

# An Overview of Lost Foam Casting Technology Development in China

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## ABSTRACT

China has had an unprecedented economic boom within the foundry industry in the past two decades. Lost foam casting technology has gained increasing popularity during this time. In China, about two hundred foundries have lost foam casting operations with total annual casting production of approximately 300,000 tons in 2006. This paper reviews the current lost foam casting industry in China with discussions of market size, castings produced, government support, investor's outlook, and cost analysis. Moreover, this paper provides insight on lost foam technology development in China with particular emphasis on its advantages in iron casting. Advancement in equipment design and innovation, tooling design and manufacturing, consumables, and processing control are discussed from a technology perspective. Challenges and opportunities for lost foam technology development in China are also discussed.

## INTRODUCTION

China is the largest casting producer in the world and manufactured 24.4 million metric tons of castings in 2006. However, little is known about the development of casting technology in China. As an ambitious developing country, China has been eagerly developing modern technologies in all industries. China's foundry industry is active in adopting new processes in order to catch up with, or lead the advancement of, casting technology. Lost foam casting process has been perceived as "clean casting technology" in China. This perception has attracted significant interest from government, investors and industry in this technology. Lost foam casting technology has gained increasing popularity in foundry industry in China in the past two decades. This paper will provide an overview of lost foam casting technology development in China.

## LOST FOAM CASTING TECHNOLOGY DEVELOPMENT HISTORY IN CHINA

China was among the earliest countries developing lost foam technology in the world.<sup>1</sup> The initial research and development on lost foam technology was launched in China in 1965. The first project was actually a full mold process in which the EPS foam pattern was compacted in bonded sand. That was specifically developed for very large castings. Iron parts were first successfully poured in 1967 at Shanghai Heavy Machine Factory and steel parts were cast in 1971 at Shanghai Paper Machine Factory by full mold process. At that time, the largest casting made by lost foam (full mold) process was 32.5 tons for iron and 52 tons for steel, so far the largest castings made in China. There are about 30 full mold foundries in operation in China, with annual production of about 105,000 tons in 2005; about half of that for true lost foam process using unbounded sand. In China, the lost foam process is regarded as a special case of full mold process, a full mold process with unbounded sand. Because lost foam and full mold processes are related to each other, the full mold process will also be discussed in this paper.

The lost foam process evolved from the full mold process. In 1981, the first lost foam casting trial production line in China was established for research purpose at The Chinese Academy of Science.

Lost foam technology has been promoted by the Chinese government as a primary high-tech industry since the 1990s. The reason, for this is the low volatile organic compounds (VOC) from the operation of this technology. It is regarded as the so-called "green casting process" for the 21<sup>st</sup> century. Another critical reason for its increasing application in China is due to the relatively low initial investment on equipment compared to conventional sand casting and permanent mold processes, as well as the overall reduced costs to cast parts with complicated design that cannot be cast by other methods.

In response to the increased interest in lost foam technology in the industry, the Full Mold Casting Committee was founded by the China Foundry Association (CFA) in 1988. Later in 1995, China Lost Foam Society was established by Foundry Institute of Chinese Mechanical Engineering Society (FICMES). Both associations have been actively promoting lost foam technology in the metal casting community. The Full Mold Casting Committee focuses more on helping corporate members with government policy and marketing related issues, while the China Lost Foam Society provides more academic research and technical services to the industry. An international conference on full mold technology and another conference on lost foam technology are held every two years, organized by these two associations. About ten universities and research institutes

are participating in lost foam technology development and research work. Foundry equipment manufacturers, consumable materials suppliers, tooling designers and manufacturers, as well as lost foam foundries have been devoted to developing this new technology in China.

There are approximately twenty books on lost foam technology published in China. About 500 research papers have been published in scientific and technical journals. The National Science Foundation of China has sponsored research projects on lost foam technology.

## THE MARKET FOR LOST FOAM CASTING PROCESS IN CHINA

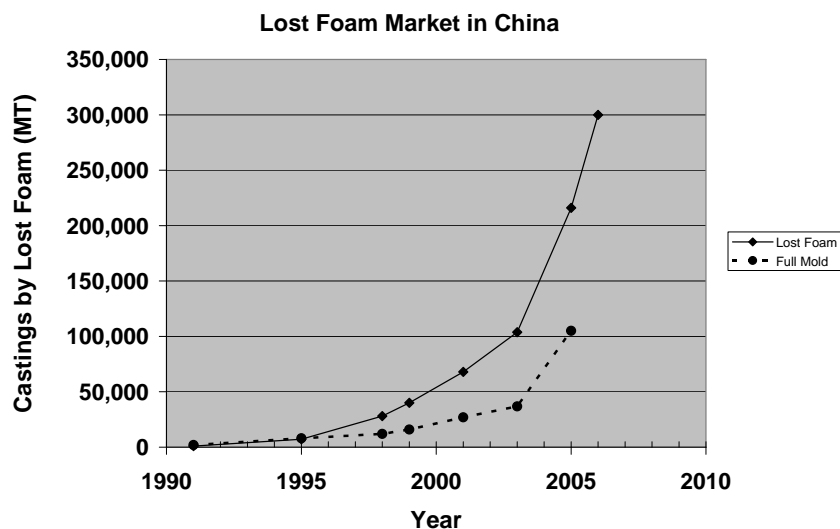
### MARKET SIZE

According to the survey by the CFA Full Mold Casting Committee and the China Lost Foam Society, it is estimated that two hundred foundries have lost foam casting operations in China with total casting production of about 216,000 tons per annum in 2005.<sup>1</sup> Total castings produced by lost foam are estimated as about 300,000 tons in 2006.<sup>2</sup>

**Table 1. Production Of Castings (Ton) by Lost Foam Process in China from 1991 To 2006<sup>1,2</sup>**

Year	1991	1995	1998	1999	2001	2003	2005	2006
Lost Foam	300	7,200	28,000	40,000	68,000	103,800	216,000	300,000
Full Mold	2,000	8,000	12,000	16,000	27,000	36,800	105,000	n/a

Table 1 shows the tonnage of castings made in the lost foam process in China since 1991. Casting production from full mold process at the same time period is also listed. There has been a tremendous increase (300 tons in 1991 to 300,000 tons in 2006) in production of castings by lost foam technology. This is also shown in Figure 1. The increase in tonnage in the past fifteen years is exponential.



**Fig. 1. Lost foam casting production growth in China, 1990 to 2006**

Major lost foam foundries are medium-sized and small-sized foundries.<sup>1</sup> Many of them are private companies, while state-owned operations still dominate the whole foundry industry in China. Prior to 2003, two-thirds of lost foam foundries produced less than 2,000 tons of castings per year, and about half of lost foam foundries produced no more than 1,000 tons of castings per year. In recent years, the foundry industry in China has been under reconstruction as its macro economy has become more and more market oriented and more competitive. Some lost foam foundries, especially those small operations established by private investors with the perception of low initial investment on lost foam process, have been closed due to unexpected technology challenges and the consequential financial difficulties. At the same time, some lost foam foundries have gained significant improvement in this technology and have expanded their lost foam operations. In 2005, twelve foundries reached production of more than 8,000 ton castings per year by lost foam process respectively. In 2006, four foundries have individually achieved the annual production of more than 10,000 tons of castings by the lost foam process. In 2007, FAST Group (hereafter referenced as Group B) built a brand new lost foam operation with the capacity of 20,000 tons of castings per year and will have its capacity doubled by 2009. In contrast, the number of lost foam foundries with annual

production of less than 1,000 tons of castings decreased to less than 15% of all lost foam foundries in 2006. In the past ten years, China has experienced extraordinary improvement in lost foam technology including equipment, tooling, materials, casting design, process control, and personnel training. The whole foundry community has gained more confidence with this new technology. Several state-owned large foundries are either building, or evaluating the feasibility of building, lost foam operations for mass production of castings.

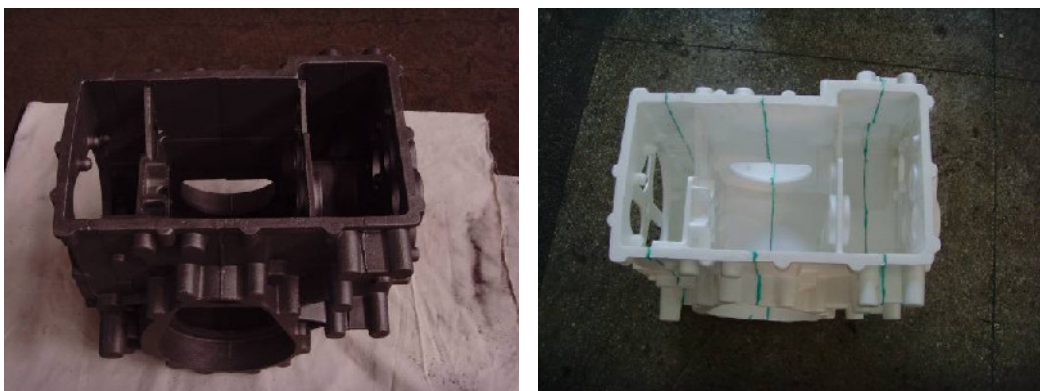
Although China is the largest exporter of castings to the United States, more than 90% of castings manufactured in China are consumed in domestic market.<sup>3</sup> This statement also holds for castings produced by the lost foam process. The driving force for development of lost foam technology in China is from the challenge inside the Chinese foundry industry. The expansion of lost foam operations is also due to the increasing demand from the Chinese domestic market. In fact, castings manufactured by the top ten lost foam foundries in terms of tonnage are almost all machined and assembled into the final products sold in China. The above mentioned large state-owned foundries, which are seeking to build new lost foam operations, intend to cast parts by lost foam for domestic consumption only.

## CASTINGS MADE BY LOST FOAM PROCESS

The lost foam process is described as best suited for mass production of castings with complicated design features that cannot otherwise be made by other processes. This appears to be true in developed countries such as in the United States and several European countries where there exist lost foam operations. Lost foam process has been successfully utilized to manufacture aluminum engine blocks and heads for automobiles and marine boats in mass production in the United States. Those parts are indeed designed exclusively for the lost foam casting process. The advantages of the lost foam process have been demonstrated to the world foundry community by these successful operations. In China, lost foam technology development has shown the virtues of this process from a somewhat different perspective. In China, the lost foam process is used mostly for iron and steel production. It is used to cast a variety of parts, from relatively simple castings to those with complicated features. In addition, it has been applied to different operations including mass production, jobbing, and even prototyping.

The metals cast by the lost foam process in China are mostly iron and steel. A survey conducted by the China Foundry Association Full Mold Committee<sup>1</sup> in 2003 showed the breakdown at 90.5% for iron, 9.4% for steel and 0.1% for aluminum. This statistic in 2005 has changed to: 86.3% for iron, 13.6% for steel and 0.1% for aluminum. Although this statistic included both lost foam and full mold processes, it is still a fairly accurate estimate of the relative percentages of metals cast by the lost foam process in China. The lost foam process is predominantly applied to iron; but its application to steel is increasing.

Various castings have been manufactured by the lost foam process in China.<sup>4</sup> According to a summary from the China Lost Foam Association in 2006, the top three most popular castings produced by lost foam process in China are: grey iron box-type castings, ductile iron valves and fittings, and alloyed steel parts. Figure 2 shows a grey iron gear box cast by lost foam process from Heli Group (hereafter referenced as Group A). The dimensions are 480 X 450 X 360 mm and weights 75 kg. It has a very complicated design which would be very difficult to be cast by other processes, if not totally impossible. Another example is a grey iron transmission box for heavy trucks from Chenggong Group, with dimensions of 1025 X 583 X 595 mm and a weight of 320 kg.

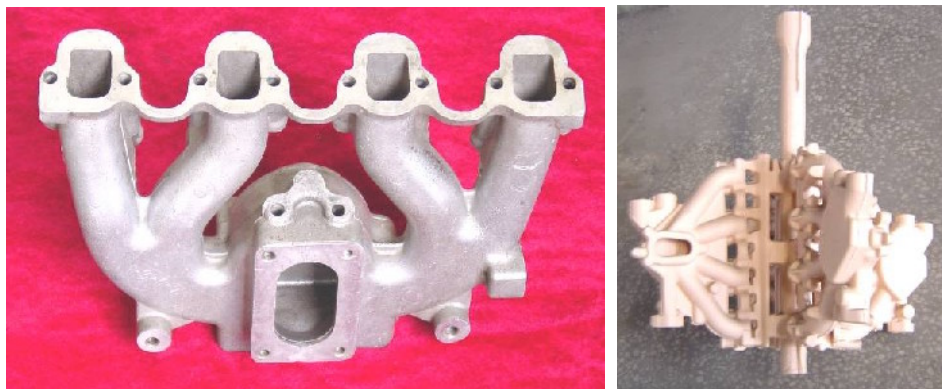


**Fig. 2. Casting (Left) and foam pattern (Right) of a gear box produced by Group A, (Courtesy of Hongchao Sun, Heli)**

Valves and fittings/connectors are the second largest market for lost foam technology in China.<sup>4</sup> There are approximately 40 lost foam foundries in this business in China. The largest valve made by lost foam is DN1200 with a weight of 900 kg. As China economy continues to grow, this market will continue to expand in its infrastructure modernization.

Lost foam applications for steel castings have been growing even faster than iron in China in the recent five years. Castings include high-alloy steel forging molds, alloyed steel cages for high temperature applications such as in heat treatment furnace, anti-abrasion parts, etc. As lost foam technology advanced, the steel casting market is expected to grow faster than iron in China.

Lost foam applications for aluminum in China is limited. First Automobile Works (FAW) had successfully used the lost foam process to produce aluminum castings for intake manifolds for passenger cars since 1992. The casting and foam patterns can be seen in Figure 3. The thinnest wall measures only  $4 \pm 0.5$  mm. The material is ASTM6876 (319) aluminum alloy. About 400,000 of intake manifolds had been manufactured before this product went to the end of its life cycle as auto engine design was changed. FAW is the only major auto maker in China that has stepped into making aluminum parts by lost foam process.



**Fig. 3. Casting (Left) and foam patterns (Right) of an aluminum intake manifolds produced by FAW, (Courtesy of Zhenjia Xia, FAW)**

Lost foam technology has also been widely used for art castings in China, following its origin when it was first developed in the US.<sup>5</sup> Aluminum, bronze and iron are popular for usage in this market. Although the absolute market value is limited, the technical challenge is even higher than mass production in industry. A competition on lost foam art castings was held several years ago by the China Lost Foam Association. The big bell in Shenzhen stock exchange market, one of the only two stock exchange markets in China, was made from the lost foam process.

Prototyping is another big application of lost foam technology in China, although this application is not normally presented to the lost foam industry. In fact, prototyping has been carried out to make tooling for foam patterns for lost foam process.

As mentioned above, the full mold process has a big market share in China. Forging molds or dies is the largest application for full mold castings.<sup>6</sup> These castings normally are big in size and are high value added. As the domestic automobile market grows in China, demand for these castings increases at a double-digit percentage rate. China is the third largest automakers in the world, following the United States and Japan. China manufactured 5.85 million automobiles in 2005 and 7.2 million in 2006. The demand for castings of forging molds or dies was 110,000 ton in 2005, only 50% to 60% were produced in China. It is predicted that automobile production in China will be 10 million units in 2010. The corresponding demand for castings of forging molds or dies will reach up to 200,000 ton in 2010.

## **INVESTOR'S OPINION**

Lost foam technology has been promoted by the Chinese government as an alternative “green” casting process in hope of reducing pollution that can come to the environment from the casting process. The most attractive feature of the lost foam process for investors is its relatively lower investment compared to conventional sand casting and other processes. The complicated equipment for core and mold making for sand casting are replaced by foam molding and gluing machines which are cheaper. In addition, sand reclamation is easier for the lost foam process than that for sand casting. Foam molding and gluing are labor intensive. Foam molding and gluing machines are manually operated in many lost foam foundries in China. This is an additional advantage of the lost foam process for China. Although the economic advantage of the lost foam process is achieved only if the quantity of castings poured reaches an adequate amount, quite a lot of investors jumped into lost foam casting industry just because of the lower initial investment for equipment. A lot of these investors were fortunate and

successful, as can be seen in figure 1 by the rapid increase in casting tonnage by the lost foam process in recent years. This has been beneficial to the advancement of this technology in China since its early development stage. As the whole industry has been gaining confidence with this technology, some investors are expanding their lost foam facilities and several more investors are planning to apply this process for mass production. But some investors were less fortunate, they failed completely when they found out that they could hardly produce qualified castings because they had not acquired the most advanced knowledge on the technology itself and they are even more in need of experience on process control.

It is interesting that none of the lost foam foundries in China are partially or wholly owned by foreign investors although a lot of foundries owned by foreign investors have already been well established in China.

## THE PRESENT STATUS OF LOST FOAM TECHNOLOGY

### EQUIPMENT

Equipment currently in operation in lost foam foundries in China are at various levels, from the simple, manually operated, to the top-quality, automatically operated, with sophisticated features. This just reflects the current status of the lost foam industry and the whole foundry industry in China. Equipment innovation is a critical part of lost foam technology development.

Fully automatic batch type pre-expanders were developed in China in 2005 for foam bead pre-expansion. Steam is used for bead pre-expansion. Novel design provides even heating on foam beads. It can be used for EPS, EPMMA and co-polymers. Productivity of the pre-expander is 20 to 30 kg/h. Density of pre-expanded beads can be controlled to  $\pm 1\%$  accuracy. One lost foam foundry in China developed its own fully automatic foam bead pre-expander, using an electric heating system replacing the complicated steaming system. Pre-expansion of beads is 40 to 60 times as the original volume.

Most of the foam molding machines for pattern blowing in service are designed and manufactured in China. More and more lost foam foundries have adopted fully automatic models with hydraulic operation systems becoming more affordable. Some foundries are still using the semi-automatic or manually operated foam molding machines with screw driven systems. Vertical operation mode (horizontal parting line) is the most popular, especially for small foundries. Vertical parting molding machines are operated in a few large lost foam foundries for mass production; one example is the casting shown in Figure 2.

For sand filling and compaction, the compaction table probably is the most critical piece of equipment. Several domestic suppliers in China have been involved in developing compaction tables specifically for the lost foam process. The challenge is to compact the sand particles tightly enough inside the cavities of foam patterns without causing too much deformation. One patented technology is the so-called "compaction table with circular motion".<sup>7</sup> It is claimed that three dimensional vibration is achieved by using circular motion along the X- and Y-axis vertically and that along the Z-axis horizontally. It is also claimed that the driving motor is separated from the table top so there is no moving of the motor itself, which would eliminate resonance to reduce the deformation on foam patterns.

Automatic flask handling and pouring systems can be designed, manufactured and installed by several Chinese equipment suppliers, including sand filling and compaction, pouring stations, sand cooling, sand reclamation, and casting parts cleaning. A mechanical or conveyor transportation system is the predominant operation mode. It offers reliable operation with flexibility of process control at a reasonable cost. Current production lines in operation can pour up to 10,000 tons of casting per year. Figure 4 shows two lost foam production lines, one is at Group A with annual casting capacity of 5,000 ton and another at Group B with annual production output of 10,000 ton.

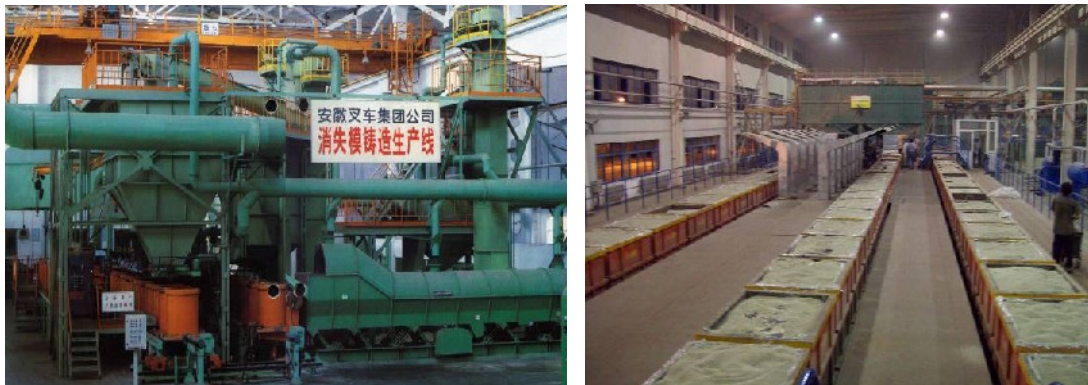


Fig. 4. Lost foam production lines at Group A (left) and at Group B (right)

## TOOLING

Traditional work flow of tooling manufacturing is as follows: design mold based on casting and get the 2D drawing of molds; make wood molds; pour mold parts by sand casting, machine; finish and repair mold parts. This process takes a long lead time to get the finished tooling. The precision of tooling can be limited.

Several top tooling suppliers have adopted the rapid prototyping method for tooling. A 3D design of tooling is first developed using CAD software. Computer files of the tooling design are transferred to the prototyping machine and molds are made in the prototyping machine in several hours. Prototyped molds can be sand, wax, layered paper, plastic, or sintered metal powder, depending on the prototyping method. Castings for the tooling are then made from the molds and machined. Prototyping method can greatly reduce the lead time for tooling. The lost foam process has been demonstrated as a good method to manufacture tooling for the lost foam process itself! A foam pattern can be machined by a digitally controlled machining center based upon the CAD file of tooling design. The foam pattern is then used to pour the mold casting by the lost foam process.

This research has shown that tooling is the part of the whole process that has adopted the most advanced technologies in the lost foam casting industry in China. CAD/CAM is widely used for tooling design and manufacturing.

## CONSUMABLE MATERIALS

The material used to produce foam patterns was expandable polystyrene (EPS) for packaging in the early stages of lost foam process development. Because the lost foam process is mostly used for iron and steel castings in China, carbon related defects became a big concern for lost foam foundries. Development work on foam materials for the lost foam process started in the 1990s. Now several companies can provide foam materials developed exclusively for the lost foam process, including EPS, expanded polymethyl methacrylate (EPMMA), blends of EPS and EPMMA, and certain copolymers such as styrene-methyl methacrylate copolymer (StMMA). A patented copolymer foam material (StMMA) from a Chinese supplier is sold in the Chinese domestic markets and exported to Korea, Europe, and the United States.

A wide variety of glues are used to join two or more molded foam sections together to form the foam pattern in China: one-part cold glue, two-part cold glue, one-part hot-melt glue, etc.<sup>8</sup> Modified polyvinyl acetate (PVAC) and polyacrylate/epoxy emulsions are the two most popular cold glues for the lost foam process. Hot melt glues include polyethyl vinyl acetate (EVA) and polyamide (PA) based formulations. A study in China has shown the possibility to use recycled EPS as the primary material to formulate cold glue and hot melt glue for foam assembly. This has great implications in terms of enhancing glue compatibility with EPS foam and reducing EPS waste. Cold glues are used more often than hot melt glues. Gluing remains a mostly manual process in China, with automatic machines only used in some foundries.

Coatings are critical to the lost foam process. It is estimated that about 60% of casting defects are coating related for the iron and steel lost foam process in China. Some lost foam foundries have imported coatings from a major supplier in the United States. These imported coatings are mostly in powder form. Foundries mix the powder coatings with water to the desired viscosity at high shear speed before application. To reduce the time for transportation and lower cost, a major US supplier has established a new facility in China to manufacture lost foam coatings for customers in China. Several domestic manufacturers can supply lost foam coatings, mostly in powdered form, to reduce transportation cost. Improper use of powdered coatings remains a serious issue for lost foam foundries. Lack of quality control on the mixing of powder coatings with water in foundries results in large variation in coating properties, and thus generates high scrap rate of castings. A lot of lost foam foundries are still making coatings in house. The advantages of making coatings in-house include lower cost, ability to quickly adjust coating properties in response to processing variation, and short logistics. But in most cases, lost foam foundries lack of the ability of developing right coating formulations for the process. They get the so-called standard formulations from equipment suppliers or other sources, but the formulations might not be a good fit to the process. Inadequate quality control on coating manufacturing is even more problematic. For iron lost foam casting, when using domestically made coatings, the coatings have to be applied at least twice to yield a final thickness between 1.5 to 3.0mm. In comparison, some imported coatings need only to be applied once, yielding dry thickness less than 1 mm, and its performance surpasses the domestic brands and those made in-house. It is a common practice to use high vacuum level (0.02 to 0.07 MPa) in the flask in order to assist the generated gas during pouring to pass through the coating layer and compacted sand. A plastic film normally covers the top of the sand in the flask to facilitate this operation.

Silica sand is the most popular filling media for compaction due to its low cost. Its performance is acceptable for most iron lost foam foundries. Synthetic mullite is used in a few foundries as filling medium for steel lost foam castings. Olivine has been successfully used as filling sand and as refractory materials in coatings for high-magnesium steels and alloys. Practice in lost foam foundries in China has shown that olivine sand has 6 to 8 times longer longevity than silica sand. No free silica in olivine sand is another benefit to operators.

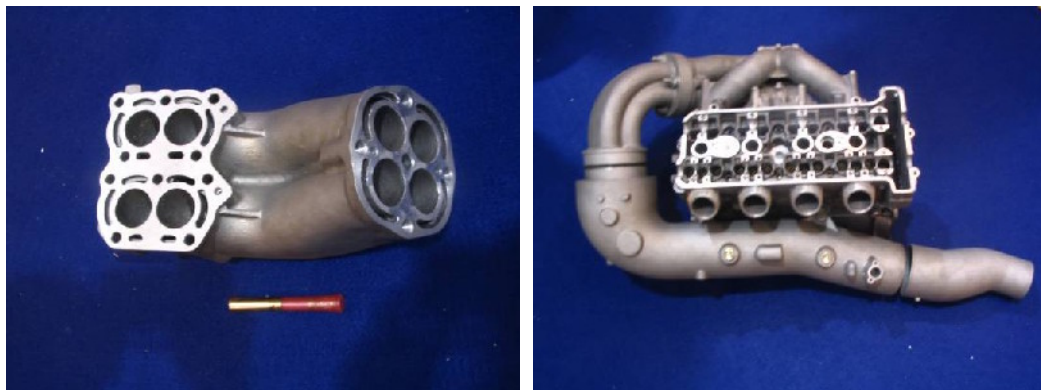
## PROCESS CONTROL

Process control is always a challenge for engineers in lost foam foundries anywhere in the world. It is even more challenging for some lost foam foundries in China where tremendous variations can come from manually operated equipments and under-qualified consumables.

## THE FUTURE OF LOST FOAM CASTING TECHNOLOGY IN CHINA

China lost foam technology has passed its own forty-year history of development. This promising technology has been maturing in China, especially for iron and steel casting. All the equipments, tooling, raw materials and consumables are available and can be produced in China. China has established some advantages in the lost foam casting process in iron and steel, considering the fact that minimal investment has been put into this technology. This has provided enough confidence for investors to increase their investment in this process. Castings made by lost foam are only about 1.2% of the total castings produced in China in 2006. As more large state-owned foundries are investing in lost foam operations or are planning to adopt or expand lost foam operations, there would be an steady increase primarily in iron and steel castings by lost foam technology in the coming years.

Although aluminum castings made by the lost foam process are very limited in quantity in China due to technical difficulties in aluminum lost foam process in mass production, there have been significant advancements in aluminum lost foam casting technology in China in the past three years. One primary driving force is the increasing application of aluminum castings in cars and trucks. Figure 5 shows an aluminum exhaust pipe made by lost foam process. The scrap rate for this part is less than 10% in pilot production. It appears that China's lost foam community is making solid progress in aluminum lost foam technology. It would not be surprising that there is a tremendous increase in aluminum castings produced by lost foam process in the next several years in China.



**Fig. 5. Aluminum casting made by lost foam process, (courtesy of Shengping Ye, HUST). Left is part of the exhaust pipe, right is the assembly of exhaust pipe attached to engine head.**

There will be an increasing demand for equipment and consumable materials for the lost foam process. Upgrading of outdated equipment in current lost foam operations is occurring to increase the productivity and capacity. More lost foam foundries will be built in the coming years as this promising technology becomes mature. In addition, as Chinese government regulations on health, safety and environmental protection become increasingly strict, lost foam foundries, will adopt more and more state-of-art equipment and safer consumable materials so they meet or fall well within safety guidelines for foundry operations in China.

## SUMMARY

China's foundry community is a pioneer in lost foam casting technology development and has established advantages in the iron and steel lost foam casting process. The market for the lost foam process will continue its rapid growth in iron, steel and aluminum in China.

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