

Analysis of Lead Dust Treatment System Based on Cold Sintering Technology

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Abstract: *This paper presents a preliminary design for a lead dust treatment system based on cold sintering technology. The system aims to achieve energy savings by leveraging the low-energy consumption advantage of cold sintering over traditional high-temperature sintering methods in the sintering industry. Furthermore, it utilises marble waste residue and cement as joint solidifiers to reduce the porosity of the solidification products, thereby seeking to stabilise lead dust and resource-recycle solid waste. This paper completes the preliminary design of the system and explores the feasibility of its technical principles, laying the theoretical foundation for subsequent experimental validation. This work represents only an initial technical concept and has not undergone rigorous mathematical derivation, experimental verification, or data support. Further in-depth research and systematic evaluation are required.*

Keywords: *Cold Sintering Technology, Lead Dust Treatment, Marble Waste Residue, Preliminary Concept*

1. Introduction

Lead is present in essential production and daily necessities such as lead-acid batteries and building materials, yet the world currently faces a severe lead pollution crisis. Addressing these challenges, this project has researched and designed a lead dust treatment system based on cold sintering technology. As a low-energy consolidation technique, cold sintering has been experimentally applied to the solidification of heavy metals in incinerator fly ash, demonstrating significant energy-saving and stabilisation potential [1]. Furthermore, replacing cement with appropriate quantities of marble powder can reduce the porosity of cement paste [2]. Inspired by these studies, this research aims to integrate both approaches, leading to the design of a lead dust treatment system. This paper will focus on presenting the overall design scheme and operating principles of this system.

2. Design Proposal

2.1 Overall Design Proposal

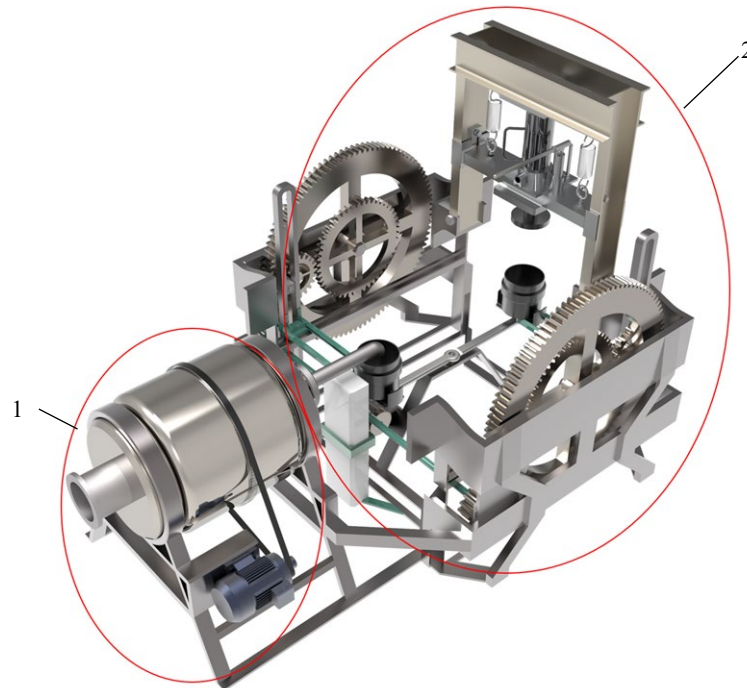
Based on the fundamental technical principles outlined in the introduction, this project has designed the integrated apparatus shown in Figure 1. The apparatus comprises two components: a pre-treatment module and a cold sintering module.

The crushing and mixing apparatus within the pre-treatment module is a modified small-scale ball mill. Springs have been installed between the inner and outer cylinders to increase the impact of the grinding media on the marble waste residue and amplify the device's vibration amplitude. This ensures more thorough crushing of the marble waste and more uniform mixing with the lead-containing dust.

The cold sintering module employs a dual-mould station mechanism, enabling the concurrent execution of heating and hydraulic processes—both time-consuming operations—thereby enhancing overall efficiency. Within the curing mould, a cam mechanism raises the inner base plate, facilitating smoother demoulding of the solidified product.

During operation, marble waste residue and lead-containing dust are first conveyed to the pre-treatment module for processing. This stage primarily involves the pulverisation and grinding of the marble waste residue, followed by its uniform blending with the lead-containing dust. The crushing and grinding apparatus within the pre-treatment module fulfils these requirements through rotational and

abrasive operations. The uniformly blended marble powder and lead-containing dust are then blown into the curing moulds within the cold sintering module. Heating pads subsequently raise the mould temperature to approximately 200°C to achieve the requisite cold sintering conditions. Thereafter, the mould is transferred from the heating station to the hydraulic station via a dual-station mould transfer mechanism. Subsequently, the hydraulic system activates, applying uniaxial downward pressure to the mould to meet cold sintering pressure requirements. After approximately 100 minutes, the cold sintering process concludes. A cam mechanism ejects the cured product from the mould for subsequent processing.



(1) Pre-treatment module; (2) Cold sintering module.

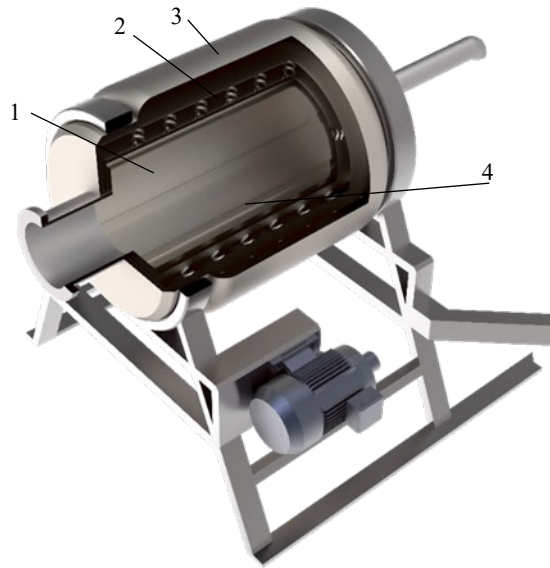
Figure 1: Overall assembly drawing.

2.2 Pre-treatment Module Design Proposal

The pre-treatment module primarily comprises a crushing and grinding apparatus, motor, pulley, and bearing bracket. During operation, the motor drives the crushing and grinding apparatus via the pulley, enabling thorough pulverisation and uniform mixing of marble waste residue and lead-containing dust. The crushing and grinding apparatus is detailed below.

As illustrated in Figure 2, the crushing and grinding apparatus comprises a rotating cylindrical grinding disc fitted with internal liners, a rotating sleeve, and high-pressure springs that secure and connect the two components. The inner wall of the rotating sleeve features several rows of axially distributed spring grooves, enabling secure fixation of the high-pressure springs. Correspondingly, the outer wall of the rotating cylindrical grinding disc bears an identical number of spring grooves. This arrangement allows the grinding disc to connect with the inner wall of the rotating sleeve via the high-pressure springs, enabling synchronous high-speed rotation.

During operation, the motor drives the rotating sleeve via a pulley to spin at high speed around its own centre. Under the influence of gravity from the rotating cylindrical grinding disc, the high-pressure spring positioned beneath the disc undergoes additional compression, while the compression of the upper high-pressure spring consequently diminishes. This causes the rotating cylindrical grinding disc to descend by a certain height. The steel balls within the disc are ejected before the disc completes its descent, consequently extending the steel balls' descent time. This enables more vigorous crushing and grinding of the marble waste residue. Simultaneously, the upward radial elastic force generated by the compressed lower spring is indirectly transmitted to the marble waste residue, thereby exerting greater force for its fragmentation and grinding. Furthermore, the descent of the rotating drum grinding disc causes its central shaft to become misaligned with the rotating sleeve's spindle, generating an eccentric vibration effect. This vibration ensures the marble waste is crushed, ground, and mixed more thoroughly, uniformly, and efficiently.

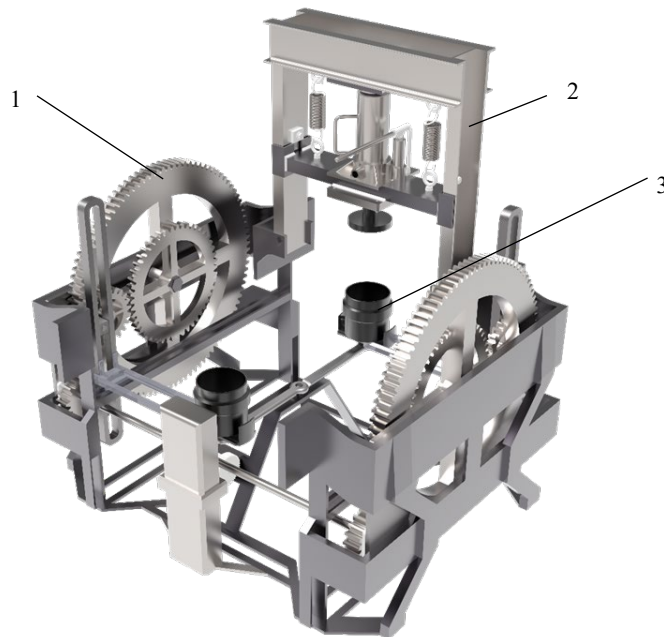


(1) Rotating cylindrical grinding disc; (2) High-pressure springs; (3) Rotating sleeve; (4) Internal liners.

Figure 2: Crushing and grinding apparatus.

2.3 Cold Sintering Module Design Proposal

As illustrated in Figure 3, the cold sintering module comprises a curing mould, a hydraulic assembly, and a dual-mould station transfer device. During operation, heating pads first warm the curing mould, after which the dual-mould station transfer device relocates the mould beneath the hydraulic assembly for pressurisation, yielding the cured product.



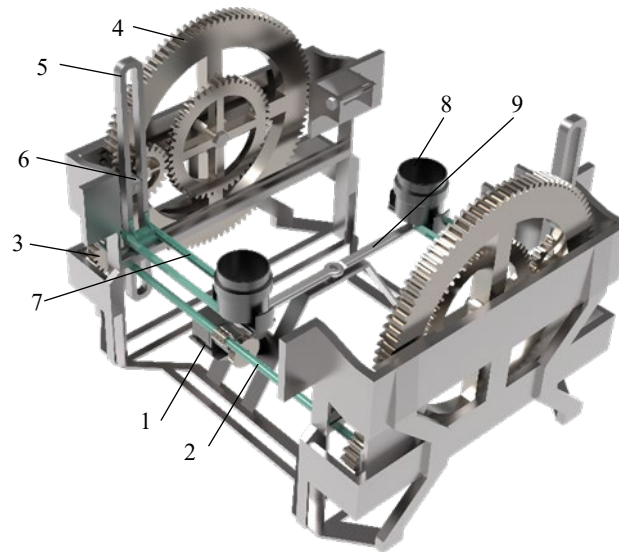
(1) Dual-mould station transfer device; (2) Hydraulic assembly; (3) Curing mould.

Figure 3: Cold sintering module.

2.3.1 Dual-Mould Station Transfer Device

As illustrated in Figure 4, this apparatus comprises a motor, drive rod, gear 1, gear 2, slide groove, mould slide rail, curing mould, and connecting rod. One end of the connecting rod articulates with the central shaft of the base to form a hinge, while the other end articulates with the central shaft at the bottom of the mould to form another hinge. Consequently, the mould can perform circular motion about the central shaft of the base. This, in conjunction with the lateral drive provided by the sinusoidal motion

device, enables the mould to rapidly traverse from the heating station to the hydraulic station.



(1) Motor; (2) Drive rod; (3) Gear 1; (4) Gear 2; (5) Slide groove; (6) Slider; (7) Mould slide rail; (8) Curing mould; (9) Connecting rod.

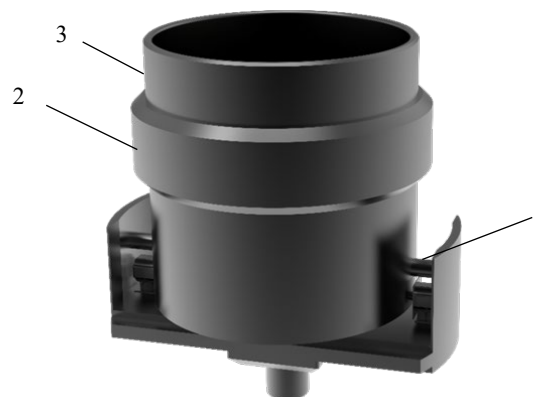
Figure 4: Dual-mould station transfer device.

During operation, the motor drives the drive rod to rotate. The drive rod transmits rotation to gear 2 via gear 1. Gear 2 transmits this rotation to the slide via a slider, converting it into the slide's x-axis movement. The mould slide rail, mounted on the slide, follows this x-axis motion. Consequently, the curing mould moves x-directionally with the slide rail. Simultaneously, as the connecting rod's length remains fixed, the curing mould necessarily moves y-directionally along the slide rail under the constraint of the connecting rod during its x-axis travel. It follows that the mould traverses a semi-circular trajectory between the two stations.

This apparatus enables the concurrent execution of heating and hydraulic processes—both time-consuming operations—thereby enhancing overall system efficiency.

2.3.2 Curing Mould

As illustrated in Figure 5, the curing mould comprises a rotary shaft, thermal insulation layer, mould body, and externally mounted heating pads. The insulation layer is constructed from ceramic material, which, in conjunction with the heating pads, enables the mould to maintain a cold sintering temperature of 200°C during the hydraulic process.

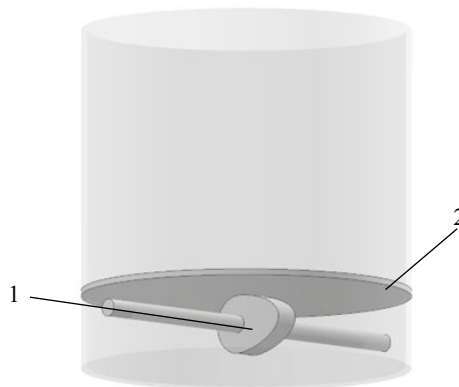


(1) Rotary shaft; (2) Thermal insulation layer; (3) Mould body.

Figure 5: Curing mould.

Figure 6 illustrates the internal structure of the curing mould. Upon completion of the cold sintering process, the rotary shaft drives the cam to rotate approximately 45 degrees. During this rotation, the cam causes the mould's base plate to move upwards along the mould's inner wall, thereby ejecting the cured

product and completing demoulding.



(1) Cam; (2) Mould's base plate.

Figure 6: Internal structure diagram of curing mould.

3. Prospects for Application

This paper designs a system utilising cold sintering technology principles, incorporating marble waste residue and cement as solidifying agents for the synergistic solidification of lead-containing dust.

Technologically, the cold sintering technique employed by this apparatus offers energy-saving advantages over high-temperature sintering solidification methods. Firstly, the required temperature is significantly lower than that demanded by high-temperature sintering solidification. Secondly, the process duration is shorter than that of high-temperature sintering solidification [3]. Consequently, the cold sintering technology employed in this project offers the advantages of low energy consumption and high efficiency.

Regarding the use of solidifiers, the apparatus utilises marble waste residue and cement as synergistic solidifiers. Existing research indicates that the addition of appropriate quantities of marble waste residue can reduce the porosity of cement [2]. Building upon this observation, this study hypothesises that under the low temperatures and uniaxial pressure conditions of cold sintering, marble waste residue can still function to reduce the porosity of the solidification product, thereby suppressing the release of lead dust. Furthermore, as marble waste residue itself constitutes solid waste, its utilisation achieves waste recycling, reducing the consumption of natural resources such as gypsum and calcium-silicon minerals.

Regarding product applications, marble waste residue itself can be resourcefully utilised as a construction material [4-5], while cement is extensively employed in the construction industry. The solidification product obtained by combining these two as a solidifier holds promise for application in the construction of open structures such as roads and bridges, thereby realising its practical value.

Regarding transferable applications, the lead dust treatment technology employed in this apparatus is cold sintering. This technique involves uniformly mixing lead-containing dust with marble powder and cement powder before compacting it into a dense solid. This technology holds promise for the solidification treatment of other heavy metal powders, thereby enabling transferable applications.

4. Conclusion

This study proposes and designs a preliminary lead dust solidification treatment system based on cold sintering technology, utilising marble waste residue and cement as co-solidifiers. It aims to provide an energy-efficient, resource-recycling pathway for addressing lead pollution. By integrating a pre-treatment crushing and grinding unit with a dual-station cold sintering solidification module, the system theoretically enables low-energy stabilisation of lead dust and resource recovery from solid waste.

It must be explicitly stated, however, that this research remains at the conceptual design and preliminary principle exploration stage. The technical advantages, treatment efficiency, and properties of the solidified products described herein are based on literature review and theoretical derivation, and have not yet been validated through experimental data, mathematical modelling, or physical prototypes. Critical issues such as the optimal range of cold sintering process parameters (temperature, pressure,

holding time), the optimal mixing ratio of marble waste residue and cement, and the long-term stability and heavy metal leaching toxicity of the solidification products all require systematic evaluation through subsequent in-depth experimental research.

Subsequent work will focus on establishing an experimental platform to rigorously validate the system's practical performance, quantify its energy consumption metrics and treatment efficacy, and investigate the microscopic mechanisms governing marble waste residue behaviour during cold sintering. This aims to provide robust data support and theoretical foundations for the technology's practical implementation.

References

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