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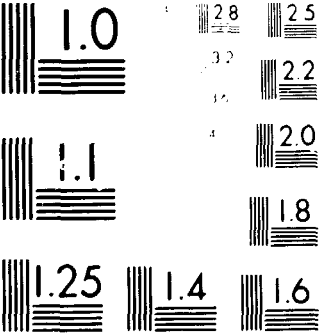
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METHODS OF EVALUATION AND PROSPECTS OF UTILIZATION OF WASTE AND BONE COAL AS FUEL AND RAW MATERIALS IN THE CEMENT INDUSTRY *

by

Qin Zhigang **
Jiang Zhigan **
Wang Yiguing **

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** Engineers, The Division of Cement, Research Institute of Building Materials, The People's Republic of China

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Preface

Coal is a major source of energy in China. The development of our national economy calls for production of more coal, and, as a result, the amount of spoil increases. According to statistics of the Ministry of Coal, the amount of spoil dumped up throughout the country at present has exceeded 1,000 million tons and is still increasing yearly. Of this figure, spoil with a heat value of 2,000 Kcal/kg claims 15 million tons; dressed spoil with a heat value of 1500-2,000 Kcal/kg heaped up on various coal-dressing mills has exceeded 15 million tons; thus, the total of combustible soil exceeds 30 million tons. According to a rough estimate, spoil dumped up in the vicinity of large-, medium- and a number of small-sized cement works in our country have exceeded 120 million tons. Spoil is occupying more and more land daily causing serious pollution. At some newly-built coal bases, there is little land to occupy, thereby, affecting the development of coal production. How to make effective use of spoil, therefore, has come into the attention of more people.

In south China there are large deposits of bone coal. Bone coal is a kind of coal inferior in quality and stone in appearance. Its geological term is carbonaceous rock. Its ash content is generally 50 - 90% and heat value 800 2,500 Kcal/kg. To a region that lacks high quality coal like south China, this forms a fuel resource not to be overlooked.

According to research carried out in our country, to utilise spoil and bone coal as raw material and fuel to substitute clay and coal partially or wholly to produce cement will not only broaden building material resources, but also form a source of energy that can be used comprehensively, thereby, minimizhing pollution and protecting the environment. This is an important measure in broadening the scope of energy resources, enlarging raw material sources and developing the cement industry as well as an important approach in the comprehensive utilisation of spoil and bone coal. Here we give a brief introduction of our research work and utilisation in this respect and present our concepts for further research for your discussion and study.

I. Spoil and bone coal as raw material for cement

1. The properties of spoil and bone coal and their influence on cement production

Spoil is the vein sandwiched between coal layers of a mine isolated in the process of mining and dressing. In reality, it is a mixture of carbonaceous rocks (carbonaceous shale, carbonaceous limestone and also a small amount of coal) and other rocks (shale, sandstone, etc.). As the geological age of the coal strata, the condition of mine formation, and the method of mining differ, the composition and structure of spoil also differ. When used as raw material for cement, differentiation is necessary so as to ensure rational utilisation.

Burnt (self-combusted or spoil slag) or unburnt spoil can both be used as raw material for cement. The composition of spoil from tunnelling and from the peel-off layer of open mines is complicated and of very low carbon content. They are mostly hard rocks like sandstone which generally cannot be used as raw material for cement.

; Bone coal is mostly poor quality coal formed by lower plants like fungi and algae of the paleozoic and late paleozoic periods. The nature of its composition and formation are not at all essentially different to mud carbon, lignite, bituminous coal and anthracite for they are all combustible deposited rocks. What is different is that it is lower in contents of carbon and volatile matter, higher in ash content than ordinary coal, and concomitant with some kinds of metallic elements. it is similar to low alumina spoil which primarily forms carbonaceous shale. In order to make a comprehensive use of spoil and bone coal, several institutions have done much research work on it.

A brief narration of their work is given below:

(1) Rock characteristics and mineral composition

Spoil and coal coexist in a geological stratum and belong mainly to the category of deposited rocks. Generally, this species of rock includes clayey rock, sandstone, carbonate and aluminous rocks. The composition of spoil and bone coal are mostly clayey minerals and α-quartz. It is possible to distinguish mineral species by their characteristics, and then deduce its composition and its influence on production.

(2) Chemical composition

The chemical composition of spoil is based on rock species and the variation of mineral composition. For instance, spoils of the clayey rock species are chiefly composed of SiO_2 and Al_2O_3. SiO_2 content fluctuates between 40-60%, while Al_2O_3 between 15-30%. The sandstone type of spoil has the highest SiO_2 content, generally reaching 70%. The Al_2O_3 content of the aluminous rock type is around 40%. The CaO content of carbonate spoil is around 30%.

The chemical composition of spoil and bone coal is the important basis for estimating their properties and determining their usage. Due to the influence of the variation in ash content, ignition losses will fluctuate, making it difficult to differentiate composition changes. In order to facilitate analytical study, the table below is listed according to the ash content in contrast to clay content.

Table I The chemical composition of some spoils, bone coals and clay (%)

Name of production locality	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Nanpiao Zhaojiatun spoil	48.60	42.00	3.81	2.42	0.35
Note: Mineralogical analysis: high aluminaous andalusite, -quartz with small amounts of calciclasitite, scaly quartz and hard anhydrite					
Yangquan Hanhe spoil	55.10	35.60	2.40	3.51	0.62
Anhui Lieshan Mine spoil	65.60	28.80	2.13	1.05	0.61
Shandong Hutian Mine spoil	60.28	28.37	4.94	0.92	1.26
Shandong Feicheng Mine spoil	60.90	22.41	6.76	2.94	1.70
Note: Mineralogical analysis: Kaolin, -quartz with small amounts of calciclasitite.					
Handan Fengfeng Mine spoil	58.88	22.37	5.20	6.27	2.07
Note: Mineralogical analysis: Kaolin ite, -quartz with small amounts of calciclasitite plagioclasite and carbonate of calcium-magnesium.					
Chenxi Mine spoil	76.50	16.45	3.45	1.32	0.60
Anhui Suxian clay	72.00	16.10	5.78	1.27	0.90
Handan Pengcheng clay	64.00	13.90	5.96	8.20	2.48
Zhejiarg Changshan bone coal	64.66	10.82	8.68	1.71	4.05
Hunan Changde bone coal	61.58	15.41	9.90	3.86	5.56
Changshan high silica bone coal	81.41	6.72	5.56	2.22	-

A look at the statistics in table I shows that the variation of spoil composition is very large. For convenience, we can divide the spoil into 3 kinds according to its Al_2O_3 content which affects proportioning considerably: low- (20 ± 5%), middle- (30 ± 5%) and high-alumina content (40 ± 5%). When mixed with commonly used limestone (divided into 3 types according to CaO content) and iron ore, and prepared according to the method of calculation of material for cement preparations for ordinary portland cement and "double-quick" (quick setting, quick hardening) cement (ash content of combustible coal included in the calculation of spoil ash content), we can show roughly the trend of variation of Al_2O_3 content in clinker and the type of cement we may expect to get:

Table II

Limestone CaO (%) → / Spoil (ash) Al_2O_3 (%) ↓ / Al_2O_3 cotent (%) in clinker, type of cement	53 ± 2		49 ± 2		47	
	Al_2O_3	Type of cement	Al_2O_3	Type of cement	Al_2O_3	Type of cement
Low alumina 20 ± 5	7	Portland cement Jet cement	≤7	Sulfate-resistant P.C. Portland cement	≤6	Oil well cement Sulfate resistant cement
Middle alumina 30 ± 5	7-10	Portland cement (High Al.) Jet cement	≤8	Portland cement (High alumina)	≤7	Portland cement
High alumina 40 ± 5	≥10	Jet cement Quick setting & quick hardening P.C.	7-10	Portland cement (High Al.) Jet cement	≤8	Portland cement (High alumina)

As the amount of silica contained in some limestones of one locality is high and in another low, and the quality of iron ore and other supplementary raw material and fuel vary a good deal, so the ingredients of spoil differ markedly. Therefore, the above table can only be used to estimate the trend of variation of cement.

(3) Proximate analysis

Proximate analysis includes the determination of water (W), ash content (A), volatile matter (V) and fixed carbon (C). From the results of proximate analysis, it is possible to estimate the amount of heat value, and carry out proportioning of raw mix and determine the amount of coal to mix. Heating value is an important index in appraising coal quality. Therefore, the proximate analysis of spoil and bone coal should be made as it was the basic data which must be determined when we use them as raw material and fuel for cement. Spoil and bone coal with high volatility should not be dumped high nor stored long so as to prevent spontaneous combustion. When heat is used to dry them, it is proper to some allowance for a higher moisture quota. When fire prevention measures are considered, they should receive the same treatment as coal used. Those that have low volatility and high ash content need not receive such an attention.

(4) Other problems

The chemical composition of spoils produced and dressed from the same coal seam is more stable. With different seams, fluctuation will be greater, and so it is necessary to heap them up separately when they are turned out of the mine and steps should be taken to prehomogenize them. To use them as raw material and fuel for cement, it is optimum to use the dressed the spoil at the present moment. Spoils that are of hard texture and difficult to grind, the additional installation for two-stage crushing is necessary. Some spoils contain rocks like sandstone and diabase. Although their composition is almost similar to clay, but due to their hard texture and their difficulty to be ground as well as their low carbon content, they are unsuitable for use as cement raw material. Nevertheless, as construction material for refilling mines, reclaiming lands and building roads, they are probably suitable. If spoil is far from cement works, the cost of transportation is too high to make its use economically rational, because the process of transportation itself consumes energy, thereby, losing the very meaning of utilising the spoil to save energy.

2. The production of ordinary Portland cement

In using low-alumina spoil and bone coal (for instance, those of Changshan and Changde) for the production of ordinary portland cement, the raw mix proportioning is practically the same as that for the ordinary raw material. Besides paying attention to crushing and prehomogenization, no special requirements are necessary in production.

In using middle- and high-alumina spoil for the production of ordinary Portland cement, it is necessary to consider the problem of quick setting and high f CaO content caused by high-alumina and low-silica character of the component of clinker derived. The solution can be got by changing the composition of the clinker or by using mineral additive to improve the properties of the cem ᵗ produced. The purpose is to use spoil entirely to replace clay as much as possible in order to introduce more heat into the kiln and achieve the result of more substitution of clay and greater economy in the use of coal. But in order to produce ord..nary Portland cement whose properties fully conform with the national standard specifications of cement whose demand would be the largest, partial minging of spoil into it is a very realistic measure. Besides producing clinker, calcinated spoil can also be used as mineral additive to produce pozzolanic cement and low clinker spoil cement. For instance, the Xuzhou Lime Works has succeeded in making use of spoil-fluidized bed furnace slag, etc. and blast furnace slag cement to be ground into the "gypsum spoil-fluidized bed furnace slag cement" with the collaboration of the Building Material Institute of Xuzhou and the Nanjing Institute of Chemical Technology. Its compression strength has reached 200 - 400 kg/cm^2 in three days, and 400 - 700 kg/cm^2 in 28 days. It is as convenient to produce as non-clinker cement, but if commercial cement of this kind is used instead of lime, the properties would be very much better than the non-clinker cement. This feature makes the speedy utilisation of local slags turned out from fluidized bed furnaces burning spoil on a broad scale and in huge amounts possible and full of practical significance. This type of cement, under the stimulation of a little amount of clinker will have a relatively higher degree of mechanism of hydration and hardening worthy of research, and so there are quite a good number of institutions in our country that are engaged in research work in this respect.

3. The production of special cement

Using middle- and high-alumina spoil instead of clay and bauxite can provide sufficient Al_2O_3 to produce a series of special cement with different setting time and quick hardening properties, and compounding material with early strengthening qualities for ordinary portland cement or with expansion agents for expanding cement. They can be divided into clinker containing calcium sulphoaluminate or calcium fluoaluminate (or both) minerals or silicate cement clinker containing relatively more calcium aluminates (C_3A, $C_{12}A_7$).

These types of cement have the following features:

(1) Quick setting and hardening, and conspicuous early strengthening. In general those with strength reaching 150-300 kg/cm^2 daily, and 400-800 kg/cm^2 in 28 days, can all be classified as the rapid-hardening cement type; (2) those used for anchor spraying of mine-tunnel supports can effectively replace the use of rapid setting agents that are not only inconvenient to use but also affect long-term performance; (3) in order to make use of early strength and high alkalinity properties of such cement, large quantities of industrial slag as spoil, fly ash, and slag can be mixed on site to produce large wall elements and building blocks, and save the trouble of steam curing; and (4) as mineralizer such as gypsum and fluorite are added into grown and early-strengthened mineral, it will bring about mineralisztion, hence lowering clinkering calcination temperature by 100 - 200°C.

Based on properties and experience in use, we know that this type of cement can also be used effectively in building underground tubes, tunnel works, spray coating material walls, cement for freezing well casing and well wall as well as repairing national defence construction feats such as underground facilities, emergency repair of airdrome runways, bridges, etc., in order to make some contribution in enhancing the development of industrialisation in architecture and speeding up the four modernisations.

By using low alumina spoil, for instance, Chenxi spoil, it is possible to produce $C_3A < 3\%$ sulfate-resistant cement. By using high silica bone coal (SiO_2 reaching 81.41%), it is possible to produce n = 3.5 - 5 clinker with quality reaching No. 500. It is not difficult to burn and its f, CaO content is 1 - 3%.

Let us introduce the properties of a few types of cement prepared from spoil and bone coal mixtures (see table III).

Table III The physical properties of cement

Type of cement	Fineness (%), or Specific aren(cm²/g)	Soundness	Setting time (hr:min) Initial set	Final set	Tensile strength kg/cm² 1 d.	3 d.	7 d.	28 d.	Compressive strength kg/cm² 1 d.	3 d	7 d	28 d.
Portland cement: Changshan bone coal.	5.6	Qualified	4:27	6:07	-	17.3	19.5	28.0	-	207	289	480
Portland cement: Handan spoil	(3139	"	2:01	3:25	-	25.6	27.9	30.4	-	390	479	617
Quick hardening P.C.: Anhui spoil	5.1	"	1:01	3:02	24.8	27.5	29.0	33.2	271	424	518	647
Jet cement: Guangdong	5.3	"	0:20	0:24	21.8	26.1	28.0	33.5	230	449	527	699
Quick set'g. Quick hard'g P.C.: Henan spoil	9.0	"	0:09	0:12	22.3	26.3	27.3	32.8	392	590	602	776
High strength P.C. Bldg. meter-ials Inst.	(3250)	"	1:33	2:25	24.6	32.8	34.4	40.9	358	523	672	852*

* Burning in rotary kiln

II. Spoil and bone coal as fuel for cement

1. The basic principles and technical approach

According to our research, the technological skill in using bone coal as fuel to burn cement clinker in a shaft kiln is based on the basic principle that after the combustion of fuel in the shaft kiln, heat is transmitted mainly in the conduction to the material with the feature of a very high efficiency of heat transfer. Raw materials such as bone coal and limestone should be ground mutually into raw meal with a definite chemical composition to form the "black" raw mix, and then add water to form pellets to be put into the kiln for burning. The combustibles in bone coal will serve as fuel to provide the heat, and its ash content as clayey raw material to become the clinker component.

In order to exploit the possible effect of bone coal as raw material and fuel to replace fine quality coal, the crux of the problem lies in diminishing heat loss by all means. Thus, heat value that satisfies composition requirements by mixing bone coal into it also meets the heat consumption required in burning raw material ial into clinker. In this way, there is no need to use any fine quality coal to burn cement clinker.

As to bone coal with too low heat value, the measure to be taken is to reproportion the composition or add into the mixture a small amount of powdered bone coal or fine quality coal so as to meat heat consumption requirements. With bone coal of high heat value, such methods as the preparation of high KH burning-endurable material, and the reduction of the flux amount of clinker can be used to proportion a proper mixture.

The principle in using spoil to replace clay and a portion of fuel is similar to the above.

2. Usage condition and actual results

using spoil and bone coal to produce ordinary Portland cement had been in practice for many years. As long as raw material can be obtained locally and long distance transportation can be avoided, financial advantages like economising the use of coal, substituting the use of clay and lowering cost can be realised. For example, the Liaoning Huazi Cement Works has a history of producing slag cement(ranked No. 400), ordinary Portland cement (ranked No. 500) for more than ten years. By 1978, the total output has exceeded 1.2 million tons - using up 140,000 tons of spoil and 90,000 tons of spontaneously burnt spoil. Besides economising the use of coal and substituting the use of clay, it has also offered protection to the environment. Large batches of cement products such as concrete electric poles, prestressed concrete sleepers, cement tiles, etc., have catered the needs of various in the whole province, while there are still products to be sold to other provinces. Structures like buildings in industrial plants, high-storey frames, chimneys and cylindrical storage bins made by this type of cement have, after more than ten years of service, proved themselves to be able to meet the requirements of their respective conditions of use just like the cement produced by the ordinary raw materials.

The number of shaft kiln works using spoil to produce cement in various provinces of our country so far reported has reached several scores.

After the Changshan Building Materials Works in Zhejiang province has succeeded in using bone coal to calcinate cement in 1975, the Changde Cement Works in Hunan, the Caijiagang Cement Works, and the Jiangshan Laohushan Cement Works in Zhejiang have also successively succeeded in their trial burning. At the end of 1977, a technical appraisal has been made. By 1979, Zhejiang province has built more than 30 new cement works utilizing bone coal with an annual output of 7,000 - 10,000 tons each. Hunan province has 25 cement works utilizing spoil and bone coal, of which the Xingxiang Tiangchong Cement Works with a Ø2.3 x 10 m semi-mechanical shaft kiln and the Yiyang Region Cement Works with a Ø2.5 x 10 m tower-grate type mechanical shaft kiln. Thus, this research item has enabled small cement works of places originally short of coal to develop rapidly. The cement produced has been widely used in local industrial and agricultural construction.

Viewed from the aspect of economic results, after the Changshan construction Materials Works has burned bone coal for manufacturing cement, production cost has been lowered by 25% approximately. To transport coal from the far north for this purpose is not at all profitable economically. Besides, workers who burn the kiln say that bone coal raw mix burns more easily than that with coal from north China. As such, although it has its north-China coal quota, no use is made of such coal for this purpose. The Changde Cement Works was originally running at a loss every year, but since began to use bone coal for burning cement in 1977, the savings in coal and the substitution of clay have combined to reduce production cost. Coupled with the promotion of technical management level, that very year the balance showed a gain instead of the usual loss.

At present the heat consumption of common shaft kiln cement works is 1,000 Kcal/kg clinker. If we use spoil with a 1,000 Kcal/kg heat value to substitute clay as an ingredient in the raw mix, it will introduce into the kiln 300 Kcal/kg heat for clinker, saving about 30% fine quality coal. Plus the easy combustibility of spoil, the actual heat consumption can still be lowered.

According to statistics in 1978, the standard coal consumption of clinker in Changshan Building Material Works (using bone raw mix) is 108.4 kg/ton; that for the Anhui Suxian Cement Works (using raw mix) is 110 kg/ton; and that for the Tunxi Cement Works (using bone coal, coal slag raw mix) is 115 kg/ton. They rank first, second and third as advanced units in low coal consumption (the Yunnan Haikou Cement Works and Suxian Cement Works tie for the second) for the whole country. When compared with average standard coal consumption quota for the same type of advanced cement works, theirs are still lower by 30% strong. The coal-saving effect of using spoil and bone coal mixtures is evident.

III. Prospects

1. The preliminary research results of spoil and bone coal as raw material and fuel for manufacturing cement have unveiled a new source of raw material and fuel for the cement industry, especially those cement works of small scale that are distributed throughout the whole country. A further development of this work will enable small cement enterprises of small scale to make full use of inferior quality fuel, such as spoil, bone coal, coal slag and even fly ash cement raw material,

and convert spoil, once considered an industrial waste, into a building material resource to be effectively utilised for the benefit of mankind through our endeavour.

2. The cement industry needs to consume a large amount of fuel. therefore, the study of how to broaden the source of fuel, to raise the rate of heat utilisation, and to make use of energy rationally are problems of great significance. Our research indicates that using spoil and bone coal raw mix in shaft kilns will economise a large amount of high quality fuel. To utilise fully the heat furnished by carbonaceous material as spoil, raises the rate of heat utilisation and lowers heat consumption, and so to increase the amount of fuel burned in the kilns or the whole burning equipment (for instance, grate preheated kiln, or preheater kiln) may possibly be effective measures that will tap the potential to increase production of present rotary kilns.

3. In order to achieve the purpose of economising energy effectively, research needs also be made in a finer grinding of spoil to serve as mineral additive of cement and prepare low clinker cement from spoil. This will use up less clinker and will decrease the amount of spoil and cement to be transported for long distances.

4. The amount of spoil used up in producing cement is quite limited; but when cement is used as a kind of concrete material, spoil with required physico mechanical properties can be used as the aggregates for cement products. According to our study, in material used for walls having spoil-made cement to bind the aggregates made of spoil, spoil used amounting to

80 - 85% of the whole. Therefore, cement production has become one of the effective measures in furthering the comprehensive utilisation of spoil and bone coal slag.

Cement produced from spoil with a high Al_2O_3 content sets and hardens rapidly that poses a problem. But if the prepared mixture is immediately poured into the mould after mixing during the making of a product, fast setting and hardening may do away with steam curing and become an advantageous factor. In concentrated use in factories such technical measures as the application of water reducing agents and setting retarders may be taken when necessary. Therefore, using spoil entirely to substitute clay as much as possible (will bring in more heat) to produce quick setting and quick hardening cement is also an effective way to economise the use of energy.

IV. Summary

1. In trying to use spoil and bone coal to substitute clay and partial bauxite as cement raw material to produce ordinary portland cement and special cement, we have explored the use of spoil and bone coal with various ingredients in producing cement of different properties, and mastered their major technical breakthroughs in production and their technical performance. From now on we intend to do more service tests and to make a deeper study of the problems (like prehomogenization measures, etc.) in production and service performance, especially the long-term service performance, that we may provide data for further development.

2. Using spoil and bone coal as fuel for shaft cement kilns, the results in economising good quality fuel and lowering heat consumption are conspicuous. In places where there are conditions to do so, it should be introduced as a technical measure to economise energy. To substitute them for clay in mixtures for rotary kilns, encouraging results in increased production and economy in coal have also been obtained. Thus, it is worth the pains to carry out more intensive

tests in large- and medium-sized works for gradual dissemination.

3. Using spoil and bone coal to produce cement is an important approach in their comprehensive utilisation. Cement as a raw material for bonding spoil and bone coal slag to produce cement products is not only an effective means in using spoil and bone coal slag comprehensively, in reducing pollution and protecting environment, but also in diminishing energy consumed in excavating natural material for building purposes.

4. The investigation in using spoil and bone coal as raw material and fuel for cement has for many years been taken as an important research topic in broadening the scope of construction material resources, saving fine quality coal, lowering heat consumption, using energy resources rationally, reducing pollution and protecting the environment of our country. Much work has been done in this direction and preliminary results have been got in industrial production. However, most of it is still production on a small scale at present, and research and development of special cement is still in the intermediate expermental stage. Further research is still necessary so as to embark on long-term, large-scale production that a more extensive financial benefit may be achieved.