Contribution to determination of the life time of chemically self-hardening mould sand

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Abstract

The article presents the problem of quality of casting moulds made of self-hardening sand, especially for manufacturing moulds for large-sized iron alloy castings. In such cases, unequivocal determination of so-called time of life of moulding sand is one of the most important issues, since it affects usability of a self-hardening sand for making subsequent layers of the mould prepared in time above one hour. Life time, measured in minutes, is dependent on the type of used sand grains, resins and their hardeners (catalysts) and also on the temperature and air humidity. Companies which manufacture and sell binding materials estimate the time of life according to their own criteria, which do not always correspond with real conditions. This article shows the experiences of the author, who has been working as an expert in European foundries for many years. New proposed parameter named FIP characterizing a life time of tested sands is also presented.

Keywords: Self-hardening furan sand, Mould rigidity, Nodular cast iron, Large-sized castings, Sand life time

1. Introduction

Problems discussed in the article are strictly related to a synergic approach to control of castings quality. The article is a continuation of author’s work in the subject of modeling and control of the processes of solidification and casting quality testing in industrial conditions. Mechanical properties of special types of nodular cast iron can presently easily achieve a level so far attributable to carbon and low-alloyed cast steel. Using this material instead of cast steel brings some evident benefits:

- greater yield of liquid metal, above 80% (cast steel – 60% on the average),
- attractive lower energy consumption (twice as low in comparison with cast steel).

The article describes the conditions of success of manufacturing large-sized castings from nodular cast iron, which became a challenge for foundries understanding that an attractive yield of liquid metal is in their reach. It is related, among other things, to the rigidity of the mould, which is dependent on the strength of moulding sand and the conception of stiffening the whole mould. Such high yield of liquid metal is an effect of a professional use of the self-feeding phenomenon, which has a different course in comparison with grey iron with graphite flakes [1-8]. An important condition of obtaining such a result is resistance of mould assembly (hardened sand forming the mould cavity, cores, moulding boxes (flasks), mould clamp system) to the enormous pressure of graphitization occuring in the solid-liquid phase of solidifying nodular cast iron with eutectic composition [8]. This pressure can sometimes momentarily reach values above 10 MPa [4]. It occurs when the fraction of solid
phase in the casting or its parts has reached circa 0.75 and back flow of the metal through too large riser necks has not been cut (if such necks are used). Intensity and dynamics of this phenomenon are dependent on the metallurgical quality of the nodular cast iron [2-5]. High strength of the mould sand influences the mould rigidity (bending strength determined basing on standard samples – 22.4x22.4x146 mm – should not be lower than 2.5 MPa, but also should not exceed 3.5 MPa). Maintaining the stability of moulding sand strength affects the state and repeatability of microporosity location in large-sized, thick-walled castings of nodular cast iron. Wrong estimation of moulding sand life time, which is dependent on many dynamically changing factors, may introduce some significant perturbations in the process.

2. Life time of furan mould sand in aspect of manufacturing conditions in an iron foundry

The problem of life time of self-hardening sand in a specific foundry should be always considered taking real conditions and applied sand and reclamation technologies into account. Issues regarding reclamation station and the quality of obtained reclaimed sands were a subject of author’s research and are described in series of publications [9-15], which analyze the following problems:

- the conception of a mould sand reclamation station in case of technologies using different chemical constitution of binding sands,
- the role of pneumatic transport in reclamation stations, realized mechanically,
- magnetic retrieval of chromite sand, in station of mechanical reclamation,
- specificity of aiding the mechanical reclamation by thermal reclamation of furan sands in industrial conditions.

The author in [8,15] analyzed the stability of quality of a sand reclaimed in a selected foundry (heavy castings of steel and cast iron alloys) using mostly furan sands and approximately 10% sands of polyurethane resin of alkaline character. To ensure this stability, systematical operational examinations has to be performed very thoroughly.

The examinations concerns both the reclaim and the furan sand made of this sand and they consist of:

- taking the sample of reclaimed sand on the “input” to a chosen continuous mixer, in a quantity allowing examination mentioned below (for example 4-5 kg),
- examining the granularity of reclaim, with special attention paid to the amount of the fraction below 0.106mm (0.5% is an acceptable value), to evaluate the effectiveness of the station and especially its anti-dusting systems,
- examining the losses of roasting of the reclaim, to inspect the efficiency of the grain rubbing process (2% roasting losses is an acceptable number, result above 3% causes checking activities of the main subassembly of the vibratory regenerator),
- indication of pH level and need for acid/base, to estimate the repeatability of the conditions of catalysis of resin-hardener system during sand binding,

- scrupulous simultaneous compaction of 6-8 samples for bending strength tests (R_b) of sand made in continuous mixer (daily verification of resin and hardener dosage correctness),
- indication of R_b after 24 hours (with weighing the samples beforehand),
- in case of R_b strength below assumed level, preparing sand of identical composition in the laboratory mixer, then repetition of the R_b examination after 24 hours,
- evaluation of correctness of sand reclaim and mixing system functioning, with decisions regarding possible rectification.

For instance, authors [16,17,18] propose other original methods for testing the quality of the reclaimed sands in foundry conditions. Special examination [8,19] should be performed periodically, according to the recommendations prepared by the author of this article:

- determination of FIP – parameter of binding intensity, allowing precise estimation of furan sand life time (possible processing time for moulding operation),
- application of thermostatic chambers to indicate FIP and R_b, to re-create the environmental conditions (summer or winter) in laboratory conditions.

This quite complex approach to the mould sand study brings excellent results and allows to react on deviations from assumed criteria of quality of the sand and the mould made of it.

As mentioned above, most frequently used binder in the selected foundry is a furan resin and PTS acid is applied as a hardener. To be more precise, two hardeners are in use, with extremely different concentrations, which requires adjustments of continuous mixers (three independent dosing systems, working in parallel). As it will turn out further, it allows to respond very precisely and adjust acid concentration to current moulding operations.

If during preparation of one part of the mould (60 tons of furan sand) assembly of a great number of chills and reinforcements is required, then time needed for realization of this task increases to 2-3 hours. Mould areas with model facing sand are compacted simultaneously with placing quite heavy chills (few hundred per one casting on the average) and then the life time of the sand must be appropriately prolonged. Mould areas, where moulding does not consist in such subtle operations can be performed more thoroughly. The examination concerns both the reclaim and the furan sand made of this sand and they consist of:

- taking the sample of reclaimed sand on the “input” to a chosen continuous mixer, in a quantity allowing examination mentioned below (for example 4-5 kg),
- examining the granularity of reclaim, with special attention paid to the amount of the fraction below 0.106mm (0.5% is an acceptable value), to evaluate the effectiveness of the station and especially its anti-dusting systems,
- examining the losses of roasting of the reclaim, to inspect the efficiency of the grain rubbing process (2% roasting losses is an acceptable number, result above 3% causes checking activities of the main subassembly of the vibratory regenerator),
- indication of pH level and need for acid/base, to estimate the repeatability of the conditions of catalysis of resin-hardener system during sand binding,
perturbations may be caused by factors like: temperature of the reclaimed sand feeding the continuous mixer, temperature and humidity of the environment, contamination of reclaim with grains with remains of binder bridges of alkaline character (including chromite sand), etc. All of this cumulates with pauses (breaks) in operation of the continuous mixer, planned during preparing one mould, caused by operations like, for example, assembly of another part of chills and lagging and compaction of sand around them. To what extent the stability and homogeneity of mould properties can be achieved in such conditions?

Let us shortly analyze the processes occurring during binding of described furan sand, which dominates in area of manufacturing moulds for large-sized castings of steel and cast iron alloys.

3. Furan sands – practical compendium of their application

The furan resin binder first appeared in second half of the 50s. New types of resin, developed during subsequent years (modification with furfuryl alcohol and silanes, mastering the processes of polycondensation and crosslinking), have led to improvement of wettability of sand grains (adhesion) and strengthening of binder bridges (cohesion), which allowed to reduce the amount of resin below 1% and reduction of gas production from sand (defined too by ignition losses). Water, emitted during exothermic reaction of hardening in required acid environment, and its elimination by evaporation controls the speed of the reaction. Hence the presence of water in the air (humidity), amount of water in the sand and rate of its elimination from furan sand in a state of binding (through natural drying), together decide of the time of hardening. It is thought (it has to be treated as an approximation) [20], that raising the temperature of hardening by 10°C increases the speed of reaction twice. At the same time, presence of reclaim originating from acidic furan process among grains or presence of other impurities of base character in a quantity difficult to predict affects the kinetics of the binding. Intuitive course of various speeds of sand binding reaction is shown in the graph in Fig. 1.

Influencing the speed of reaction begins from selecting the type of resin, which determines specific manufacturing procedure. Even using the same components in a reactor, depending on course of condensation process, resins with different proportions of free furfuryl alcohol, free formaldehyde and phenol can be obtained. The amount of water in resin varies in a similar way. Value of pH can be also diversified, from slightly base to slightly acidic character. Still, real unknowns appear when the resin starts being affected by the catalyst – hardener (both are used interchangeably in this paper), most often with chemical constitution not revealed to a foundryman, if it comes to components controlling the kinetics of the reaction. It is known that the more furfuryl alcohol, the lower viscosity of the resin, the better laying of resin over grains (wettability, important with short mixing times in the continuous mixer), the faster binding, the higher temperature of bonding degradation after metal inflow and the lower gas production. Unfortunately, it increases the price of the resin.

Recommended temperature of binding is 25-30°C (reference temperature). Some manufacturers attempt to adjust the phase composition of the resin and constitution of both catalysts to conditions specific for the particular foundry (pH values, dusting of the reclaim, sometimes to the average reclaim temperature and time of year), all the time assuming the subtle adjustment of acidity level of the mixture by the concentration of catalysts (this leads to a necessity of having dosing system for two catalysts, so-called slow and fast). Sand temperature below 10°C and cold tooling (models, core boxes), despite the heat of exothermic reaction do not favour fixed proportions of catalysts even for mildly higher temperatures, not mentioning the significantly higher.

Too high temperature is also not preferred (it should not exceed 35°C). Neutralization of basic ions, possibly present in the reclaim, also depends on temperature. Superposition of two, dependent on local conditions, kinetics of reaction of hardening and neutralization of mentioned ions is later expressed by influence on sand life time and its final strength (after 24 hrs). Precise determination of hardeners proportion (fast and slow) requires mentioned before, running examination in each foundry, including application of thermostatic mini-chambers [8].

Defining the kinetics of the binding is the problem for manufacturers of furan resin – catalysts set. Values of life time of furan sand (time of usability of the sand to make a good mould), prepared using proposed set, named by manufacturers are usually higher than actual values, obtained in real conditions of the foundry (this is a marketing stunt).

Methods applied by manufacturers (and also by foundries) to determine the life time of furan sand after its mixing on the continuous mixer consist in:

- observation of gradual change of new sand color (from yellow to dark green color)
- observation of grains of sand moving on poured cone,
- application of modified Dieter hardness tester (with very low rigidity of the spring)
- preparation of consecutive strength samples ($R_3$) in determined time intervals and testing their strength after 24 hours (aim: obtaining a curve of strength decrease in function of time elapsed since the sand mixing)

First methods are of qualitative character.

Fig. 1. Hypothetical graphs presenting extreme variability of kinetics of sand hardening reaction (surface layers): A. sufficient life time and relatively quick hardening reaction, B. too low life time and too slow binding
The last mentioned method appears to be the best to characterize the usability time of furan sand for making mould, with guarantee of limiting value of $R_b$ (2.5 MPa).

Character of strength decrease curve is presented on Fig. 2.

Fig. 2. Character of decrease of furan sand strength $R_b$ in function of time elapsed since the mixing of the sand, in relation to life time criteria (3 tests for furan sand, to compare with Fig. 6, N)

It can be therefore assumed that higher initial $R_b$ value should help to prolong the life time of the sand. It is however dependent on the slope of a binding curve, which in turn depends on mentioned above factors.

Method created by the author enables quite fast and precise determination of the moment of beginning of hardening of bonding bridges between grains of sand and allows to estimate the speed of increment of binding bridges strength.

4. FIP parameter – examples of tests in industrial conditions

Method created by the author allows to estimate the bond strengths of sand grains by indirect measurement in real time [8]. Tested in conditions of several foundries, the method was proven to be more precise in determining the kinetics of the process than methods used so far.

As examples for applying the FIP method to evaluate the kinetics of increase of bond strength between sand grains as a result of hardening of binding bridges, the following cases were selected:

1. evaluation of temperature influence during hardening of sand of selected composition, in conditions of thermostatic chamber (foundry A, Fig. 3),
2. influence of hardener type (fast, slow) from different resin manufacturer (foundries A and B, Fig. 4),
3. influence of hardener type (fast, slow) for picked resin type and sand reclaimed using two methods: mechanically and thermally (foundry C, Fig. 5)

Fig. 3. Variability of FIP parameter over time for the same furan sand in conditions of case 1 (foundry A) for ambient temperatures: 15, 26 and 33°C (thermostatic laboratory chamber)

Fig. 4. Comparison of FIP factor variability over time for furan sands based on the same fresh (new) sand and two types of binder – catalyst set. Foundry A: binder X and catalyst X1 “slow” and X2 “fast”, foundry B: resin Y, catalysts Y1 “slow” and Y2 “fast”, for ambient temperatures 20°C (case 2)

Fig. 5. Variability of FIP factor over time for furan sands for two different reclaimed sand grains (A – mechanically, B – thermally) and for the same resin using two extreme catalysts: Z1 “slow” and Z2 “fast” (foundry C), ambient temperatures approx. 25°C (case 3)
In second case (Fig. 4), study was performed on moulding sand from sand reclaimed with different type of furan resin and hardeners, also named by the manufacturer for foundry B as “fast” X2 (for winter season) and “slow” X1 (for summer season). Foundry B uses continuous mixers equipped in only one system of hardener dosing. Average sand temperature during examination was about 20°C. Life time increased from 12 min to 24 min and time of achieving the maximal bonding speed parameter increased from 22 min to 37 min Fig. 4 contains also a comparison of these times with hardeners supplied to foundry A. Here, respectively for two hardeners (“slow” Y1 and “fast” Y2) the life time increased from 3 min to 21 min and the time to obtain maximal FIP values – from 6 min to 27 min. Comparison of these two cases can lead to conclusion, that resin manufacturer in foundry B applies different approach to hardener reactivity than other one in case of foundry A.

Third case (Fig. 5) comprised comparison of influence of two hardeners (continuous mixer option of dosing two hardeners at the same time) on speed of binding for furan sands prepared on the basis of two different reclaimed sands (foundry C). Comparing the values of life time and maximal bond speed parameter, the following tlife/ max-FIP were obtained (temperature range of 22-27oC, average 25°C): for “fast” hardener and sand from mechanical reclamation – 16 min./25 min., for sand from thermal reclamation too – 16 min./25 min. For “slow” hardener appropriately: 20 min./35 min. and 40 min./70 min. The last result confirms the presence of Na+ and K+ ions, unexpectedly remaining on grains of sand originating from thermal reclamation of furan sand. This unexpected phenomenon was signalized first time in the literature and described by the author ten years ago in [11].

The fourth test (Fig. 6) concerned the evaluation of solution adopted in foundry A, where, depending on requirements, either fresh (new) sand, sand from mechanical reclamation or sand from thermal reclamation was applied. Graphs allow to conclude, among other things, that increase of concentration of acidic ions lowers the difference in values of life time and time of maximal binding speed parameter. Naturally, applying only “slow” hardener increased life time twice for moulding sands of fresh sand and from mechanical reclamation and nearly four times for sand from thermal reclamation.

The fifth test (Fig. 7) was conducted also for a moulding shop of foundry A, during summer (environment and sand temperature – approx. 30°C). Quantitative evaluation of increasing proportion of “fast” hardener (from 10 to 40%) to the “slow” one was performed. Variation courses of characteristic times prove one more time that there is a threshold, above which the life time grows, but as proven by further research (conducted always in parallel with research described above), Rth value lowers. Along with prolonging the time of binding, the neutralization of acidic environment may proceed, caused by impurities of base character staying on grains of sand.

The method of determining the FIP coefficient is quick and unequivocal. It does not directly lead to Rth value, but it can be used to prepare the effective plan for determining the strength Rth, especially with estimated life time.
5. Summary

The life time defined by resin manufacturers in technical specifications is estimated for mixtures of binder and hardener with fresh (rinsed) sand. These values are usually higher than actual values and are used by the manufacturer for advertising. The method used for FIP measurements presented in the article has been used for several years [8]. Results obtained using the method give the foundry a warranty when selecting the supplier and best solution for resin-hardener (hardeners) system.

Moreover, these tests allow determining the optimal proportions: fast hardener / slow hardener and recording them in control programs of dosing system (stepper motors + gear pumps) in continuous mixers of newest generation. This optimization is based on criterion of life time and also time of obtaining maximal speed of binding. After some calculations, the result is time, after which operation of model or core removal can be started.

References

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