Characteristic and Utilization Applicability Analysis of Fly Ash in Coal-fired Power Plant

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Abstract. A coal-fired power plant in Northwest China was selected to evaluate the way and scope of comprehensive utilization of fly ash, through the detection of various properties of fly ash, the local industrial and transportation conditions, so as to provide guidance for the comprehensive utilization of fly ash. The fly ash of the coal-fired power plant can be used for filling and soil restoration, but the soil environment monitoring and agricultural products collaborative monitoring should be strengthened; due to incomplete combustion of the boiler; the fly ash does not meet the preparation conditions of ceramsite; it can be used for making silicate products such as bricks and for road subgrade construction; it has the potential to extract carbon particles and magnetic beads, but not to extract Al₂O₃ and SiO₂; it meets the requirements of radioactivity, and the way of use is not restricted by reflection; it can be used for the preparation of new materials such as environmental adsorption; it can be transported to Beijing, Tianjin and Hebei province carried by railway.

1. Introduction

In 2016, the total output of fly ash in China was 600 million tons, and the average comprehensive utilization rate of fly ash in China was 70% [1]. However, the comprehensive utilization rate of fly ash in Northwest China, which is the most widely distributed coal-fired power plant and produces the largest amount of fly ash, is only 30% [2]. In Northwest China, more than 100 million tons of unused fly ash was piled up in the ash yard every year. With the passage of time, the ash yard was piled higher and higher, and covers more and more land. Due to the lack of treatment measures, once the dam of ash yard was break, it will cause immeasurable harm to environment and people. The comprehensive utilization of fly ash can turn waste into useful goods [3-5]. Therefore, the comprehensive utilization of coal-fired power plant fly ash has become an important technical and economic policy in China's economic construction [6]. However, the present situation of comprehensive utilization of fly ash in Northwest China is not optimistic, forming a vicious economic and ecological environment: underdeveloped economy-industrial structure biased to heavy industry-increased amount of coal-fired fly ash-lack of effective control due to economic factors-harmful to ecological environment. A large amount of fly ash produced in Northwest China needs to be actively used according to local conditions.

In this paper, a coal-fired power plant in Northwest China was selected to evaluate the way and scope of its comprehensive utilization of fly ash through the detection of various properties, combined
with the local industrial and transportation conditions, so as to provide guidance for the comprehensive utilization of fly ash in the power plant.

2. Experiment and method
The content of heavy metals, leaching toxicity, various physical and chemical properties, mineral composition, radioactivity and micro morphology of the collected fly ash were tested. The detection and analysis of physical and chemical properties of fly ash were mainly based on: <Chemical analysis methods for cement> (GB/T 176-2017), <Analytical methods for arsenic, pickaxe, chromium, copper, nickel, lead and zinc in fly ash> (DL/T 867-2004) and <Identification standard for hazardous wastes-identification of leaching toxicity> (GB 5085.3-2007).

The test instruments include: X-ray powder diffraction, plasma mass spectrometer, electronic balance, burette, spectrophotometer, atomic absorption, scanning electron microscope, laser particle size meter, gamma spectrometer, specific surface area tester, UV visible spectrophotometer, electronic balance.

3. Results and discussions
3.1. Heavy metal content
The content of heavy metals in fly ash was listed in Table 1. The Zn content in fly ash exceeds the risk screening value of heavy metal content in the local soil: if fly ash was directly used as soil, there may be pollution risk for agricultural land, so the environmental monitoring and agricultural product collaborative monitoring should be strengthened; all metal content were less than the most stringent standard of local soil risk management value, so it is not restricted by the prohibition of planting edible agricultural products; if fly ash is used as soil conditioner, it is necessary to further test the mixed soil with fly ash to determine whether further detection is needed.

| Fly ash | Cd  | Cr  | Pb  | As  | Hg  | Cu  | Ni  | Zn  | pH  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Samper 1| 0.312 | 44.44 | 46.45 | 12.11 | 0.29 | 68.43 | 38.89 | 332.1 | 9.76 |
| Samper 2| 0.243 | 46.54 | 39.45 | 11.46 | 0.33 | 66.41 | 39.03 | 335.2 | 10.21 |
| Average | 0.278 | 45.49 | 42.95 | 11.79 | 0.31 | 67.42 | 38.96 | 333.7 | 9.99 |

GB 15618-2018
- Risk screening value: pH>7.5
- Risk management value: pH>7.5
- Risk screening value for class I land
- Risk screening value for class II land
- Risk management value for class I land
- Risk management value for class II land

| GB 15618-2018 | Cd  | Cr  | Pb  | As  | Hg  | Cu  | Ni  | Zn  | pH  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Samper 1      | 0.6 | 250 | 170 | 25  | 3.4 | 100 | 190 | 300 | /   |
| Samper 2      | 4.0 | 1300| 1000| 100 | 6.0 | /   | /   | /   | /   |
| Average       | 20  | 400 | 20  | 8   | 2000| 150 | /   | /   | /   |

GB 36600-2018
- Risk screening value for class I land
- Risk screening value for class II land
- Risk management value for class I land
- Risk management value for class II land

| GB 36600-2018 | Cd  | Cr  | Pb  | As  | Hg  | Cu  | Ni  | Zn  | pH  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Samper 1      | 172 | 2500| 140 | 82  | 36000| 2000| /   | /   | /   |
| Samper 2      | 0.3 | 100 | 85  | 30  | 0.3 | 40  | 40  | 150 | /   |
| Average       | 0.6 | 200 | 300 | 35  | 1.0 | 200 | 80  | 300 | /   |
| Level I       | 1.0 | 250 | 450 | 40  | 1.5 | 350 | 150 | 450 | /   |
| Level II      | 1.2 | 380 | 530 | 55  | 1.8 | 500 | 220 | 650 | /   |

CJ/T 340-2011
- Level I
- Level II
- Level III
- Level IV

| CJ/T 340-2011 | Cd  | Cr  | Pb  | As  | Hg  | Cu  | Ni  | Zn  | pH  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Samper 1      | 10  | 500 | 500 | 75  | 250 | 300 | /   | 8.7 | /   |
| Samper 2      | 0.6 | 200 | 300 | 35  | 1.0 | 200 | 80  | 300 | /   |
| Average       | 1.0 | 250 | 450 | 40  | 1.5 | 350 | 150 | 450 | /   |
| Level I       | 1.2 | 380 | 530 | 55  | 1.8 | 500 | 220 | 650 | /   |

GB 8173-1987
- pH (soil)>6.5

| GB 8173-1987 | Cd  | Cr  | Pb  | As  | Hg  | Cu  | Ni  | Zn  | pH  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Samper 1     | 10  | 500 | 500 | 75  | 250 | 300 | /   | 8.7 | /   |
| Samper 2     | 0.6 | 200 | 300 | 35  | 1.0 | 200 | 80  | 300 | /   |
| Average      | 1.0 | 250 | 450 | 40  | 1.5 | 350 | 150 | 450 | /   |
| Level I      | 1.2 | 380 | 530 | 55  | 1.8 | 500 | 220 | 650 | /   |
3.2. Leaching toxicity

The leaching toxicity values of fly ash were shown in Table 2. Most of the metal contents are lower than the detection limit of the method, but they were all lower than the standard value in <Identification standard for hazardous waste leaching toxicity identification> (GB 5085.3-2007), indicating that fly ash belongs to general solid waste.

Because most of the metal content of fly ash was lower than the detection limit, so the worst quality of fly ash (the content below the detection limit shall be regarded as the content of the metal) was used to compared with the limit values of metal content in groundwater in <groundwater quality standard> (GB/T 14848-2017): the harmful metal content extracted from fly ash meets the requirements of class IV water (applicable to agricultural and industrial water) and class V water (high chemical component content of groundwater, other water can be selected according to the purpose of use). For Pb and Cd, it is necessary to select a lower detection limit method to finally evaluate the final risk level of the fly ash to groundwater. However, the existing detection limits have been proved to meet the water quality requirements of class IV and V groundwater.

Table 2. Leaching toxicity of fly ash (mg/L).

| Fly ash | Cd   | Cr   | Cr⁶⁺ | Pb   | Cu   | Ni   | Zn   |
|---------|------|------|------|------|------|------|------|
| Samper 1 | <0.003 | <0.01  | <0.004  | <0.05  | <0.01  | 0.07  | 0.034  |
| Samper 2 | <0.003 | <0.01  | <0.004  | <0.05  | <0.01  | 0.07  | 0.026  |
| Average | <0.003 | <0.01  | <0.004  | <0.05  | <0.01  | 0.07  | 0.030  |
| GB 5085.3-2007 | 0.3  | 10  | 1.5  | 3  | 50  | 10  | 50  |
| Level I | 0.0001 | /  | 0.005  | 0.005  | 0.01  | /  | 0.05  |
| Level II | 0.001  | /  | 0.01  | 0.005  | 0.05  | /  | 0.5  |
| Level III | 0.005 | /  | 0.05  | 0.01  | 1  | /  | 1  |
| Level IV | 0.01 | /  | 0.1  | 0.1  | 1.5  | /  | 5  |
| Level V | >0.01 | /  | >0.1  | >0.1  | >1.5  | /  | >1  |

3.3. Radioactivity content

Table 3 and 4 shows the test results of chemical composition and physical properties of fly ash. It can be seen from the Table 3 and 4 that: the characteristics of fly ash do not meet the requirements of <Light aggregates and their test methods, Part 1 light aggregates> (GB/T 17431.1-2010), which is mainly due to high ignition loss (carbon content) in fly ash and is caused by raw coal incomplete combustion of pulverized coal; if the effective combustion adjustment of power plant was carried out, the loss on ignition in fly ash can be reduced, and the fly ash can meet the quality requirements of ceramsite ceramic sand; the characteristics of coal ash meet the requirements of <Fly ash for silicate building products> (JC/T 409-2016), so it can be used for making silicate products such as brick; the fly ash of meets the requirements of <Code for construction and acceptance of urban road subgrade engineering> (CJJ 44-1991), and can be used for road subgrade construction.

The average loss on ignition of the coal-fired power plant is 6.67%, and the carbon content is more than 4%, which has the potential to extract carbon particles; the average content of Fe₂O₄ is 2.62, which has the potential to extract magnetic beads. The average content of Al₂O₃ in the coal-fired power plant is 30.83%, less than 35%. It is not high alumina ash and has no potential to extract Al₂O₃. Because the current extraction process of silicon oxide is generally synchronous with the extraction of alumina, the economy of silicon oxide extraction alone is poor [7].

Table 3. Content of mineral components in fly ash (%).

| Fly ash | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | TiO₂ | C% | Fe₂O₄ |
|---------|------|------|------|-----|-----|-----|------|-----|------|
| Samper 1 | 44.35 | 32.34 | 2.76 | 3.15 | 0.34 | 0.58 | 1.01 | 6.88 | 2.72 |
| Samper 2 | 43.87 | 29.32 | 2.39 | 3.21 | 0.65 | 0.51 | 1.12 | 6.45 | 2.52 |
| Average | 44.11 | 30.83 | 2.58 | 3.18 | 0.50 | 0.55 | 1.07 | 6.67 | 2.62 |
| GB/T 1596-2017 | / | / | / | / | / | / | / | / |
| Class F≤70.0 | / | / | / | / | / | / | / | / |
| Class C≤50.0 | / | / | / | / | / | / | / | / |
| Level I≤5.0 | / | / | / | / | / | / | / | / |
| Level II≤8.0 | / | / | / | / | / | / | / | / |
| Level III≤10.0 | / | / | / | / | / | / | / | / |
| GB/T 17431.1-2010 | / | / | ≤10% | / | / | ≤10 | / | ≤5 |
| JC/T 409-2016 | ≥40 | / | / | / | / | ≤20 | / | ≤8 |
| CJJ 44-1991 | ≥70.0 | / | / | / | / | / | / | ≤10.0 |
Table 4. Common physical and chemical properties of fly ash.

| Fly ash | Particle size (μm) | Specific surface area (m²/g) | Fineness (0.045mm residue)% | pH | Soluble salt (%) | CEC (mmol/100g) | Density (g/cm³) |
|---------|--------------------|-------------------------------|-----------------------------|----|-----------------|-----------------|----------------|
| Samper 1| 15.25              | 3.543                         | 0                           | 9.87| 0.45            | 1.89            | 2.22           |
| Samper 2| 16.45              | 3.123                         | 0                           | 10.23| 0.66            | 2.78            | 2.16           |
| Average | 15.85              | 3.333                         | 0                           | 10.05| 0.555           | 2.33            | 2.19           |

GB/T 1596-2017
- Level I: ≤ 12.0
- Level II: ≤ 30.0
- Level III: ≤ 45.0

GB/T 17431.1-2010
- / / ≤ 45.0 / / / /

JC/T 409-2016
- 0.080mm residue ≤ 25 / / / /

3.4. Radioactivity content

Table 5 shows the test results of radioactivity in fly ash of the coal-fired power plant (I_Ra: internal radiation index, I: external radiation index). The results show that the fly ash meets the requirements of <limits of radionuclides in building materials> (GB 6566-2010), and the production and use range of products containing the fly ash were not limited by radioactivity.

Table 5. Radioactivity content of fly ash (Bq/kg).

| Fly ash | 226Ra | 232Th | 40K | I_Ra | I |
|---------|-------|-------|-----|------|---|
| Samper 1| 132.34| 112.64| 145.22| 0.65 | 0.71|
| Samper 2| 129.34| 113.45| 144.23| 0.70 | 0.68|
| Average | 130.84| 113.05| 144.73| 0.68 | 0.70|

GB 6566-2010
- Class A: There are no restrictions on production and use range
- Class B: It cannot be used for interior decoration of class I civil buildings, but can be used for interior decoration of class II civil buildings, industrial buildings and all other external finishes
- Class C: It can only be used for buildings and other outdoor uses

3.5. Market analysis

Due to the fact that the coal-fired power plant is far away from cities and towns, and the demand for building materials in this area is low, the fly ash produced by the coal-fired power plant is short of market. However, the coal-fired power plant has a railway transportation line next to the coal-fired power plant. Compared with the road transportation, the coal-fired power plant has a larger radius of its own fly-ash products through the railway service area (the area with high comprehensive utilization rate of fly ash). The price of fly ash in Beijing-Tianjin-Hebei region is 180 yuan/ton, and the railway freight from this region to Beijing-Tianjin-Hebei region is 0.03 yuan/(ton*km). According to calculation, the economic transportation radius of fly ash from this region to Beijing-Tianjin-Hebei region is 600 km, and the transportation cost will be increased by 30 yuan/ton for every 100km, so it is possible to carry out research on transportation consumption in different places. The fly ash of coal-fired power plant has an annual output of 1.5 million tons. If the transportation exceeds 600 km, it will bring huge economic cost to the coal-fired power plant.

4. Conclusions

The fly ash of coal-fired power plant can be used for filling and soil remediation, but the soil environmental monitoring and agricultural products collaborative monitoring should be strengthened; the unit combustion needs to be adjusted to reduce the carbon content of fly ash before it can be used to prepare ceramsite pottery sand; it can be used for road subgrade construction; it has the potential of extracting carbon particles and magnetic beads; it can also be used for the preparation of ceramsite; It has no potential to extract Al₂O₃ and SiO₂; it is not restricted by reflection due to meeting the requirements of radioactivity; it can be transported to Beijing-Tianjin-Hebei region by railway for partial absorption.
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