Application of Machine-made Sand Concrete in Airport Pavement Construction

Bin Luo[1], Ling Chen[2], Jinghao Li[1] and Jingkun Li[1*]

[1] CCCC First Harbor Engineering Co., Ltd., Tianjin 300000, China
[2] Tianjin City of Design Urban Developement Co., Ltd., Tianjin 300000, China

*Corresponding author's e-mail: 18330102873@163.com

Abstract. The primary difference between machine-made sand and river sand lies in the presence of stone powder. This paper conducts research on the application of machine-made sand concrete in airport pavement construction, specifically focusing on the application of machine-made sand concrete with stone powder in airport pavement construction. Through practical engineering applications, it summarizes the key operational differences compared to traditional river sand concrete in airport pavement construction, preventive measures for common defects, as well as the factors affecting the performance of airport pavement concrete and its economic benefits when using machine-made sand.

Keywords: Machine-made sand concrete; Quality control; Operational points; Economic process.

1 Introduction

In response to the national airport construction strategic planning and layout, there is a significant increase in the number of new, expanded, and renovated airports, resulting in a substantial demand for concrete [1-4]. Guided by the principle that "green mountains and clear waters are akin to mountains of gold and silver," this study focuses on the technical application of machine-made sand concrete in airport pavement construction. The objective is to accumulate valuable experience in using machine-made sand as a substitute for river sand in airport construction, especially in regions where river sand is scarce. By setting an example and prioritizing practical implementation, this research aims to provide a foundation for the future promotion of machine-made sand concrete technology in airport pavement construction.

2 The Impact of Machine-made sand on Concrete

Machine-made sand is not composed of single particles but rather consists of a mixture of fine particles with a particle size smaller than 0.075mm, referred to as stone powder, and rock particles with a size less than 4.75mm. Based on the analysis of stone powder content in machine-made sand and the observation of concrete performance during

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construction, maintaining the stone powder content within 12% or lower can improve the workability, bleeding resistance, and cohesion of concrete. This, in turn, facilitates better compaction during the paving of machine-made sand concrete for road surfaces, ultimately enhancing construction efficiency.

When the stone powder content exceeds 12%, the workability, bleeding resistance, and cohesion of the concrete deteriorate significantly. Among these properties, cohesion is most affected, leading to difficulties in consolidation and resulting in a mortar layer of ≤3mm. This can lead to the overall flexural concrete pavement exhibiting a rubbery, soft, and bouncy behavior, negatively impacting surface smoothness and making it challenging to achieve sufficient texture depth or perform texture dragging.

In summary, controlling the stone powder content within 12% or below is crucial for optimizing the performance of machine-made sand concrete in road surface construction, as it enhances workability, bleeding resistance, cohesion, and overall construction efficiency. Exceeding this threshold can result in undesirable characteristics, including poor cohesion and surface quality. The proportion of machine-made sand 5.0 flexural concrete is shown in Table 1:

Table 1. Proportions of Machine-made sand 5.0 Flexural Concrete Mix (in kg)

Number	Cement	Machine-made sand	5-10 Crushed Stone	10-20 Crushed Stone	20-40 Crushed Stone	Water	Admixture
1	320	656	209	55.8	627	155	0.64
2	Range of Water Usage 155-175； Slump 1-3cm；						

Machine-made sand Flexural Concrete Surface Layer has Poor Water Retention. The flexural concrete surface layer made with machine-made sand exhibits poor water retention characteristics. When the ambient temperature is equal to or exceeds 20°C, or when there is wind blowing at or above a wind force of 3, the surface layer loses moisture rapidly. This can result in the occurrence of false setting and surface drying, often referred to as "dry shell" phenomena. Consequently, it imposes high demands on the moisture preservation during concrete transport and the coordination of construction processes. The texture effect is shown in Figure 1.

Fig. 1. Illustration of Water Bleeding Texture Effect

The Influence of Admixture Dosage on Machine-made sand Concrete's Initial Setting

The dosage of admixtures has a significant impact on the initial setting of machine-made sand concrete. Different dosages can lead to distinctly different physical properties. Based on experimental mix proportions and observations of concrete performance during construction, it is recommended to limit the admixture dosage to within 0.3%. The texture effect is shown in Figure 2.

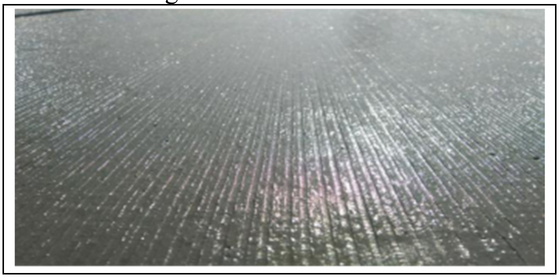

Fig. 2. Texture Effect of Machine-made sand Flexural Concrete with Admixtures ≥ 0.3% in Machine-made sand Flexural Concrete

Wide Range of Mixing Water for Machine-made sand Flexural Concrete

The amount of mixing water for machine-made sand flexural concrete can vary significantly based on temperature fluctuations. It is essential to adjust the mixing water volume as needed to accommodate changing weather conditions.

Using Medium-Coarse Machine-made sand in Concrete Mixtures. When medium-coarse machine-made sand is used in concrete mixtures, small voids may exist within the concrete. To ensure the smoothness and visual quality of airport pavement, as well as to meet the requirements for texture dragging during construction, it is advisable to add an appropriate proportion of cementitious materials during actual construction. This addition helps fill the small voids within the machine-made sand concrete, resulting in improved compaction. By filling these small voids, this method effectively enhances two crucial indicators of machine-made sand concrete: stability and workability.

3 Key Construction Operation Points

3.1 Quality Control

Transportation and Paving.

Transporting and paving machine-made sand concrete requires strict quality control measures due to its higher flowability compared to river sand concrete, primarily owing to the presence of stone powder. To prevent segregation during loading from the batching plant and transportation, as well as to avoid spillage along the route, the dump truck's rear gate must be securely closed and a dedicated concrete transportation route should be established.

Concrete should be loaded into the truck bed following the "first load front, second load rear, and final load in the middle" principle, and it should not be overfilled (maintaining the truck bed at approximately 2/3 full). To prevent segregation during transportation and ensure safety, especially during high winds, temperatures ≥20°C, or rainy weather, cover the concrete with canvas to retain moisture. Additionally, strict speed limits (≤20 km/h) must be observed during transportation. Avoid sudden braking, abrupt stops, or rapid turns, especially on tight curves.

These measures are essential to maintain the integrity of the machine-made sand concrete during transportation and ensure safe and effective paving at the construction site.

Before pouring and paving machine-made sand concrete on the road surface, the water-stabilized surface should be wetted thoroughly with water. The water demand for wetting is higher than that of traditional river sand flexural concrete, as fully wetting the stabilized surface can compensate for the moisture lost by the machine-made sand concrete during transportation and pouring[5,6]. The paving construction site is shown in Figure 3

Fig. 3. Concrete Paving Construction

The pouring and paving process is primarily carried out using a small excavator, with manual labor assisting the operation. During the process, a designated person uses a round-mouthed shovel to select uniformly fine-grained machine-made sand concrete. The concrete should be poured at the edges and joint positions of the concrete slab. To prevent segregation, it is strictly prohibited to forcefully throw the concrete onto the pavement.

To avoid concrete segregation during paving, the discharge height of concrete from the dump truck should not exceed 1.5 meters. If the height exceeds 1.5 meters, a chute should be added. The concrete unloading and paving construction is shown in Figure 4.

Fig. 4. Concrete Unloading and Paving

Paving machine-made sand concrete and compaction operations need to be conducted continuously. In case of temporary work stoppage due to uncontrollable factors during construction, the already-paved machine-made sand concrete should be compacted immediately, and it should be covered with damp fabric to prevent moisture loss. If the work stoppage lasts for an extended period and exceeds the demolding time specified in Table 2 below, the machine-made sand concrete must be removed. The demolding time is significantly shorter for machine-made sand concrete compared to river sand concrete. The removed machine-made sand concrete should not be used in the molds of subsequent pours, and it should not be mixed with newly mixed machine-made sand concrete.

The maximum allowable time for transporting machine-made sand concrete from the mixer to the construction site and starting the pouring, compacting, and troweling operations (excluding texture dragging) is as follows[7,8]:

Table 2. Comparison of Construction Time Parameters for Traditional River Sand and Machine-made sand Flexural Concrete

Number	Construction Temperature°C	Maximum Permissible Time for River Sand Concrete	Maximum Permissible Time for Machine-made sand Concrete
1	5-10	120min	70min
2	10-20	90min	50min
3	20-30	75min	30min
4	30-35	60min	20min

Key Points for Compaction.

Compaction work in machine-made sand concrete road surface construction is a critical process aimed at eliminating hollows, honeycombing, surface irregularities, and transverse and longitudinal cracks while preventing slab breakage. Self-propelled high-frequency compactors, along with insert-type vibratory probes, are the primary compaction equipment used in machine-made sand concrete airport pavement construction.

To enhance compaction effectiveness and ensure thorough compaction without missing any areas, self-propelled high-frequency compactors are employed. After compaction, the surface of the machine-made sand concrete should exhibit uniform surface paste, be generally flat with no exposed stones, and show stable surface paste without further separation or air bubbles. In the case of river sand concrete pavement, the self-propelled high-frequency compactor should not exceed a speed of 0.8 meters per minute to avoid issues like honeycombing. However, during machine-made sand concrete pavement compaction, the driving speed can be controlled within the range of 1.0 to 1.2 meters per minute, significantly improving compaction efficiency. The concrete vibration construction is shown in Figure 5 and Figure 6.

Fig. 5. Concrete Compaction (Vibration) Construction

Fig. 6. Detailed Illustration of Concrete Compaction (Vibration) Construction

To prevent self-propelled high-frequency compactors from colliding with the steel molds at the edges during operation, which could deform the steel molds and affect the appearance quality of the pavement, maintain a minimum distance of ≥15 cm between the outermost compaction probe and the steel molds. Within this range, use insert-type vibratory probes (φ70) for 10-20 seconds of compaction to ensure proper compaction.

Machine-made sand flexural concrete can achieve leveling and eliminate hollows, honeycombing, and exposed stones using self-propelled high-frequency compactors, simplifying the construction process and cost-effectively replacing the need for using flat vibrators along each concrete slab, as required in river sand flexural concrete.

Surface Leveling and Troweling.

Surface smoothness is primarily controlled through the surface leveling process. Machine-made sand concrete is known for its good workability, making it suitable for surface leveling. A dragging wooden vibrating beam is used to vibrate the surface twice to achieve proper leveling.

During the leveling process, the wooden vibrating beam should move slowly and at a consistent speed to remove any remaining air bubbles, ensuring a uniform surface paste on the machine-made sand concrete. It's natural to encounter minor irregularities during the dragging process. When such irregularities occur, workers should promptly use shovels to fill them with machine-made sand concrete that does not contain large-sized stones. Pure machine-made sand mortar is not allowed for filling irregularities. The construction of vibration beam leveling and slurry extraction is shown in Figure 7.

Fig. 7. Vibrating Beam Surface Leveling and Slurry Work

Honeycombing and surface irregularities are common issues encountered in airport pavement construction. Leveraging the good workability, bleeding resistance, and cohesion properties of machine-made sand concrete, a steel tube rolling process can be employed to achieve a smooth and uniform surface paste. This technique, involving back-and-forth rolling with a steel tube roller, is effective in preventing honeycombing and surface irregularities in machine-made sand concrete airport pavement. As shown in Figure 8.

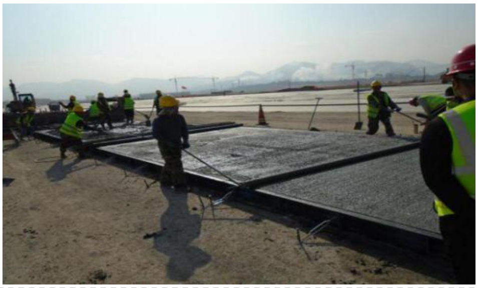

Fig. 8. Roller Troweling Operation

Machine-made sand concrete has the advantage of producing mortar more easily than river sand concrete. During the troweling process, the use of steel rollers ensures good linearity. Two steel rollers are used for mortar troweling, with two passes of back-and-forth rolling, followed by two fixed roller drags, and finally, two more passes of rolling. This process allows the mortar layer on the concrete slab surface to achieve a thickness of 3-5mm. The detailed effect of kneading is shown in Figure 9.

Fig. 9. Detailed Illustration of Troweling Effect

Texture Dragging.

Texture Dragging Process.

Texture dragging is essential to eliminate surface imperfections such as sand holes and air bubbles and ensure the quality of surface texture depth. It is crucial to control the timing and steps of the texture dragging process. Texture dragging can begin as soon as there is no visible surface water. Based on construction experience, a technique involving two wood sweeps, one large iron sweep, and one long-handled small iron sweep (regular small iron sweeps are used for edges and corners) has been developed for texture dragging. This approach improves construction efficiency and addresses the challenge of the short allowable time for texture dragging in machine-made sand concrete pavement construction. The key points of the process are as follows:

After mortar troweling, immediately proceed with the first pass using a wooden trowel to press down and level the surface of the machine-made sand concrete, ensuring even distribution of mortar on the surface. The recommended thickness of the mortar layer on the concrete slab surface is 3-5mm. The wooden plastering operation is shown in Figure 10.

Fig. 10. Wood Troweling Operation

Following the first pass with the wooden trowel, promptly apply the second pass with the wooden trowel, and use the first large iron trowel to compact and level the surface mortar. This process ensures a relatively uniform distribution of mortar on the concrete surface, improving the uniformity and smoothness of the surface mortar, reducing trowel marks, and enhancing the uniformity of moisture distribution on the concrete surface. As shown in Figures 11 and 12.

Based on experience and observation of good moisture uniformity in the mortar, you can proceed with the application of one pass with a long-handled small iron trowel, pressing the sand into the mortar to achieve a smooth and level surface on the concrete slab.

Fig. 11. Illustration of One Pass with LargeIron Trowel in Texture Dragging

Fig. 12. Illustration of One Pass with Long-Handled Small Iron Trowel in Texture Dragging

Texture Dragging Process.

For river sand flexural concrete, texture dragging can be performed when the surface mortar is no longer sticky to the touch and fingerprints can be left on the cement mortar. In contrast, machine-made sand flexural concrete experiences rapid moisture loss on the surface, and the optimal time for texture dragging is within 10 minutes after completing the texture troweling. This reduces the time between process steps and eliminates the issue of texture dragging personnel waiting for an extended period.

During texture dragging, a positioning guide is used to ensure straight and aligned texture lines, while the operator applies balanced pressure to maintain uniform line thickness and depth. The roughening process and texture effect of the finished product are shown in Figures 13 and 14.

Fig. 13. Texture Dragging Process Illustration

Fig. 14. Finished Texture Depth Effect

To prevent overlapping or missed texture brushing between successive texture dragging operations, it is essential to measure and control the spacing between the brush strokes using a steel ruler before each texture dragging. This ensures that the displacement between brush strokes is equal for each pass, with a brush overlap spacing of 1-2 cm.

The use of brushes that shed bristles, are deformed, or have broken bristles is strictly prohibited. After each texture brushing operation, the brushes must be cleaned to remove any attached materials.

Pavement Curing.

To ensure the proper curing of machine-made sand concrete pavement, lightly press the surface of the concrete slabs with your fingers. If there are no visible marks, proceed to sprinkle water and cover the curing material to allow the machine-made sand concrete to undergo full hydration reactions, enhance flexural strength, and prevent inadequate curing, which can lead to surface peeling and texture detachment. The temperature difference between the curing water and the freshly poured concrete should not exceed 15°C.

4 Economic Benefit Analysis

In the construction of airport pavements, flexural concrete is primarily supplied through commercial concrete plants and on-site batching plants. An analysis comparing the economic benefits of commercial concrete supply and on-site batching supply has been conducted to select the most cost-effective supply method.

The airport construction project is located in Guangxi, where the supply of river sand is limited, and the demand for 5.0 flexural concrete in the construction of the airport exceeds 120,000 cubic meters. After conducting a price survey and analysis of river sand, machine-made sand, commercial 5.0 flexural concrete, and on-site mixed 5.0 flexural concrete in Guangxi, it was determined that the most cost-effective supply method is on-site batching using machine-made sand for 5.0 flexural concrete. The economic benefit analysis is outlined in Table 3.

Please note that the actual figures in Table 3 would need to be provided based on the specific economic data and pricing information for the project in Guangxi.

Table 3. Economic Benefit Analysis Comparison (Including Taxes)

Number	River Sand	Machine-made sand	5.0 Flexural Strength Commercial Concrete	5.0 Flexural Strength Self-Mixed Concrete
1	190yuan/t	60 yuan /t	450 yuan /m³	370 yuan /m³
2	Save130 yuan /t		Save 80 yuan /m³	

5 Conclusion

Airport construction projects require a significant amount of concrete, and in many regions of China, the supply of river sand is limited. According to the national airport construction strategy, there is a need for a large number of new airports, making the substitution of river sand with machine-made sand a promising solution. However, there have been relatively few cases of using machine-made sand in the construction of airport pavement concrete, despite its advantages in workability, bleeding resistance, and cohesion.

Through engineering examples, we have summarized a streamlined construction process and key operational points for machine-made sand airport pavement concrete. This approach aims to prevent issues such as honeycombing, surface irregularities, longitudinal and transverse cracks, plate fracture, sand holes, and air bubbles. It makes the operation process more efficient, improves the coordination between humans and machines, optimizes traditional processes, and ultimately saves costs.

The use of machine-made sand in airport pavement construction holds great potential, and by following the outlined practices and principles, it can contribute to more efficient and cost-effective airport infrastructure development in China.

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