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Studies of Binding Kinetics and Choice of Self-Hardening Moulding and Core Sands Used for Casting Massive Parts for Wind Power Industry under the Conditions of Krakodlew Foundry

M. Rączka *, B. Isendorf
Cracow University of Technology, Podkowińskiego 1/46, 31-321 Krakow, Poland
*Corresponding author. E-mail address: mraczka@pk.edu.pl

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Abstract

In highly developed countries, a significant progress in the use of alternative and clean energy sources has recently been observed. The European Union has implemented a programme to build wind turbines. It is estimated that in the coming years, thanks to the support in tax and credit, the global energy will develop very intensively.

Many components of the wind turbines are castings. The basic material used for these castings is ductile iron, which in this particular case must meet high requirements imposed by the operating conditions of wind turbines. Anticipating an increase in customer demand for this type of castings, Krakodlew SA has decided to modernize its foundry using the ability to obtain external financing.

The ductile iron manufacturing technology is now being developed and adapted to the specific conditions of the foundry plant, including the melting process yielding cast material with the required chemical composition, the technology of moulding, and the conditions for possible secondary metallurgy, spheroidizing treatment and graphitizing inoculation. The fulfilment of the imposed conditions for the casting production demands the use of advanced casting technologies introduced to the manufacturing process.

The development of technology to launch the production of ductile iron castings for the wind power industry was supported by The National Centre for Research and Development (NCBiR). This article presents part of research on the binding kinetics of furan resin sands and choice of their composition for moulds and cores to make heavy castings used as components of equipment for the wind power industry.

Keywords: Wind energy, Innovative materials and casting technologies, Environmental protection, Ductile iron, Testing of moulding sands

1. Introduction

The studies described in this article have been done within the framework of a research project supported by NCBiR and financed by the European Regional Development Fund, Measure 1.4 PO IG, Agreement No: OPIE 01.04.00-12-116/12.

The scope of work included:

— development of casting technology,

— choice of moulding and core-making technology,
— design and construction of a facility for the manufacture of moulds and moulding sand reclamation.

Under this programme, Cracow University of Technology was the contractor of industrial research including:

— technical guidelines for the mould-making process,
— technical guidelines for the metal melting process,
— technical guidelines for the heat treatment.

This article describes studies of the binding kinetics and selection of foundry sand components for moulds and cores to make castings applicable in the power industry.

2. Description of test methods

2.1. Characteristics of sands with furan resin

Furan resin sands containing furfuryl alcohol are used in the piece, and small and large lot production of moulds and cores for iron castings as a technology of loose self-hardening sands (SMS), chemically bonded at ambient temperature. The addition of resin with furfuryl alcohol to the sand is 0.8 - 1.5% relative to the pure sand weight, while the addition of hardener is 30 - 60% relative to the resin content. Depending on the resin composition, during mixing and hardening of the sand, the emission of formaldehyde, phenol and/or furfuryl alcohol may take place. However, at room temperature, at which these operations are performed, the vapour pressure of the chemical compounds is low and at certain consumption speeds the emissions are negligible. [1,2]

In the technology of furan sands it is very important to keep the temperature of the sand mixture at a constant level of 15 - 25°C. This allows control of the binder hardening time and reduces the addition of hardener. Any direct contact between the resin and hardener should be avoided, because the reaction is exothermic and can be violent. A characteristic feature of the technology of moulding sands with resin containing furfuryl alcohol is the flexibility of possible uses and sand properties. Sands with furan resins are characterized by relatively low thermal resistance and thermal conductivity. [3,4]

The hardening process of the resin contained in the sand starts immediately upon entering the acidic hardening agent, which causes an exothermic reaction of polycondensation. The binder represents only 1% to 3 parts by weight, but its cost is 30 to 60% of the cost of all raw materials used in the sand mixture. Rational management of binding materials allows individual foundries to reduce this cost by 5 ÷ 10%. Using modern advanced systems of control of the sand mixing operation (mixer-slinger devices), a 5% reduction in the binder addition can be easily obtained, with the level of defective moulds reduced by 1 to 3%. [5]. Sulfonic acid significantly affected the tensile and strength of the resin bonded sand moulds[6]. Optimized consumption of resin and catalyst helps to reduce emissions of the gaseous pollutants, including volatile organic compounds (VOCs) which make up to 50 - 60% of these contaminants.

Sands with furan resins are generally subjected to the process of mechanical reclamation. The problem is post-reclamation dust generated in this process, the more that the modern foundry industry has no efficient and complex solutions in this field. The quality of reclaim, and mainly the degree of dust removal, control the consumption of binder and hardener, and thus the cost of the sand. [2,6].

2.2. Purpose and course of the study

The aim of the study was to search for the optimal composition of sand mixtures for moulds and cores suitable for the manufacture of massive castings from ductile iron, which are components of wind power equipment, such as e.g. the rotor hubs.

The sand mixtures were prepared in an LM-1 laboratory edge runner mixer. Samples for testing were moulded in an LUZ-1 device for vibratory compaction of moulding sand, while mechanical testing was performed in a versatile LRU-2e apparatus for the determination of mechanical strength. The conducted tests and studies included the evaluation of reclaim quality and of the possibility to use it in sand mixture preparation.

2.3 Studies of grain size distribution in the green silica sand and its reclaim

The test programme covered furan resin Furanol FR75A, hardener PU6, a reclaim from the mechanical reclamation of furan resin sand mixture and green silica sand from Szczakowa mine.

The characteristics of the green silica sand and its reclaim are given below. The sand humidity was 0.11%, while the humidity of the reclaim was 0.10%. The base sand had different pH values, amounting to 7.56 and 3.38 for the green sand and the reclaim, respectively. The loss on ignition in the case of the reclaim was 1.77%.

Table 1.
Analysis of grain size distribution in the green silica sand from Szczakowa mine

Sand					
Sieve No.	Mesh fraction, g Sample I	Mesh fraction, g Sample II	Mesh fraction total, %	Mesh fraction converted,%	
1,600	0,00	0,06	0,06	0,06	Average grain size d_L= 0.29 mm
0,800	0,08	0,18	0,26	0,26	
0,630	0,66	0,71	1,37	1,37	Average grain size D50=0.35 mm
0,400	13,83	15,88	29,71	29,71	
0,320	15,39	13,70	29,09	29,09	
0,200	16,40	14,65	31,05	31,05	Main fraction F_g = 89.85 %
0,160	2,36	3,22	5,58	5,58	
0,100	1,22	1,53	2,75	2,75	
0,071	0,02	0,02	0,04	0,04	Homogeneity index GG=63.00 %
0,056	0,00	0,01	0,01	0,01	
Pan	0,04	0,04	0,08	0,08	
Subtotal	50,00	50,00	100,00	100,00	Specific surface S_w= 9.644 m^2/kg
Clay content	0,00	0,00	0,00		
Total	50,00	50,00	100,00		

Table 1.
Analysis of grain size distribution in the reclaim

Reclaim					
Sieve No.	Mesh fraction, g Sample I	Mesh fraction, g Sample II	Mesh fraction total, %	Mesh fraction converted, %	
1,600	0,04	0,00	0,04	0,04	Average grain size d_L= 0.30 mm Average grain size D50=0.36 mm Main fraction F_g = 89.89 % Homogeneity index GG=63.00 % Specific surface S_w= 9.4 m^2/kg
0,800	0,25	0,36	0,61	0,61	
0,630	0,73	0,70	1,43	1,43	
0,400	14,70	14,99	29,69	29,69	
0,320	13,90	15,28	29,18	29,18	
0,200	16,61	14,41	31,02	31,02	
0,160	3,06	3,45	6,51	6,51	
0,100	0,46	0,56	1,02	1,02	
0,071	0,25	0,25	0,50	0,50	
0,056	0,00	0,00	0,00	0,00	
Pan	0,00	0,00	0,00	0,00	
Subtotal	50,00	50,00	100,00	100,00	
Clay content	0,00	0,00	0,00		
Total	50,00	50,00	100,00		

Table 1 shows the results of the analysis of grain size distribution in the green sand, while Table 2 shows the same results obtained for the reclaim. The content of the main fraction (0.400/0.320/0.200) was 89.85% in the green sand and 89.89% in the reclaim. The dust fraction (<0.100 mm) in the green sand was 2.88% and 1.52% in the reclaim. The specific surface area of the green sand was 9.64 m^2/kg, while in the case of the reclaim it amounted to 9.4 m^2/kg. All these values prove very high efficiency of the operation of dust removal from the reclaim.

2.4 Sand strength testing and discussion of results

Sand strength testing consisted in the determination of bending strength R_{GU} and tensile strength R_{MU} after the hardening time of 0.5; 1; 2; 3 and 24 h. Sand mixtures were prepared from either green sand or reclaim with the resin addition in an amount of 1 part by weight and a variable content of hardener amounting to 60%, 40% and 20% relative to the resin content. The test results are summarized in Tables 3-6. As regards the tensile and bending strengths of the sand mixtures based on green sand, their mechanical properties after complete hardening were slightly superior to the sand mixtures containing the reclaim. In the initial periods of hardening, i.e. after 0.5 and 1 h, the sand mixtures based on reclaim were characterized by slightly higher strength. The conducted studies have demonstrated high quality of the reclaim, but at the same time allowed drawing the conclusion that sand mixtures based on the reclaim have shorter bench life, as evidenced by the rapid increase of strength in the initial stages of hardening. At the same time it was observed that the highest strength after total hardening (24 hours) was reached by the sand containing 20% of hardener relative to the resin content. Table 6 shows the results of the sand strength testing in the case of a variable resin content of 1.2; 1.0; 0.8 parts by weight and constant hardener content of 40% relative to the resin content. The prepared sand mixtures contained green silica sand, and it was confirmed that the sand mixture strength after complete hardening was increasing with the increasing resin content.

Table 3.
The strength of moulding mixture containing green sand, reclaim and 60% of hardener addition

Sand composition:	-silica sand - 100 pbw -resin - 1.0 pbw -hardener - 60%		--reclaim - 100 pbw -resin - 1.0 pbw -hardener - 60%	
Sand hardening time [hours]	Rg[N/cm^2]	Rm[N/cm^2]	Rg[N/cm^2]	Rm[N/cm^2]
0,5	157,2	43,6	168,4	49,3
1	236,7	68,9	249,2	72,1
2	317,7	105,2	306,5	98,7
3	340,6	105,6	316,2	97,2
24	423,6	158,2	395,7	135,3

Table 2.
The strength of moulding mixture containing green sand, reclaim and 40% of hardener addition

Sand composition:	-silica sand - 100 pbw -resin - 1.0 pbw -hardener - 40%		--reclaim - 100 pbw -resin - 1.0 pbw -hardener - 40%	
Sand hardening time [hours]	Rg[N/cm^2]	Rm[N/cm^2]	Rg[N/cm^2]	Rm[N/cm^2]
0,5	141,2	41,1	148,5	50,6
1	235,4	65,5	243,7	193,5
2	306,5	105,0	295,4	275,4
3	362,0	134,5	354,5	356,0
24	437,5	172,0	414,0	175,5

Table 3.
The strength of moulding mixture containing green sand, reclaim and 20% of hardener addition

Sand composition:	-silica sand - 100 pbw -resin - 1.0 pbw -hardener - 20%		--reclaim - 100 pbw -resin - 1.0 pbw -hardener - 20%	
Sand hardening time [hours]	Rg[N/cm^2]	Rm[N/cm^2]	Rg[N/cm^2]	Rm[N/cm^2]
0,5	111,3	37,1	113,4	42,3
1	184,7	52,4	189,5	59,3
2	265,3	99,3	263,7	101,2
3	315,7	101,7	303,5	105,4
24	485,7	195,4	453,2	182,1

Table 4.
Sand strength vs resin content

Sand composition:	-silica sand - 100 pbw -resin - 1.0 pbw -hardener - 40%		-- reclaim - 100 pbw -resin - 1.0 pbw -hardener - 40%		- reclaim-100 pbw - resin- 0.8 pbw - hardener - 40%	
Sand hardening time [hours]	Rg [N/cm^2]	Rm [N/cm^2]	Rg [N/cm^2]	Rm [N/cm^2]	Rg [N/cm^2]	Rm [N/cm^2]
0,5	140,2	39,0	141,2	41,1	153,0	41,0
1	224,5	58,2	235,4	65,5	219,6	81,0
2	286,0	120,0	306,5	105,0	320,2	122,0
3	385,0	132,5	362,0	134,5	315,0	121,5
24	494,0	215,0	437,5	172,0	376,0	178,0

2.5 Sand bench life testing and discussion of results

The sand bench life is a property indicating the time during which the sand preserves its mouldability. This time is calculated from the instant when all the sand components introduced into the mixer and required for the binding reaction enter into contact with each other. However, different criteria for the assessment of sand bench life are applied. Sometimes it is the sand strength loss of 30%, sometimes of 20%, and on other occasions it is the measurement of sand flowability that serves as a bench life criterion.

Table 7.
The results of sand bench life testing

Sand composition:
- silica sand – 100 pbw
- resin – 1,00 pbw
- "winter" hardener – 40%

Sand maturing time before compaction [min]	Tensile strength R_m^u [N/cm^2]
2	114
3	118
4	146
5	127
6	115
6	89
7	101
8	93
9	70
10	82
11	87
12	60
14	55
15	44
16	37
17	51
18	36
19	30
20	24
21	25
21	22
22	24
23	19
24	19
25	21
26	18
26	25
27	12
28	15

In the technology of self-hardening sands, the bench life is a very important parameter, because in the mixer there are all sand ingredients and when they contact each other, a reaction of binder polymerization starts, followed by the formation of bonding bridges. The type of the hardening process that takes place in the self-hardening sands makes their bench life either very short (10 minutes) or relatively short (30 minutes).

The determination of the bench life of the examined sand mixtures consisted in plotting the curves of characteristic changes in the ultimate tensile strength R^u_m, measured on eight-shaped specimens as a function of the sand maturing time before final compaction. The specimens were compacted by three blows of the standard ram. As a criterion in the conducted tests for the determination of sand bench life was adopted the time after which the sand was losing 30% of its highest (achievable) strength. Table 7 and Figure 2 show, respectively, the data and a graph to study the bench life of the sand with the following composition: green sand - 100 parts by weight, resin - 1.00 part by weight, hardener - 40% relative to the resin content.

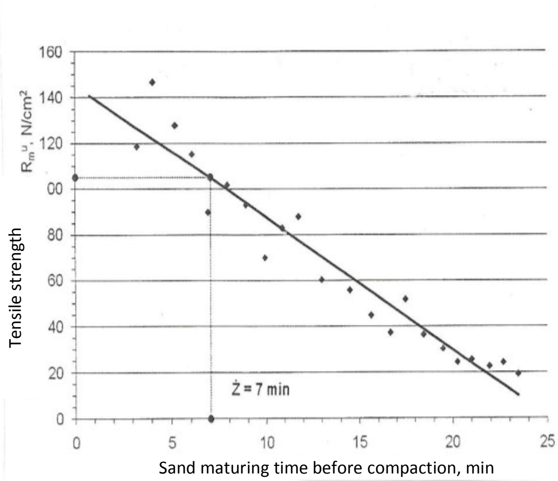

Fig. 2. The determination of sand bench life

3. Summary and conclusions

As a result of the conducted studies, it seems reasonable to make moulds from furan resin sands containing 0.8 ÷ 1.0 part by weight of resin and 20% of hardener (relative to the resin content), and pouring moulds 24 hours after their manufacture.

In the case of moulds poured after a shorter time of hardening, the content of the hardener should be raised to 40% (relative to the resin content).

In the production of cores, it seems reasonable to use sands containing 1.0 ÷ 1.2 parts by weight of resin. It is also recommended to use green sand as a base material.

Self-hardening sands should be made from the following materials:

- silica sand medium or coarse 1K or 2K
  - main fraction 0.40 / 0.32 / 0.20
  - binder content ≤ 0.2% or ≤ 0.5%, respectively
  - homogeneity index J ≥ 85
  - sintering temperature> 1500º C
  - dust fraction (<0.100 mm) - less than 3% (these requirements are met by the sand from the mines of Szczakowa, Grudzeń Las and Biała Góra)

- sand reclaim from the furan resin process
  - the main fraction of reclaim should match the main fraction of the green sand - 0.40 / 0.32 / 0.20
  - dust fraction (<0.100 mm) - <3%
  - loss on ignition ≤ 2.20
  - pH = 2.5 ÷ 3.5
  - humidity ≤ 0.10%
- furan resin
- slow-acting hardener,
- fast-acting hardener.

It is recommended to have the content of furan resin in the sand at a level of 0.85 ÷ 1.20 parts by weight depending on the casting size and shape intricacy.

The content of hardener in the sand mixture should be 0.2 ÷ 0.4 relative to the resin content.

The use of two types of hardener is anticipated:

- slow-acting hardener when the ambient temperature is >15ºC;
- fast-acting hardener when the ambient temperature is <15°C;

The facing sand should be made either entirely from the green sand or from a mixture of the green sand (about 30%) and reclaim (about 70%).

The backing sand may contain up to 100% of reclaim as a base material.

Cores of highly intricate shapes should be made from a core mixture based entirely on the green silica sand.

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