Review Article

A review study on performance improvement of coal gangue as coarse aggregate in concrete

ABSTRACT

The use of coal gangue as coarse aggregate alleviates the dependence of concrete on natural aggregates and improves the utilization rate of coal gangue resources. The direct use of coal gangue coarse aggregate in the preparation of concrete limits the scope of its use due to the deterioration of its performance. Therefore, the improvement of the performance of coal gangue coarse aggregate concrete should become a research focus. This article briefly describes the basic characteristics that coal gangue coarse aggregate should have and the shortcomings of existing research. It summarizes the existing methods for improving the performance of coal gangue coarse aggregate concrete. After pre wetting treatment, calcination, slurry coating, and material adjustment, the performance of coal gangue coarse aggregate concrete is improved. Multiple methods of collaborative treatment can improve the comprehensive performance of coal gangue coarse aggregate concrete, To provide some reference for achieving efficient utilization of coal gangue.

Keywords:Coal gangue; Coarse aggregate; Concrete performance improvement.

1. INTRODUCTION

Coal gangue and natural aggregate have similar physical and chemical composition and rock characteristics, which makes it become a hot spot in the study of replacing natural concrete aggregate, and also provides a new idea for solving the environmental problems caused by a large amount of coal gangue accumulation[1]. The resource utilization of coal gangue is realized in the fields of power generation, building materials, landfill, chemical industry and high value -added industries, but the annual utilization rate is still only about 65%, which is one of the largest industrial solid waste varieties in China[2].

The fluctuation of performance and mineral composition caused by different places of coal gangue directly determine whether coal gangue can replace natural aggregate for the preparation of concrete[3]. The study of using coal gangue as concrete coarse aggregate shows that with the increase of coal gangue coarse aggregate content, the fluidity of concrete decreases [4-6], and the strength of concrete also decreases [7,8]. The coarse aggregate of coal gangue has the characteristics of low strength, large water absorption rate, pores and cracks, which improves the capillary water absorption characteristics of concrete and seriously affects the durability of concrete[9]. The deterioration of the performance of concrete directly prepared by coal gangue as coarse aggregate makes the improvement of the performance of coal gangue coarse aggregate concrete become the focus of research.

This paper briefly describes the basic characteristics of coal gangue as a coarse aggregate of concrete, summarizes and discusses the existing ways to improve the performance of coal gangue concrete, explores the change of the performance of coal gangue coarse ag-

gregate concrete after improvement and its practical feasibility, which has reference significance for realizing the efficient utilization of coal gangue. It is of great economic and practical significance to accelerate the resource utilization of large amount of industrial solid waste and realize sustainable development.

2. BASIC PROPERTIES OF COAL GANGUE COARSE AGGREGATE

2.1Physical and chemical properties of coal gangue

Coal gangue is a carbon-bearing rock produced with coal, which can be divided into two categories: spontaneous combustion coal gangue (reddish brown or yellow) and undisturbed coal gangue (gray or brown black). Compared with natural crushed stone, it has the characteristics of porous, high-water absorption and high pressure crushing value[8]. With the increase of carbon content, water absorption and crushing value increase, and apparent density decreases [10]. The main chemical composition of coal gangue is SiO_2 and Al_2O_3, containing a small amount of metal oxide and carbon, according to the oxide content can be divided into four categories: clay rock gangue, sandstone gangue, aluminum rock gangue and calcareous rock gangue [11]. Its main mineral composition includes: kaolinite, quartz, illite, feldspar, montmorillonite, calcite and Muscovite and so on[12].

2.2 Safety of coal gangue coarse aggregate concrete

As the main part of modern buildings, concrete is in close contact with people for a long time. Thermal insulation concrete and foam concrete are prepared with coal gangue coarse aggregate, which must ensure that it is not harmful to human body. Few existing studies take safety as a consideration factor in feasibility studies. Bai Guoliang et al.[3] conducted radioactivity tests on coal gangue from different mining sources in northern Shanxi, and the test results met the radioactivity requirements of rubble production from waste rock. GB 6566 -2010, Radionuclide Limit for Building Materials, proposed that the internal and external radiation index of the main building material should not be greater than 1.0. When coal gangue is used as concrete coarse aggregate, the radioactive detection and harmful substance content detection should be paid attention to in order to avoid harm to human body.

2.3Mineral composition of coarse aggregate of coal gangue

The proportion of SiO_2 and Al_2O_3, the main chemical components of coal gangue, is an important influencing factor in the utilization of coal gangue. According to the different mineral composition and mineral content, it can be divided into clay rocks, carbonates, quartzites, etc. Quartzites can be used as concrete aggregates[13].Coal gangue with low mass fraction of organic matter, high mass proportion of rock facies and high hardness has the potential to be used as concrete aggregate[14]. "Code for Design of Environmental Protection of Coal Industry" GB 50821 -2012 classifies the main utilization ways of coal gangue according to its rock characteristics. Among them, sandy mudstone, sandstone and limestone can be used as raw materials for the production of crushed stone and concrete dense aggregate for construction projects.

The chemical composition and mineral composition of coal gangue will be decisive factors for its strength [10]. Bai Guoliang et al. [3]found that the mineral groups of coal gangue in various mining areas in northern Shanxi are mainly quartz and clay minerals, which have similar mineral composition to sandstone, and can be used as coarse aggregate for concrete. Chen Leizhang et al. [15] used mixed gangue, sandstone gangue and shale gangue as coarse aggregates to prepare concrete, and found that sandstone is harder and denser, and sandstone gangue was ideal as coarse aggregate for concrete. Xiao[16] found that with

the increase of SiO_2 content, the strength of coarse aggregate of coal gangue also increases. When the SiO_2 content is greater than 70%, it belongs to sandstone gangue, which highlights the characteristics of large particle size and poor plasticity. Qiu Jisheng et al. [17] found that the chemical composition has a certain influence on whether it can be used as coarse aggregate, and the coal gangue with high SiO_2, CaO and Al_2O_3 content and relatively low Fe_2O_3 content should be selected as the coarse concrete aggregate. Benarchid Y et al. [10]showed that with the increase of Al_2O_3 content, the water absorption and dewatering of the formed kaolinite increased the dry shrinkage and wet expansion of concrete, deteriorated quality and reduced durability.

2.4Carbon content of coarse aggregate of coal gangue

"Coal industry environmental protection design Code" GB 50821-2012 according to the different carbon content and calorific value of coal gangue, the utilization of coal gangue is divided into four categories. A kind of coal gangue that can be used as concrete coarse aggregate and building materials raw materials should meet the requirements of calorific value less than 2090 $kJ \cdot kg^{-1}$ and carbon content less than 4%. The research[10] shows that the carbon content of coal gangue and calorific value are roughly positive correlation, the lower the carbon content and calorific value, the closer the property of coal gangue is to natural coarse aggregate,the lower the water absorption rate and crushing value, the greater the apparent density.

3.PERFORMANCE IMPROVEMENT METHOD OF COAL GANGUE COARSE AGGREGATE CONCRETE

The performance of coal gangue coarse aggregate concrete is mainly restricted by the defects of coal gangue aggregate itself, and the improvement of its performance is the key link to improve the utilization efficiency of coal gangue [19]. The commonly used ways to improve the performance of coal gangue coarse aggregate concrete in existing research include: bulk treatment of coal gangue coarse aggregate, such as pre-wet treatment, modification technology; Material adjustment of coal gangue coarse aggregate concrete, such as adjusting sand rate, adding admixture, fiber and adjusting water reducing agent, etc.

3.1 Improvement of concrete performance by bulk treatment

Prewetting treatment of coal gangue coarse aggregate can improve the working performance of concrete. Zhou Mei et al.[20] found that when the amount of additional water reached 80% of the saturated water absorption rate of coal gangue aggregate, it could meet the workability requirements of large flow concrete. Prolonging the pre-wetting time can enhance the secondary hydration effect and increase the microhardness value at the interface[21].Research [22, 23] found that the amount of additional water has an impact on the performance of no-spontaneous combustion gangue concrete. The saturated surface dry state can improve the compressive strength and elastic modulus of the concrete, but it will reduce the splitting tensile strength of the concrete; Duan Xiaomu et al. [24] found that after pre wetting the coal gangue aggregate for 24 hours and without pre wetting, the internal water molecules of spontaneous combustion gangue aggregate filled the pores and did not absorb the water inside the cement matrix. Compared with the non pre wetting group, the compressive strength and elastic modulus of the concrete were improved. After pre-wetting of no-spontaneous combustion gangue aggregate, the internal water molecules are not completely absorbed by the aggregate, and the water cement ratio of the cement slurry increases, resulting in a decrease in compressive strength and elastic modulus compared to the non pre wetting group.

After high temperature calcination, the carbon and organic matter in the coal gangue are removed, and the kaolinite is transformed into active metakaolinite[11]. The internal structure and interface transition zone performance of the concrete prepared under this condition are improved [19]. Yang et al. [25] found that with the increase of calcination time, the water absorption rate of coal gangue increases, and the fluidity of its concrete mixture gradually decreases; The strength of calcined coal gangue coarse aggregate concrete is higher than that of natural coal gangue coarse aggregate concrete, and surface activated coal gangue can improve the strength of concrete more than fully activated coal gangue, that is, thermal activation treatment only needs to ensure the surface activation of the aggregate. Chen Jiuquan et al. [26] also concluded that the compressive strength of concrete prepared by calcining coal gangue coarse aggregate is higher than that of the non calcined group. Zhu et al. [27] prepared concrete by calcining coal gangue aggregates at 750℃. The compressive strength and microhardness at the interface transition zone at 7 and 28 days were significantly improved compared to the original coal gangue concrete, and the performance was improved. After calcination, active SiO_2, Al_2O_3 and cement hydration product $Ca(OH)_2$ on the surface of coal gangue aggregate undergo secondary hydration, and the C-S-H gel generated can compact the internal pores, reduce the transmission channel of CO_2, and have better anti-carbonization properties [28].

Cement slurry forms a coating shell on the surface of coal gangue, which can improve the structure of coal gangue coarse aggregate, and the C-S-H gel generated by hydration can improve the strength and performance of coal gangue coarse aggregate. Yao Zhixin et al.[14] found that the performance of the undisturbed coarse aggregate of coal gangue after slurry coating was improved, and the strength and durability of the concrete prepared by it were also enhanced, and the performance of concrete had a good correlation with the performance of aggregate.Gao Wenzhi [29] treated coal gangue coarse aggregate with slurry and prepared concrete with strength grades of C15~C40. It was found that the compressive strength of the concrete after 28 days was higher than that of untreated coal gangue coarse aggregate concrete, and the compressive strength of coal gangue coarse aggregate concrete continued to increase. When active mineral powder is added to cement grout, it can be rehydrated with cement hydration product $Ca(OH)_2$to generate C-S-H gel, which further improves the strength and performance of aggregate. The use of coal gangue coarse aggregate is equivalent to increasing the amount of cement, reducing the water-binder ratio, and filling the pores and interfacial transition area of coal gangue coarse aggregate concrete[30].

3.2Material adjustment to improve the performance of concrete

3.2.1 Working performance

Adding fly ash or using high efficiency water reducing agent can improve the performance of concrete. Zhu Kai [31] found that with the addition of fly ash, its ball effect makes the slump of newly mixed concrete gradually increase, which improves the working performance of spontaneous combustion coal gangue aggregate concrete. Li Yongjing et al.[32] found that compared with the use of naphthalene superplasticizer, the use of polycarboxylic acid superplasticizer can more efficiently reduce the slump loss over time, and the combined use of polycarboxylicacid superplasticizer and air entraining agent has a better effect.

3.2.2 Mechanical properties

Wang et al.[33] found that the grading of coal gangue aggregate is related to the strength of concrete. When the grading index of the fuller's grading curve is n=0.62, both the density and strength of concrete reach the maximum, and can meet the strength requirements of C30 concrete. Wang Shuangzhen et al. [34]added different proportions of steel fibers into

coal gangue coarse aggregate concrete and found that when the content was 2%, the 28d compressive strength, tensile strength and flexural strength of coal gangue aggregate concrete increased by 16.4%, 66.5% and 72.3%, respectively, compared with the concrete without steel fibers. Yang Qiuning et al.[35] mixed polyvinyl alcohol (PVA), polypropylene (PP) and steel fiber (ST) into coal gangue coarse aggregate concrete, and found that there was the best dosage, and its mechanical properties were not lower than that of ordinary coal gangue aggregate concrete, and the splitting tensile properties were improved more significantly. The study found that adding a certain amount of basalt fiber [36] or glass fiber [37] can improve the compressive strength and splitting tensile strength of coal gangue aggregate concrete, and within a certain range, increasing the fiber content can reduce the cracking of coal gangue aggregate concrete.

3.2.3 Durability performance

Research has found that water cement ratio and concrete strength are the main factors affecting the durability of coal gangue coarse aggregate concrete [38-41],due to the existence of its own cracks and pores, coal gangue improves the capillary water absorption characteristics of concrete, and harmful ions enter into the concrete matrixwith water molecules, which seriously affects the durability of concrete[9]. The antifreeze property of coal gangue aggregate concrete can be improved by using high efficiency water reducing agent[42]. When the coal gangue aggregate concrete is mixed with slag micro-powder or fly ash, silica fume and slag, the porosity of the concrete can be improved, and the frost resistance, chloride ion permeability and sulfate erosion resistance can be improved[43-46]. Zhu Kai et al.[47] found that the addition of polypropylene fiber can inhibit the microcracks of coal gangue pavement concrete, and achieve the purpose of improving the freeze -resistance of spontaneous combustion coal gangue pavement concrete. Wang Shuangzhen et al.[34] found that the addition of steel fiber can reduce the micro-cracks of mortar matrix and improve the chloride ion penetration resistance of coal gangue aggregate concrete.

4. CONCLUSION

Coal gangue as a coarse aggregate of concrete provides a new idea for its bulk utilization, and the improvement of the performance of coal gangue coarse aggregate concrete can make up for the performance defects of concrete caused by poor basic performance of coal gangue, which has practical significance for its large-scale application in concrete. As the main body of the building, coal gangue must be tested for radioactive and harmful substances in the process of use to meet the requirements of no harm to the human body. In the process of use, the difference in the basic performance of aggregate has a significant impact on the performance of concrete. In addition to the control of water absorption and crushing value and other indicators, it is still necessary to control the mineral composition and carbon content of coal gangue coarse aggregate. A single performance improvement method can not improve the performance of coal gangue coarse aggregate concrete in a full range, the use of a variety of performance improvement methods combined use of means, can better meet the needs of concrete performance in the actual project.

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