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Short Communication

Overview of research on adhesion reduction and desorption technology of soil-contact construction equipment

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Abstract

Earthmoving machinery is prone to adhesion problems when working against soil media, resulting in a decline in construction efficiency and quality. This paper summarizes the development of soil adhesion mechanisms, describes the research progress of experts and scholars in various countries in the field of adhesion and desorption, and prospects the research on adhesion and desorption of soil contacting components of construction machinery.

Introduction

Rotary drilling, double-wheel milling, horizontal directional drilling, etc. are typical operating equipment for soil media, and the reliability of their operating devices is a key influencing factor for operating efficiency and construction quality, etc. When facing the typical underground construction media of soil and rock, the adhesion of the construction media to the operating devices leads to high working resistance, low operating efficiency, and poor construction quality, which are the main factors affecting the quality of underground construction and drilling and milling efficiency one of the main factors affecting the quality of underground construction and the efficiency of drilling and milling [1,2]. According to the device and construction conditions, its adhesion can be divided into two types of cases: first, adhesion to the inner surface of the barrel and box structure tools, such as rotary drilling barrel drill; second, adhesion to the outer surface of the disc and plate structure tools, such as double-wheel milling wheels. According to incomplete statistics of on-site construction, the influence of sticky wet soil on the adhesion of the cartridge drill leads to its effective volume utilization rate of only about 60%, and the heavy adhesion of soil media is less than 40%, which reduces the operational efficiency, increases energy consumption and delays the construction progress. On the other hand, the clay soil increases the resistance of soil-touching parts, intensifies the abrasion loss effect, and secondly, it needs to be shaken by the machine, collision, and detachment, which causes damage to the reducer, motor, and overall reliability of the machine [3,4]. Therefore, it is significant to solve the adhesion of earth-moving machinery for the development of a double carbon strategy.

Discussion

Adhesion mechanism of soil media

Many researchers have discussed and studied the mechanism of soil adhesion extensively and systematically based on the natural properties of soil and daily industrial and agricultural production practices, and a variety of theories of soil adhesion and theories of soil adhesion have been developed to explain the phenomena and laws of soil adhesion from different perspectives.

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Moisture tension theory

The most cited research in the field of soil adhesion is Fountaine's water tension theory, also known as water film theory [5]. He considered the adsorption of water by agglomerated soil solid particles, the water film pressure difference Laplace, and the bonding force as the main factors of water tension and fluctuating with the soil water content. To further investigate the relationship between moisture tension and soil adhesion, tests using a designed moisture tension measurement device revealed that the moisture tension decreased with increasing soil water content, and the soil moisture tension was zero at supersaturated water content. And for the difference in moisture tension trend of clay and sandy soil, it was proposed that two contact states of continuous or discontinuous water film will occur at the contact interface between soil and other materials, and the value of soil adhesion is the product of moisture tension and water film area at the contact interface JS Mcfarlane, et al. [6]. suggested that surface tension plays an important role in soil adhesion, and the adhesion was measured using the developed adhesion measuring device The measurement results showed that the adhesion force value was about 9.8 × 10^{-9} N. Further, Qian Dinghua, et al. [7]. proposed a five-layer interface theory based on the thermodynamic point of view for the adhesion test of soil to metal materials, i.e., metal layer, a metal surface-water interface layer, water film layer, soil surface-water interface layer, and soil layer. He believed that based on the surface energy viewpoint, the occurrence of damage in the five-layer model depends on the weakest water film layer, i.e., overcoming the attraction tension between the metal surface and the soil surface due to the water film layer, so the magnitude of the soil adhesion force value depends on the thickness, continuity, contact area, and water film tension of the water film Figure 1.

Capillary adhesion theory

In capillary adhesion theory, molecular interactions at the interface of solid, liquid, and gas phases, with water inside the soil playing a major role, were first proposed by R.E. Baier [8] and others and further studied and refined by Fisher, Nichols, Japanese scholars such as Shio Yokai and Yutaka Akiyama [9,10]. Considering the soil as a unified body composed of numerous particles, which is essentially an accumulation of granular materials, the soil was equated to uniform spherical particles, and the relationship between the radius of soil spherical particles, the surface contact angle of solid materials, and capillary forces were explored. When the thickness of the water film is certain, the soil adhesion force decreases with increasing particle radius and decreases with increasing contact angle.

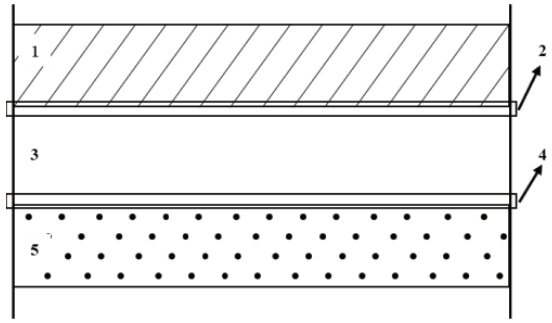

Figure 1: Five-layer interface model diagram of soil adhesion.
1: Metal layer; 2: Metal surface - water interface layer; 3: Water film layer; 4: Soil surface - water interface layer; 5: Soil layer.

Theory of combined force model

According to ПомаПоВ, et al. the soil adhesion force is the result of a combination of forces, and the soil structure consists of soil particles and their agglomerates, water inside the soil, and air. In the contact between soil and metal surfaces, intermolecular gravitational forces are generated at the microscopic contact points, the soil itself has a large negative charge, which attracts positive ions from the aqueous solution inside the soil to form a double electric layer, which adsorbs positive ions to the particle surface, the metal surface forms electrostatic gravitational forces, the water film tension formed by the contact between the soil and the metal surface, the sticking resistance due to the failure to form a sufficient water film, and the chemical potential difference between the water film outside the interface and the aqueous solution in the pore generated by the breaking force. Different surface interface adhesion systems and different internal conditions play different roles for each component force. In subsequent studies, some scholars believe that the negative pressure of air at the interface is also an integral part of the adhesion force value.

Molecular model theory

Zhang Jixian [11] and others analyzed the soil adhesion mechanism from the perspective of interfacial free energy. The defined interfacial high-energy adhesion water film layer energy decreases when soil-free water molecules bond with the solid material surface, and the damage occurs in the central layer of the interfacial water film when the water film layer thickness is sufficient, and the size depends on the cohesive force of water molecules. When the thickness of the water film layer is not enough, the defined interfacial high-energy adhesion water film layer energy is lower than the free water energy, increasing the soil adhesion force, determined by the state of the adhesion water film layer, the type of soil, solid materials on the adhesion water film layer molecules.

Other theories

The above theories and doctrines have promoted the development of soil adhesion research, but still lack some extension in some specific areas. Other domestic researchers, such as the team of academician Ren Luquan of Jilin University [12-14], have explored and researched the soil adhesion mechanism around soil properties, contact body materials, adhesion interfaces, and experimental conditions, and derived the technical discipline of bionic adhesion reduction, which has solved the adhesion problems of series of agricultural machinery and ground machinery and promoted the combination of theory and practice, whose significance cannot be overstated.

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Research status of viscosity reduction and desorption technology

In response to many issues such as reduced operational efficiency, reduced construction quality, and lack of product life caused by the adhesion of soil media, relevant scholars and experts have done a lot of theoretical and experimental research to solve industry problems and promote high-quality, green, and low-carbon development of the industry. Liu Hongjun [15] and others designed a mechanical device for reducing viscosity, resistance, and compaction, which reduced soil adhesion with traditional devices by 34.8%. Cheng Chao [16] and others conducted research on heating viscosity reduction for rice machines, achieving a desorption rate of over 65%. In order to reduce the soil adhesion of plowshare tools, M. Barzegar [17] and others coated the plowshare with ultra-high molecular chain polyethylene (UHMWPE) coating for surface modification, showing significant viscosity reduction effects. Jilin University [18] has reduced the contact area between soil and plow walls by welding structures with different shapes on the soil contacting parts of agricultural machinery such as potato harvesters and plowshares, thereby avoiding soil adhesion, reducing operational resistance, and improving the operational quality of agricultural machinery.

Biomimetic viscosity reduction technology for biological structures is mainly used to study the characteristics of biological surfaces in nature, such as dung beetles, lizards, beetles, grubs, sharks, and lotus leaves [19,20], which have characteristics of resistance reduction, viscosity reduction, and anti-adhesion. Cong Qian from Jilin University [21] and others have studied the factors that affect the viscosity reduction efficiency of electroosmosis and established a relationship model between electroosmosis energy consumption and soil adhesion. As evolution continues, there have gradually emerged the fact of multiple functional synergies in the evolution of organisms, such as the synergistic effect of the dorsal scales and claws of pangolins, the comprehensive effect of the micro/nano texture on the surface of lotus leaves and their own hydrophobicity, and the coordination of the bioelectric system of earthworms from the body surface with flexible bodies. Two or more different parts or different characteristics of organisms are coupled to play a role in the functional characteristics of desorption, drag reduction, wear resistance, and adhesion resistance.

Conclusion

The research on adhesion mechanism and the development of adhesion reduction technology have promoted the development of the industry to a certain extent, but their role and effect are limited. The “ceiling” phenomenon in the application process of a single adhesion reduction technology is significant. Composite, intelligent, and digital will be the necessary means for on-site actual adhesion issues and the mainstream direction for the development of adhesion reduction technology in the future.

1. Due to the service characteristics and low value-added economic characteristics of products such as construction machinery, it is of great significance to improve the design of soil contact components and combine them with traditional surface modifications or biological structures.

2. Realizing visual operation from worker sites to remote digital displays and intelligent viscosity reduction parameter matching is a technological development trend. According to the on-site soil media environment, real-time feedback and adaptive viscosity reduction process parameter matching are implemented to meet the demand for dynamic viscosity reduction.

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