Influence of engineering properties of machine-made sand on concrete performance: A review

Abstract: As the demand for high-quality concrete in the construction industry increases, mechanically produced sand, which is a substitute for natural sand, has received widespread attention due to its abundant resources and environmental friendliness. This review aims to explore the engineering properties (such as particle shape, gradation, and fines content) of manufactured sand and their impact on concrete performance, emphasizing its important role in promoting green construction and sustainable development. By systematically reviewing recent relevant studies, this paper determines the optimal range of fines content and discusses the impact of different particle shapes on workability and strength, highlighting the critical role of reasonable gradation and parent rock properties. The study shows that the application of manufactured sand can significantly improve the mechanical and durability properties of concrete, reduce dependence on natural resources, and reduce carbon emissions. To further promote research and technological progress in this field, it is suggested that future studies should explore the long-term durability of manufactured sand, develop more efficient sand production technologies, and optimize the mix design to achieve more environmentally friendly and economical construction solutions.

Key words: machine-made sand, parent rock lithology, particle gradation, particle shape, stone powder content, concrete performance.

0 Introduction

With the gradual emphasis on environmental issues in China, natural sand, as a non-renewable resource, has its extraction restricted to a certain extent. To address

this issue, scholars [1-4] have suggested, after research, that natural sand be replaced with machine-made sand obtained by removing soil, crushing, and screening raw materials such as granite and limestone, thereby obtaining machine-made sand concrete with performance similar to that of traditional concrete. The substitution of increasingly scarce natural sand with machine-made sand has become an inevitable trend in the development of ecological building materials. Machine-made sand is characterized by numerous angular edges, multiple cracks, irregular shapes, a large number of flaky particles, and a high content of stone powder [30,31]. These characteristics can lead to errors in gradation design and affect the working performance and mechanical properties of machine-made sand concrete. To meet the requirements of construction and strength, this paper analyzes and summarizes the influences of particle shape, fineness modulus, stone powder content, etc. on the performance of machine-made sand concrete. Based on the deficiencies in existing research, suggestions are proposed for reference in subsequent studies.

1 Characteristics of machine-made sand

The emergence of machine-made sand, to a certain extent, can replace river sand as a fine aggregate of concrete, the reasons are: first of all, in order to meet a variety of engineering requirements, specific projects need to use customized machine-made sand, through mechanical grinding machine-made sand grading is convenient and reliable; Secondly, in terms of surface roughness, natural sand is smoother than machine-made sand, the former is eroded by rain, while the latter is made by mechanical crushing, so machine-made sand can better play the role of fine aggregate filling than natural river sand, thereby improving the workability of concrete; Secondly, in terms of mechanical properties, the compressive, tensile and flexural strength of machine-made sand concrete are higher than that of river sand concrete, and the dry shrinkage rate is lower; Finally, the production of machine-made sand is more green, economic and environmental protection, and can be produced by concrete waste or crushed stone to

realize waste utilization [32-34]. However, it also has some shortcomings, such as the boundary of 0.075mm, below this grade of machine-made sand made of concrete is less strong. The characteristics of machine-made sand are described in detail below. Production characteristics:

（1）Particle grading: The particle distribution of machine-made sand can be roughly summarized as the characteristics of large two ends and less in the middle, with 2.36mm and 0.15mm as the boundary. There are more particles than the former and less than the latter, and there is still a grain grade without sand. In general, the gradation of machine-made sand can meet the technical specification requirements of river sand.

（2）Particle shape: The production of machine-made sand is made by mechanical crushing of rock, ore or building waste material, so its shape is mostly irregular, which is mostly flaky particles. the rough surface of the particles and its irregular shape can help the cement mix better.

（3）Stone powder content: The presence of stone powder distinguishes machine-made sand from natural river sand. The addition of stone powder can improve the workability, pumping performance and aggregate grading of concrete. The performance of all aspects of concrete has been significantly improved. However, too much stone powder has a significant impact on its working performance, so the content of stone powder needs a limit[29].

2 Mechanism the effect of sand mother rock lithology on concrete performance

Essentially, manufactured sand is the small-sized product that conforms to standards after crushing the large-sized raw materials such as natural rocks, engineering waste or mining tailings. Therefore, the properties of manufactured sand are closely related to those of its parent rock. In different regions, due to the variations in natural and geographical factors, the properties of rocks such as limestone and granite, which serve as the parent rocks for manufactured sand, differ significantly, and thus have different influences on the properties of manufactured sand. Therefore, many

researchers have conducted a large number of experiments and discovered that the properties of manufactured sand of different lithologies vary considerably, thereby leading to certain differences in the properties of manufactured sand concrete. [15].

Wang Jili[1]ang studied the influence of six representative lithology stone powders such as quartzite, gneiss, granite, basalt, limestone and marble on the effect of chemical admixtures and on the performance of concrete. The results show that the change of lithology of stone powder has a slight effect on the workability, strength and volume stability of concrete, but the difference is not significant, and the change of lithology of stone powder has no effect on concrete durability.

Zhong Guoca[2] used diorite, granite, basalt, and limestone as parent rocks and produced sand from them under the same production process. He systematically tested the gradation, fineness modulus, particle morphology, angularity, and specific surface area of the four types of manufactured sand. The test results show that the fineness modulus of the manufactured sand prepared from the parent rock is larger when the fine-modulus deviation from the design value is larger, the specific surface area is smaller, the angularity is stronger, and the particle morphology is more irregular.

Song Shaom[3]in et al., under the condition of the same gradation and grain shape of machine-made sand, carried out concrete performance tests on 6 kinds of common machine-made sand with different lithology, and studied the influence of machine-made sandstone properties on the properties of colloidal sand and concrete. The results show that the lithology of machine-made sand has a great influence on the workability of concrete, and the calcareous machine-made sand is superior to the siliceous machine-made sand on the whole. Granite, tuff and gneiss sand have great influence on the workability of concrete. The surface texture, stone powder adsorption and chemical composition of sand with different lithology mechanism have no significant influence on the strength of concrete.

Taking limestone, pebble and basalt sand as fine aggregate and concrete strength grade as variable parameter, Xie Kaizhong[4] et al. found that the failure forms of these three lithologic sand concrete were roughly the same during uniaxial compressive test. The mechanical properties of machine-made sand concrete are related to the physical

characteristics of fine aggregates of different lithology.[28] With the increase of fineness modulus or the increase of stone powder content, the peak stress and peak strain of machine-made sand concrete specimens increase first and then decrease. The elastic modulus of pebble-made sand concrete is higher than that of limestone and basalt made sand concrete.

3 Effect of sand particle shape on concrete performance

The difference between machine-made sand and natural sand in particle shape morphology mainly lies in the difference between particle shape and surface roughness. Under the long-term action of water erosion and wind erosion, natural sand has a more rounded surface and is more like a spherical particle as a whole compared with the formation conditions of mechanical crushing of machine-made sand. The surface of the machine sand is rough, and the shape is varied, there are more needle-like and flaky particles, relatively speaking, angular. Therefore, in some more demanding projects, such as road and railway beams, pile foundation and other road projects, natural sand concrete can often show better working performance than machine-made sand concrete.

Generally speaking, spherical particles have better compactness, that is, a smaller void ratio. Due to the "inherent deficiencies" of manufactured sand, during the concrete mixing process, the manufactured sand particles must be adequately coated with slurry materials to form a particle shape similar to that of natural sand in order to exert better working performance. Therefore, for the same volume of manufactured sand concrete, more colloidal materials such as water and cement are required to fill the more voids of manufactured sand compared to natural sand. This is prone to causing bleeding and segregation during the concrete mixing process, reducing the working performance of concrete.

However, the increase of voidage makes the slurry material more perfect, which

can improve the durability and flexural strength of concrete, that is, the mechanical properties of concrete are more significant.

Chen Can[25] et al. explored the relationship between the mechanical sand type and the fluidity, rheology parameters and strength of mortar by studying the influence of different mechanism sand types on the workability, rheology and mechanical properties of mortar. It is found that machine-made sand with better grain type can effectively improve the workability and rheology of mortar, and the strength of machine-made sand mortar is basically greater than that of natural sand, and the overall correlation between mortar workability and rheology is good.

Zhou Xinwen et al. [26] employed digital image processing (DIP) technology to quantitatively characterize the shape of sand particles and discovered that the degree of rod-shaped and flake-shaped particles in manufactured sand was higher than that in natural river sand. The rheological curve of mortar indicated that the irregular shape of sand particles would lead to an increase in the flow resistance of mortar. The yield stress of mortar composed of manufactured sand was 1.5 times that of natural river sand mortar. The apparent viscosity of manufactured sand mortar was greater than that of natural river sand mortar, especially at low shear rates. The rough surface feature of manufactured sand particles also exerts an influence on the workability of concrete, but the impact is not as significant as that of particle shape. Therefore, there are relatively fewer research achievements in this regard.

Ahn[27] believes that in the case of the relatively rough surface of the machine-made sand, although the bonding performance of the slurry material has been improved, relative to the whole, these improvements are a drop in the bucket, because the change of roughness will also lead to changes in voidage, etc., which will also have an adverse impact on the shear and tensile strength of concrete. On the contrary, the strength and performance of concrete are declining.

4 Effect of sand and gravel powder content on concrete performance

One of the differences between machine-made sand and natural sand is that in the production of machine-made sand, a certain amount of stone powder will be produced, which is the same material as the mother rock of machine-made sand. According to the content of stone powder, the grading of machine-made sand will have different effects. Even the same content of stone powder will have different consequences on the working performance and mechanical properties of concrete. Therefore, at present, scholars at home and abroad have carried out a lot of research on the influence of stone powder content on concrete performance, but there are still huge controversies.

However, for the influence of stone powder on the performance of concrete, there is a consensus that the appropriate amount of stone powder can improve the performance of concrete, but if the limit is exceeded, it will have an adverse impact on the performance of concrete. Therefore, for the content of stone powder in machine-made sand, there is a limit value in all countries, the maximum limit value is 10% in our country, 7% in the United States, Japan, and up to 15% in Britain, France and other countries. However, due to the actual situation of different parts of the country, local standards are different on the basis of national standards, such as in Shanxi, the content of stone powder below C25 is up to 20%, C30~C55 is up to 15%, and C60 is 6%.

Liu Shuhua[16] studied the hydration properties and hydration products of limestone powder in composite cementing materials and found that the incorporation of limestone powder will reduce the strength of composite cementing materials, but the influence on the later strength will gradually decrease; In the early stage, the hydration degree of limestone powder and ordinary silicate cement is low, and in the later stage, it will hydrate with aluminate to produce hydrated calcium carboaluminate; Under the excitation of calcium aluminate cement, limestone powder can participate in the hydration to produce calcium aluminate hydrate in the early stage. Therefore, the stone powder can improve the early strength of the concrete material, but it is not good for the

later strength.

Sherong Zhang[17] et al. found that concrete with 10% SF and 5~ 20% WMP has the best mechanical properties; SF and WMP have significant effects on the water absorption of concrete; The optimum concrete mix has obvious sulfate acid resistance; The addition of SF and WMP improves the microstructure of concrete.

Yu Zewen [18] et al. conducted an experimental study to explore the influence of stone powder content on the workability, mechanical properties, homogeneity, and dry shrinkage of C40 machine-made sand concrete. It was discovered that stone powder can enhance the cohesion and water retention of the machine-made sand concrete mixture, avoid bleeding and segregation, and simultaneously increase the flexural, splitting tensile, and compressive strengths of the concrete. Moreover, when the stone powder content is within the range of 10% to 15%, the improvement effect on the concrete's workability and strength is the best. With the increase in stone powder content, the homogeneity of the concrete improves. However, when the stone powder content exceeds 10%, the improvement in homogeneity tends to stabilize. The early dry shrinkage of machine-made sand concrete increases with the increase in stone powder content, while the dry shrinkage after 7 days is the maximum when the stone powder content is 10%.

CAI Jiwei[19] studied the influence of stone powder on the properties of cement and concrete. For the poorly graded machine-made sand, stone powder can improve the workability of machine-made sand concrete. The content of stone powder has an effect on the compressive strength, flexural strength and dry shrinkage of concrete. The content of stone powder can also affect the axial compressive strength and splitting tensile strength of machine-made sand concrete, and the enhancement amplitude increases with the increase of stone powder content. The elastic modulus depends on the influence of stone powder on the strength and the amount of slurry. Stone powder can enhance the impermeability of concrete. High strength machine-made sand concrete has high frost resistance, and the influence of stone powder content on it is not obvious. The frost resistance of medium and low strength machine-made sand concrete is lower than that of natural sand concrete, and stone powder can slightly improve the

frost resistance. Stone powder can make the transition zone of concrete dense and improve the pore structure, so as to enhance the performance of machine-made sand concrete.

Hong Jinxiang [20], Yue Haijun [21], Li Beixing [22] et al. conducted a large amount of research on the stone powder content of manufactured sand and its influence on the performance of concrete, including the influence on concrete of different strength grades and the experience in the preparation of high-strength concrete. Yu Bentian [23] et al., through the analysis of the stone powder content of manufactured sand based on granite lithology, obtained that concrete has better mechanical and durability properties when the stone powder content is 8%.

LAN Cong[24] et al. 's study on the mechanical sand powder content of limestone lithology shows that different sources of limestone mechanical sand powder mainly affect the unit water consumption, water reducing agent content and mechanical properties of concrete. High-quality limestone sand powder can obviously improve the interfacial transition zone of concrete and increase the compressive strength of concrete.

5 Effect of mechanical sand particle grade on concrete performance

The distinction between manufactured sand and natural sand in terms of grain shape and morphology mainly resides in the differences in particle shape and surface roughness. Under the long-term influence of water flow scouring and wind erosion, natural sand has a smoother surface and is more spherical in shape compared to the formation conditions of mechanically crushed manufactured sand. The surface of manufactured sand is rougher, and the shapes are more diverse, with more needle-like and flake-like particles, and are relatively angular. Therefore, in some engineering projects with higher requirements, such as road projects like beams and slabs of highways and railways, and pile foundations, the concrete with natural sand often demonstrates superior work performance compared to that with manufactured sand.

Generally, the more spherical the particles are, the better the compactness is, that is, the smaller the void ratio is. Due to the "congenital deficiency" of manufactured sand, during the concrete mixing process, the particles of manufactured sand must be fully wrapped with slurry materials to form particle shapes similar to those of natural sand in order to exert better working performance. Consequently, the same volume of manufactured sand concrete requires more colloidal materials such as water and cement to fill the more voids of manufactured sand compared to natural sand. This is prone to causing water bleeding and segregation during the concrete mixing process, reducing the working performance of the concrete. However, the increase of voidage makes the slurry material more perfect, which can improve the durability and flexural strength of concrete, that is, the mechanical properties of concrete are more significant. [17]

Chen Can[25] et al. explored the relationship between the mechanical sand type and the fluidity, rheology parameters and strength of mortar by studying the influence of different mechanism sand types on the workability, rheology and mechanical properties of mortar. It is found that machine-made sand with better grain type can effectively improve the workability and rheology of mortar, and the strength of machine-made sand mortar is basically greater than that of natural sand, and the overall correlation between mortar workability and rheology is good.

Zhou Xinwen[26] et al. used digital image processing technology (DIP) to quantitatively characterize the shape of sand particles, and found that the rod-like and flaky degree of machine-made sand was higher than that of natural river sand. The rheological curve of mortar shows that the irregular shape of sand particles will lead to the increase of mortar flow resistance. The yield stress of machine-made sand is 1.5 times that of natural river sand. The apparent viscosity of machine-made sand mortar is greater than that of natural river sand, especially at low shear rate. The surface roughness of machine-made sand particles will also affect the working performance of concrete, but the impact is not as great as the shape of the particles, so there are few research results on this.

Ahn[27] believes that in the case of the relatively rough surface of the machine-made sand, although the bonding performance of the slurry material has been

improved, relative to the whole, these improvements are a drop in the bucket, because the change of roughness will also lead to changes in voidage, etc., which will also have an adverse impact on the shear and tensile strength of concrete. On the contrary, the strength and performance of concrete are declining.

6 Conclusion

This paper discusses the influence of machine-made sand properties on concrete performance from four aspects: lithology, particle gradation, stone powder content and particle shape.

（1）Parent rock lithology: the different parent rock lithology has a certain effect on the work and strength of concrete, but has little effect on the durability, and calcareous sand is better than siliceous sand on the whole.

（2）Particle shape: the grain shape of the made sand is irregular and the surface is rough, which is helpful to improve the compactness and mechanical properties of the concrete, but it may also lead to problems such as bleeding, segregation and poor workability. The machine-made sand with better grain shape can significantly improve the workability and rheology of the mortar, and the strength is usually higher than that of natural sand mortar.

（3）Particle grading: The particle distribution of machine-made sand presents the characteristics of "big at both ends and less in the middle", which can generally meet the technical specification requirements of river sand. The poor grading of machine-made sand will lead to an increase in voidage and require more cement slurry material to fill, thus affecting the working performance and cost of concrete.

（4）Stone powder content: The right amount of stone powder (usually between 5%-10%) can improve the workability and pumping performance of concrete, enhance the strength and durability of concrete, too much stone powder will reduce the working performance of concrete, and may have an adverse effect on the later strength.

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