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Effect of material feed rate on sieving performance of vibrating screen for batch mixing equipment

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A B S T R A C T

Sieving or screening has been the most important unit operation for industrial separation of solid particles. Sieving performance of batch asphalt mixing equipment has an important effect on final asphalt mixture gradation. A Weibull probability distribution model along sieve surface was developed to investigate the effect of material feed rate on the sieving behaviour of material was developed based on the sieving probability analysis of particle swarm. The residence time of particles on the sieve surface is regarded as a random variable, and the sieving process is converted into a life problem. In addition, in order to ensure the accuracy and stability of asphalt mixture gradation, material is divided into two categories, easy-to-sieve particles (ESP) and hard-to-sieve particles (HSP) according to the order of passing through the sieve. Further, a full-scale test in a highway project was conducted to test and verify the influence of material feed rate on sieving performance of vibrating screen. The results are summarized as following: (1) The overlap region between sieving probability density curves of HSP and ESP indicates a poor sieving result including the mixing bin and channeling bin of hot materials. (2) There is an optimum matching between feed rate and sieve surface length for the purpose of stable sieving performance: If the length of sieve surface is the corresponding abscissa value of the intersection, increasing the feed rate would aggravate channeling bin. Conversely, decreasing the feed rate would aggravate mixing bin. (3) It was also indicated that material feed rate will sensitively affect the mixing and channeling rate of materials and it is better to select the curve intersection or its vicinity on the sieving probability density curves of HSP and ESP as feed rate based on the sieve surface length, and avoid substantial changes in feed rate.

1. Introduction

Aggregates of asphalt mixtures account for >95% of mix mass or 85% of the overall volume [1]. Therefore, the quality of aggregates has direct influence on the performance of hot-mix asphalt (HMA). The size, shape, distribution and interaction of aggregates directly affect the elastic, viscoelastic and other mechanical properties of asphalt mixture [2-3]. Many studies have been conducted on the gradation control and the relationship to the performance of asphalt pavements [4–8].

Generally, the realization of production gradation control is accomplished by using the vibrating screen to control the different specifications of material entering each individual hot bin. For batch asphalt mixing plan with multilayer sieve mesh, the sieving performance of each layer mesh directly determines gradation composition of the final mixture, and the accurate and stable gradation is the basis to guarantee the screening quality [9, 10]. Therefore, improving the sieving performance is one of the important goals for the design and use of vibrating screen for achieving better asphalt mixture [11].

Many studies have been conducted to improve the sieving performance by using the screening theory of particle swarm. Ray analyzed the vibration stratification theory of particle swarm in detail by using the single particle research as a starting point [12]. Lawrence and Beddow showed that the content of fine particles in the particle swarm directly influences the layered effect of particles. When the content of fine particles is <30%, the layered effect is better; when the content of fine particles is >60%, the layering process almost do not occur [13]. Based on the particle swarm and a dynamic model of the sieving process, Wang studied the relation between fine particle ratio, rate of particles layered sieve-passing, sieve surface length and time under different screening parameters, then noted that the relationship between the screening effect and screening time should be further analyzed to improve the sieving efficiency [14]. Wang et al. suggest that configuration of screen surface for batch asphalt mixing plant affect the sieving efficiency of vibrating screen on the basis of material sieving theory and a model between sieving efficiency and screen size [15]. At the same time, many researchers have studied the structure, sieve aperture

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Table 1
Comparison of Standard Sieve Aperture Sizes and Equivalent Sieve aperture sizes of Batch Asphalt Mixing Plant.

Standard aperture sizes /mm	2.36	4.75	9.5	13.2	16	19	26.5	31.5	37.5	53
Equivalent aperture sizes /mm	3–4	6–7	11	15	19	22	30	35	41	60

size and screening efficiency of vibrating screen [16–26], and the sieving efficiency was regarded as the main indexes to evaluate the performance of screening equipment [27, 28].

As the demands for the asphalt pavement have increased, the requirements for aggregate gradation have become increasingly strict during asphalt pavement construction. As for the widely used multi-layer vibrating screens which are the key component of asphalt mixing plants, their screening efficiency and performance affect the pavement quality and construction speed [29]. Therefore, how to use vibrating screen scientifically and rationally is the key to improve sieving performance in practical engineering for existing mixing equipment. The main objective of this study was to utilize Weibull distribution function to describe the sieving probability of particles along the length of sieve surface. Some parameters related to the materials flow rate were used to evaluate the sieving performance of vibrating screen based on the sieving probability analysis. And the influence law of flow rate on sieving performance of vibrating screen of mixing equipments was obtained.

2. Basic theory

According to the theory of vibration sieving, there is a close relationship between the sieve surface length and the sieving performance. When other conditions affecting sieving performance are constant, such as the same size and shape of particles relative to the sieve aperture, the same mesh size of the sieve itself, the amount of material on the sieve surface is constant, the direction of movement of the sieve and the rate of movement of the material relative to the sieve surface is stable, etc., the longer the sieve surface length is, the higher sieving performance is [30]. However, in practice, for the vibrating screen of batch asphalt mixing plant, its installation angle is usually between 12–30 degrees, it is hard to keep the sieve surface long enough due to limitations of structure size. Therefore, considering the screening ability and the limitations of structure size, usually the actual sieve aperture size is enlarged. Table 1 shows the relationship between the equivalent sieve aperture sizes recommended by the national standard and the standard sieve aperture sizes [31], and the actual aperture sizes of the vibrating screen used in this paper were among the range of equivalent aperture sizes. So, it is considered that the material, whose particle size is less than the size of the standard sieve aperture, is defined as easy-to-sieving particles (ESP). And also the material whose particle size is larger than the size of standard sieve aperture is defined as hard-to-sieving particles (HSP). In this case, there are two kinds of undesired

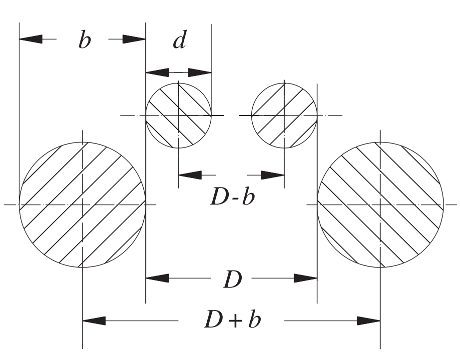

Fig. 1. Particles vertically pass sieve.

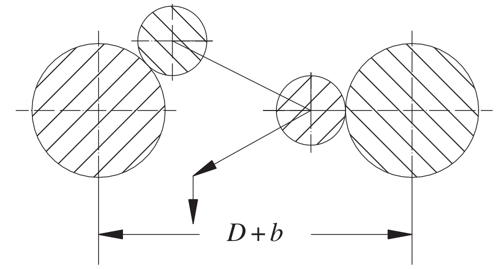

Fig. 2. Particles pass sieve after collision.

conditions: channeling bin and mixing bin. Channeling bin means the particle with size smaller than the standard sieve aperture does not enter into the corresponding hot bin but go into coarser bins. Mixing bin means undesired particle with size larger than the standard sieve aperture enters in the bin for desired materials. Both of two conditions affect the sieving performance.

Previous studies have shown that it is difficult to establish the model of screening efficiency of vibrating screen with the method of theoretical derivation, but the probability analysis method can be used. For the particles size of d, when it falls vertically to the sieve surface whose size is D (d ≤ D) and sieve wire diameter is b, some of the particles can directly pass through the sieve (As shown in Fig. 1) while the remaining particles do not pass through the sieve and will collide against the sieve mesh. Among the particles colliding against the sieve mesh, some of them passes through the sieve (As shown in Fig. 2) while other particles fail to pass through the sieve and jump down to next sieve aperture. The above analysis shows that the sieving probability after each bounce of particle can be approximated as the ratio of the equivalent area of passing sieve to total area of sieve surface, as shown in Formula (1) [32].

$$P=\frac{D-d+\psi b}{D+b}\cdot\frac{(D+b)\cos\alpha-(b+d)+\psi b}{D+b\cos\alpha}=\frac{\left(1+\frac{d}{D}+\psi\frac{b}{D}\right)\left[\left(1+\frac{b}{D}\right)\cos\alpha-\left(\frac{b}{D}+\frac{d}{D}\right)+\psi\frac{b}{D}\right]}{\left(1+\frac{b}{D}\right)^2\cos\alpha} \quad (1)$$

where P is sieving probability of the particles whose size is smaller than the sieve aperture size, α is angle of sieve plate (°), ψ is a coefficient considering particle passing sieve after colliding sieve mesh. $\frac{b}{D}$ is defined as sieve mesh ration, $\frac{d}{D}$ is defined as particle ratio coefficient. When $\frac{d}{D}$=0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, the corresponding value of ψ is 0.2, 0.15, 0.12, 0.10, 0.07, 0.05, 0.04 respectively [33].

The relation among sieve mesh ration, particle ratio and sieving probability is shown in Fig. 3.

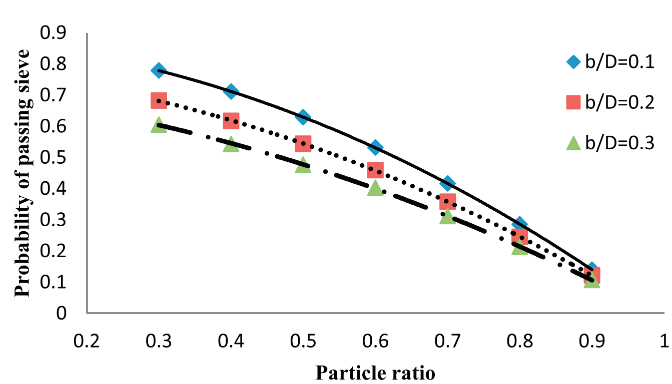

Fig. 3. Sieving probability versus particle ratio.