

EPMMA is the ideal white model material

I. Characteristics and Advantages of EPMMA

The foam materials currently used in the lost foam casting industry mainly include EPS, STMMA, and EPMMA. The primary difference among these three materials lies in their PEO and PMMA content: EPS is composed entirely of PEO (100%), STMMA consists of 30% PEO and 70% PMMA, while EPMMA is made entirely of PMMA (100%).

The application of these materials in lost foam casting differs significantly.

EPS typically results in a carbon pickup of 0.1%–0.3%, which is relatively high, and therefore is mainly used for low-end castings (such as cast iron and gray iron). Its advantage lies in relatively low gas evolution.

STMMA usually leads to a carbon pickup of **0.03%–0.04%**, lower than EPS, making it suitable for medium- to high-end castings (such as ductile iron and lower-grade stainless steel), although its gas evolution is higher than that of EPS.

EPMMA generally produces a carbon pickup of **0.02%–0.03%**, the lowest among the three, making it ideal for high-end castings (such as low-carbon stainless steel and other non-ferrous alloys), while its gas evolution is higher than STMMA.

The differences in carbon pickup and gas evolution are primarily due to the distinct thermal depolymerization mechanisms of polystyrene and polymethyl methacrylate during casting:

a. The thermal decomposition of polystyrene mainly occurs via random scission of its molecular chains. The resulting styryl radicals ($\text{C}_6\text{H}_5\text{CHCH}_2\bullet$), stabilized by the conjugated benzene ring, tend to recombine into dimers or trimers rather than forming small gaseous molecules. At casting temperatures around 1500 °C, the benzene rings undergo cyclization reactions (including Diels–Alder additions), forming polycyclic aromatic hydrocarbons that ultimately graphitize into carbon black. Thus, the benzene ring side groups in polystyrene (EPS) are the key limiting factor for its performance, resulting in low gas evolution but relatively high carbon pickup.

b. Polymethyl methacrylate (PMMA) chains contain abundant ester groups ($-\text{COOCH}_3$), whose C–O bonds have relatively low bond energy, while the α -hydrogens adjacent to the ester groups are easily activated. Upon heating, β -scission occurs preferentially, triggering a “zipper-like depolymerization” that generates methyl methacrylate (MMA) monomers completely, leaving no solid

residue. At casting temperatures around 1500 °C, the MMA monomers undergo full oxidative decomposition into small molecular gases such as CO₂, CO, and CH₄. These gases expand dramatically—by several orders of magnitude—producing substantial gas pressure. If this pressure is not promptly vented during casting, it can cause “metal backflow” or “blowback” defects. Therefore, negative-pressure casting is essential to ensure smooth, defect-free production with EPMMA.

Based on the differences in thermal decomposition behavior and the resulting by-products, EPMMA generates significantly less carbon than STMMA, making it more effective in minimizing carbon pickup in lost foam castings. This advantage is especially critical for stainless steel castings, where the allowable carbon increase is strictly limited to 0.02%–0.05%.

However, because EPMMA releases more gas during decomposition compared to STMMA, applying it directly with conventional STMMA casting practices can easily lead to “backfiring” or gas blowback defects. To mitigate this, adjustments in process design are required, such as improving coating permeability, increasing vacuum levels, and optimizing both pouring rate and gating system design.

Once these process modifications are implemented, EPMMA can deliver significant improvements in casting quality by virtually eliminating carbon-related defects due to its inherently low carbon contribution. This not only enhances the metallurgical quality of castings but also increases yield rates, positioning EPMMA as a breakthrough material for advancing green and high-quality lost foam casting technology.

2. Exhaust efficiency as the core parameter of the EPMMA process system

1. Exhaust is the foundation of the lost foam casting process.

(1) The mechanical strength of the sand mold is generated through negative pressure, which relies on efficient exhaust. Only with smooth and sufficient exhaust can a stable negative pressure be maintained, ensuring adequate sand mold strength and reducing the risk of defects such as sand inclusion, metal penetration, mold swelling, or collapse.

(2) During decomposition, the foam pattern generates a large volume of gases that must be promptly vented from the mold cavity. Adequate exhaust capacity enables a stable pouring process, eliminates issues such as “flow inhibition” and “backfiring,” and prevents casting defects including carbonaceous residues, wrinkled surfaces, gas porosity, skinning, and cold shuts.

2. EPMMA generates a higher volume of gas, which requires a correspondingly faster exhaust rate to ensure that decomposition gases from the foam pattern are promptly discharged from the mold cavity, thereby facilitating a smooth pouring process.

To achieve this, the exhaust system must deliver higher efficiency—meaning greater gas removal capacity per unit time. This necessitates the establishment of a highly efficient exhaust system designed to handle the increased gas evolution of EPMMA.

3. Establishing an Efficient Exhaust System to Maximize the Advantages of EPMMA

(I) Fundamental Factors for Promoting Exhaust

1. Adequate Exhaust Power

- (1) Ensure sufficiently high exhaust capacity, meaning that the power of the vacuum pump—or the total system power—must be large enough to handle the required gas removal.
- (2) Maintain a sufficiently high and relatively stable negative pressure during pouring. Concerns about so-called “wall effects” are unnecessary; the assumption that high negative pressure will inevitably cause mold collapse or draw molten metal out of the cavity is a misconception.

2. Smooth Exhaust Channels

(1) Optimized Sand Box Design

Ensure the negative pressure zone is evenly distributed; the layout should be dense rather than sparse, with emphasis on bottom extraction.

Increase the number and total area of vent holes as much as possible. Sand screens must be maintained regularly and promptly to preserve high air permeability.

(2) Adequate Main and Branch Pipeline Diameters

The cross-sectional area of all passages through which gases are discharged from the mold cavity must be sufficiently large and free of obstructions.

Any potential “bottlenecks” should be avoided to ensure smooth and efficient gas evacuation.

3. Coating with High Air Permeability

The coating must exhibit excellent air permeability.

Ensure uniform application with controllable and consistent thickness.

Thoroughly dry the coating before casting.

4. Maintain Proper Sand Condition and Granular Structure

Keep the sand mold fully dry and maintain an optimal granular structure.

During continuous production, maintain the sand temperature within 30–50 °C.

Ensure complete dust removal to preserve mold quality and ventilation.

(II) Key Considerations for Smooth Pouring of EPMMA

Smooth pouring of EPMMA is primarily achieved by improving exhaust efficiency and enabling rapid gas evacuation.

Theoretical Basis:

Exhaust efficiency can be expressed as the product of exhaust pressure and effective exhaust cross-sectional area. Here, the negative pressure represents the exhaust pressure, while the vacuum pump power corresponds to the effective exhaust area—an increase in pump power is equivalent to enlarging the exhaust cross-section.

Main Directions to Improve Exhaust Efficiency:

1. Increase negative pressure

2. Increase vacuum pump power

3. Reduce flow resistance

1. Negative pressure should not be the sole focus

Although negative pressure is a key factor influencing exhaust efficiency, relying solely on increasing it has limited effect. The theoretical maximum design pressure of a water-ring vacuum pump is 0.1 MPa, and in actual production, the negative pressure during pouring rarely exceeds 0.075 MPa. Therefore, the potential to improve exhaust efficiency through pressure alone is limited.

2. Increasing vacuum pump power is the preferred approach

Vacuum pump motor power is directly proportional to exhaust efficiency—higher power increases the gas evacuation rate per unit time. The required exhaust power is primarily determined by the sand box volume, the number of boxes cast per batch, and the number of pouring cups per box. Coating permeability must also be considered: for low-permeability coatings, exhaust power must be increased proportionally to overcome the resistance of the coating.

Experimental Reference for EPMMA Casting:

Using a coating that allows smooth STMMA casting:

Sand box volume: $< 2 \text{ m}^3$

Casting batch: ≤ 4 boxes at a time, 2 pouring cups per box

Recommended Vacuum Pump Power:

1.Cast steel production: pouring temperature $> 1600 \text{ }^\circ\text{C} \rightarrow \geq 180 \text{ kW}$

2.Cast iron production: pouring temperature $< 1500 \text{ }^\circ\text{C} \rightarrow \geq 150 \text{ kW}$

For larger sand boxes or casting large components, the vacuum pump power should be increased proportionally to ensure smooth pouring.

3. Development of Ultra-High Permeability Coatings to Minimize Exhaust Resistance

Full dust removal from the sand and maintaining an appropriate particle size distribution can reduce gas flow resistance to a very low level, which is relatively easy to achieve. Therefore, the main source of exhaust resistance is the coating itself, and improving coating permeability is the primary way to reduce exhaust resistance.

The inherent air permeability of the coating is a fundamental prerequisite for obtaining a highly permeable coating. Coatings with poor inherent permeability cannot achieve good permeability, regardless of application.

With continuous advancements in the lost foam casting process, coating permeability has received increasing attention. Most commercially available coatings now meet the basic requirements for smooth STMMA casting. However, when applied to EPMMA, which generates significantly more gas, there remains a considerable gap that currently must be compensated by increasing exhaust power.

Ultra-high permeability coatings can exponentially reduce exhaust resistance. For the same exhaust efficiency, lower vacuum pump power is required, enabling a reduction in high-power exhaust operation and lowering energy consumption.

According to our preliminary experiments, coatings with permeability greater than 200 (tested at 1 mm thickness) allow smooth EPMMA casting at approximately 110 kW for ductile iron and 150 kW for cast steel—comparable to the power required for smooth STMMA casting.

The development of ultra-high permeability coatings is expected to enable a significant leap forward in EPMMA applications.

4. Strictly Control Coating Application and Drying Process to Achieve Ultra-High Permeability Coatings

The air permeability of a coating is determined by both the inherent permeability of the coating material and the precision of the application and drying process—both are indispensable. Ultra-high permeability coatings require stricter operational control to fully realize their advantages.

Key considerations include:

1.Optimal coating concentration: Ensure appropriate surface tension to improve leveling and promote uniformity of the coating.

2.Stable concentration: Monitor regularly and adjust in a timely manner to maintain consistency.

3.Controlled flow direction: Vary the coating flow direction to avoid repeated flow in the same direction.

3.Drying conditions: Maintain a stable drying temperature, sufficiently low relative humidity, and adequate drying time. For the final coating layer, a drying period of over 24 hours is recommended.

4.Post-drying handling: Yellow molds should be packed immediately after leaving the drying oven, with strict control of outdoor exposure to prevent the coating from cooling to room temperature and absorbing moisture.

5.Target permeability: The coating permeability should meet or exceed the specified high-permeability threshold (value to be defined based on experimental standards).

5. Recommendations for Exhaust Channel Parameters

Enlarging the exhaust channels has two main benefits: first, it increases the exhaust cross-sectional area, thereby accelerating gas evacuation; second, it enhances the gas storage and buffering capacity of the piping system, which helps improve and stabilize exhaust efficiency while reducing fluctuations in the pouring negative pressure.

Specific recommendations:

1.Sand box exhaust pipe diameter: Recommended to be ≥ 90 mm, with at least one pipe per cubic meter of sand box volume.

2.Main pipeline diameter: Should match the exhaust power; a diameter ≥ 300 mm is preferred.

3.Buffer tank volume: Should be ≥ 5 m³.

4.Sand screen mesh: Preferably < 80 mesh; 60 mesh is optimal.

Solid residues from white mold decomposition cannot be discharged from the cavity, which is an inherent limitation of the lost foam process. Minimizing the generation of these residues is the most effective approach; therefore, the white mold must be fully vaporized.

As the most advanced white mold material, EPMMA's high degree of gasification is a key advantage, and its substantial gas generation is an inherent characteristic. By prioritizing the design and optimization of the exhaust system, improving exhaust efficiency, and achieving rapid gas evacuation, issues such as "flow suppression" and "backstreaming" can be effectively eliminated, ensuring smooth pouring. This approach fully utilizes EPMMA's strengths, minimizes carbon

addition, eliminates carbon residue defects, and advances the lost foam casting process to a higher level of quality and reliability.