Application of Kailin Ceramic Foundry Sand in Cold Box Process

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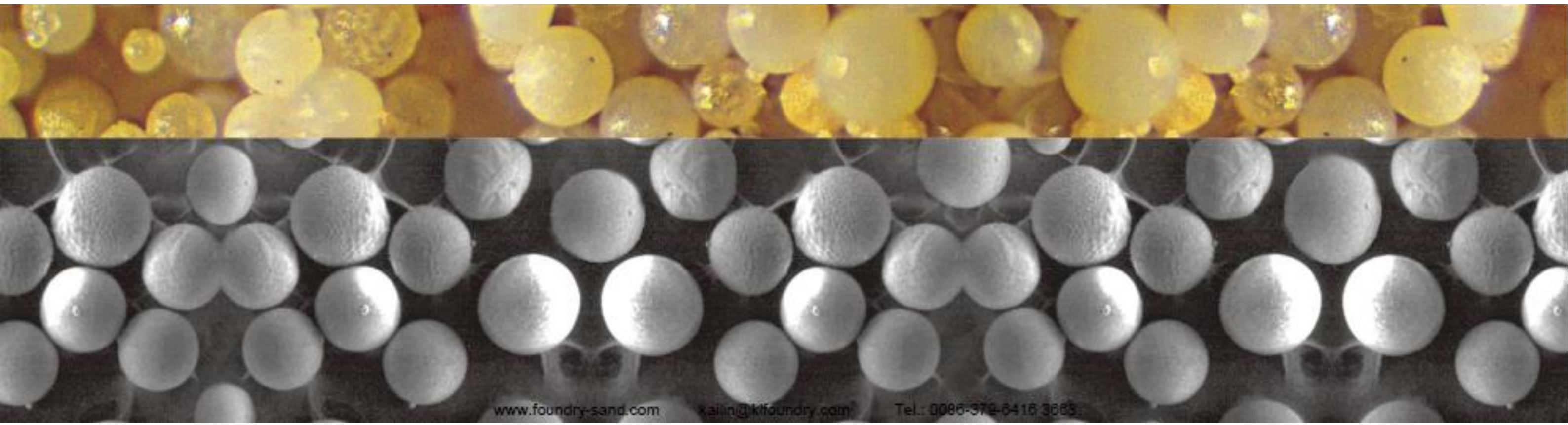


Table Content

Abstract

The term “cold box” implies the room temperature curing of the sand-binder mixture accelerated by vapour or gas catalyst that is passed through the sand. The phenolic urethane cold-box (PUCB) process is a three-part system, with two liquid binder components. Part I is the reactive component, a phenol－formaldehyde polymer blended with solvents and additives to produce a low-viscosity resin solution. Part II is polymeric isocyanate (polyisocyanate), again blended with solvents and additives. The hydroxyl groups provided by Part I react with the isocyanate groups in Part II forming a solid urethane polymer (polyurethane, PUR) in the presence of the third component, a gaseous catalyst. Two types of tertiary amine catalysts are commonly used to cure the resin and the isocyanate: triethylamine (TEA) and dimethylethylamine (DMEA).

The cold box process is so fast and produces such strong cores that it is the most widely used gas triggered process for high volume core production. Good engineering has enabled the environmental problems to be overcome. It is suitable for mass production and is widely used in the automotive diesel engine industry. Reduced free phenol resins are being produced to assist with sand disposal problems.

Diesel engine castings, such as cylinder heads, cylinder blocks, intake and exhaust manifests, etc., generally have inner cavity of complex shape, with a thin cross-section. The cores are likely to have inaccurate dimension and fractures, and due to the relatively large expansion rate of silica sand, the probability of casting defects including sand burn-on, veins and pore is also high. In practice，using Kailin Ceramic Sand or to mix with silica sand in proportion can reduce the resin consumption by 20~30%. The above mentioned defects have been significantly reduced. Moreover, the core collapsibility has been remarkably improved, which reduces the cleaning workload. As a result, in recent years, almost all large-scale engine part foundries have employed Kailin Ceramic Sand cold-box process.

Kailin Ceramic Sand, originally developed in China by Luoyang Kailin Foundry Material, is a kind of artificial foundry sand with superior properties such as spherical grain shape, high refractory, chemical inertness and good crushing resistance. Since the beginning of 21st century, Kailin Ceramic Sand, in virtue of its exceptional characteristics in foundry use, has been successfully employed in many factories of sand casting (green sand, sodium-silicate bonded sand, no-bake, hot-box, and cold-box, for sand moulding and core-making) and EPC process to produce iron, steel and Non-Ferrous castings. Foundries have gained enormous benefits of binder consumption savings, casting defects reduction, wastes emissions elimination, and quality promotion.

1. The introduction and physical & chemical properties of Kailin Ceramic Sand

Kailin Ceramic Sand, technically named as “fused ceramic foundry sand”, is made from Baked bauxite which main content is aluminum oxide (Al_2O_3), processed by arc melting, blowing, sieving and blending. The particle size of Kailin Ceramic Sand for foundry is generally between 0.053 ~ 3.53mm (270 mesh ~ 6 mesh). Kailin Ceramic Sand has a mineralogical composition of mullite, corundum and trace amorphous substances. Its refractoriness is generally more than 1800℃ and is one kind of aluminum-silicon refractory material of high grain hardness. The appearance of Kailin Ceramic Sand is taupe, black brown round particles. Figure 1 shows the grain shape of Kailin Ceramic Sand and silica sand (50x)

Kailin Ceramic Sand silica sand

Fig.1 Grain shape of ceramic sand and silica sand（50x）

Kailin Ceramic Sand has a small thermal expansion coefficient; high thermal conductivity, spherical shape, good flowability and compactability; smooth surface, no cracks. As a neutral material, it is suitable for various casting alloys. It also has high particle crush resistance, high refractoriness， wide particle size range, so can be customized according to process requirements and other performance characteristics. Tab.1 and Tab.2 show the chemical composition and physical properties of Kailin Ceramic Sand.

Tab.1 Chemical composition of Kailin Ceramic Sand

Al_2O_3	SiO_2	TiO_2	Fe_2O_3	K_2O+Na_2O
≥70%	15-22%	≤4%	≤3%	≤1%

Tab.2 Physical Properties of Kailin Ceramic Sand

Grain Shape	Spherical
Angularity Factor	≤1.1
Particle Size（mm）	0.053~3.36
Refractoriness (℃)	≥1800
Bulk Density (g/cm^3)	1.95 -2.05
Specific l Density (g/cm^3)	3.3-3.4
pH	7~7.8
Thermal Conductivity (1200℃)	5.27 W/M·K
Thermal Expansion (10 Mins @ 1000℃)	0.13%
Lin. Exp. Coeff. (20~1000℃,10^{-6} / ℃)	6
Mohs’ Hardness	8~9
Specific Heat Capacity (J/kg•K）	2210
Mineralogical Composition	Mullite + Corundum
Humidity	≤0.1%
Clay Content	≤0.2%

2. Defects and analysis of engine parts produced by cold box process

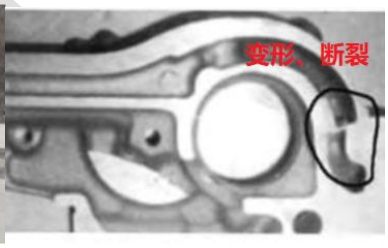
The core of cylinder block and cylinder head is generally made by cold-box process. As the most important castings of engine, their inner cavity have a complex shape, require high dimensional accuracy and good finish. Besides, the sand moulds are popularly made by green sand process with a high pressure or air-flow squeeze molding line.

The cores of cylinder block and head have complex shape, thin cross-section, some of the thinnest part of the water jacket core of cylinder blocks and cylinder heads is only 3-3.5mm, and the sand outlet is narrow too. After pouring, the sand core is surrounded by high-temperature molten iron for a long time, which make it is difficult to clean and requires special cleaning equipment. In the past, silica sand was commonly used in foundry production, which often causes the occurrence of defects such as veining and sand burn-on in cylinder block and head castings, along with distortion of oil passenger core and core fracture. These problems are difficult to solve. Figure 2 illustrates some frequently occurred defects on inner surface of cylinder blocks and cylinder heads.

sand burn-on

veins/fins

metal penetration



distortion and fracture

Fig.2 Frequently occurred defects on inner surface of cylinder blocks and cylinder heads

Among the above mentioned defects showed in Fig.2, veins is the most common casting defect. The veins are mostly occurred at the corners of the inner surface of the casting and at the high-temperature hot spots, mostly in stripes. Veins has a severe effect to the quality of the inner cavity of the casting, especially in the closed or semi-closed areas of the engine block and the water jacket of the cylinder head. Once defects occur, it is difficult to detect and remove. The remained veins in the air passage area of the cylinder head will seriously affect the flow direction of the intake and exhaust airflow, thereby affecting the eddy current characteristics of the air passage，ultimately affect engine performance and hazards emission. Fig.3 shows some examples of veins on the surface of some casting parts.

Fig.3 Veis on the surface of some casting parts.

(Pictures are from HA Germany Public Account)

Till now， silica sand, which main component is quartz, is the most important base material of casting sand mold (core). However, due to the disadvantages of low refractoriness, poor fluidity and high thermal expansion rate, it is still difficult to solve the defects of castings such as sand burn-on, veins, metal penetration, distortion and fracture. In recent years, the application of Kailin Ceramic Sand makes it possible to solve such problems. Because of the low thermal expansion rate of Kailin Ceramic sand – the thermal expansion rate is 0.13% (heated at 1000℃ for 10 mins), which is much lower than the thermal expansion rate of silica sand of 1.5% (heated at 1000℃ for 10 mins), so the use of Kailin Ceramic Sand or to mix with silica sand in proportion, not only can reduce the amount of resin added by 20~30%, but also the veins defects can be significantly improved. Meanwhile, the core collapsibility is very good, which reduces the cleaning workload.

3. The performance of the Kailin Ceramic Sand in cold box process

To fully grasp the principle of the use of application advantages of Kailin Ceramic Sand in the cold box, and to take advantages from it, two sets of experiments are now carried out. The first group compares with silica sand, Kailin Ceramic Sand and chromite sand, and the second group compares to silica sand, Kailin Ceramic Sand and sintered ceramsite sand. The experimental analysis will compare the results of the tensile strength of dog bone test specimen and the gas evolution of the core.

3.1 Sets 1: Silica sand, Kailin Ceramic Sand and Chromite Sand

The resin used in the experiment is the cold-box resin of HA Company, which consists of two components of phenolic resin and polyisocyanate in a ratio of 1:1. When mixing, the base sand was prepared by pre-mixing of 30s, add polyisocyanate in mixer and mill for 1.5 minutes, then add phenolic resin and mill for another 2 minutes. After mixing, the dog bone test specimen is made on a special cold-box core shooting machine. We have the following tensile strength and gas evolution testing results:

Tab.3. Comparison of silica sand, Kailin Ceramic Sand and chromite sand by cold box process

Sand	Resin Content (%)	Tensile strength after 2 hrs (MPa)	Gas evolution (ml/g)
Kailin Ceramic Sand	1.5	2.098	10.34
Scrubbed Silica Sand	1.5	1.105	13.4
Baked Silica Sand	1.5	1.088	12.9
Kailin Ceramic Sand + Scrubbed Silica Sand	1.5	1.815	12.5
Kailin Ceramic Sand + Baked Sand	1.5	1.851	12.35
Chromite Sand + Scrubbed Silica Sand	1.5	0.801	10.85
Chromite Sand + Baked Sand	1.5	0.821	10.74

The following conclusions can be drawn from Tab. 3

- By the same amount of resin content, the tensile strength of Kailin Ceramic Sand is the highest among those various of base sand
- The gas evolution of Kailin Ceramic Sand is the smallest
- The tensile strength is obviously improved and the gas evolution is decreased after Kailin Ceramic Sand is added and mixed in silica sand core
- The tensile strength is reduced and the gas evolution is decreased after chromite sand is added and mixed in silica sand core
- Compared with Baked sand, the tensile strength of scrubbed sand is slightly lower than that of baked sand, and the gas evolution of scrubbed sand is higher than that of Baked sand

By the experimental results, the core performance of baked sand is higher than that of scrubbed silica sand. Because of polygonal grain shape of chromite sand, the strength of core sand is significantly weakened, of all the experimental scenarios in the table above, Kailin Ceramic Sand has the highest tensile strength and lowest gas evolution. When the resin content is 1.5%, the tensile strength exceeds 2 MPa, which more than twice the tensile strength of other original sand cores. Therefore, under the same core strength, the amount of resin content can be reduced by at least 30% of Kailin Ceramic Sand. At the same time, the gas evolution of 1.5% resin content is 20% to 30% lower than that of other sands, which can effectively reduce the probability of casting defects.

3.2 Sets 2: Silica sand, Kailin Ceramic Sand and sintered ceramsite sand

Although the appearance of sintered ceramsite sand and Kailin Ceramic Sand are similar, the production process is totally different, resulting in different sand properties (Please refer to “Overview of Properties and Application of Common Artificial Foundry Sand” for details). The following two tables list the physical and chemical parameters of a total of five samples.

Tab.4 Chemical composition of sand samples（mass %）

Tab.5 Physical properties of sand samples

Sand	Al_2O_3	SiO_2	Fe_2O_3
Sintered Ceramsite Sand 1	62.32	35.21	2.52
Sintered Ceramsite Sand 2	60.00	38.05	1.21
Kailin Ceramic Sand	69.69	20.99	3.34
Scrubbed Sand	/	91.80	/
Baked Sand	/	92.00	/

Sand	Clay Content(%)	Acid Demand Value(ml/50g)	Ignition Loss(%)	Real Density(g/cm^3)	Thermal Expan.(%，1000℃)	Bulk Density(g/cm^3)
Sintered Ceramsite Sand 1	0.17	2.0	0.05	2.83	0.12	1.73
Sintered Ceramsite Sand 2	0.12	1.8	0.08	2.93	0.12	1.76
Kailin Ceramic Sand	0.05	0.8	0.03	3.07	0.10	1.90
Scrubbed Sand	0.25	3.2	0.35	2.71	1.34	1.67
Baked Sand	0.12	1.2	0.15	2.72	1.25	1.66

The cold box resin is composed of phenolic resin and polyisocyanate in ratio of 1:1. The total amount of the resin is 1.4% and mixed with the samples for 3 mins. Then the dog bone test specimen is produced on a special cold-box core shooting machine. The data in Table 6 were obtained after the tensile strength test. The 0 h, 24h in the table respectively represent the immediate strength after sand mixing, the strength after 24 hours.

Tab.6. Comparison of silica sand, Kailin Ceramic Sand and sintered ceramsite sand by cold box process

Sand	0 h	24 h
Scrubbed Sand	1.30	1.73
Baked Sand	1.52	2.12
Sintered Ceramsite Sand 1	1.40	1.99
Sintered Ceramsite Sand 2	0.96	1.34
Kailin Ceramic Sand	2.34	3.61

The following conclusion can be drawn from Table 6:

- The tensile strength of Kailin Ceramic Sand is the highest at any periods of time
- The tensile strength of same type of sand is improved after being placed for 24h

- The tensile strength of baked sand is greater than that of scrubbed sand at the same time
- The overall performance of sintered ceramsite sand 1 is better than that of sinered ceramsite sand 2
- The overall performance of the sintered ceramsite sand is better than that of the scrubbed sand, but not as good as that of the Baked sand.

Therefore, the strength of sintered ceramsite sand is lower than that of baked sand, and the strength of sintered ceramsite sand 2 is also lower than that of scrubbed silica sand, which indicates that the cold-box process is more sensitive to the surface condition of the original sand and has higher requirements. Meanwhile, from the comparison of experimental results, Kailin Ceramic Sand is the highest tensile strength among the above-mentioned sand when it is applied to the cold-box process which could be due to the spherical grain shape of Kailin Ceramic Sand, the surface is smooth and the resin utilization rate is high.

4. Customer Case – the application of Kailin Ceramic Sand to solve casting defects

4.1 Customer Status

The castings of an engine foundry in Anhui, China often experienced sand burn-on, veins, deformation and fracture of the core. In order to effectively improve the quality of castings, increase the yield, and reduce the difficulty of casting cleaning. In 2015, on the basis of investigation and demonstration, the factory decided to adopt the small batch test of Kailin Ceramic Sand with particle size of 50/100.

4.2 Testing Results

First of all, a laboratory test was carried out. The triethylamine catalyzed cold-box process was used to make the core, and the amount of resin content was 1.6%. The tensile strength test results are shown in Table 7

Tab. 7 Tensile strength testing results of ceramic sand by cold-box process

Particle Size	Resin	Curing Agent	Amount of Resin content（%）	Tensile Strength (M Pa, Avg)
50/100	XY Cold-box Resin	Triethylamine	Two Parts，0.8 each	4.5

The average tensile strength of the test specimen tested is as high as 4.5MPa, while the average tensile strength of the silica sand used in field production is 1.95MPa under the same conditions, which is 2.3 times that of the latter. This leads the reduction of Kailin Ceramic Sand consumption and the weight of core.

For the second trial, using Kailin Ceramic Sand and scrubbed silica sand each 50%, the amount of resin content was reduced to 1.4%. The cold-box shooting machine produced 4 pieces of water jacket core and oil passenger cores of a four-cylinder block on site (see Figure 4). After pouring and anatomical inspection, the inner cavity was smooth and clean, with no sand burn-on and veins, and the casting wall thickness was uniform, which was a complete success (see Figure 5). Since then, Kailin Ceramic Sand mixed scrubbed sand has been gradually promoted in the cold-box process, and has been applied to the cylinder head water jacket core, and has been in stable production for more than 7 years. At present, the overall usage of the cold-box core is as followed: according to the shape and size of the core, the amount of Kailin Ceramic Sand is 30% to 50%, the amount of resin content is 12% to 1.8%, tensile strength is 2.2~2.7MPa.

water jacket sand core of cylinder block

oil passenger cores

water jacket sand core of cylinder head

main oil passenger cores

Fig. 4 Sand cores by cold-box process using ceramic sand

Fig. 5 Cylinder block and castings produced by Kailin Ceramic Sand cold-box process

4.3 Case Analysis

Cylinder blocks and heads contain many narrow inner cavity structures. The pouring temperature is generally between 1440-1550℃. The thin-walled part of the core is easily sintered under the action of high-temperature molten iron. When the interface reaction occurs, sand burn-on is formed. The refractoriness of Kailin Ceramic Sand is greater than 1800℃, and the real density of the Kailin Ceramic Sand is relatively high. The kinetic energy of the Kailin Ceramic Sand particles with the same diameter and rate in sand shooting is 1.28 times of that of silica sand particles, which can improve the density of the core.

Cylinder block and head water jackets, inlet and exhaust parts often appear the defect of veins. A large number of studies and casting practices show that the root cause of the vein defect on the surface of the casting is the phase transformation expansion of silica sand, and the thermal stress causes the surface layer of the core to crack, and the molten iron penetrates into the crack. Especially when the cold-box process is used, the tendency of veins is greater. In fact, the thermal expansion rate of silica sand is as high as 1.5%, while the thermal expansion rate of Kailin Ceramic Sand is only 0.13%. The possibility of cracking on the surface of the core caused by thermal expansion stress is very small, so the use of Kailin Ceramic Sand in the core of the cylinder head and block is a simple and effective solution to the problem of veins.

4.4 Case Conclusion

Complex, thin-walled, long and narrow cylinder head water jacket cores and oil passenger cores require high strength (including high temperature strength) and toughness, and control the gas evolution of the core. Therefore, the use of Kailin Ceramic Sand reduces the amount of resin content, and achieves the effect of high strength and low gas evolution.

5. Cold-box with Kailin Ceramic Sand ， Examples

Fig. 6 Cylinder hear, cylinder block, water jacket core and casting produced by Kailin Ceramic Sand cold-box process

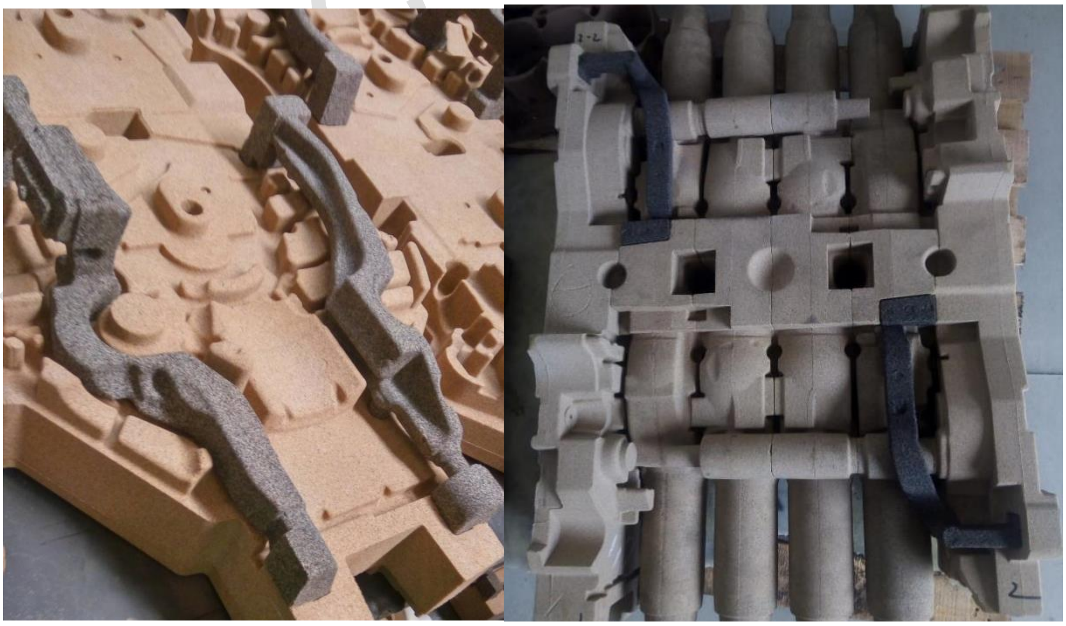


Fig.7 oil passenger cores produced by Kailin Ceramic Sand cold-box process