Parametric Optimization of Green Sand Moulding Process Based on Wet Tensile Strength – A Full Factorial Experimental Approach

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Abstract

Wet tensile strength is an important mould characteristic which specifies the strength of the mould at elevated temperature. Wet Tensile strength has a direct bearing on casting defects like scabs, rattails, buckle etc. Foundries usually concentrate on mould characteristics like green compression strength, green shear strength, permeability etc. but ignore wet tensile strength Hence in present investigation optimization of process parameters of green sand molding for maintaining minimum required value of wet tensile strength with reasonably good values of Green Compression Strength and Permeability is attempted. Process parameters considered are percentage of bentonite, mulling time and compact ability. A full factorial experimental approach is adopted for the purpose. It is observed that 9% bentonite, 11 minutes mulling time with a compact ability of 45 is the optimum level of process parameter for minmum required value of Wet tensile Strength with reasonably good values of green compression strength and permeability.

Keywords: *Wet Tensile Strength, Mould scabbing, Expansion rattail, Green compression strength, Green shear strength, Mulling time.*

1 Introduction

Casting is one of the prominent primary manufacturing processes. Though several casting processes are available sand casting is widely used in India. Majority of the engineering components are made up of ferrous materials and more importantly by gray cast iron and steel. Green sand molding is one of the extensively used molding process for producing the gray cast iron and nodular cast iron castings in bulk due to its simplicity, cost effectiveness and ease of automation [1].The quality of the castings produced and productivity in green sand molding mainly depends upon the type of additions (like binder, moisture etc.) that are made to the silica sand [2]. Hence, in order to yield a casting of sound quality one has to exercise a perfect control over the molding sand properties. Molding sand properties can be influenced by quality and quantity of binder, amount of moisture content (water addition) and mulling time. As the green sand is mulled properly the moisture content of the mould is more or less uniform till the molten metal is poured in [3]. As the molten metal is poured in, the moisture in sand mould near to metal mould interface vaporizes and escapes to relatively colder areas through porosity in sand mould and gets condensed. Consequently a thin layer of sand that is saturated with water, called condensation or wet layer zone is formed. Beyond this layer the sand contains normal moisture percentage i.e. the moisture content throughout the mould is not uniform. A dry hot and moisture free zone near the metal mould interface and next to that is wet weak condensation zone followed by unaffected zone. Thereby a water condensation zone is formed between dry and still wet sand i.e. a thin layer of dry sand separates from rest of still wet sand. To prevent scabs, which is one of the prominent casting defects, the strength of sand in water condensation zone should be high and this strength is known as wet tensile strength which has high impact on scabbing tendency of mould. The minimum wet tensile strength to be maintained for green sand mould is 25 gm/sq cm. About 50% of the defects in castings are related to the sand like mould scabbing, rattail, penetration etc [4]. Mould scab is breaking of small piece of mould at the metal mould interface and falling into the hot metal. Hence the present investigation is concentrated on optimizing process parameters of green sand molding for better wet tensile strength.

1.1 Objective

Primary objective of this investigation is to experimentally determine the optimum values of process parameters of green sand molding for better wet tensile strength.

1.2 Methodology

Deciding the process parameters of the process that affect wet tensile strength and deciding the level values of each parameter based on previous experience and literature. Deciding experimental plan. Deciding optimum levels of process parameters based on experimentally obtained values of wet tensile strength.

2. Process parameters and their level values

Process parameters considered are quantity of bentonite, mulling time and compactability.

2.1 Quantity of Bentonite

Bentonite is one type of clay used as a bonding agent in green sand mould preparation. It is a fine grained clay containing predominantly mantmorlianite (>85%). Bentonite flakes are clustered with chemical substances which ionize readily in water. It has a strong negative imbalance and has a capability of base exchange. Though other clays like kaolinite and illlite are available but their base exchange capacity is less compared to bentonite. Hence bentonite is considered as main bonding agent of the process. Literature reveals that usually 7 to 10% of bentonite is used [7]. So in the present work four levels 7%, 8%, 9% and 10% bentonites are used.

mulling over mixing process is perfect blending of the materials that can't be easily dispersed by virtue of their high viscosity. The Muller utilizes wheels

3. Response characteristics

Response characteristics considered are wet tensile strength, green compression strength and permeability [7].

3.1**.** Wet tensile strength

Wet tensile strength is prime responsible for sand expansion defects like scabbing [4, 5]. From the sand layers adjacent to casting the water moves away. There by a water condensation zone is formed between dry and still wet sand. Thin layer of dry sand separates from the rest of still wet sand. To prevent scab the strength of the sand in water condensation zone should be high and this strength is called wet tensile strength. Minimum wet tensile strength to be maintained for green sand mould is 25 gm/sq.cm [6].

3.2. Permeability

Permeability values of molding sand should not be too high and should not be too low. Too high permeability weakens the mold and too low permeability lead to defects like porosity etc. Attempt of every foundry men is to maximize the strength with sufficient permeability [7].

3.3. Mulling time

Mulling imposes a strong force on a mixture in order to develop strength and plasticity of the clay bond and also to coat sand grains uniformly with a thin film of developed clay and water. Superiority of mulling over mixing process is perfect blending of the materials that cannot be easily dispersed by virtue of their high viscosity. The Muller utilizes wheels that incorporate both compressive and shearing force to activate the bentonite particles and coat the Bentonite putty on the sand grains influencing the strength development process of green sand mould. Mulling time is an important factor because too low mulling times hampers the strength development process. Usually a mulling time of around 10 minutes is used in laboratory scale mulling. In the present work four levels of mulling time from 7 minutes to 13 minutes are considered (table1)

3.4. Compactability

Compactability level of molding sand should be selected on the basis of molding performance and casting quality. Too high compactability values produce voids on the vertical faces of the mould. Increase in moisture content is the indication of increase in compactibility which may lead to blow holes, pin holes, expansion defects etc. Normal levels of compactibility are 35 to 40 for conventional grey iron castings and for steel casting it may be even up to 50. Hence four levels of compactibility 35, 40, 45 and 50 are considered (table-1)

3.5. Green compression strength

Green compression strength is the ability of sand mould to withstand pressure of molten metal. A minimum 1600gm/cm^2 green compression strength is to be maintained.

4. Experimental procedure

In pursuit of optimizing process parameters of green sand molding process full factorial experimental approach is adopted i.e. by varying one factor at a time. Four levels of bentonite addition, four levels of mulling time and four levels of compact ability are considered. For each sand mix green compression strength,permeability and, wet tensile strength determined. Experimental plan is depicted inTable1.

Table1: Experimental plan

Bentonite additions	7% 8% 9% 10% [4]
Mulling times(min) for each addition of bentonite	7 9 11 13 [4 X 4]
Compactability values for each bentonit addition and for each mulling time	35 40 45 50 [4 X 4 X 4]
Total mixes	4 X 4 X 4 = 64

4.1 Experimentation

Initially grain fineness number of silica sand is determined. Silica sand with grain fineness number of 59.49 is selected for the present work. Grain fineness number and sieve distribution of the silica sand under consideration is given in Table -2.

Table-2

U.S. Sieve Number	Multiplying Factor(M)	Weight of sand retained on each sieve (F)	M * F
20	10	Nil	0
30	20	1.24	24.8
40	30	10.1	303
50	40	13.24	529.6
70	50	41.58	2079
100	70	19.04	1332.8
140	100	12.36	1236
200	145	1.36	197.2
270	200	0.72	144
Pan	300	0.34	102
		∑F = 99.98	∑M*F = 5948.4

G.F.N=(∑Mi.Fi)

G.F.N=5948.4/99.98=59.49

Where Mi = Multiplying factor for the ith sieve

Fi = Amount of sand retained on the ith sieve

4.2 **Mulling sequence**

Initially sand is dry mulled along with bentonite for one minute and then wet mixed with proper quantity of water to yield desired compactibility.

4.3. Determination of mould characteristics

As per **ASTM** standard (2” x 2” cylindrical) sand samples are prepared with all the 64 mixes as mentioned in the experimental plan. For all the samples green compression strength is determined with universal sand strength testing machine, permeability is measured with permeability meter, wet tensile strength is determined with wet tensile strength testing machine and the results are tabulated in Table-3[a] and Table-3[b].

5. Results and discussion

The following observations are made through experimentally obtained values of Wet Tensile Strength, Green compression strength and permeability at various levels of parameters considered in the experimental plan (Table 1 and Table 2) for any of the mulling times considered: As the percentage of bentonite increases Wet Tensile Strength increases. The rate of increase is initially low and between 8% and 9% additions Wet Tensile Strength increases more steeply. However for the mulling times of 7 minutes and 9 minutes the wet tensile strengths are less than minimum requirements of Wet Tensile Strength values. Hence it can be concluded that mulling times below 11 minutes is not at all producing encouraging results. In few cases (with 10% bentonite and 50 compactability) Wet Tensile Strength crossed the bare minimum value of 25grms/sq cm, but corresponding Green compression strength values are much lower than minimum. Hence it can be concluded that any mulling times below 11 minutes cannot produce satisfactory results and cannot be considered. Hence the next option is observing the experimental values at 11 minutes and 13 minutes mulling times. During the experimentation it is experienced that, for 9 to 11 minutes mixes, quantity of water addition is decreasing to get same compactability. But it is increasing again for 13 minutes mixing. Probably the excessive heating of the sand grains during the mulling times beyond 11 minutes could be attributed to this kind of behavior.

By observing the properties of mixes with 11 minutes 13 minutes mulling bentonite additions beyond 8% and compactability values beyond 40 are producing good values. Hence the bentonite additions with 9% and 10% at 11 minutes and 13 minutes mulling times with combactability values of ’45’ and ‘50’ are to be considered. Through the mixes with 10% bentonite, 11 minutes mixing and compactability of 45 and 50 are slightly better than 9% bentonite mixes we prefer to have 9% bentonite mixes in economy point of view 1% bentonite. 9% bentonite mix with 11 minutes mulling time at 45 and 50 compactability levels producing sufficiently good Wet Tensile Strength vales but Green compression strength values slightly less than the minimum value at compactability of 50. Hence a mix with 9% bentonite, 11 minutes mulling time with a compactability of 45 is producing good wet tensile strength with resonbly go Green compression strength od and permeability.

Table-3(a)

% of Bentonite		Mulling time					
		7 minutes			9 minutes		
		WTS	GCS	P	WTS	GCS	P
7%	35	12.6	900	85	14	1000	112
	40	15	1000	96	14.06	1000	102
	45	15.4	1100	102	14.06	1000	112
	50	15.9	1200	119	16.3	1100	115
%	35	15.2	1150	99	15.27	1000	82
	40	18.5	1250	115	16.23	1300	93
	45	19	1400	126	18.06	1350	102
	50	19.4	1300	122	18.96	1450	108
9%	35	19.2	1000	85	18.6	1100	85
	40	19.6	1100	99	22.1	1400	105
	45	23	1350	119	22.16	1200	108
	50	23.6	1350	115	24.4	1450	119
10%	35	20	1200	82	21.93	1500	77
	40	20.26	1100	88	21.96	1350	90
	45	23.2	1150	105	22.16	1300	96
	50	25.56	1250	122	25.9	1500	115

Table-3(b)

% of Bentonite		Mulling time					
		11 minutes			13 minutes		
		WTS	GCS	P	WTS	GCS	P
7%	35	15	1250	104	15.9	1350	105
	40	17	1250	104	17.4	1350	102
	45	17.1	1250	108	17.6	1250	119
	50	17.6	1350	105	17.8	1250	138
8%	35	15.6	1150	99	18.5	1250	96
	40	16.8	1400	126	18.86	1400	115
	45	18.4	1400	119	19.57	1450	115
	50	18.8	1300	115	22.76	1450	119
9%	35	21	1500	99	22	1550	93
	40	22.6	1200	115	22.13	1650	99
	45	25.5	1600	122	26.9	1650	105
	50	27.23	1450	126	29.9	1700	115
10%	35	22.86	1500	85	25.8	1700	108
	40	25.3	1750	90	26.8	1750	119
	45	25.7	1600	99	29	1850	122
	50	27.6	1700	112	29.13	1650	138

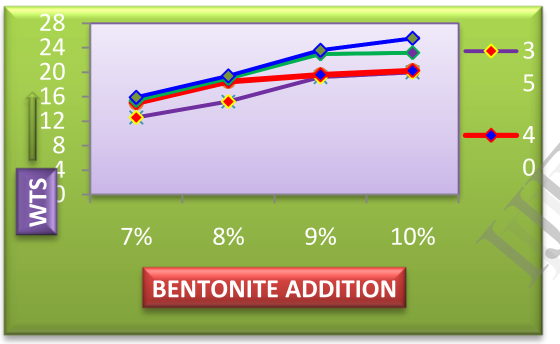

Fig 1: Variation of wet tensile strength as function of Bentonite addition at various compactibniluty values for 7 minutes

9 Minutes mulling

	7%	8%	9%	10%
35	12.6	15.2	19.2	20
40	15	18.5	19.6	20.26
45	15.4	19	23	23.2
50	15.9	19.4	23.6	25.56

7 Minutes mulling

	7%	8%	9%	10%
35	12.6	15.2	19.2	20
40	15	18.5	19.6	20.26
45	15.4	19	23	23.2
50	15.9	19.4	23.6	25.56

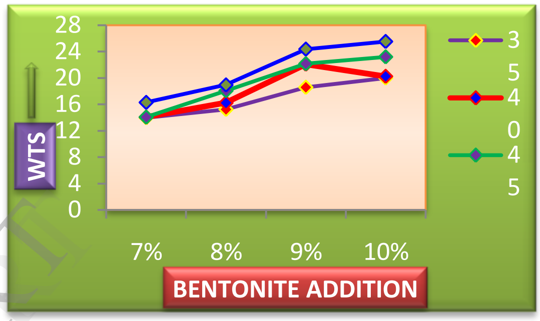

Fig 2: Variation of wet tensile strength as function of Bentonite addition at various compatibility values for 9 minutes

11 Minutes mulling

	7%	8%	9%	10%
35	15	15.6	21	22.86
40	17	16.8	22.6	25.3
45	17.1	18.4	25.5	25.7
50	17.6	18.8	27.23	27.6

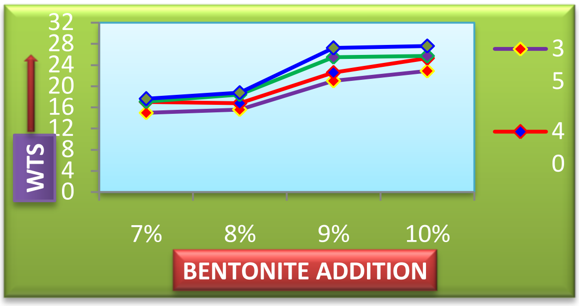

Fig 3: Variation of wet tensile strength as function of Bentonite addition at various compatibility values for 11 minutes mulling time.

13 Minutes mulling

	7%	8%	9%	10%
35	15.90	18.50	22.00	25.80
40	17.40	18.86	22.13	26.80
45	17.60	19.57	26.90	29.00
50	17.80	22.76	29.90	29.13

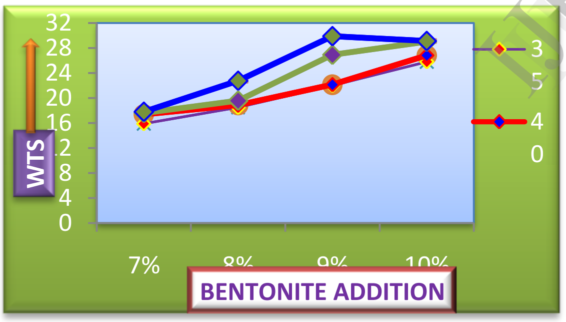

Fig 4: Variation of wet tensile strength as function of Bentonite addition at various compatibility values for 13 minutes mulling time.

It has been observed that any mixing time of below 11 minutes is not producing good results. In few cases wet tensile strength is good enough but green compression strength is less than required value. It suggests that a minimum of 10 minutes is needed when sand is being mulled. It is experienced that quantity of water addition is decreasing to get the same compactability for 9 to 11- minute mixes, while it is increasing again for 13 minute mix. This suggests that the sand grains are getting heated during the 13th minute due to which the water absorption is increasing probably. There is considerable increase in Wet Tensile Strength with increase in the percentage of bentonite added. Increase in Wet Tensile Strength was recorded with increase in compactability. Wet tensile strength involves exposing the surface layer of sand to a high temperature and so this property was found to be good in sands having higher percentage of moisture, than sands having lower percentage of moisture. Considerable increase in Wet Tensile Strength was found with increased mulling times. For mixes with 9 & 10% bentonite, 11 and 13-minute mixes are good in all the properties, i.e., the percentage of bentonite was sufficient to produce the required properties. The mix with 10% bentonite and mulling times of 11 minutes and 13 minutes with compactabilities of 45 and 50 can be considered the best in 10% mixes. (fig 1 to4 and table 2). With 9% bentonite, for a mulling time of 11 minutes and a compactability of around 45 to 50 can be considered to be the optimum mix in the whole 64 mixes because there wet tensile strength is more than 25gm/sq.cm . Though the mixes with 10% bentonite, 11 minute mixing and a compactability of 45 and 50 are better than 9% bentonite mixes, it is not been preferred as 1% more bentonite incurs more expenditure for a very meager rise in properties. Further at 9% bentonite additions higher mulling times the permeability values are also observed to be better than mixes of 10% bentonite additions. (tables 2)So it is concluded that optimum values of parameters are 9% bentonite, 11 minutes mulling time and a compactability of 45.

Conclusions

It is observed that bentonite addition, mulling time and compactabilty have significant influence on wet tensile strength. It is concluded that 9% bentonite 11 minutes mulling time with a compactaibility of 45 is the optimum level of process parameters for maximizing wet tensile strength along with reasonably good values of green compression strength and permeability.

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