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Study on the Preparation Process of BN Water-based Coating for Casting by Ultrasonic Ball Milling

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Abstract

In order to improve the preparation efficiency and performance of casting coatings, this article developed an ultrasonic ball milling process for preparing water-based casting coatings by applying an ultrasonic energy field with a high-magnification ultrasonic horn during the rod-type stirring ball milling process, used h-BN as the main refractory aggregate to design a semi-insulating metal mold casting coating formulation, used aluminum alloy metal mold casting as the application scenario to design the detection and evaluation methods of heat insulation and lubrication performance, studied the influence of h-BN concentration, ultrasonic power, crushing speed and crushing time on the performance of coatings. The results show that the ultrasonic/ stirred ball milling process can effectively reduce the D [4,3] of h-BN water-based aluminum alloy metal mold casting coatings, and the D [4,3] is reduced from 13.69 μm to 4.85 μm, which can effectively improve the coating's lubrication, thermal insulation and brushing performance. A set of optimal ultrasonic ball milling process parameters were obtained through orthogonal experiments: h-BN concentration 32.5 wt%, ultrasonic power 1000 W, working speed 350 r/min, working time 180 min.

Keywords

Aluminum Alloy; Metal Mold Casting Coating; H-BN; Ultrasonic Dispersion; Stirring Ball-milling.

1. Introduction

Metal casting coatings have two main functions: heat preservation and insulation, easiler ejection. It can form a semi-permanent coating with a certain heat transfer function on the inner wall or core surface of the metal mold, which can improve the dimensional accuracy and surface performance of the casting while protecting the metal mold. Therefore, the selection and rational application of metal mold casting coating is equally critical to the design of metal molds, the treatment of metal melts, and the casting system.

The formulation, preparation technology and equipment of the coating are the main factors affecting the quality of the coating. At present, graphite powder, zircon powder, and talc powder are mostly used as refractory aggregate of metal mold casting coating, graphite powder is used to provide lubricity or balance the thermal insulation capacity of the coating [1], but graphite is black and delicate, the water-based and oil-based graphite currently used is seriously polluted. In recent years, hexagonal boron nitride (h-BN), which has a structure and properties similar to graphite, has been used in casting coating formulations [2,3], researchers have found that this type of casting coating can protect refractory materials, metal molds and ceramic vessels that are in direct contact with molten

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aluminum, magnesium, copper, zinc alloys and molten slag, and has the effect of significantly prolonging the service life of the substrate [4], therefore, boron nitride (BN) casting coatings have the application prospect of replacing graphite casting coatings; For water-based and most solvent-based casting coatings that do not require high performance, they can be prepared directly by a mixer. The production of high-performance casting coatings requires the use of dispersion and grinding equipment [5]. Dispersing equipment provides agitation and mixing, including wheel mills and high-speed dispersers. Grinding equipment mainly includes three-roll mills, ball mills, and colloid mills. The raw materials of ultrafine powder are expensive and the processing method is complicated, the working process is long, and the efficiency is low [6]. Generally speaking, It's an effective way to improve the grinding performance of grinding equipment to improve the performance of casting coatings.

Cavitation and acoustic flow effects occur when ultrasonic waves propagate in liquid media [7,8], the strong mechanical force produced by the two effects has a powerful crushing and dispersing effect on the solid particles in the medium [9,10], While the particle size of the material is reduced [11,12], the physical properties, chemical properties and crystal structure changes at the same time [13]. So far, the research on ultrasonic pulverization has mainly focused on the fields of medicine and biology, and the research on mineral materials needs to be further developed. In this paper, by applying a certain intensity of ultrasonic energy field in the process of stirring ball milling, the process of preparing h-BN water-based aluminum alloy metal mold casting coatings by ultrasonic ball milling is studied, in order to improve the working efficiency of the casting coating preparation process and the performance of the coating products, specifically studied the influence of h-BN concentration, ultrasonic power, working speed and working time on the particle size, heat preservation and insulation of the casting coating, and a set of suitable process parameters for preparing h-BN water-based aluminum alloy metal mold casting coatings by ultrasonic ball milling was obtained through orthogonal experiments, which provided a laboratory research basis for the industrial application of the method.

2. Experimental research

2.1 Formulation design

Heat accumulating type of metal mold casting coating are divided into three types: thermal insulation, lubrication/thermal conductivity, and semi-insulation. The semi-insulating casting coating with ultra-fine aggregate has good demoulding performance and moderate heat insulation performance, and is widely used in the casting of light alloys and can be used to produce smooth casting surfaces. In this paper, a semi-insulating casting coating formulation with high requirements for the preparation technology and crushing ability of the equipment is selected using aluminum alloy metal mold casting as the use scene: high lubricity, high thermal conductivity refractory aggregate h-BN (particle size 8.5 μm); high thermal conductivity refractory aggregate Al_2O_3 (particle size 75μm); low thermal conductivity refractory aggregate muscovite (particle size 2.6 μm); binder 5wt% PVA solution; extender pigment barium sulfate (particle size 12 μm); suspending agent s Na-bentonite (particle size 48 μm).

2.2 Ultrasonic-stirring ball mill preparation device

The ultrasonic-stirring ball mill used in this article is independently developed, the effect of the ultrasonic pulverization system mainly depends on the magnitude of the vibration displacement [14], the choice of the ultrasonic amplitude transformer is the key, the ultrasonic pulverization system designed in this paper is composed of an ultrasonic generator, an ultrasonic transducer, an ultrasonic amplitude transformer and a working tank, when the system is working, the ultrasonic wave is transmitted to the liquid slurry through the amplitude transformer and generates an ultrasonic energy field, the amplitude transformer amplifies the displacement of the mechanical vibration and concentrates the sound wave energy on a small area [15,16], the solid material in the slurry is crushed under the action of the ultrasonic energy field, in theory, the larger the amplitude required for

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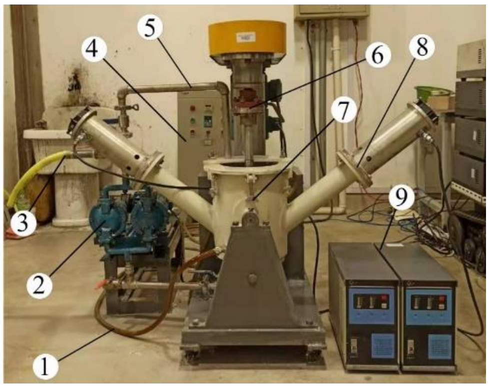
ultrasonic pulverization, the better the pulverization effect, therefore, this article chooses the ultrasonic amplitude transformer with a large amplification ratio (20 kHz). There are mainly three types of stirring rods: disc type, rod type and spiral type, ZHANG Guowang [17] used computational fluid dynamics method to simulate the flow field of the stirring ball mill and conducted a comparative experiment using different stirring rods, the flow field characteristic velocity gradient, flow field shear rate distribution and viscous dissipation rate of the three stirring rods are analyzed, and it is found that the flow field of the rod-type stirring ball mill has the largest velocity gradient in the circumferential direction, and the flow field shear rate has the most uniform distribution, and it's a kind of agitating ball mill with a large speed gradient, uniform stress distribution, and low resistance, accordingly, this article uses a rod-type ball mill stirring rod, which is made of high wear-resistant alloy. The specific structure of the ultrasonic-stirring ball mill is shown in Figure 1. The rotation of the stirring rod drives the rotation of the grinding balls in the working tank. When the grinding balls collide with each other, friction and impact are generated. At the same time, the ultrasonic energy field formed in the working tank crushes and disperses the viscous slurry [18,19]. Diaphragm pumps are used to circulate and discharge the slurry during the working process. The working tank is equipped with 10kg zirconia grinding balls (Ø2 mm).



1—water-cooling unit; 2—diaphragm pump; 3—discharge pipe; 4—industrial boxes; 5—material circulation pipe; 6—stirring system; 7—working tank;8—ultrasonic amplitude transformer;9—ultrasonic power

Fig. 1 Ultrasonic vertical type stirring ball mill

2.3 Experimental method

(1) Weigh the powder in proportion, muscovite: Al_2O_3: $BaSO_2$: Na-bentonite=5:2:5:2, and weigh an appropriate amount of h-BN powder.

(2) Add aggregates, extender pigments, and suspending agents to the working tank, add an appropriate amount of demineralized water (2.5 times the mass of the solid), mix at 150 r/min for 10 min to a slurry shape, and then turn on the ultrasonic-enhanced stirring ball mill. Add the binder to the working tank, mix it well and store it in a sealed container. Initial parameters: ultrasonic power: 1000 W, working speed: 400 r/min, working time: 150 min.

(3) The effect of h-BN concentration, ultrasonic power, working speed and working time on performance is studied through single factor experiment, and the best value of each parameter in its range is determined through orthogonal experiment.

2.4 Performance testing and evaluation methods

(1) The particle size of the coating has a significant impact on the thermal conductivity of the coating, and at the same time affects the lubricity of the coating by affecting the paintability. In this paper, the PSD wet method is used to detect the volume average particle size of the coating particle size [1] (D[4,3]).

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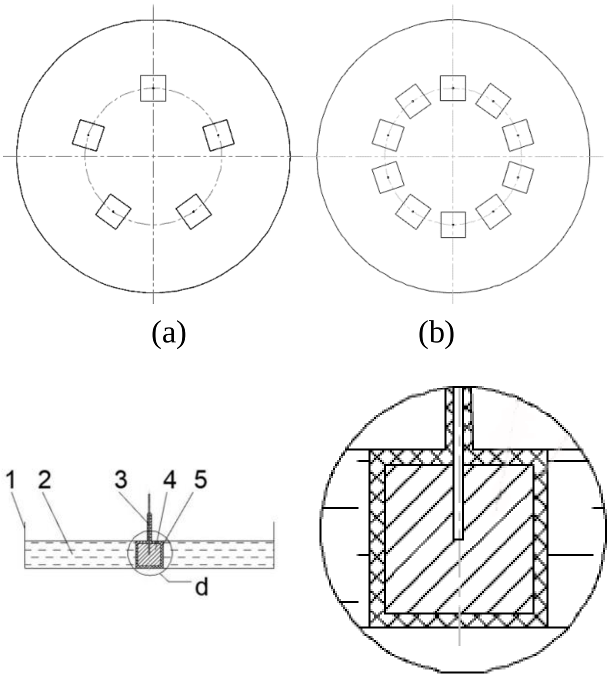
(2) In order to test and evaluate the thermal insulation performance of the coating, the experiment shown in Figure 2 is designed. (a) and (b) are the top views and (c) is the side view. The forged steel block 4 (the edge length is 50 mm, the center is drilled, Ø3 mm, and the depth is 25 mm) coated with 0.5 mm thickness [1,20] coating 5 was quickly immersed in a vessel 1 containing molten aluminum liquid 2 (keep at 740 °C molten state for 3 h). The temperature of the center of the block was measured with a thermocouple 3, the vessels in Figures (a) and (b) are equipped with 5 and 10 forged steel squares at the same time. They are all placed symmetrically at the midpoint of the vessel radius. The thickness of the coating is controlled by weighing the coating droplets of equal mass. Figure (d) is an enlarged schematic diagram of the experimental block in the melt. Each group of experiments is added with an uncoated control group. The thermal insulation performance is reflected in the thermal shock resistance during the temperature rise period, the stability during the constant temperature period, and the delayed temperature drop during the temperature drop period.

(3) In order to test the lubrication performance of the coating, a 0.5 mm thick coating was applied to the 20×20×5 mm steel plate, and the CFT-I material surface performance comprehensive tester was used to determine the dynamic friction coefficient (μ) of the coating, select the reciprocating friction measurement method, load 1 N, reciprocate length 5 mm, sampling length 3 mm, speed 25 mm/s, sampling 60 s at a frequency of 1 Hz, and draw the friction coefficient curve as a result, take the average line as the current μ value, repeat three times to take the average value to characterize the lubrication performance of the coating, and draw the average change curve of the friction coefficient.



(a) (b)

(c) (d)

1—utensil; 2—molten aluminum; 3—thermocouple; 4—forged steel square; 5—coating

Fig. 2 Thermal insulation property test

3. Experimental results and analysis

3.1 Single factor experimental results and analysis

3.1.1 Influence and analysis of h-BN concentration

Set the ultrasonic power, working speed, and working time under the initial conditions, Four h-BN concentrations of 15, 20, 25, and 30 wt% [21] were selected to study the influence of different h-BN concentrations on the pulverization ability of ultrasonic ball milling process and the heat insulation property and lubricity of coatings, the results are shown in Figure 3 (a), (b), (c).

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It can be seen from Figure 3(a) that as the concentration of h-BN increases, the particle size of the casting coatings decreases simultaneously. This is because when the mass fraction of h-BN with a small particle size in the solid raw material increases, the overall particle size of the raw material powder decreases, and the difficulty of initial pulverization decreases; The particle size reduction speed slows down in the interval 25-30 relative to the interval 15-25. This is because the difficulty of powder pulverization continues to increase with the continuous decrease of the slurry particle size, the crushing effect of the ultrasonic ball milling process on the powder with lower particle size cannot maintain the original efficiency, and the specific surface area and surface energy of the powder increase with the decrease of the particle size, the surface activity is enhanced, and the tendency of particles to agglomerate continues to increase, which inhibits the effect of powder refinement.

Observing Figure 3(b), compared with the cast steel block that is not protected by the coating, the heating process of the cast steel block protected by the coating is slower and gentler, and the thermal shock is significantly weakened, among them, the 15 wt% h-BN coating has the strongest weakening effect on thermal shock, and the weakening effects of the other three coatings are similar and relatively weak; During the constant temperature period, the 15 wt% h-BN coating has obvious heat insulation effect, and the 20 wt% h-BN, 25 wt% h-BN, and 30 wt% h-BN coatings have no obvious heat insulation effect; During the temperature drop, the thermal insulation property gradually deteriorates as the concentration increases. In summary, the thermal insulation performance of the coating gradually weakens with the increasing concentration of h-BN. This is due to the weakening effect of the high thermal conductivity of h-BN on the thermal insulation performance of the coating increases as the concentration of h-BN increases, The decrease rate of the thermal insulation performance of the coating is slower in the range of 25~30 wt% than that in the range of 15~25 wt%. This is because the thermal conductivity of h-BN decreases when it is broken into smaller particles; As the particle size of the finished coating continues to decrease, the porosity of the coating tends to be stable, which improves the thermal insulation performance of the coating [1]. It can be seen from Figure 3(c) that the lubricating performance of the coating gradually increases with the increasing concentration of h-BN. This is due to the high lubricity of h-BN among the four solid raw materials, and the increase of its concentration can directly and effectively improve the lubricating performance of the coating on the composition, at the same time, generally speaking, the good brushability of the fine particle size paint improves the lubricating performance.

Since the requirements for heat insulation of ultra-fine semi-insulated metal casting coatings are between heat conduction and heat insulation, the insulation strength can be changed by changing the thickness of the coating, and there are higher requirements for particle size, therefore, 30 wt% is selected as the best parameter among the four concentrations.

3.1.2 Influence and analysis of ultrasonic power

Choose 30 wt% h-BN, set the working speed and time under initial conditions, and choose five ultrasonic powers of 0, 500, 1000, 1500, 2000 W to study the effect of different ultrasonic powers on particle size, thermal insulation property and lubricity.

Because the ultrasonic amplitude is in the small range of 1~100 μm, the material cannot be brittle failure, so it is judged that the failure mode of ultrasonic pulverization is fatigue failure. The ultrasonic amplitude changes according to the sine law. Under the action of high-frequency sinusoidal load, the cracks and defects in the particle and its own will reach the critical value with the continuous application of force, which will cause the material to smash. In the meantime, the tiny bubbles attached to the micro-cracks inside the particles and the solid-solution interface are constantly moving, growing and accumulating the sound field energy under the action of alternating sound pressure with the vibration of the surrounding medium. When it expands to a certain extent, it quickly closes and collapses, releasing huge energy. The surrounding liquid suddenly rushes into the bubbles to generate local high temperature and high pressure, and generates a powerful impact micro-jet, which has a significant crushing and dispersing effect on nearby particles and particle groups. At the same time, when the ultrasonic wave propagates in the viscous slurry, the sound pressure gradient is generated

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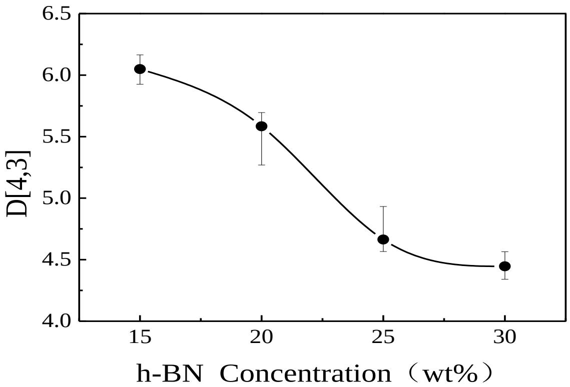
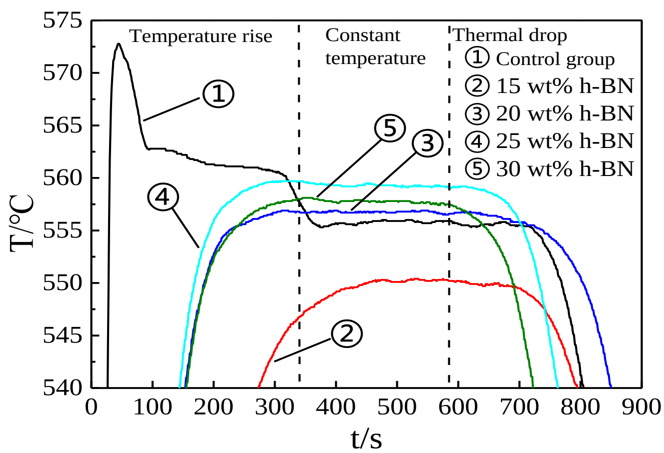
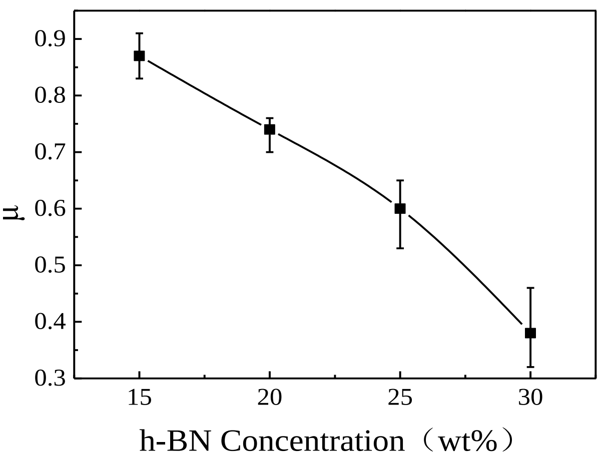
due to the viscous attenuation to form the acoustic current driving force, thereby generating the Eckart acoustic current phenomenon with the size of the container to disperse the slurry [22,23]. When the rod-type agitating ball mill is working, the grinding balls collide with each other to generate impact force, the rotating motion of the grinding balls generates friction and shearing force, and the difference in speed of each layer of the grinding balls forms a shearing force. The particles are deformed, broken and crushed mainly by friction, and have a certain degree of mixing effect.



(a) D[4,3]



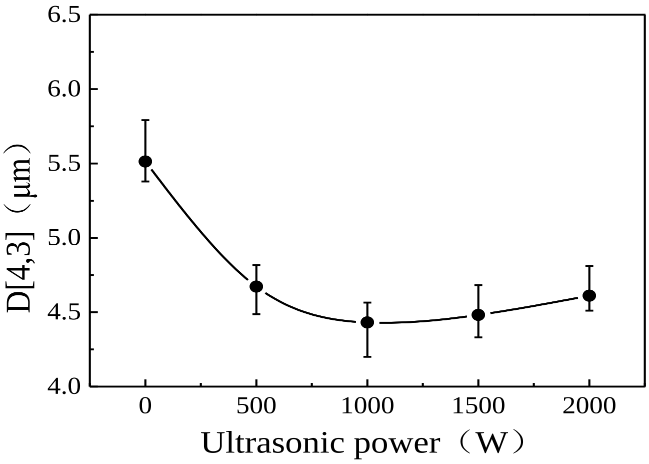
(b) thermal insulation property



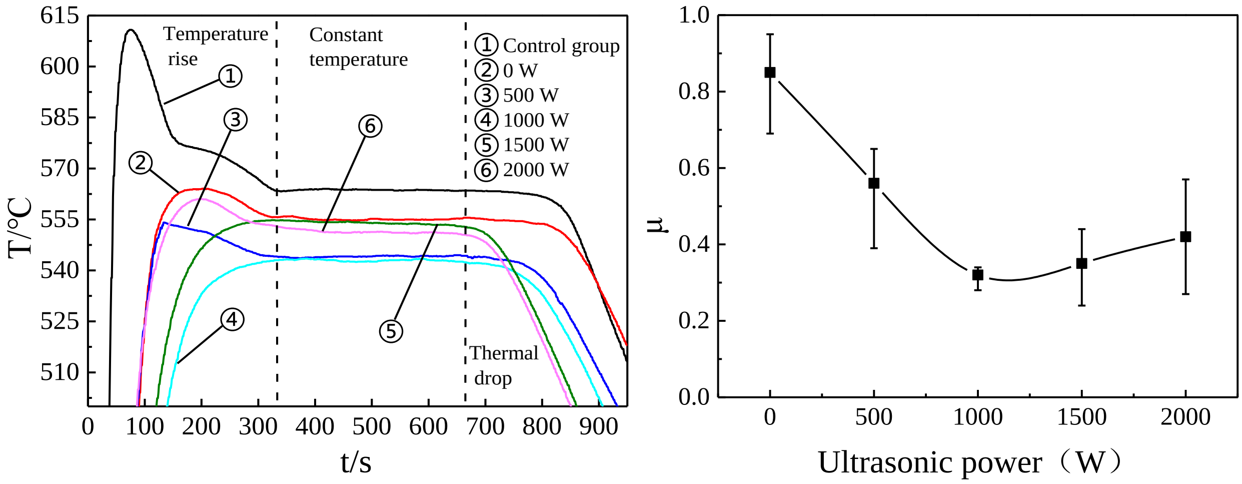
(c) lubricity

Fig. 3 Particle size of coatings, thermal insulation property and lubricity under different h-BN concentrations

It can be seen from Figure 4(a) that in the range of 0~1000W, the particle size decreases with the increase of power. This is because the gradual enhancement of the acoustic current effect and the cavitation effect enhances the smashing effect of the system, and at the same time makes the shock wave and the micro jet to push the particles in the slurry more strongly to collide with the grinding ball nearby, so that the pulverization strength of the stirring ball mill is strengthened. The ball mill stirring rod drives the slurry to circulate in the ultrasonic energy field, so that the solid particles are uniformly crushed and dispersed by the ultrasonic energy field, and a certain number of air bubbles are introduced, so that cavitation can occur effectively for a long time, thereby improving the utilization rate of ultrasonic energy; In the range of 1000~2000 W, the particle size gradually increases with the increase of the power. This is because the surface activity of the powder increases with the decrease of the particle size, and the pulverization effect is inhibited. As the pulverization effect of the ultrasonic-rod stirring ball mill system continues to increase, the suppression effect of the pulverization effect and the enhanced pulverization and dispersion effect offset and thereby inhibit the pulverization effect, and even the apparent particle size of the particles becomes larger. In the field of ultrasonic pulverization and ball mill pulverization, reports [24] have pointed out that when no surfactant is added, the ultrafine powder particles will agglomerate and the powder refining effect will be weakened [25].



(a) D[4,3]



(b) thermal insulation property (c) lubricity

Fig. 4 Particle size of coatings, thermal insulation property and lubricity under different ultrasonic power

It can be seen from Figure 4(b) that the heating process of the cast steel block protected by the coating is slow and gentle, and the thermal shock is significantly weakened, the thermal insulation performance first rises and then decreases with the increase of power, during the constant temperature period, the thermal insulation performance of the coating first rises and then decreases with the increase in power. During the temperature drop, the thermal insulation performance of the coating without ultrasonic treatment is better, and the thermal insulation performance of the four sets of coatings with ultrasonic treatment is similar, and the comprehensive thermal insulation performance first increases and then decreases, it can be seen that in the range of 0~1000 W, the reduction of the particle size reduces the thermal conductivity of h-BN while increasing the stability of the porosity of the coating, thereby improving the thermal insulation performance [1]; In the interval of 1000~2000 W, the thermal insulation performance decreases and tends to be flat. This is because the particle size gradually increases in this interval, and the lamellar structure of mica may be damaged to a certain extent, which weakens its thermal insulation effect. It can be seen from Figure 4(c) that the lubrication performance is similar to the change trend of particle size, and with the increase of power, it first increases and then decreases. This is because: the smaller the particle size, the better the leveling and flowability of the coating, the better the leveling during curing, and the easier it is to get a smooth surface.

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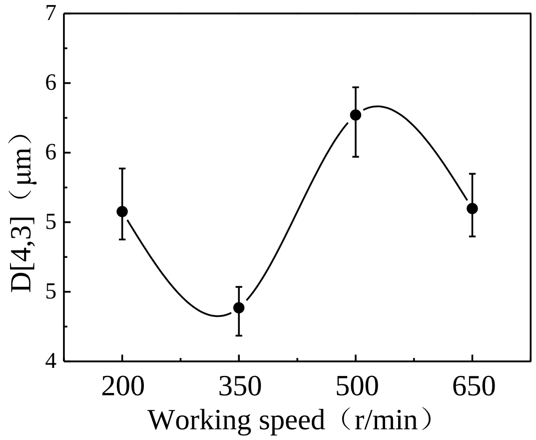
In summary, 1000 W ultrasonic power can get the greatest refinement effect, highest heat insulation, and lubrication performance. Choose 1000 W as the best value among the five power options.

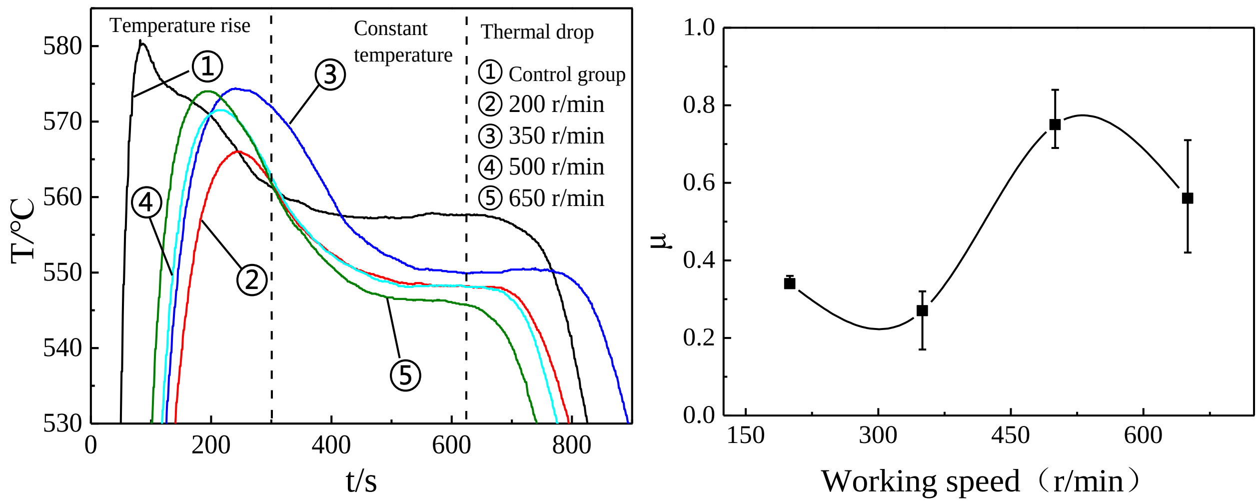
3.1.3 The influence and analysis of working speed

Choose 30 wt% h-BN, ultrasonic power 1000 W, set the working time under the initial conditions, choose 200, 350, 500, 650 r/min these four speeds to study the influence of different working speeds on the particle size, thermal insulation property and lubricity.

It can be seen from Figure 5(a) that in the range of 200~650 r/min, with the increase of the speed, the particle size shows a cosine-like change, and the refinement effect is stronger in this range at about 350 r/min. For a simple stirring ball mill system, when the speed of the ball mill is low, the shearing force and impact force of the grinding ball on the powder particles is small, and the crushing effect is weak. As the rotation speed increases, the excessive centrifugal force on the large-size particles causes it to rotate with the flow field, which weakens the ball milling effect; In addition, it is possible that at certain speed nodes, the acoustic flow field formed by the ultrasonic energy field and the flow field formed by the rod-type stirring have strong interference, which weakens the pulverization effect of the stirring ball mill.



(a) D[4,3]



(b) thermal insulation property (c) lubricity

Fig. 5 Particle size of coatings, thermal insulation property and lubricity under different working speed

It can be seen from Figure 5(b) that during the temperature rise, as the speed increases, the thermal insulation performance first increases and then decreases; during the constant temperature period, there is no obvious change in the thermal insulation performance; during the temperature drop, as the speed increases, the thermal insulation performance gradually decreases. In general, as the speed

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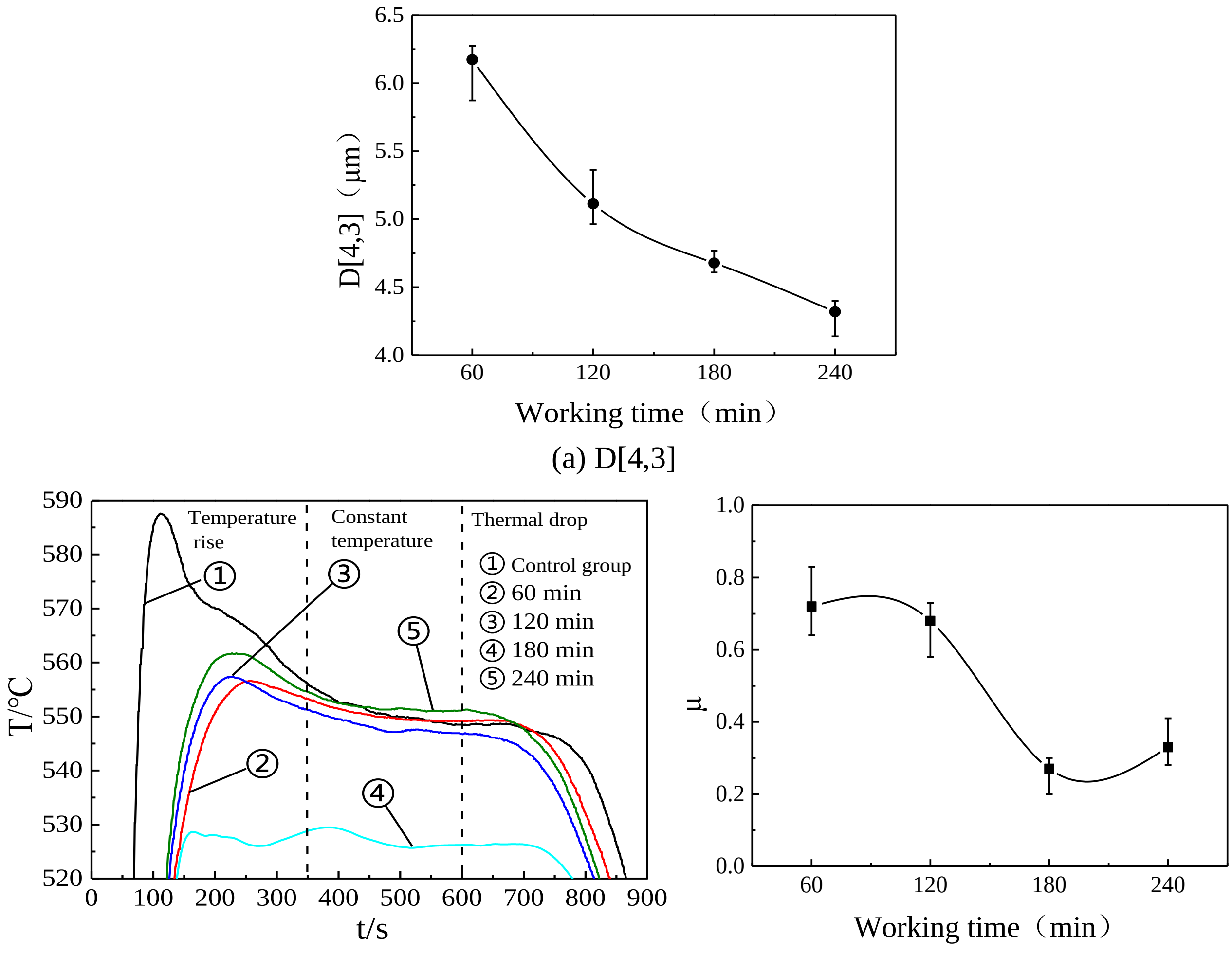
increases, the comprehensive heat insulation performance first increases and then decreases. This is because the thermal conductivity of the h-BN component of the coating with a smaller particle size decreases, which reduces the overall thermal conductivity and stabilizes the porosity. In the range of 500~600 r/min, the particle size decreases while the thermal insulation performance decreases. This may be due to the damage of the muscovite flake structure due to the excessively high rotation speed. It can be seen from Fig. 5(c) that the lubrication performance and particle size show synchronous cosine-like changes, and the area with higher lubrication performance is in the range of 200~400 r/min. Combining the effects of different h-BN concentrations and different ultrasonic powers on the particle size and lubricating properties of the coating, it can be inferred that the lubricating properties of the coating are negatively correlated with the particle size. This correlation is related to the viscosity, brushability, and leveling of the coating. The smaller the particle size, the better the brushability and leveling performance, so that the surface of the coating tends to be smooth and flat.

In summary, the parameter scheme of 350 r/min can obtain the greatest refinement effect, the highest heat insulation and lubrication performance, so 350 r/min is selected as the best value of the four pulverizing speed schemes.

3.1.4 The influence and analysis of working time

Choose 30 wt% h-BN, ultrasonic power 1000 W, working speed 350 r/min, choose 60, 120, 180, 240 min four working hours to study the influence of different working time on the particle size and heat insulation and lubrication properties of the coating.



(b) thermal insulation property (c) lubricity

Fig. 6 Particle size of coatings, thermal insulation property and lubricity under different working time

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As shown in Figure 6(a), the particle size continues to decrease with the increase of working time, the refinement enhancement effect in the range of 60-120 min is obvious, and the refinement enhancement effect in the range of 120-240 min is weakened. This is because in the early stage of the crushing process, the particle size of the powder is larger and the crushing effect is better, as the particle size continues to decrease, the difficulty of crushing continues to increase, and the crushing effect decreases. It can be seen from Figure 6(b) that during the temperature rise and constant temperature period, as the working time increases, the thermal insulation performance first increases and then decreases, during the temperature drop, with the increase of working time, the thermal insulation performance first drops and then rises. As the working hours increase, the comprehensive thermal insulation performance first increases and then decreases. This is because in the range of 60 to 180 min, as the particle size decreases, the thermal insulation performance of the coating gradually increases. In the range of 180~240 min, the muscovite layered structure may be destroyed. It can be seen from Figure 6(c) that as the working time increases, the lubrication performance first decreases and then slightly increases, and the change in particle size is consistent with the previous inference that particle size is negatively related to lubrication performance, the increasing refinement effect in the range of 180~240 min may damage the structure of h-BN and weaken the lubricating performance [26].

In summary, the parameter scheme of 180 min can obtain the greatest refinement effect, the highest heat insulation and lubrication performance, so 180 min is selected as the best value of the four pulverizing speed schemes.

3.2 Orthogonal experiment results and analysis

In order to study the influence of various factors on the particle size and thermal insulation and lubrication properties of casting coatings and determine the optimal combination of synergistic effects of different process parameters, the design standard L9(3^4) orthogonal experiment is shown in Table 1, the value of the level is allocated according to the results of the single factor experiment.

Table 1. Ultrasonic enhanced ball milling orthogonal experimen

Level	A	B	C	D
	h-BN concentration (wt%)	Ultrasonic power (w)	Working speed (r/min)	Working time (min)
1	27.5	800	300	150
2	30	1000	350	180
3	32.5	1200	400	210

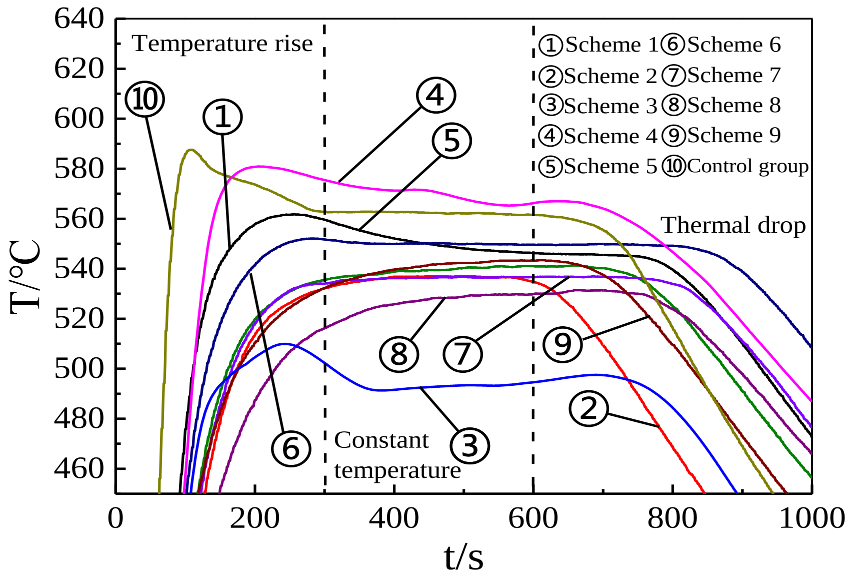

Fig. 7 Orthogonal experiment thermal insulation property curve

The digitization of the results of the orthogonal experiment of the thermal insulation performance of the coating: compare the performance during the temperature rise, constant temperature, and temperature drop, and evaluate the grades 1~9 from poor to excellent (the same performance is rated at the same level, and the highest level of the stage does not need to be 9), According to the importance of temperature rise, constant temperature, and temperature drop period, weighted 3, 2, and 1 points in turn, $\sum$ grade × weighted score = total score.

Table 2. Thermal insulation property evalution

Rank	1	2	3	4	5	6	7	8	9
Temperature rise	2	6	6	1	4	3	4	7	5
Constant temperature	2	4	7	1	4	3	4	5	6
Thermal drop	5	1	2	2	2	4	3	2	2
Total weighted score	15	27	34	7	22	19	23	33	29

Table 3. Summary of orthogonal experiment results

Scheme	Parameter combination	lubricity	thermal insulation property	D[4,3]/μm
1	$A_1B_1C_1D_1$	0.57	15	4.707
2	$A_1B_2C_2D_2$	0.32	27	4.507
3	$A_1B_3C_3D_3$	0.39	34	5.729
4	$A_2B_1C_2D_3$	0.29	7	4.710
5	$A_2B_2C_3D_1$	0.29	22	4.620
6	$A_2B_3C_1D_2$	0.32	19	5.223
7	$A_3B_1C_3D_2$	0.27	23	4.396
8	$A_3B_2C_1D_3$	0.31	33	4.447
9	$A_3B_3C_2D_1$	0.28	29	5.063

Table 4. Analysis of orthogonal experiment results

Peformance	Analysis	Factors			
		A	B	C	D
D[4,3]/μm	Delta	0.346	0.814	0.155	0.253
	Row rank	2	1	4	3
Thermal insulation property	Delta	12.33	12.33	5.33	2.67
	Row rank	1.5	1.5	3	4
Lubricity	Delta	0.140	0.070	0.103	0.077
	Row rank	1	4	2	3

In order to compare the changes in particle size, the 30 wt% h-BN parameter scheme was used as the initial object. The particle size of the coating directly prepared by the stirring method was detected, and the D[4,3] was 13.69 μm, which corresponds to the k2 row of the particle size range analysis result in column A of Table 4: 4.85 μm, indicating that the average refinement was 2.82 times. The ranking results of the particle size in Table 4 show that the ultrasonic power has the greatest influence on the particle size, the h-BN concentration and working time have little influence and the influence is less than half of the ultrasonic power, and the working speed has the smallest influence.

The best process parameters are selected based on heat insulation and lubrication performance: For h-BN concentration, rank 1 (lubrication performance order)>1.5 (heat insulation performance order), so the lubrication performance is the first, and $k_1>k_2>k_3$ shows that k_3 is the best level. For the ultrasonic power, rank 4<1.5, so the heat insulation performance is the first. Because $k_1<k_2=k_3$, the lubricity judgment is added, and the lubricity $k_3>k_2$ knows that k_2 is the best level. For the working speed, rank 2>3, so the lubrication performance is the first, and $k_1>k_3>k_2$ knows that k_2 is the best level. For working hours, rank 3>4, so the lubrication performance is the first, and $k_1>k_3>k_2$ knows that k_2 is the best level. A set of optimal process parameters can be obtained: h-BN concentration 32.5 wt%, ultrasonic power 1000 W, working speed 350 r/min, working time 180 min.

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4. Conclusions and Prospects

(1) When the D[4,3] of h-BN decreases, the thermal conductivity will decrease;

(2) With the increase of ultrasonic power, working speed and time, the effect of ultrasonic ball milling on particle smashing and refining is enhanced, and the D[4,3] is reduced, which improves the stability of coating porosity and is beneficial to thermal insulation;

(3) The friction coefficient of the coating formed by h-BN water-based aluminum alloy metal casting coating has a similar change trend with the D[4,3] of the casting coating. The overall performance is that the smaller the D[4,3], the better the lubrication performance;

(4) In the preparation process of ultrasonic ball milling, the change of the D[4,3] of the h-BN water-based aluminum alloy metal mold casting coating is most affected by the ultrasonic power, within the range of the experimental parameters, the comprehensive ultrasonic ball milling process can reduce the D[4,3] of the casting coating from 13.69μm to 4.85μm, So as to effectively improve the lubricity and the thermal insulation property of the casting coating;

(5) Taking heat insulation performance and lubrication performance as indicators, a set of optimal ultrasonic ball milling process parameters were obtained through orthogonal experiments: h-BN concentration 32.5 wt%, ultrasonic power 1000 W, working speed 350 r/min, working time 180 min;

(6) The ultrasonic ball milling process produces a synergistic pulverization effect while providing agitated ball mill pulverization and ultrasonic pulverization, which enhances the pulverization effect and provides a powerful dispersion effect, as a new and effective method for preparing casting coatings, it is worthy of further research and popularization and application to the preparation of other casting coatings. At the same time, the possible interaction between the refinement, dispersion effect, mechanism and various process parameters of the larger ultrasonic power needs to be further experimentally studied and discussed.

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