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Analysis of Coal Combustion By-Products (CCBs) in Mongolia in Consideration of the Characteristics to be suitable for Backfilling and Securing of abandoned Small Scale Coal Mines

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Abstract

The research aimed to evaluate the possibility to use CCBs and industrial wastes for backfilling material for underground mines. Hundreds of thousand tons of CCBs in Mongolia is being landfilled despite its economical and beneficial properties. Following tests and analyses were made to evaluate CCBs and industrial wastes: sieve analysis, SEM analysis, radioactivity detection, moisture content analysis, XRF chemical content analysis, uniaxial compression test, elution test and FTIR analysis. Total of 9 CCBs and 1 electric-arc furnace slag from 7 different location/plant have been evaluated to represent Mongolian CCBs. Backfill mix designs were designed to compare the materials and to choose the best suited material for backfilling purpose.

During the research, fly ash from the thermal plant #4 and ger district bottom ash had been proven as a suitable material for backfilling while other material can be utilized but, other binder additives such as portland cement must be used. Any of the evaluated materials in this research are investigated not being harmful to environment and to human health.

Fly ash and ger district ash are the most common CCBs in Mongolia. More than 200 thousand tons of fly ash and another 200-230 thousand tons of ger district bottom ash are being generated annually.

Table of Contents

Table of Figures

List of Tables

Appendix List

List of abbreviation

CCB	Coal combustion by-product
TPP	Thermal power plant
ASTM	American Society for Testing and Materials
ESP	Electro-static precipitator
ASM	Artisanal and Small-scale mine
PM 2.5	Particulate matter that is smaller than 2.5µm
PM 10	Particulate matter that is smaller than 10µm
MNT	Mongolian tugrug
BASMIC	Backfilling and Securing of abandoned Small Scale Coal Mines with Coal Combustion By-Products (CCBs) generated at Power Plant Sites and with Domestic Coal Combustion By-Products generated at Ger District Sites
OECD	Organization for Economic Co-operation and Development
FGD	Flue-gas desulfurization materials
FTIR	Fourier-transform infrared spectroscopy
SEM	Scanning Electron Microscopy
XRF	X-ray fluorescence

1 Introduction

Coal-combustion-by-products (CCBs) are generated during the process of burning coal. Approximately 10-30% of total input of the coal mass transforms into CCBs. Hundreds of million tons of CCBs are being generated annually worldwide but only portion of the generated CCBs being utilized. CCBs can be divided into the following products: bottom ash or boiler slag, fly ash and flue gas desulfurization materials while Mongolia only produces bottom ash or boiler slag except the thermal power plant (TPP) #4. The reason is simply because TPPs are so old that it does not have electro-static precipitator (ESP) and desulfurization technology. Moreover, in the long and harsh winter time of Mongolia another type of bottom ash is generated in the ger district for heating purpose. More than the half of the citizen of Ulaanbaatar, capital of Mongolia, live in the ger district.

The main source of energy in Mongolia is coal while slight portion is produced from renewable energy sources such as solar, wind and hydro. Mongolia's coal consumption is over 8 million tons per year and 500-600 thousand tons of CCBs are produced in which 200-230 thousand tons of bottom ash from the ger district and 200 thousand tons of fly ash from TPP#4 (1). This reported CCBs production number seems to be much lower. Due to that only slight amount of fly ash from the TPP#4 is currently being recycled for construction material and the other CCBs are being landfilled. Which shows significance of CCBs in Mongolia is insignificant and, CCBs usually seen as waste materials. Thus, records on CCBs in Mongolia are not accurate.

Underground mining creates cavities in the ground, in the most cases it has backfilled. The backfilling operation provides an option to dispose waste materials underground rather than on the surface for example landfills. Additionally, the using of the waste materials such as mine waste, CCBs and process plant waste stabilizes the surrounding rock mass. As a result, it prevents collapse of the mining cavities that results disruption to ore production, ore loss and more importantly resulting a compromise on safety of the workers or subsidence on surrounding constructions and surface. In contrast, potential negative consequences of the CCB backfilling must be determined such as leaching, releasing of heavy metals, radiation and drainage.

Artisanal and Small-Scale mining (ASM) is abundant in Mongolia like other developing nations with natural resources. Nalaikh had been one of the most concentrated area with ASM if not the most and still has considerable amount of ASM.

Most of ASM were unauthorized, low capital intensive and used high labor-intensive methods. Equipment were presumably primitive equipment (shovel & pickaxe). Due to the low-qualification and lack of safety knowledge of the mining of the miners has been causing accidents often. As of 2017, approximately 240 miners died, and 735 miners are fatally injured in 22 years (2). ASM in Nalaikh is posing permanent threat to the miners to themselves, to neighboring communities and surface constructions.

In Mongolia, the experience and the knowledge of a beneficial usage or recycling of CCBs is lacking. It is only being landfilled into the environment despite its economic value and benefits. Huge amount landfill volumes could be saved by recycling the CCBs for the proper purpose. Recycling the CCBs also benefits human health because some ger district bottom ash is being thrown out into the streets which leads to the fine CCBs (PM2.5 & PM10) to escape to the atmosphere, to radiate and possible heavy metals in the CCB to be released. Generation of CCBs projected to increase dramatically for the next decade worldwide and the utilization rate has been high in the industrialized countries, while in Mongolia, only slight portion of the fly ash that is produced in the TPP#4 is recycled as an additive for construction material.

CCBs hold a property called pozzolanic activity. The pozzolanic reaction converts calcium hydroxide or calcium oxide and silicic acid with the presence of water to the product called calcium silicate hydrate (C-S-H). The pozzolanic reaction leads to cementation of the matrix.

Due to that CCBs hold pozzolanic property, it has been used for mine cavity filling for the last decades in industrialized countries like Germany. It has been proven that CCBs improved the stability both in the subsurface and on the surface in Germany while being very economical and ecological friendly.

Moreover, space and finance for landfilling of CCBs is heavily concerned. For example, TPP#4 currently has 5 tailing and the 6^{th} is currently being constructed. The total cost estimate to build a tailing pond is 5-6 billion MNT. The tailing ponds range from 1.2-1.9 million cubic meters in volume (3). Due to the limited space in Ulaanbaatar 5^{th} tailing pond was constructed on the old tailing pond.

The study aims to investigate theoretical possibilities to use CCBs and other waste materials such as electric arc furnace slag from the Darkhan metallurgical plant and ESP dust from the ger districts for backfilling and securing underground mines under the project “Backfilling and Securing of abandoned Small Scale Coal Mines with Coal Combustion By-Products (CCBs) generated at Power Plant Sites and with Domestic Coal Combustion By-Products generated at Ger District Sites (BASMIC)”.

2 Literature Review

2.1.0 Coal

Coal is a heterogeneous, sedimentary rock material that comprised of fossilized carbon, which originates from plants and vegetation and accumulated in sediment basins. The parent organic material was mainly consisted of trees, plants, leaves, roots, branches, pollen, and pores. As these materials accumulated in a saturated environment, partially decayed vegetation would settle to the bottom of the swamp and transform into peat. Suitable acidity and anaerobic conditions existed to prevent the full decay of the peat. Over the time peat was sedimented and buried, which led to high pressure and temperature. Moisture is reduced via dehydration, while carboxylic acids and volatile matter (primarily methane), along with CO2, are also reduced as pressure compacts organic material into a denser solid. With time, heat, and pressure, peat matures into lignite, then to subbituminous coal, then into bituminous coal, and eventually into anthracite. The various stages that occur over time result in changes to the chemistry of the organic matter during the coalification process (4). In the Mankind has been using coal since 4000 BC in China by Neolithic inhabitants (5). Until 1700s coal usage was low. The invention of steam engine and industrial revolution led to the large-scale usage of coal (6). From that period, coal became major source of energy.

The coal ranks can vary country to country but generally formation begins with peat and presses to lignite, subbituminous coal, bituminous coal and then anthracite. Table 1 (7) shows classification of American Society for Testing and Materials (ASTM), which is generally accepted classification scheme. In this table, carbon content and volatile matter are expressed on a dry mineral matter free basis (dmmf), while calorific value is expressed on a moist mineral matter free basis (mmf).

Coal ranks are classified by their physiochemical properties such as carbon content, volatile matter, gross calorific value, Sulphur content, ash content, trace elements, etc. There are two classifications for lignite and three classifications for subbituminous, all based on calorific value. The bituminous coal rank is determined by both calorific value and composition (i.e., fixed carbon and volatile matter). The high-volatile-matter subbituminous coals all contain <69% fixed carbon and >31% volatile matter. The calorific value increases with rank, as volatile matter is converted into fixed carbon as the coalification process proceeds. Through continued coalification, increasing amounts of volatile matter are converted into fixed carbon, as rank increases to low volatile bituminous. Once the amount of fixed carbon increases to 86% and the volatile matter decreases to 14%, the rank is classified as Anthracite.

		Fixed carbon	Volatile matter	Gross calorific value		
		%	%	Btu/lb	MJ/kg	
Coal rank		dmmf	dmmf	Moisture mmf	Moisture mmf	Agglomerating characteristics
Anthracite	Meta-anthracite	≥98%	<2%			Non-agglomerating
	Anthracite	92–98%	2–8%			
	Semianthracite	86–92%	8–14%			
Bituminous	Low-volatile bituminous	78–86%	14–22%			Commonly agglomerating
	Medium-volatile bituminous	69–78%	22–31%			
	High-volatile A Bituminous	<69%	>31%	≥14,000	≥32.557	
	High-volatile B Bituminous	<69%	>31%	13,000–14,000	30.232–32.557	
	High-volatile C Bituminous	<69%	>31%	11,500–13,000	26.743–30.232	
	High-volatile C Bituminous		>31%	10,500–11,500	24.418–26.743	Agglomerating
Subbituminous	Subbituminous A			10,500–11,500	24.418–26.743	
	Subbituminous B			9500–10,500	22.09–24.418	
	Subbituminous C			8300–9500	19.30–22.09	
Lignite	Lignite A			6300–8300	14.65–19.30	Nonagglomerating
	Lignite B			<6300	<14.65	

Table 1 *Classification of Coal by rank (ASTM D388-15) (7)*

One very important observation is that as coalification proceeds through the various ranks, volatile matter is converted into fixed carbon, resulting in an increasing energy density (4). However, higher content of carbon does not always lead to higher calorific value as show in the Figure 1 (8).

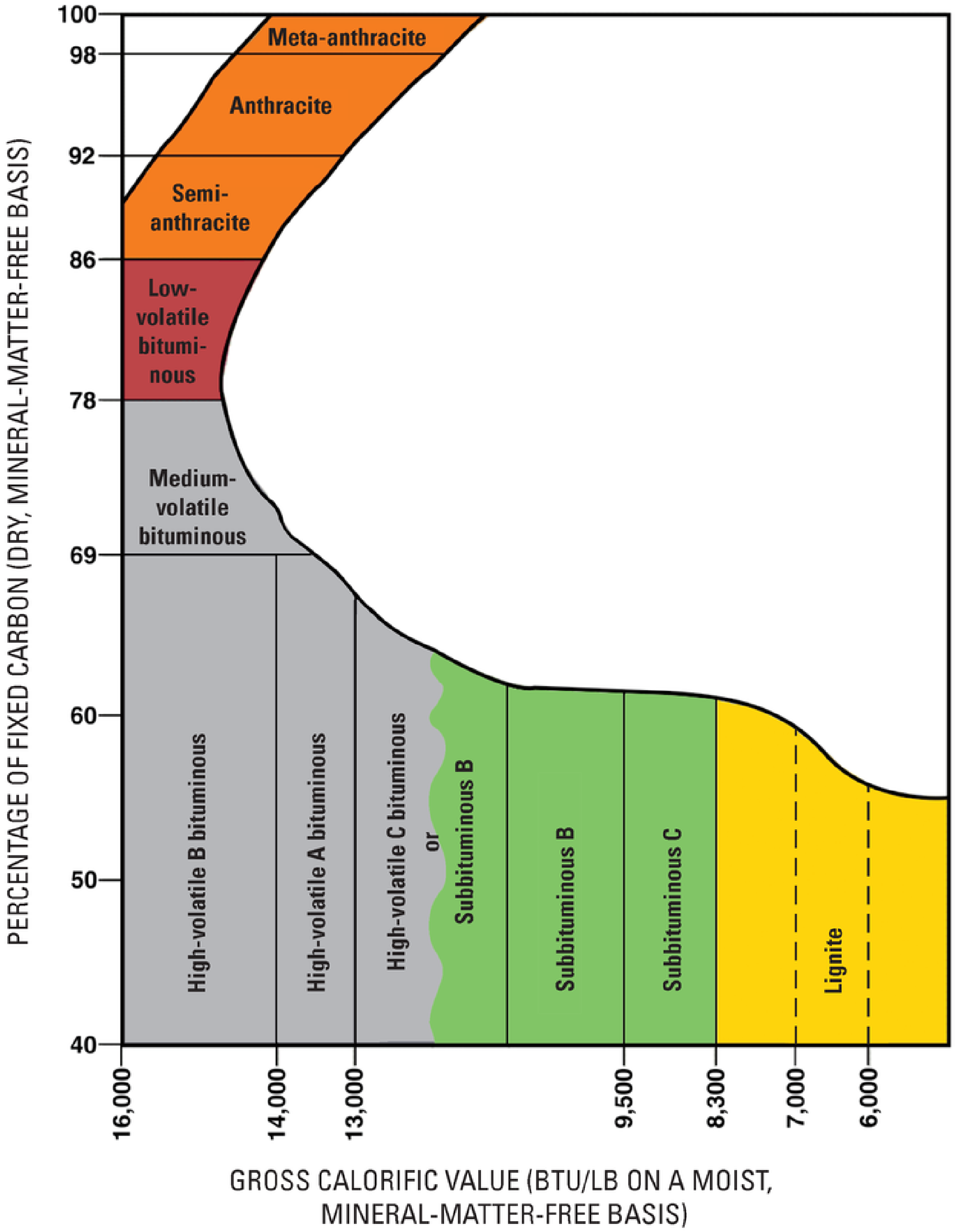


Figure 1 *Coal ranks (8)*

2.1.1 Coal composition and Minerals

Coal composition and minerals in coal are crucial when it comes to the utilization of the CCBs, because usually depending on the composition and minerals, those compounds and minerals in the coal remains in the CCBs.

Coal is comprised of complex mixtures of organic and inorganic compounds. The organic compounds are inherited from the parent vegetation. There are usually more than hundred inorganic compounds in the coal. Those inorganic compounds in the coal either were introduced into the swamp from water-borne or wind-borne sediment or were derived from elements in the original vegetation; for example, some inorganic compounds are absorbed by the original vegetation which is crucial to the original vegetation to grow. After the original vegetation decompose, the inorganic compounds remain in the swamp. Some of those compounds combine to form discrete minerals, such as pyrite.

Coal may contain as many as 76 of the 94 naturally occurring elements. However, most of those elements occurs as a trace element (Figure 2). Sometimes, some hazardous elements (cadmium, selenium, arsenic, etc.) can be more concentrated than the trace amounts. Although, coal have been identified to contain as many as 120 different minerals, 33 of them commonly found in coal and only 8 of them are abundant enough to be considered major elements (8).

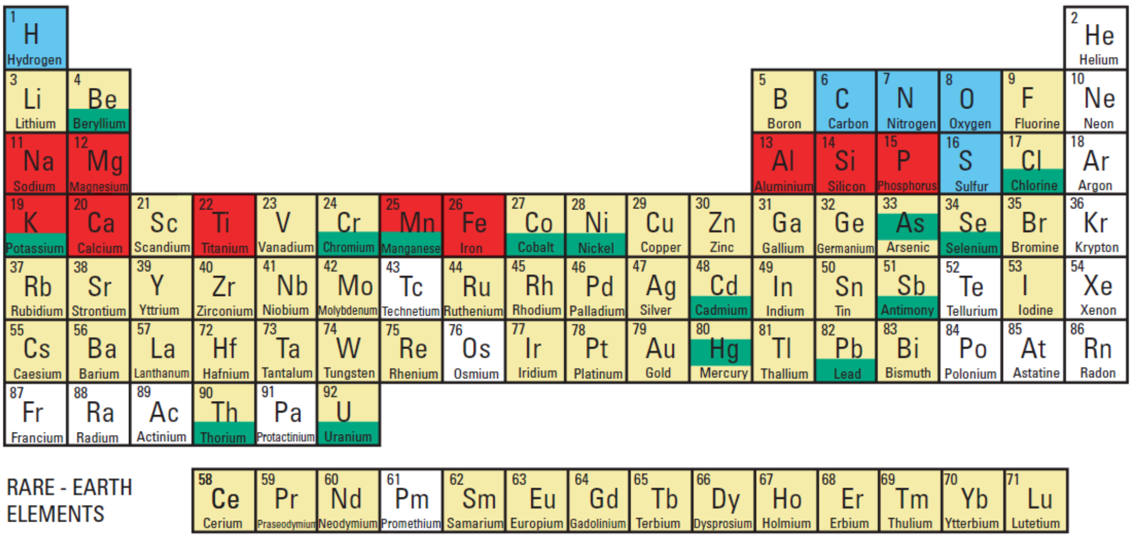


Figure 2 *Periodic table of the elements showing naturally occurring elements on Earth. Elements highlighted by their abundancy in the coal, as follows: blue, major element (1%<); red, minor element (0.01%=<); yellow, trace elements (0.01%>). Green, potentially hazardous air pollutants (8)*

The most common minerals in the coal are quartz, clay minerals, pyrite, calcite, and siderite. These minerals mostly made up of the most common elements such as oxygen, aluminum, silicon, iron, sulfur, and calcium. Minerals in the coal commonly occur as a single crystals or clusters of crystals that are mixed with organic matter or fill void spaces in the coal. Minerals in the coal can be as little as sizes of mineral grains to submicroscopic to a few inches. However, in the coal veins or balls minerals can be reach sizes of as much as several feet across.

When coal is incinerated, most of the minerals and trace elements generally generates ash. However, some minerals or trace elements can break down to the gaseous compounds; for example: pyrite breaks down to sulfur oxide (g) and iron oxide.

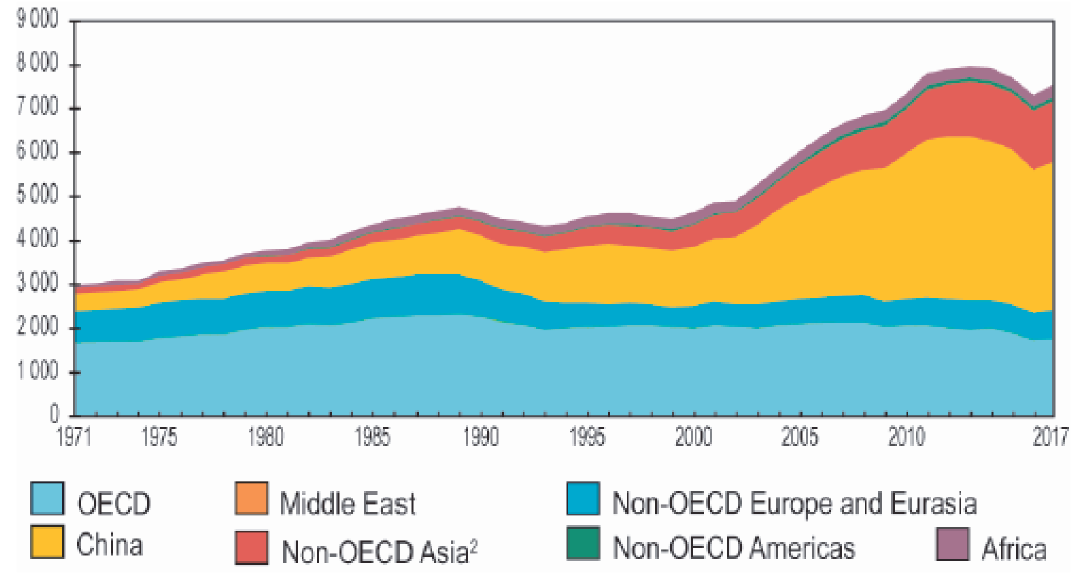
The coal mineral content determines what kind of ash will be generated when it is incinerated. The melting temperature of the ash determines the design of boilers. In generally, if the melting temperature is low, then the molten ash is collected at the bottom of the boiler as a bottom ash or potash, requiring one design, but, if the melting temperature is high, some ash (fly ash) does not melt and it is blown through the boiler then it should be collected by the electro-static precipitator, requiring a different design. If an electricity-generating or heating plant is designed to burn one type of coal, then it must continue to be supplied with a similar coal or undergo an extensive and costly redesign in order to adapt to a different type of coal. Boilers designed to use coal that has high energy density will suffer severe losses in efficiency if they must accept coal that burns with less energy density coal (8).

2.1.2 Coal utilization

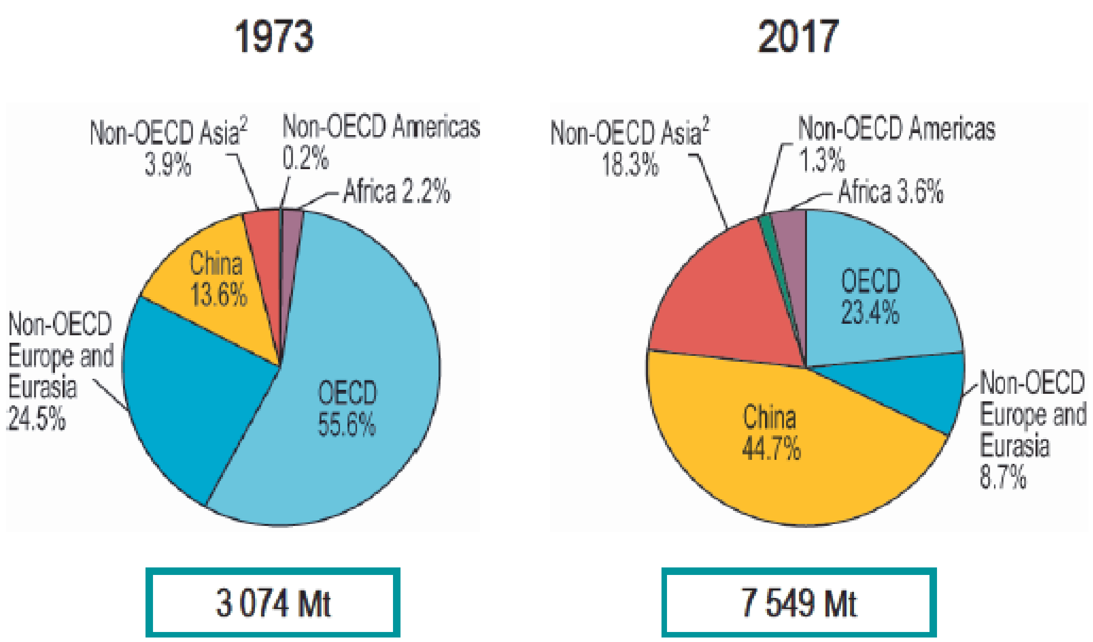
It is impossible to imagine modern civilization without electricity, running water, heating, cooling and any other needs. But all those needs require energy source. Coal supplies approximately a quarter of the world’s primary energy and two-fifths of its electricity. Coal production has been steadily increasing for the last 50 years. As of 2017, coal production is more than doubled in 40 years as shown in the Figure 3 (9). This significant increase in coal production can be related to developing countries economic growth and industrialization. This can be showed from the Figure 3 and Figure 4, in 1973, Organization for Economic Co-operation and Development (OECD) countries produced 55.6% and Non-OECD Europe and Eurasia produced 24.5% of the world production. However, as of 2017, the numbers look totally different, China and Non-OECD Asian countries produced 63% of total world coal production. It is estimated that there are over 850 Gt of proven coal reserves worldwide; which is enough to last more than 130 years at current rates of production. Coal currently supplies third of the primary energy and

38% of global electricity generation (10). World coal association forecasted coal to rise over 50% of primary energy to 2030, with developing countries responsible for 97% of this increase.

World coal[1] production from 1971 to 2017 by region (Mt)



1973 and 2017 regional shares of coal[1] production



1. Includes steam coal, coking coal, lignite and recovered coal.
2. Non-OECD Asia excludes China.

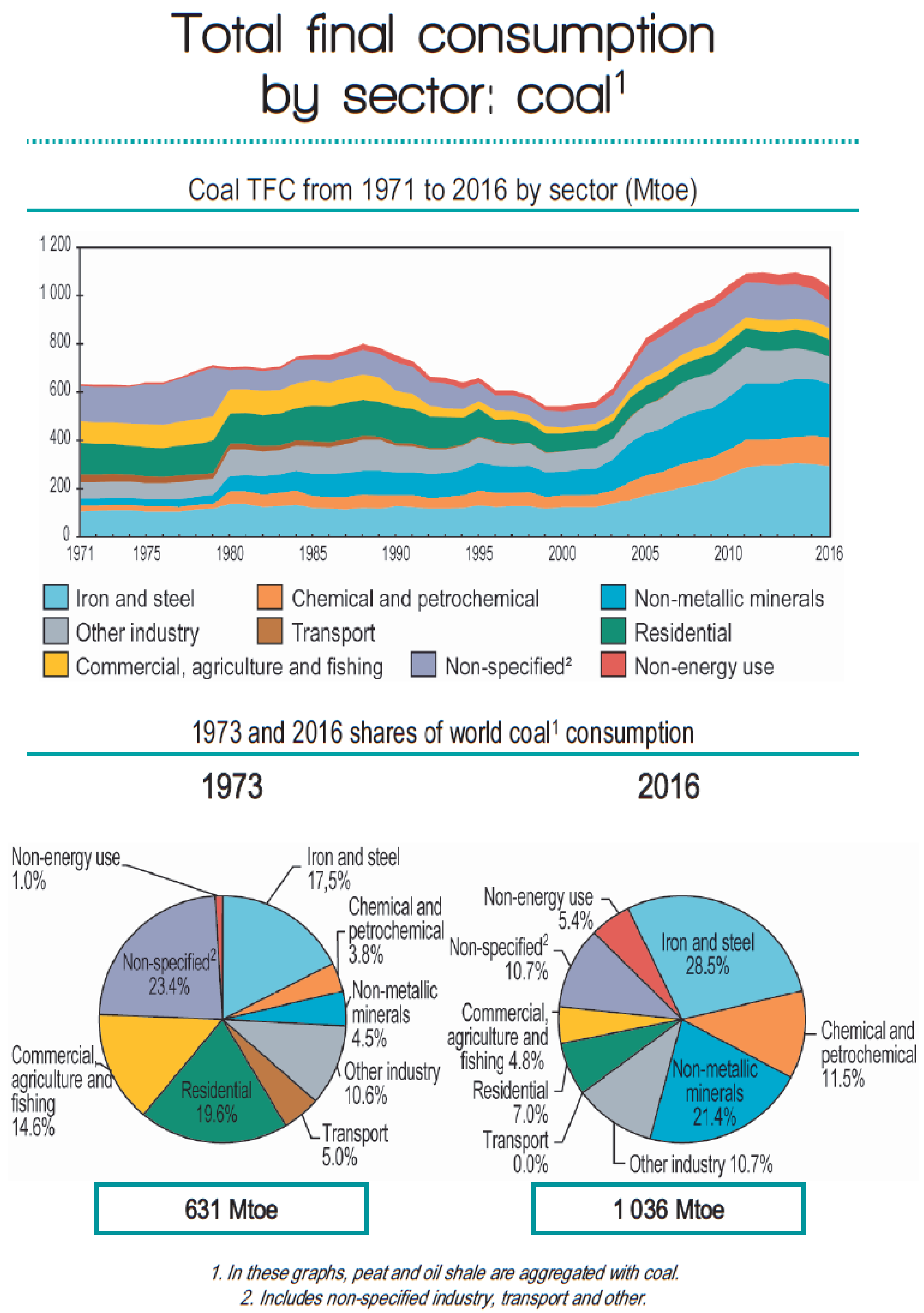


Figure 4 *Total final consumption of coal (9)*

As mentioned above, world coal production has doubled in the last 40 years. However, electricity generation showed even more steep jump. It has quadrupled in the last 40 years. Coal has always been the major source for electricity generation. In 1973, 38.3%

(Figure 5) of the total world electricity generation was produced by coal burning power plants, however, as of 2016, coal burning power plants produced 38.4% of the total world electricity generation. To conclude from this fact, coal has always been the major source of energy and it will likely to be major energy source for the following decades.

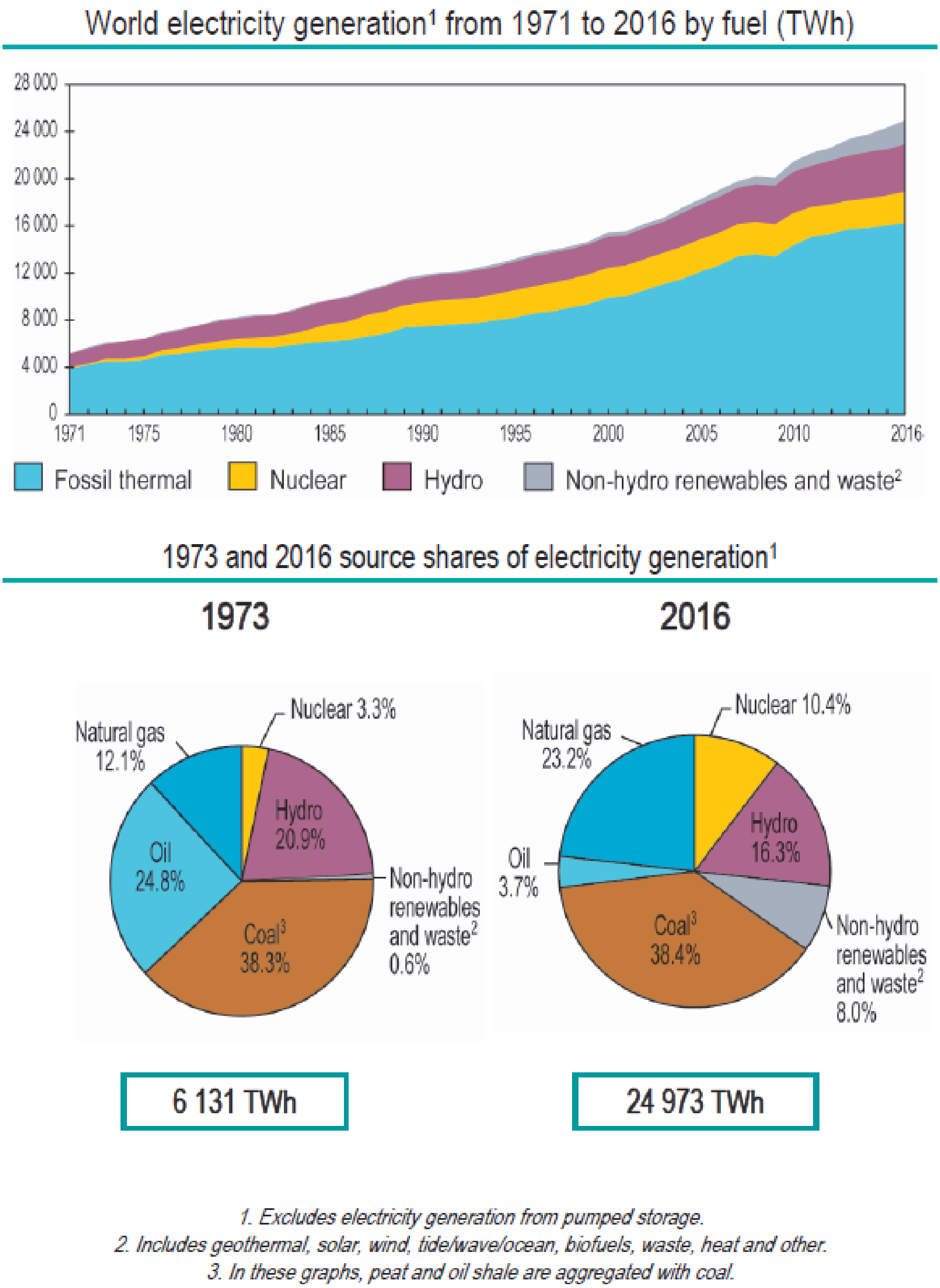


Figure 5 *World electricity generation from 1971 to 2016 by specific fuels (TWh) (9)*

2.1.3 Mongolia

Coal is a very crucial resource for Mongolia in terms of energy and economy. In 2017, Mongolia produced 48 Mt, used 8.6 Mt for energy purpose and exported about 30 Mt of coal (10) ash shown in Table 2 and Figure 6. This ranked Mongolia at 7th place among the coal exporter countries. Mongolian coal production has been increasing significantly. In the last decade, coal production has been quintupled, however, domestic usage has been relatively stable. Mongolia has proven coal reserve of 173.3 billion tons in 49 deposits (11).

Coal is the monopoly source of energy in Mongolia. In 2013, thermal power plants provided 95.48% of total capacity of electricity production followed by hydro-electric stations 3.4% then solar stations 0.64% and windfarms 0.48% (12).

Coal in Mt	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total production	10.1	14.4	25.2	32.0	29.9	30.1	25.3	24.2	35.5	48.1
Usage	5.8	6.4	6.9	6.8	7.3	8.0	8.0	7.6	8.4	8.6
Usage of TPPs	4.8	5.1	5.5	5.4	5.8	6.4	6.7	6.7	6.7	7.3
Usage of organizations and households	1.0	1.3	1.4	1.4	1.5	1.6	1.3	1.0	1.7	1.4
Export	4.2	7.1	16.7	16.6	15.5	12.6	14.3	13.3	24.1	29.0

Table 2 *Mongolian coal balance (10)*

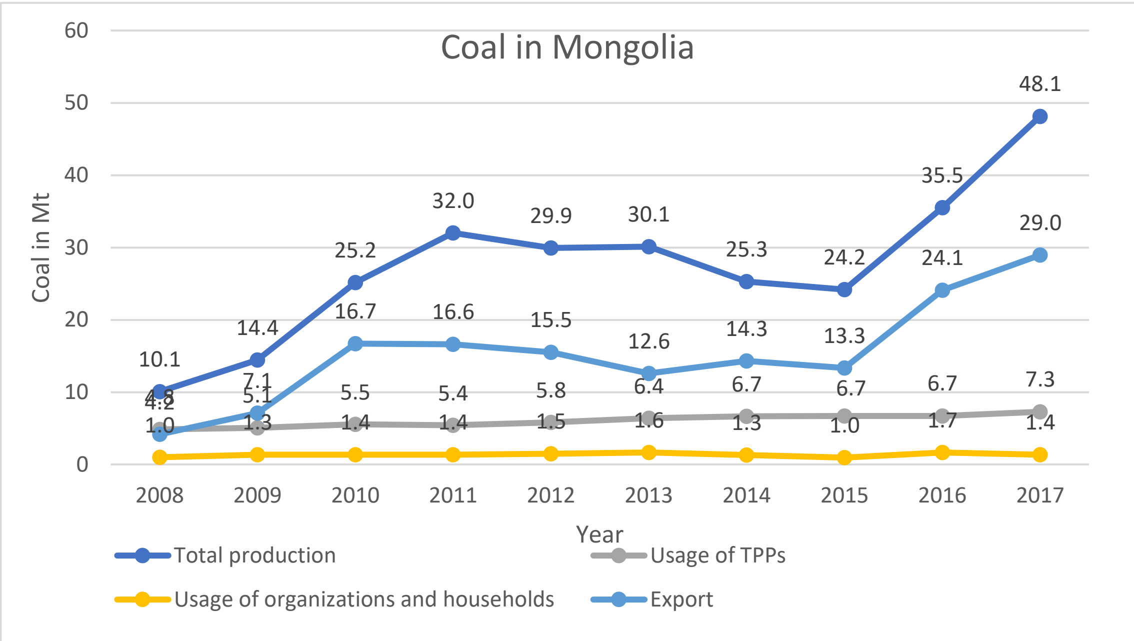


Figure 6 *Mongolian coal balance (10)*

2.2.0 Backfilling

Any underground mining activity, whether its ASM or mining company, create cavities in the ground. This cavity might affect to the surface caused by subsidence movement. In many cases it must be backfilled.

Figure 8 *Children's hospital damaged by underground mine subsidence in Oppenhaim, Germany (13)*

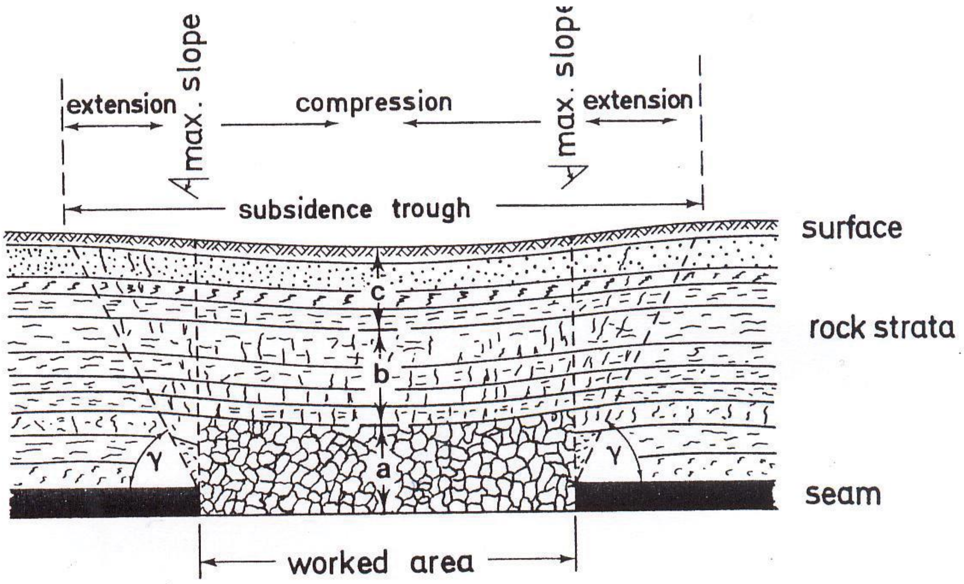


Figure 7 *Cross-section of underground mine subsidence (13)*

The backfilling is used in the mining industry for several reasons.

- Ground stabilization
- To extract ore from adjacent or under another block of ore/stope
- To extend the life of the mine
- To lower the cost of mine closure
- To improve mine ventilation
- To reduce inflow of hazardous gases
- To reduce mine damages in the mine and at the surface

- To insulate abandoned mining areas to prevent possible fire, to reduce or to stop the inflow of hazardous gases or to improve the air conditioning.
- To reduce acid mine drainage etc.

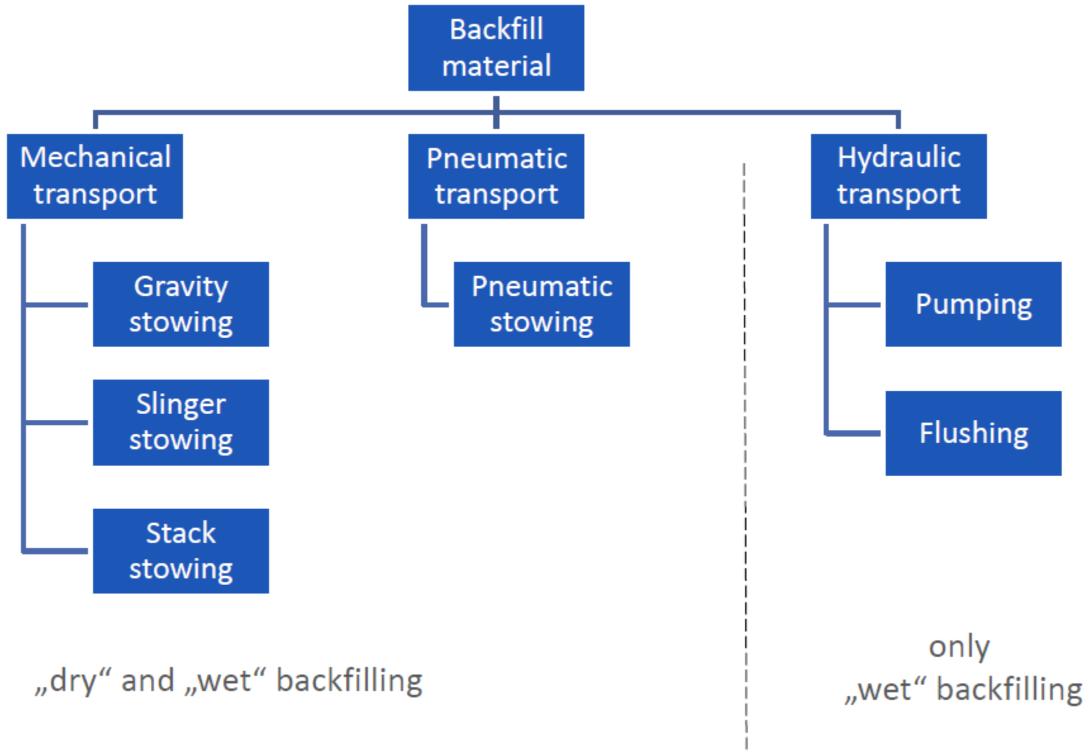


Figure 9 *Backfilling techniques*

Backfilling may be done by mechanical, hydraulic and pneumatic techniques, using wide range of materials such as run of mine waste rock, milled tailings, natural sands, aggregate, pozzolans or CCBs and may include cement, lime or other modifiers to increase strength. It may also have a beneficial effect on the environment by addressing water quality impacts, such as from acid mine drainage, reducing waste rock disposal requirements, reducing ground fissuring, and increasing long-term strata stability and providing roof support. However, backfilling does not eliminate the subsidence entirely, but only reduces the amount of subsidence (13). Backfilling operation provides an opportunity to utilize waste material as ground support. Important properties to ensure that the waste material or backfill material for backfill meets legal requirements and has effects the stability of openings:

- Material stiffness
- Compressive strength
- Stable consistency
- Limited porosity
- Defined final compactness

- Low permeability
- No leaching properties

The systematic selection procedure of backfill consist of following steps (Figure 11):

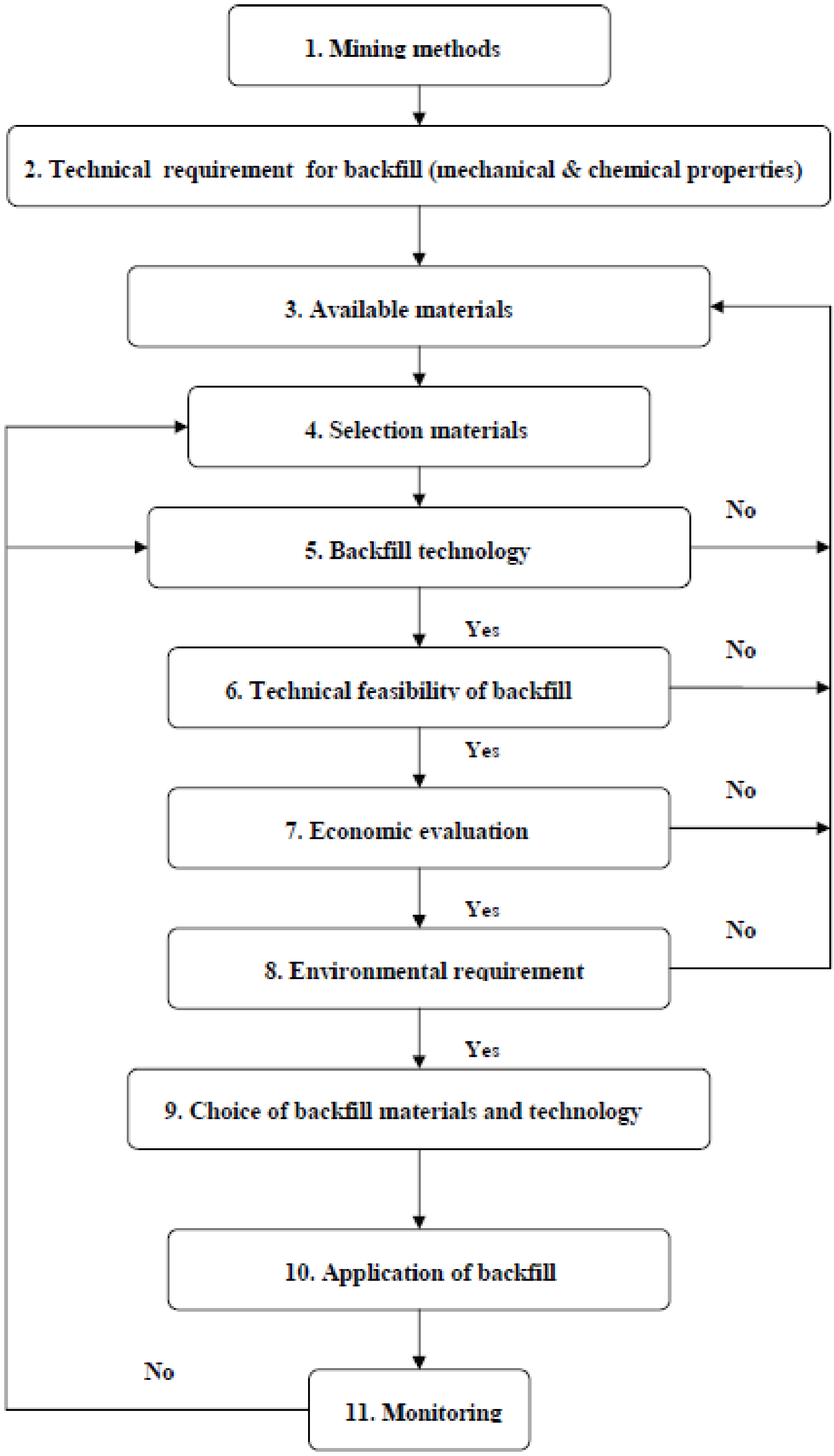


__Figure 10__ Systematic selection and application of backfill flowsheet (13)

2.2.1 Backfill technologies

Backfilling technologies can be classified as gravity backfill, hand backfill, mechanical backfill, pneumatic backfill, hydraulic backfill and paste backfill. Hand backfill require the presence of personnel near the face for packing dirt, which is the least effective technology due to very low quality. Gravity backfilling requires high dipping ore seams so that backfill material can roll into the void created by mining. Mechanical backfilling has been left out mainly due to its lack of effectiveness. In this method waste material is introduced using some kind of mechanical device like conveyor belts, slinger belt and load-hauldump (LHD) into voids created by mining (13).

Mechanical backfill

Mechanical backfilling technology were initially developed with the introduction of conveyor belt systems into the underground mine. It has been used for backfilling with waste rock material and for the construction of pack walls. Mechanical backfill technology demands less labor force and allows more rapid construction of the pack wall compared to hand packing and offers support to the roof in a shorter time.

Backfill materials can be stopped in the following ways:

Slushing; material slushed directly from a waste raise to the stope area. Usually, rail car, front-end loader, or LHD are used to transport the backfilling material

Slinger belt placement; this method utilizes a high-speed belt and hopper supplied by truck or LHD (Figure 12). Slinger belt method offers good compaction and stronger fill if gradation of the materials is proper.

Figure 11 *Mechanical backfilling (13)*

Pneumatic backfill

Pneumatic backfilling is backfilling that utilizes air stream to transport backfilling material through a pipeline by applying pressure and subsequently dumping the material. Material is fed into the system by feeder that is shown in the Figure 13. The material should be free flowing and dry. The pump should not work without material or substantially underloaded. Hence, pump operates only when material is available for conveying.

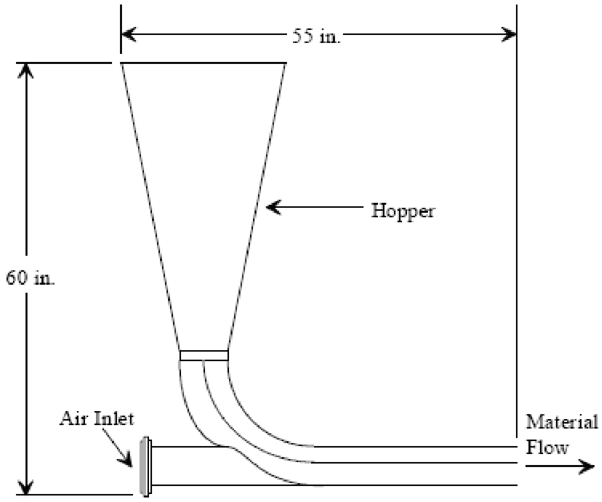


Figure 12 *Pneumatic pipe feeder (13)*

Hydraulic backfill

Hydraulic backfilling utilizes water as a transporting medium to fill voids and cavities (Figure 14). The typical system consists of slurry mixer, pump, and pipe for distribution.

Figure 13 *Hydraulic backfilling (13)*

Hydraulic backfilling requires high amount of cement (approx. 10%). Therefore, the economic benefits derived from it should be calculated. Major disadvantage of hydraulic backfilling is the water, transporting medium. It may or may not available for the mine globally. Thus, hydraulic backfilling cannot be used universally. To contrast pneumatic backfilling has no such disadvantage but, hydraulic backfilling provides a much greater strength of backfill.

Hydraulic backfill is the most suited for the small-scale mines in Nalaikh, Mongolia. Small-scale mines in Nalaikh do not have safe support to operate inside the mine which is limiting the use of other backfill techniques such as paste fill, pneumatic fill and mechanical field.

Paste backfill

Paste backfill (Figure 16) is a uniform, low permeability, usually consisting of high solids density mixture with around 15% -45µm fines content. This lets fine particles form annulus around a plug of coarser particles to act like a lubrication to reduce the pipeline frictional resistance. Thus, paste backfill requires less water in the paste or slurry.

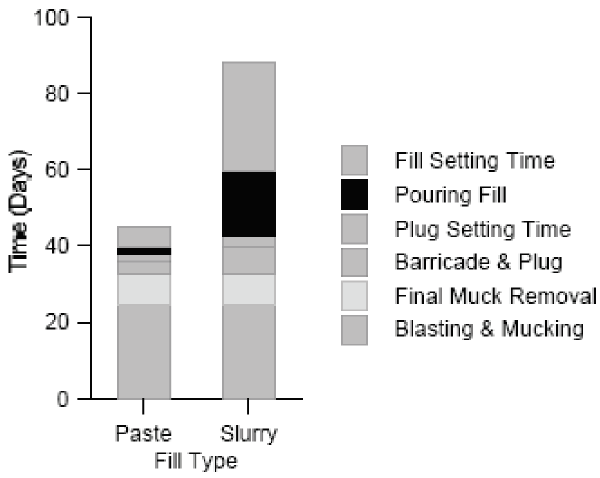


Figure 14 *Mine cycle comparison between slurry and paste backfilling*

Figure 15 *Paste backfill (13)*

Paste backfilling can reduce the mining cycle. Example shown in the Figure 15 where vertical retreat mining stope is being backfilled with paste fill and slurry fill. Complete backfilling and the curing of the backfill can be substantially faster for the paste backfilling due to higher solid ratio and reduced need for removing excess medium (water).

2.2.2 Importance of backfilling in small-scale mines of Nalaikh, Mongolia

Coal mine of Nalaikh started its operation in 1915 with capacity of 4000 tons per year. Coal mine of Nalaikh was the first official mine in Mongolia. Until 2015, total of 31 million tons of coal has been extracted. Total proven reserve is estimated about 60 million tons. Official mine has been closed in 1995, but miners continued their operation as small-scale mine or artisanal mine.

As reported in Mongolian mining journal (14), there had been numerous reports about a subsidence in residence areas close to the small-scale mine from residences in Nalaikh. Authorities made a few evaluations on the subsidence in Nalaikh and they concluded that the subsidence was in a severe level. Moreover, authorities also discovered that subsidence also affected the railways in Nalaikh.

According to the mining law of Mongolia, mining activity should not proceed under 50 meters to the infrastructure and constructions. Due to that reason, mining licenses of 2 companies out of 31 in Nalaikh have been terminated by authorities. Unfortunately, backfilling had not been done, only compensation had been done to the household that were affected by the subsidence.

There were neither studies nor practices on backfilling of underground mine in Mongolia.

2.3.0 Coal-Combustion-by-Products

Definitions

When coal is burnt, CCBs are generated by the thermal transformation of the mineral matter present in the coal into amorphous inorganic oxides. CCBs can be divided into fly ash, bottom ash, bottom slag, and flue gas desulfurization materials. Table 4 shows definitions for CCBs that is produced from numerous standards (e.g. EN 197-1, EN 450-1, US ASTM 618, etc.) across the world provide guidance and definitions for their use. CCBs are well-defined. There are definitions of CCBs within various standards across the world. The acceptance of a consistent terminology and definitions will endorse consistent nomenclature which can be used by all stakeholders that differentiates CCBs for other ashes.

Term	Definition
Coal Combustion Products	Coal combustion products (CCPs) include fly ash, bottom ash, boiler slag, fluidized-bed combustion (FBC) ash, or flue gas desulfurization (FGD) material produced primarily from the combustion of coal or the cleaning of the stack gases. The term coal ash is used interchangeable for the different ash types..
Fly ash	The finer ash produced in a coal-fired power station, which is collected using electro-static precipitators. Sometimes spelt as 'fly ash'. This is also known as Pulverized Fuel Ash (PFA) is some countries. About 85+% of the ash produced is fly ash.
Bottom ash	The coarse ash that falls to the bottom of a furnace. The molten ash adheres to the boiler tubes, eventually falling to the base of the furnace. In many furnaces there is a water system that rapidly cools this ash, so-called 'wet bottomed' ash. Usually <15% of the ash produced is bottom ash (BA), in some countries also known as furnace bottom ash (FBA)
Cenospheres	Hollow ash particles that form in the furnace gas stream. Sometime these particles will contain smaller ash spheres. They float on water and are usually collected from lagoons, where ash/water disposal systems are being used. Only 1 to 2% of the ash produced are cenospheres and with the reduction in ash/water transportation, fewer are collected/available
Conditioned ash	Where fly ash is mixed with a proportion of water (10 to 20% by dry mass typically) in order that it can be transported in normal tipping vehicles without problems with dust for sale or disposal or interim stockpile.
Flue Gas De-Sulfurisation	Where a source of Calcium is injected into the furnace gas stream to remove sulfur compounds. In wet systems a slurry with ground limestone is sprayed in gas stream. After decomposition of the limestone the sulfur reacts with lime and after oxidization forms calcium sulfate. This flue gas desulphurization gypsum (FGD) is used in the gypsum industry as replacement for natural gypsum.

Table 3 *Draft global definitions for CCB (14)*

Production and Utilization

Approximately 10-30% of the total input of the coal mass transforms into CCBs. In 2011, worldwide usage of coal was about 7.5 billion tons (9). In contrast, the worldwide CCBs production was approximately 780 Mt. The world coal consumption was also around 7.5 billion tons in 2017, thus we can expect similar amount of CCBs produced in 2011. From 780 Mt produced, “Coal Combustion Product: a Global Perspective” (15) reported 415 Mt or 53% were utilized however other sources suggesting global average utilization is about 25% (16). Table 5 shows CCBs' production, utilization, utilization rate, CCBs production per capita and CCBs utilization per capita.

Country/Region	CCPs Production (Mt)	CCPs Utilisation (Mt)	Utilisation Rate %	CCPs Production/ person (Mt)	CCPs Utilisation/ person (Mt)
Australia	13.1	6.0	45.8%	0.60	0.27
Canada	6.8	2.3	33.8%	0.20	0.07
China*	395.0	265	67.1%	0.29	0.20
Europe (EU15)	52.6	47.8	90.9%	0.11	0.10
India*	105.0	14.5	13.8%	0.09	0.01
Japan	11.1	10.7	96.4%	0.09	0.08
Middle East & Africa	32.2	3.4	10.6%	0.02	0.01
United States of America	118.0	49.7	42.1%	0.37	0.16
Other Asia*	16.7	11.1	66.5%	0.05	0.03
Russian Federation	26.6	5.0	18.8%	0.19	0.04
Total/s	**777.1**	**415.5**	**53.5%**		

Notes: * Non-members of WWCCPN

Table 4 *Estimated annual production, Utilization rates by Countries and Regions (14)*

As referred to earlier, produced CCB's content will depend on the parent coal that has been used. In table 6, typical range of elemental composition for CCBs from different parent coals.

Element	Bituminous	Sub-bituminous	Lignite
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	10-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-15
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4
LOI	0-15	0-3	0-5

***Table 5** Typical range of elemental composition for CCBs from different parent coals, wt% (14)*

2.3.1 CCBs in Mongolia

In 2014, thermal power plants (2,3,4) consumed 6.7 Mt and 190 thousand ger district households consumed 1.3 Mt which resulted total consumption of Mongolia to 8 Mt (17). It is estimated that production of CCBs were 500-600 thousand tons including 200-230 thousand tons of bottom ash from ger district (1). The latest estimate for coal consumption of Mongolia and households in ger district was 8.6 million tons and 217 thousand respectively in 2017. It also reported that in 2016, thermal power plant #4 generated 340 thousand tons of CCBs alone (18) and at least 200 thousand tons of generated CCBs reported to be fly ash.

In Mongolia, there are only 4 types of CCBs, which are bottom ash, bottom slag, fly ash and cyclone ash. Only thermal power plant #4 can produce fly ash due to the power plants being outdated. However, other thermal power plants and thermal plants for heating uses cyclone separator to capture fine particles in the flue gas by centrifugal force but it cannot work efficiently as the ESP to filter out more finer particles (fly ash).

Moreover, space and finance for landfilling of CCBs is heavily concerned in Ulaanbaatar. For example, TPP#4 currently has 5 tailing and the 6th is currently being constructed. The total cost estimate to build a tailing pond is 5-6 billion MNT. The tailing ponds range from 1.2-1.9 million cubic meters in volume (3). Due to the limited space in Ulaanbaatar 5th tailing pond was constructed on the old tailing pond. Also, in the ger districts there is no system for disposing of bottom ash that is generated in the ger stoves. It usually mixed with the municipal waste and disposed to the landfills. Sometimes, it is disposed to the gullies or even to the streets which can lead the fine particles in the ash to become airborne and contaminating the environment with excess heavy metals.

2.4.0 Backfilling with CCBs

CCBs utilization can date back to a century when large quantity of amounts of CCBs began to become available from coal combusting plants. Utilization of CCBs began as construction and groundwork material. Nowadays, CCBs utilization has become broader than ever before. For instance, USA utilize CCBs as a concrete additive, cement production additive, flowable fill, structural fill/ embarkments, road base/ sub-base, soil modifier, mineral filter in asphalt, snow and ice control material, blasting grit/ roofing granules, mine fill, gypsum panel production material, waste stabilizer/ solidifier, agriculture usage, aggregate, and etc. In generally, CCBs used mostly for construction.

CCBs has been used as backfill material for decades in the industrialized countries like USA, Germany etc. CCBs has a property so-called pozzolanic property. As stated in the ASTM, A pozzolan is a siliceous or siliceous and aluminous material which possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide (lime) at ordinary temperature to form compounds possessing cementitious properties. Thus, CCBs can be used as a binder in the backfill. However, only fly ash and flue-gas desulfurization (FGD) have been used as a binder due to that other CCBs do not contain enough pozzolanic property primarily caused by its large particle size to be effective in the practice, but those CCBs mostly used as aggregate for the backfill.

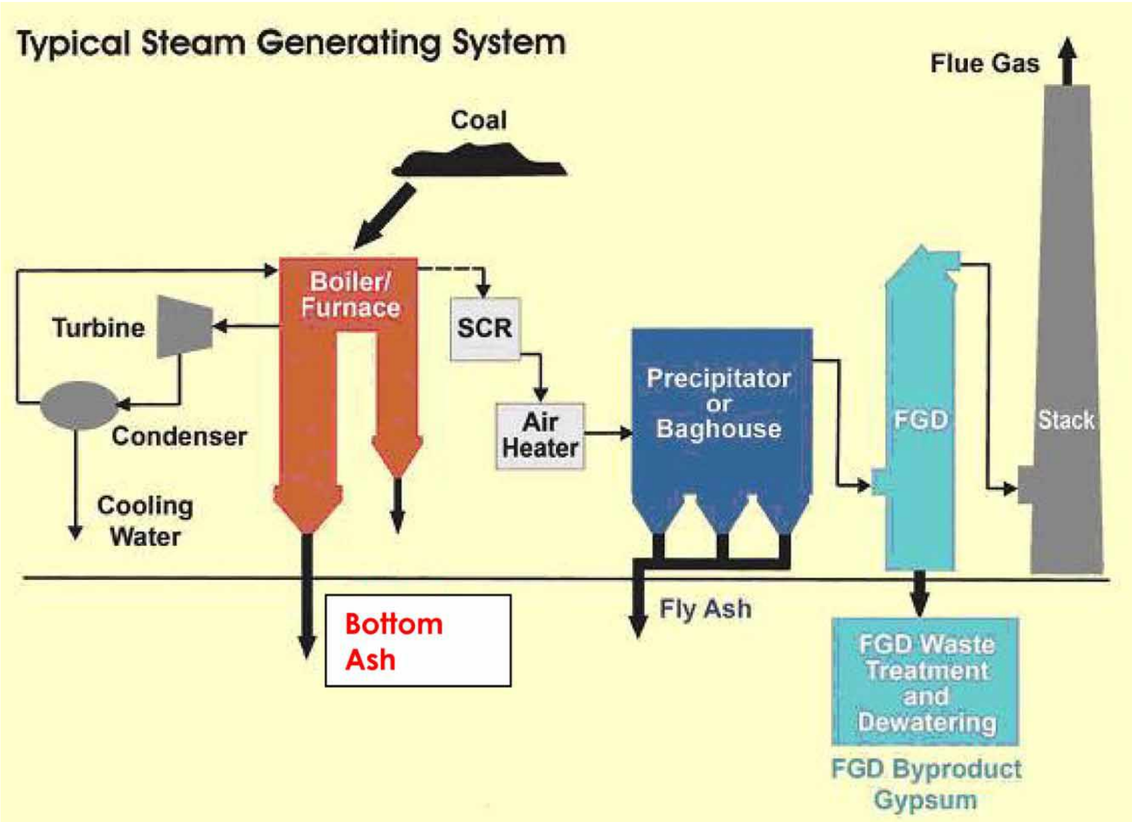


Figure 16 *Typical power plant scheme*

There are 2 types of fly ash: Class-C, which has higher lime content, is self-cementitious and produced from sub-bituminous or lignite parent coals; and Class-F, which has lower lime content and more lime should be added to show cementitious property, produced from bituminous parent coal. CCBs usually contains heavy metals and other potential hazardous compounds and may be radioactive.

Review of case studies in the USA has been made on usage of CCBs in mine reclamation (19) and they concluded:

The utilization of CCBs in mined land reclamation has been beneficial in some cases, neutral in some cases and harmful in some cases. While each case and CCBs form a unique set of situations requiring individual investigation and evaluation, a few generalizations has been made.

1. As a mine filler, CCBs can be used to neutralize acidic groundwater, encapsulate toxic materials, bring the land surface to approximate original contour, prevent subsidence and control hydraulic pressure build-up in underground mines.
2. CCP-filled areas introduce an alkaline component into the mine fill. By neutralizing acid and metal laden water in the backfill or underground mine, CCPs tend to cause metals to precipitate, lowering the concentrations of nearly allmetal ions in solution.No casewas found where metal loads increased beyond either toxicity characteristic leaching procedure or drinking water limits due to the application of CCPs in mine backfills. Neutralization of mine spoil or refuse is best accomplished by blending the CCP with pyritic materials in appropriate ratios.
3. Grouting mixtures from CCPs have been successfully used in a variety of settings for filling underground mines and for treating mine pools.
4. Non-fixated FGD materials contain almost no neutralization potential and are presently not very useful in mine land reclamation. However, fixated FGDcontains excess alkalinity with low permeability. Fixated FGD materials can be useful inAMD abatement, subsidence control and used as a barrier material to encapsulate acidic materials or seal pit floors on surface mines. Both materials can contain high chloride levels that are concentrated in the FGD units.

From the review, every CCBs should be analyzed and evaluated for suitability of backfill material since each CCBs shows unique outcomes even though CCBs are from the same parent coal due to the various designs of boilers is concluded.

3. Methods

As referred earlier, the most suitable technique of backfilling for small-scale mines in Nalaikh is hydraulic backfilling. Hydraulic backfilling mix consists of filler material, binder material and aggregates. The components are mixed together with water to produce grout. The binding will occur between the binder and the filler material while aggregates are present to occupy volume passively. Therefore, decision was made to find suitable filler materials, aggregates and binder materials from CCBs in Mongolia. The goal was to produce fill mixture that shows high compressive strength. However, other assessments were made to ensure that the fill is not decrementing the soil or groundwater or even to the human health.

For the experiment, 9 different types of CCBs that can represent Mongolian CCBs and an electric arc furnace slag (AFC) are collected then examined.

No.	Ash / Slag used as filler	Abbreviation
1.	Baganuur cyclone ash	BCA
2.	Baganuur bottom ash	BBA
3.	Nalaikh military heating boiler bottom ash	MBA
4.	Nalaikh heating plant cyclone ash	NCA
5.	Nalaikh heating plant bottom ash	NBA
6.	Nalaikh ger district bottom ash	GBA
7.	Thermal power plant #4 fly ash	FA
8.	Thermal power plant #4 bottom ash	TBA
9.	GLEAR project ash	GPA
10.	Darkhan metallurgical plant electic arc furnace slag	DS

Table 6 *Ashes and slag abbreviation*

All the CCBs and electric-arc furnace slag mentioned above were used as filler material in the experiment. Based on the chemical content analysis, which will be explained later in the paper, portland cement, electric-arc furnace slag and fly ash were nominated to be candidates as binder materials. The candidates were chosen based on their calcium content. Portland cement was used to compare the filler materials and binders.

Darkhan metallurgical plant recycles scrap steels with electric arc furnace and produces steel beams, billets, mill balls etc. During the process of smelting steel scrap, lime is added to the furnace to remove any contaminants and to neutralize compounds such as sulfur. Finally, before casting the molten steel, the top layer of the molten steel in the furnace is poured out of the furnace because lime any contaminants and lime residue floats on the top. The electric arc furnace slag is known to be rich in calcium due to addition of lime into the furnace. The slag is extremely hard and due to the high metal content. The electric arc furnace slag can be a very good binder if the cooling technology is present. It must be cooled rapidly to avoid calcium to bond with other compound to produce crystal structures. Unfortunately, at Darkhan metallurgical plant there is no cooling technology for the slag. Slag is cooled naturally. Although, it is cooled naturally decision was made to use it as a binder material.

No.	Binders	Abbreviation
1.	Darkhan metallurgical plant electic arc furnace slag	DS
2.	Portland Cement	CEM
3.	Thermal power plant #4 fly ash	FA

Table 7 *Binder materials and their abbreviations*

In the mixing process, components were mixed together by a specific design with water. After literature reviews on similar papers, decision was made on cement mix to use 90% of filler material and 10% of CEM. The main purpose of cement mix was to compare the filler materials. In other mixes where FA and DS used as binder, the purpose was to examine the potential to be binder in the backfill. For those mixes, the ratio between the filler and the binder was 1:1. The ratio was estimated based on the ratio between the CaO and SiO_2. Moreover, DS had to be crushed down to -2mm in order to be used as a binder because smaller the particle size is the more reactive it is. Initial plan was to produce backfill mixes using DS as a binder but crushing operation was so difficult that the equipments are not match to it. This was the reason that DS is prepared only a little that is just enough to be consumed for only 1 set of block production. To examine potential use of DS as binder comparison was made between the FA and DS. In the produced 1 set of block production it was mixed with FA with 1:1 ratio and later it was compared with 100% FA mix. Another plan was to test more percent of cement with a selected ash. This is just to demonstrate the more cement, the harder the backfill is.

The added water amount varies mix by mix. The water content determination was made with visually. Water is added to the mix until it appears to be flowable.

The prepared mixes were poured into cubical molds, then confined with external pressure. The cubical mold has walls of 100mm. The pressing effort is to eliminate the porosity of the mix. Uniformity is crucial factor for having reliable results. To ensure the results, 3 blocks of cubes of fill was made for each mix. The mixes are kept in the mold for 24 hours and cured for 28 days in water buckets of water. After the curing, blocks are dried in the air for a day, then underwent uniaxial compression test. Not every block was able to standstill in water. Some were disintegrating when the blocks placed in the water. The survived block were mostly the ones that used cement as a binder material, but fly mixes used FA as a binder material showed remarkable results in uniaxial compression test.

To sum up, 9 ashes as filler, 3 selected binders are mixed together through specified mix design to produce backfill mixes. Throughout the research, the following tests and analyzes were conducted:

1. XRF – Chemical content analysis
2. Moisture content analysis
3. Sieve analysis
4. SEM analysis
5. FTIR analysis
6. Elution test
7. Uniaxial compressive strength test
8. Radiation test
9. Element analysis on GLEAR project ash

3.1.0 Sampling

Ashes came with big bags from the ash suppliers. A portion of each ash is separated to an open tray where it resided for most of the research time. The remaining portion was kept in the bags as additional source. From the tray of ashes, samples were prepared for each of the evaluation. For the some of the ashes and DFS crushing was needed, since it came as bulk.

Test samples were drawn from the sample trays with required amount. Sieve analysis was conducted twice on some ashes. As pozzolanic reaction takes place well in fine particles. The upper size limit was set. From the initial sieve analysis, ashes having bigger particles than 2mm went through crushing with jaw crusher then roll crusher to reduce the maximum particle size -2mm. Subsequently, the second sieve test took place. Moreover, GBA needed to be separated from the municipal waste. For that purpose, 2mm mesh was used to separate the GBA from waste.

The most effort was paid to sample preparation for uniaxial compression test. The mixing was done by hand. A heat release when mixing the mix was noticed on some mixes. Mold surface was oiled thoroughly with vegetable oil. In the time frames of research laboratory had room temperature and moisture.

For some cases, the prepared blocks after resided in the mold for 24 hours disintegrated when submerged into the water. These instances were considered as failures.

For FTIR analysis, samples were prepared from raw ashes, and from broken parts of blocks after the uniaxial compression test. Not all filler and binder combinations were tested. From the uniaxial compression test results, components of and fractured arts of the top three hard block were analyzed. The intention was to quantify difference between components individual and mixed.

3.2.0 Experimental setting

Sieve analysis

For the sieve analysis, 1kg of each material (except for FA and NBA) was sieved. To take sample from the trays, coning and quartering method was used to take homogeneous sample. Materials were weighed before and after the sieving. A minor amount of weight loss was detected as expected. Following sizes of mesh was used: 0.063, 0.125, 0.25, 0.5, 1, 2, 4, 8mm.

X-ray fluorescence (XRF) – Chemical content analysis

A thorough mixing was applied before sampling the materials. Samples of 18 different prospective materials for fillers and binders were sent to central geological laboratory of Mongolia for XRF – chemical content analysis. Each sample was no less than 100gr and sent in plastic bags. Materials with higher particles sizes or bulk materials were crushed by jaw and roll crusher then milled with ring mill.

Moisture content measurement

A mixing was applied before sampling. Random amount of ashes was sampled and weighed before and after drying. The weight loss was converted into percentages.

Radiation measurement

Radioactivity detector (RADEX RD1008) were used to measure betta and gamma rays. The radioactivity detectors had not been calibrated. Therefore, 2 radioactivity detectors were used side by side to ensure the result. The measurement had been done directly in the open trays as shown below.

Elution test

200ml of water was sampled in the plastic bag from buckets where all the blocks cured for 28 days. The purpose of test pertains to environmental issues in terms of releasable compounds to groundwater or leaching. The sampled liquids were tested for a search of Arsenic, Mercury, Chromium, Lead, and Cadmium. On the delivery to the external laboratory, a sample water of MBA was lost due to seal breakage. The sample was not reproducible by any other manner. To account amounts of nominated elements' release in the water, the virgin tap water, accompanied the samples to the external laboratory for comparing purpose.

Uniaxial compression test

The produced blocks were placed on the center of the compression deck. Most flat surfaces of blocks were faced up and down on the deck. It was done due to some uneven surface on the top side of the block.

Fourier-transform infrared spectroscopy (FTIR) analysis

From the result of uniaxial compression test, a sample selection of the hardest 3 blocks is made for FTIR analysis. Studying other mixes showed poor results was unnecessary. The components and broken pieces of blocks were sampled. Mixing was applied before sampling the components. The sample of components were not less than 100gr.

Scanning Electron Microscope (SEM) analysis

Mixing was applied before sampling. All the ashes were sampled with the amount of not less than 100gr of ash from trays.

3.3.0 Experiment conduction

Sieve analysis

The sieving operation run for 10 minutes with shaking intensity of 65 (equipment scale) on the samples. After the sieving operation ceases, the sieves were remained calm for few minutes to settle down the airborne fine ashes. Then, sieves were emptied, and the fractions was weighed individually. To remove fine ashes from the mesh, brushing and tapping was done. Attention was paid to minimal mass loss. After weighing of each fraction, the ashes were put back to the trays.

Moisture content measurement

Approximately 100gr of samples were put into oven for 2 hours at 120C. After drying process, samples were weighed to estimate the moisture content by mass loss.

XRF – Chemical content analysis

The sampled materials were sent to central geological laboratory of Mongolia. Chemical content analysis was conducted to evaluate content of SiO_2, CaO, Fe_2O_3, Al_2O_3.

Radiation measurement

The measurement devices were rested on ashes inside the trays for a minute, then the reading is register in every minute for 5 times. The measurement was conducted twice on each component.

Elution test

The samples were sent to Khanlab laboratory. Arsenic, Mercury, Chromium, Lead, and Cadmium contents were determined.

Uniaxial compression test

The blocks were tested by Universal Testing Machine (WDW-100) after 28 days of curing. Load was applied gradually at the rate of 140kg/cm^2 per minute until the blocks fail. Load at the failure divided by area of block gives the compressive strength of fill. Failure loads curves were recorded. After each compression test, deck was cleaned to assure no influence on the next compression test. Initial plan was to have each fill mix to have 3 blocks and the average failure load should be taken as a result. However, some blocks were not successfully survived until the test. Maximum load that can be applied from the machine was 100kN. Therefore, blocks that can exceed the 100kN load was tested with concrete hammer.

FTIR analysis

The sampled materials were sent to Institute of Physics and Technology laboratory of Mongolia. Used equipment: IR Prestige-21. Frequency: 400-4000cm^{-1}

SEM analysis

The sampled materials were sent to Institute of Chemistry and Chemical Technology.

3.4.0 Data analysis and Results

Sieve analysis

From sieve analysis following graph was produced. Decision was made to crush some bottom ashes to compare with other finer ashes. Pozzolanic reaction is more reactive when the particles are finer. Received ashes were widely varying in size.

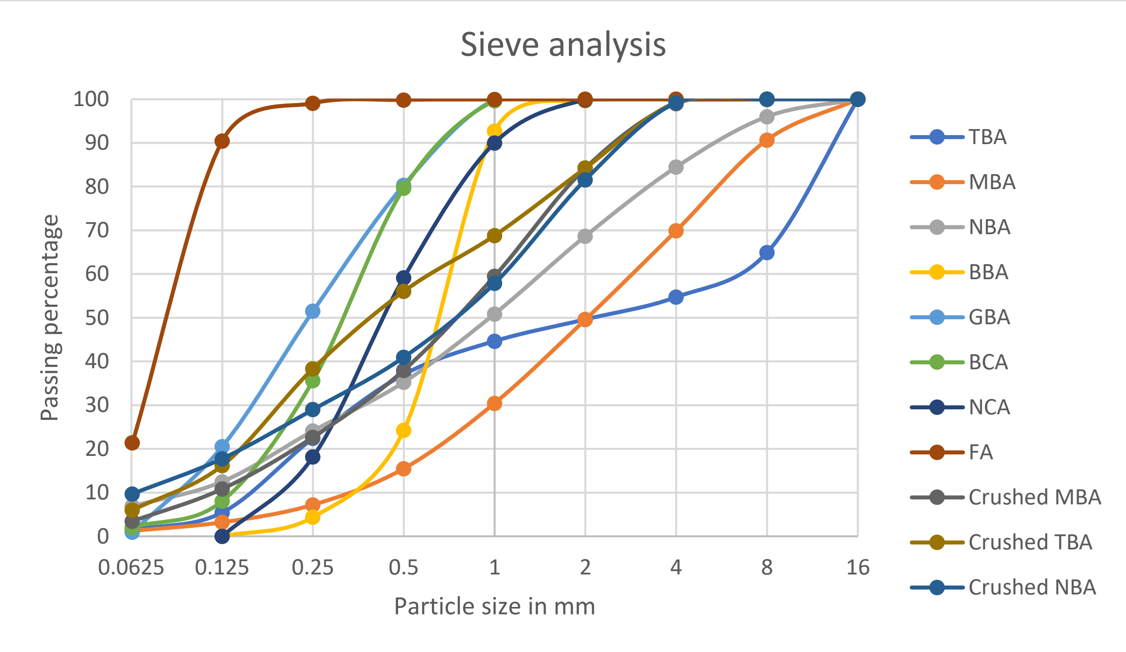


Figure 17 *Sieve analysis*

Moisture content measurement

Following results were produced.

Material	Moisture content (%)
GBA	0.31
TBA	0.11
NCA	1.28
BCA	0.74
BBA	4.36
MBA	0.74
FA	0.06
NBA	7.90
CEM	0.21

Table 8 *Moisture contents*

BBA and NBA show highest moisture content due to that both ashes transported by water to the ash pond. Having too much moisture content can have undesired results. The pozzolanic and cementitious reactions occur when water is present. Therefore, the wanted reaction may occur before beneficial use. Due to this reason winter FA from TPP #4 is not usable in production of construction materials.

XRF – Chemical content analysis

The result is presented in the following table. Following 18 prospective materials' chemical content was evaluated.

Material	SiO_2 (%)	CaO (%)	Al_2O_3 (%)	Fe_2O_3 (%)
BCA	44.52	3.12	11.74	10.23
MBA	40.46	7.39	13.94	5.68
NCA	44.79	10.13	12.54	7.63
TBA	47	19.46	12.19	15.48
GBA	49.17	13.57	10.31	6.93
NBA	33.35	3.78	10.92	3.68
FA	42.29	22.97	12.55	10.58
BBA	45.76	6.33	12.51	11.4
Nalaikh soil grey	57.57	10.51	12	2.93
Construction waste	72.39	5.15	11.34	1.43
DS	14.59	45.7	4.35	24.88
Nalaikh soil brown	69.68	1.85	14.37	3.5
Nailaikh mine dump	58.09	1.07	18.93	4.86
Gypsum	12.86	30.58	0.08	0.1
CEM	21.32	59.55	5.23	3.81
Copper enrichment plant tailing	72.62	0.55	14.65	2.54
DS loose	27.84	30.68	8.69	15.56
Limestone	1.74	54.59	0.08	0.16

***Table 9** XRF - Chemical content analysis result*

As mentioned in the literature review, SiO_2 make most of the ash mass. Here it 33%-47%, it is due to their sandy components. As we expected, FA shows the highest CaO content (22.97%) and followed by TBA (19.46%). A significant amount of CaO was detected in GBA with 13.57%. It was expected that blocks made of these ashes would show the highest strength. As for binders, CEM and DS contain SiO_2 not as high as fillers. But this is preferred in that way and they contain substantial amount of CaO. Therefore, DS and FA were selected as binder material. On the other hand, CEM was used as binder material to compare filler materials.

Radiation measurement

Following table summarized all the radiation measurements in terms of average and standard deviation. Total of 10 measurements were made on each material. TBA, GPA, DS were missed out of the measurement. GPA was not yet obtained at the time of measurement. TBA were run out at the time of measurement. DS was not crushed enough to measure.

Ash	Average reading of gamma ray in µSv/h	St.dev
FA	0.193	0.013
BBA	0.209	0.03
BCA	0.205	0.015
NCA	0.205	0.035
NBA	0.194	0.025
MBA	0.185	0.011
CEM	0.188	0.016

Table 10 *Radiation measurement*

Betta ray was not detected in any of the ashes. The worldwide average natural dose to humans is about 2.4 mSv per year. It is converted to dosage of 0.27 µSv/h. Thus, the ashes were completely safe for in terms of gamma and betta radiation. To put into perspective, single dental x-ray radiation exposure is 100 µSv and flight from New York to Los Angeles exposure is 40 µSv.

Elution test

The results of elution test are shown in the following table. Following conclusion can be made from the results. The tap water, which was used for elution test for accommodating produced blocks for 28 days, contains As, Pb, Hg each less than 0.01mg/L, Cd and Cr each less than 0.005mg/L. The measurement reads the same for TBA, BBA, BCA, NCA, NBA, except GPD with Pb of 0.02mg/L. The readings imply that the blocks did not release any of the suspected elements into the water. A remarkable amount of Cr was detected for TFA. This can be related to the particle size of FA. Although 0.212mg/L of Chromium is still considered as in a safe range. Therefore, from the test results, the fills do not leach much hazardous compounds to groundwater to raise environmental problems.

Ashes	Suspended hazardous elements, mg/L				
	As	**Cd**	**Cr**	**Pb**	**Hg**
GBA	<0.01	<0.005	<0.005	0.02	<0.005
TBA	<0.01	<0.005	<0.005	<0.01	<0.005
FA	0.03	<0.005	0.212	0.01	<0.005
BCA	<0.01	<0.005	<0.005	<0.01	<0.005
BBA	<0.01	<0.005	<0.005	<0.01	<0.005
NCA	<0.01	<0.005	<0.005	<0.01	<0.005
NBA	<0.01	<0.005	<0.005	<0.01	<0.005
Tap water	<0.01	<0.005	<0.005	<0.01	<0.005
GPA	0.06	0.031	<0.005	0.01	<0.005

Table 11 *Elution test result*

Uniaxial compression test

Not every produced fill mix survived until the compression test. Some failed when exposed into water. This can be explained by lack of binder material. From the test load vs. time graph were made. Graph can be shown in the appendix section. Following are the conclusions on each fill material mix. Block dimension is 10cm x 10cm x 10 cm and cross-sectional area is $0.1m^2$. To simplify conversion, divide the load data to compressive strength in kN to 10 (to use it on the graphs).

1. Filler material comparison:
    a. 90% FA + 10% CEM: 2 cubes survived until the test. The load exceeded 100kN. So, concrete hammer was used to measure average strength. The average compressive strength was 15 MPA.
    b. 90% TBA + 10% CEM: 1 cube survived until the test. Compressive strength was 1.335 MPa.
    c. 90% BBA + 10% CEM: All 3 cubes survived until the test. Average compressive strength was 0.352 MPa
    d. 90% NCA + 10% CEM: 1 cube survived until the test. Compressive strength was 0.353 MPa
    e. 90% NBA + 10% CEM: All 3 cubes survived until the test. Average compressive strength was 0.66 MPa.
    f. 90% MBA + 10% CEM: All 3 cubes survived until the test. Average compressive strength was 1.28 MPa.
    g. 90% GBA + 10% CEM: 2 cubes survived until the test. Average compressive strength was 1.71 MPa.
2. Test results of BCA mixed with varying amount of CEM (Cement content comparison):
    a. 80% BCA + 20% CEM: Compressive strength was 1.17 MPa.
    b. 70% BCA + 30% CEM: Compressive strength was 6.22 MPa.
    c. 60% BCA + 40% CEM: Compressive strength was 19 MPa. Concrete hammer was used.
3. Potential binder comparison (FA, DS and GBA):
    a. 100% FA: Average compressive strength was 3.7 MPa.
    b. 50% DS + 50% FA: Average compressive strength was 2.4 MPa.
    c. 100% GBA: Average compressive strength was 0.5 MPa.

To sum up, from the filler comparison results, FA and CEM mixture were standing out with high compressive strength of 15 MPa. The more cement, the more strength was observed. From all the cubes, minimum average strength was 0.352 MPa (BBA). In practice, there were some cases that used backfill mixture with compressive strength of as low as 0.24 MPa. Therefore, all the ashes can be used as filler, but economic standpoint should also be considered. The most appealing CCB material for backfilling is FA without a question. Other potential binders DS and GBA showed significantly worse strengths. Uncemented FA (100%) backfill mixture showed more compressive strength than every other cemented mix except itself. All compressive strengths are summed up and listed below.

Backfill mixes	Compressive strength in Mpa
90% FA + 10% CEM	15
90% TBA + 10% CEM	1.335
90% BBA + 10% CEM	0.352
90% NCA + 10% CEM	0.353
90% NBA + 10% CEM	0.66
90% MBA + 10% CEM	1.28
90% GBA + 10% CEM	1.71
80% BCA + 20% CEM	1.17
70% BCA + 30% CEM	6.22
60% BCA + 40% CEM	19
100% FA	3.7
50% DS + 50% FA	2.4
100% GBA	0.5

Table 12 *Average uniaxial compressive strengths*

FTIR analysis

The analysis was performed in an external laboratory mentioned before. In the following, data is presented. FTIR spectroscopy is an established technique for quality control when evaluating industrially manufactured material, and can often serve as the first step in the material analysis process. A change in the characteristic pattern of absorption bands clearly indicates a change in the composition of the material or the presence of contamination. This technique is useful for analyzing the chemical composition of smaller particles, typically 10 -50 microns, as well as larger areas on the surface.

The analysis was used to compare components and product backfill mixes. It is noted that pozzolanic and cementitious reaction underwent, but in different scales. Following results can be read by IR Spectrum table. All 3 backfill mix ratios were 10% CEM + 90% ash by weight

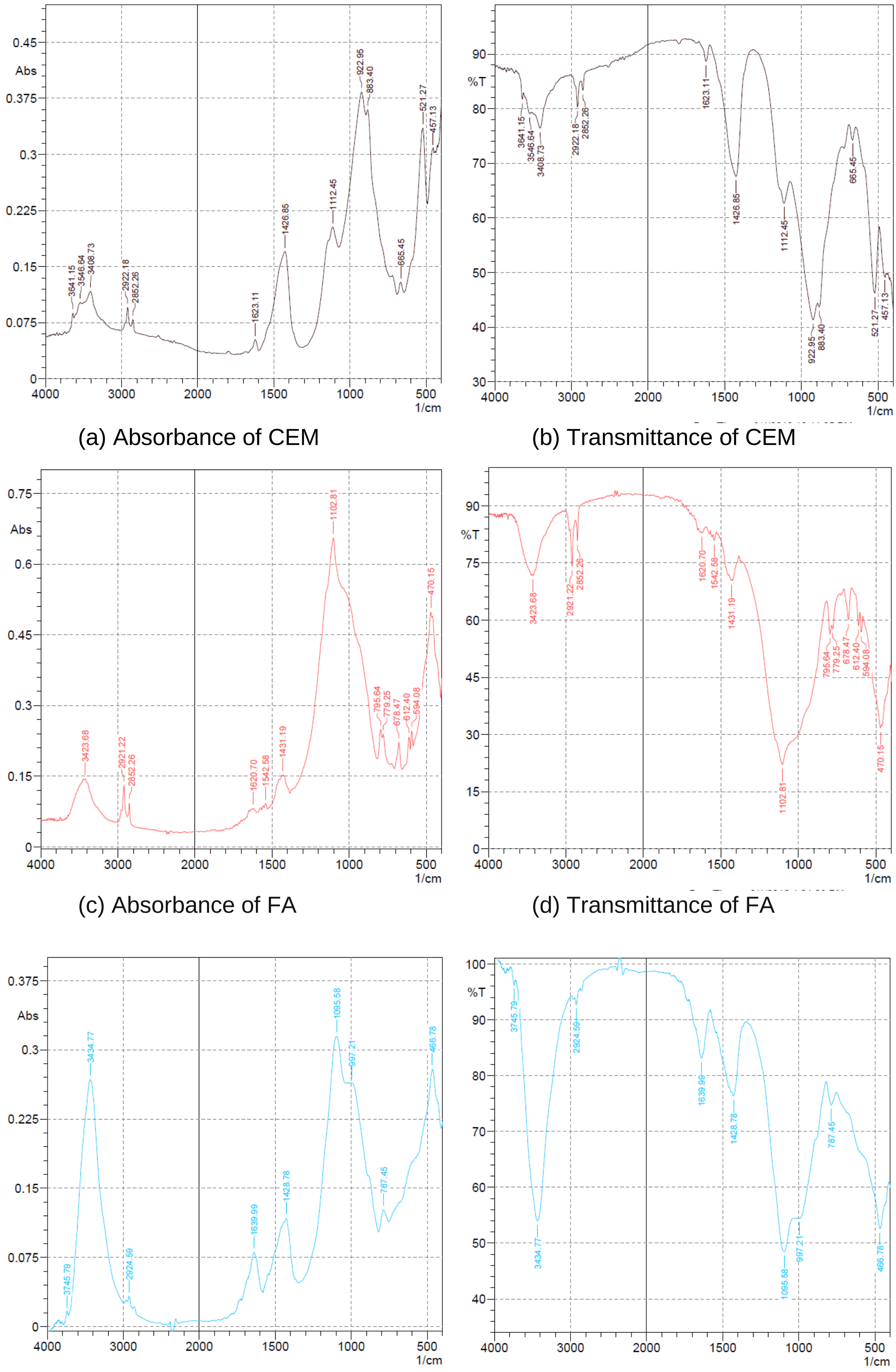
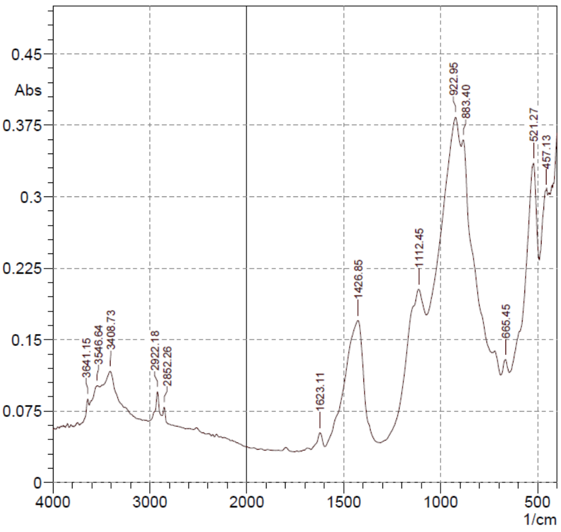
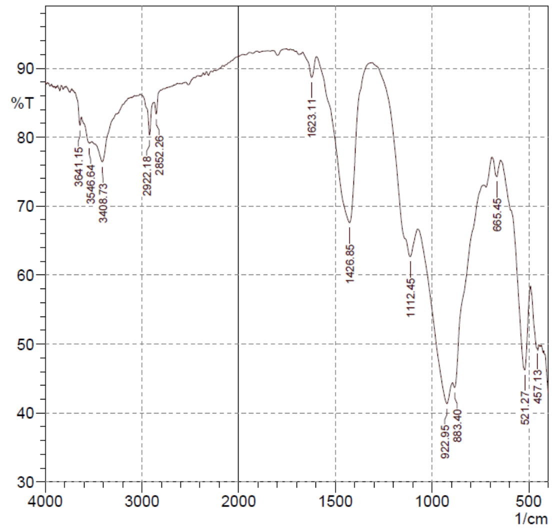


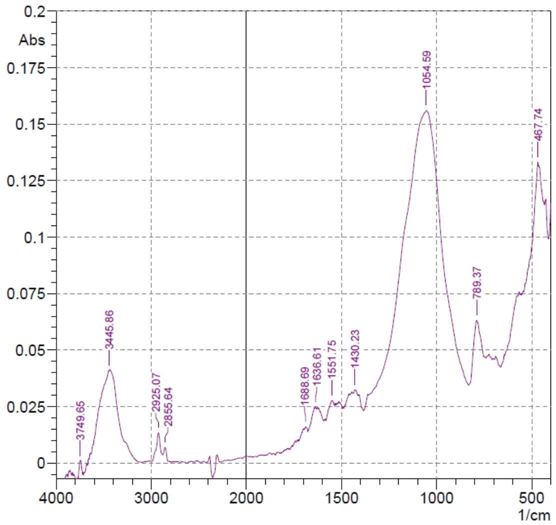
***Figure 18** FTIR absorbance and transmittance before and after the pozzolanic reaction between CEM and FA*



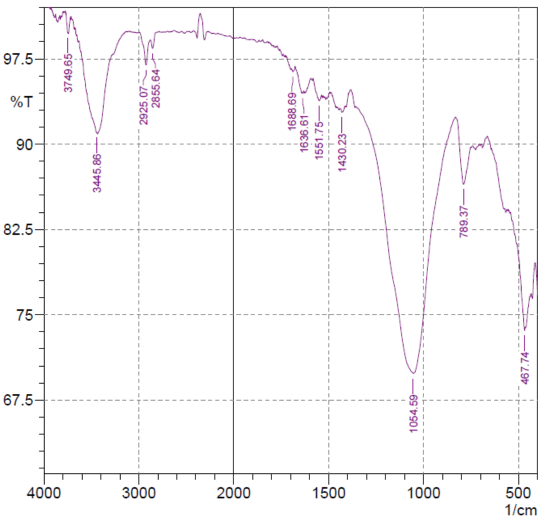
(a) Absorbance of CEM



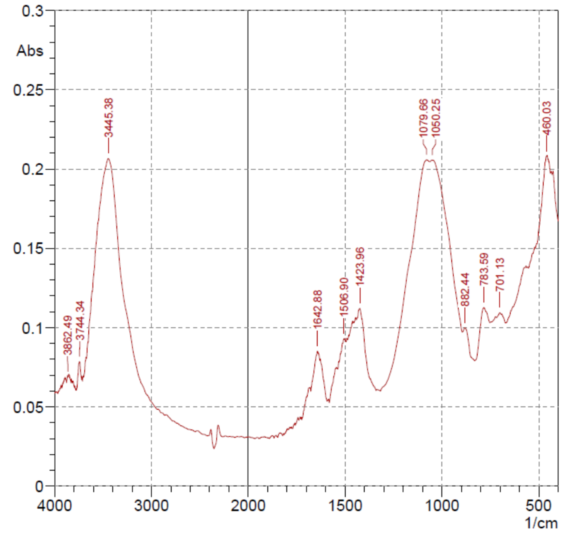
(b) Transmittance of CEM



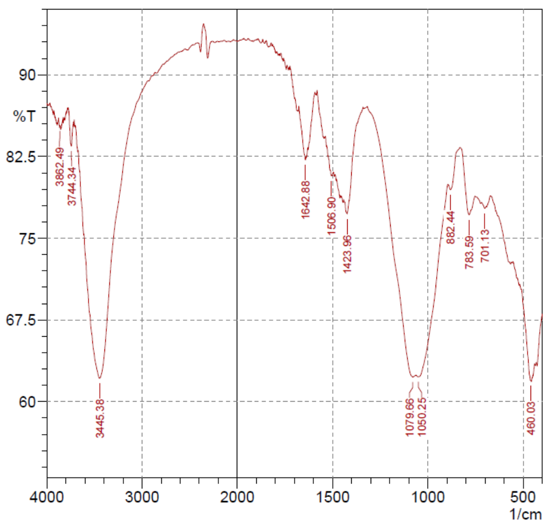
(c) Absorbance of MBA



(d) Transmittance of MBA

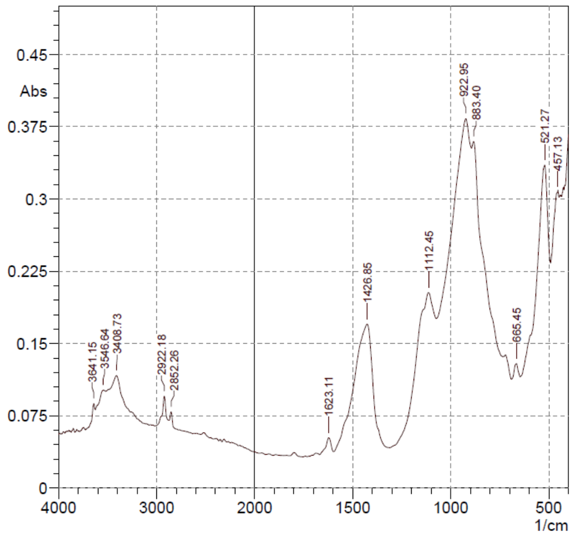


(e) Absorbance of CEM+MBA

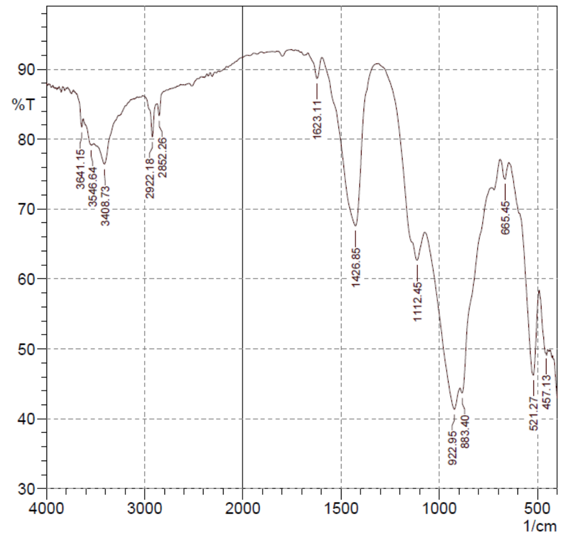


(f) Transmittance of CEM+MBA

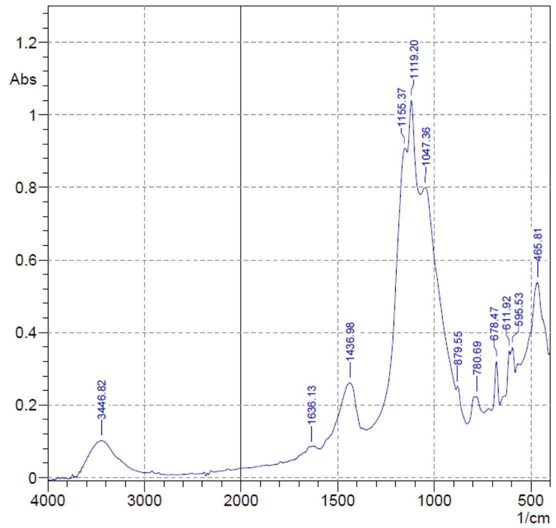
Figure 19 *FTIR absorbance and transmittance before and after the pozzolanic reaction between CEM and MBA*



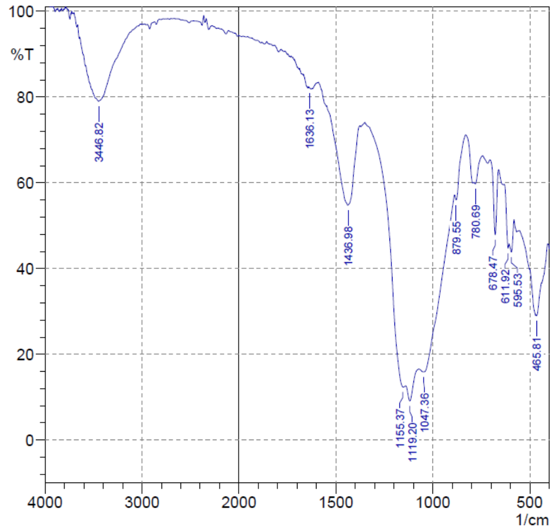
(a) Absorbance of CEM



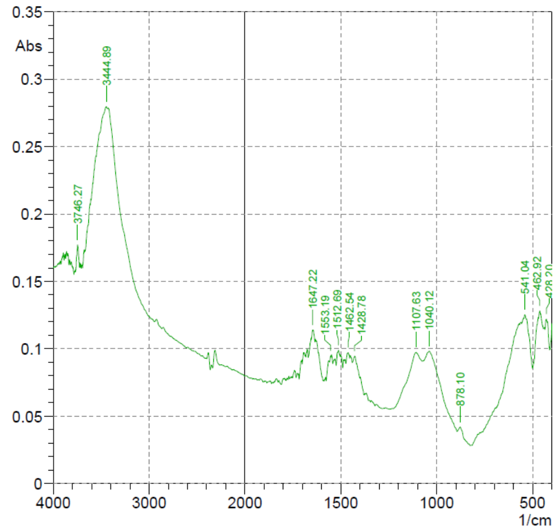
(b) Transmittance of CEM



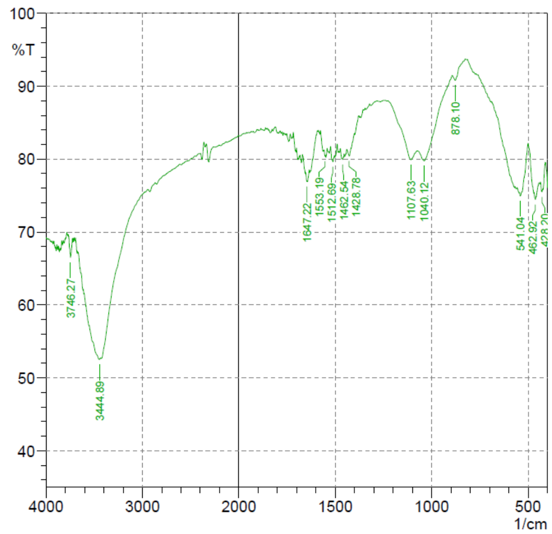
(c) Absorbance of GBA



(d) Transmittance of GBA



(e) Absorbance of CEM+GBA



(f) Transmittance of CEM+GBA

Figure 20 *FTIR absorbance and transmittance before and after the pozzolanic reaction between GBA and CEM*

SEM analysis

The analysis was performed in NUM’s laboratory. Results are shown below. The images show particle sizes and shapes of ashes. SEM analysis provides high-resolution images useful for evaluating various materials for surface fractures, flaws, contamination, corrosion, particle size and shapes.

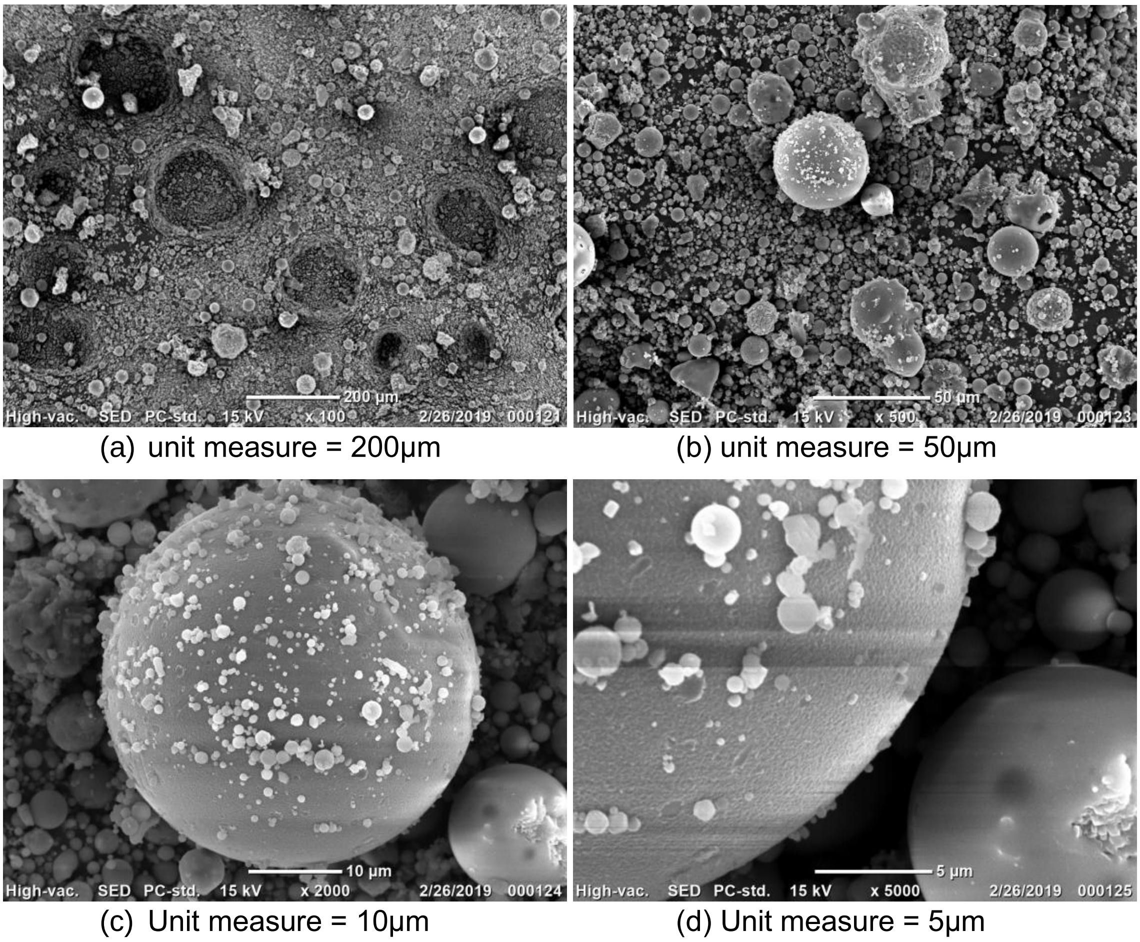
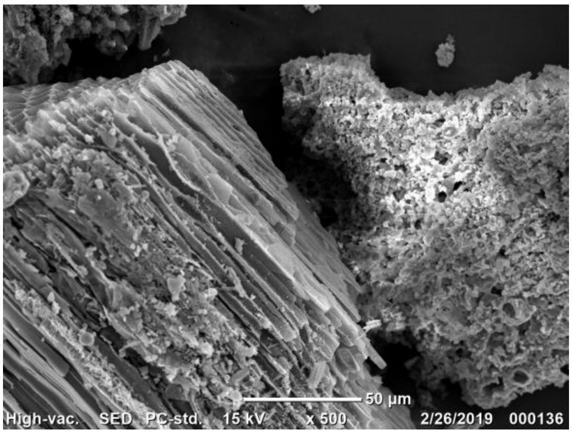
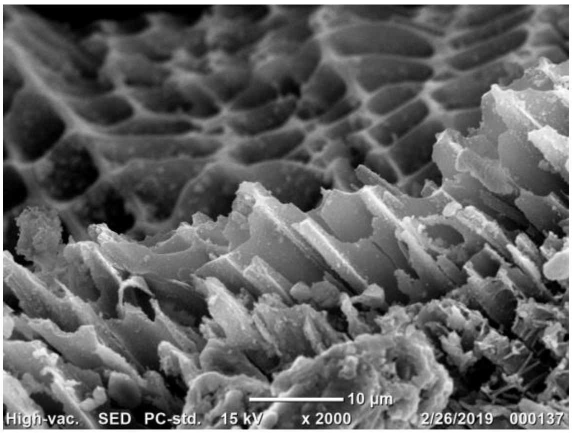


Figure 21 *SEM images of FA*

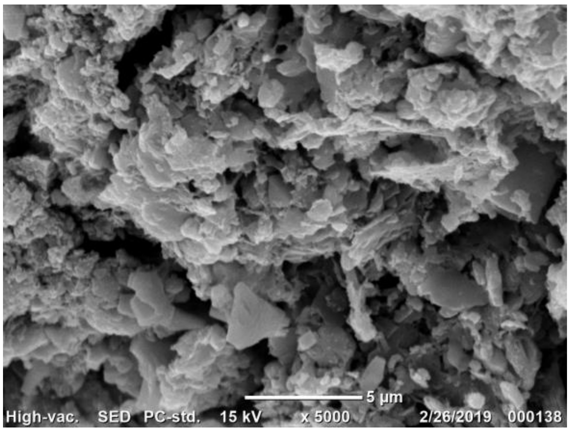
It was expected that FA would be spherical due to that fly ashes mostly spherical and it was proven by SEM images of FA. From sieve analysis, only 20% of the FA passed through 62.5μm sieve, but from SEM images most of the particles seems to be smaller than 62.5μm. It can be explained by looking into images more deeply, fly ash shows the most pozzolanic property compared to other CCBs. Therefore, particles are adhered with each other forming more bulk particles. Through the literatures, it has been mentioned that spherical shapes of fly ash benefit its application as construction material.



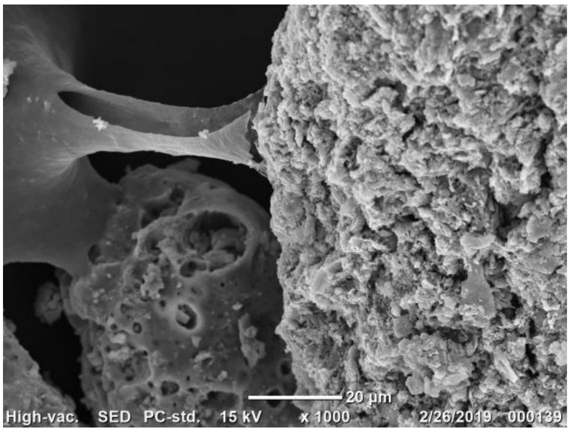
(a) unit measure = 50µm



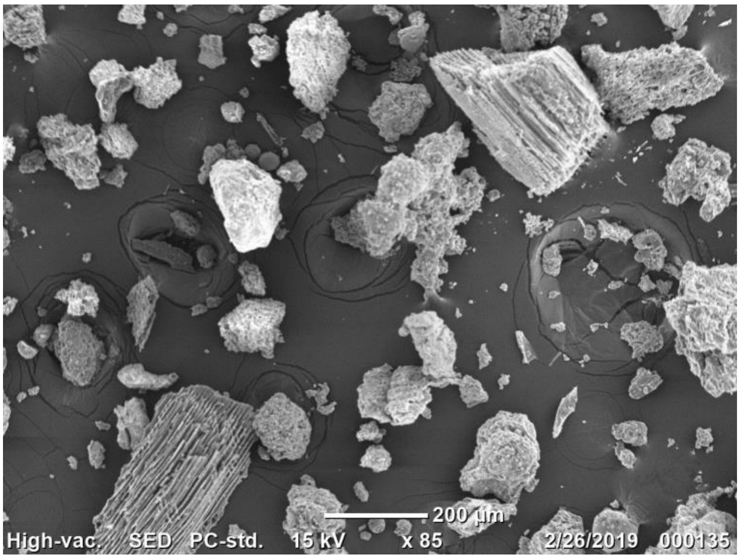
(b) unit measure = 10µm



(c) unit measure = 5µm



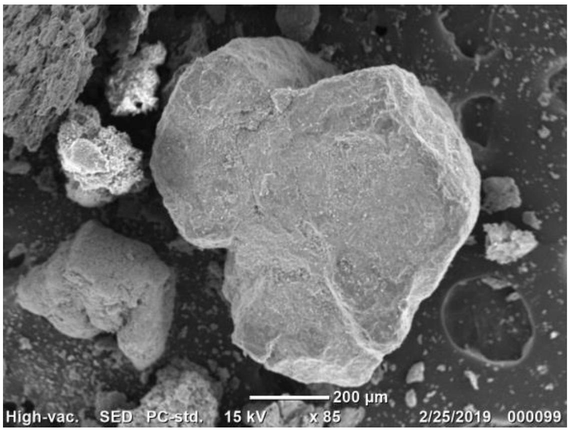
(d) unit measure = 20µm



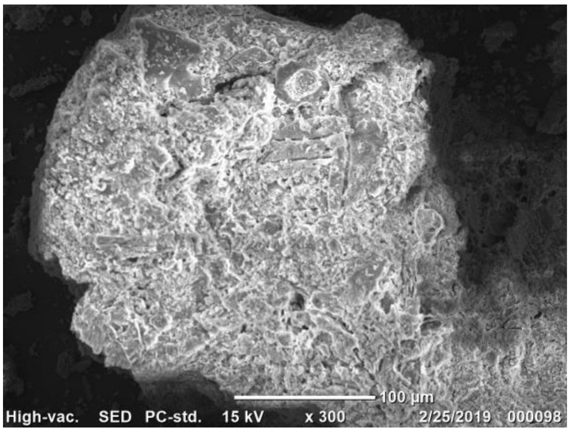
(e) unit measure = 200µm

Figure 22 *SEM images of BBA*

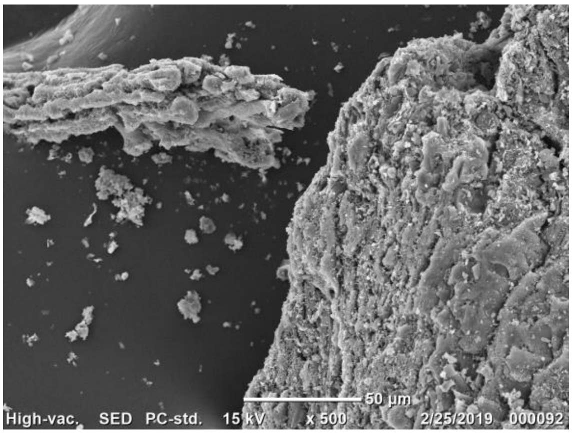
BBA shows two unique porous structures that looks like extended honeycomb and abrasive grains.



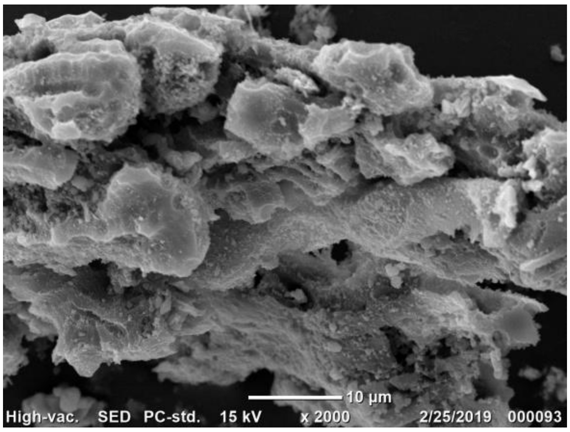
(a) unit measure = 200μm



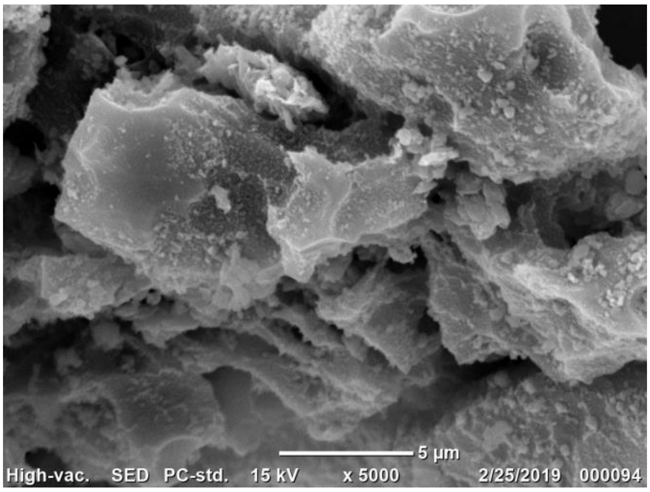
(b) unit measure = 100μm



(c) unit measure = 50μm



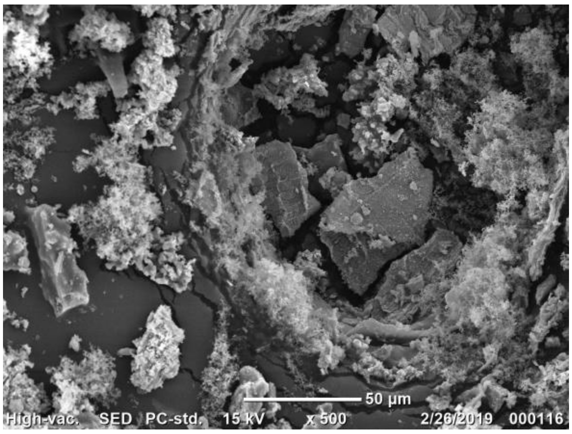
(d) unit measure = 10μm



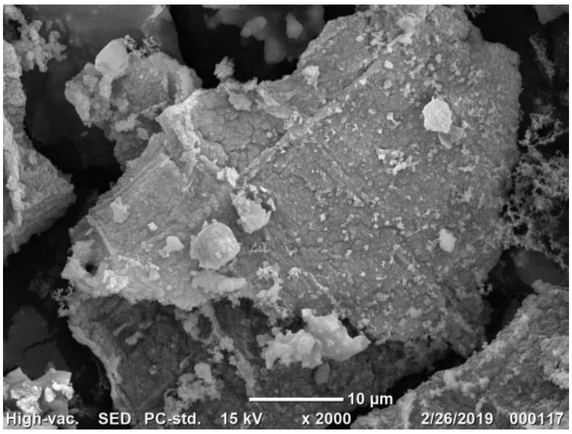
(e) unit measure = 5μm

Figure 23 *SEM images of BCA*

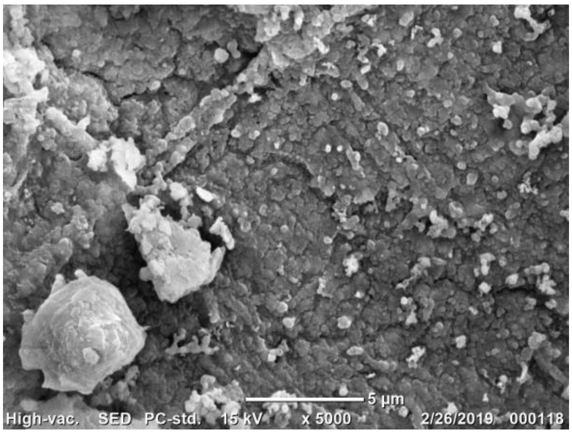
From the SEM images of BCA, particles appear to be rigid, bulkier and nonporous.



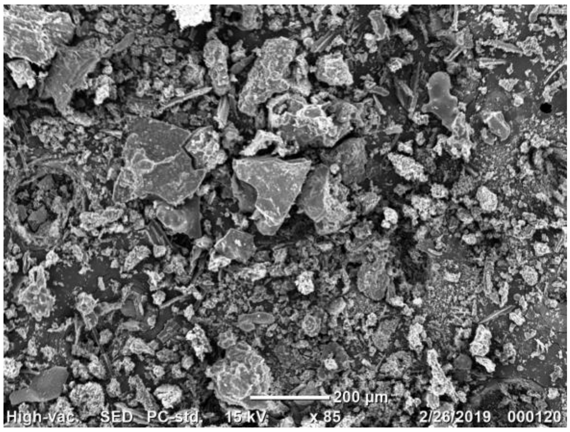
(a) unit measure = 50µm



(b) unit measure = 10µm



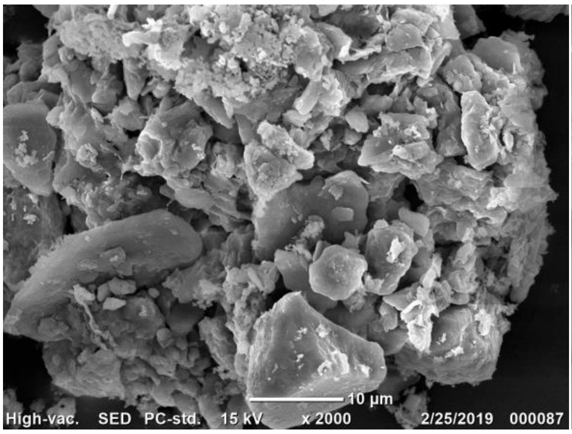
(c) unit measure = 5µm

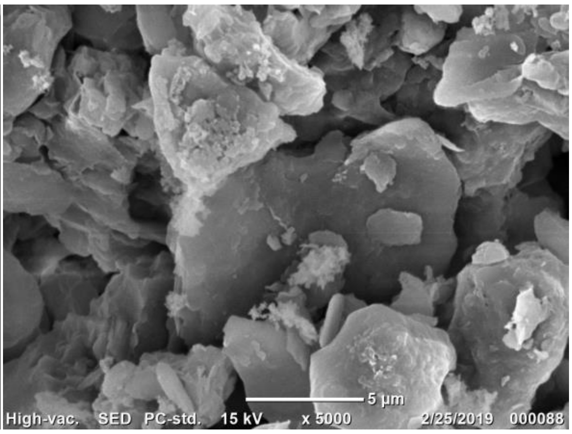


(d) unit measure = 200µm

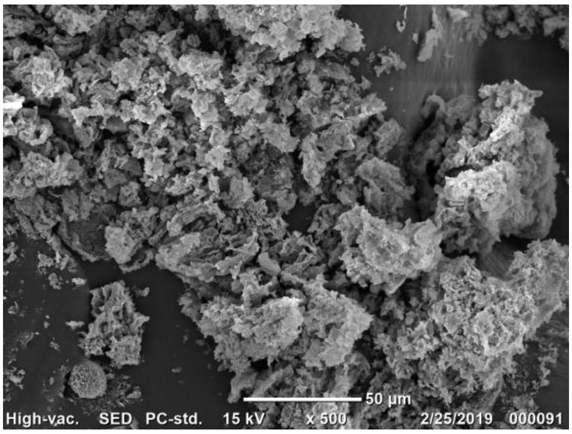
Figure 24 *SEM images of GBA*

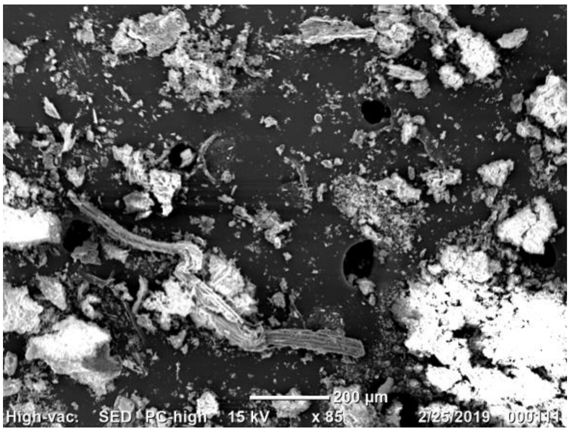
From the SEM images of GBA, GBA has various particle sizes. The shape of the particles is irregular and nonuniform. Also, particles are bulked together as other ashes and has low porosity.



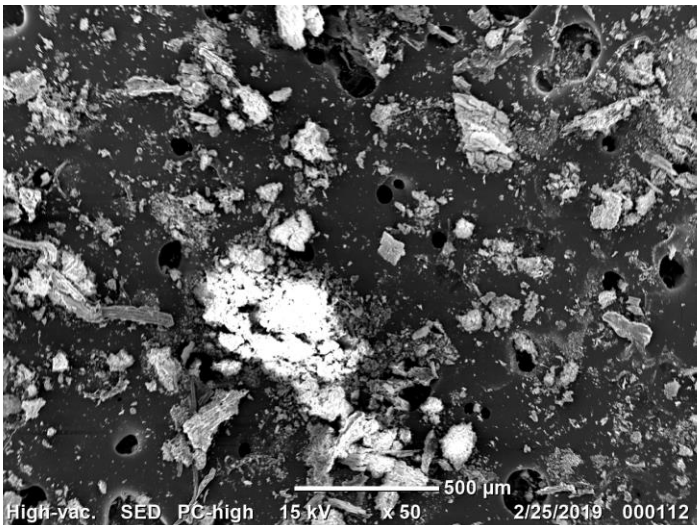


(a) unit measure = 10μm (b) unit measure = 5μm





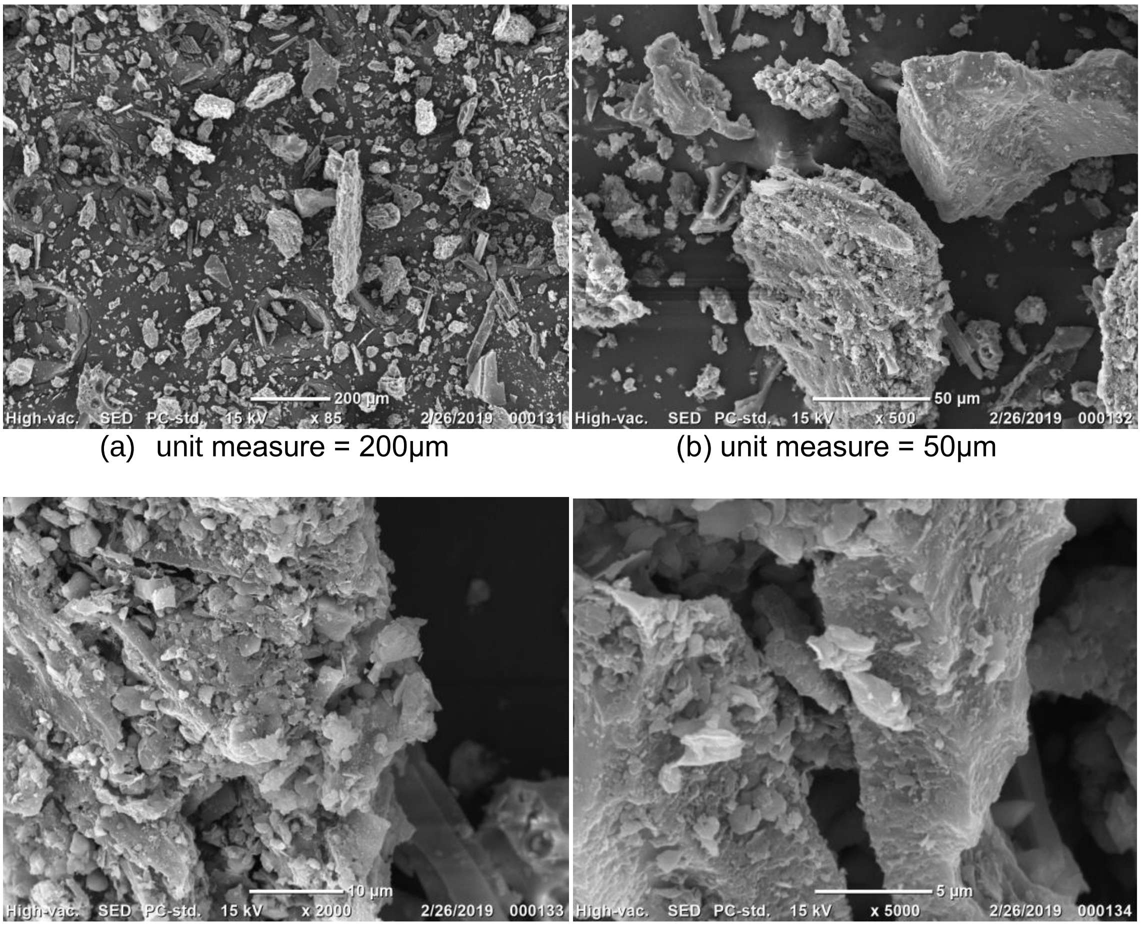
(c) unit measure = 50μm (d) unit measure = 200μm



(e) unit measure = 500μm

Figure 25 *SEM images of GPA*

GPA showed that it has agglomerating property. From the SEM images of GPA, the property can be also shown in the image (a) and particles being bulked together.

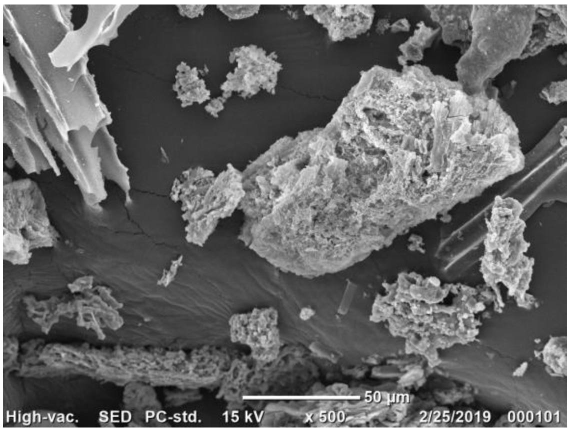


(a) unit measure = 200μm (b) unit measure = 50μm

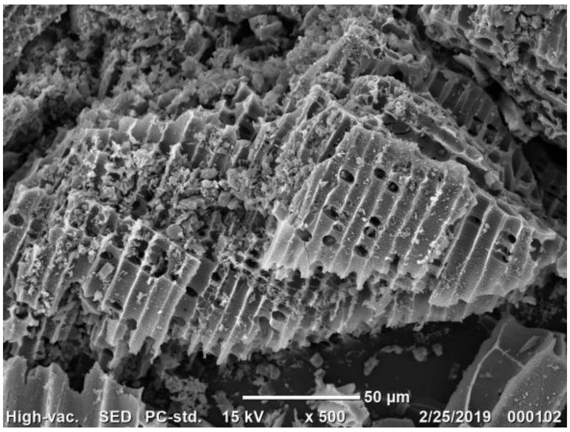
(c) unit measure = 10μm (d) unit measure = 5μm

Figure 26 *SEM images of NBA*

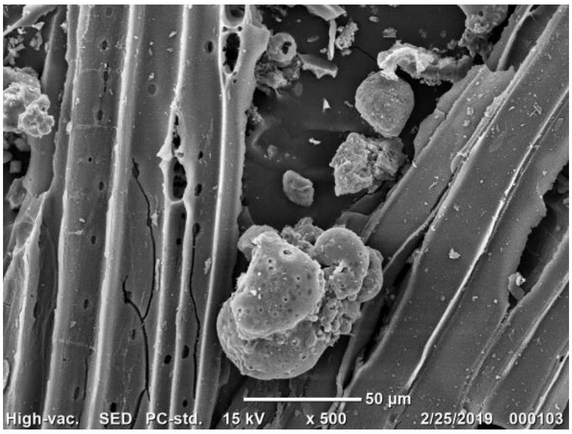
From the SEM images of NBA, NBA has various particle sizes. The shape of the particles is irregular and nonuniform. Also, particles are bulked together as other ashes and has low porosity. It is very similar to GBA, but NBA is more stretched.



(a) unit measure = 50µm

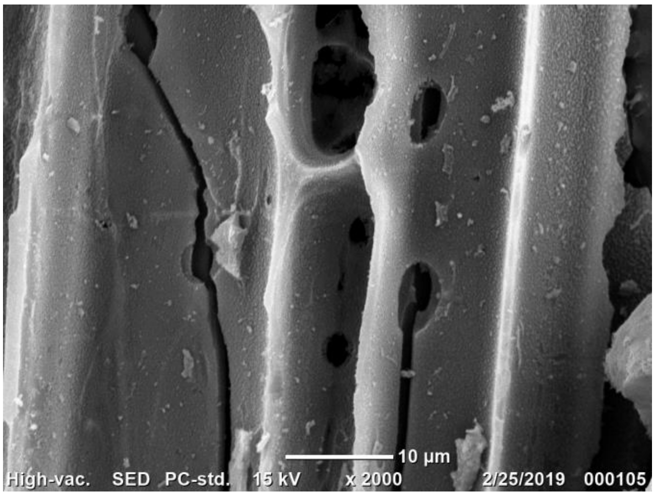


(b) unit measure = 50µm



(c) unit measure = 50µm

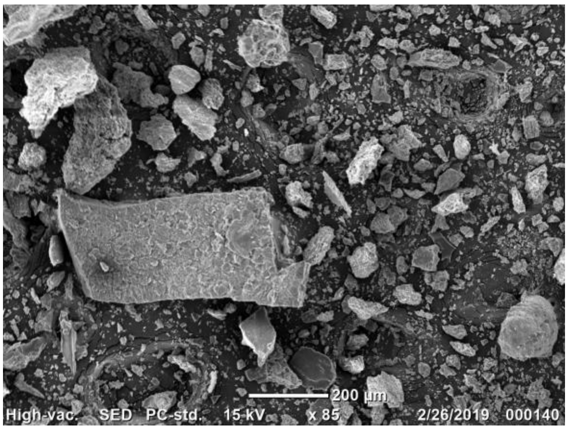
(d) unit measure = 200µm



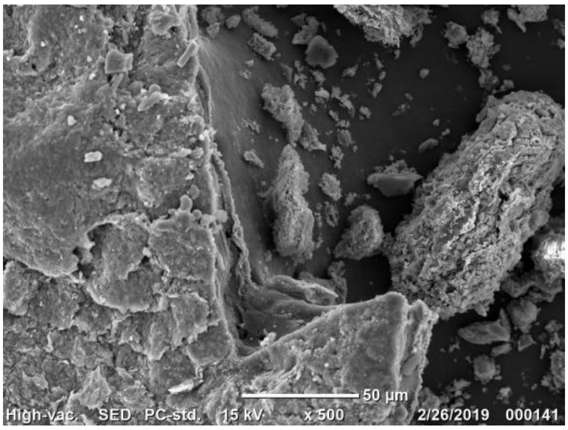
(e) unit measure = 10µm

Figure 27 *SEM images of NCA*

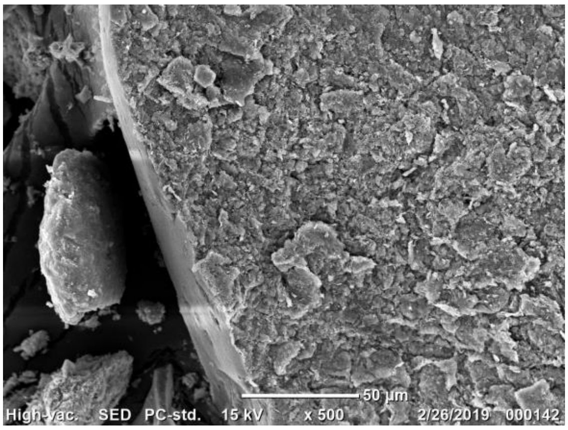
NCA appears to be extended honeycomb structured like BBA. The extended honeycomb structure is reasonably uniform in NCA unlike BBA. Some spherical particles are present in the image (d), which are most likely fly ash particles. Extended honeycomb structure is porous.



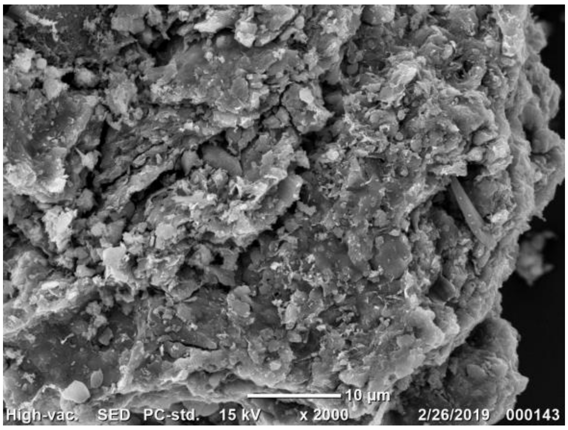
(a) unit measure = 200µm



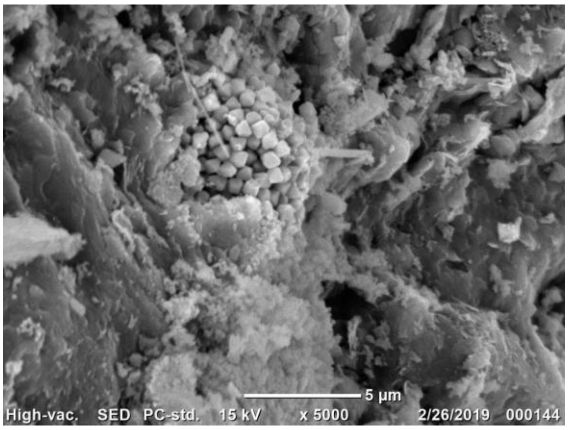
(b) unit measure = 50µm



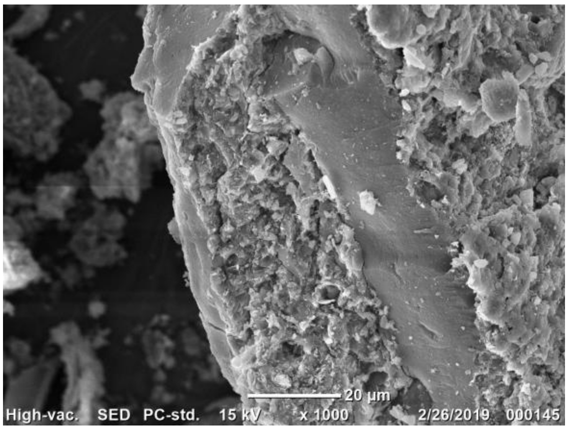
(c) unit measure = 50µm



(d) unit measure = 10µm



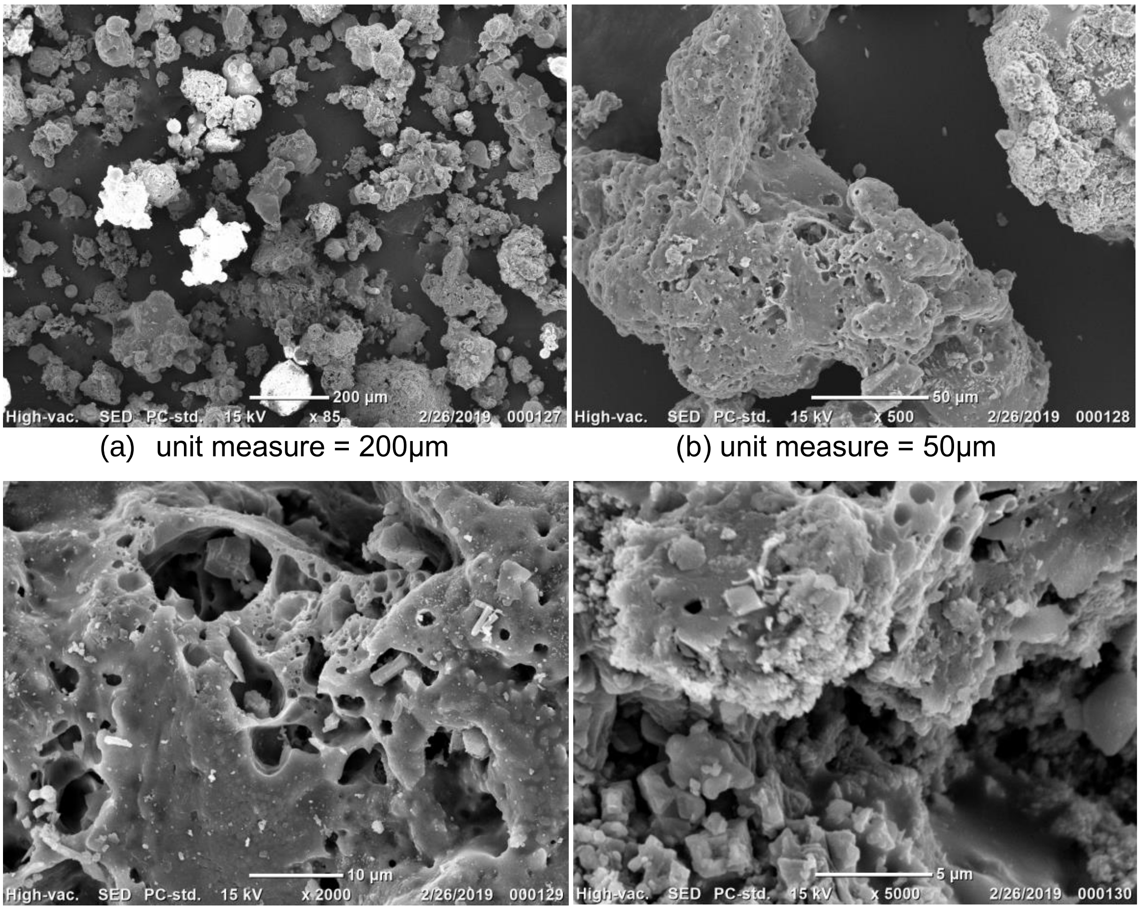
(e) unit measure = 5µm



(f) unit measure = 20µm

Figure 28 *SEM images of MBA*

MBA was substantially coarser than other ashes except TFA, but SEM images shows that particles sizes are various. Particles are irregular and no defined structure.



(a) unit measure = 200μm (b) unit measure = 50μm

(c) unit measure = 10μm (d) unit measure = 5μm

Figure 29 *SEM images of TBA*

TBA has irregular shapes, highly porous and the most course ash in the list. TBA has vesicular texture and the vesicles may formed by gas bubbles.

To sum up SEM analysis, almost every ash possessing unique ash particle structures and texture. The ashes also vary in particle porosity. The structure and textures of ashes will depend on boilers used and parent coal properties. For example, NBA, NCA, BBA, BCA have all same parent coal which is Baganuur mine coal. Even though particle structures and textures vary because of the different boilers used. It can be noted that bigger particles attract smaller particles. It most likely due to electrostatic force or pozzolanic reaction.

3.5.0 Apparatus

Jaw crusher

5E-JCA150×125 Jaw Crusher was used. Discharge size was set to minimum. The jaw crusher was used as an initial stage crusher. Technical parameters are shown below, and an image of the crusher is presented in the appendix section.

Model	5E-JCA150×125 Jaw Crusher
Size of Feed Inlet	150×125mm
Feed Size	≤100mm
Discharge Size	≤6-38mm adjustable
Moisture Adaptability	≤12%
Approx. Hardness of Feeding Sample	HRC48-55
Throughput	500~2000kg/h
Power Supply	3 phases, AC380V±10%, 50/60Hz , 4kW
Noise	≤85dB
Net Weight	378kg
Dimensions(L×W×H)	1046mm×600mm×1090mm

Table 13 *Jaw crusher specification*

Roll crusher

LMRC100 Roll crusher was used as secondary stage crusher. Clearance between the rolls were adjusted to 2mm. Image of the roll crusher presented in appendix section.

Power	1.1 kW
Roll size (Dia. x Width)	200 x 150
Dimensions (WxDxH)	1089 x 674 x 1095
Weight	370 kg
Roller speed	380 RPM
Standard Roll face	Smooth
Max feed size	30mm
End-fineness	<1mm

Table 14 *Roll crusher specification*

Ring mill

Ring mill was used to grind the samples. Image of the ring mill is presented in appendix section.

Power	0.18kW
Max feed size	Recommended 2-5mm sample, 8mm maximum
Product size	Typically 95%-100µm, samples can be pulverized <75µm
Dimensions (WxDxH)	410 x 510 x 410mm
Sample size	1g-100g

Table 15 *Rind mill specification*

Sieve analyzer

SV005 electromagnetic sieve shaker was used for sieve analysis. Image of the SV005 is presented in appendix section. The shaker impulses to impart vertical, lateral and rotational vibrating action. 315mm diameter sieves were used.

Accepted sieve diameter	200mm, 250mm, 300mm, 315mm, 8 inch, 12 inch
Digital control panel funtions	Timer, Vibration intensity
Rating	450/750W
Dimensions	380 x 440 x 1080mm

Table 16 *Sieve shaker specification*

Universal testing machine (Uniaxial compression test)

WDW-100 Computer controlled electronic universal testing machine was used. Image of the machine is presented in appendix section.

Max. Load (kN)	100
Load range	2%~100%FS
Load resolution	1/300000
Range of deformation	4%-100%FS
Accuracy of displacement	Within ±0.5% of indicating load
Dimension	1000x550x2076mm

Table 17 *Universal testing machine specification for uniaxial compression test*

Concrete hammer

Original Schmidt rebound hammer was used to test blocks that exceeded 10 MPa. The universal testing machine has maximum load of 100kN. Therefore, it was necessary to use rebound hammer. The hammer's range of measurement is 10 MPa to 70 MPa. Image of the rebound hammer is presented in appendix section.

Radioactivity detector

Radex RD1008 was used to detect any radioactivity. Image of the Radex RD1008 is presented in appendix section.

Range of dose rate, μSv/h	0,1 to 999
Range of flux density measurement, 1/(cm2 * min)	6 to 999
Range of dose measurement	0,01 μSv to 350 mSv
Range of photon ionizing radiation, MeV	0,05 to 3,0
Range of beta radiation, MeV	0,05 to 3,5

Table 18 *Radioactivity detector specification*

4. Results and Discussion

Following analyses and test were conducted on ash/slag samples, sieve analysis, SEM analysis, radioactivity detection, moisture content analysis, XRF chemical content analysis. With the cubic blocks that was produced from mixing different ashes, slags and binders uniaxial compression test was done. FTIR samples were taken from the components of mix and the broken blocks. Elution test sample was drawn from the curing water for the cubes.

All backfill mixes that was produced are proven that they would neither harm the environment nor human health because there was neither radiation nor the leached toxins that exceeded the safety standards. Most of the mix designs that used CEM as a binder satisfied the requirements, especially the FA mix showed great compressive strength. But, BCA, NCA, GPA and DS should be avoided as a filler material due blocks that had been produced from these materials disintegrated in the curing water even though 10% CEM was used as a binder. On the other hand, mix designs that used FA and DS as binders did not satisfy the requirement. Those block mixes usually disintegrated after they had been introduced to the curing water. Only FA only, GBA only and FA:DS (1:1) mix designs fulfilled the requirement. DS and TBA have excellent amount of CaO and SiO_2 but from result of the compression test it can be concluded that CaO in the DS and TBA was trapped in other unwanted crystal structures. FTIR analysis was done on the 3 most successful mix designs with CEM (GBA, MBA, FA) according to the uniaxial compression test. The result showed that pozzolanic reaction took place in those mixes. In short, CEM must be used when utilizing the ashes other than FA and GBA while FA only and GBA only mix designs with aggregates could also work.

BCA has got the lowest CaO content. Therefore, it was chosen to be mixed with variable CEM content of 10%, 20%, 30% and 40%. The main aim for this experiment was to determine the percentage of CEM that is needed to utilize the lowest CaO content ash. The 10% CEM block disintegrated but 20% CEM block hold up and showed compressive strength of 1.17 MPa. In summary, some ashes may require 15-20% of CEM to be used as a backfill. Therefore, choosing the right filler material is crucial for economic reason.

From the uniaxial compression test results of the best mix designs, following conclusion can be made. Particle size and shaper matters. For example, the most promising mix designs are with FA and GBA. Those ashes have the finest particle sizes. Various sized spheres are the best shape to fill the gaps with even distribution. On the other hand, irregular shaped particles tend fill the gaps less efficiently. This gives the FA advantage over the GBA, but this is not the only reason why the FA performed better than the GBA. Content of the CaO, SiO_2, Al_2O_3 and Fe_2O_3 contents matter. But the oxides, especially CaO, should be free and not locked in the other unwanted crystals. Otherwise, it will not be able to crystallize to produce calcium silicate hydrate (C-S-H) like in the cases of TBA and DS.

Moreover, the backfill mixes were mixed with weight%, same as the other similar researches. But every ash has its own density, which leads to inconsistent volume ratio with the binder material. So, the volume ratio should also be considered in some cases.

5. Conclusion

The research aimed to evaluate the possibility to use CCBs and industrial wastes for backfilling material for underground mines. Hundreds of thousand tons of CCBs in Mongolia is being landfilled despite its economical and beneficial properties annually. Furthermore, space for landfilling and construction of tailing pond have risen to a major problem in capital city Ulaanbaatar, home to more than 1.4 million people. To represent the CCBs in Mongolia 9 different ashes from 6 different plants/locations and an electric-arc furnace slag had been sampled. Typical backfill mix consists binder, filler and aggregate material. From the sampled ashes potential 2 candidates for binder material was nominated and tested. For the filler materials, materials were mixed with portland cement by specific design and compared.

Fly ash from thermal power plant #4 and electric arc furnace from Darkhan metallurgical plant were nominated as binders. The main criterion was the CaO content. Fly ash has binder property but no that much. It easily exceed the minimum requirement of the backfill only by itself. When the fly ash was mixed with other filler CCBs with ratio of 1:1 most of them disintegrated during the process of curing. On the other hand, electric-arc furnace showed no binding property even though it has the highest CaO content. From this result, CaO in the electric-arc furnace slag is trapped or associated with other unwanted crystals is concluded. After thorough data analyzing fly ash and ger district bottom ash had been proven as a suitable material for backfilling while other material can be utilized with additives like portland cement. Many of the research suggested that CCBs may be harmful to human health and environment for the construction purpose. However, in this research case, CCBs have been proven that it can be used as construction and backfill material.

6. Recommendation

The thesis work was done under the project BASMIC. For the BASMIC II project, following studies are recommended.

Detailed study on small-scale mines in Nalaikh. The study should aim to investigate general method for small-scale mines in Nalaikh, structure of the mines (including depth, drift of adit lengths, total backfill required volume, etc.), surrounding rock mass properties and more. Perhaps, investigation of two closed mine that caused subsidence in residence area and railroads are more effective.

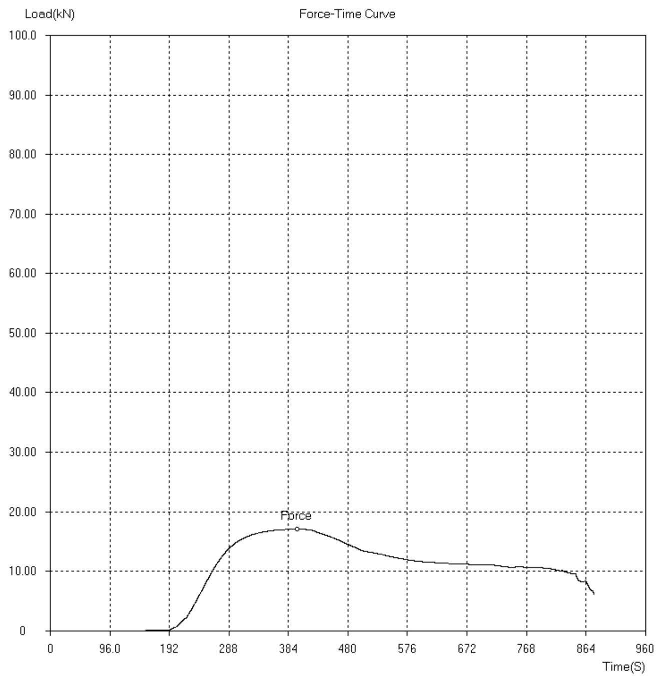
More detailed study should be made on choosing suitable backfilling method. This study should be based on the first suggested study.

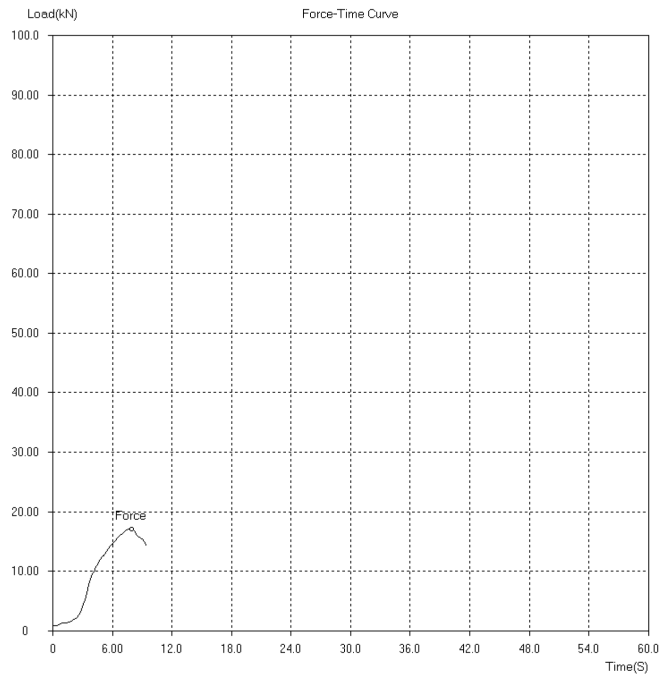
Moreover, economic feasibility study should be done. The study should make an economic evaluation to utilizing various ashes and binders. Transportation, backfilling equipment, labor, ash price etc. should be considered.

7. Appendix

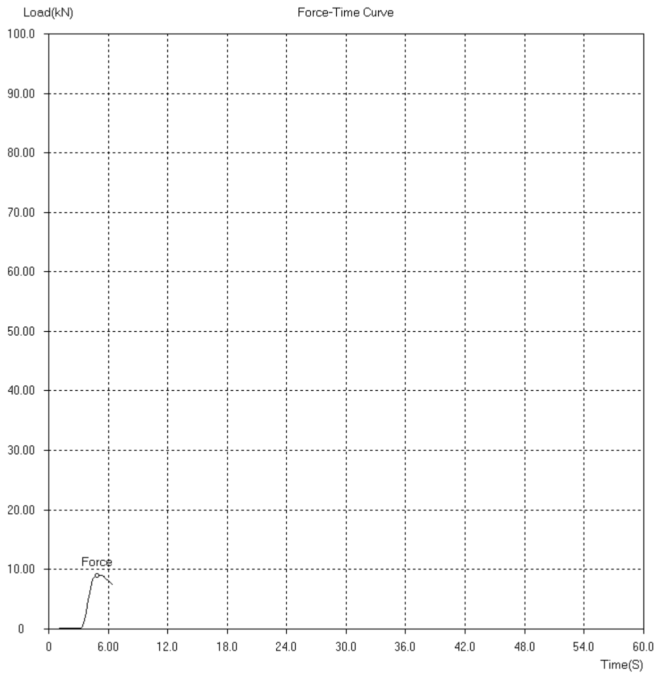
	Ash mass distribution in grams										
	Bottom ash / Bottom slag					Crushed Bottom ash			Cyclone		Fly Ash
Sieve size in mm	TBA	MBA	NBA	BBA	GBA	MBA	TBA	NBA	BCA	NCA	FA
8	948.1	93.3	9.9	0	0	0	0	0	0	0	0
4	275.1	207.6	28.7	0	0.2	9.8	7.3	2	0.25	0	0
2	137.7	203.3	39.3	3	0.2	147.3	150.2	45.4	0.3	0.2	0
1	134.4	191.6	44.3	68.6	0.9	246.9	154.3	61	2.6	0.3	0.5
0.5	206.2	149.6	38.9	675.7	193.3	214.7	127.7	43.5	200.1	1	1
0.25	394.1	82.9	27.7	195.7	285.7	152.9	176.9	30.8	439.25	98.1	7.6
0.125	459.7	40.1	28.9	43.4	307.3	118.3	221.9	28.9	274.9	307.2	86.1
0.063	107.9	19.5	14	0	193.3	73.7	101.7	20.7	59.9	408.6	685.5
Rest	38.9	12.5	17.1	0	9.7	34.3	60	25	20.5	180.9	212.4
Total mass in g	2702.1	1000.4	248.8	986.4	990.6	997.9	1000	257.3	997.8	996.3	993.1

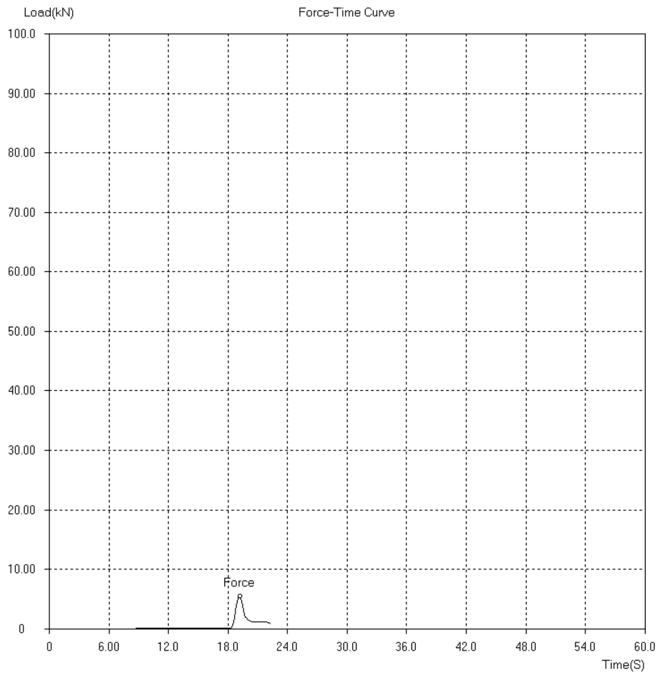
Appendix 1 *Sieve analysis raw data*

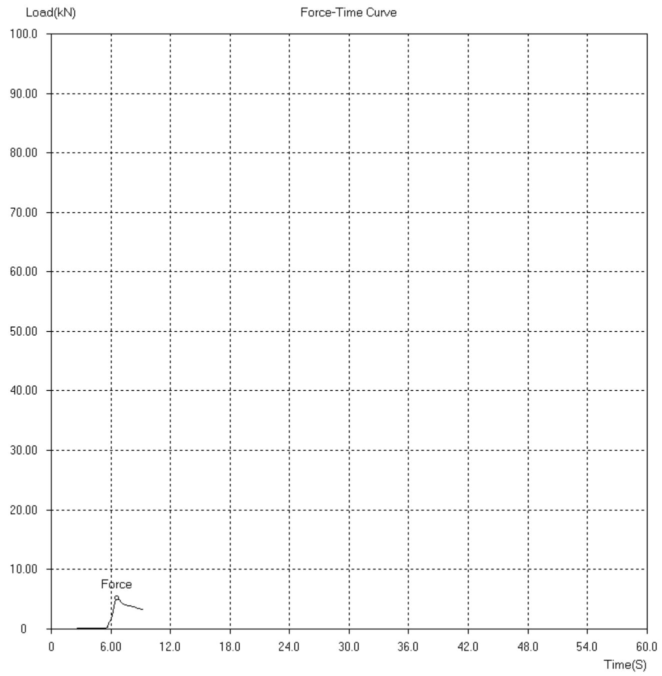




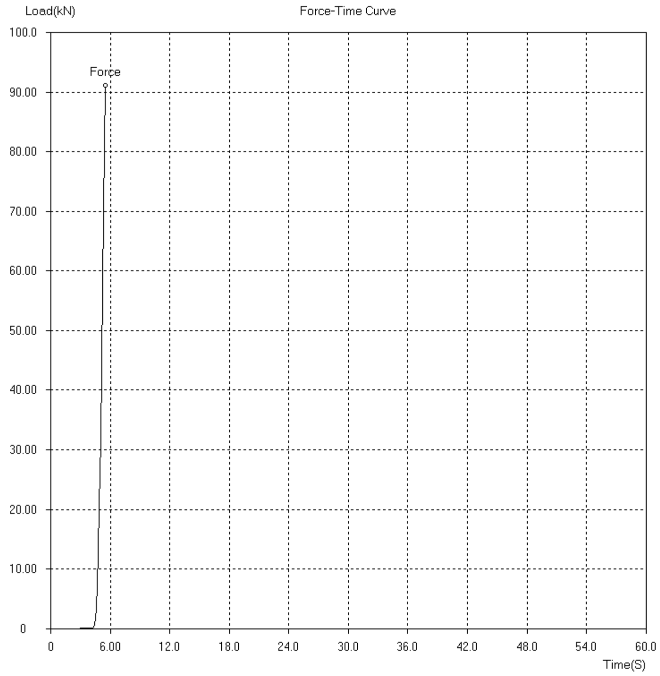
Appendix 2 *GBA with 10% CEM compressive strength data*

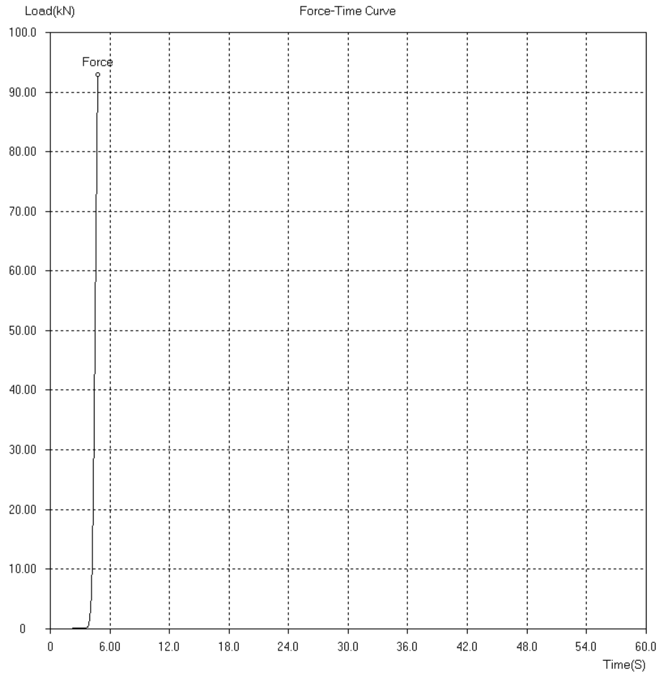




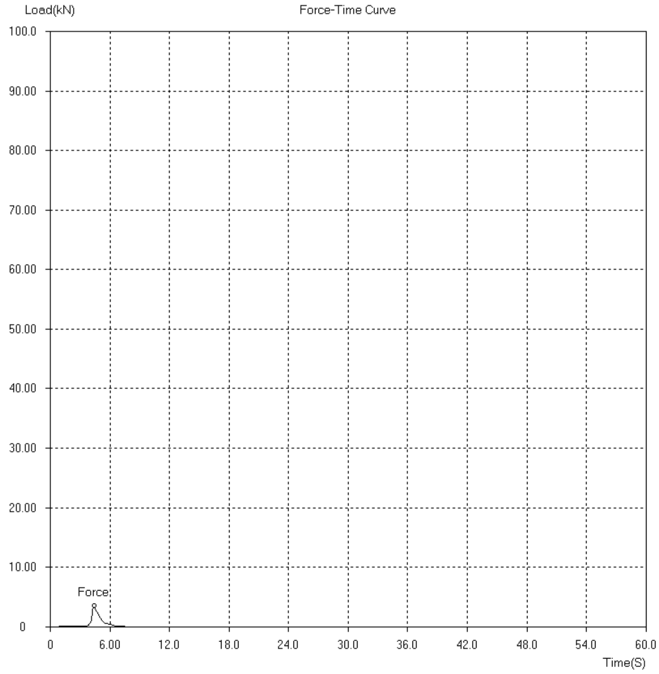


Appendix 3 *NBA with 10% CEM compressive strength data*

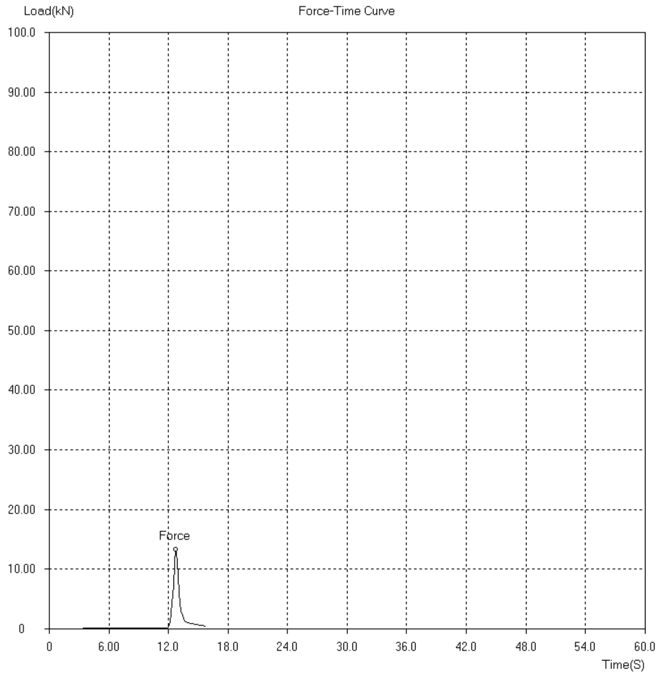


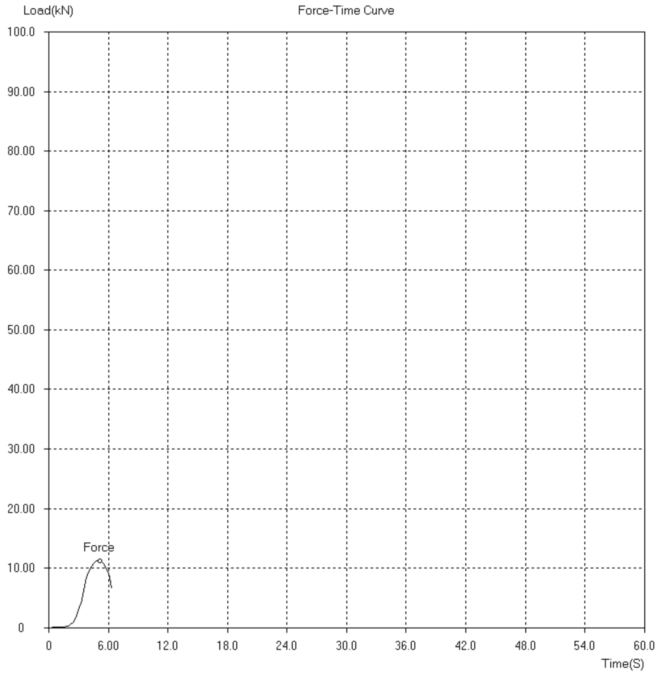


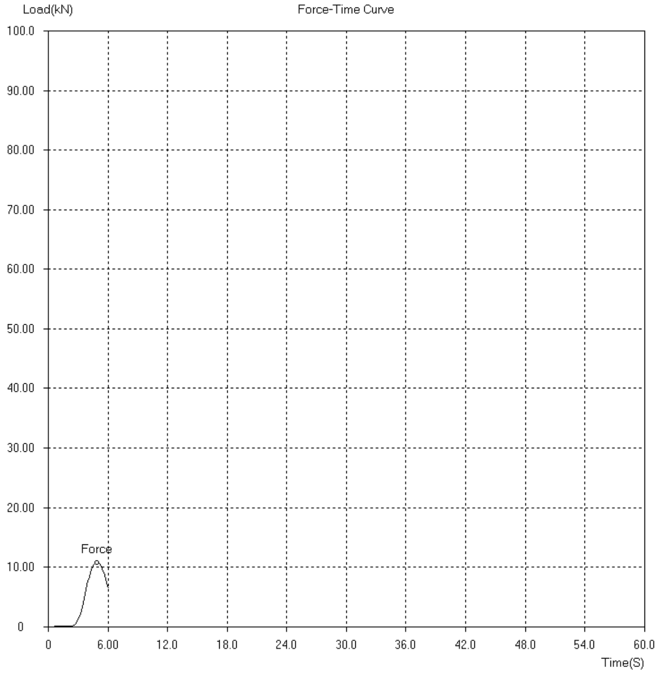
Appendix 4 *FA with 10% CEM compressive strength data*



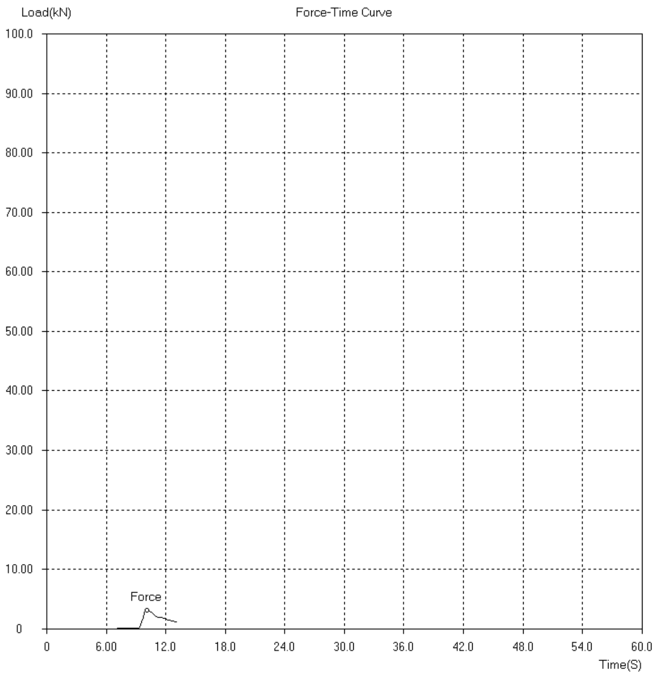
Appendix 5 *NCA with 10% CEM compressive strength data*

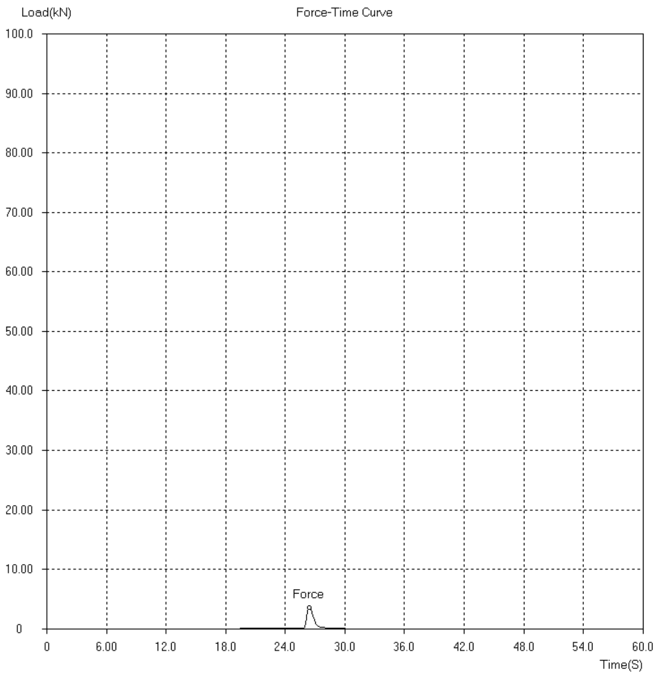


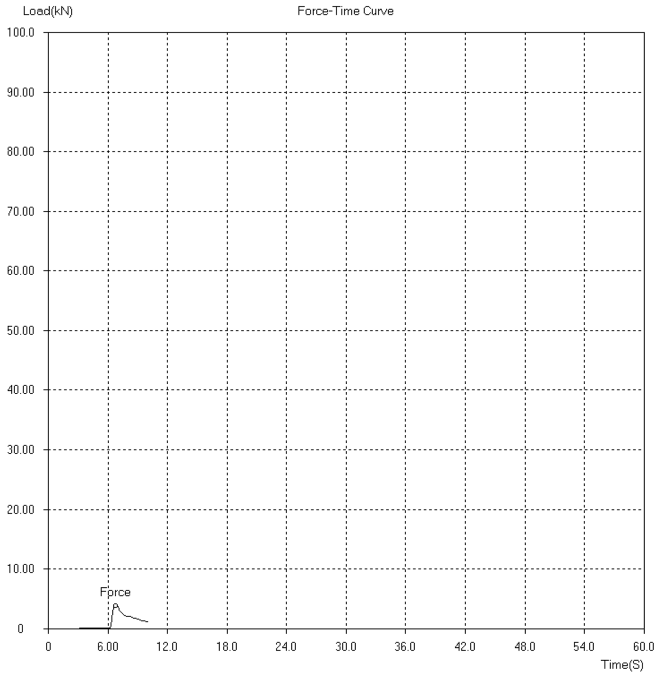




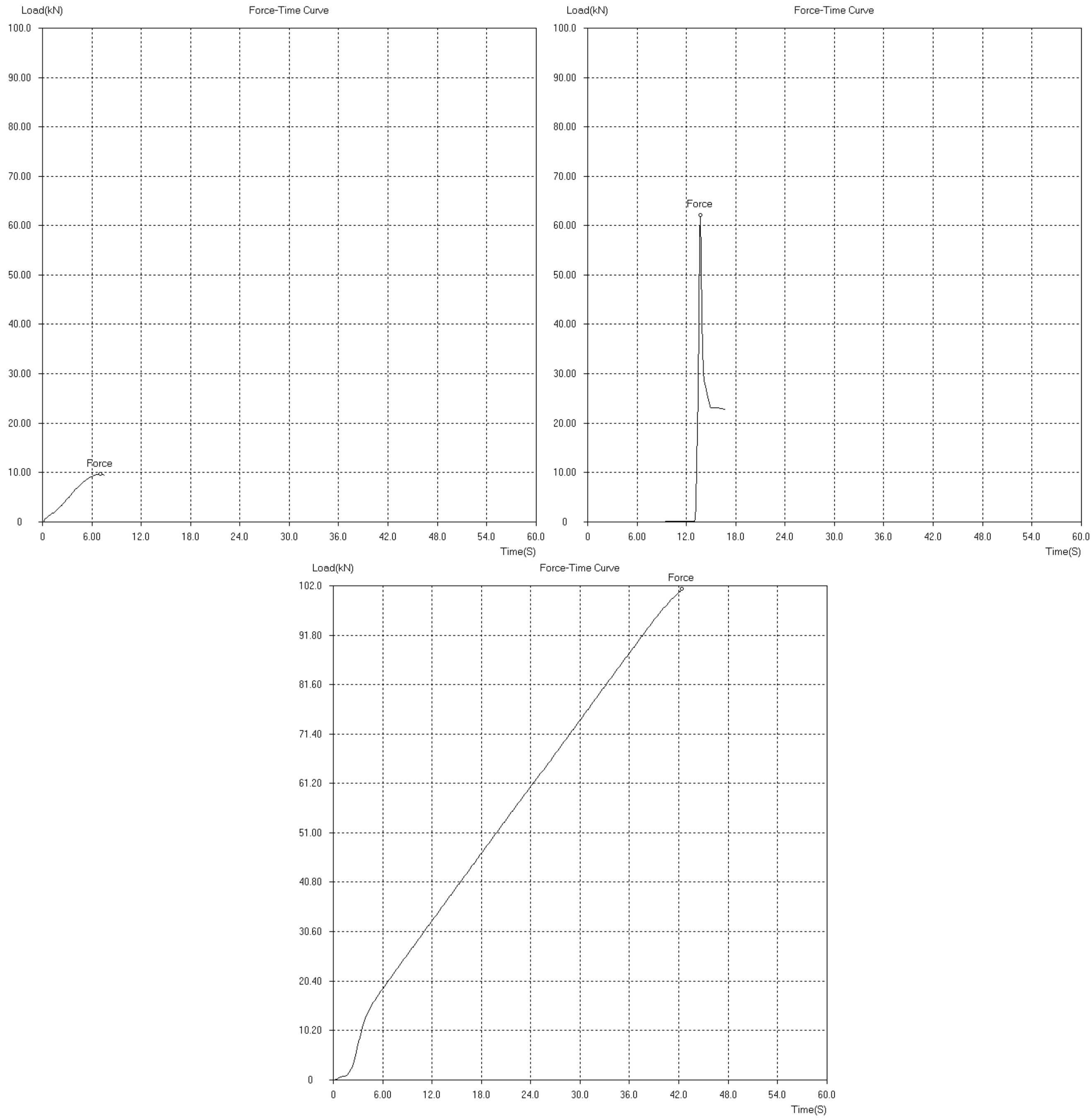
Appendix 6 *MBA with 10% CEM compressive strength data*



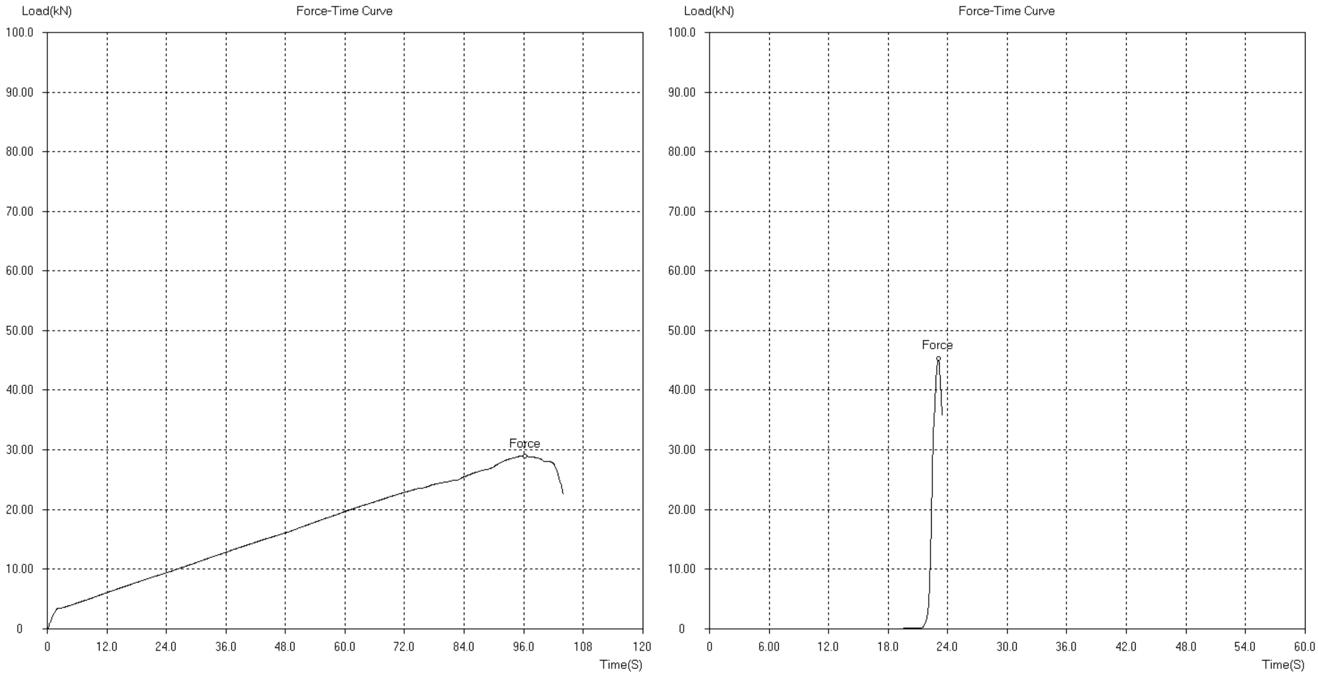




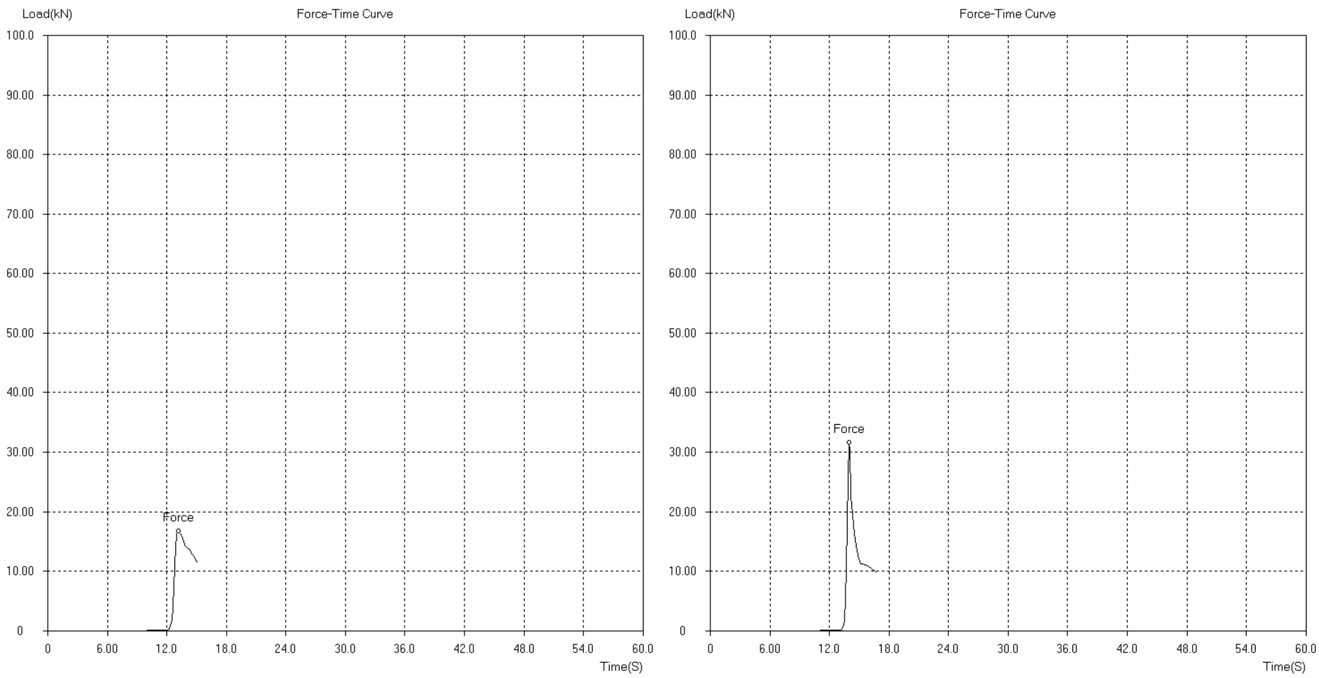
Appendix 7 *BBA with 10% CEM compressive strength data*



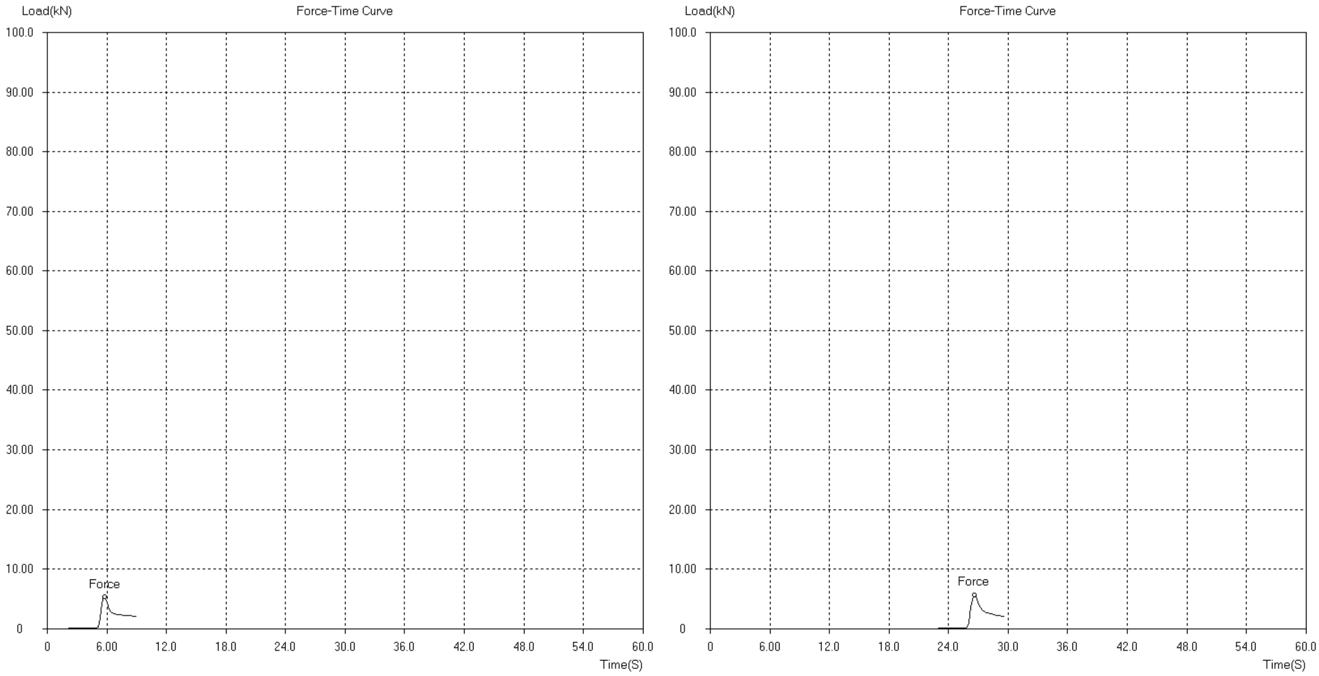
Appendix 8 *BCA with 20%,30% and 40% CEM compressive strength data*



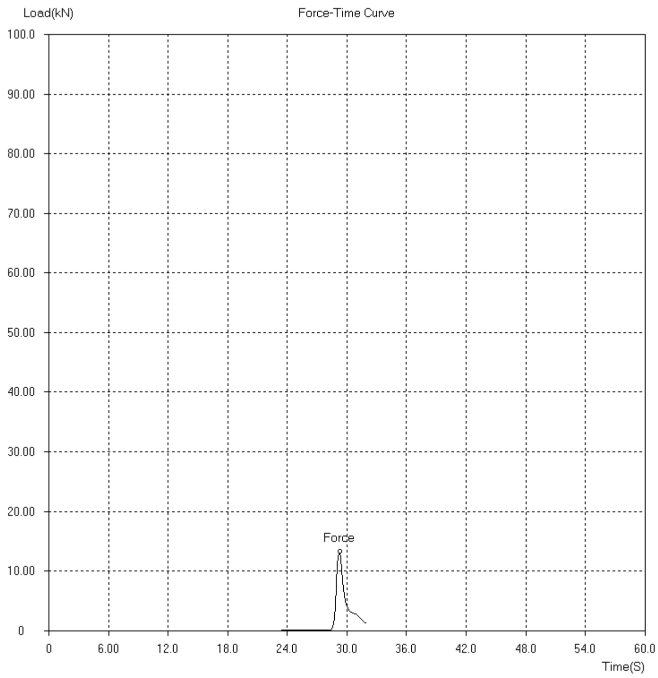
***Appendix 9** FA 100% compressive strength data*



***Appendix 10** FA 50% and DS 50% compressive strength data*



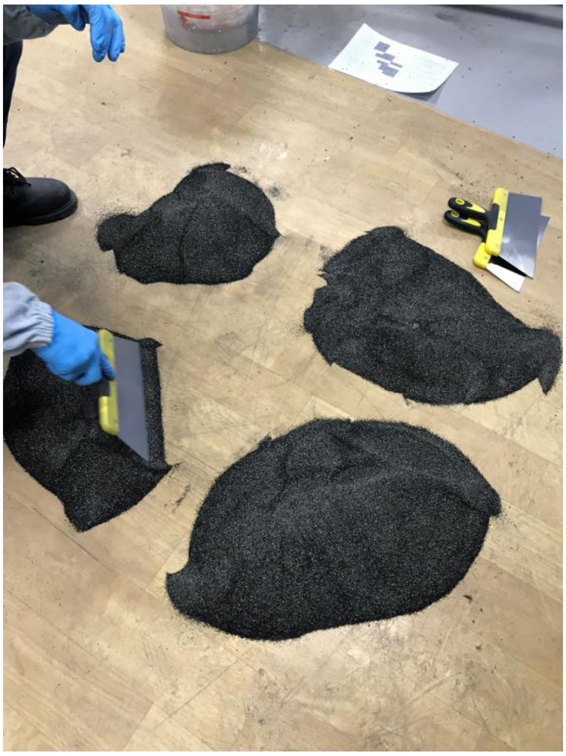
Appendix 11 *GBA 100% compressive strength data*



Appendix 12 *TBA with 10% CEM compressive strength data*

Appendix 13 *DS before and after crushing*

Appendix 15 *Ash samples in trays*



Appendix 14 *Coning and quartering*

Appendix 16 *Sieve shaker*

Appendix 17 *Size fractions*

Appendix 19 *Mixing process*

Appendix 18 *Molding process of mix*

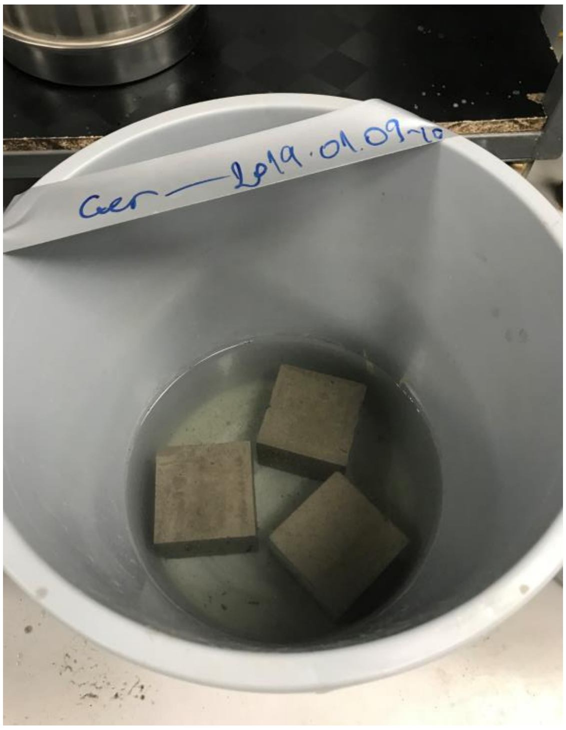
Appendix 20 *Curing process*

Appendix 21 *After curing process*

Appendix 22 Before compression test

Appendix 23 After compression test

Appendix 24 *FTIR sample*



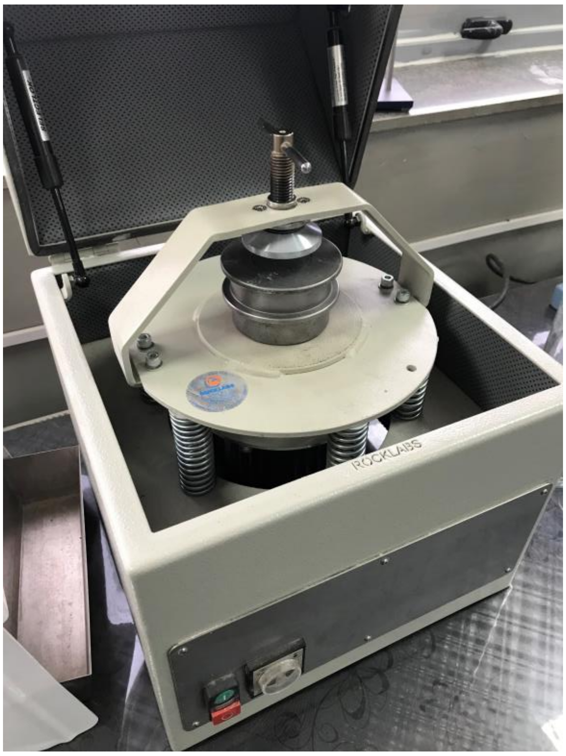
Appendix 25 *Curing process (Note: Elution test samples are withdrawn from curing waters)*

Appendix 26 *Radiation measurement with radioactivity detector*

Appendix 27 *Universal testing machine*

Appendix 28 *Jaw crusher*

Appendix 29 *Roll crusher*



Appendix 30 *Ring mill*

Appendix 31 *Concrete hammer*

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