Resource Utilization Categorization Standard of Fly Ash for Coal-fired Power Plants

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ABSTRACT

Fly ash has been used as the raw material for various applications, such as cement, concrete, wall materials, road construction, backfilling, mine filling, agricultural uses, ceramic products, fillers, etc. A new industry standard DL/T 2297-2021 effective on Oct. 26, 2021 in China is established to help coal-fired power plants categorize their fly ash differentiated from unsuitable ones for specific resource utilization as raw material by the designed labeling system and test methods. The categorization of this standard is based on 6 chemical compositions and particle fineness/shape of fly ash.

Chemical compositions for categorization include the content of carbon (or LOI), calcium oxide/free calcium oxide ion, sulfur trioxide, alumina oxide, iron oxide, and ammonia ion with at least high and low levels. Particle fineness is categorized into 7 levels: the first 3 fine particle content levels based on D90, the last 3 coarse particle content levels based on amount retained using 45 μm sieve residue, and the middle level based on both criteria. Particle shape categorization has 2 types: round or irregular shapes. This standard also allows specifying certain harmful or valuable chemical compositions according to existing standards.

The coal-fired power plant can produce the suitable fly ash tested and recognized

with the appropriate mark by this standard to meet the selected application. For example, high alumina fly ash, marked as A_H ash, can be used to replace bauxite to make low-density and high-strength fracturing proppant used in oil & gas field applications. Fly ash with the marking of C_{II}-F_5 meets LOI and particle fineness requirements of fly ash used for concrete application in various standards, such as GB/T 1596-2017 in China, ASTM C618-2019 in USA and EN-450-1-2012 in Europe.

KEYWORDS: fly ash, categorization, resource utilization, chemical compositions, particle size, particle shape

1. Introduction

Fly ash is a kind of micrometer-size particulate material captured and collected from the flue gas after the coal is burned in the boiler. From the point of view of material science, all fly ash has three fundamental material properties: 1) chemical composition, 2) particle size distribution and shape and 3) mineral composition. The chemical composition includes major elements, secondary elements, and trace elements. Fly ash has two major chemical elements: Si and Al with the content always much greater than 10%. The secondary elements typically have the content greater than 1%, such as Fe, Ca, C, S, Mg, Na, K, and Ti. The trace elements have the contents less than 1%, such as Pb, Ga, Ge, Se, Zr, Nb, U, Cr, Ni, Cu, Zn, Mn, P, Co, Rb, Sr, Y, Ba, Ta, Ce, Hf, W, Th, Cl, F, etc. The particle size distribution is from 0.1 to 600 micron with the average particle size in the range of 10 – 60 microns. The mineral composition typically has the content of glassy aluminosilicate phase in the range of 40 – 70%. The crystalline phase of the mineral composition typically has quartz (SiO_2) and mullite ($(3Al_2O_3•2SiO_2)$) or metakaolinite $Al_2O_3·2SiO_2$ corresponding to two major chemical elements. The other possible mineral compositions include lime (CaO), anhydrite ($CaSO_4$), anorthite ($CaO.Al_2O_3.2SiO_2$),

gehlenite ($Ca_2[Al_2SiO_7]$), magnetite (Fe_3O_4), hematite (Fe_2O_3), corundum (α-Al_2O_3), etc.

These 3 fundamental materials properties are directly related to three material property performance effects for its application uses, 1) particle effect, 2) chemical compositional effect, and 3) mineral compositional effect. The particle effect is used for aggregate or filler purpose. The chemical compositional effect is used due to the similarity to clay compositions, high carbon content and structure, limitation to certain harmful element contents, and useful content to extract valuable elements, etc. The mineral compositional effect is due to its gelation under alkaline conditions based on the glassy phase content. The performance requirements of each application are actually related to three fundamental properties through these three material performance effects. The applications include fillers, building materials, soil improvement, road construction, backfilling reclamation, mine filling, ceramic products and others.

Different coal-fired power plant, even the same coal-fired power plant during a different production period, can produce fly ash with different values or ranges in these three fundamental materials properties which directly affect its properties for the target application due to the differences in coal type, combustion process and environmental protection process conditions. Chemical compositions of fly ash are determined by the inorganic compositions in coal, the combustion efficiency of the boiler and extra chemicals from the environmental protection process. For example, incomplete combustion results in high carbon content. Desulfurization inside the boiler results in high sulfur and calcium content. The improper control of denitrification results in high ammonia content. Desulfurization wastewater injected into the flue gas stream can increase chloride ion content in fly ash. The particle shape of fly ash depends on the boiler type, pulverized coal boiler or circulating fluidized bed boiler, producing most of fly ash in a round or irregular shape, respectively. The particle size distribution depends on the coal pretreatment, combustion conditions of boiler and dust removal system. Mineral compositions are determined by the inorganic compositions in coal and the boiler temperature.

Figure 1 shows how three fundamental properties of fly ash are controlled by coal-fired power plant and related to the material performance properties to the applications. Therefore, there is a need to establish a categorization standard to help each coal-fired power plant to produce the suitable material properties of fly ash, particularly chemical compositions and particle size distribution/shape by controlling their operational conditions for the selected application.

2. Fly ash categorization standard

The fly ash categorization standard is DL/T 2297-2021, effective on October 26, 2021 in China, named as specification for resource utilization categorization of fly ash from coal-fired power plant.

2.1 Scope

This standard specifies the classification and marking method of resource utilization of fly ash from coal-fired power plants. This standard is applicable to the classification of resource utilization of fly ash from coal-fired power plants. Fly ash produced by other industrial coal-fired boilers can be implemented by reference.

2.2 Definitions

Fly Ash is the collection of solid particulate matters that are carried out of the furnace chamber by flue gas after coal combustion in the boiler and collected by dust removal or other equipment, and the sum of SiO_2, Al_2O_3 and Fe_2O_3 contents of solid particulate matter shall not be less than 50%.

Spherical particle has sphericity and roundness not less than 0.8. The definition of sphericity and roundness shall be based on SY/T 5108.

2.3 Classification and marking

Resource utilization categorization of fly ash has main and auxiliary classification. Main classification is composed of 5 chemical compositions including carbon content or Loss on Ignition for pulverized ash only, calcium oxide or free calcium oxide ion content, sulfur oxide content, aluminum oxide content and iron oxide content. Auxiliary classification is composed of particle fineness, particle shape

and ammonium ion content. Table 1 lists classification types, modes, indicators and categories.

The marks of main classification are based on the content of 5 chemical compositions, including carbon content or Loss on Ignition (LOI), calcium oxide content/free calcium oxide content, sulfur oxide content, alumina oxide content and iron oxide content, represented by capital English letters C, K, S, A and I, respectively. Each chemical composition is divided into two grades: high content and low content, which are represented by the capital letter subscripts H and L corresponding to the composition, respectively. The contents of the above five chemical compositions meet the requirements of corresponding low content, which is called ordinary ash and represented by capital letter, "O". The pulverized fly ash can be classified according to Loss on Ignition (LOI) of GB / T 1596. The LOI of no more than 8% is the low carbon content, further divided into two sublevels, no more than 5% and 8%, represented by C_{I} and C_{II} respectively. If the LOI is greater than 8%, it is the high carbon content, further divided into two sublevels, greater than 8% but not greater than 10%, and greater than 10%, represented by C_{III} and C_{H}, respectively. The categories, value index and marks of main classification are listed in Tables 2.

The valuable or harmful classification and limits of other chemical compositions in fly ash except Si, Al, C, Ca, S, and Fe shall be implemented according to the existing national, industrial, local and group standards in the field according to the field of resource utilization.

Auxiliary classification is composed of particle fineness, particle shape, and ammonium ion content and has different categories, value index and marks as listed in Table 3. Test methods for classification are listed in Table 4. Classification marking is shown in Figure 2. The A_H ash means fly ash with the alumina oxide content not less than 40%. The $C_{II}K_LS_L$-F_5M_R ash means fly ash with LOI not higher than 8% but greater than 5%, calcium oxide content not higher than 10% and free calcium oxide content not higher than 1%, sulfur content not higher than 3.5%, 45μm sieve residue

not greater than 30% but greater than 12%, and round particle shape.

3. Use examples of fly ash categorization

High alumina fly ash according to this standard can be marked as A_H which has been successfully used to replace bauxite to make low-density and high strength proppant which meet the international standard ISO13503-2 and Chinese standard SY/T5108-2014 proppant property requirements. This standard helps the coal-fired power plant produces fly ash meeting the A_H requirement to use the mark to differentiate from the other types of fly ash as a valuable raw material to replace bauxite to make low-density and high strength proppant. Coal-fired power plant produces fly ash having the C_I-F_5 mark which meets Class I particle fineness and LOI according to GB/T 1596-2017.

4. Conclusions

DL/T 2297-2021, specification for resource utilization categorization of fly ash from coal-fired power plant, is newly established in China to help coal-fired power plants categorize their fly ash differentiated from unsuitable ones for specific resource utilization as raw material by the designed labeling system and test methods. How each coal-fired power plant can learn and use this standard to control the quality of their fly ash differentiated from the rest is the next important work to follow.

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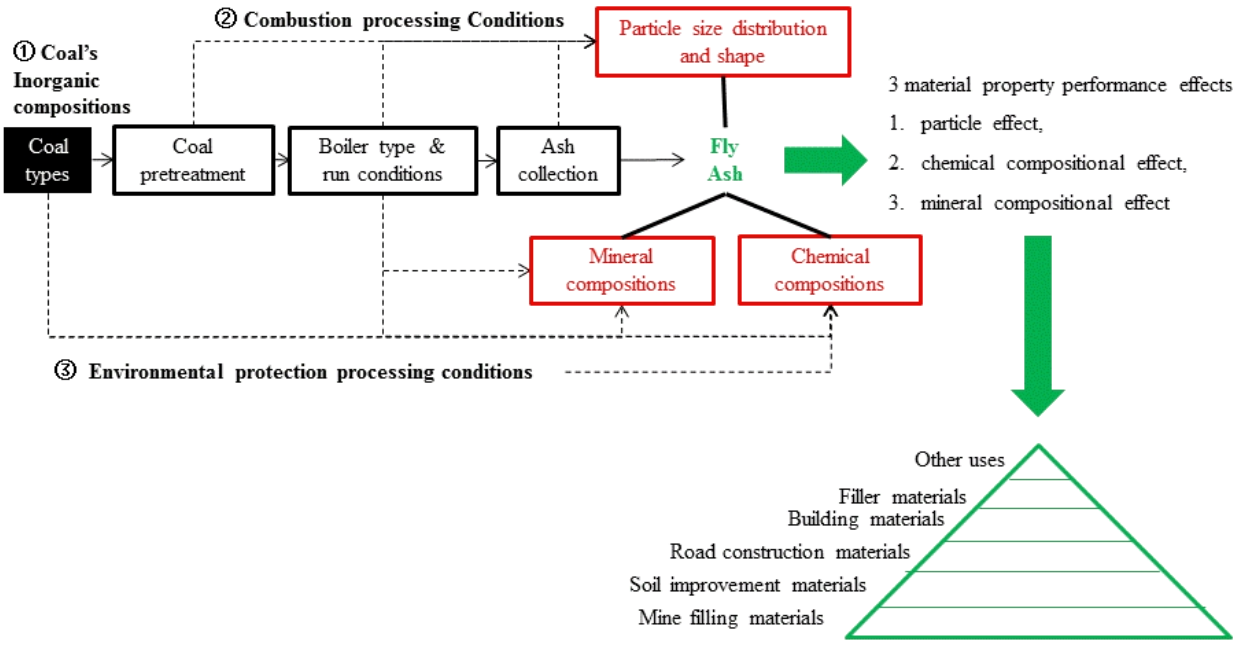

Fig. 1. Coal-fired power plant controlling factors to fly ash properties and uses

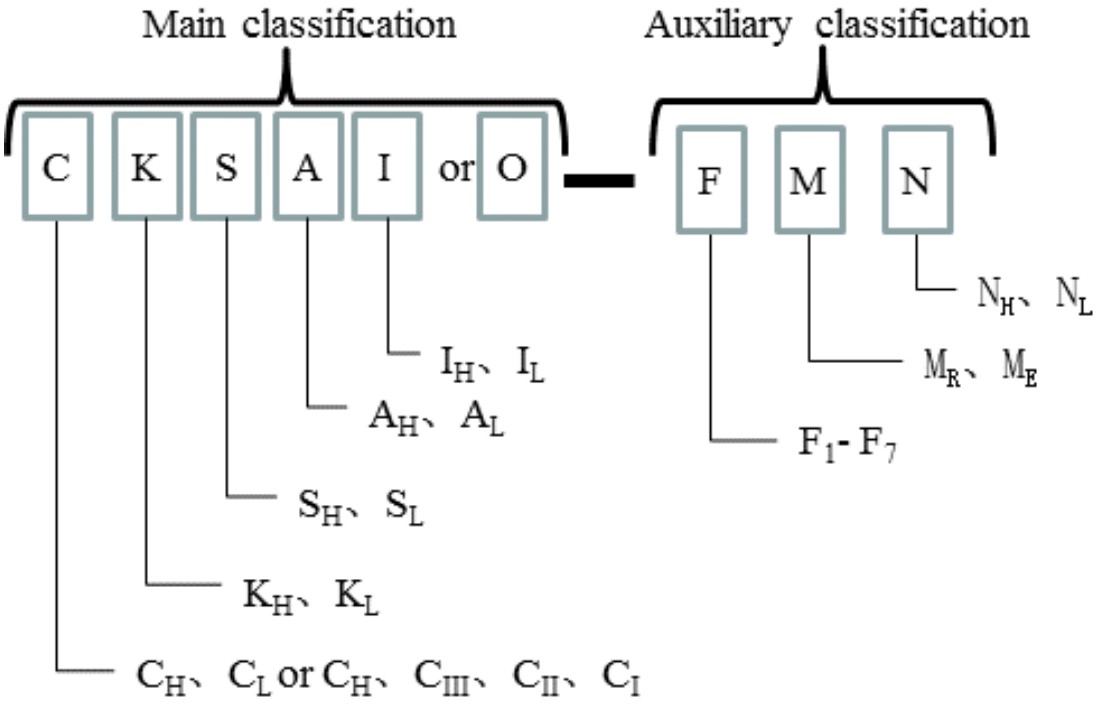

Fig. 2. Classification Marking

Table 1 classification types, modes, indicators and categories

Type	Mode	Indicators	Categories
Main classification	Chemical composition content	Carbon content or Loss on Ignition for pulverized ash only	High or low carbon ash
		Calcium oxide or free calcium oxide content	High or low calcium ash
		Sulfur oxide content	High or low sulfur ash
		Aluminum oxide content	High or low aluminum ash
		Ion oxide content	High or low iorn ash
		The above 5 cretieria meeting the low content level	Ordinary ash
Auxiliary classification	Particle fineness	D90 and 45 μm sieve residue	F_1–F_7 ash
	Particle shape	% spherical particles	Spherical shape ash or irregular shape ash
	Ammonium ion content content	Ammonium ion content	High or low ammonium ash

Table 2 Categories, index value and marks of main classification

Categories	Index value	Mark
High Carbon Ash	Carbon content > 5%	C_H
	LOI > 10% only for pulverized ash	C_H
	8% < LOI ≤ 10% only for pulverized ash	C_{III}
Low Carbon Ash	Carbon content ≤ 5%	C_L
	5% < LOI ≤ 8% only for pulverized ash	C_{II}
	LOI ≤ 5% only for pulverized ash	C_I

High Calcium Ash	Calcium oxide content> 10% or Free calcium oxide content>1%	K_H
Low Calcium Ash	Calcium oxide content ≤ 10% and free calcium oxide content ≤1%	K_L
High Sulfur Ash	Sulfur trioxide content > 3.5%	S_H
Low Sulfur Ash	Sulfur trioxide content ≤ 3.5%	S_L
High Aluminum Ash	Aluminum oxide content≥ 40%	A_H
Low Aluminum Ash	Aluminum oxide content< 40%	A_L
High Iron Ash	Ion oxide content > 8%	I_H
Low Iron Ash	Ion oxide content ≤ 8%	I_L
Ordinary Ash	All above are low contents	O

Table 3 Categories, index value and marks of auxiliary classification

Categories	Index value	Mark
Particle fineness	D90 ≤ 5 μm	F_1
	D90 ≤ 10 μm	F_2
	D90≤ 25 μm	F_3
	D90> 25 μm, 45 μm sieve residue ≤ 12%	F_4
	12% < 45 μm sieve residue ≤ 30%	F_5
	30% < 45 μm sieve residue ≤ 45%	F_6
	45 μm sieve residue > 45%	F_7
Round Shape Ash	Spherical particle content ratio ≥ 70%	M_R
Irregular Shape Ash	Spherical particle content ratio< 70%	M_E
High Ammonia Ash	Ammonium ion content >210 mg/kg	N_H
Low Ammonia Ash	Ammonium ion content ≤210 mg/kg	N_L

Table 4 Test methods for classification

Test Items	Test Method
Carbon content	T/CBMF 90 Appendix A
LOI	GB/T 176 for pulverized ash
Calcium oxide content	GB/T 176
Free calcium oxide content	DL/T 498
Sulfur oxide content	GB/T 176 suitable for pulverized ash GB/T 5484 suitable for circulating fluidized bed ash
Alumina content	GB/T 176
Ion oxide content	GB/T 176
D90	GB/T 19077
45 μm sieve residue	GB/T 1345
Spherical particle content	SY/T 5108
Ammonia content	DL/T 1984