Process Characteristics of Water-based Self-curing Coatings for Sand Casting

Qingqing Bian\textsuperscript{1,2}, Shengshan Feng\textsuperscript{1,2,*}, Huang Dong\textsuperscript{2,3}, Shuzhong Xie\textsuperscript{4,5}, Chunjing Liu\textsuperscript{4,5}, Chunyi Zhan\textsuperscript{2,3}, Jianli Chen\textsuperscript{2,3}, Weifeng Wu\textsuperscript{2,3}, Jiahao Liang\textsuperscript{4,5} and Yunhua Gao\textsuperscript{4}

1. Introduction

Water-based self-curing coatings for sand casting have the advantages of safe and reliable, convenient transportation, lower cost, no-contamination, good suspension property and brushability, fast speed of self-curing etc. It overcomes the problems of alcohol-based coating such as inflammability, explosion, toxicity, suspension instability, serious brush marks when brushing and the problems of common water-based coating such as need for baking, easy hygroscopicity of coating and so on. From the aspects of saving energy, reducing resource consumption and improvement of operating environment, production safety and casting surface quality and so on, water-based self-curing coatings...
is technological trend of sand casting coating. But so far, there have been few reports on the systematic research of water-based self-curing coatings for sand casting [1–4].

We took the lead in developing water-based self-curing coatings for sand casting in China, using the natural refractory material without calcination or electric melting as base material and self-made normal temperature cured modified polymer emulsion organic binder as main self-curing binder at room temperature, using the fast-drying silicate binder as main high temperature. The water-based self-curing coatings have good brushing and low permeability conditions under the condition of high viscosity and solid content. It can be fast self-curing under the condition of high ambient-temperature, low humidity and good ventilation conditions without worsening the strength of sand mould. The dried coating has good moisture resistant absorption ability, which provides good conditions for foundry enterprises to save energy consumption, improving environmental conditions and the quality of castings [5]. We have systematically studied the self-curing mechanism of water-based self-curing casting coatings and main process characteristics, the influence of environmental conditions such as temperature and humidity and other factors on the coating’s self-curing speed, the residual moisture after coating curing, and the effect of the coating on strength of the resin sand molds or core [6–7]. In order to better apply water-based self-curing coatings, the influence of rheological property, gas evolution characteristics and coating-thickness on the coating self-curing speed have been studied in this paper.

2. Performance characterization and test method

2.1. Conditional viscosity

The test conditions and methods of conditional viscosity are: firstly fully stir the coating sample evenly and then lay it aside for 30 min in the constant temperature and humidity laboratory with the temperature of 25°C±1°C; then test its flow completion time by the viscosity cup with an outlet diameter of 6mm. The viscosity of the coating is indirectly characterized by the average of five test values and the unit is seconds (s).

2.2. Rheological property

The rheological property of coatings include structural thixotropy and time thixotropy.

Structural thixotropy is characterized by brushing index, which refers to the ratio of the apparent viscosity of the coating at low shear rates to that at high shear rates. The higher the brushing index, the stronger the shearing thinning of the coating and the better the brushability. The test method is to fully stir the coating sample evenly and then lay it aside for 30 min in the constant temperature and humidity laboratory with the temperature 25°C±1°C; then test the apparent viscosity η₆ and η₆₀ using NDJ-1 rotary viscometer after rotating for 30s at the speeds of 6rpm and 60rpm respectively. M, namely brushing index, is calculated as the formula (1):

$$M = \frac{\eta_6}{\eta_{60}}$$

Time thixotropy is the changing rate of the apparent viscosity η of the coating, which is changing with the stirring time. The greater the changing rate, the higher the time thixotropy rate, the better the coating leveling property, but the worse anti-flowing property. The test method is: firstly fully stir the coating sample in the constant temperature and humidity laboratory with the temperature 25°C±1°C; then lay it aside for 30 min; test the curve of apparent viscosity changing with stirring time by NDJ-1 rotary viscometer at the rotating speeds 6rpm. Time thixotropy is usually characterized by thixotropic rate. The thixotropic rate N is calculated as the following formula:

$$N = \frac{(\eta_{0.5} - \eta_{10})}{\eta_{0.5} \times 100}$$

In the type: η₀.₅ and η₁₀ respectively refer to the apparent viscosity after rotating for 0.5 min and 10 min.

2.3. Coating-thickness

The scraping thickness of coatings is controlled by adjustable paint film preparation instrument.
2.4. Self-curing time

Self-curing time of coatings is tested on the planar basement of furan resin binder sand using QGZ type paint film drying time tester under the condition of 25°C±1°C and 43%±3%RH. It characterizes self-curing speed of the coatings and its unit is minutes (min). The shorter the coating self-curing time, the faster the self-curing speed.

2.5. Gas evolution characteristics

The gas evolution characteristics of coating includes the gas evolution volume and the gas evolution speed.

The test method is to use SFL type recording gas evolution tester to record the curve of gas evolution volume (ml/g) generated when a certain amount of coating samples are heated in a closed high-temperature furnace with temperature 1000°C±5°C with time.

3. Test results and analysis

3.1. Rheological property

Various coating methods of casting coatings, such as brushing, flow coating, spraying, and dipping, all require structural thixotropy (brushing index) as high as possible.

The coating used by brush is required thixotropic fluid characteristics, namely time thixotropy. When the brush is fully dipped in the coating and then moved on the sand mold (shearing force is applied), the viscosity of the coating gradually decreases; when the brush leaves the sand mold (the shear force is removed), the coating viscosity adhered to the sand mold (core) gradually recovers at a moderate speed, and there is a process for the recovery of the viscosity. If the brush marks of the coating can be levelled and disappear before the viscosity recovers, the levelling property is good. However, if the coating brushed on the vertical plane flows down inevitably, the anti-flowability is poor. Which indicates poor flow resistance. The higher the thixotropy rate of the coating, which shows the better time its thixotropy of coating, and the better the levelling property, but the worse the anti-flowing property. Therefore, the thixotropic rate of the brush coating should be moderate in order to strike a balance between flow-levelling and anti-flowability.

The coating during dipping should have the characteristics of pseudoplastic fluid, that is, it should not have time thixotropy. When the sand core enters the coating, the shear force is applied and the viscosity of the coating decreases sharply, so the surface of the sand core is covered with a layer of coating completely. Then it is taken out, the shear force of the coating disappears, which causes the coating viscosity covered on the sand core to return and recover rapidly. It stops the dripping of the coating, thereby avoiding dripping marks of the coating.

The requirements of flow coating and spray coating are similar to those of dip coating, that is, pseudoplastic fluid.

Based on the above analysis, it can be known:
- The time thixotropy of coating during dipping, flowing or spraying should be as low as possible;
- The time thixotropy is required to be moderate when we brush the coating;
- The structure thixotropy, namely brushing index, should be as high as possible for various coating methods.

Typical characteristic curve of time thixotropy of a new water-based self-curing coating over time is shown in figure 1.

As shown in figure 1, the new water-based self-curing coating has obvious time thixotropy in the early stage of uniform shear (within 4min), and appears good thixotropic fluid characteristics. However in the late stage of uniform shear (after 4min), it doesn’t have time thixotropy and the viscosity doesn’t change with shear time, which shows typical pseudoplastic fluid characteristics. That is to say, the new water-based self-curing coating both has the characteristics of thixotropic fluid and pseudoplastic fluid. The thixotropic rate is 31.6%, which is moderate.
Fig 1. Typical characteristic curve of time thixotropy of zirconium-containing composite silicate coating

Fig 2. The effect of coating-thickness on self-curing time of the coatings

Tips:
① Using zirconium-containing composite silicate coating.
② The conditional viscosity of the coating is 26s.

The test results show that the brushing index of water-based self-curing coatings are higher than 6.4. Therefore, the new water-based self-curing coating has good brushablity and excellent comprehensive balance between levelling and anti-flowablility, which can meet the rheological requirements by various coating methods such as brushing, flowing, spraying and dipping.

3.2. Effect of coating-thickness on self-curing speed

The experimental results of the effect of coating-thickness on self-curing time of coatings are shown in Fig 2.

It can be seen from fig.2 that the self-curing time of water-based self-curing coating basically is approximate linearly prolonged with the increase of coatings’ thickness, the coatings’ self-curing speed basically is approximate linearly decreased with the increase of coatings’ thickness as well. Therefore, the coating’ thickness should also be as thin as possible in the premise of ensuring its surface quality from the perspective of improving casting production efficiency.

When producing large heavy castings, the coatings' thickness needs to be increased appropriately. We also tested the variation of coatings' self-curing time when the thick coating was prepared and dried step by step, as shown in Table1.

| Sample No. | Layer No. | Conditional viscosity/s | Water /% | self-curing time /min |
|------------|-----------|-------------------------|----------|-----------------------|
| 1          | 1         | 26                      | 47       | 107                   |
|            | 2         | 26                      | 47       | 95                    |
|            | 3         | 26                      | 47       | 98                    |
| 2          | 1         | 26                      | 47       | 107                   |
|            | 2         | 23                      | 49       | 105                   |
|            | 3         | 19                      | 51       | 123                   |

Tips:
① Using zirconium-containing composite silicate coating.
② The thickness of scraping coating is 0.5mm each time.

When the coating with the same viscosity is applied on the applied coating for the next time, the coating-thickness will increase because there is no penetration of the first coating to the sand mold. When we brush the surface coating, the viscosity is generally required to be low in order to improve
the levelling property and minimize or eliminate the brush marks. Therefore, we also tested the variation of self-curing time of thick coating during step by step preparations and drying when the viscosity is the same and the viscosity is lower gradually.

It can be seen from Table 1:

● When the coating with the same viscosity is applied on the painted coating for the second time, the self-curing speed of the coating is significantly increased because there is no penetration of the first coating into the sand mold matrix. However, when the coating with the same viscosity is applied for the third time, the self-curing speed of the third time coating is slightly reduced due to large thickness of the bottom moisture regain coating or the high moisture of the surface layer.

● When applying the coating with a lower viscosity on the applied coating for the second time, although there is no penetration of the first coating into the sand mold matrix, it is helpful to improve the self-curing speed of the coating. Meanwhile, it is unfavourable for improving the self-curing speed of the coating because of the large amount of moisture in the second coating. The self-curing speed of the second coating is slightly improved caused by the combined effect of the two results. However, when the coating with lower viscosity is applied for the third time, the self-curing speed of the third time coating is significantly reduced due to large thickness of bottom moisture regain coating and high moisture of the surface layer.

● The actual 0.8mm thickness of coating painting in one operation shown in Fig2 should be approximately equal to the actual total thickness of coating with successive decreased viscosity when painted twice in Table1. But the self-curing time of the former is 125min, whereas the total self-curing time of the latter is 212 min. So the self-curing speed of thick coating painting in one operation is faster than that of thick coating prepared step by step due to the bottom coating of moisture regain needs to be recurred again. Therefore, the thick coating should be painted at one time instead of step by step painting.

3.3. Gas evolution characteristics

Gas evolution is the main factor affecting gas hole defect of casting, so it is strictly controlled by coating standards at home and abroad.

At present, gas evolution volume of water-based coatings is generally less than 20ml/g according to Chinese Machinery Industry Standards (Coatings for Sand Casting, JBT 9226-2008), and that of graphite powder and talc powder coatings can be relaxed to less than 35ml/g.

The speed of gas evolution also has a great impact on gas hole defect of casting. The difference of coating’s gas evolution speed is mainly reflected in the initial stage. Whether the gas produced by the coating or not causes gas hole defects in the casting mainly depends on whether the casting surface curing during gas evolution. Even if the gas evolution volume of the coating is approximately equal, when the gas evolution speed is too fast, it is more likely to invade the gas at the initial stage of pouring when the surface of the casting is not curing and result in gas hole defect. On the contrary, if the speed is slow, it is difficult for the gas to invade after the initial curing of the casting surface and the possibility of gas hole defect in the casting is reduced.

![Fig.3 The gas evolution curves of a water-based self-curing coating compared with that a water-based baking commercial coating](image-url)
Fig. 3 shows the gas evolution curve of a water-based self-curing powder quartz coating compared with that of a water-based baking quartz powder commercial coating.

It can be seen from test results: although the gas evolution volume of the two coatings are approximately equal (about 19ml/g), the time required for the gas evolution of water-based baking quartz powder coatings to reach the peak is only about 15s, whereas that of water-based self-curing powder quartz coatings is about 30s. The gas evolution speed is almost half of water-based baking quartz powder coatings, especially in the first 5s there is a big difference. We believe that the main reason is that the polymer emulsions adopted in water-based self-curing powder quartz coatings contains a large number of benzene ring C structures, and its thermal decomposition temperature is relatively higher than those of ordinary organic binder with chain C structure, and its thermal decomposition speed is relatively slow.

4. Conclusion
The new water-based self-curing coating has the both characteristics of thixotropic fluid and pseudoplastic fluid, which has moderate thixotropy rate and high brushing index, good brushability and excellent comprehensive balance of flow-levelling and anti-flowability. It can meet the rheological requirements of various application methods.

The self-curing speed of coatings increases in an approximately linear manner with the decrease of its thickness. For improving casting production efficiency, the coating's thickness should also be as thin as possible in the premise of ensuring its surface quality and thick coating should be best to paint at one time in the premise of ensuring its surface quality.

Although the gas evolution volume of the new water-based self-curing coating is approximately equal to that of ordinary water-based baking coatings, but the gas evolution speed of self-curing coatings is almost half as that of the latter, especially in the first 5s there is a big difference, which provides good conditions for preventing gas hole defect of casting.

Acknowledgements
In this paper, the research was sponsored by special fund for scientific and technological development (collaborative innovation and platform environment construction) of Guangdong Province (Project No. 2016B090919094) and research project of Guangdong Cadre Institute of Science and Technology (XJJS202107).

References
[1] Wang J., Zhao L. (2017) Foundry Coating Technology Based on Green Development Concept. J. Foundry Technology, 9: 2240-2242.
[2] Li X.Q., Mu F., Peng C.Y. (2018)Discussion on the Development and Application of Green Eco-friendly Foundry Coatings. In: China Foundry week Symposium. China.1-5.
[3] Feng S.S., Xie S.Z., Liu C.J., et al. (2013) Research Progress of Quick-Drying / Self-Drying Water-Base Coatings for Sand Casting Process. J. Foundry Engineering, 1: 11-16.
[4] Liu S.Y., Sun X.H., Jin X.C., et al. (2008) Development the Water-based coating for cold box process. In: China Foundry week Symposium.China.351-357.
[5] Feng S.S., Xie S.Z., Liu C.J., et al. (2013) Research and application of the Water-based self-drying and fast-drying Coatings for Sand Casting Process. In: China Foundry week Symposium.China.930-939.
[6] Zhang C.Y., Feng S.S., Xie S.Z., et al. (2015)Curing Properties of Water-based Self-drying/Fast-drying Foundry Coating. In:3rd International Conference on Material, Mechanical and Manufacturing Engineering(IC3ME).China.1984-1989.
[7] Feng S.S., Zhan C.Y., Xie S.Z., et al. (2015)Influence Factors of Drying Speed on Water-based Self-drying/Fast-drying Foundry Coatings. In:5th International Conference on Information Engineering for Mechanics and Materials (ICIMM).China.636-641.