Analysis on Research Status of Road Performance of Machine-made Sand Concrete

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Abstract—In order to analyze the application status of machine-made sand in concrete pavement structure, and discuss new ideas for the development of machine-made sand concrete pavement, researches on several key issues of machine-made sand concrete pavement were reviewed and summarized, including wear resistance, mechanical properties and dry shrinkage performance; the requirements of industry standard and three local standards for the quality index of machine-made sand were compared and analyzed. The results show that the machine-made sand can meet the performance requirements of cement concrete pavement; many local standards have few differences in the quality of machine-made sand, but more differences in the technical indexes of the best performance of machine-made sand concrete.

1. INTRODUCTION
In the process of highway construction, the concrete pavement as a classic pavement structure is widely used. The natural sand is the main material for the road construction, but it is nearly exhausted. In order to solve the problem of insufficient supply of natural sand, it has become a new idea to replace the natural sand with the artificial sand as a new road construction material [1]. Foreign scholars Dukatz and Marke [2] conducted the experimental research on the machine-made sand concrete. Results show that when the mix proportion is fixed, the strength of machine-made sand concrete mixed with a small amount of stone powder is better than that of natural sand concrete. Luo Yao [3] analyzed the application of machine-made sand. It is found that the machine-made sand can not only replace the river sand to produce concrete, but also reduce more than 10% cost. Wang Luqiao [4] proposed that on the premise of meeting the requirements of quality, the application of machine-made sand extended the service life of highway and reduced the project cost.

Although China's research on the machine-made sand lagged behind foreign countries, coastal cities, such as Jiangsu, Zhejiang, Shanghai and Tianjin, have started to study the machine-made sand in the 1970s [5]. It was not until 2002 that the Sand for Construction (GB / T 14684-2001) [6] was implemented, and the machine-made sand was determined as the new source of sand. The production of machine-made sand in China is mainly based on rocks and cobblestones, and the machine-made sand is produced by mechanical crushing and sieving [7]. At present, limestone machine-made sand shown in Fig. 1 is the most widely used.
Considering that physical and chemical properties of machine-made sand is different from river sand’s, its wear resistance, anti-slip performance, mechanical properties and dry shrinkage performance applied in concrete pavement structure have been drawn much attention. The application of machine-made sand concrete to the pavement structure of highway engineering was taken as the breakthrough point in this study. The research status of road performance of machine-made sand was summarized and demonstrated. Three representative local standards in China was then selected to compare and analyze the technical requirements of quality of machine-made sand. Finally, some suggestions on the development of machine-made sand concrete pavement were put forward.

2. RESEARCH STATUS ON THE ROAD PERFORMANCE OF MACHINE-MADE SAND

In the past two decades, the amount of machine-made sand in China has been increasing, and the technical standards and specifications related to machine-made sand also have been gradually improved. The application of machine-made sand to the road construction is actively promoted currently. The research on the road performance of machine-made sand concrete mainly focuses on the anti-slip performance, wear resistance, strength and dry shrinkage performance.

2.1. Wear resistance

Wear resistance is the main index of durability of cement concrete pavement. It is related to the service life of pavement structure and driving safety, and has always been the key to applying the machine-made sand to the cement concrete pavement. Ke Guoju [8, 9] et al. researched on the wear resistance of machine-made sand cement concrete. Results show that the wear resistance of machine-made sand concrete is positively correlated with its strength, which is related to the limit value of stone powder content. In order to explore the influencing law of strength and stone powder content on the wear resistance of machine-made sand concrete, the wear resistance of machine-made sand pavement of a second-level highway in Guangxi was tested, and its experimental results were shown in Figs. 2 and 3.
Fig. 3: Influencing law of stone powder content on wear resistance

In Fig. 2, it is shown that the correlation coefficients of wear loss with concrete C30 and C40 are 0.90.9 and 0.9328 respectively, showing a clear negative correlation. As shown in Fig. 3, the wear resistance of concrete is related to the content of stone powder, and the optimal content of stone powder is 9%. It is found that the effect of stone powder on wear resistance is similar to most research results, but there are certain differences in the optimal content of stone powder.

Huo Ming [10] studied the anti-slide performance of concrete pavement. It is shown that the wear resistance of concrete is provided by the cement mortar and coarse aggregate. Liu TC [11] and Laplante P [12] found that the strength and wear resistance of concrete increased with the decrease of water-cement ratio. Sadegzaden M [13] carried out experimental research on the wear resistance of concrete. It is shown that the wear resistance of concrete is related to the matrix and pore structure of wear zone through . Kilic [14] explored the effect of different lithological aggregates on the wear resistance of high-strength concrete. The study shows that the better the wear resistance of aggregate, the better the wear resistance of concrete. Based on the research results of wear resistance of machine-made sand concrete pavement, the influencing factors and laws of wear resistance were explored, and the results were shown in Table 1.

| Influencing factors           | Laws                                                                 | Analysis                                                                 |
|-------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------|
| Stone powder content          | There is a certain limit value (about 10%) in the stone powder content. Within the limit value, the wear resistance is positively correlated with the content of stone powder; beyond the limit value, the wear resistance decreases. | Appropriate amount of stone powder can improve the physical configuration of concrete and the interface structure of mortar, and increase the strength, hardness and wear resistance of concrete. |
| Compressive strength          | The wear resistance is positively correlated with the strength.       | The higher the strength, the stronger the adhesion of mortar matrix to the aggregate and the better the wear resistance. |
| Water-cement ratio            | When the water-cement ratio ranges from 0.30-0.40, the wear resistance is negatively correlated with the water-cement ratio. | Under the condition of meeting the requirements of mixing performance, reducing the water-cement ratio is conducive to the improvement of strength and wear resistance. |
When the sand rate ranges from 0.30-0.38, the wear resistance increases as the sand rate increases. When the sand rate increases properly, the wear interface enlarges, and the wear resistance increases.

The wear resistance is negatively correlated with the crushing value. The smaller the crushing value, the larger the strength and the stronger the wear resistance.

Based on relevant researches on the wear resistance of machine-made sand concrete, several conclusions can be drawn: (1) The influencing factors of wear resistance of machine-made sand concrete are comprehensive, such as strength, stone powder content, gradation, granular shape, crushing value, water-cement ratio, etc.. (2) In the mechanism study of wear resistance of machine-made sand concrete, the mortar and coarse aggregate play a major role in the wear resistance, which is more in line with the characteristics of wear resistance of actual road concrete structure.(3)In the study of wear-resistance model of machine-made sand concrete, it is found that the special structure of machine-made sand concrete can enhance the bonding of concrete interface by refining the micro-pore structure of concrete, thereby improving the wear resistance of concrete.

2.2. Mechanical properties
In the current pavement design of cement concrete, the flexural strength is taken as the strength index. Zhao Jun [15] researched on the mechanical properties of machine-made sand concrete. It is shown that the strength of cement concrete prepared with machine-made sand is slightly higher than that prepared with natural sand. Yan Jie [16] found that the strength, workability and other properties of machine-made sand cement concrete C50 reached the best when the machine-made sand cement content was 5%. Yang Lu [17] et al. conducted the study on the performance of machine-made sand concrete. Results show that the compressive strength of machine-made sand concrete is equivalent to that of river sand concrete. However, the flexural strength of machine-made sand concrete is higher.

The effect of stone powder content on the compressive strength and flexural strength of machine-made sand concrete C40 was analyzed by Guangxi local standards [18], as shown in Fig. 4. It is indicated that the compressive strength, flexural strength and tensile strength of concrete reach the peak when the content of stone powder is 8%. The effect of stone powder on the compressive strength is more significant than that on bending strength.

![Fig. 4: Relationship of stone powder content with the compressive strength and flexural strength of concrete](image)

Fan Qing [19] researched the performance of machine-made sand concrete in Yunnan. It is shown that when the water-cement ratio ranges from 0.4–0.6, 8–18% stone powder content has no negative influence on the strength of machine-made sand concrete. In this study, the law of water-cement ratio and compressive strength of machine-made sand concrete in Guangxi Yongfu to Baishou Highway Project was shown in Fig. 5. It can be seen from the data analysis that the water-cement ratio has
significant influence on the strength of concrete. Therefore, the water consumption should be reasonably controlled during construction to reduce the water-cement ratio.

Fig. 5: Influencing law of water-cement ratio on the strength of concrete

Based on the above researches, several conclusions can be drawn: (1) In the preparation of high-strength machine-made concrete (C50 and above), the limit value of stone powder content should be strictly controlled, but its quantification varies. (2) Generally, the aggregates of machine-made sand are rough and angular. The mechanical properties of machine-made sand concrete are superior to those of river sand concrete. (3) Water-cement ratio, mix proportion design, stone powder content, and gradation are the key factors affecting the mechanical properties of machine-made sand concrete. Therefore, the field test should be paid much attention in the construction.

2.3. Dry shrinkage performance
In the construction of cement concrete pavement, the dry shrinkage is the main cause of shrinkage cracks in the concrete surface, which directly affects the durability of structure. The mechanism of dry shrinkage cracks is that the bottom of surface course of concrete pavement is constrained by the base course. When the temperature gradient or shrinkage stress caused by the dry shrinkage appears on the surface course, the tensile stress is easily generated on the upper surface course and then the dry shrinkage cracks.

Yan Congjin [20] carried out the experimental research on the effect of stone powder content of machine-made sand on different grades of concretes. It is concluded that the shrinkage rates of concretes with grades of C30, C40, and C60 are the maximum when stone powder contents are 10%, 7%, and 8%; 7%~10% stone powder content has the greatest influence on the dry shrinkage of machine-made sand concrete.

Li Pansheng [21] studied the effect of MB value on the early plastic cracking and dry shrinkage performance of machine-made sand concrete. It is found that the MB value is detrimental to the dry shrinkage properties of machine-made sand concrete. When the MB value is more than 1.45, the dry shrinkage increases significantly. In order to verify the effect of MB value on the early plastic cracking and dry shrinkage performance of machine-made sand concrete, 7 kinds of mud powder (0 ~ 6%, corresponding to J0 ~ J6) in the Guangxi Luocheng-Huanjiang Secondary Road were taken as variables, and the effect of MB value on the dry shrinkage properties of machine-made sand concrete was explored under the condition of the same mix proportion, as shown in Fig. 6.
In this study, the influencing factors and laws of dry-shrinkage performance of machine-made sand concrete was statistically analyzed by reviewing the literature. The results were shown in Table 2.

Table 2: Influencing Factors and laws of dry shrinkage performance

| Influencing factors | Laws |
|---------------------|------|
| Aggregate           | The aggregate has restrictive influence on the dry shrinkage. The more aggregate per unit volume, the smaller the dry shrinkage. |
| Stone powder        | 7% ~ 10% stone powder has the greatest influence on the shrinkage performance. |
| Fly ash             | Adding fly ash can improve the dry shrinkage performance of concrete. |
| Water-cement ratio  | The larger the water-cement ratio, the better the shrinkage. |
| MB value            | The MB value reflects the sand content of machine-made sand. When the MB value increases, the dry shrinkage rate of concrete increases. |

Based on the above researches on the shrinkage of concrete, the following conclusions can be drawn: (1) The influencing factors of dry shrinkage of sand concrete include environmental factors, mud powder content, aggregate, water-cement ratio, admixture, and maintenance. (2) Some methods can be effective to reduce the dry shrinkage of concrete and prevent the occurrence of dry shrinkage cracks, including ensuring the environmental humidity, timely maintenance, adding appropriate amount of fly ash, increasing the unit volume of rigid aggregate, and reducing the water-cement ratio.

3. REQUIREMENTS FOR MACHINE-MADE SAND QUALITY OF VARIOUS STANDARDS

The Standard [22] first defined machine-made sand as artificial sand. Li Hong [23] et al. proposed that the quality of raw materials was considered as the prime principle in the Technical Requirements for Raw Materials of Cement Concrete. Compared with natural river sand, the machine-made sand as a new construction raw material has rough, angular particle surface and most of its gradation is poor. Its particle size of 0.3~0.6 mm is relatively small, and it contains stone powder less than 0.075 mm [24].
At the beginning, the machine-made sand was questioned by many engineers. In this study, the industry standards [25] and the technical standards of machine-made sand quality in local standards of machine-made sands in three regions Gansu [26], Hunan [27] and Guangxi [28] were compared and analyzed to explore the current requirements for machine-made sand quality.

3.1. Comparison of main technical indexes of machine-made sand

In this study, the quality standard of grade II machine-made sand applicable to grade C30~C55 concrete in the specification was selected. The comparison results of quality standards of machine-made sand in each specification were shown in Table 3.

| Items                                      | Industry standard | Gansu standard | Hunan standard | Guangxi standard | Difference |
|--------------------------------------------|-------------------|----------------|----------------|------------------|------------|
| Compressive strength of source rock MPa ≥ | 60.0              | 60.0           | 60.0           | 60.0             | -          |
| Polishing value of source rock ≥           | 35.0              | 35.0           | 35.0           | 35.0             | -          |
| Crushing value % ≤                         | 25.0              | 25.0           | 25.0           | 25.0             | -          |
| Mud content % ≤                           | 0.5               | /              | 1.0            | /                | Higher     |
| Stone powder content % MB<1.4              | 5.0               | 7.0            | 5.0            | 10.0             | Higher     |
| Stone powder content % MB≥1.4              | 3.0               | 3.0            | 3.0            | 3.0              | -          |
| Stack density kg/m3 ≥                      | 1400.0            | 1400.0         | 1400.0         | 1400.0           | -          |
| Porosity% ≤                               | 45.0              | 45.0           | 44.0           | 44.0             | Lower      |
| Alkaline active reaction                    | Not allowed       | Not allowed    | Not allowed    | Not allowed      | -          |

According to Table 3, it can be analyzed that among selected local standards of Gansu, Hunan, and Guangxi, the mud content, stone powder content, and porosity in quality standards of machine-made sand have slight differences, other indexes are basically the same and consistent with the highway engineering industry standards.

3.2. Comparison of gradation of machine-made sand

The machine-made sand is divided into grade I, grade II and grade III according to the gradation. The grade II sand is used for preparing concrete in priority. The fineness modulus of grade II sand in Hunan's local standards is 1.95 ~ 3.28. Gansu and Guangxi’s are both 2.3 ~ 3.0. The fineness modulus of grade I sand in industry standards is 2.3 ~ 3.1. The cumulative screening curves of grade II of machine-made sand, industry standards, and three local standards of Gansu, Hunan, and Guangxi were shown in Fig. 7.
From the comparison of screening curves, it can be seen that the difference of gradation of machine-made sand between the industry standard and local standard mainly appears when the particle size ranges from 2.36~4.75, and coarse particles of machine-made sand of industry standard are slightly higher than those of other three local standards.

4. CONCLUSION

By reviewing and summarizing the research status of road performance of machine-made sand concrete, and analyzing the requirements of the above-mentioned specifications and standards for the quality of machine-made sand, it is concluded that the current law of the road performance of machine-made sand concrete is basically clear and the definition of requirements is consistent. However, the quantification differences of technical indexes of machine-made sand quality for preparing the pavement concrete with good performance exist in the current researches. The relevant requirements of specifications and standards are still far from producing high-quality machine-made sand concrete.

In the future, high-quality machine-made sand, high-performance machine-made sand concrete, standardized pavement structure construction and inspection methods are the key to the further promotion of machine-made sand concrete. To further promote the application of machine-made sand concrete pavement structure, the following aspects are worthy of in-depth discussion and research:

1. The machine-made sand produced by mechanical crushing has angular shape and poor gradation. The sand-made equipment is rough, and the measurement methods of particle shape are limited. To develop better sand-made equipment and machine-made sand quality identification system is an effective measure to improve the quality of machine-made sand.

2. At present, scholars have different opinions on the effect mechanism of performance of machine-made sand concrete. Such as the wear resistance of pavement concrete, most researchers advocate “strength factor” while some think that it is related to the “interface, matrix, gap, and aggregate”. Therefore, the performance mechanism of machine-made sand concrete is also worth further exploring.

3. We can establish the correlation model between the wear resistance of machine-made sand concrete, and the wear resistance or anti-slide performance of machine-made sand concrete pavement. Considering actual time effect, load and environmental factors, we can also study the wear resistance and anti-slide performance of machine-made sand concrete pavement structure.

Subject source
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REFERENCE
[1] XIE Hong-bo, LI Yan, et al. Application of machine-made sand in pavement concrete [J]. Journal of Conference Proceedings of China Silicate Society, 2006, 244-248. (in Chinese)
[2] E L Dukatz, C R Marke. Evaluation of Manufactured Stone sand for use in Virginia. Construction Materials Research and Development, 1985, 33-38.
[3] LUO Yao. Application technology and cost of machine-made sand [J]. Journal of Highway transportation science and Technology Application Technology Edition, 2018, 12: 46-48. (in Chinese)
[4] WANG Lu-qiao. Application analysis of road concrete machine-made sand [J]. Journal of Transportation World, 2019, 35: 25-26. (in Chinese)
[5] SONG Wei. Study on the influence of mechanical aggregate on the performance of concrete [D]. Degree of Master Thesis of Da-lian University of Technology, Dalian China, 2007, 12-15. (in Chinese)
[6] GB/T 14684-2001, Standard of Construction sand [S]. Beijing China: China Standards Press, 2001, 3-4. (in Chinese)
[7] KE Guo-ju. Study on the influence factors of the wear resistance of the pavement mechanism sand cement concrete [D]. Degree of Master Thesis of Wuhan University of Technology, Wuhan China, 2010: 19-30. (in Chinese)
[8] KE Guo-ju, LI Bei-xing, ZHAO Shang-chuan. Study on the strength and wear resistance of road surface machine-made sand cement concrete [J]. Journal of Concrete, 2009, 10: 77-79. (in Chinese)
[9] KE Guo-ju, LU Zhong-fei, HAO Yi-dang, LI Bei-xing, WANG Ji-lian. Grey correlation analysis of the factors influencing the wear resistance of the pavement mechanism sand cement concrete [J]. Journal of Silicate Bulletin, 2011, 1(30): 216-219. (in Chinese)
[10] HUO Ming. Study on attenuation law and evaluation method of anti-sliding function of cement concrete pavement [D]. Degree of Master Thesis of Changan University, Xian China, 2009, 15-19.
[11] Liu T. Abrasion Resistance of Concrete [J]. ACI Material Journal, 1981, 256-259.
[12] Laplante P. Abrasion Resistance of Concrete [J]. ACI Material Journal, 1991, 124-127.
[13] Sadegzaden M. Surface Microstructure and Abrasion Resistance of Concrete [J]. Rement and Concrete Research, 2003, 12-16.
[14] Kilic A. The Influence of Aggregate type on the strength and abrasion resistance of high strength concrete [J], 2008, 45-50.
[15] ZHAO Jun. Performance test of road cement concrete prepared by machine-made sand [J]. Journal of China Municipal Engineering, 2009, 2: 13-14. (in Chinese)
[16] YAN Jie. Study on the effect of stone powder content on the performance of machine-made sand concrete [J]. Journal of Sichuan Building Materials, 2013, 3: 19-20. (in Chinese)
[17] YANG Lu, TAN Yan-bin, et al. Study on the performance of concrete made of limestone with high content of stone powder [J]. Journal of Railway Engineering, 2015, 119-122. (in Chinese)
[18] DB45/T 1621-2017, Technical code for application of manufactured sand and concrete [S]. Nanning China, 2017, 12-18.
[19] FAN Qing. Study on the performance of concrete made of machine-made sand in some areas of Yunnan Province [D]. Degree of Master Thesis of Chongqing Jiaotong University, 2010, 56-67. (in Chinese)
[20] YAN Cong-jin. Study on the effect of mechanical sand properties on concrete performance [D]. Degree of Chongqing University, 2014, 48-68. (in Chinese)
[21] LI Pan-sen. Effect of MB value of machine-made sand on early plastic cracking and dry shrinkage of high strength concrete [J]. Journal of Highway Transportation Science and Technology Application Technology Edition, 2018, 1: 41-43. (in Chinese)
[22] GB/T 14684-2011, Standard of Construction sand[S]. Beijing China: China Standards Press, 2011, 15-19. (in Chinese)

[23] LI Hong, FU Zhi. Technical requirements for raw materials of cement concrete[J]. Journal of Highway, 2003, 7(25): 25-30. (in Chinese)

[24] WANG Li-yu, WANG Wei-dong, et al. Study on the determination of stone powder content of medium and low strength machine-made sand concrete[J]. Journal of Journal of Civil and Environmental Engineering, 2012, 5(34): 154-158. (in Chinese)

[25] JTG/T F30-2014, Technical rules for construction of Highway Cement Concrete Pavement[S]. Beijing China. People's Communications Press, 2015-20. (in Chinese)

[26] DB60/T 2917-2018, Specification for application of machine-made sand concrete[S]. Lanzhou China, 2018-2018. (in Chinese)

[27] DB43/T 1287-2017, Technical specification for sand concrete application in Highway Engineering[S]. Changsha China, 2017-2017. (in Chinese)

[28] DB45/T 1621-2017, Technical code for application of manufactured sand and concrete[S]. Nanjing China, 2017-2017. (in Chinese)