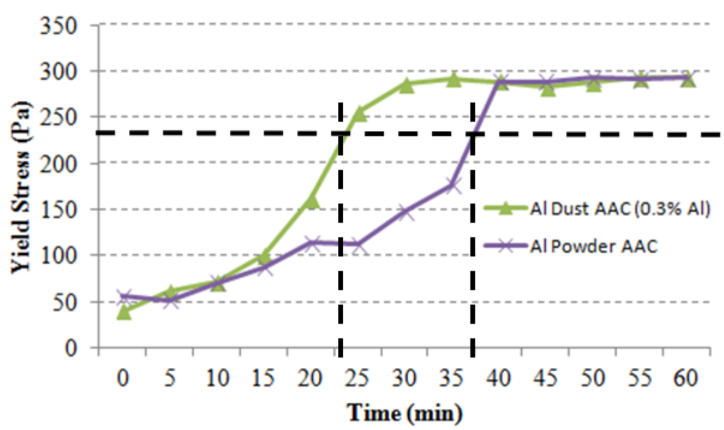

Figure 10. Yield stress of Al powder AAC and Al dust AAC with 0.3% metallic aluminum

Figure 11 shows the void structure of cross section of Al dust AAC and Al powder AAC. As can be seen, the void size of Al dust AAC is smaller than Al powder AAC, which verifies the above analysis.

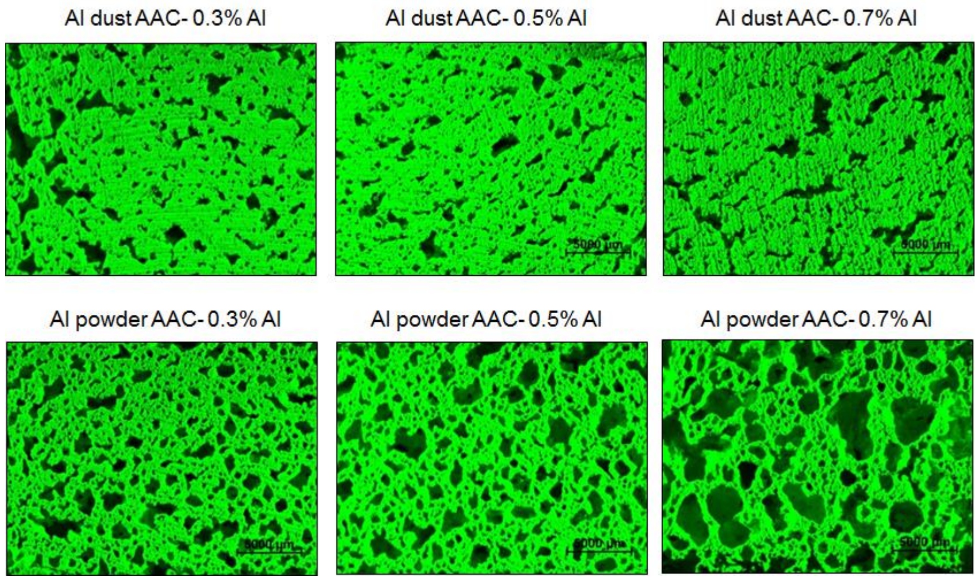

Figure11. Void structure of Al powder AAC and Al dust AAC

Figure 12 shows the change of rising height when metallic aluminum content increased from 0.5% to 0.7% for Al powder AAC and Al dust AAC. Unlike Al powder AAC, which has larger rising height increase, Al dust AAC has only a little bit rising height increase when metallic aluminum increases by 0.2%, which results in little change of void ratio.

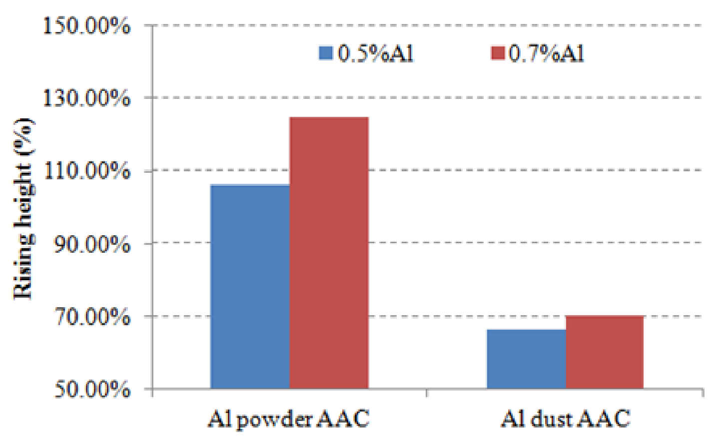

Figure 12. Rising height of Al powder AAC and Al dust AAC with metallic aluminum content 0.5% and 0.7%

Figure 13 shows the yield stress of Al dust AAC with 0.5% and 0.7% metallic aluminum content. As can be seen, higher Al dust dosage leads to faster yield stress gain. Similar analysis can be done just like the analysis done for Figure 10, and it can be concluded that higher Al dust dosage lowers the rising height and void ratio, which sacrifices the gas generation capacity from more metallic aluminum content in Al dust with 0.7% metallic aluminum, and finally similar rising heights are gotten for both samples.

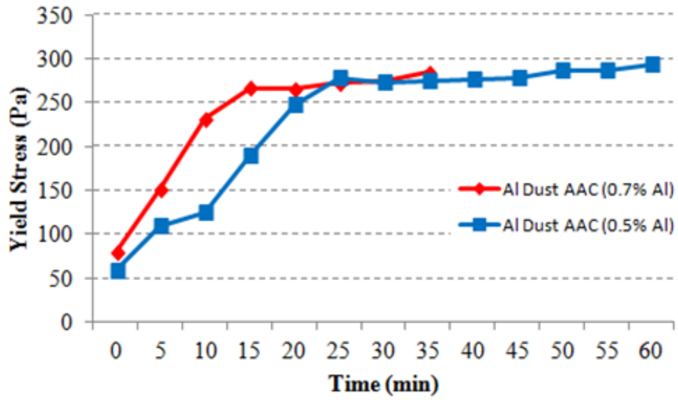

Figure 13. Yield stress of Al dust AAC with 0.5% and 0.7% metallic aluminum content

CONCLUSION

The following general conclusions can be drawn from the study provided in the paper:

- Al dust is able to be used as aerating agent to produce AAC. For gas generation capacity, 1 g Al powder equals 15.6 g Al dust.
- Al-dust AAC has smaller pore size, lower porosity, higher density and higher compressive strength than Al powder AAC due to faster yield stress gain.
- The void ratio of Al-dust AAC cannot be further increased by increasing Al dust dosage because higher Al dust dosage results in faster yield.

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REFERENCES

ASTM C 230 / C 230M. "Standard Specification for Flow Table for Use in Tests of Hydraulic Cement." 6 pages.

Ebadat, Vahid, and Richard W. Prugh. (2007). "Case study: Aluminum-dust explosion." *Process Safety Progress*, 26.4: 324-329.

Eckhoff, Rolf. (2003). "Dust explosions in the process industries: identification, assessment and control of dust hazards." Gulf professional publishing.

Melo, J. P., Aguilar, A. S., and Olivares, F. H. (2014). "Rheological properties of aerated cement pastes with fly ash, metakaolin and sepiolite additions." *Construction and Building Materials*, 65, 566-573.

Myers, Timothy J. (2008). "Reducing aluminum dust explosion hazards: Case study of dust inerting in an aluminum buffing operation." *Journal of hazardous materials*, 159.1: 72-80.

Song, Yuanming, et al. (2015). "Feasibility study on utilization of municipal solid waste incineration bottom ash as aerating agent for the production of autoclaved aerated concrete." *Cement and Concrete Composites,* 56 (2015): 51-58.

Stephen T. Smith. (2003). "Disposal costs for treated wood as hazardous versus non-hazardous waste." <http://www.wwpinstitute.org/documents/DisposalCostsEvaluation2.pdf> (Jun. 29, 2015).