Research on the influence of machine-made sand gradation and fineness modulus on the workability and rheological properties of mortar

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Abstract. The gradation and fineness modulus of machine-made sand are important factors affecting the performance of mortar. By studying the influence of different machine-made sand gradation and fineness modulus on the workability and rheological properties of mortar, the gradation and fineness of machine-made sand are explored. The relationship between modulus and mortar fluidity, yield stress and plastic viscosity. Research shows that with the increase of the cumulative screening rate and fineness modulus of machine-made sand with different gradations, the fluidity of the mortar increases and the workability of the mortar increases. The cumulative screening rate and fineness modulus of machine-made sand are negatively correlated with the yield stress and plastic viscosity of the mortar. The cumulative screening rate and fineness modulus of machine-made sand have a good correlation with the yield stress of the mortar, and the mechanism is 1.18-0.6mm Sand gradation is significantly negatively correlated with the yield stress of mortar, and the cumulative sieving rate and fineness modulus of machine-made sand have poor correlation with the plastic viscosity of mortar.

1. Introduction

Fine aggregate plays a role in filling compaction and lubrication in concrete, and is an important factor affecting concrete workability and mechanical properties. However, with the gradual decrease in the reserves of river sand resources, many areas have experienced shortages of river sand and even the depletion of river sand resources[1]. In order to cope with the problem of the shortage of fine aggregate resources, the use of machine-made sand as an alternative resource has become an inevitable trend[2]. Compared with natural sand, due to the different production processes of machine-made sand in different regions, there are problems such as poor gradation of machine-made sand, large fineness modulus, high accumulation porosity, and obvious angularity, which have many adverse effects on the performance of concrete and mortar[3-5]. At present, there are many researches on the grading of machine-made sand. The research results show that the machine-made sand gradation mainly affects the workability of concrete. The machine-made sand with different gradations has the largest bulk density, and the mixed mortar has the best work performance[6-9]. In this paper, based on the gradation of machine-made sand in Zone II, by adjusting the screening rate of different particle sizes of machine-made sand, the machine-made sand of different gradations was prepared, aiming to study the influence of machine-made sand gradation and fineness modulus on the workability and performance of mortar. The influence of rheological properties provides a test basis...
for the application of machine-made sand in cement-based materials.

2. Raw materials and test methods

2.1. Raw materials

Cement: Jinyang brand P·II 52.5R cement produced by Guangzhou Yuebao Cement Co., Ltd.
Sand: Machine-made sand produced by dry granite.
Water: Tap water for laboratory use.

2.2. Mix ratio

The basic mix ratio of mortar is cement (g): sand (g): water (g) = 450:1350:270. The machine-made sand is adjusted to different gradations. The cumulative sieving rate and fineness modulus of machine-made sand particles are shown in Table 1. As shown, the particle grading curve of machine-made sand is shown in Figure 1.

| Numbering | 4.75-2.36m mm/% | 2.36-1.18m mm/% | 1.18-0.6mm mm/% | 0.6-0.3mm mm/% | 0.3-0.15mm mm/% | 0.15-0.075mm mm/% | <0.075mm % | Fineness modulus |
|-----------|-----------------|-----------------|-----------------|----------------|----------------|------------------|-------------|-----------------|
| A1        | 10              | 20              | 35              | 80             | 94             | 98               | 100         | 2.39            |
| A2        | 13              | 32              | 49              | 77             | 94             | 98               | 100         | 2.65            |
| A3        | 10              | 39              | 68              | 83             | 94             | 98               | 100         | 2.94            |
| A4        | 20              | 45              | 70              | 88             | 94             | 98               | 100         | 3.17            |
| A5        | 33              | 55              | 72              | 85             | 94             | 98               | 100         | 3.39            |

Figure 1. Machine-made sand particle grading curve

2.3. Experimental test

① Workability

The workability of the freshly mixed mortar shall be carried out in accordance with the relevant regulations in the "Method for Measuring Fluidity of Cement Mortar" (GB/T 2419-2005).

② Rheological properties

The rheological properties of fresh mortar refer to the ability of the mortar to flow and deform
under the action of external shear, which is quantitatively characterized by yield stress, plastic viscosity and other indicators. The RST-SST rheometer produced by BROOKFIELD is used to test the rheological properties of the mortar. The test program is shown in Figure 2.

![Figure 2. Mortar rheological test procedure](image)

3. Results and discussion

3.1. Influence of machine-made sand gradation and fineness modulus on workability of mortar

The influence of machine-made sand grading on the workability of mortar is shown in Figure 3.

![Figure 3. Influence of machine-made sand gradation and fineness modulus on workability of mortar](image)

It can be seen from Figure 3(a) that the cumulative screening rate of machine-made sand is positively correlated with the fluidity of the mortar, and the correlation coefficients $R^2$ are 0.4426, 0.8513, 0.8141 and 0.2495, respectively, of which 2.36-1.18mm and 1.18-0.6mm machine-made sand gradation has a good correlation with the fluidity of the mortar. When the correlation coefficient $R^2$ is greater than 0.95, it can be evaluated as significant correlation, when it is greater than 0.8 and less than 0.95, it can be evaluated as high correlation, when it is greater than 0.5 and less than 0.8, it can be evaluated as medium degree relevance. It can be seen that the 2.36-1.18mm and 1.18-0.6mm machine-made sand gradations are highly positively correlated with the fluidity of the mortar. It can be seen from Figure 3(b) that as the fineness modulus of machine-made sand increases, the fluidity of the mortar increases. The correlation coefficient $R^2$ between the fineness modulus of machine-made sand
and the fluidity of mortar is 0.8158, which is a highly positive correlation. The fineness modulus of machine-made sand has a good correlation with the fluidity of the mortar. As the fineness modulus of machine-made sand increases, the workability of the mortar tends to increase. This is because when the fineness modulus of machine-made sand increases, the proportion of coarse particles of machine-made sand gradually increases, and the specific surface area gradually decreases, which reduces the amount of water adsorption and improves the workability of the mortar[10-11].

3.2. Influence of machine-made sand gradation and fineness modulus on rheological properties of mortar

The influence of machine-made sand gradation and fineness modulus on the yield stress of mortar is shown in Figure 4.

It can be seen from Figure 4(a) that the cumulative screening rate of machine-made sand is negatively correlated with the yield stress of mortar, and the correlation coefficients $R^2$ are 0.5289, 0.9438, 0.9722 and 0.6338, respectively, of which the 1.18-0.6mm machine-made sand gradation and mortar yield The stress correlation is relatively good, which is a significant negative correlation. The 2.36-1.18mm machine-made sand gradation has the second highest correlation with the mortar yield stress, which is a highly negative correlation. It can be seen from Figure 4(b) that as the fineness modulus of machine-made sand increases, the yield stress of the mortar decreases. The correlation coefficient $R^2$ between the fineness modulus of machine-made sand and the yield stress of mortar is 0.979, which is a significant negative correlation. The fineness modulus of machine-made sand has a good correlation with the yield stress of mortar. With the increase of the fineness modulus of machine-made sand, the yield stress of mortar tends to decrease. The flow resistance in the cement slurry decreases, and its yield stress decreases, thereby improving the rheology of the mortar [12].

The influence of machine-made sand gradation and fineness modulus on the plastic viscosity of mortar is shown in Figure 5.
It can be seen from Figure 5(a) that the cumulative screening rate of machine-made sand is negatively correlated with the plastic viscosity of the mortar, and the correlation coefficients $R^2$ are 0.2116, 0.6445, 0.7118 and 0.1358, respectively, of which 2.36-1.18mm and 1.18-0.6mm machine-made sand The gradation has a good correlation with the plastic viscosity of the mortar, which is a moderately negative correlation. It can be seen from Figure 5(b) that as the fineness modulus of machine-made sand increases, the plastic viscosity of the mortar decreases. The correlation coefficient $R^2$ between the fineness modulus of machine-made sand and the plastic viscosity of mortar is 0.619, which is a moderately negative correlation. When the fineness modulus of machine-made sand increases, the plastic viscosity of the mortar tends to decrease. This is because the thickness of sand particles also has a certain influence on the viscosity of the mortar. The increase in water demand in the cement slurry leads to an increase in the viscosity of the mortar, which slows down the flow rate of the mortar and reduces the rheology of the mortar[13].

4. Conclusion

(1) The cumulative screening rate of machine-made sand is positively correlated with the fluidity of the mortar. The gradation of machine-made sand of 2.36-1.18mm and 1.18-0.6mm has a good correlation with the fluidity of the mortar, which is a highly positive correlation. The correlation between the fineness modulus of machine-made sand and the fluidity of the mortar is highly positive. As the fineness modulus of machine-made sand increases, the fluidity of the mortar increases and the workability of the mortar increases.

(2) The cumulative screening rate of machine-made sand is negatively correlated with the yield stress and plastic viscosity of the mortar. The cumulative screening rate of machine-made sand has a good correlation with the yield stress of the mortar, and the 1.18-0.6mm machine-made sand gradation is related to the yield stress of the mortar. It is a significant negative correlation. However, the cumulative screening rate of machine-made sand has a poor correlation with the plastic viscosity of the mortar, and the highest correlation is only a moderate correlation.

(3) As the fineness modulus of machine-made sand increases, the yield stress and plastic viscosity of the mortar decrease. The fineness modulus and the yield stress of the mortar have a good correlation, which is a significant negative correlation, but the fineness modulus and the plasticity of the mortar The viscosity correlation is poor, and it is a moderately negative correlation.

Acknowledgments
Key research and development project of Guangdong Province, key technology of steel shell concrete
immersed tube tunnel construction in complex marine environment. (2019B111105002)

References

[1] Zhu, J.L., Lang, X.G., Jia, X.E. (2001) Production status and development of machine-made sand[J]. Mining and Metallurgy. (04): 38-42.

[2] Qiu, H.Q. (2015) The influence of machine-made sand particle shape and stone powder content on concrete performance[D]. Shenzhen University.

[3] Ai, C.F., Peng, H., Hu, C., etc. (2013) The influence law and effect of machine-made sand gradation on concrete performance[J]. Concrete, (1): 73-76.

[4] Shen, W., Liu, Y., Wang, Z., etc. (2018) Influence of manufactured sand's characteristics on its concrete performance[J]. Construction and Building Materials, 172(MAY30):574-583.

[5] Goncalves, J.P., Tavares, L.M., etc. (2007) Comparison of natural and manufactured fine aggregates in cement mortars [J]. Cement and Concrete Research, 37(6):924-932.

[6] Huang, Y.M., Wang, L.H. (2017) Effect of Particle Shape of Limestone Manufactured Sand and Natural Sand on Concrete. 210:87-92.

[7] Liu, G.F., Li, S.C., Qin, Y.L., etc. (2013) The influence of different machine-made sand gradations on the properties of dry-mix mortar[J]. Concrete, (09): 112-114+117.

[8] Rui, J., Liu, T.Z., Wang, B., etc. (2014) Research on the effect of machine-made sand gradation on the properties of high-strength concrete[J]. China and Foreign Highway, 34(01): 298-300.

[9] Ai, C.F., Peng, H., Hu, C., etc. (2013) The influence law and effect of machine-made sand gradation on concrete performance[J]. Concrete, (01): 73-76.

[10] Ai, Z.Y., Li, J.Y., Shu, X.P., etc. (2019) The influence of machine-made sand grading on the performance of high-strength concrete[J]. Transportation Science and Technology, (03): 135-138.

[11] Chen, J., Lan, C., Liu, D., etc. (2017) Research on the effect of machine-made sand gradation on the properties of mortar and concrete[J]. Commercial Concrete, (06): 34-37.

[12] Liu, Y.F. (2014) Research on rheological properties of machine-made sand cement mortar[D]. Chongqing Jiaotong University.

[13] Cortes, D.D., Kim, H.K., Palomino, A.M., etc. (2008) Rheological and mechanical properties of mortars prepared with natural and manufactured sands[J]. Cement & Concrete Research, 38(10):1142-1147.