Analysis of quality and defects in lost foam casting process

Author: Li Zengming, chairman at China LFC&VPC Foundry Society
Translator: Wu Jong, Oversea Manager at Castchem INC
Email: info@zj-castchem.com ,
wujong@aliyun.com

Casting quality standard formulating in lost foam

Casting quality between the precision casting and sand casting technology, more similar to precision casting.

For instance

Shifting fork（USA）

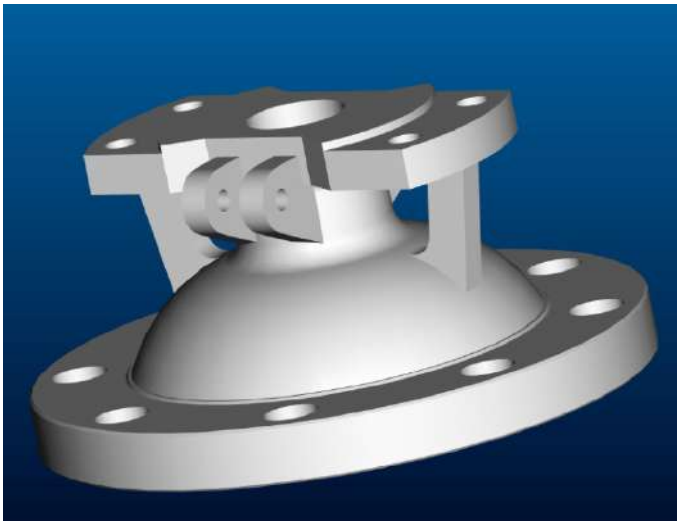
Drawing indicated 'Drawing Dimension and Toleranced for Lost Foam Process Only'

Castings technical requirements:

(1)Appearance: no surface adhering sand, no fold defect/cold shut defects/porosity/inclusions in castings.

(2)The surface roughness is lower than Ra 1.25 m.

(3)Casting size tolerance is equivalent to sand mold casting GBCT5 - level 7
(4)Internal defects: through X-ray flaw detection. According to ASTM E44611, Porosity/sand (residue) holes/fold defects within level 2 are acceptable. Dendritic folds and any crack or porosity and residues more than level 3 are meaning waste products.



Valve deck（Japan）
Castings technical requirements:
(1)Surface defect: within JISG088 level 2
(2)The surface roughness is Ra≤12.5 m
(3)Casting size tolerance is equivalent to sand mold casting GBCT5- level 8
(4)Castings material：FCD45-10， b≥450N/mm2， δ≥10%，rate of spheroidization>80%，graphite >20 m；
(5)Pressure-tight test: water pressure=20kg/cm2

The conclusion

(1)The lost foam casting process is precise casting, the surface roughness is between 12.5-25m；
(2)The precision of LFC process is between precision-investment casting and sand mold casting dimensional tolerance is GBCT5~level 9
(3)The casting weight tolerance in LFC process is in the same level with precision-investment casting,it is GBMT5~level 7,much better than clay sand mold casting's GBMT5 level8~10 and resin sand mold casting's GBMT5 level11~13

Quality assessment method for LFC process

GB/T 26658-2011 Quality assessment method

Content including:
Surface roughness, castings weight tolerance and dimensional tolerance,national standard for casting material GB/T15056-94,GB6414-86,GB/T1135-89.

Other three points: Casting shaping, casting surface defects and casting internal defects use the standard GB/T 26658-2011.
The GB/T 26658-2011 Standard stipulated that the batch production of casting less than 300kgs shall achieve the quality class listed as below:

Quality class **Quality name**		**Superior class**	**First-class**	**Qualified class**	**Rejects**
Casting shaping		≤1	≤2	≤3	4~5
Castings surface defects	Slag inclusion （sand holes、slag holes）	≤1	≤2	≤3	4~5
	Porosity	≤1	≤2	≤3	4~5
	Folds	<1	≤1	≤2	3~5
	Cold shut	<1	≤1	≤2	3~5
	Cracks	≤1	≤2	≤4	5
	Sand-adhering	≤1	≤2	≤3	4~5
	Metal protrusions	≤1	≤2	≤3	4~5
	Cutting traces on pouring gate	≤1	≤2	≤3	4~5
	Weld area	≤1	≤2	≤3	4~5
Surface roughness		≤1 (Ra≤12.5um)	<2 (Ra≤12.5um)	≤3 (Ra≤25um)	4~5 (Ra≥25um)
Dimensional tolerances		≤1 / ≤CT6	≤2 / ≤CT7	≤3 / ≤CT9	4~5 / ≥CT9
Weight tolerance		≤1 / ≤MT6	≤2 / ≤MT6	≤3 / ≤MT7	4~5 / ≥MT8
Casting internal defects	Porosity	<1	≤1	≤2	3~5
	Slag inclusions	<1	≤1	≤2	3~5
	Folds	<1	≤1	≤2	3~5
	Cracks	0	0	0	1~5
Materials	Mechanical properties	According to common standards			
	Microstructure	According to common standards			

	Chemical composition	According to common standards

Effect of Casting Process on Casting Quality

Influencing factors (several aspects, each major aspect contains a number of small aspects)

*The foam-pattern quality

*The coating material quality

*Dry sand vibration filling compact quality

*Casting process design quality

*Metal smelting quality, etc

Common defects in Lost Foam Casting

4 kinds of defects：

（1）The castings forming or dimensional shape is not good

（2）Surface defects

（3）Internal defects

（4）Material defects

The casting forming or dimensional shape are not good

Collapse

Insufficiently pouring

Deformation

Poor dimensional accuracy

Surface defects

Sand adhered

Surface protrusion

Cold shut and cold-lap

Surface holes and pit defects

Surface lustrous carbon(fold defects)

Internal defects

Non-metallic inclusions

Porosity

Shrinkages

Material defects

Cast steel carbon defects

Clusters castings are not homogeneous

The castings forming or dimensional shape is not good

Collapse ：

Due to pouring filling and solidification of the initial movement of sand, the mold is partially destroyed, the liquid metal can not completely replace the bubble shape of the location, resulting in casting can not be formed.

Result: Casting scrapped

Causes of Collapse

（1）Dry sand compactness is not enough, dry sand filling dissatisfaction;

（2）Sand in the top of the casting mould is not enough, negative pressure is not enough, the liquid metal buoyancy makes the sand on the top collapse, resulting in poor casting;

（3）Liquid metal filling speed is too slow or pause, it makes the gap between the metal and mold is too large, the pressure inside the mold and sand pressure is greater than the total pressure within the gap, resulting in mold movement or collapse, so casting poor shape.

Preventive measures

（1）Making the dry sand vibration filling compact enough, full filling every part in the mold cavity.

（2）Increase the amount of sand at the top of the flask, to maintain moderate negative pressure, especially to ensure that the negative pressure is constant in all parts of the cavity.

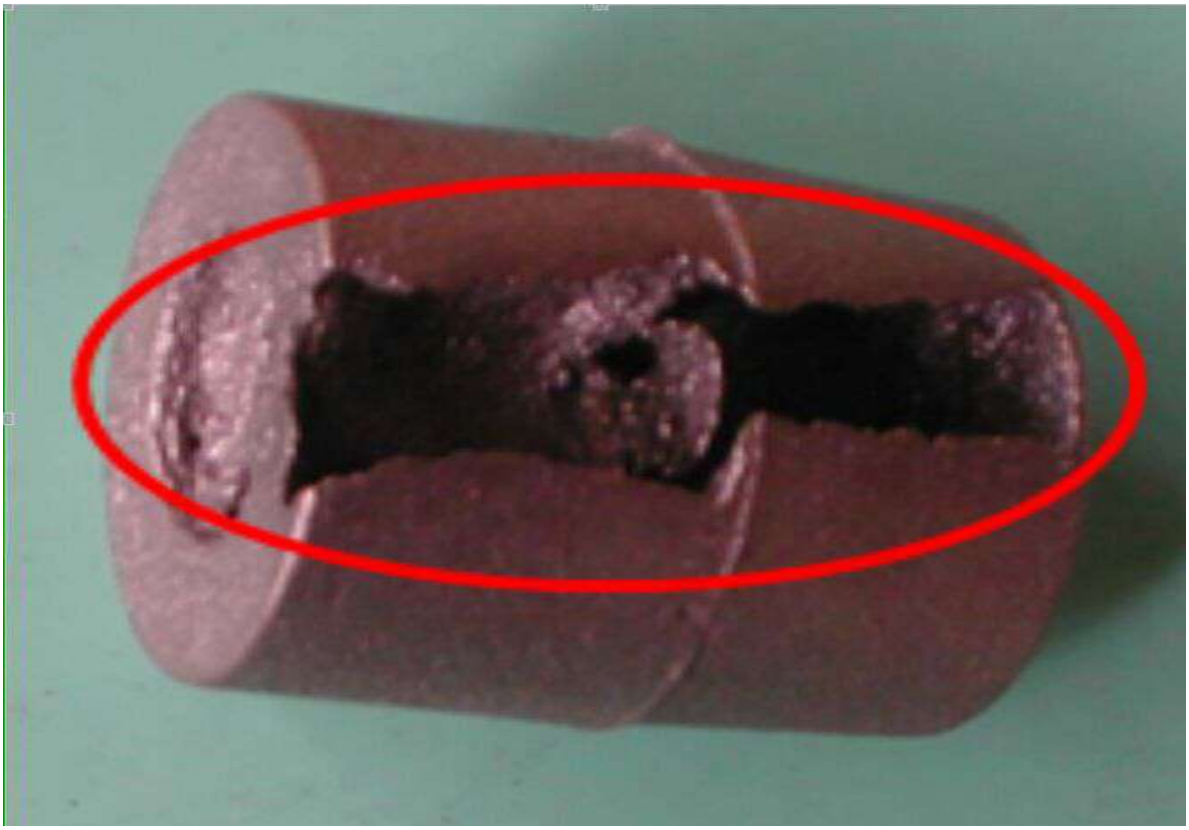
（2）To put something heavy on the top of the flask.

（3）To reduce the metal pressure head.

（4）Keep constant pouring of melted metal.

Insufficiently pouring

The top, end or thin wall of the mold is not replaced by the liquid metal, so that some part of the casting is not fully formed.
Results: scrapped; small area or a small pieces can be welded to fill.



The causes of insufficiently pouring

During the the replacement process for melted metal and the foam-pattern, the resistance for melted metal moving front is too large or metal temperature is too low, so that the melted metal is solidified before time, can not continue to flow and will prevent the melted metal moving forward, after pouring enough to produce inadequate defects.

Preventive measures

（1）To reduce the gasification :Change the foam-pattern material, reduce the density of pattern. Make sure the mold and coating is dried.

（2）Pouring molten metal with higher temperature.

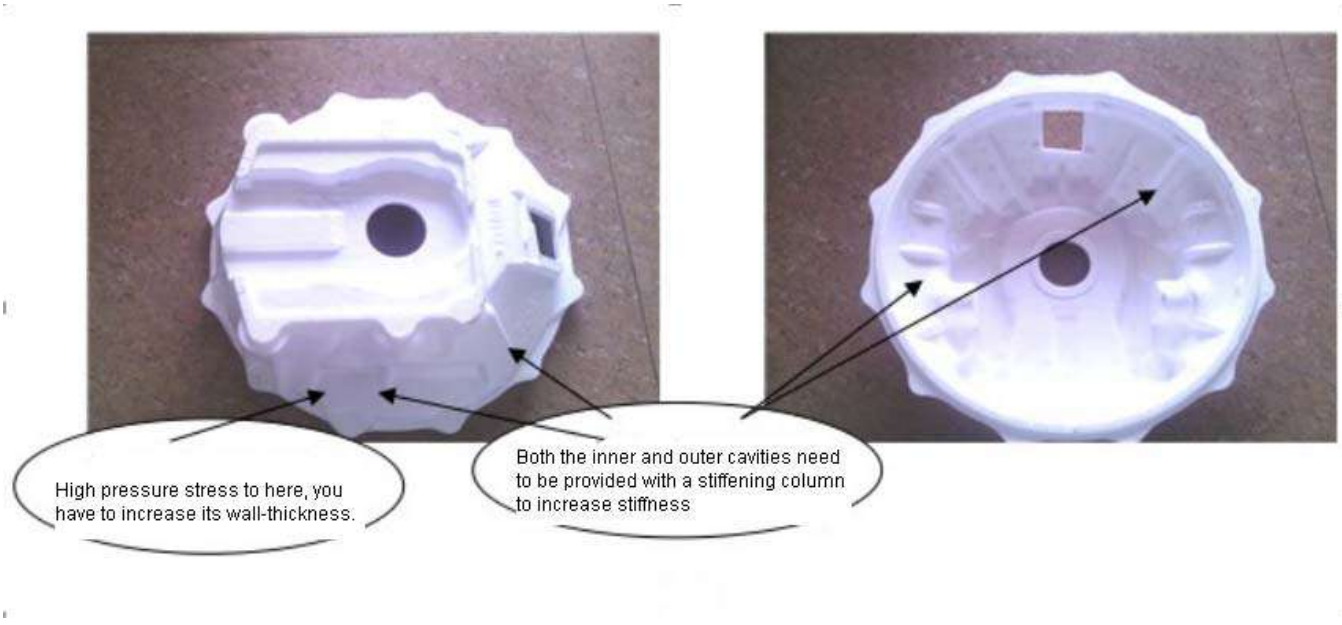
（3）Increase the vacuum pressure, improve the exhausting speed

（4）Adjust the pouring operation, to pour quickly in case of there is no back-jet.

Casting deformation

Casting geometry distortion, such as casting bending, our of round, wall thickness changes, and so on.

Results: scrapped, some castings can be straightened.



The cause of the deformation

（1）The foam-pattern was distorted after glueing

（2）Coating preparation process is in improper such as wrong operation in dip coating method

and drying when placed, and so on;

（３） Inappropriate sand filling and vibration compact operation lead to foam-pattern deformation, large-scale thin-walled parts appear more such problems.

（4）During the casting process, the pattern is partially heated and changes are made before the metal replaces the pattern. Pay attention to this kind of problem when several castings in one flask

（5）The gas pressure distributed in the casting cavity is not constant.

Preventive measures

（1）Use combined glueing for pattern or pattern pieces, operate and inspect it strictly

（2） Coating thickness should not be too thick but workable, to dry in reasonable place, to wear working suit during the work.

（3）With rain sanding, keep vibrating when sanding to prevent the foam-pattern from strong impacting. To improve the vibration table, don't let the pattern to be impacted in the sand flask

（4）Don't let the pouring gate too close to the pattern or pattern cluster.

（5）Keep a constant, fast, continuous filling of molten metal, to prevent cutoff or flash flowing during the filling process

（6）To prevent the molten metal back-jet when pouring

（7）If there are several castings in the same flask, make sure they are separated.

Poor dimensional accuracy

Casting dimensional accuracy can not meet the requirements of the drawings, or dimensional distribution is unconstant, poor casting dimension

Results: The dimension is less than the tolerance, the casting can not be processed and has to be scrapped; Dimension is greater than the tolerance, increase the processing work.

The causes of poor dimensional accuracy

（1）Improper mold scale contraction, low processing accuracy;

（2）Foam-pattern raw material beads , parameters and operation of pre-expansion and pre-forming process, foam-pattern drying time are not constant.

（3）Pouring temperature are fluctuating

（4）Mold compactness is not enough

Preventive measures

（1）Mold design and manufacturing lead to dimensional deviation, revision must be done to the mold;

（2）Find the best solution for foam-pattern raw material, pre-expansion and pre-forming process, pattern aging conditions and time;

（3）Reduce the casting temperature fluctuations

（4）Keep a high mold compactness

Casting surface defects

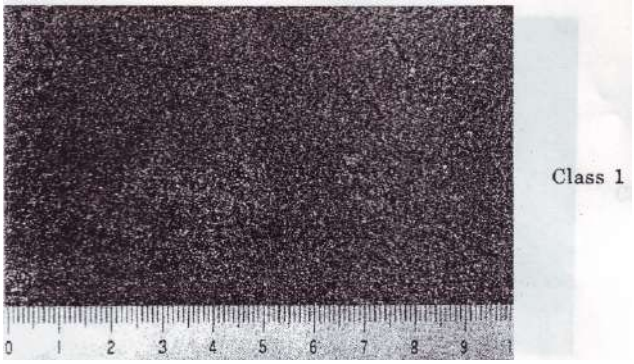
Lost Foam Casting surfaces are prone to defects such as sand sticking, acupuncture, nodulation, cold-shut , surface protrusions, and wrinkle defects in the absence of correct process.

Sand sticking

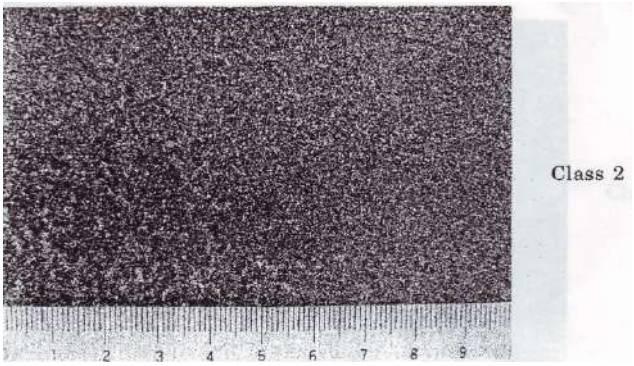
When the molten metal flows into the sand, a metal and sand mechanical mixture formed - mechanical sand sticking

The mechanical sand sticking is the major sand sticking problem in lost foam casting.

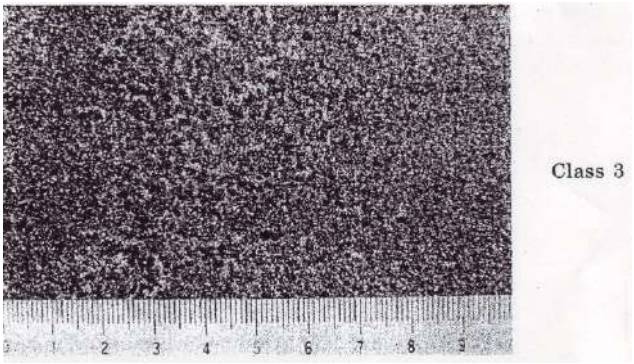
There are two kinds of mechanical sand sticking problem: 1) The molten metal penetrates into the sand by the cracking of the coating, this is easy to be clear. 2)The molten metal penetrates into the sand by tiny gaps in the coating, this will be very difficult to be clear.



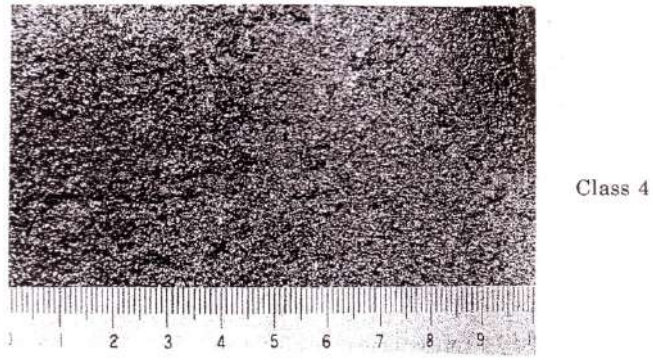
No sand sticking



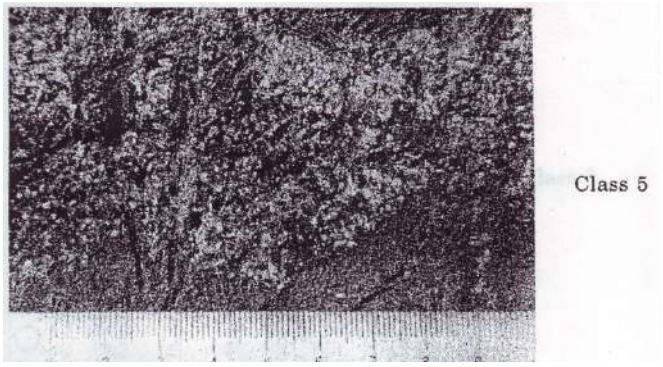
Slightly sand sticking（surface treatment can be done）



Moderately sand sticking（surface treatment can be done）



Heavy sand sticking(It is hard to do the surface treatment)



Seriously sand sticking and iron oxide coated sand （Very difficult to be clear）

The major causes

（1）Coating cracked, sand filling or tightness is not enough, sand particle size is too large and negative pressure is too high, the molten metal flows into sand through the breakages of the coating, or dry sand filling is not enough or lack of tightness lead to metal "Crush" coating and get into the sand, or high negative pressure to force the molten metal to produce a strong "wall effect" and filling pressure, and then "break" coating into the sand, that will result in the mechanical sand sticking problem.

（2）The coating is too thin or foam-pattern is partially uncoated, the molten metal temperature is too high and negative pressure is too big, the molten metal passes through the coating small gaps enters the sand.

Preventive measures

（1） Preparation of good coating: Constant, complete coating with a certain thickness, especially in the cavity surface and corners;

（2）Keep proper pouring temperature

（3）Using a reasonable negative pressure

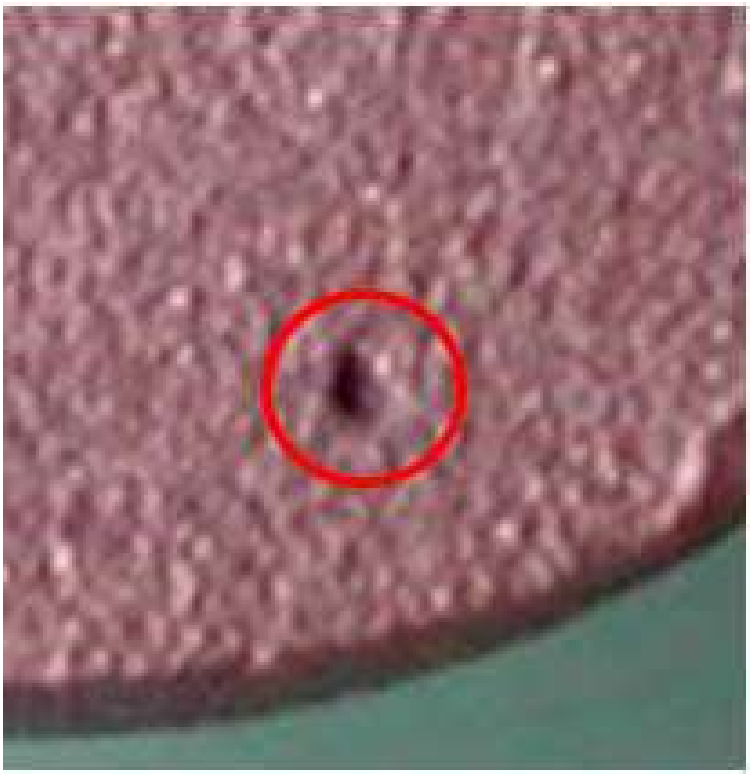
（4）Using the fine sand

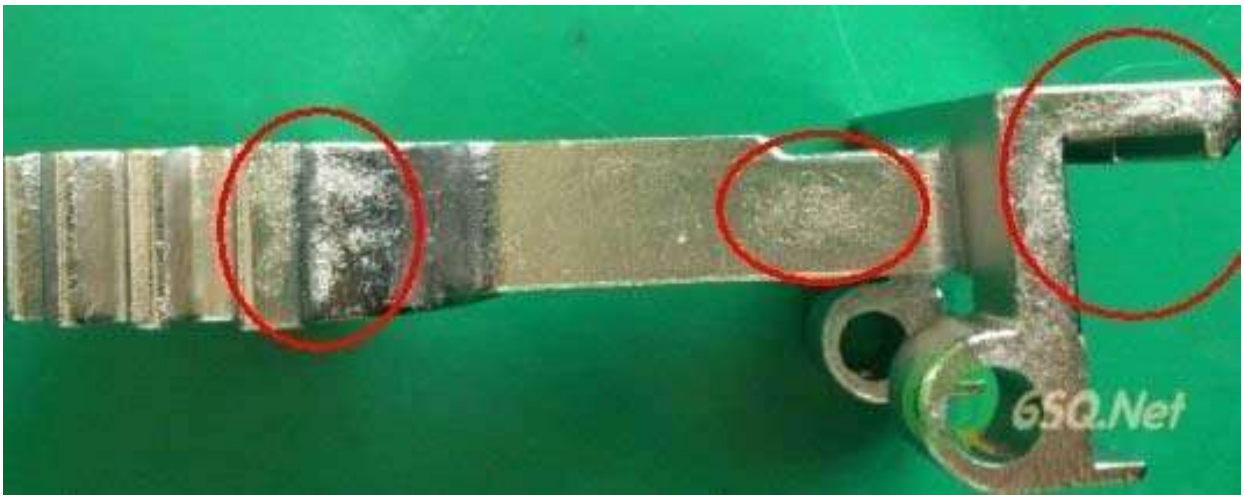
（5）Dry sand vibrating enough

Casting surface protrusions

Casting surface evenly distributed semicircular protrusion, larger tumor-like protrusions.

Results: some are difficult to be removed, castings scrap





The main causes for the formation of metal protrusions

（1）Mold surface casting defects (pores, shrinkage, etc.), the exhaust plug hole is too large, there are protrusions on the surface of the foam-pattern, vacuum assist casting process makes the surface has metal protrusions;

（2）The inner surface of the coating has small pores or large bubbles. After vacuum assist pouring, metal protrusions in same shape and size(spot or tumor) will form in the casting surface

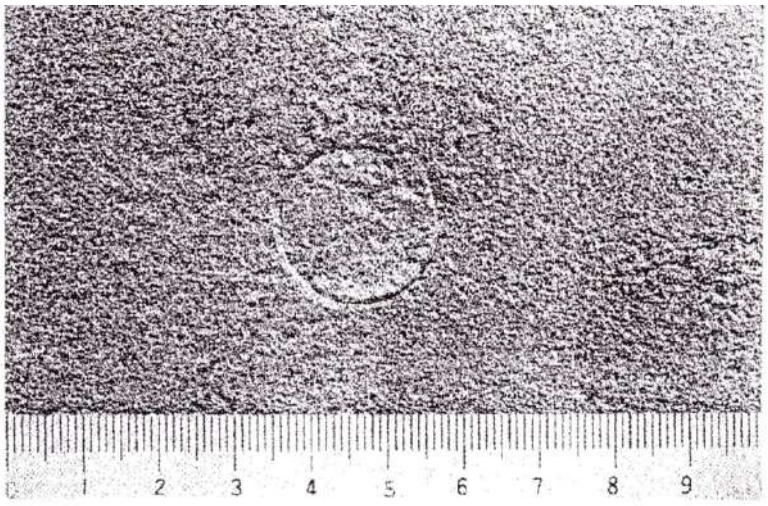
（3）With poor sand filling, under vacuum assist process, there will form hollows beneath the dry sand in the bottom of coating, molten metal breaks into the mold cavity and form nodules through the coating cracks, removal is very difficult.

Preventive measures

（1）To improve the surface quality of the mold, to grind the surface protrusions into smooth.
（2）To ensure the quality of coating, fermented coating material can not be used. Use suitbale viscosity coatings, to coat the first layer in thin, so that the coating can be constant;
（3）Improve the coating drying process to prevent the foam-pattern from porosity and accumulating coatings in inner corners, to prevent coating surface cracks and vacancies
（4）Improve the vibration parameters to make the sand fill with a good fit, pay attention to the surface sand tightening. In the inner cavities which are difficult to be filled, filled and fixed with resin sand or water glass sand in advance.

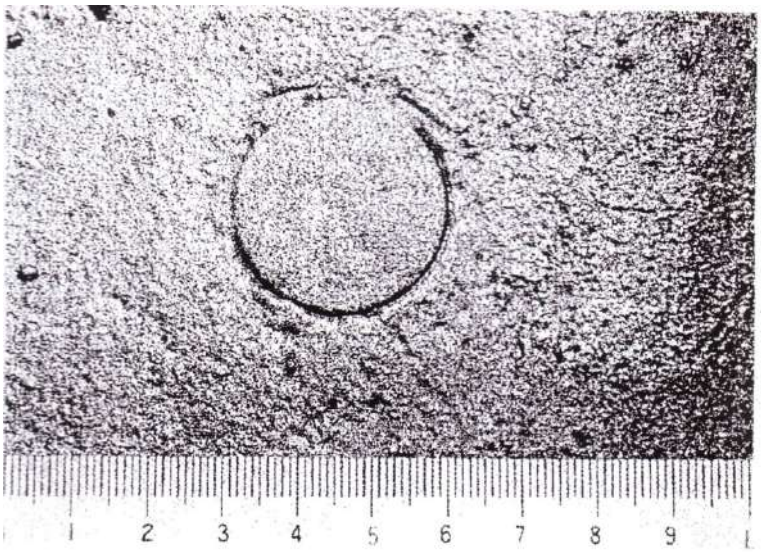
Cold-shut and fold defect

When the technological process is not appropriate, the cold-shut defect will happen in lost foam casting, obvious marks will form in casting surface, it becomes fold defects when the situation is very serious.
Results: Castings scrapped when the defects are very severe; It can be patched when in slight situation.

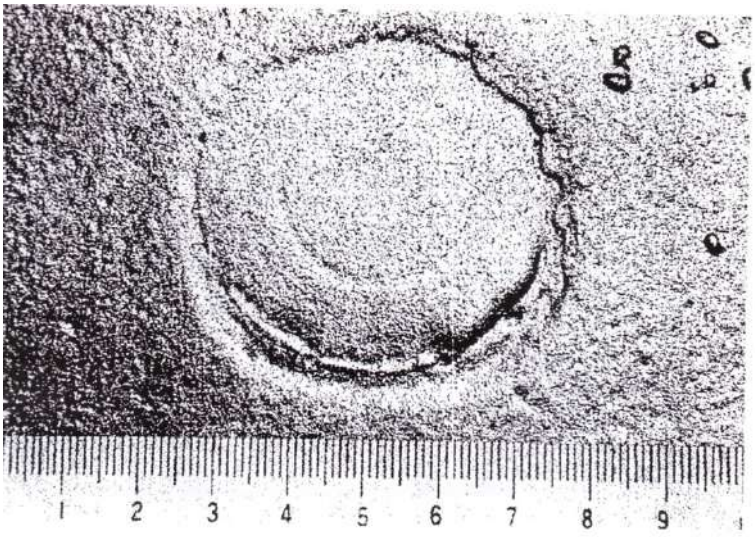


Class 3

Moderate cold-shut



Severe cold-shut



Severe cold-shut

The causes of cold-shut defects

（1）Molten metal is divided into two flows and meet with each other on the top of the mold or in the bottom, the temperature is too low so that it can not be a good fusion, then it forms of significant groove marks, we called it cold-shut. The thinner the castings wall is, the lower the pouring temperature will be, of course it will be more easy to form a cold-shut defect.

（2）Negative pressure was too large during filling process of molten metal , under wall attachment effect, the molten metal rises along the wall was faster than in the internal cavity. When the temperature is lowing, a thin layer of metal shell will form along the sides of mold. After the metal filling, it will has heavy fold defects if there is no enough heat to melt the metal shell.

Preventive measures

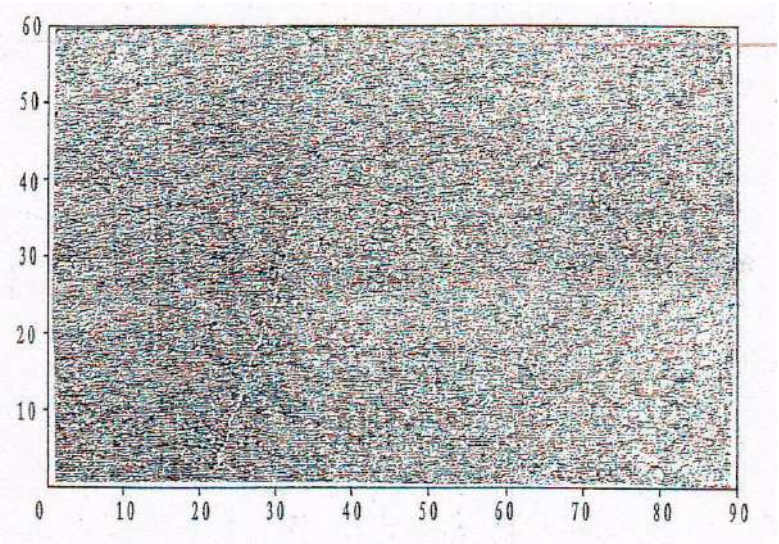
（1）To make an appropriate increase in pouring temperature, so that there is sufficient heat fusion of two metal flows;

（2）Improve the pouring system, pay attantion to the system with several pouring gates that make sure molten metal flows filling a reasonable balance, to have a reasonable increase of filling speed;

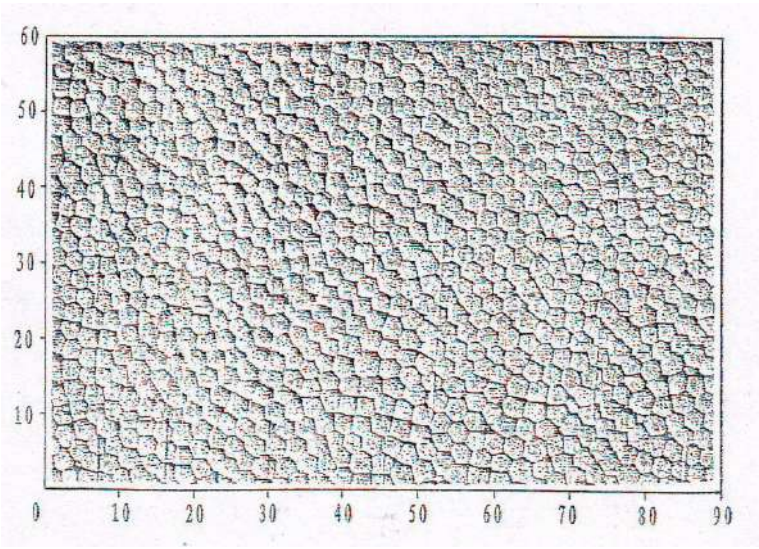
（3）To ensure that the mold in sand won't collapse, try to reduce the negative pressure and have an appropriate increase in negative pressure pumping flow.

Defect of surface holes

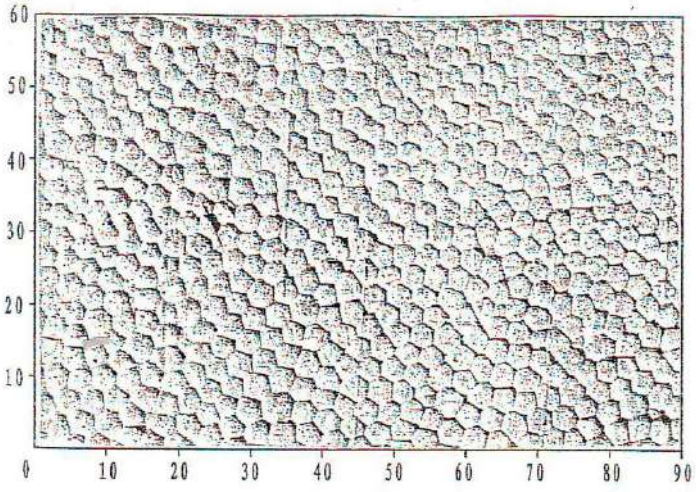
With improper technological process and operation, the casting surface will has defects such as slag holes, sand holes, shrinkage and lacunose surface. That means poor surface quality. As a result: Poor surface quality or castings have to be scrapped.



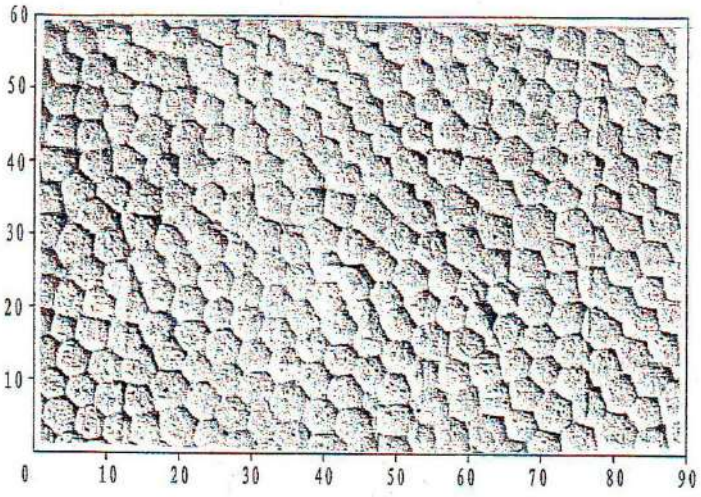
The deep of surface holes ≤0.2mm



Holes diameter（φ≤2mm),deep≤0.5mm



Diameter（φ≤3mm），deep≤1.0mm



Big cracks，deep＞1.0mm

Surface slag holes, surface sand holes

（1）Molten metal entrained slag and thermal decomposition gasification curing residues can not be discharged and accumulated in the casting surface. After shot blasting, the casting surface has irregular holes, there are gray black irregular inclusions in these holes.

（2）Surface sand hole: During the pouring process, the sand gets into the molten metal and floating in the casting surface due to its light weight in granular type. After shot blasting, the surface sand become white inlaid objects which can not be clear. If the sand is cleaned off, it becomes holes mesh in the casting surface.

（3）Surface shrinkage, cracks: Molten metal fills bad at the connections between castings and pouring gate or riser, easy to form the surface shrinkage defect.

（4）Surface cracks and perlitic defects：Beads fusion in the foam-pattern surface is not good so that the coating infiltrated the beads, it becomes cracks after surface clearing, or become perlitic defects if in very serious situation. Another cause is because of the high temperature or partial quick heating when in foam-pattern drying.

Preventive measures

1）Surface slag hole: Strictly prevent of slag in pouring. Set a filter. Improve the gating system so that it will help to remove slag. Appropriately improve the pouring temperature.

（2）Surface sand hole: the pattern cluster should be tightly connected; Hollow sprue should be sealed well; Don't gluing cluster in the flask. Pouring gate connects well with pattern.

（3）Casting surface shrinkage: Have an appropriate increase in the gating system filling capacity. Improve the temperature of molten metal; Use heat retention and unbent sprues.

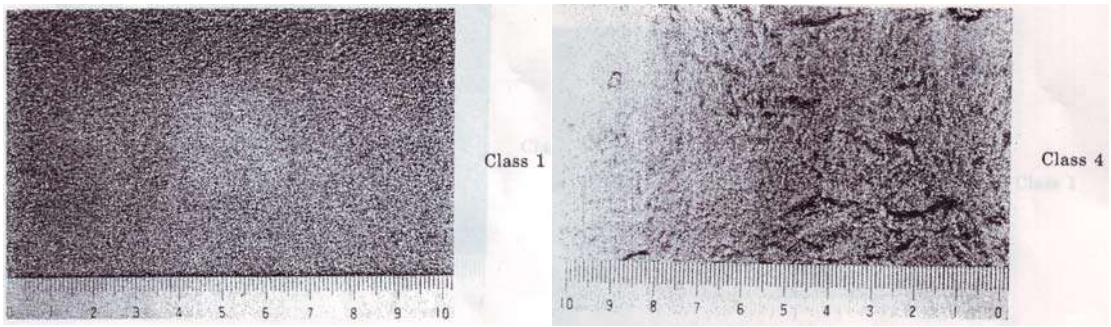
（4）Casting surface cracks and bead-like defects: to improve the pattern surface quality. Use small beads; Make sure the blowing agent content is appropriate; To improve the foam molding process; Foam-pattern drying process is reasonable and prevent of partial rapid

overheating.

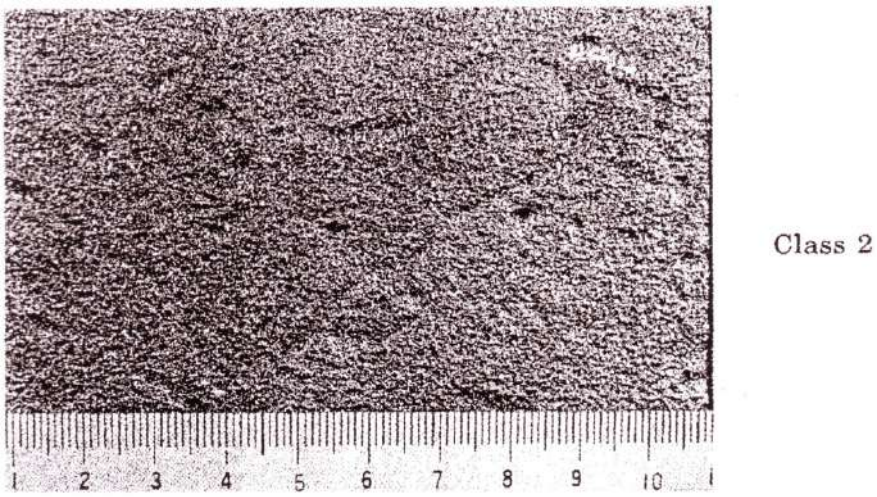
Casting surface lustrous carbon(wrinkles defect)

Defects of cast iron in lost foam casting.

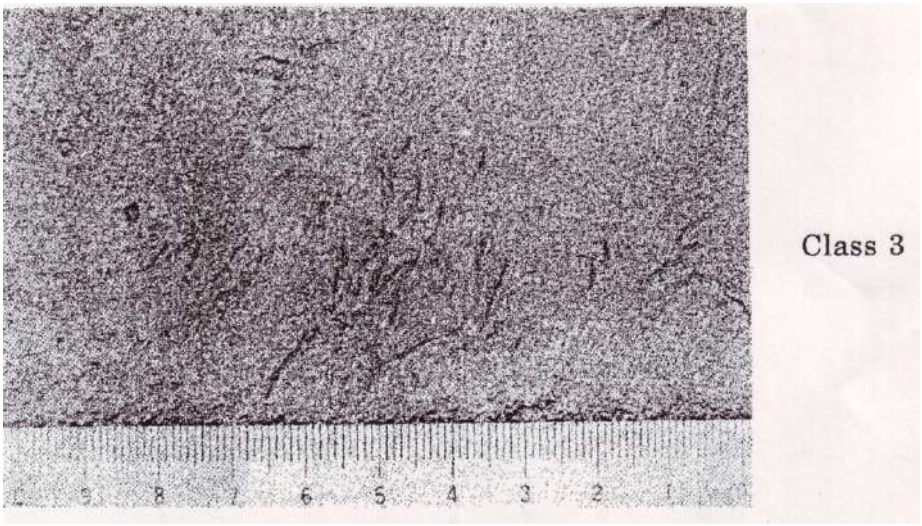
Casting surface has a layer of lustrous carbon deposition, after cleaning showed orange peel, we call it wrinkles defect . For big castings, the fold defects are on the upside part of the casting. For thin wall-thickness castings, the folds defect should be in the top or middle of the casting.



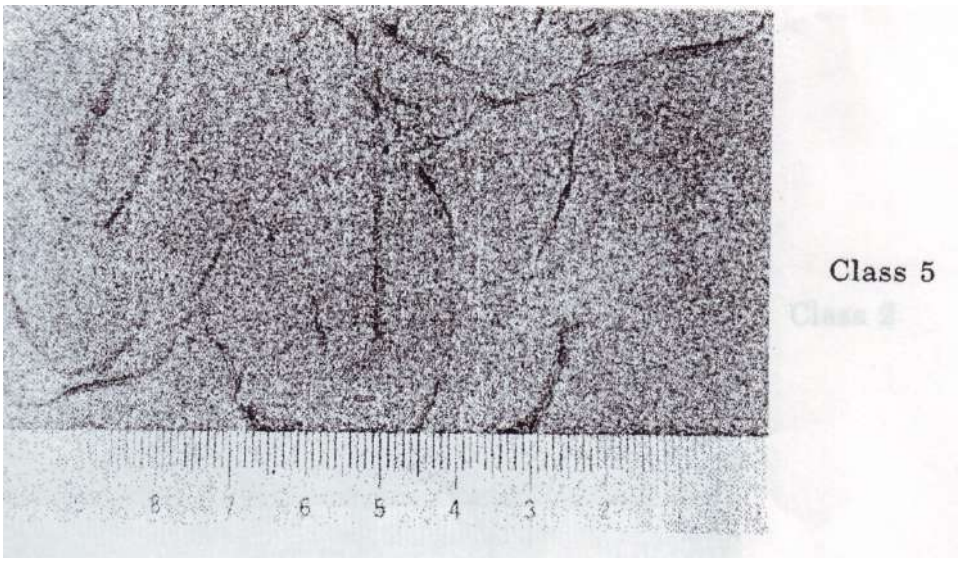
Slight lustrous carbon



moderate lustrous carbon



heavy lustrous carbon



Serious lustrous carbon

The causes of lustrous carbon

In iron casting, the thermal decompositions of polystyrene are both styrene monomer gas and liquid dimer,trimer and other liquid polymer,viscous asphalt-like liquid.The decomposition product remains on the side of the coating by the casting, partially absorbed by the coating, and partially forms a polymer film between the metal and the coating. In the reducing atmosphere, it will form a layer of lustrous carbon which is in low density and easy to form a carbon deposition layer in the castings.

The direct causes of lustrous carbon

（1）Pattern Material: EPS pattern is easier to form lustrous carbon than the STMMA , the carbon content in EPS is up to 92%, but only 62% in STMMA

（2）Pattern density: the higher the density, the more material and carbon contained, thermal decomposition of liquid products will be more and easy to form wrinkles.

（3）Alloy material: For low carbon material, the carbon in foam-pattern can be partially dissolved, which is not easy to produce wrinkles defect. For high carbon containing ductile iron, it is most likely to form wrinkles.

（4）Casting structure: EPS pyrolysis residues can be discharged in time is closely related to the casting structure, and the ratio of casting volume from surface area. Small ratio is conducive to discharge of pyrolysis residues, lustrous carbon defects tend to produce small.

（5）The pouring gate system has a significant effect on the flow field and the temperature field of the molten metal, which has an important effect on the pyrolysis residues and its flowing direction. Top pouring has a smaller chance of forming wrinkles defect than Bottom pouring. A top pouring gate is conducive to eliminate wrinkles.

（6）Negative pressure(vacuum): increased with negative pressure, wrinkle defects reduced or eliminated. The greater the negative pressure, the faster the filling speed and the shorter the pouring time will be. As the low viscosity liquid residue is too late to turn into a high viscosity liquid decomposition residue, the lustrous carbon decreases. High negative pressure is conducive to discharge pyrolysis residues into the sand through the coating layers, it is aslo conducive to reducing the tendency of wrinkles defect.

（7）Pouring temperature: When other conditions are fixed, wrinkles defect will be decreased as the temperature increased . The thermal decomposition of foam-pattern is complete in high temperature, but the percent of gasifying is increased and liquid and solid residues decreased, is conducive to reducing wrinkles defects.

（8）Coating and sand permeability: High permeability coating layer and sand is conducive to pyrolysis residues discharging, wrinkle defects tend to be less. Thin coating layer, coating powder and sand with big mesh size, are conducive to reducing wrinkles defect.

Casting internal defects

Non-metallic inclusions: sand, paint inclusions, slag inclusions and the foam-pattern thermal decomposition residues

Porosity: Porosity caused by poor drying of the coating layer, inclusions porosity, foam-pattern porosity, and porosity caused by gluing material

Shrinkage of casting

The causes of sand inclusion

Partially cracks in coating layer.

The connection between the sprue and pouring gate is not sealed.

The bonding part between the coated foam-pattern and the pouring system in flask is not sealed.

Sand inclusion Prevention

① Keep constant coating layer. , To keep the integrity of the coating layer during drying, transfering, storage, vibration modeling;
② Make sure the connection between the foam-pattern and the inner pouring gate is smooth to prevent sand accumulating in sharp corners.
③ The gluing side of the pattern cluster must be strictly sealed, do not combinate it in the flask.

Coating material inclusion and preventive measures

① Improve the coating formula and preparation technology to increase the coating layer strength both in low temperature and high temperature.
② The gluing sides of the foam-pattern cluster should be strictly sealed, so that the coating material can not get into the gaps.
③ The pouring system should be made by mould forming with smooth surface, no cracks and holes. In case of any cutting to the pouring system, the cutting surface should be polished by sand-paper and paste a thin paper on it

Prevention Measures for Inclusion of Metal Slag

① Work out a precise feeding radio for each raw material during smelting, improve the slag removing process such as using a dregs remover. Furnace liner material should be in appropriate proportion to metal content.
② Use a screen filter to prevent slags getting into pouring system, the screen filter should position in right place. Screen filter is not suitable for steel casting.

Prevention of pyrolysis residues

① Using a low-density foam-pattern. The total material mass of the pattern is reduced, in that case the total amount of pyrolysis residues is reduced, and the possibility of defects is reduced
② For the pyrolysis residue that has entered the cavity, it is removed by setting the slagging riser.
③ Improve the pouring speed, speed up the slag discharge speed

Prevention measures for porosity inclusion

① Use the closed-ended pouring system, The sprue cross-sectional area is the largest in the entire pouring system and the flow gate has the smallest gross area. Keep everywhere in pouring system is always filled with molten metal.
② During the pouring operation, there is always a certain amount of liquid metal in the sprue cup to ensure that the sprue gate is always full.

Prevention measures for porosity caused by foam-pattern residues

① Improve the pouring system and the procedure in order to replace molten metal layer by layer without turbulent flow.
② Increase the pouring speed, increase the gap between the front molten metal and the non-pyrolysis pattern, and expand the outward diffusion area of the gas;
③ To increase the negative pressure in the precondition of molten metal is not turbulent, improve the speed of discharging the pyrolysis gas. If porosity is caused by turbulent flow, to reduce the negative pressure so that dry sand mould does not collapse.
④ Improve the permeability of the coating layer and sand, expand the pyrolysis gas discharge channel, speed up the gas efflux.

Porosity caused by poor drying of foam-pattern

The moisture content in the pattern is too high, the blowing agent content is too high. Too much evaporation produced during the pouring porcess and makes back-spraying in sprue gate. The casting is very easy to have porosity defect when back-spraying happened. If the coating is not dry thoroughly, the humidity is too large, the moisture content is higher, the moisture in the coating is heated to produce a large amount of gas during the pouring process, it will be very easy to form porosity defect.
Tests show that the gasification of water vaporization volume is greater than the amount of foam-pattern pyrolysis gas, in that case the pattern and coating layer must be thoroughly dry.

Preventive measures for porostiy caused by moisture of pattern and coating layer

① Foam-pattern must be dried after forming, of course the cooling water remained during forming should be removed first.
② The coating layer must be dried completely,to strengthen the air flow in the drying room , set up ventilation holes in the wall to remove the humid air, to avoid dried coating layer going back to moist;
③ Sand must be dry, moisture contains in sand should be not more than 0.2%. If the moisture is excessive, should be used after drying.

Porosity caused by the glue

When using too many glues for assembling the patern, the glue on the adhesive parts will produce a lot of gas during pouring the molten metal. if the gas can not be discharged quickly, it will result in the porosity defect.

Preventive measures of causing the porosity by gluing

① In ensuring the gluing strength and efficiency, to use a low gas content glue.
② In ensuring the gluing strength of pattern cluster, to use the glue as less as possible. For thick wall pattern, just gluing at the edge of the cross-section, use less or don't use glue in internal.

Material defects

Carburization defect and hydrogen defects in steel casting.
Unconstant pouring for pattern cluster.

Preventive measures for carburization defect and hydrogen defects in steel casting

（1）Use the STMMA instead of using EPS
（2）Reduce the density of foam-pattern, enlarge the wall-thickness or partially form a hollow pattern.
（3）Using a reasonable pouring system, exhaust the polluted molten metal through the outlet.
（4）During pouring, increase the negative pressure and strengthen the exhaust speed and efficiency
（5）To cut down the casting time, reduce contacting time by liquid metal and the pyrolysis gas from the foam-pattern
（6）Improve the coating and sand permeability, smooth gas discharging channel.

General situation for defects in Lost Foam Casting

Lost Foam Casting defects are influential and complex, and cross each other.
The quality of raw and auxiliary materials is very important, in that case the procurement of material has to be very careful.
Fine process management and convergence, to strengthen the fine control of the process.
Responsibility is more important than the system, to strengthen discipline and supervision, assign responsibility to every staff.
Improve the theoretical quality of workers and good operating habits.