The influence of the installation angle and structure design of the throw-out plate on the effect of throwing waste

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Abstract. The efficiency of throwing waste is the main performance index of pavement milling machine. Structure design, installation angle and surface treatment of the throw-out plate have a direct impact on the efficiency of throwing waste. On the full factorial design, the structural form and installation angle of the throw-out plate are the influencing factor, and the number of throwing waste is the evaluation index by dynamic analysis. The wear resistance of the improved throw-out plate is tested and analysed. At the same time, the plasma surfacing process is used to optimize and verify the wear resistance. The results show when the throw-out plate has no groove and the installation angle is 0°, the number of throwing waste is the most and the quantity of waste is 3340. Without surface strengthening, the wear resistant of the new throw-out plate is 0.614g⁻¹. With surface strengthening, the wear resistant of the improved throw-out plate increases to 9.174g⁻¹. The unimproved throw-out plate is about 1500 hours. Through the contrast experiment, wear time per unit thickness of the improved throw-out plate enhances 300 hours to 600 hours, which provide important guidance for structure design and process design.

1. Introduction

Milling efficiency and pavement effect are important indexes for the performance of milling machine. With the optimization design and material process improvement of rotor cutters, milling efficiency has been significantly improved, and the research of milling effect has also been significantly improved through the wear resistance improvement of sliding shoes and scrapers. To avoid the accumulation of waste particles in the milling room, the throw-out plate is designed on the milling drum and the waste of the rotor tool surface is thrown into the milling room. The waste particles that have not been thrown into the milling room will remain on the road, and are collected by the slipper and scraper, which cause resistance and impact to the slipper and scraper. Therefore, the quality of the throwing effect affects the pavement milling effect of the slipper and the scraper [1-3]. The improvement of the throw-out plate structure and the installation angle has a direct effect on the throwing waste effect.

Many experts have done much research on the milling system design and the milling efficiency. According to the milling process and structure forms, Ma P. Y. et al. [4] established the mathematical model of motor drive system to analyze and discuss and the relationship between the load and the speed. Gao L. et al. [5] has designed different milling drum surface, milling speed and milling depth, which...
will influence the skid resistance. The faster the milling speed, the higher the skid resistance will be better, and the higher the milling efficiency. With the milling efficiency improvement, it puts forward higher requirements for the effect of throwing waste. The installation angle of the throw-out plate has an influence on the trajectory of the waste particles in the air, so it influences on the throwing waste effect. At the same time, the surface of the throw-out plate is mainly rectangular, which is fixed on the milling drum by bolts, and the influence of the surface structure on the throwing efficiency is less. Therefore, the throw-out plate installation angle and surface structure has influence on the pavement milling effect.

Taking the throw-out plate as the research object, analyze the trajectory of throwing waste, surface structure, installation angle as the impact factor, the number of throwing waste as the evaluation index. Design the full factorial experimental. Dynamic simulation is carried out, and the throw-out plate sample is tested. At the same time, the wear resistance of the service life index is taken into account, and the comparison test and loading test are carried out.

2. Methodology

2.1. Surface structural design of a throw-out plate.
The material of the throwing plate is ordinary carbon steel, and the surface is strengthened by plasma surfacing. To study the effect of the surface structure on the throwing waste effect, two forms of surface with grooves and no grooves are designed as shown in figure 1.

(a) The surface structure with grooves (b) The surface structure with no grooves
Figure 1. A diagram of the unimproved throw-out plate

The surface structure is mainly based on the bionics, and grooves produce "dynamic pressure effect" [6] that the surface of the grooves can produce more compressive strain in contact process to make stress get slow release and enhance wear resistance. The surface structure with no grooves is from the impact force to aggravate the wear of structural parts. However, from the bonding effect of milling waste, it is more conducive to the smooth surface of the throwing waste.

2.2. Analysis of the trajectory of throwing waste.
During the establishing model, the milling drum, the throw-out plate and the milling boom have greater hardness than the asphalt concrete pavement. And almost no deformation occurs during the milling process, so they are rigid bodies. The density is 7.8 x 10³ g/mm³, the modulus of elasticity is 2.1 x 10⁵ Mpa, and the Poisson's ratio is 0.3. The asphalt concrete pavement is established in EDEM, which simplifies waste as spherical particles, and Hertz-Mindlin with bonding is used as binder between particles and particles of asphalt mixture. The static relaxation iteration method and the dynamic relaxation iterative method are used to calculate the cyclic iteration.

To make more waste into the collecting room, study the throwing waste trajectory of the throw-out plate, as shown in figure 2.

The trajectory of the waste is a parabolic motion, respectively, at the top and bottom of the collecting room. The formula [6] for calculating the movement of waste in the horizontal and vertical direction is shown as in equation (1) and equation (2).

\[ x = vt \cos \alpha \]  
\[ y = vt \sin \alpha + \frac{gt^2}{2} \]
Formula: X is the horizontal distance from the throw-out plate to the bottom of the collecting room; y is the vertical direction distance of the waste; v is the speed of leaving the throw-out plate; t is the running time of the waste.

The waste falls into the collecting room to ensure that the vertical direction distance of the waste is between the upper entrance and the lower port of the collecting room that the formula is satisfied as in equation (3).

\[ y_{up} < y < y_{down} \]  \hspace{1cm} (3)

Formula: \( y_{up} \) is the vertical distance from the throw-out plate to the upper of the collecting room; \( y_{down} \) is the vertical distance from the throw-out plate to the bottom of the collecting room.

![Figure 2. The schematic diagram of the trajectory of throwing waste](image)

2.3. The full factor experimental design.

Through the analysis of the throwing waste trajectory, it is determined that the factor that affects the efficiency of the throwing waste is the installation angle. Combined with the surface structural design, the structural surface form is taken two levels of grooves and no grooves. The installation angle is -15°, -10°, -5°, 0°, 5°, 10°, and 15°. The full factor test design is carried out. The experiments are needed for dynamic analysis shown in table 1.

| Surface structure | Installation angle |
|-------------------|--------------------|
| 1                 | Grooves -15°       |
| 2                 | Grooves -10°       |
| 3                 | Grooves -5°        |
| 4                 | Grooves 0°         |
| 5                 | Grooves 5°         |
| 6                 | Grooves 10°        |
| 7                 | Grooves 15°        |
| 8                 | No grooves -15°    |
| 9                 | No grooves -10°    |
| 10                | No grooves -5°     |
| 11                | No grooves 0°      |
| 12                | No grooves 5°      |
| 13                | No grooves 10°     |
| 14                | No grooves 15°     |
3. Result analysis and discussion

3.1. The effect analysis of throwing waste.
By simulation, the number of waste falling into the collecting room is calculated to evaluate the throwing waste effect. The calculation results of the full factor experimental design scheme are obtained respectively shown in Figure 3. According to the statistics of the test results, the statistical analysis is carried out by Minitab software, and the results are shown in figure 3.

Figure 3. The throwing waste effect simulation of the throw-out plate

Figure 4. The interaction diagram of throwing waste effect
From figure 3, when the throw-out plate has no groove and the installation angle is 0°, the number of throwing material that is 3340 is the most. The throw-out plate is designed with the groove and the installation angle is 0°, the number of throwing material that is 3190 is the most. The track and distribution pattern of waste are basically the same in the air, but there are still a small number of waste attached to the grooves of throw-out plate, so the grooves has a negative effect on the throwing waste effect. Considering throwing waste and bonding, the groove design between waste and waste, and between waste and throw-out plate is more effective. In actual conditions, it will weaken the number of throwing waste, so no groove design is more suitable for improving the throwing waste effect.

From figure 4, the A is the factor of surface structure that 1 is the grooves design and 2 is the no grooves design The B is the factor of installation angle, where 1~7 corresponds to the installation angle of -15°, -10°, -5°, 0°, 5°, 10°, 15°. The surface structure and the installation angle have interaction effect on the throwing waste effect of the throw-out plate. The surface structure is positive correlation to the effect of throwing waste. Under the fixed installation angle, the design without grooves is more beneficial to the throwing waste effect. The installation angle is -15°, -5° and 0° are positively related to throwing waste effect, and the installation angle is -10°, 5°, 10°, 15°, which has negative correlation with throwing waste effect. So the surface structure of the throw-out plate is designed to be no grooves, and the installation angle is 0°.

3.2. Test verification.
On the above research, the samples of the throw-out plate are tried and made. The trial process is shown in figure 5.

![Figure 5. The trial sample of the throw-out plate](image)

Wear resistance is an important index of the throw-out plate performance. The wear resistance of the new structure is tested by the pin wear test, and the wear performance of the throw-out plate is shown in table 2.

| The sample | Weigh before test (g) | Weigh after test (g) | loss (g) | Wear resistance (g⁻¹) |
|------------|----------------------|---------------------|---------|-----------------------|
| 1          | 10.785               | 9.134               | 1.628   | 0.614                 |
| 2          | 10.673               | 9.069               | 1.606   | 0.614                 |

The table 2 shows that wear resistance of the throw-out plate is poor, which will reduce the service life, so it is necessary to enhance the wear resistance. Considering the fixed installation angle, the surface structure is positively related to the effect of the throwing waste, and the throw-out plate should be as smooth as possible after the improvement of the surface structure. To avoid affecting the bolt holes used for assembly, the surfacing is strengthened on both sides of the throw-out plate. Therefore, plasma spray welding technology is applied. The Fe60 powder is commonly used as surface hardening material, and the samples of the throw-out plate are obtained as shown in figure 6.
In the same way, the wear resistance test of the new structure is carried out, and the wear performance of the throw-out plate is shown in table 3.

From table 3, that the wear resistance of the throw-out plate has been greatly improved. In the application, the installation angle of the throw-out plate is 0°, and the throw-out plate with no grooves in the surface structure is surfaced into a smaller plate. The optimized samples can not only improve the wear resistance, but also improve the effect of the throwing waste, and help to improve the service life of the throw-out plate. The optimized throw-out plate is carried out the loading test. Through the comparison of throw-out plates, the original structure throw-out plate works for about 1500 hours, and the unit thickness wear time is 300 hours. The unit thickness wear time increases to 600 hours after improvement. It has been applied in milling machine manufacturing.

![Figure 6. The samples of the throw-out plate](image)

Table 3. The wear performance of the surfacing layer.

| The sample | Weigh before test (g) | Weigh after test (g) | loss (g) | Wear resistance (g⁻¹) |
|------------|-----------------------|----------------------|----------|----------------------|
| 1          | 11.213                | 11.154               | 0.061    | 16.393               |
| 2          | 11.125                | 11.062               |          |                      |

4. Conclusions

To effectively improve the throwing waste effect of throw-out plate, this research begins with establishing the installation angle and the surface structural dynamic model, and designs the full factorial test. Considering the wear resistance, the process improvement of the throw-out plate is carried out, and the wear resistance of the unimproved and improved throw-out plate is compared and verified, and the loading test is carried out. Through the study, the following conclusions are drawn. There is no groove in the surface structure, and the installation angle is 0°, which helps to improve the effect of throwing waste. When the throwing effect is not too much reduction, plasma spray welding technology is applied to improve the wear resistance. Through the test and comparison of the throw-out plate before and after the improvement, the unit thickness wear time is raised to 2 times that of the original level. The calculation model of the throw-out plate under different structural and technological conditions is established, which has important significance for guiding the research of the coupling relationship between the structural design and the assembly design. Due to the selection of surfacing materials and the lack of detailed analysis of welding parameters, the research is carried out with experience. The full factor test can be used to further optimize the welding process.

References

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