Reduction in Sand-Related Scrap Through Effective Sand Cooling

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ABSTRACT

Hot sand is sand that has a temperature so high that difficulties are encountered in preparation of the sand, in the molding of the sand, and in the casting results. The actual temperature of hot sand varies according to the authors cited. Generally, sand of 120F or higher is considered hot. Schumacher¹ stated that sand over 160F (71C) does not mull to any consistency in physical properties, but sand below 120F develops uniformity when mulled. Between 120F and 160F mulling produces sand that is inconsistent and difficult to control.

This paper presents data on sand temperatures taken over a long period of time before and after the sand cooler installations. The effects of hot sand on various properties, and on the scrap rate before and after sand cooler installations, are discussed. Here again, the time period is in months of data. A discussion of sand cooling principles is included as an appendix..

INTRODUCTION

Hot sand is the number one problem in foundry green sand systems and is the cause of more casting scrap than any other sand system problem. Hot sand is any sand so high in temperature that difficulties are encountered in the preparation of the sand, in the molding of the sand, and/or in the casting results. The actual temperature of hot sand varies according to the author cited. Generally sand of 120F or higher is considered hot. Schumacher¹ stated that sand over 160F (71C) does not mull to any consistency in physical properties, but sand below 120F develop uniformity when properly mulled. Between 120F and 160F, mulling produces sand that is inconsistent and difficult to control.

The data presented was taken over a long period of time. The temperature data covers several weeks before and after cooler installation and the scrap data covers a nine-month period before cooler installation and nine months after installation. The long term trends are shown in temperature reduction as well as scrap reduction.

The foundryman has been aware of the problem of hot sand and its many ramifications, but has done very little about it. What has caused the new interest in the subject? The more restrictive quality requirements that have come with the greater competitiveness of the world casting market, lower sand-to-metal ratios, higher line utilization, and insufficient sand storage space have been large factors in this interest. Casting requirements have become more stringent and today's customer will not accept the castings that were sold several years ago. The casting must be made right the first time, with less rework than in the past.

HOT SAND: WHERE DOES IT COME FROM?

In a regenerative green sand system, the composition of the sand mix is formulated to meet the requirements of the molding method and the type of casting produced. The typical system sand contains varying percentages of sand, bond, additives, and water. The sand system, the muller, and the molding machine process this mixture into a finished mold. To form the casting, molten metal is poured into the mold after which the heat of the metal causes damage to the mold and its materials. The damage that occurs will vary directly with the distance from the metal-mold interface. With successive cycles, if there is no cooling period, the heat content in the sand builds up to excessive levels.

How Does Hot Sand Affect the Foundry?

Hot sand will affect every aspect of a green sand molding operation. Depending on the foundry's ability to control the sand temperature, the results can range from higher than normal scrap rate to complete loss of system control.

Among the casting defects caused by hot sand are: sand inclusions, washes or erosion scabs, surface roughness, pin holes, crushes and broken molds. Sand inclusions, whether from erosion type of defects or expansion type of defects, and their reduction with the use of cooled sand, are the major consideration in this paper. Erosion defects are surface defects that consist of lump-like protrusions of metal above the intended surface of the casting. The lump replicates the depression caused by the erosion of the mold. Loose sand may or may not become embedded in the surface of the casting. The excess metal must be removed. Even more important than the removal of the scab is the location of the loose sand. This embedded sand may or may not scrap the casting, but it will cause a detrimental effect on any required machining.

The mechanism of erosion defects is the dislodging of sand grains or sand masses from the mold surface by metal impingement, metal turbulence, or gad agitation. Increased moisture in the molding sand enhances the erosion tendency. The increased moisture gives increased steam potential, which gives rise to more turbulence in the metal flow.

Scabbing defects are caused by the mold surface rapidly heating and converting the moisture into steam. The steam moves further in to the mold and condenses and adds to the normal moisture content of the sand. This combination forms a condensation layer of high moisture content. If the expansion forces developed by the expanding sand grains in the dry layer exceed the strength of the wet layer and the constraints of the mold, the mold surface begins to deform and expansion defects result. Rattails buckles, and scabs occur when the mold surface is unable t accommodate the expansion of the sand on heating by the metal poured. Rattails and buckles are the same type of defects in an insipient form, which did not have time to develop into scabs before the mold was filled and the casting solidified. Rattails occur primarily on the drag surface, while buckles and scabs usually occur on the cope surface or on vertical surfaces.

TOTAL SAND SYSTEM CONSIDERATIONS

In the late 1970's an Ad Hoc Committee of the AFS Molding Methods and Materials Division was formed to determine what needed to be done to foundry system sand to prepare it for green sand molding. In the 1980 AFS *Transactions*, Lee[2], principal author, reported the committee's findings. The conclusions reached were the following:

1) There is a wide and unfavorable variability in the quality of molding sand produced in mechanized foundries.

2) Standard sand testing does not generate enough significant data to design or control sand systems.

3) There is not sufficient time or control in the muller to correct for imbalances created in use, shakeout, and handling of sand.

4) Moisture control by automatic final-state correction is inadequate.

5) It is a conceptual error to concentrate controls in the muller, a sand system includes the mold pouring and cooling zone, shakeout, return belts and elevators, screens, bins and hoppers, and prepared sand delivery-as well as the molding machine.

6) Control must be exercised in each part of a sand system in order to effect control of prepared sand.

7) Used sand must be monitored and makeup additions adjusted accordingly.

Because of the variability that the total system contributes, the muller cannot be relied upon to maintain control and reduce the variability. Completeness of mulling is a very important factor in developing the maximum strength of the bond available and plays a very important part in resistance to erosion and expansion defects. The main objective in the preparation of molding sand is the uniform and complete dispersion of the clay binders and the water, in the proper amounts, in the sand aggregate. For the successful production of castings, it is essential that the supply of molding sand be consistent in properties and quality. Because system shakeout sand varies widely in moisture content, residual binder, and temperature, some means of compensation for these variations must be developed. The use of a sand cooler to control the variable temperature of the return sand is one way to compensate for the shortcomings of the system.

Appendix A gives more detail on the principles of physics that ate applied in cooling sand.

FOUNDRY SAND AND CASTING SCRAP RESULTS

The foundry to be considered is a gray iron foundry located in the Midwest of the United States. The foundry decided that because of the very high temperature of the prepared sand and the high variability of the sand, which in turn produced a high scrap, they would install coolers in both of their production molding lines. The shakeout sand temperature before the cooler installation are listed in Table 1. The data show that the foundry's assessment of the sand temperature, but it was also extremely variable within a day, or from day to day.

The type of cooler installed is the double-pan continuous cooler shown in Figure 1. The unique design of this cooler, which utilizes the evaporative cooling of air and water with controlled retention tie, meets the requirements for consistency in properties and quality of return sand. The cooler capacity/volume is relatively large in relation to the feed rate and, therefore, the retained mass absorbs the variations in the entering sand. The two pans each contain a counter-rotating head, to which are attached four mixing plows. The purpose of the plows is to move the sand forward, from charge point to discharge point, and to keep the sand in a state of agitation. This allows the cooling water and the air to be intimately mixed with the sand causes evaporative as well as convective cooling. Because the incoming sand is highly variable, the double-pan design and counter-rotating plows will constantly back-blend the sand. The plows are set at different vertical heights from the cooler bottom to get overlap in mixing from top to bottom.

The cooling air, supplied from a separate motor-driven fan, is introduced not the plenum chamber behind the cooler's inner wall. The air purges the sand of the water vapor produced by controlled moisture additions to the hot return sand. A self-adjusting door keeps the discharge rate equal to the incoming rate. The door is actuated by an electro-hydraulic device that controls the desired volume and retention time of the and in the cooler.

The amount of moisture added will depend on the sand geed rate and the temperature of the incoming sand. The moisture content is maintained at a level that will assure enough water for cooling with a targeted residual water in the sand discharge.

Table 1 shows the shakeout temperature data from line #1 prior to the cooler installation. All the shakeout sand temperatures exceed 230F and have a large range in temperatures. The shakeout sand went into one bucket elevator and two transfer belts before entering the sand storage bin. Additional ambient cooling would take place at all of these points. The temperature data from line 2 (not shown) is similar in nature. Both lines operate with the same type of molding equipment, and patterns are run interchangeably on both lines. The foundry has kept records on prepared sand temperature and still does record the temperature of each tested sand sample.

Table 2 gives the data on the average, range, and standard deviation of prepared sand temperatures for both lines. These sand sample temperatures are compared for February, a cold ambient temperature period, and July and August, a warm ambient temperature period, and for both before cooler installation and after cooler installation. It must be noted that these are temperature of sands prepared on two separate but similar lines. Variations come from slight metal mix changes, mulling equipment, and handling equipment. The decrease in temperature, in actual degrees change and also in the percent change in the range and standard deviation, indicates that in all cases the sand temperature is lowered and the variability has been lowered on the "after sand cooler installation" samples. The more consistent the sand is the more consistent the molds will be and, in turn, the more consistent the castings will be.

Figure 2 presents the shakeout sand temperature before and after the cooler installation. This data, which is based on a single complete day's comparison, shows the effect of the cooler in the system. Before the cooler was installed the average shakeout temperature was 375F, and after the cooler was installed the shakeout temperature was 258F, with the cooler in the system the heat buildup in the sand system was controlled to a lower average shakeout sand temperature.

Table 1
Line #1 Shakeout Sand Temperature Prior to Cooler Installation

	Temperature °C	**Temperature °F**
12:00 PM	220	428
12:30	220	428
1:00	120	248
1:30	200	392
2:00	190	372
2:30	220	428
3:00	220	428
4:00	220	428
5:30	160	320
6:00	330	626
6:30	260	500
7:30	150	302
8:00	150	302
8:30	150	302
9:00	160	320
9:30	220	428
10:00	110	230
10:30	130	266
Average Temp	190	375

Figure 3 shows the shakeout temperature and the out-of-cooler temperature for the same day on line #1. The shakeout sand temperature, even with a cooler in the line, has a great deal of variability, while the out-of-cooler sand runs in a very narrow band on temperature. The sand out of the cooler has retained moisture, therefore, the amount of moisture required for temper at the muller is less. This increased moisture makes the mulling of the sand less difficult.

Figure 4 shows the difference in prepared sand temperature for July and August, a high ambient temperature period for line #1, while Figure 5 shows the difference n prepared sand temperature for February, a low ambient temperature for sand, before the cooler was installed, was higher for the cold month of February. This was most likely due to the sand-to-metal ratio and line utilization at that time. The average prepared sand temperature, after cooler installation, in both cases was below 110F. The higher temperature of the ambient air used in the cooler may explain why the cooling, percentage-wise, in the warm months was not as great as in the cold.

Table 2.
Prepared Sand Temperature for Both Lines
Before and After Cooler Installation

LINE #1

	Before Cooler Installation	After Cooler Installation	Actual Change	Percent Change
	February	February		
Average Temp (F)	141.3	100.2	-41.1	-29.1
Range	30.1	13.0	-18.1	-60.1
Standard Deviation	12.9	5.6	-7.3	-56.6
	July & August	July & August		
Average Temp (F)	135.0	107.2	-27.2	-20.1
Range	18.3	13.0	-6.3	-34.4
Standard Deviation	7.9	5.6	-2.2	-40.5

LINE #2

	Before Cooler Installation	After Cooler Installation	Actual Change	Percent Change
	February	February		
Average Temp (F)	139.8	94.8	-45.0	-32.2
Range	19.2	15.1	-4.1	-21.3
Standard Deviation	8.3	6.5	-2.8	-33.7
	July & August	July & August		
Average Temp (F)	144.8	100.9	-43.9	-30.9
Range	24.9	9.7	-15.2	-61.0
Standard Deviation	10.8	4.1	-6.7	-62.0

Figure 6 shows the difference in temperature for line #2 for July and August, the warm period, while Figure 7 show the temperature for February, the cold period. On these two graphs the temperature of the prepared sand was higher for the warm months than the cold month sand, as would be expected. In both cases the temperature of the prepared sand was around 100F or less.

Table 3 lists the sand properties before and after the cooler installation on line #1 and Table 4 lists the same properties before and after cooler installation on line #2. The sand properties have not changed significantly. The standard deviation has gone down in many cases and stayed constant in the others. The molds made are more consistent and the scrap rate is lower after cooler installation. The amount of bond added, per batch, has not changed. The MB clay is slightly higher than on the before-cooler sand. The cooler sand allows the water to combine with the bond in a shorter time and, in turn, this appears to tie up the bond so not as much is drawn out by the dust collection system on the mullers.

Table 3.
Line #1 Prepared Sand Properties
Before and After Cooler Installation

	February (Cold Ambient Air)		July & August (Warm Ambient Air)	
	Before Cooler Installation	After Cooler Installation	Before Cooler Installation	After Cooler Installation
Moisture				
Average	3.1	3.7	3.8	3.6
Std. Dev.	0.1	0.2	0.2	0.2
Compactability				
Average	45.7	47.4	50.0	44.0
Std. Dev.	2.7	2.0	3.7	2.5
Green Strength				
Average	17.8	19.3	16.6	18.0
Std. Dev.	1.2	1.1	1.3	1.2
M.B. Clay				
Average	7.9	8.5	8.1	8.2
Std. Dev.	0.4	0.4	0.3	0.3
Temperature				
Average (F)	141.3	100.2	135.0	107.2
Std. Dev.	12.9	5.6	7.9	5.6

Table 4
Line #2 Prepared Sand Properties
Before and After Cooler Installation

	February (Cold Ambient Air)		July & August (Warm Ambient Air)	
	Before Cooler Installation	After Cooler Installation	Before Cooler Installation	After Cooler Installation
Moisture				
Average	3.1	3.7	3.7	3.8
Std. Dev.	0.3	0.3	0.3	0.3
Compactability				
Average	43.2	44.4	50.0	43.2
Std. Dev.	3.8	4.8	4.9	4.3
Green Strength				
Average	18.2	16.9	14.4	17.0
Std. Dev.	1.2	1.1	1.7	1.4
M.B. Clay				
Average	8.3	8.3	8.0	8.3
Std. Dev.	0.5	0.3	0.6	0.3
Temperature				
Average (F)	139.8	94.8	144.8	100.9
Std. Dev.	8.3	6.5	10.9	4.1

Because of lack of data on the sand temperatures entering and exiting the cooler, line #1 was monitored completely for the two shifts run one day. The results on checks on line #2 were not significantly different, so only the line #1 data is presented. Table 5 lists all temperatures and properties for one complete day. The data gathered was the shakeout temperature, shakeout plus spill sand temperature, sand temperature out of the cooler, electronic probe temperature of sand entering the cooler, laboratory sand sample temperature, sand to metal ratio, moisture on the laboratory sample, compactibility, MB Clay, green compression, and permeability. The shakeout into the cooler and the out-of-cooler sand was sampled in a gallon paint can and a thermometer was probed into the sand in four to five places. This probing gives the range shown in Table 5. There is no explanation for the lower green compression strength for the first five to six hours of operation. The afternoon and evening strengths are back up to the expected 22-24 psi range. The molds were of comparable quality and the next day's scrap sheet did not show any significant changes.

One of the measures of the consistency of the sand is the scrap rate reduction. The principal sand defect was sand inclusions. Figure 8 shows the scrap rate before and after the cooler installation. This scrap reduction was 34.5% for the nine-month period following installation versus the nine-month period before installation. Not only was the amount of scrap reduced, but the variation in the scrap rate was also reduced. The metal mix for the two nine-month periods was very similar, and the various castings were made on both lines during both periods. The foundry stated that the reduction in scrap, due to reduced sand inclusions, was great enough to return the investment in the coolers in less than 15 months.

Table 5.
Temperatures and Properties on Line #1
*(*Typical results after sand cooler installation)

Time	**Shakeout Temp (F)**			**Out of Cooler Temp (F)**	**Sand Lab Temp (F)**	**Moisture**	**Compact (%)**	**MB Clay (%)**	**Green Compression**	**Permeability**
6:30					90	3.7	49	8.4	19.4	130
7:30					85	4.0	44	8.7	19.8	125
9:00		190-215	174	104						
9:15										
9:30		200-235	167		90	3.8	47	8.6	18.2	134
9:45			178							
10:00				88						
10:15		230-240	171							
10:30	200-235	210-215	187	102						
10:45										
11:00		170-190	175	107						
11:15				84						
11:30	200-215	190-210								
11:45	190-210	185-195	180	96						
12:00										
12:15										
12:30	180-195		175	93	90	4.0	48	8.5	17.4	140
12:45										
1:00	210-225	180-195								
1:15				98						
1:30		190-210	171	94						
1:45		195-230								
2:00	240-265	210-240		105						
2:15	350-500	300-325		100						
2:30	275-305	300-340		90						
2:45	230-250	200-240		106	92	3.8	45	8.8	24.0	145
3:00	250-275		180	100						
3:15				102						
3:30	250-290			96						
3:45					92	3.7	44	8.6	23.0	135
4:00	275-300			102						
4:15	260-305	200-230	190							
4:30	260-290	200-230		100						
4:45		220-250		104						
5:00										
6:35	240-270	200-230		100	96	3.7	41	8.8	24.2	130
8:40					92	3.7	38	8.8	23.6	120

SUMMARY

The high and variable temperature of molding sand makes control difficult and increases the scrap produced on any line in the foundry. Installation of sand coolers decreased the scrap produced and decreased the variability of all sand properties. The installation of the sand coolers reduced the scrap rate enough to return the investment on the coolers in less than 15 months. Not only was the scrap reduced, but the general overall casting appearance was substantially improved.

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APPENDIX A

Sand Cooling and the Laws of Physics

The total amount of the to be removed from foundry return sand is a function of: 1) the initial temperature of the sand; 2) the desired temperature of the cooled sand, and weight of sand to be cooled; 3) the ambient condition of the cooling air and to a lesser extent, 4) the temperature of the cooling water.

The cooling of foundry sand by evaporative methods follows the laws of physics. The use of water evaporation is the most economical method of cooling sand. For every pound of water evaporated approximately 1000 Btu of heat are removed from the sand. To calculate the total heat that must be removed to give the desired cooling, the following formula, ignoring residual moisture content of the sand, is used:

$$Q=(T_1-T_2)\ (c)\ (m)$$

Where
Q = Heat Expressed in British thermal units (Btu)
T_1 = Initial temperature (°F)
T_2 = Final sand temperature (°F)
c = Thermal capacity (Btu/lb/°F), app. 0.19 for silica sand
m = Sand mass in pounds

For example, to cool 1 ton of sand per minute from 300F to 100F requires the removal from the sand of

$$(300-100)\ (0.19)\ (2000) = 76{,}000 \text{ Btu per minute}$$

or roughly the evaporation of (ignoring the sensible heat effects of the water and air)

$$76{,}000 \text{ Btu}/1{,}000 \text{ Btu/lb} = 76.0 \text{ lb of water per minute}$$

the rate of heat flow is primarily limited by the thermal conductivity of the sand through which the heat must flow and the temperature differential existing between the sand grain center and its surface. No one should make the mistake of believing that just because sand grains are small heat removal can be accomplished almost instantaneously, even if the method of heat extraction is extremely efficient.

To reduce the temperature, the heat must be transferred from the sand grains to another media, which must be disposable without creating atmospheric pollution and which must be readily available at low cost. Air and water vapor fulfill these requirements, provided both are free of solids when discarded. Both the air and water must come into contact with as many sand grain surfaces as is practical. The intimately mixed air, sand, and water must be in contact a sufficient time for the heat to flow from the center of the sand grain to its surface, where the heat exchange can take place.

Whenever a liquid (water) is evaporated, heat must be supplied from some source, which, in this case, is the sand grain heat content. The higher the temperature, the higher the vapor pressure of the water and, the higher the water vapor pressure, the higher the rate of evaporation. If the sand surface temperature is over 212F (100C) the vapor pressure then exceeds the atmospheric pressure of the air around it. Below 212F the rate of evaporation is somewhat reduced, but continued evaporation at a slower rate does proceed.

The water vapor initially formed must be removed from the sand surface so that further vapor can form. By mechanically fluidizing the sand mass and mixing it with a continuous supply for fresh, cool air, the water vapor formed is flushed away from the sand surface by the fluidized air. The lower the temperature and relative humidity of the incoming air, the more effectively it will cool the sand in a given exposure or treatment time.