Performance Evaluation of Coal Ash Concrete as Building Materials in Mongolia

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KEYWORDS: fly ash, aerated cellular concrete (ACC), thermal insulation material

ABSTRACT

The Central Energy System in Mongolia consists of five power plants with a total installed capacity of 796 megawatts (MW). Every year for a heating and producing electricity, in the coal fired electric Power Plants in Mongolia, 2.7 million tons of a coal has used and have been producing approximately 531 thousand tons of coal combustion by product per year. These burned coal and coal combustion by product a quantity are increasing year to year. The objective of this study was to determine the possibilities of an effective usage of the coal combustion product of Power Plant III in Ulaanbaator. The investigation is included the determination of a classification of a coal ash which is producing in Mongolia , compared to other countries, the optimal mix proportion to produce aerated cellular concrete (ACC) which is a thermal insulation lightweight concrete with a fly ash. According to laboratory experiments, a coal ash from Power Plant III has capability to produce an aggregate for pavement, filter, heavy and lightweight concrete. It also shown that the maximum content of fly ash was 35-41% by volume at w/c= 1. The values of density are between 1200-1800kg/m^3, compressive strength 2-12MPa, thermal conductivity 0.652-0.201W/m.K. Building wall thickness will be reduce by 3.7 times comparing to traditional a brick wall.

INTRODUCTION

Currently, the Central Energy System in Mongolia consists of a five Power Plants with a total installed capacity of 796 megawatts (MW). In every year for a heating and producing an electricity, 2.7 million tons a coal is burned and generate approximately 531 thousands tons a coal combustion by product in Electric Power Plants of Mongolia in each year. The amount of a burned coal and a coal combustion product quantity increase year by year.

In case of Mongolia, the experience a beneficial usage of a coal combustion product is lacking. It is only waste into the environment. In every four year, 840 thousands meter cube land is filled with a cola ash. Furthermore, the air pollution arise a serious problem, especially in a winter season in a capital city.

The prevalent percent a heat and energy producing at Power plant in Mongolia spend for heating system in domestic and institutions in winter season. One of the ways to reduce coal burn in coal-fired power plant in Mongolia is to reduce heat loss through the building wall and to increase thermal technical quality of building wall materials in Mongolia.

Nowadays, the widely using building wall materials in Mongolia are red bricks, woods and lightweight concrete blocks. The red brick has a high thermal conductivity coefficient, therefore the outside wall thickness must be 51, 6…64 cm by thermal calculation. There loss is light and heating energy expenses are raised. Recently by the new building local code, brick wall thickness should be one meter. In this case we can reduce enough heat loss though the wall. On the other hand, in above condition will be increase amount and cost of using material for building.

Particularly in thermal insulation materials as a light thermo technical properties and extra lightweight materials, the timber comes to only one material to be used for a wall materials private houses or for the various a few floors (1-2 floors) constructions. However, the reserve of forest, which could be useful for industrial target, has a shortage. Also, we should carry out the forest carefully because it cleans the area and gives a fresh area for mankind to make a living condition. Therefore, the timber should be used somehow carefully, effectively and no wastefully. This is the requirement that the timber usage should be better to deny. Nowadays Mongolian economy is changeable. The customer’s necessity is to use quality and cheaper building material.

The world experience has various kind of usage of coal combustion by product (coal ash). The experience of the usage of the waste-coal ash as the basic raw material in one of wall material such as autoclaved aerated cellular (ACC) concrete has been widens. However, non-autoclaved aerated cellular concrete technology into the coal ash did not studied widely.

RESEARCH SIGNIFICANT

This work is aimed at evaluating the possibility of reusing waste coal ash from Power Plant III in Mongolia as an aerated cellular concrete (ACC) material for a thermal insulation material for wall.
ACC, one of the lightweight materials which are had a high thermal conductivity and a low density to compare normal building materials. In case of Mongolia, the one of the main properties of wall building material is a low thermal conductivity due to a cold long winter. Therefore to produce ACConcrete will give two benefits: reuse a waste material from Power Plant III and produce   a comfortable wall construction material with low thermal conductivity with increasing a number of types of local construction material.

CLASSIFITION OF COAL ASH IN POWER PLANT III

The developed countries have a classification standard for an effective using coal ash for a various construction proposal. The one section of the research had proposed to determine the classification of coal ash from Power Plant III thought chemical components which are investigated X-Ray test in Chemical Department in Tokyo University in Japan. The five a different parts coal ash from Power Plant III are closed for a chemical investigation. The results are shown on the Table 1-3.

	I	II	III	IY	Y
Ig.loss	2.50	17.14	2.70	1.34	5.71
SiO_2	59.38	47.22	55.87	44.22	34.95
Al_2O_3	12.58	10.43	11.52	13.02	11.24
Fe_2O_3	9.26	10.09	15.13	7.73	11.27
CaO	11.18	9.79	8.03	21.64	17.28
MgO	1.37	1.23	1.00	5.22	2.66
SO_3	0.22	1.06	1.30	3.08	14.42
Na_2O	0.50	0.48	0.97	0.83	0.90
K_2O	2.20	1.67	2.68	1.48	1.53
TiO_2	0.56	0.43	0.40	0.63	0.50
P_2O_3	0.07	0.06	0.08	0.05	0.25
MnO	0.22	0.18	0.30	0.73	0.23

Table 1. Chemical component of coal ash from different part of Power Plant III

I – Coal ash kept two years II – New coal ash from Power Plant with water
III - Coal ash from coal ash catching IY- Fly ash from a electric filter
Y- Coal ash from private house using coal ash for heating

	I	II	III	IV	V
Density,g/cm^3	2.49	2.47	2.82	2.84	2.85

Table 2. Coal ash densities

	Gi	Jn	Cu	V	Ni	As	Pb	Se	Ga	Ca
Coal ash III	0.0083	0.007	0.0081	0.0115	0.005	0.01	0.0005	0.0001	0.0006	0.0008

Table 3. Microelements contents in coal ash from Power Plant III

The comparison a chemical elements constitutes of coal ash from Power Plant III to the others development countries is made. According to ACI (American Industry Standard) it belongs to Type II coal ash and has a good pozzolanic property with ability for use in cement concrete. According to JIS(Japanese Industry Standard) it belongs to Type IY coal ash, According to Russian Standard Mongolian coal ash belongs to Type II. Due to Russian Standard this type of cola ash can be used in concrete construction and heavy, light concrete and mortar. From this comparisons, the coal ash from Power Plant III have possibilities to exploitability for any construction material.

THE OCCASION USEGE OF COAL ASH from Power Plant III

Different types of CCPs (Coal Combustion Product) possess distinct a chemical and physical properties that make the group suitable for a wide range of applications. Fly ash has silt like texture and is pozzolanic in character. The largest volume use of any one CCP is the use of fly ash in cement, concrete and grout. CCPs can also be used: kiln feed in the manufacture of cement, material for structural fill, bulking and dewatering agent in waste stabilization, a mine reclamation amendment, and road base or sub base material. [6]

From 1970, Mongolian National Standard began to contain the material requirement using in construction side in Mongolia. This standard part is developed year by year and nowadays it is becoming completely.
According to chemical component contents of construction material, the determinations of usage area are specified in building code of Mongolia. From Table 4, it can be clearly, coal ash from Power Plant II has possibilities that use coal ash instead of some raw material for other construction product except on ceramic.

1.EXPERIMENT INVESTIGATION of COAL ASH for ACConcrete

In this part introduced an experiment investigation of utilization possibilities fly ash and bottom ash in Mongolia for aerated cellular concrete. Experimental investigation contains two parts. One was the investigations of fly ash for ACC, the other was investigations of bottom ash for ACC.

The main purpose of these experiments were to determine maximum utilization of fly ash and bottom ash (coal ash) in ACC, to define optimal mix proportion ACC and to clarify influence content of aluminium powder to the mortar. The basic factors of experiment were content of coal ash, content of aluminium powder and water cement ratio of mortar.

	From Mongolian Standard Requirement for construction materials (MNS)	Content in coal ash	

Dedication	index	unit	content	Power Plant III	Offer
Aggregate for permanent	SiO_2	%	Min 35	47.22	○
	$FeO+Fe_2O_3$	%	Max 18	10.09	
	CaO	%	Max 10	9.79	
	Ig.loss	%	Max7	17.14	
Filter aggregate	SO	%	Max2	1.06	○
	Si_2O	%	Min 40	47.22	
	Ig.loss	%	Max 2	17.14	
Ceramic material	Ig.loss	%	Max 15	17.14	X
Lightweight aggregate for concrete	CaO+MgO	%	Max 16	11.02	○
	SO	%	Max 3	1.06	
	Ig.loss	%	Max 20	17.14	

Table 4. Utilization possibility of coal ash Power Plant III for some construction material

Test specimens

In the experiment was used ordinary Portland cement, aluminium powder, and fly ash type IV and clinker ash in Japan. Two water cement ratios were chose: w/c= 1 and w/c=2. The size of specimens was10 x 20 cm and 5 x 10 cm and was tested at the age of 7 days and 28 days according to the experiment plan.

Test procedure

The specimens were cast under ordinary room temperature. After casting, the specimens were sealed using siren wrap then stored in the controlled environmental room under temperature of 20^0C with a relative humidity of 60%. After 7 and 28 days specimens were measured density, had been tested compressive strength and thermal conductivity.

DETERMINATION OF THE THERMAL CONDUCTIVITY

Thermal conductivity for the analysis is currently no mathematical model. Direct measured values by using the thermal conductivity probe, TPO2 (Hukseflux ,Netherlands), of the compost with various temperature and moisture content range under closed B,C are adopted. The close B.C means during measurement heat and moisture are intentionally not allow escaping from measuring chamber. The probe TPO2 is Non-Steady-State Probe (NSSP) has proven for measurement of thermal conductivity of soil, foodstuff and various materials. It works in compliance with the ASTM D 5334-92, D 5930-97 and IEEE442-1981 standards.

Also known as transient line source, thermal needle, hot needle, heat pulse had hot wire needle has the primary advantage that measurement is not depending on sample size.
The TPO2 probe, the following figure consists of a needle with two thermocouples junction (namely thermocouple hot junction and reference junction) and heating wire. At the probe base, the Pt 1000 (Class B, IES 751:1983) temperature sensor is installed as for temperature sensitivity correction of the thermocouples signal.
The principle for thermal conductivity measurement using NSSP is that: after a short heating period through the heating wire, the temperature rise between thermocouple hot junction and reference junction, ΔT, only depends on heater power, Q and medium thermal conductivity λ by the following relationship

$$\Delta T = \frac{Q}{4\pi\lambda}\left(\ln t + B\right)$$

Where: ΔT : temperature rise between thermocouples hot and cold junction,K
Q: heater power per cable length,Watt/m
λ: thermal conductivity of the medium,W/m.K
t : elapsed time after heater is on, sec
B: constant

The thermal conductivity λ, can be calculated from two measurement at time t_1 and t_2. Generally, t_1 and t_2 are higher than 60 sec and typically 100 sec apart. By taking time difference in the previous equation can be obtained.

$$\lambda = \frac{Q}{4\pi\Delta T}\ln\frac{t_2}{t_1}$$

Now ΔT represents temperature rise at hot junction. In practice, heater power is kept to be lowest as possible, normally less that 3 Volt, to prevent over estimate the thermal conductivity due to local moisture transport/ evaporation by excessive heating, especially in high water content sample under high temperature condition. Moreover, excess heat supply may cause reflection of the heat flux on camber surface measurement interference

Photo 1. Measurement method

Photo 2. TPO2 probe

The thermal conductivity is determined by experiment test probe shown on the Photo 1 and photo 2. .The result from data logger was used to calculated thermal conductivity of material by EXCEL software and is drawn the following figures.

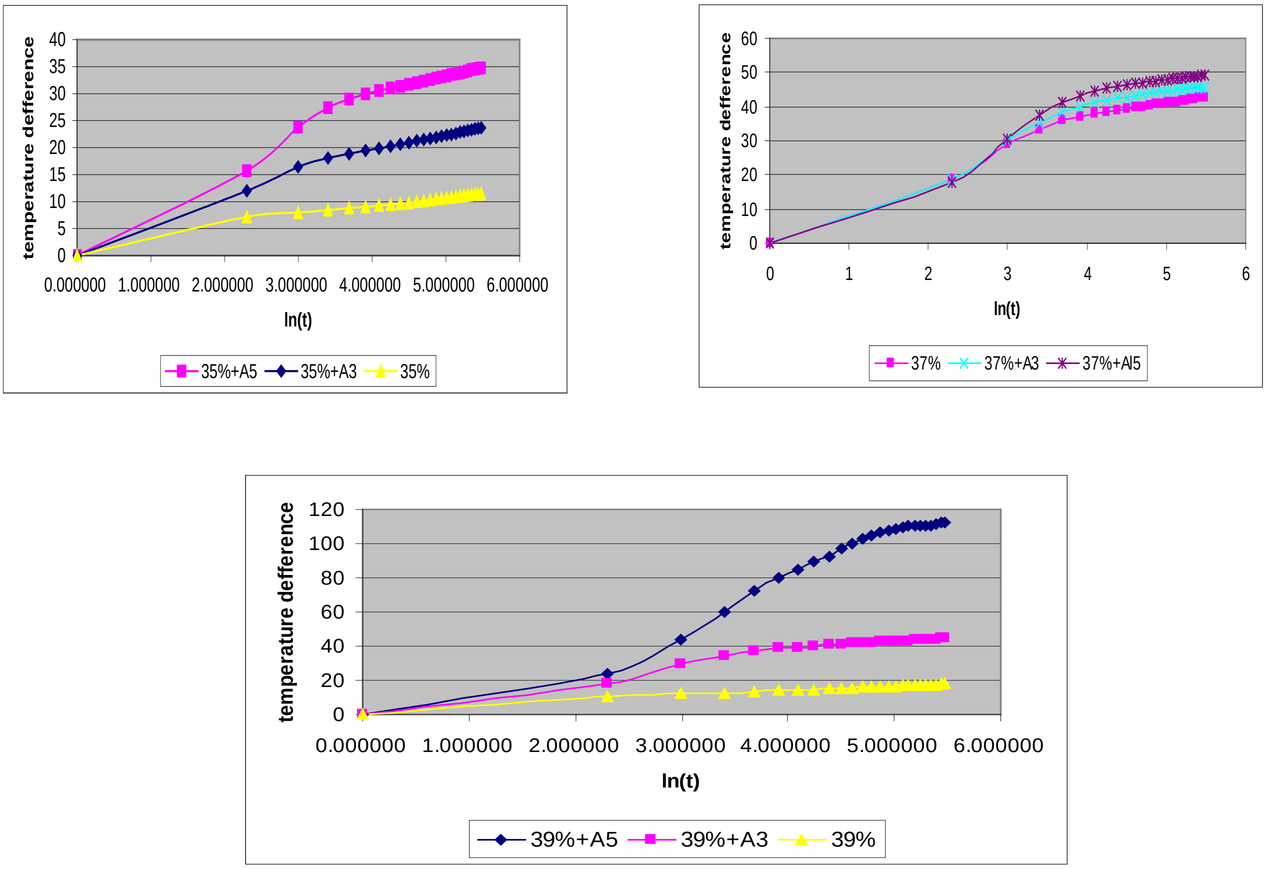

Fig. 1 Thermal conductivity after one week at W/C=1

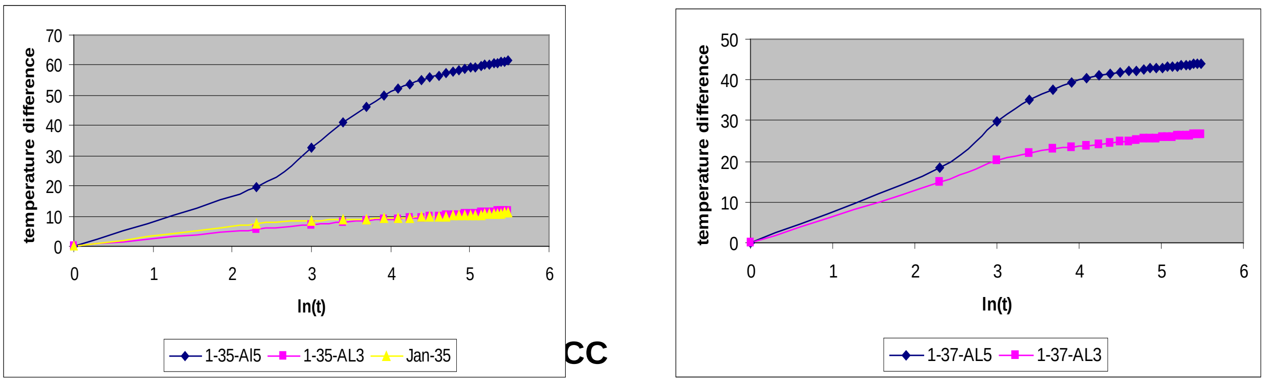

Fig.2. Thermal conductivity after four weeks at W/C=1

In this experiment was chose content of fly ash from 15% to 70% of volume. However, during the casting it is clarified that the optimal maximum content of fly ash is 50% and minimum is 15% at w/c=1and w/c=2. Therefore, from experiment process decided that will continue experiment process the following condition: fly ash content 15-45% of volume. w/c=1 and w/c=2 . In this case, also was determined influence of aluminium powder. From the manufacturing ACC experience, the common amount of aluminium powder in ACC is 200-600g/m^3. (3) Therefore, the content of aluminium powder is selected 200g/m^3, 400g/m^3 and without aluminium powder in this experiment condition.

Content of fly ash,%	Water, kg	Cement, kg	Fly ash, kg	w/p	Fly ash/cement
No ash	531	532.35	810		1.52
15	645	645.12	342	0.66	0.53
30	531	532.35	684	0.44	1.28
50	228	227.8	1140	0.25	5.00
70	228	227.8	1596	0.125	7.00

Table 5. Mix proportion for 1 m^3 mortar, w/c=1

Content of fly ash,%	Water, kg	Cement, kg	Fly ash, kg	w/p	Fly ash/cement
No ash	605	299	Limestone 30%	0.54	
15	734	365	342	1.03	0.93
30	605	299	684	0.88	2.28
45	563	272.8	1026	0.43	3.76
50	432	214.2	1146	0.32	5.39
65	390	189	1482	0.23	7.85

Table 6. Mix proportion for 1 m^3 mortar, w/c= 2

Fly ash+Al powder	W/P	Density Kg/m^3	Compressive strength MPa	Density Kg/m^3	Compressive strength MPa
		After one week		*After one months*	
15%	0.65	1854	7.95		17.22
15%+A2		1520	5.01		9.24
15%+A4		1179	2.47		4.98
30%	0.43	1734	12.72		20.89
30%+A2		1440	4.58		9.15
30%+A4		1228	2.99		5.63
35%	0.38	1743.9	14.02	1769.2	33.6
35%+A2		1422	8.05	1484.1	12.03
35%+A4		1388	2.68	1163	1.34

Table 7. Experiment result at W/C=1

A2 – aluminium powder 200g/m^3 A4 – aluminium powder 400g/m^3
15%+A2 – mixture with fly ash content 15% by volume and aluminium powder content 200g/m^3

Fig .3. Influence Al powder content On density at w/c=1 (after one week)

Fig.4. Influence Al powder on compressive strength at w/c=1 (after one week)

From Table 6 are drawn the Fig.3 and 4. The aluminium powder content strongly influence on density and compressive strength of mortar. In this way, the Al powder content is increase the density and compressive strength of mortar is degrease. The fly ash is natural porosity material; therefore the increasing fly ash content achieved the degreasing density of mortar. (1)

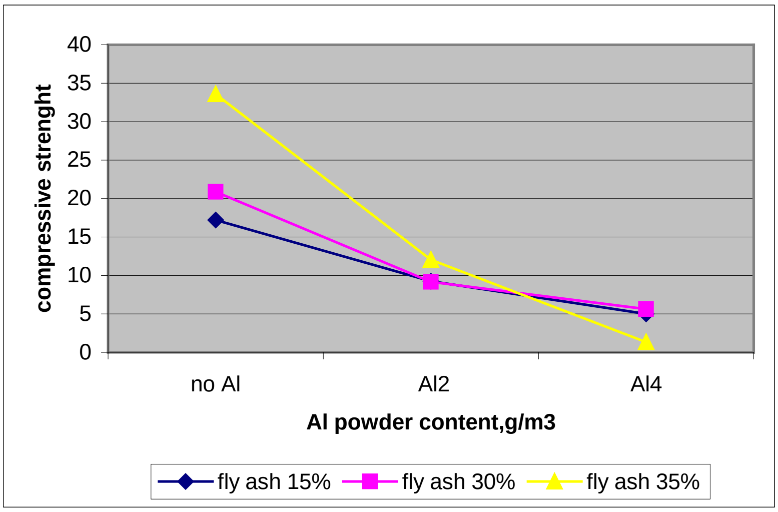

Fig.5. Influence AL powder content on compressive strength at w/c=1 (after four weeks)

The Table 8 presented the experiment result at W/C=2. The fly ash content in the mortar was from 15-45%. Unfortunately, the content of water in mixture with fly ash 15% was overmuch and the hardening process is not gone. From Table 8 data, the Fig. 6,7,8,9 was drawn. Due to reaction of aluminium powder, the inside of material derived number of pores and increase porosity of material. In contrast, the compressive strength of material is decreasing according to increasing porosity. (4)

Fly ash+Al powder	w/p	Density Kg/m^3	Compressive strength Mpa	Density Kg/m^3	Compressive strength Mpa
		After one week		***After one months***	
15%	1.03	No hardening			
15%+A2					
15%+A4					
30%	0.88	1633.1	2.6	1555	4.9
30%+A2		1312.7	1	1298	1.59
30%+A4		1162.2	0.93	1078	1.84
35%	0.52	1634.3	3.97	1514	5.14
35%+A2		1368.7	1.78	1251.5	1.9
30%+A4		1193.2	1.32	1030	2.0
40%	0.44	1708.1	4.86	1484.7	6.25
40%+A2		1364.3	1.91	1398.7	2.19
40%+A4		1263.3	0.82	1198.9	1.5
45%	0.37	1721	5.74	1716.8	7.65
45%+A2		1460.4	2.19	1443.8	3.6
45%+A4		-	0.96	860.67	1.15

Table 8. Experimental result at w/c=2

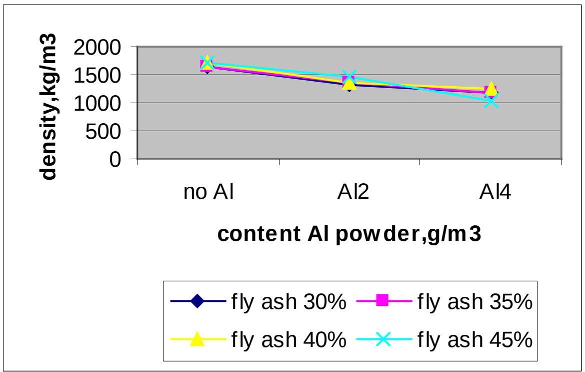

Fig.6. Influence AL powder on density at w/c=2 (after one week)

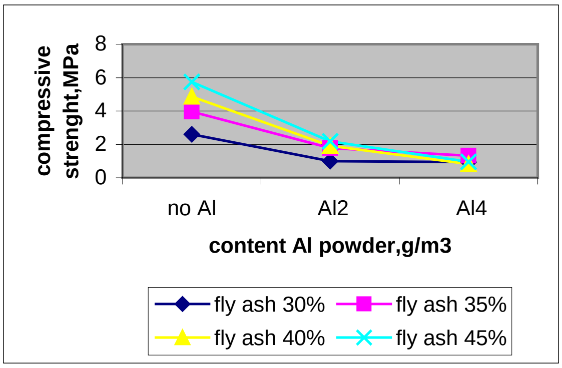

Fig.7. Influence AL powder on compressive strength at w/c=2 (after one week)

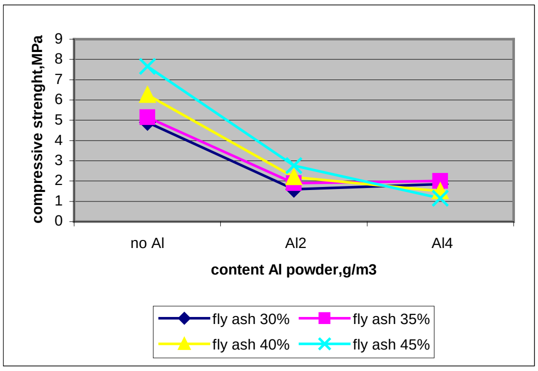

Fig.8. Experiment result at w/c=2 (after four weeks)

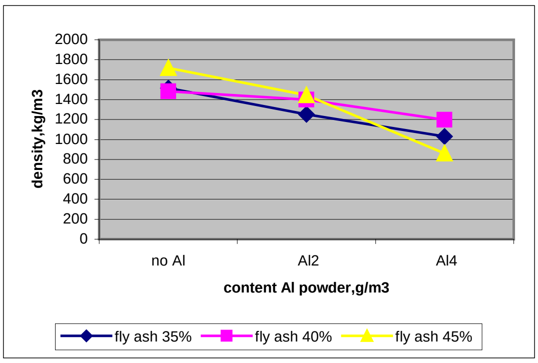

Fig.9. Experiment result at w/c=2 (after four weeks)

2. EXPERIMENT RESULT of BOTTOM ASH for ACConcrete

In this experiment was used bottom ash (clinker ash) in Japan. The methodology of the experiment is the same with fly ash experiment. But the first we didn't consider influence of aluminium powder to mortar. In this experiment : W/C=1 and W/C=2 ; bottom ash content 30%, 35%, 40%; determined properties density, compressive strength, thermal conductivity and porosity; curing time 7 days

Bottom ash content,%	Density Kg/m^3	Compressive strength, MPa	Thermal conductivity, W/m.K
30	1720	10.48	0.694
35	1690	7.93	0.618
40	1608.8	5.9	0.585
30	1795.8	8.15	-
35	1646.5	2.22	0.569
40	1616.1	2.49	0.583

Table 9. Experiment result at w/c=1

From Table 9 it can draw the following figures.

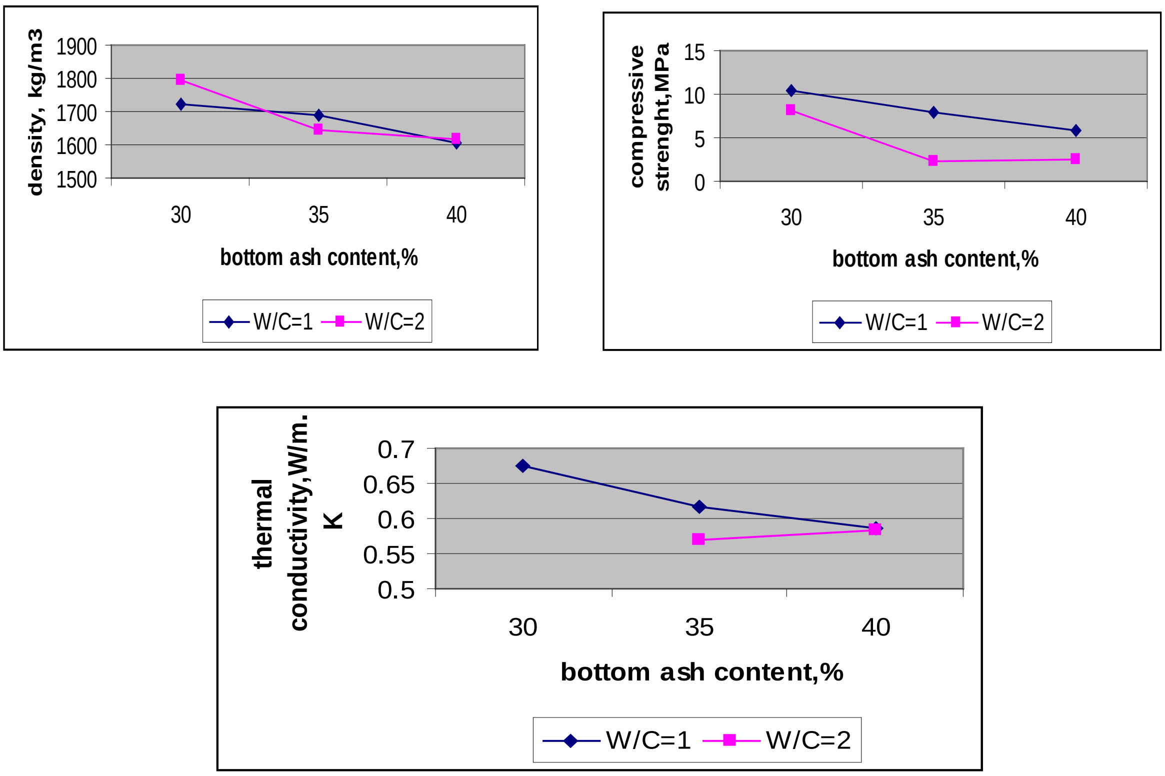

Fig.10. Influence bottom ash content on density, compressive strength and thermal Conductivity

Then was continued experiment to check how influence aluminium powder content to the mortar properties and also to choose the optimal mix proportion bottom ash ACC from experiment result. But in this experiment we didn't take the condition W/=2. From the above experiment result it was presented that at W/C=2 the compressive strength of mortar was degrease strongly in all mix proportion. The increasing water content is following the bad results. Therefore, this condition is ignored experiment of influence aluminium powder content on mortar at W/C=2. The experimental condition were: bottom ash content 35%, 37%, 39%, 41%, 43% of volume; aluminium powder content 300g/m^3 (Al3), 500g/m^3 (Al5) and without aluminium powder; the determined properties density, compressive strength, thermal conductivity , porosity and cost.

Mix types	***After one week***				
	Density,kg/m^3	**Compressive strength,MPa**	**Thermal conductivity, W/m.K**	**Open porosity, %**	**Cost, $**
35%	1500.71	1.36	0.663	41.93	32.13
35%+Al3	1318.8	0.31	0.375	34.09	33.03
35%+Al5	1295.09	0.39	0.302	34.95	33.63
37%	1553.26	0.98	0.200	40.50	31.15
37%+Al3	1366.99	0.35	0.218	33.22	32.05
37%+Al5	1350.32	0.35	0.254	34.39	32.65
39%	1556.47	0.84	0.414	41.68	30.14
39%+Al3	1403.33	0.30	0.23	34.34	31.04
39%+Al5	1345.7	0.39	0.039	35.16	31.64
41%	1562.28	0.77	0.446		29.14
43%	1559.1	0.61	0.418		

Table 10. Experiment result at W/C=1 (after one week)

Mix types	***After one month***				
	Density,kg/m^3	**Compressive strength,MPa**	**Thermal conductivity, W/m.K**	**Open porosity, %**	**Cost, $**
35%	1657.3	6.09	0.946	41.93	32.13
35%+Al3	1393.9	1.7	0.535	34.09	33.03
35%+Al5	128	1.38	0.111	34.95	33.63
37%	1579.7	4.62	0.652	40.50	31.15
37%+Al3	1373.1	2.6	0.461	33.22	32.05
37%+Al5	1320.8	2.4	0.263	34.39	32.65
39%	1630.5	3.9	0.454	41.68	30.14
39%+Al3	1374.5	2.6	0.255	34.34	31.04
39%+Al5	**1302.5**	**2.16**	**0.201**	**35.16**	**31.64**
41%	1570.8	3.11	0.432		29.14
43%	1550.4	3.25	0.399		

Table 11. Experiment result at W/C=1 (after four weeks)

Al3 – aluminum powder content 300g/m^3 Al5 - aluminum powder content 500g/m^3
35%+Al3 – bottom ash 35% of volume an aluminium powde 300g/m^3

From Table 10 and 11 were drawing the following figures.

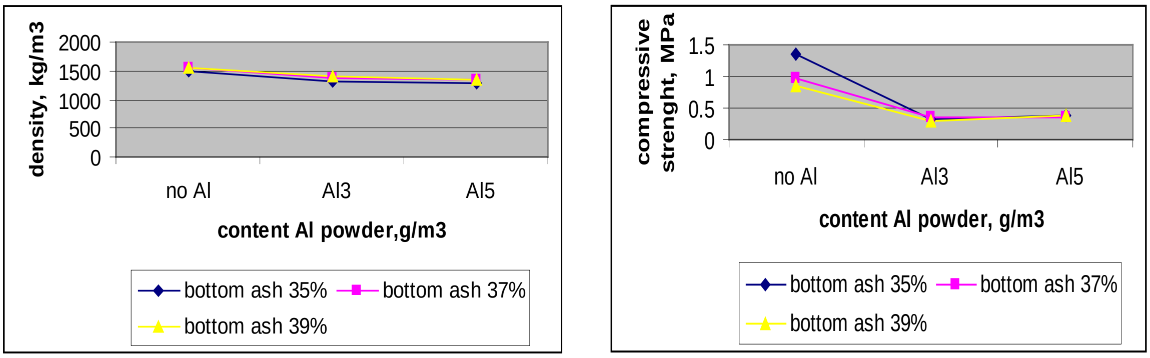

Fig.11. Influence Al powder content to on density, compressive strength (after one week)

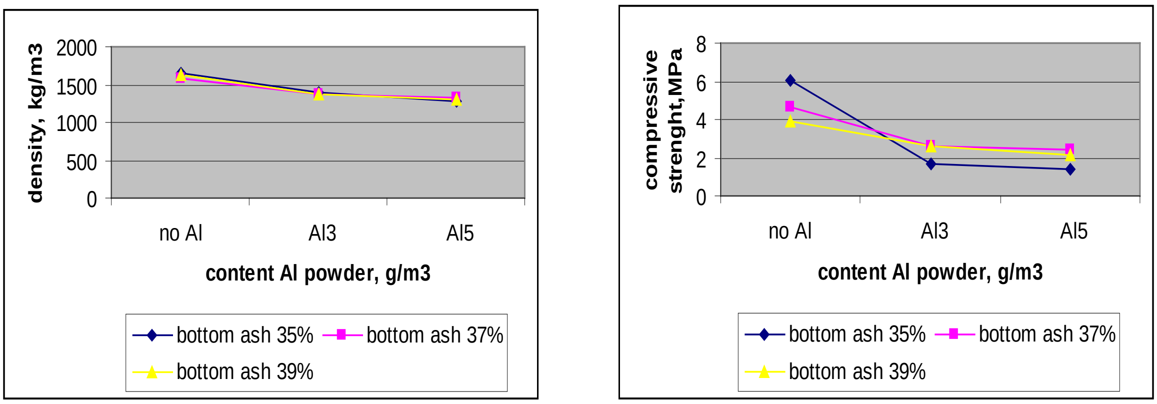

Fig.12. Influence Al powder content to on density, compressive strength (after four weeks)

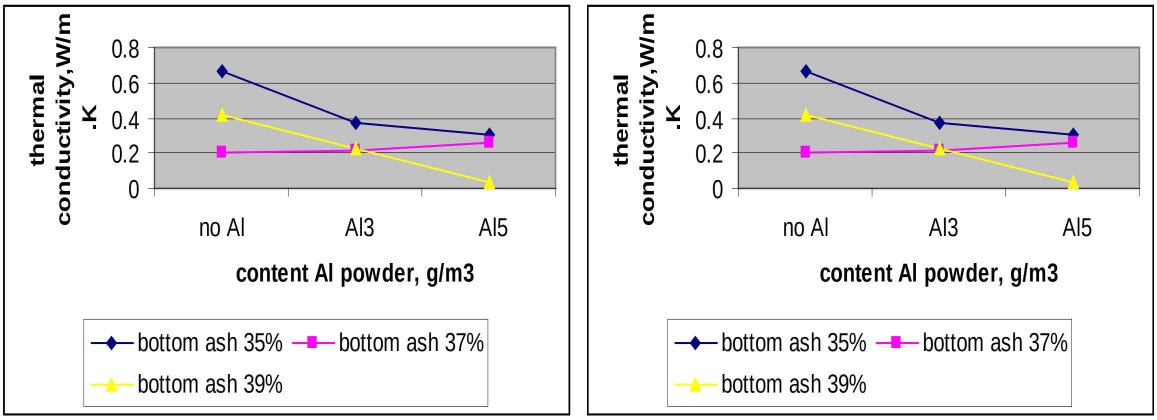

Fig.13. Influence Al powder content to on thermal conductivity of mortar (after one month)

3. PERFORMANCE EVALUATION of ACConcrete

Recently, in Mongolia the basic building materials are red bricks and a cellular concrete blocks. .For the evaluation of ACC and to determine optimal mix proportion from experimental result the evaluation pentagon is drawn for ACC by some properties range widely using wall material (red brick and cellular concrete) in Mongolia

Properties	**Red brick**	**Cellular concrete blocks**	**For evaluation ACC**
Density,kg/m^3	1800	700	**1800-700**
Thermal conductivity, W/m.K	0.81	0.14	**0.81-0.14**
Compressive strength,MPa	8-10	2	**8-2**
Amount of ash,%			**15-45**
Saved cost ,%			**1-30**

Table 12. ACC comparison table with other widely using wall materials

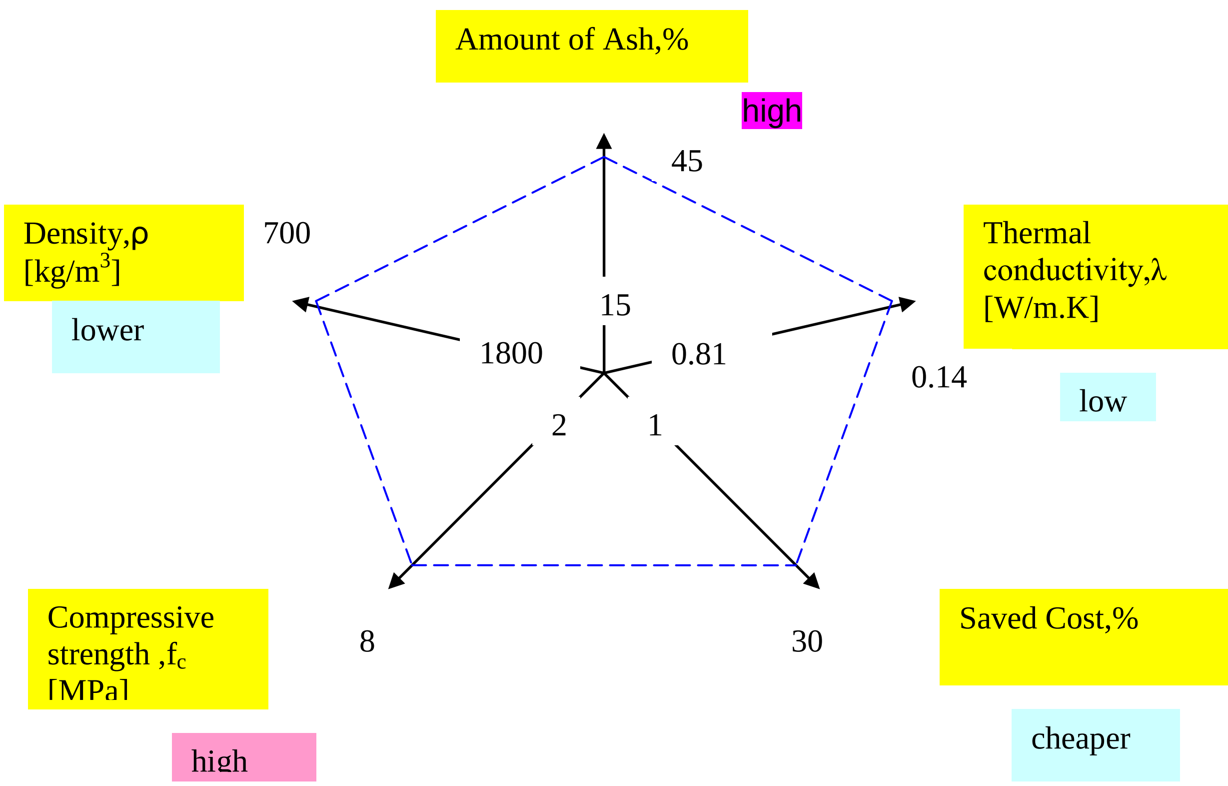

Fig.14. Performance evaluation pentagon for ACC

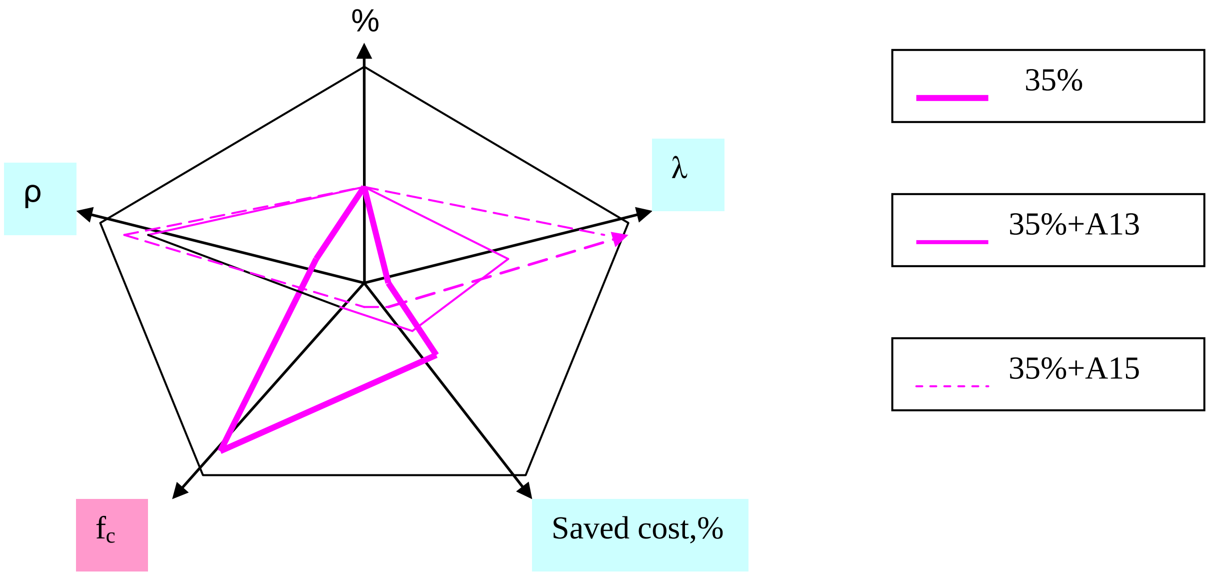

Fig. 15. Evaluation for mix proportion with 35% ash by volume

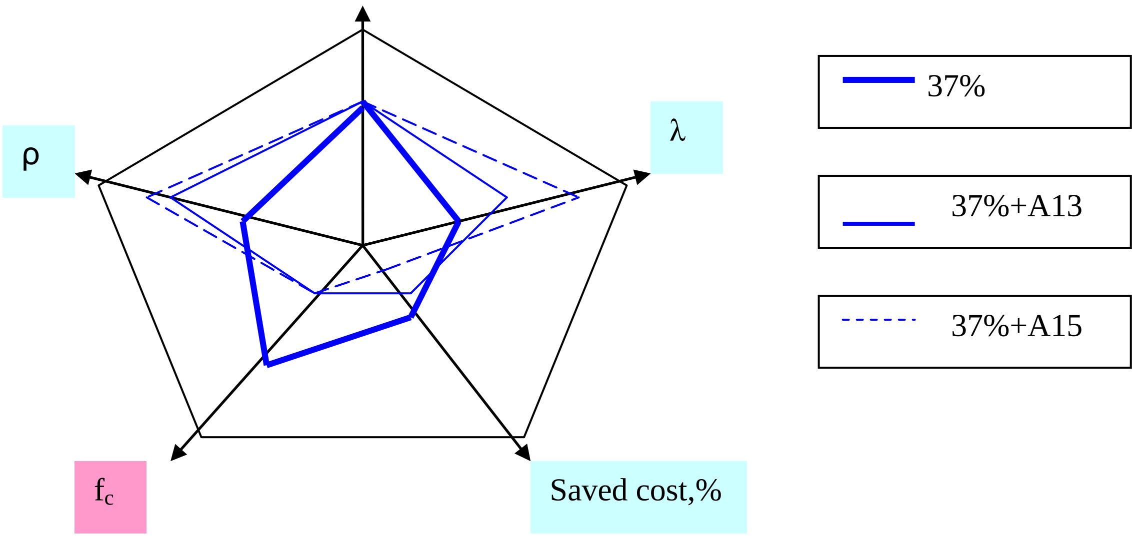

Fig. 16. Evaluation for mix proportion with 37% ash by volume

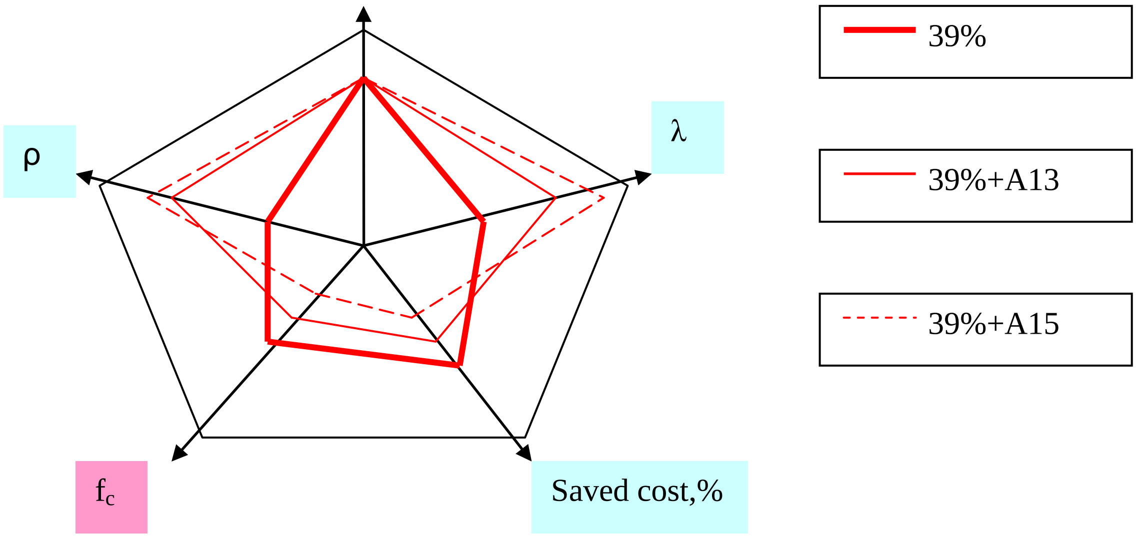

Fig. 17. Evaluation for mix proportion with 39% ash by volume

Comparing figures 14,15 and 16 the size of figure 16 was bigger than others. According to evaluation pentagon figure 15 big size figures shows good properties mix proportion and this ACConcrete is comfortable for building wall material in case of Mongolia. From figure 16, mix proportion with 39% ash by volume and 500g/m^3 aluminium powder content had satisfied requirement too close than others.

CONCLUSION

Base on research and experimental results, the following conclusions can be drawn:

1. Both physical and chemical analyses of coal ash itself were carried out. By adapting several classifications specified in other developed countries to the coal ash in Mongolia, it was shown that we have possibilities to use coal ash from Power Plant III for aggregate for pavement, filter and concrete. Also it can be used for concrete construction and heavy and lightweight concrete, and mortar.
2. Thorough the investigation of different mix proportion, the following conclusions were obtained:
   a) It is affordable to produce ACC block by coal ash in Mongolia. In this case maximum content of coal ash is 35-41% by volume at water cement ratio 1.0. The values of density between 1200 and 1800 [kg/m^3], compressive strength changes 2-12 MPa after one month. The changing of density depends on aluminium powder content in the mixture directly.
   b) Can we use this ACC block for building wall material in Mongolia, especially instead of traditional brick? For the answer, we made performance evaluation pentagon for ACC. Comparing, ACC properties from experiment result to this evaluation pentagon, will able to use ACC block instead of brick, especially with mix proportion which had 39% bottom ash by volume and 400[g/m^3] aluminium powder. In this case can see the following advantages of ACC comparing to traditional brick:

- The thermal conductivity of ACC is lower than brick, therefore wall thickness will reduce from 100 [cm] to 27 [cm] (by 3.7 times). This decreasing not achieved to any damage
- The degreasing wall thickness achieved to degrease material spends and constructed time of building.
- It can produce ACC block with any sizes.
- If use ACC block for building wall instead of brick, the material total cost of building wall will degrease about 30%.

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