Analysis of reasons causing riser feeding failure in nodular iron castings production

ZHOU Gen

(Wuxi Diesel Engine Works, Jiefang Automobile Co. Ltd., China First Automobile Group, Wuxi 214026, P. R. China)

Abstract: In addition to mold rigidity and metallurgical quality of iron melting, the main reasons causing riser feeding failure in nodular iron castings production are: (a) open and cold metal flowing-over risers were adopted; (b) riser location was not proper; (c) riser was too small or not enough high; (d) ingates did not freeze up instantly as soon as pouring finished; (e) there're isolated hot spots in the casting which are not connected with feeding channel of the riser; (f) the feeding channel of castings with small size and thin sections is too narrow for feeding liquid to enter casting; and so on.

Key words: nodular iron; shrinkage; feeding

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1 Introduction

It is clarified by reference [1] that, in order to avoid shrinkage defects, a nodular iron casting must be fed from an outside feeding source in addition to use graphitization expansion to compensate it for its volumetric contraction. Because the feeding capacity of gating system is much lower than that of the riser, the mold conditions and other process condition requirements for riserless foundry method are more strict than that of the riser feeding method. Therefore, the riser feeding foundry method is usually the main method in nodular iron castings production till now. But there are also many failure instances in application of riser feeding method, and to analyze reasons causing these failures will be helpful to correctly design foundry method for nodular iron castings.

According to author's practice, besides rigidity of the mold, chemical composition, metal melting and treating process, the reasons causing riser feeding failure were summarized as follows.

2 Using open and cold metal flowing-over risers caused shrinkage defects

Many reports gave typical cases to show that shrinkage defects of some nodular iron castings were not avoided by riser feeding, but could be eliminated only by adopting riserless method. As showed in Fig.1 by reference [2],

when the casting was cast in green sand mold with a large riser on the top of casting (Fig.1A), shrinkage cavity occurred at riser area of the casting, and when the casting was overturned and cast in dried sand mold, with a heavy section chill on its bottom surface and without riser, the shrinkage defects was eliminated, so the writer considered that producing the casting in dried sand mold without riser is the only way to obtain sound castings.

ZHOUGH Ge: Male, born in 1937, senior engineer, being engaged in the research on the nodular iron production and application technology.
E-mail: yyj@wxdew.com

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The typical case of Fig.2 was showed by S. I. Karsay. There are shrinkages in the casting cast with riser feeding method (Fig.2 left), but sound castings were obtained by changing the method into the riserless method (Fig.2 right).

In another case showed in Fig.3 by reference [4], a large nodular iron flywheel casting had serious shrinkage at the riser neck area of the casting when the casting was cast in furan resin sand mold with annular gating system, a large cold riser with flash-neck (thickness of flash-neck was 10 mm) and chills at the top and the bottom, and the problem was solved only when the riser was removed.

Forty years ago, when various nodular cast iron gear wheels were trial-produced at Wuxi Diesel Engine Works (WXDEW), there were serious shrinkage defects in riser neck areas and gating areas of castings, when the gear wheels were cast with cold riser as showed in Fig.4 and Fig.5. The dimensions of risers and the types of gating system had been changed several times, the problems were still never solved; and the bigger were the risers, the more serious were the shrinkages. At last, the shrinkage defects were eliminated when adopting a gating through hot riser on the top of the boss, as shown in Fig.6.

Compared with the method in Fig.6, it is easy to see that the failures of riser feeding methods showed in Fig. 1-Fig.5 are caused by the same reason as following:

1. Adopting open riser, which leads to relaxation of graphitization expansion pressure, and is not favorable to use the expansion to compensate casting for its volumetric contraction;

2. Cold metal flowing-outer risers were adopted, and as a result, liquid metal first enter the mold cavity and then come from mold cavity into the riser, thus the temperature of liquid metal in the riser is always lower than that in the mold cavity, so the riser is called as ‘cold riser’, which usually solidifies earlier than the casting, and sucks liquid metal from the casting, so causes shrinkage in the casting.

In order to solve problem, some method engineers attempted to reduce the solidification rate of the riser and increase its feeding capacity by increasing the size of riser, but the bigger the cold riser, the more the liquid metal passing through the mold cavity, and the more severe overheated is the mold cavity, whereas temperature of the riser is still lower than that of the mold cavity, thus the shrinkage defects even increase. Adding some hot liquid metal into the open riser as soon as the pouring stopped is often considered as a way to increase the temperature of cold riser, however, because only a little quantity of liquid metal can be added to the riser, the temperature of the riser is still lower than casting, the mold cavity overheating still can not be avoided, so the shrinkage problem can not be solved yet. It was a typical case that from 1983 to 1998, WXDEW had adopted exactly such a method to produce 6110 cylinder head which is to be cast with vermicular iron having shrinkage tendency quite
similar to nodular iron, the problem of shrinkage and blowhole-shrinkage could never be solved, and the rejection ratio had been always higher than 20% for about 15 years.

The method showed in Fig.6 is quite a contrary to above described cold riser method: at the first the liquid metal from gating system enter the riser set on the top of the casting, then enter casting cavity of the mold from the riser, so the temperature of the riser is always higher than that of casting which makes riser have the feeding effect. Therefore, this type of riser usually called as 'hot riser' or 'hot feeder', which solidifies always later than the casting and can feed the hub of the wheel directly. Besides, as the spoke of the wheel has wide area for dispersing heat, when the liquid metal flows through the spoke to the rim area of the wheel, its temperature rapidly decreases, and, in addition, the top riser has relatively higher liquid pressure, so the shrinkage at the rim area usually can be prevented too.

With the desire to prevent shrinkage at the riser neck area of castings by reducing liquid metal suction of riser from casting, reference [6] suggested to use cold riser with thin neck or setting chills at the neck area of the cold riser to make the neck solidify quickly after pouring finished. However, because overheating of the mold cavity can't be avoided, the shrinkage can not be prevented yet. What showed in Fig.3 is exactly such a case.

According to author's practice [5], increasing venting area is not always an effective approach to solve blowhole and slag inclusion problem. It is taken by some method designers that increasing discharge of liquid metal from mold cavity can rise temperature of liquid metal in top area of the mold cavity, so is of benefit to expel gas and slag into riser, but practice showed that only the liquid metal in the limited area near the riser neck can be changed by increasing discharge, and the slag inclusions floating up to the top of the mold cavity always don't enter the riser as they desired, but stick to the top wall of the mold. In addition, even though the temperature in top area of the mold cavity can be raised by increasing liquid metal discharge from mold cavity to the cold riser, the originally higher temperature in lower part of mold cavity will be raised too and will become even higher, the situation that the temperature of top part is lower than that of lower part will be even more serious, so the result will be still that solid skin or slag forms at the top of the cavity first and prevent gas to be expelled from mold. Therefore, it is a waste of liquid metal at least to adopt cold riser, if there are no shrinkage in the casting.

The author's practice [5] shows that venting of mold cavity can not only rely on increasing venting area, but also should rely on the pressure of the liquid metal, and setting gating through hot risers on the top of the casting is the best way to increase the liquid pressure of the mold cavity. In order to prevent the shrinkage caused by cold risers, it is best to change them into venting holes, reduce number of venting holes and minimize their size as far as possible to reduce quantity of cold metal flowing off from mold cavity. In addition, it is better to use side venting holes instead of body venting holes, and the joining channels connecting venting holes and the casting should be as thin as possible, otherwise hot spot will form at the joining area, shrinkage and blowhole-shrinkage wouldn't be avoided.

3 Locations of risers were not proper

The foundry method shown in Fig.6 was used at WXDEW for producing a variety of nodular cast iron gear wheels for a long term, the quality of the gear wheels was stable at all times. However the method needs 3 flasks for making each mold, so it is not suitable for production on molding line. In order to adapt the method of Fig.6 to production on line and use only two flasks per mold, side riser showed in Fig.7 and kiss riser showed in Fig.8 were used. These two methods are used popularly by a majority of foundry shops at present, but the quality of the gear wheels was not very stable at all times, shrinkage still occurred from time to time at some locations of hub and/or rim area; even two risers were used for one casting and chills was set inside the hub, shrinkage still could not be eliminated. Because there is a ring-shaped hot spot inside the rim, which is too narrow and long for the feeding liquid to flow through, and the flowing direction of liquid from risers is indefinite (forward, leftward or rightward), the solidification sequence of the casting is disordered, so the feeding liquid can not be sent to everywhere it is needed. That is the reason causing shrinkage inside rim and/or hub. In addition, it was found by metallographic examination that, compared with other areas of the wheel rim, the graphite size is obviously larger and graphite count is obviously less in the riser area, which caused uneven distribution of mechanical properties along the wheel rim. The problem can be avoided by using the method showed in Fig.6.

In order to realize production on line and at the same time keep the method showed in Fig.6, the method showed in Fig.9 is suggested for producing multi-pieces of small gear wheels in one mold. For large size gear wheels, it...
necessary to set several arc-shaped kiss risers around the rim area and use sand core with chills or iron core to form the hub hole as showed in Fig. 10. With the purpose to increase process yield rate, an alternative method is to use a large size ring-shaped runner as the kiss riser. But compared with this method, the method of Fig. 10 has two advantages:

1) The mold can be filled uniformly, all parts of the casting will solidify synchronously, and pouring rate is easy to be controlled.

2) By adopting thin and wide section, ingates can freeze up immediately as soon as pouring stopped that can avoid relaxation of pressure generated by graphitization expansion and is favorable for preventing shrinkage.

The instances of Fig.6 and Fig. 11 showed that riser should be set on the hot spot to ensure the hot spot can be fed directly from it. For those castings which have multiple small hot spots or a thin and long hot spot (as the ring-shaped hot spot in the rim area of the wheel in Fig.6), if multiple risers could not be used, those hot spots that could not be fed by risers directly should be set far from the risers, letting the liquid metal flow to the hot spots after passing a long way to drop its temperature. Such a riser design will be helpful to eliminate or reduce shrinkage in those hot spots. If a casting has more than one large hot spot and one riser can not feed all of them, it is the only way to avoid shrinkage that each large hot spot is fed by its own hot riser as showed in Fig. 11C.

4 Riser is not big enough or/and not high enough

When riser is smaller than the hot spot of casting, it will solidify ahead of hot spot of casting, not only can not feed the casting, but instead will suck liquid metal from the hot spot of the casting. When the riser is not enough high, its liquid pressure will be relatively lower and can't drive liquid metal into the hot spot. Both two factors can result in shrinkage in the casting.

Reference [6] considered that a casting can be fed by a riser solidifying earlier than it, and too large riser would
cause shrinkage in the riser neck area of casting, whereas the author has different experience. For example, from 1957 to 1965, a large spheroidal riser with diameter of 200 mm and neck of 140 mm in diameter (see Fig. 12A) was used for the 4A110 nodular iron crankshaft which was poured horizontally and cooled vertically to increase feeding efficiency. Both the riser and the riser neck were far bigger than hot spot of the casting, shrinkage never was found in the riser neck area of casting. The reason can be explained as following: the ingate entering the riser was very thin, it freeze up soon after pouring finished; and, in addition, the sprue was blocked with a clay plug as soon as pouring stopped and before the mold was turned from horizontal position to vertical position, that makes the sprue freeze up also quickly, and, as a result, both riser and the casting were blocked together, preventing pressure of graphitization expansion to be loosen. As the riser and the riser neck are far bigger than hot spot of the casting, the latter solidities earlier and receives sufficient feeding from the riser. The disadvantage of the method is that the process yield rate relatively low, and the riser must be cut down by machine tool.

Since 1965 the test to reduce the size of the riser and riser neck had been conducted repeatedly for a long time. At first a column-shaped riser with diameter of 80 mm and neck with diameter of 40 mm as showed in Fig. 12B had been tested several times, there was always severe shrinkage at riser neck area of the casting. In another series tests, according to the empirical relational formula that the proper ratio of riser neck modulus /hot spot modulus should be 0.5 - 0.6, at first the diameter of the neck was fixed on 70 mm, the diameter of the riser was increased gradually, it was found that, to prevent the riser neck area from shrinkage, the diameter of the riser must be not less than 130 mm, i.e. some larger than the hot spot of the casting with diameter of 120 mm. Afterward, fixing diameter of the riser on 130 mm, the diameter of the neck was reduced gradually, the result showed that the neck should be not less than 65 mm to avoid shrinkage, but the riser was difficult to be knocked off. At last, by using knock-off core to shorten the length of the neck to 10 mm to reduce its cooling speed, the diameter of the neck was reduced to 55 mm (as showed in Fig. 12C), the riser could be knocked off with easy, and shrinkage at neck area was eliminated basically. However, whenever there was some fluctuation of process factors, shrinkage would occur again, the casting quality was not as stable as the case with large riser and large neck. For example, we had repeated such a experiment ten times that the addition amount of nodularizing alloy was increased from normal 1.2wt% to 1.4wt%, the crankshafts with both the riser of Fig.12A and riser of Fig.12C were poured with the same iron. As a result, no one casting with the riser of Fig.12A, but all castings with the riser of Fig.12C had shrinkage at riser neck area.

Since 1972 the process of "pouring vertically and cooling horizontally" is used no longer at WXDEW, all crankshafts are produced with the process of pouring and cooling in horizontal position. The diameter of large end of the 6110 crankshaft is of 112 mm, its riser diameter is of 120 mm, the neck diameter is of 55 mm, as showed in Fig.12D. There was still shrinkage at neck area occasionally. Experiments have proved that it is necessary for eliminating the shrinkage to increase the neck size that, however, would cause the riser knocking off to be difficult. At last, having no other choice but setting two arc-shaped thick chills on the top and bottom of the flange of the crankshaft to minimize its hot spot, only then the problem was solved. The above fact showed that the size of riser should not be smaller than hot spot of the casting and the neck of the riser should not be too small for preventing shrinkage.

5 There are isolated hot spots in the casting which were not connected with feeding channel of the riser

In the production of a variety of crankshafts, the author found that riser could feed centerline parts of every crank journal effectively, however, hardly had any feeding effect for corner areas on inner side of every crank. An experiment showed in Fig. 13 had been conducted that two 6110 crankshafts were cast simultaneously in one mold
(mold was made on HWS line) with riser-feeding method and riserless method respectively. It was found by dissecting the test crankshafts that there was no shrinkage at centerline parts of every crank journal of the crankshaft fed with riser, and every crank journal of the crankshaft with no riser had centerline shrinkage with size of Φ20-Φ30 mm. The experiment indicated that there is a liquid feeding channel running from the riser and through all crank journals of the crankshaft, and the result is just accorded with the computer solidification simulation which showed also that there is a last solidifying zone passing through the centerline area of all crank journals. For this reason, there would be no shrinkage in all hot spots the feeding channel passing through when the casting being fed with a suitable riser; and there would be shrinkage when there was no riser to feed the casting. Another fact was that magnaflux inspection of crankshafts in routine production often found that there is shrinkage at corner areas on inner side of cranks of crankshafts whether with or without riser. It indicates that there’re isolated hot spots in these areas which aren’t connected with feeding channel of the riser, so chills must be used at these areas to avoid shrinkage.

Fig. 13 Comparison test between two methods of 6110 crankshaft (moulding on HWS line)

It could be imagined that these isolated hot spots can present in some other castings. For example, if a wheel has thick rim and/or thin spoke, or biggish cast holes at the spoke, its spoke will freeze rapidly, isolated hot spots shall be in the rim. If this kind of wheel is cast with the method showed in Fig.6, chills must be set around the rim. Fig. 14 shows such an instance. A top segment of a piston, which has a wheel-like shape, is to be made with nodular iron. Its top is very thin, and its rim has a heavy section, so it is very difficult to avoid the shrinkage in the section of the rim. The casting had been produced on trial repeatedly with the methods similar to those showed in Fig. 7 and Fig. 8 at first, but no one sound casting was obtained. The succeed came at last only by using the method of Fig.6 and setting chills around the thick ring-shaped rim. The instance indicated that, in order to prevent shrinkage in isolated hot spot, using chills are often necessary besides riser feeding, but the number and size of chills can be reduced with riser feeding method compared with the riserless method.

Fig. 14 Casting drawing of a nodular iron top segment of an assembled piston

6 Ingate could not freeze up instantly after pouring stopped, and no ‘funnel pipe’ formed in riser top

It was reported by R W Heine that if open shrinkage cavity (he called it as ‘funnel pipe’) forms in riser top, there is usually no shrinkage at the riser neck area of casting. If the riser fails to pipe, but has a shrinkage cavity in its middle or low part, the shrinkage will extent into the riser neck area of casting, as a result, the casting will be rejected. In order to cause the riser to pipe, one of the key conditions is that the ingate should freeze up instantly as soon as pouring stopped, therefore ingate should be as thin as possible, secondly the shape of the riser should be in favor of freezing from the top to the bottom. Thus after pouring stopped, the ingate freezes up, the liquid pressure from the sprue is shut off; when liquid metal in the mold cavity shrinks, the level of liquid metal in the riser will fall, open shrinkage cavity will form in the riser top, liquid metal of the riser is fed into the casting, there will be no shrinkage in the casting. The author considers that, besides what R W Heine has mentioned above, rapid freezing up of the ingate after pouring stopped has another two even more important advantages:

(1) preventing gating system together with the casting to draw liquid metal from riser neck area simultaneously that will cause shrinkage at the riser neck area of casting, and bring the feeding capacity of the riser into full play;
(2) helping to block up the riser together with the casting to avoid relaxation of pressure generated by graphitization expansion.

In 1999, when the production of 6110 crankshaft castings was moved from shop floor onto HWS molding line at the works, the chills set originally at flange of the crankshaft could be no longer used due to automatic molding, and increasing the size of the riser neck was not permitted for riser knocking off. Shrinkage occurred again at the riser neck area of casting though the hardness of the sand mold.
was increased. The riser had been enlarged, however no successful result was obtained. This problem was solved at last only by changing the dimensions of the ingate from 45 mm ×20 mm into 109 mm × 8 mm to reduce its thickness by keeping its section area unchanged and ensure it freeze up rapidly as soon as pouring stopped. The same problem arose with the 6110 nodular iron camshaft and was solved also by using a thin and long ingate (with thickness of 4 mm only), as showed in Fig. 15.

![Fig.15 Gating system and tapered feeder for 6110 camshaft (6 pcs/ per mould)](image)

7 Feeding channel of small and thin section castings was too narrow for feeding liquid to enter casting

Small and thin section castings usually freeze rapidly, and have high nodule count and eutectic cell count, their solid-liquid zone develops rapidly during solidification, causing the feeding channel become very narrow and easy to be blocked, the feeding liquid can not enter casting, especially can not be sent through a long distance, that often is the reason leading to failure of riser feeding and resulting in shrinkage defects. Following countermeasures should be adopted for the situation:

(1) Using supplemental machining allowance to expand liquid feeding channel.

The production of nodular iron cylinder liner began in 1950s at WXDEW. The original method for it was showed in Fig.16A. Having uniform wall thickness from top to bottom and a shower gating system set on its top, the casting was poured and cooled vertically. There were often centerline shrinkage defects inside the casting wall for the reason that feeding channel was easy to be locked. Finally the method was modified as showed in Fig.16B. The wall thickness of bottom end of the casting was reduced than before, and by using supplemental machining allowance, increased the wall thickness gradually from bottom to top, and the taper of the riser was increased too. As a result, the cooling rate of the casting decreases gradually from its bottom to top that is favorable to form a feeding channel expanding towards the riser and move the shrinkage into the riser. Since then, the shrinkage problem was solved thoroughly.

![Fig. 16 Method of A110 nodular iron cylinder liner](image)

(2) Riser should be set on the hot spot of the casting directly and relatively bigger ratio of riser size / casting thickness should be adopted.

Because the hot spot solidifies later than other parts of casting, so it is the best entrance to introduce feeding liquid metal and is exactly the best location for setting the riser. As the feeding channel of small and thin section castings is easy to freeze up, the ratio of riser size / casting thickness should be relatively bigger in order to lengthen the freezing time of the channel.

The author's practice shows that for shaft-shaped castings with diameter more than 60 mm, the riser diameter /casting diameter ratio of 1.1-1.2 is sufficient. Whereas, for those small castings with wall thickness of 10-20 mm, the riser diameter must be 50-60 mm and even bigger, i.e. the diameter of riser must be 3-6 times of the wall thickness of the casting.

(3) Extending the covering range of riser neck as far as possible.

For castings with small size and thin section having multiple hot spots or long and narrow hot spot, as their own liquid channels are usually too narrow for feeding liquid to flow, it is better to use gating through kiss risers or side risers with the shape following the casting, and the neck or kissing area of the risers should be as wide as possible in order to expand the entrance for introducing feeding liquid, making it possible that risers can feed more hot spots directly. As for those hot spots which can't be fed by risers directly, it is best for preventing shrinkage to keep them far from risers to increase temperature drop of the liquid metal by lengthening its flowing distance.

As mentioned above, the rejection rate of 6110 vermicular iron cylinder heads had been higher than 20% for many years when the castings were produced at the
shop floor. In 1999 the shop floor production was changed into production on HWS line. As a trial foundry method, six kiss risers with dimensions of Φ80 mm×200 mm were set on the exhaust pipe side of the cylinder head, as showed in Fig. 17 A. The kissing area of each riser was 60 mm×8 mm at first. The result showed that shrinkage and blowhole rejection rate was 30%-40%. Then the kissing area had been reduced to 60 mm×6 mm, and the rejection rate suddenly raised up to 62.5%. The above fact helped the author to discover the actual reason causing the failure. Because there are a lot of hot spots on the exhaust pipe side of the cylinder head, and the kissing area of six risers was too small for covering all hot spots, so many hot spots have quite high temperature caused by being not far from risers, however they can not be fed by risers because of being not directly under the risers. That is the reason of high rejection rate. Subsequently three oblong kiss risers with dimensions of 55 mm(thick)×9 mm(high)×200 mm (length) were used and kissing area of each riser was expanded to 200 mm×10 mm (the wall thickness of kissed part of the casting is 14 mm only), as showed in Fig. 17B, so all hot spots on the exhaust pipe side of the casting were covered by risers, and could be fed directly by risers. As a result, the rejection rate falls to 5% sharply, and the total weight of risers per casting is also reduced from 31.2 kg of former method to 16.8 kg.

Fig. 17 Two methods of 6110 vermicular iron cylinder head

8 Conclusions

(1) Applying the cold riser to the nodular iron casting would increase the quantity of liquid metal flowing through the mold cavity and bring the mold cavity to be overheated that would often cause shrinkage at the riser neck area of casting. To enable a riser to have feeding ability, the riser must be a hot riser connected with the ingate, and should be set on the hot spot area of casting directly as far as possible to ensure that the riser would solidify later than the hot spot fed by it, as well as should be enough high to have sufficient pressure to send the feeding liquid into casting.

(2) In order to avoid shrinkage occurring in isolated hot spots not connected with the feeding channel of the riser, it must keep them far from the riser, or set chills at hot spot areas.

(3) Fast freezing up of the ingate between riser and runner bar as soon as pouring stopped has the advantage that it is possible to avoid that the gating system together with the casting draw liquid metal simultaneously from the riser neck area and cause shrinkage in this area, bring the feeding capacity of the riser into full play, as well as to avoid the graphitization expansion pressure from being relaxed, ensuring the expansion to be used fully to feed the casting.

(4) As the feeding channel of castings with small size and thin sections is too narrow for feeding liquid to flow through and enter the casting, the shrinkage tendency of these casting is relatively acute. The countermeasures should be as follows:
- Adopting supplemental machining allowance to expand feeding channel.
- Increasing the ratio of riser size to wall thickness of the casting.
- The covering range of riser and its neck should be extended as far as possible.

References