Development, Application and Problem of Ductile Iron Lost Foam Casting Technology in China

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Lost-foam casting is a 21st century green casting technology. Over the past decade, there has been an extraordinary development in lost-foam casting in China; and ductile iron lost-foam casting has developed even more rapidly in foundry equipment, foundry raw materials, and casting engineers. There are 13 representative enterprises specializing in the production of ductile iron castings in China, which are listed in Table 1.

Table 1: Business information about China's ductile iron lost-foam casting

No.	Company name	Production status (tonnes per year)
1	Shanxi Huaen (Group) Co. Ltd.	3,000 (Auto parts)
2	Taojiang Xinxing Pipe Fittings Co. Ltd.	20,000 (Casing pipe)
3	Mill and Roll Factory of Wuhan Steel Co. Ltd.	1,000 (Auto parts)
4	Yancheng Zhongyu Casting Co. Ltd.	20,000
5	Maanshan Fuchuang Metallurgy Co. Ltd.	3,000 (Auto supporter)
6	Zhonghengtong (Fujian) Machinery Co. Ltd.	5,000 (Speed reducer)
7	Yangcheng Huawang General Centrifugal Casting Pipe Co. Ltd.	2,000 (Casing pipe)
8	Tangshan Chenqi Auto Parts Co. Ltd.	3,000
9	Jiaxin Auto Parts Casting Co. Ltd.	1,000 (Auto shell)
10	Loudi Modern Investment Casting Co. Ltd.	1,000 (Casing pipe)
11	Henan Xingyang Machinery Co. Ltd.	1,000 (Auto shell)
12	Jiangxi Fenyi Drive Axle Co. Ltd.	1,000 (Auto supporter)
13	Shiyan Famous Industry Development Co. Ltd.	3,000 (Auto shell)

According to incomplete statistics, the annual production capacity of ductile iron lost-foam castings in China is about 77,000 tonnes. Thirteen (13) ductile iron producers in Table 1 hold the highest level of ductile iron lost-foam casting production technology in China. The annual production volume for most of them is in the range 1,000 to 3,000 tonnes per year, except for Taojiang Xinxing Pipe Fittings Co., Ltd. and Yancheng Zhongyu Casting Co. Ltd, which both produce over 10,000 tonnes per year. On the whole, they belong to the category of small-scale business enterprises. The authors in the article visited dozens of ductile iron lost-foam casting enterprises. We found that LFC in China has been greatly developed in ductile iron, with a 2:1 ratio of grey iron to ductile iron. The production volume of ductile iron castings will have the trend of continuing growth with a down-trend in grey iron castings. Ductile iron lost-foam casting production in China is already No.1 in the world. The following explores the application and existing problem, from three aspects, in the production of ductile iron lost-foam castings in China.

1. The choice of foam materials in LFC

The key to LFC is producing a high-quality foam pattern, and the key to a high-quality foam pattern is high-quality foam beads. The most widely used LFC pattern material is expanded polystyrene (referred to as EPS). Firstly, because the gasification of low-density EPS is rapid, gas evolution is small, and it can be easily formed without using a high vapor pressure. Secondly, because EPS raw material is plentiful, EPS is relatively inexpensive. However, EPS has significant drawbacks. The formula EPS can be expressed as $(C_6H_5 \cdot C_2H_3)_n$, which contains a large amount of thermodynamically stabe the carbon-rich benzene ring structure, and carbon content of up to 92%. Not only that, the pyrolysis of EPS is disorderly and slow fracturing, and it is easy to form a solid pyrolytic carbon residue, resulting in lost-foam casting defects such as pores and flow marks.

In 2001, Castchem (Hangzhou), Inc. successfully developed a LFC–specific copolymer material, and has applied for United States and China patents (US 6770681 B2, CN 1422878A). This copolymer material (its name is shortened to STMMA) is made of 30% styrene and 70% methyl–methacrylate (carbon content of 69.6%). Compared with EPS, STMMA has significantly lower carbon content. STMMA contains oxygen, which is able to further reduce the amount of residual carbon by combining with carbon atoms. STMMA also has good formability and steady pouring property. So far, it has been widely used in over 30 companies producing ductile iron castings. Castchem's STMMA has great effect in reducing the defects in ductile iron castings, such as the surface carbon defects, flow marks, and carbon inclusions. Figure 1 shows serious flow mark defects for general EPS production; Figure 2 shows high quality castings produced by Castchem's STMMA under the same production conditions.

Table 2 lists the comparison between Japanese STMMA and Chinese STMMA in terms of basic performance indicators.

The comparison between Japanese STMMA and Chinese STMMA in terms of the original bead particle sizes and uniformity is shown in Figs. 3 – 6.

Fig. 1: Flow mark pipe (EPS)

Fig. 2: Fine pipe (STMMA)

Table 2: Comparison between Japanese STMMA and Chinese STMMA in terms of basic performance indicators

	Foaming agent (%)	Moisture (%)	Maximum magnification	Apparent density (g·cm^{-3})	Average molecular weight (ten thousand)
Chinese STMMA	9	0.3 – 0.6	90	0.540	20 – 25
Japanese STMMA	8	0.85	89	0.625	28 – 29

Japanese STMMA beads are moist, transparent and smooth. After pre–foaming, the beads are very soft, a little deflated and less flexible. With a similar density, Japanese STMMA appears of poorer strength than Chinese STMMA, but the material surface finish of the Chinese STMMA is not as good as the Japanese material whose surface quality is expected close to EPS. So, the fusion characteristic of Japanese STMMA is better than Chinese STMMA, see Figs.7 – 8.

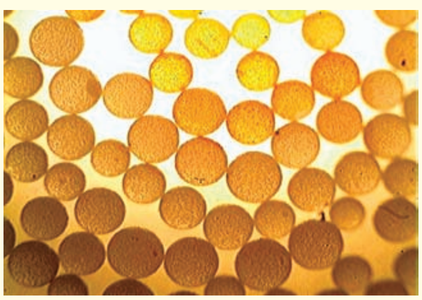

Fig. 3: Original beads (Japanese)

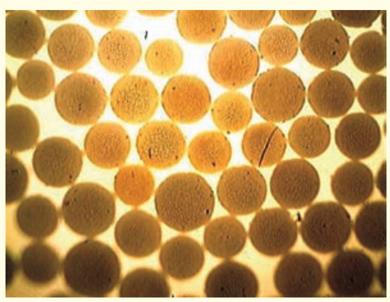

Fig. 4: Original beads (Chinese)

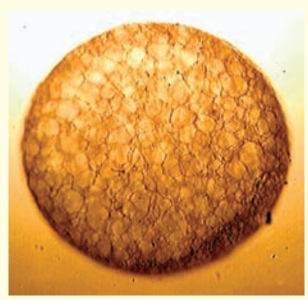

Fig. 5: Bead surface after pre-expansion (Japanese)

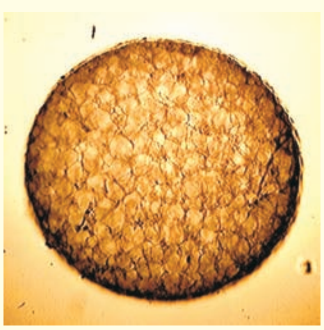

Fig. 6: Bead surface after pre-expansion (Chinese)

Fig. 7: Surface finish of foam pattern (Japanese)

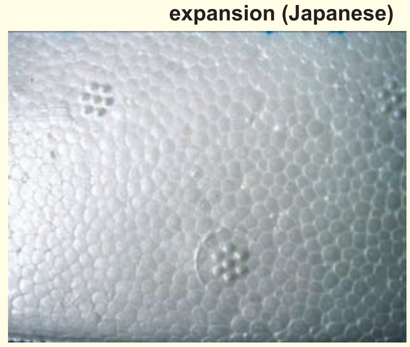

Fig. 8: Surface finish of foam pattern (Chinese)

Figure 9 shows the foaming magnification contrast (foaming temperature of 120 ℃) and Figure 10 shows the thermal gravimetric analysis.

Table 2 and Fig. 9 show that the blowing agent content and the largest foam magnification of Chinese STMMA are similar to Japanese STMMA. Although the former has a faster rate of foam expansion, decay rates are almost the same, so pre–expansion and molding characteristics of Chinese STMMA is similar to Japanese STMMA. As can be seen from Fig. 10, the thermal decomposition characteristics of the Japanese STMMA and Chinese STMMA are almost the same with similar end and initial decomposition temperatures, and the decomposition rates of each temperature range are almost the same. Therefore, the material properties of the STMMA produced by Castchem (Hangzhou), Inc. are similar to the Japanese STMMA.

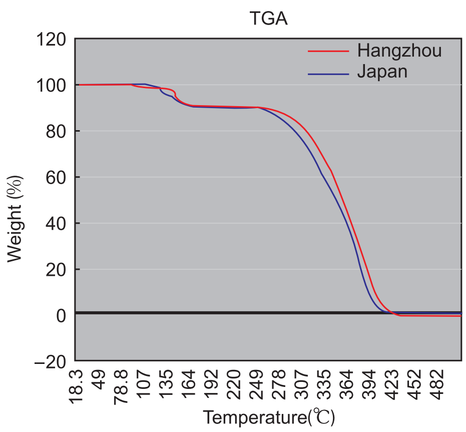

Fig. 9 Foaming magnification contrast

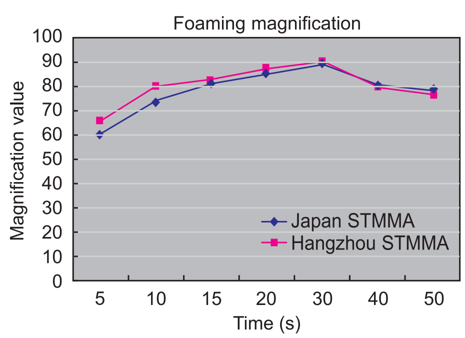

Fig. 10 Thermal gravimetric analysis contrast

2. Cases of small- and medium-sized ductile iron lost-foam castings

Lost–foam casting with dry unbonded sand and vacuum is more suitable for the production of medium–sized castings with complex structure and small parts with simple structure. The auto speed reducer shell and differential case (QT450–10) cavity is more complex, and a sand core is needed for ordinary sand casting. These have been successfully mass–produced by using LFC in China, see Figs. 11 – 12.

Fig. 11: Foam pattern and ductile iron casting of differential case

Fig. 12: Foam pattern and ductile iron castings of speed reducer shell

The ductile iron supporter embedded in high–speed rail and turnout cover (Figs. 13 – 14) requires high surface finish, which is favorable for the improvement of corrosion resistance. With ordinary sand casting it is very difficult to meet this surface quality requirement. Investment casting is able to do it, but the damage to the mold caused by the expansion of ductile iron must be considered; and it is also expensive. The weight of supporter made of ductile iron QT450–10 is only 1 kg, while the turnout cover only weights 0.65 kg. For such small parts, the production efficiency is very low using ordinary sand casting, and the percentage of pass is low. But it can be greatly improved by using a string casting process of lost–foam casting. 208 turnout cover

Fig. 13: Assembled foam patterns with coating and castings of turnout cover

Fig. 14: Foam pattern and castings of supporter

castings can be produced in a flask by this method, with a percentage of pass of 79 %; 60 supporters can be produced in a flask, with a percentage of pass of 75%.

3. Problems of ductile iron lost-foam casting

3.1 Lower level of nodularity

For ductile iron lost–foam casting manufacturers, the production technology of ductile iron castings is no longer the obstacle. Generally, the nodularity can reach Grade 3, a few reach grade 1 or 2. Through an intensive inoculation, the size of nodular graphite can be controlled to be small, generally up to class 5 or 6, even class 7 or 8 for high elongation ductile iron; but there are still some difficulties for the production of the type of ductile irons, such as QT400–18. Only a few domestic enterprises can produce it using the LFC process. The main problem is that the nodularity is low, and the graphite spheroids are not round enough, which make the elongation lower. Most companies use the pour–over process in a spheroidization process which is simple and quick, but has a low rate of absorption of magnesium.

3.2 Typical casting defects

The general problems of ductile iron lost–foam casting are the flow marks and carbon inclusions. LFC always uses foam which contains carbon, whether it is EPS or STMMA. The presence of carbon is a great obstacle for ductile iron lost–foam casting. In the process of pouring, most of the pyrolysis product of the foam pattern has been drawn out of the cavity under the action of vacuuming, while a small amount of this product still remains in the mold. The pouring temperature of ductile iron lost–foam castings cannot be as high as for steel castings; otherwise there will be a serious decaying in the spheroidization process. So, it will not get as complete gasification as steel casting. At the same time, ductile iron with high carbon content, generally more than 3.6 %, cannot absorb the excess carbon, so the carbon from the foam can only be left on the surface of the castings which leads to flow marks, as shown in Fig. 15. Similarly, carbon inclusions are also due to the involved pyrolysis product left in the castings which neither be successfully discharged out of the cavity, nor be absorbed by the ductile iron with a high carbon content. Finally, carbon inclusions form by carbonization of foam in the product, as shown in Fig. 16.

Fig. 15: Flow mark

Fig. 16: Carbon inclusions