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The Role of Acid Hardener on the Hardening Characteristics, Collapsibility Performance, and Benchlife of the Warm-Box Sand Cores

I. Budavári *, H. Hudák, G. Fegyverneki
University of Miskolc, Faculty of Materials Science of Engineering, Institute of Foundry, Hungry
* Corresponding author: Email address: ontbudai@uni-miskolc.hu

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Abstract

The heat-cured core-making process has been applied for over 60 years to produce molds and cores for different types of castings. The following technologies can be classified into the terminology of “heat-cured coremaking process”: croning-, hot-box -, and warm-box process. The latest technology provides good workability of core mixture, good strength properties, dimensional stability, and good knockout performance of the sand cores. Despite all its advantages, the warm-box technology is less widespread in foundries due to the cost of the high quality thermosetting resin and the maintenance cost of the core box. In this study, the influence of the acid hardener content on the hardening characteristics (bending strength), collapsibility, and the benchlife of the warm-box sand cores were investigated. From the results, it can be said, that within the investigated composition range, increasing the acid hardener content will improve the bending strength of the sand cores. The increased acid hardener content results in higher thermal stability at the beginning of the thermal exposure, and smaller residual bending strength after 15 minutes of thermal loading. The acid hardener level has little effect on the benchlife of the warm-box sand cores, although the sand core mixture is very sensitive to the combined effect of the sand temperature and dwelling time.

Keywords: Warm-box, Sand cores, Bending strength, Collapsibility, Benchlife

1. Introduction

Expendable sand cores are widely used to form inner cavities and holes during the production of cast components. The composition of sand cores includes the refractory sand, organic or inorganic binder to bond the sand grains together and hardener for curing the binder substance [1–2].

In foundry practice, sand cores should meet several requirements to fulfill the customer expectations as well as to produce high-quality castings. Cores should have sufficient initial strength after the core-making process to withstand the mechanical loads induced during the handling, core placement, and mold assembly. To resist the erosion and deformation of the high-temperature liquid metal during castings, sand cores should have adequate final strength. Cores should possess high dimensional stability and low thermal expansion to maintain dimensional accuracy during thermal exposure when they interact with the liquid metal. On the other hand, cores should possess sufficient collapsibility to become easily removable from the castings after the solidification of the metal alloy. Furthermore, high gas permeability and low gas evolution is also an important property to avoid gas blow defects [1, 3–5]. These characteristic features of sand cores are strongly influenced by the quality of the foundry sand [6–8], the used binder system [9–10] as well as the applied technological parameters during the coremaking procedure. Factors such as the sand temperature [11] and the humidity [12–14] adversely affect the characteristics of sand cores.

There are several technologies available for the production of sand cores. Among them, the heat-curing core making processes have been used for over 60 years in foundries for medium – and high production rate [15]. Their main application has been in the automotive industry (e.g. cylinder heads and engine blocks) and the plumbing fixtures industry. The croning -, hot-box - and warm-box processes can be classified into the group of heat-curing core making technologies. The common feature of these processes is that the curing of the organic resin is triggered by the thermal exposure induced by the pre-heated core-box. For comprehensive reviews of these methods, the reader is referred to the relevant references[1, 5, 16–19, 20–21].

The warm-box process is similar to the hot-box technology since it uses the same hardening technique at elevated temperatures. A modified furan resin type is used in the amount of 0.9-1.4% based on the weight of foundry sand. As a catalyst special aromatic sulfonic acids dissolved in an aqueous or alcohol solution are applied, which contain Cu and Al salts. One of the characteristics of these passive catalysts is that they are very stable at ambient temperature, their thermal dissociation takes place at a temperature of 150-170°C. The catalyst level is usually 20-30% of the weight of the resin [1, 5, 16-17, 20].

During the coremaking, the previously prepared sand mixture is blown into the pre-heated core-box cavity. Due to the effect of heat loading, a polycondensation reaction takes place between the resin and the catalyst, which results in the cross-linking of the binder substance [22]. The core-box temperature is between 130 - 180°C, which is lower than in the case of the hot-box method. Furthermore, due to the lower amount of resin, and the shorter hardening time, applying the warm-box method is more advantageous than the older hot-box technology [1, 16]. Sand cores produced with the warm-box method are characterized by good dimensional stability and good collapsibility during the casting. The manufactured castings are characterized by good surface quality [16].

Despite all these, the warm-box method is rarely used core-making process in the foundry practice, since it is an expensive technology in many ways e.g. the modified resin, and the maintenance cost of the core-box. According to the literature [15], this technology is only about 8% of the total core production around the world.

There are relatively few publications on the study of the characteristics of the warm-box sand cores. For this reason, this article aims to investigate the role of the catalyst level, the combined detrimental effect of the sand temperature, and the dwelling time of the sand mixture (time interval between the preparation of the sand mixture and the core shooting procedure) on the bending strength, collapsibility, and bench-life of the warm-box sand cores.

The study was conducted at the sand laboratory of the Foundry Institute, Faculty of Materials Science and Engineering, University of Miskolc.

2. Materials and Methods

During the research work, reclaimed sand was used as a refractory base material for producing test pieces of the warm-box sand cores. The sand was previously applied in foundry production for the cold-box, hot-box, and warm-box core making process to produce sand cores. After casting, the sand grains were treated in a thermal fluidized bed thermal reclamation system, which consists of the separation of dust and fines as well as the sieving of the reclaimed sand grains.

In the first part of the experiment, preliminary tests were carried out to determine the characteristics of the reclaimed sand. Table 1. summarizes the performed test methods in detail.

The second part of the study involved the preparation of the sand core mixtures, the production of test pieces, the performance of the bending-, collapsibility- and the modified bench-life tests.

Table 1.
Preliminary tests to determine the characteristics of the reclaimed sand

Test methods	AFS Standards	Examined features
Clay, 25 Micron	AFS 2111-19-S	percentage of the clay content in the reclaimed sand
Grain Shape Classification	AFS 1107-12-S	grain morphology of the sand particles
Sieve Analysis Grain Fineness Number Calculation	AFS 1105-12-S AFS 1106-12-S	grain-size distribution, average grain size, AFS number
Surface Area, Measured, of a sand	AFS 1108-12-S	actual specific surface area
Surface Area, Calculated, of a Sand	AFS 1109-12-S	theoretical surface area
Moisture Determination	AFS 2216-19-S	the moisture content of the sand
Loss on Ignition (LOI)	AFS 5100-12-S	quantity of organic and other gas-forming impurities of the sands
Acid Demand Value (ADV) test	AFS 1114-18-S	the acidity of the used sand

For blending the various components of the sand mixtures, a laboratory blade-type mixer was applied. During the research work, sand mixtures were produced using 2000 g of reclaimed sand. First, the acid hardener (4-hydroxy-benzene-sulphonic acid) was added to the sand and mixed for 2 minutes at 80 rpm, followed by the binder (modified furan resin), which was blended for an additional 2 minutes. Table 2. represents the compositions of the sand core mixtures. The amount of acid hardener was calculated relative to the binder content, which latter was based on the sand weight. During the preparation process, the environmental temperature was 25±2 °C and the relative humidity was 30±3 %.

For the tests, rectangular cross-sectioned test bars having dimensions of 22.4 x 22.4 x 180 mm were produced with MULTISERW MOREK LUT universal core-blowing machine.

Table 2.
The composition of the used warm-box sand mixtures

Amount of reclaimed sand [g]	Amount of binder relative to the sand weight [%]	Amount of acid hardener relative to the binder content [%]
2000	1.33	20
		22.5
		24.8
		27.4
		30

The sand core mixtures were blown into three cavities preheated core-box. The technological parameters used during the core-making process were summarized in Table 3. The selection of the technological parameters was based on the foundry practice. The applied hardening temperature value will provide a faster hardening rate of the modified furan resin, thus resulting in greater bending strength of the sand cores. Thin-wall sectioned sand cores characterizing with high strength can better withstand the complex loads during the handling stages by the manipulator machine.

Table 3.
Core shooting parameters producing bending test bars

Apparatus	Multiserw LUT universal core shooter
Shooting time [s]	3
Shooting pressure [bar]	4
Core-box temperature [°C]	200
Heating time [s]	50
Test bar dimensions [mm]	22.7 x 22.7 x 185

To investigate the hardening characteristics of the warm-box sand cores containing different amounts of acid hardener, 3-point bending tests were carried out after storage times of 10 s, 35 s, 60 s, 10 min, 30 min, 5 h, and 168 h with a MULTISERW LRu-2e universal strength testing machine. The storage times were selected based on the production practice, and they were calculated from the end of the mixing process. The average value of the bending strength (R_{gI}^{b}) was calculated from the results of 6 measurements. The evaluation of storage times with 10 s, 35 s, 60 s, 10 min, and 30 min give information about the strength of sand cores while they are manipulated and transported immediately after the core making procedure. The results of the bending tests after 5 h and 168 h represent the mechanical properties of the cores while they are used during the casting production.

During the last decades, several investigations were published about the collapsibility performance of the different types of sand molds – and cores [23–25]. Dietert described a method [26] for the measurement of the retained compressive strength after exposing the sand specimens to heat, as a good laboratory method to evaluate the collapsibility behavior of the sand cores. In this study, the retained strength of the warm-box sand cores was measured on standard rectangular cross-sectioned bending test bars. During the production of the test specimens, the shooting parameters were the same as in the case of specimens used for the 3-point bending test. The produced bending sand samples were heated in an electric furnace up to 400°C applying different heat loading times: 5 min, 7.5 min, 10 min, 15 min, and 20 min.

In the preheated electric furnace, specimens were exposed to heat. After the given heating time, the samples were removed from the furnace and cooled down to room temperature. The retained strength of the specimens was determined using the 3-point bending test.

In the foundry practice, sometimes the sand core mixture has to wait several minutes in the tank of the core shooting machine before it is shot into the heated core-box. In this case, the temperature of the sand mixture can reach 40-50 °C. As the temperature of the sand grains raises the usability also called benchlife or worktime, of the sand cores decreases. In laboratory conditions, the benchlife test of the cold-box/hot-box/warm-box sand cores, described by the AFS 3186-13-S standard [27], indicates a time-period (calculated from the production of the sand mixture) during the standard tensile test specimens can be produced from the sand core mixture without drastic loss of strength.

In this experiment, to simulate the above-mentioned phenomena, the reclaimed sand was placed into a container and heated up to a temperature of 50±2 °C. To produce the warm-box sand core mixtures containing different amounts of acid hardener, the components (shown in Table 1.), were blended with the preheated sand in the laboratory blade-type mixer. At the end of the mixing process, the sand mixtures cooled down to a temperature of 40 °C. The produced sand mixtures were placed into an insulated heat storage container and dwelled for 30 minutes, then they were reblended for 1 minute. From the sand core mixtures bending test specimens were produced using the universal core shooting machine with the same conditions as can be seen in Table 2. Bending tests were conducted on samples with storage times of 10 s, 35 s, 60 s, 10 min, 30 min, 5 h, and 168 h (7 days). With this method, the effect of the sand temperature and the dwelling time of the sand core mixture on the hardening characteristics of the warm-box sand cores containing different amounts of acid hardener were taken into account.

3. Results and discussion

Characteristics of the reclaimed silica sand

Figure 1. presents stereomicroscopic images of the examined reclaimed silica sand grains at different magnifications. The results of the executed sieve analysis can be seen in Figure 2. and Table 4. summarizes the properties of the used reclaimed sand.

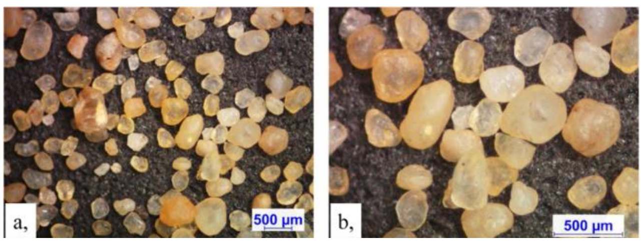

Fig. 1. Stereomicroscopic image of the reclaimed sand grains at a magnification of 20x (a) and 40x (b)

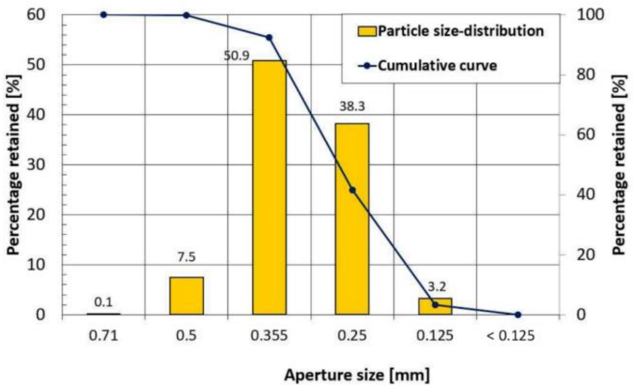

Fig. 2. Results of the sieve analysis

During the evaluation, the stereomicroscopic images were compared with a published chart from the literature [28]. As a result, it can be found that the reclaimed sand has sub-angular particles with medium sphericity.

Table 4.
Characteristics of the used reclaimed sand

Properties	Average values
Average grain size (calculated), mm	0.38
Grain fineness (AFS) number	39.05
Actual specific surface, cm^2/g	88
Theoretical Specific Surface Area, cm^2/g	62.25
Angularity factor	1.41
Moisture content, %	0.03
Clay content, %	0.07
LOI, %	0.1
ADV value	0.5

From Figure 2. it can be seen, that the base sand is concentrated in two sieves that have 0.2 mm and 0.35 mm mesh sizes. According to the calculated average grain size and AFS number, the examined reclaimed sand was characterized by coarse sand grains.

The reclaimed sand has a low theoretical and actual specific surface, which can be explained by the coarse grain size and the medium-spherical sand morphology. Based on the calculated angularity factor it can be said, that the used sand can be classified into the subangular group.

The studied reclaimed silica sand has a very low moisture content, thus, it has not influenced harmfully the curing reaction of the modified furan resin.

The executed LOI test pointed out that the reclaimed sand contains very low amounts of gas-forming impurities.

From the results of the ADV test, it can be said that the studied reclaimed sand is pure and low in impurities, that can react and neutralize the impact of the acid hardener.

The results of the conducted LOI test, and ADV test also represent the efficiency of the thermal reclamation process. There are a very low amount of gas-forming substances on the surface of the studied reclaimed sand that is derived from the resin and acid hardener used in the previous cycle.

Summarizing the results of the preliminary tests it can be established that the reclaimed silica sand shows relatively good characteristic features, which makes it suitable as refractory sand for producing warm-box sand cores.

The impact of the acid hardener on the hardening characteristics of warm-box sand cores

Results of the bending tests were summarized in Figures 3–5. In Figure 3. the bending strength of the sand specimens is shown as a function of storage time up to 60 seconds which provides useful information about the earliest hardening stage of the sand cores.

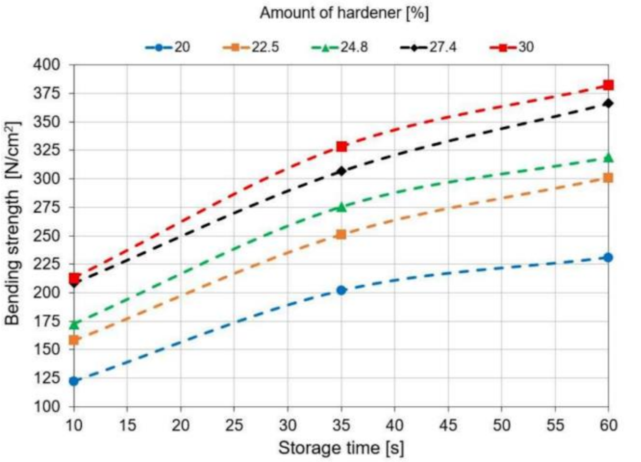

Fig. 3. The hardening characteristic of the warm-box sand specimens after removing from the core-box up to 60 s

According to the results, it can be observed that the bending strength of the warm-box test pieces is increasing continuously. In terms of the hardening characteristics of the sand samples, the effect of the acid hardener can be clearly seen. In the first minute after the production of the sand cores, intensive strength growth takes place. The bending strength of the sand specimens containing a 20 % amount of acid hardener is more than 100 N/cm^2. At the shortest storage time (10 s), the strength difference between test pieces containing the lowest and highest amount of acid hardener is almost 100 N/cm^2.

This strength difference increases at 60 seconds of storage time. Furthermore, a nearly linear relationship can be found between the amount of acid hardener and the bending strength of the sand specimens up to 1 minute of storage time.

Figure 4. represents the bending strength of sand specimens containing different amounts of acid hardener at 1 min, 10 min, 30 min, and 5 h of storage times. Results indicate that the bending strength of the sand specimens increases continuously during the studied 30 minutes of storage time.

The higher the bending strength of the sand cores the better they can be able to withstand the loading during the manipulation stage and the erosion effect of the liquid metal during the filling of the mold. In this regard, the warm-box core-making process provides excellent bending strength for the sand cores thus, it is particularly suitable for series production in the aluminum foundries.

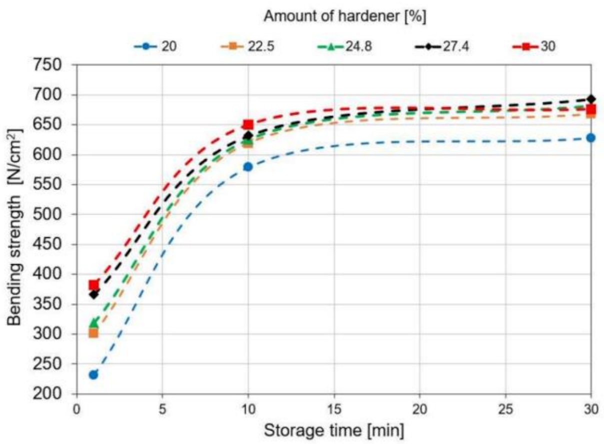

Fig. 4. Hardening characteristic of warm-box sand specimens from 10 minutes to 30 minutes of storage time

By increasing the amount of acid hardener, an average bending strength of more than 300 N/cm^2 can be achieved for test bars containing 24.8 % amount of acid hardener in 1 minute of storage time. However, the effect of the different amounts of acid hardener on the bending strength is smaller after 30 minutes of storage time. Based on this result, it is not advisable to increase the amount of acid hardener, because, with a minimal increase in strength, the amount of combustible organic matter will also increase.

In this research work, the effect of the different acid hardener contents on the storage ability of warm-box sand cores was also studied. Figure 5. shows the bending strength of the specimens stored for 5 hours and 7 days. It can be established, that the warm-box sand specimens possess high strength in the investigated time interval. The strength loss of specimens stored for 7 days is less than 15 % compared to the bending strength of test bars stored for 5 hours.

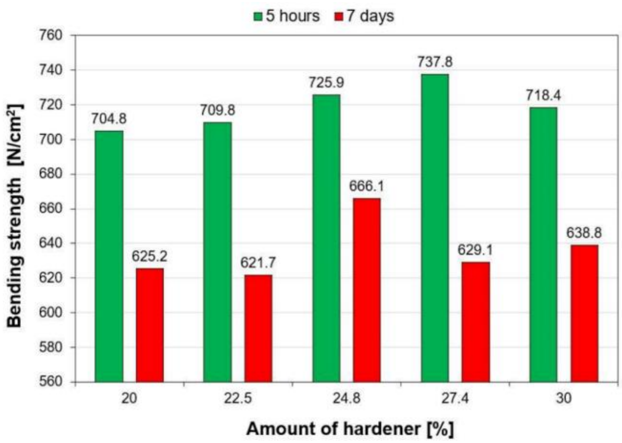

Fig. 5. Storage ability of the warm-box bending test bars

Thermal loading collapsibility tests

Figure 6. reveals the results of the residual bending strength of the sand specimens containing different amounts of acid hardener. It can be established that the test bars having 27.4 and 30 % amount of acid hardener provide better thermal stability at the beginning of the thermal exposure, and results in better collapsibility performance of the sand cores at the end of the investigated thermal loading interval. In these two cases, an increase in strength can be observed in the sand cores during the first 7 minutes of thermal loading.

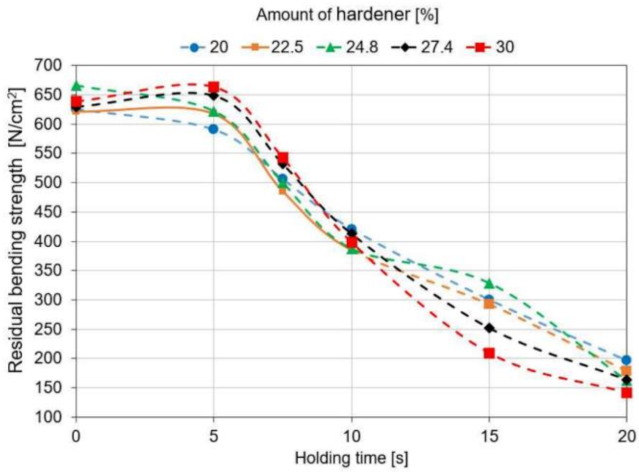

Fig. 6. Residual bending strength of sand specimens after thermal exposure

After 10 minutes of thermal loading, a significant decrease in strength can be seen. The greater amount of acid hardener may results in a higher degree of crosslinking of the binder during the curing process, which leads to the better heat resistance of the cross-linked binder.

Due to this phenomenon, the warm-box sand cores containing a higher amount of acid hardener have good thermal stability at the beginning of the heat loading, which is especially important for sand cores having a small wall thickness.

Furthermore, the higher acid hardener level results in smaller residual bending strength after 15 minutes of thermal loading.

Modified benchlife test

From the results of the conducted modified benchlife tests, it can be said that the combined effect of the sand temperature and the dwelling time of the sand mixture, has a significant negative impact on the bending strength of the warm-box sand cores (see Figure 7.).

According to the literature [1], the higher sand temperature adversely affects the hardening of the thermosetting resin due to its premature curing/cross-linking reaction. This phenomenon is clearly seen in Figure 7. The dwelling of the sand mixture at 40°C significantly decreases the strength of the produced sand cores.

This deleterious effect is more pronounced in sand cores containing a higher amount of acid hardener. In Table 5. the combined harmful effect of the sand temperature and dwelling time of the sand mixture on the strength reduction/loss of sand cores with different acid hardener levels are shown.

From the results, it can be said that sand specimens containing a 20 % percentage of acid hardener after 30 minutes of dwelling time at 40 °C and 30 minutes of storage time show a smaller decrease in strength than bending test bars having a 0.39% amount of acid hardener.

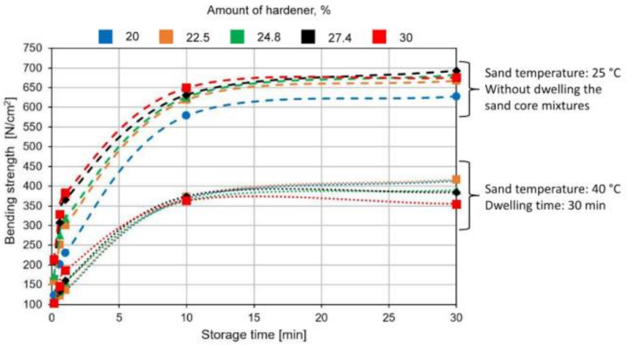

Fig. 7. The combined effect of the increased sand temperature and dwelling time on the hardening characteristic of the warm-box sand cores

According to the outcome of the modified benchlife tests, it can be stated, that the sand cores produced with the warm-box coremaking process are extremely sensitive to the combined impact of the sand temperature and dwelling time of the core mixtures on the hardening characteristics.

4. Conclusions

Based on the conducted research the following conclusions can be made:

- The warm-box sand cores having a low amount of binder content provide excellent bending strength values.
- Increasing the acid hardener content has a positive effect on the hardening characteristics of the warm-box sand cores.
- The increased acid hardener results in higher thermal stability at the beginning of the thermal exposure, and smaller residual bending strength after 15 minutes of thermal loading, thus possess good collapsibility performance.
- The warm-box sand cores are extremely sensitive to the combined effect of the dwelling time and the increased sand temperature which results in significant strength reduction during the hardening of the resin binder.

According to the literature, the warm-box coremaking process is characterized by a good working time of the sand mixture. Thus, it would be interesting to know the effect of the dwelling time and the sand temperature separately on the bench-life and the hardening characteristics of the sand cores. Furthermore, it would be important to know the impact of the different acid hardener content on the amount of gas released during the pouring process.

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