

Substitute materials of furfuryl alcohol in furan resin used for foundry and their technical properties

*Ren Yuyan and Li Yingmin

(School of Materials Science and Engineering, Shenyang University of Technology, Shenyang 110023, P. R. China)

Abstract: Based on a special synthesis process of furan resin, the furfuryl alcohol (FA), the main component of typical no-bake furan resins is substituted by ethanol and xylitol mother liquor which is relatively low price and chemically active. Through orthogonal test, the optimal amount of xylitol liquor, ethanol and modifier has been determined. Finally, the test results on technical properties show that the performance can meet the production requirement well, which indicate a success in this substituting attempt.

Key words: furan resin; furfuryl alcohol; substitution test; technical property

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The energy crisis and the increasing fierce market competition around the world have a tremendous impact on the foundry industry. Foundry is being forced to seek for energy-saving and more efficient casting methods. The no-bake furan resin bonded sand, with which self-setting of the mold and core can be achieved at room temperature, is characterized by high strength, high dimensional accuracy, fast hardening rate, high production efficiency and low labor intensity as well as abundant source of raw materials and simple production process. Therefore, furan resin is widely used in casting practice since Americans pioneered the no-bake furan resin bonded sand technology in the 1950s^[1]. It can be used for castings in various materials, different types and different structures, particularly for iron and nonferrous alloy castings^[2]. The introduction of furan resin has greatly changed core-making process in the single unit production. Mechanized molding line can be realized in the single unit production, as represented by the "high-speed molding cycle"^[3].

However, relatively high prices preclude further application of furan resin, caused mainly by large usage of furfuryl alcohol (FA) which holds very high price these years^[4]. Thus, seeking a suitable and cheaper substitute material for FA has a significant effect on wider industrial application of furan resin.

The objective of this study is to substitute FA with cheaper materials which have similar properties to fulfill industrial demand. Ethanol and xylitol liquor are selected from many

kinds of materials as substitution, and the effect of ethanol and xylitol liquor content on technical properties of the resin has been studied to determine the optimal composition.

1 Experimental details

1.1 Materials and instruments

The main chemical reagents used in the experiment include FA, formaldehyde, urea, NaOH, hydrochloric acid, xylene acid, ethanol, xylitol and other liquor. The instruments involved are a SAC hammer type of sample machine, a sand mixer, a SWY sand strength tester and a gas evolution detector for molding material.

1.2 Performance measurement

(1) Tensile strength test

A certain amount of standard sand was firstly weighed and added into the sand mixer. After 1 min of stirring, the curing agent was added in proportion, followed by additional 1 min mixing while adding the resin to make the "8" shaped samples. Then the finished specimens were put in air for natural curing for 1 h, 4 h, and 24 h, respectively. Finally, the tensile strength test was carried out on a SWY sand strength tester.

(2) Viscosity test

Viscosity measurement was carried out using a revolving viscosity meter.

(3) Collapsibility test

After being set for 24 h, the hardened sample was heated to and held at 400°C, 500°C and 530°C, respectively in a box-type resistance furnace and then cooled to room temperature for residual strength test.

(4) Gas evolution amount test

Hardened sample of 1 g was prepared and heated to 850°C in the SFL-type gas detector to determine the gas evolution

*Ren Yuyan

Male, born in 1970, senior engineer and doctoral candidate.

Research interests: new molding materials and related fabrication methods; light metals with high strength or high temperature resistance.

Email: yuyanren@126.com.

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amount.

1.3 The synthesis process

The material molar ratio of urea to formaldehyde and FA was 1:6.3:8.9. The synthesis process includes three steps: first, alkaline addition reaction is carried out at PH of 10 and 100℃ with a reaction time about 1.5 h; second, the acid resinification (reaction) was taken at PH of 6 for about 1 h at about 100℃; at last, the dehydration process was carried out to control the dehydration amount to 70% of formaldehyde solution.

2 Results and discussion

2.1 Content optimization of substitute materials

Partial substitution of FA by the xylitol liquor can markedly improve the strength of the resin, but can also cause high viscosity and instability. On the other hand, adding ethanol brings in better viscosity and stability but poor strength. Therefore, the suitable mixture of these two substances can combine the two advantages. In addition, modifier J (as shown in Table 1) is also added to enhance the stability of the resin. Then the method of orthogonal test was used for content optimization of both the two substitutes and the modifier with strength as the object. The level design of orthogonal factors is shown in Table 1. The test results are shown in Table 2 and Table 3 with 4 h strength and 24 h strength as the object, respectively. Figures 1 and 2 show the analysis results of the factors. It can be seen that the same optimization result can be achieved for both objects. The optimum contents of the substitutes and modifier are as follows: 12.5% xylitol liquor, 10% ethanol, and 0.3% modifier. After the optimum content substitution, the 4 h strength and 24 h strength of resin can reach 2.42 MPa and 2.58 MPa, respectively with lower viscosity, better liquidity and greatly enhanced stability.

Table 1: Level design of orthogonal factors

Level	Factors		
	Xylitol liquor (%)	Ethanol (%)	Modifier J (%)
1	10	5	0.2
2	12.5	7.5	0.3
3	15	10	0.4

2.2 The fractography of the resin sand specimen after substitution

The fractography of the resin sand specimen after substitution is shown in Fig. 3. It can be seen that after substitution the sand particle is fully packaged by resin, and little brittle structure can be found between evenly distributed resin layers. The sample is torn along the resin layer between the sand, the torn surface is uneven and the resin layer is relatively dense, indicating good toughness of the resin to sustain greater tensile force before fracture and leading to high strength of the sample.

Table 2: Data of orthogonal test with 4 h strength as the object

Test no.	A	B	C	4 h Strength (MPa)
1	A1	B1	C1	1.64
2	A1	B2	C2	2.17
3	A1	B3	C3	2.08
4	A2	B1	C2	2.31
5	A2	B2	C3	1.94
6	A2	B3	C1	2.13
7	A3	B1	C3	1.48
8	A3	B2	C1	1.70
9	A3	B3	C2	1.74
K1	1.96	1.81	1.82	
K2	2.13	1.94	2.07	
K3	1.64	1.98	1.83	
R	0.49	0.17	0.25	

Table 3: Data of orthogonal test with 24 h strength as the object

Test no.	A	B	C	24 h Strength (MPa)
1	A1	B1	C1	1.98
2	A1	B2	C2	2.33
3	A1	B3	C3	2.27
4	A2	B1	C2	2.53
5	A2	B2	C3	2.23
6	A2	B3	C1	2.39
7	A3	B1	C3	1.55
8	A3	B2	C1	1.86
9	A3	B3	C2	1.89
K1	2.19	2.02	2.08	
K2	2.38	2.14	2.25	
K3	1.77	2.18	2.02	
R	0.61	0.16	0.23	

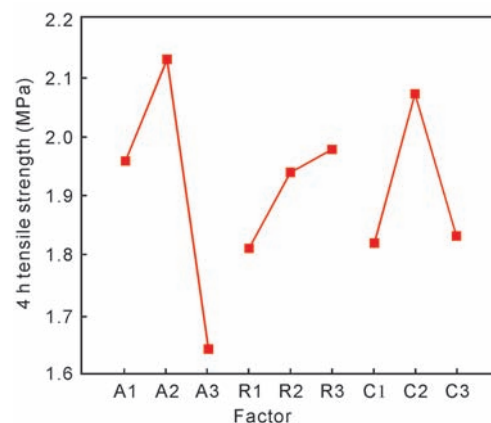


Fig.1: Effect of factors on 4 h tensile strength of resin sand

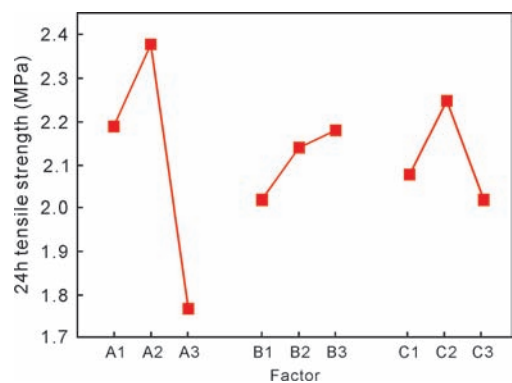


Fig.2: Effect of factors on 24 h tensile strength of resin sand

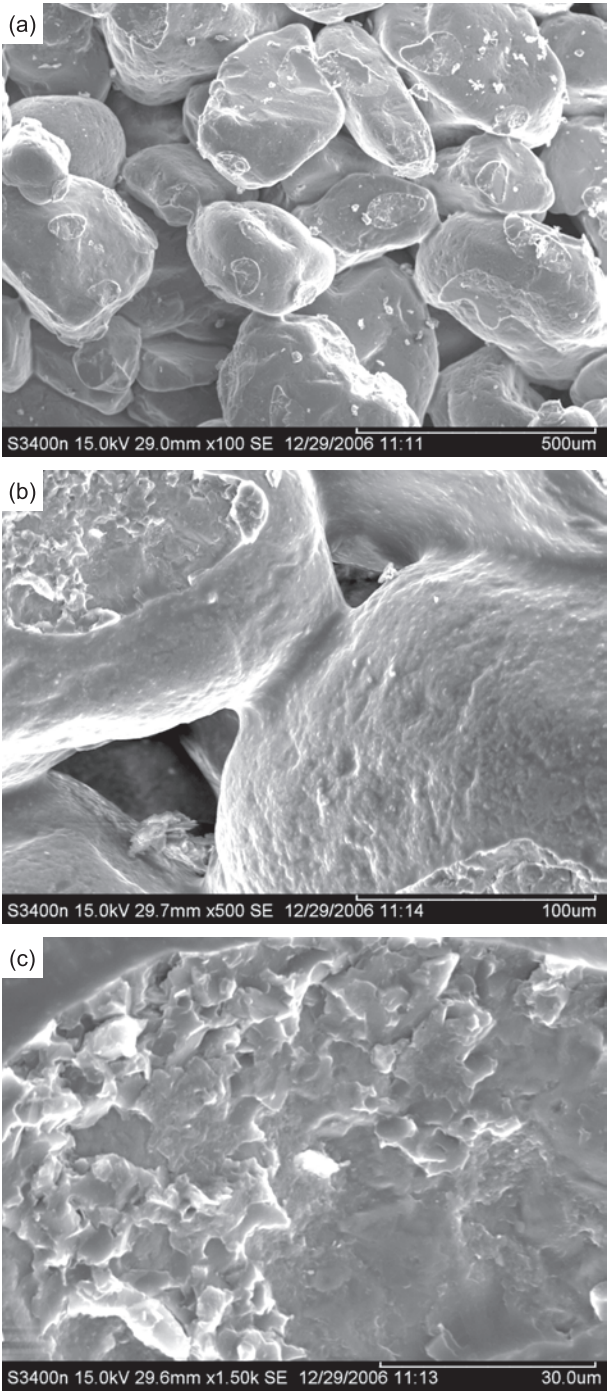


Fig.3: Fractography of test sample after substitution

3 The process property comparison

3.1 Comparison of apparent performance

Table 4 shows comparison of apparent performance of furan resin with and without substitution. The viscosity of resin slightly increases after substitution. However, its liquidity is still very good and it can be easily mixed. Although color changes slightly after substitute, the transparency increases and the stability is still good.

Table 4: Comparison of apparent performance of furan resin

Parameters	Original furan resin	Furan resin after substitution
Viscosity	54 MPa·s	60 MPa·s
Color	Dark red	Brown
Transparency	Good	Better
Stability	No precipitation	No precipitation

3.2 Comparison of tensile strength

Comparison of tensile strength between original furan resin and the furan resin with the mixture of xylitol liquor, ethanol and modifier J is given in Table 5. It can be seen that the initial strength of the substituted resin sand samples is lower than that of the original resin. But the 4 h and 24 h strength values are higher than those of the original resin and are in full compliance with the application requirements.

Table 5: Comparison of tensile strength

Tensile strength (MPa)	1 h	4 h	24 h
Original furan resin	0.90	1.78	2.23
Furan resin after substitution	0.81	1.89	2.42

3.3 Comparison of the hardening curve

The comparison of hardening time of resin sand with and without substitution (Fig.4) shows that during the initial 4 h, the strength increase rate of the original furan resin sand sample is slightly higher than furan resin sample with substitution. While after the initial 4 h, strength increase rate of the substituted resin sand sample is significantly higher than that of the original resin sand sample.

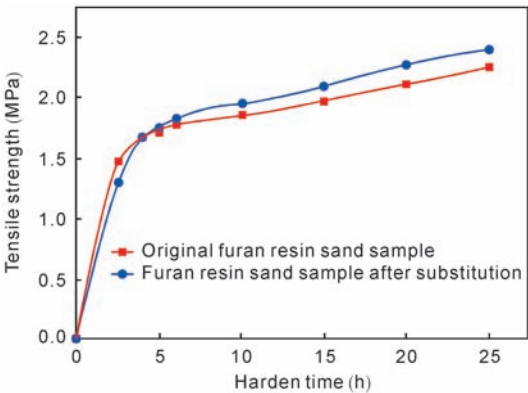


Fig.4: Comparison of harden curves of resin bonded sand with and without substitution

3.4 Comparison of gas evolution amount

Figure 5 shows the gas evolution of resin sand with and without substitution. It can be seen that in spite of a little faster gas evolution after substitution, similar overall gas evolution amount below 12 mL/g can be found during the first 120 s for both original furan resin and the substituted furan resin, suggesting that it is difficult to have porosity defect in the process of casting for the small amount of gas evolution of both furan resins.

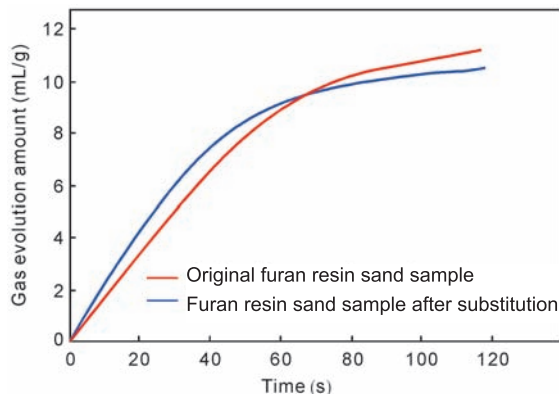


Fig.5: Comparison of gas evolution curves

3.5 Comparison of collapsibility

Good collapsibility is demanded for resin sand in addition to high thermal strength. Figure 6 shows the comparison of collapsibility between original furan resin sand and the furan resin sand with substitution. Obviously, the residual strength of both resins rapidly reduces with the increase of the temperature. At 673 K, the residual strength of the original resin sand sample is about 0.7 MPa, and the residual strength of the substituted resin sand sample is just over 1.2 MPa; At 773 K, the residual strength values of both samples approach to zero, indicating good collapsibility for both resins.

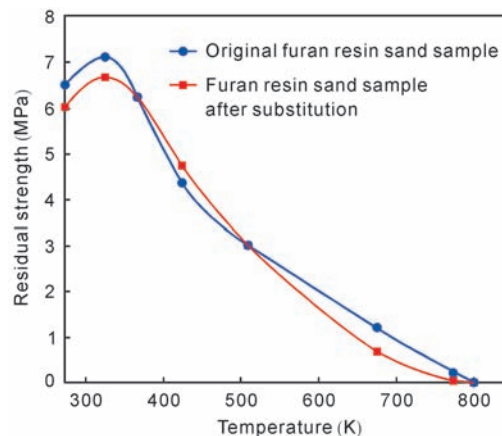


Fig.6: Comparison of collapsibility curve

4 Conclusions

(1) The resin has better stability and lower viscosity after a part of the FA is substituted by the mixture of 12.5% xylitol liquor, 10% ethanol and 0.3% modifier J. The strength of substituted resin sand reaches a higher level.

(2) There is little difference between the substituted resin and the original resin in technical properties, but both resins can meet actual production requirements.

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