Mechanical Properties and Loss on Ignition of Phenolic and Furan Resin Bonded Sand Casting

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Abstract— Resin bonded sand casting offers advantage than green sand casting in terms of strengthening of the mould by means of adding resin binders and hardeners. In this work, two sets of binders and catalyst were used to understand the effect of different ratio of these binders and hardeners to the mechanical properties and loss of ignition (LOI) of the mould. Phenolic and ester in the first set and furan and sulfonic acid in the second set were used as binders and hardeners, respectively. The moulds were then studied for their tensile, transverse and compressive properties as well as LOI. The results also suggest the best set of ratios that could comply with the nominal properties required by manufacturers. This study is a preliminary work for the development of biodegradable resin bonded sand casting.

Index Terms— Resin bonded sand casting, Phenolic Resin, Furan, Mechanical Properties, Loss on Ignition.

I. Introduction

Sand casting developed more than 6,000 years back due to the needs of shaping copper that was only can be shaped for relatively simple forms using forging process. Nowadays, sand casting is commonly used to form wide variety of metal components with intricate shape and geometries. Automotive components such as engine blocks, manifolds, cylinder heads and transmission cases are among typical components made of sand casting process besides other vast applications. Sand casting process can be divided into three operations i.e. fabrication of pattern, making of the mould and pouring of the raw materials. This study focuses on the process of mould making and therefore only this operation will be reviewed in this section.

In making of the mould, the sand particles are held together by a typical mixture of 90% silica sand, 3% water and 7% clay. Other bonding agents can be used in place of clay, including organic and inorganic binders. Additives (catalysts or hardeners) are sometimes combined with the mixture of sand and binder to enhance properties such as strength of the mould [1]. Sand casting with these mixtures is called resin bonded sand casting. It is claimed can give better dimensional accuracy on cast product than the green sand process [2].

Resin bonded sand consists of 93-99% silica and 1-3% binders [3]. Binders give bond, cohesion and strength to the mixed sand during mould ramming to ease the shaping process and retain it shape under pressure, temperature and erosion of liquid metal during pouring process. Among most common resins used in the foundry in Malaysia are phenolic and furan.

A highly alkaline phenolic resin generally containing up to 25% potassium hydroxide is used as binder in ester no bake process [4]. No bake process is another name for resin bonded sand casting in which resin is self-setting at room temperature. In phenolic-ester no bake mould, 1.5 – 2% of the phenolic resin (based on the weight of sand) is first blended into the sand, followed by about 20% of an ester (based on weight of resin) [4]. The reaction between the ester and phenolic resin leads to curing and solidification. Since the binders are free of nitrogen and sulfur, it affords foundry engineering advantages for steel, nodular iron and aluminum casting.

Furan resin is made of from fufuryl alcohol and its most important application is in foundry industry. It is somewhat more expensive than other binders but the possibility of sand reclamation is advantages. One of the advantages of furan binders over phenolic resin are in fact it has free phenol level, low formaldehyde, and produce less odor and smoke during casting process [5]. No bake furan mould is used in casting all kinds of cast steel, cast iron, non-ferrous metal castings. 100 parts by weight of sand are mixed with 20 – 30 parts of by weight of an aqueous acid catalyst and to this mixture is then added a quantity of of 1 to 2 parts by weight of suitably compounded furan resin to give a mould material solidifying to the desired strength and in the desired period of time [5]. Materials known to be suitable for curing furan resin include hydrochloric acid, sulfuric acid, nitric acid, phosphoric acid, tartaric acid, maleic acid and sulfonic acid [6]. Brown [2] suggested that hardener ratio for furan system to be between 40 – 60%.

Sand testing is essential to understand the properties of the resin bonded sand mould. Some of the most important sand testing are moisture, permeability, strength, compactability and loss of ignition (LOI) test [2]. In this study, tensile, transverse and compression testing and LOI were employed.

This study is a preliminary work for the development of biodegradable resin bonded sand casting. High cost of silica sand, the growing cost of disposing the used foundry sand and hazard due to the disposal on non-biodegradable binders and hardeners to the environment have become motivation to the development of the biodegradable sand mould.

II. Objectives Of The Study

The main objectives of this work were, firstly, to study the effect of different ratio of binders and hardeners to the tensile, transverse and compression test properties and LOI of the resin bonded sand casting moulds, secondly, to compare between the phenolic-ester and furan-sulfonic acid bonded sand casting in terms of the mechanical properties and LOI

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and, finally, to suggest set of resin-binder ratio that could give properties to those outlined by the manufacturers.

III. Experimental Methods

A. *Design of Experiment*

Based on values suggested from the review and manufacturer specification a set of variables were determined. Table 1 shows the total weight of phenolic resin and ester hardener based on the percentage ratio. Table 2 shows the total weight of furan resin and sulfonic acid hardener. The weight calculations were based on the weight of sand used to produce each sample i.e. 3kg.

TABLE I. TOTAL WEIGHT OF PHENOLIC RESIN AND ESTER BASED ON PERCENTAGE RATIO

Sample No.	Sand (kg)	Phenolic resin (%) by weight of sand	Resin Weight (g)	Ester (%) by weight of resin	Hardener Weight (g)
1	3	2.0	60	25	15
2	3	2.5	75	25	18.75
3	3	3.0	90	25	22.5
4	3	3.0	90	30	27
5	3	2.5	75	30	22.5
6	3	2.5	75	20	15
7	3	3.0	90	20	18
8	3	2.0	60	30	18
9	3	2.0	60	20	12

TABLE II. TOTAL WEIGHT OF FURAN RESIN AND SULFONIC ACID BASED ON PERCENTAGE RATIO

Sample No.	Sand (kg)	Furan resin (%) by weight of sand	Resin Weight (g)	Sulfonic acid (%) by weight of resin	Hardener Weight (g)
1	3	2.2	66	55	36.3
2	3	2.2	66	60	39.6
3	3	2.4	72	55	39.6
4	3	2.4	72	60	43.2
5	3	2.0	60	50	30
6	3	2.2	66	50	33
7	3	2.0	60	55	33
8	3	2.4	72	50	36
9	3	2.0	60	60	36

B. *Sample Preparation*

The sand, resin and hardener were weighted by using a digital scale and poured into a sand mixer. They were mixed for 10 seconds. The sand mixture was taken out from the mixture through a gate and put into moulds for tensile, transverse and compression testing. The samples were cure for 20 minutes before they were taken out of the moulds. Figure 1 shows the tensile, transverse and compression test moulds filled up with the sand mixture. The same procedures were repeated for all set of sample number. Total of 5 samples were prepared for each sample number.

Fig. 1 Moulds and samples for tensile, transverse and compression testing and LOI.

C. *Samples Testing*

Tensile testing of the samples in a shape of dumbbell or dog bone was performed after 24 hours of the moulding and curing process. Motor driven universal sand strength machine model US-M was employed for the tensile test. The samples were clamped between attachments as shown in Figure 2. The load was set to 120 kgcm^{-2}. The attachments were pendulum type. Tensile force was applied until the samples were broken into two parts. Reading was taken based on the distance where the magnet bar stopped. Tensile strength was determined by Equation 1.

$$\text{Tensile strength } (kgcm^{-2}) = 4.0 * \text{reading at magnet bar} \quad (1)$$

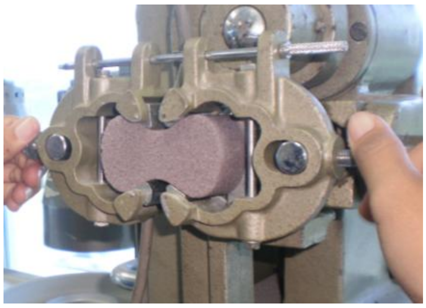
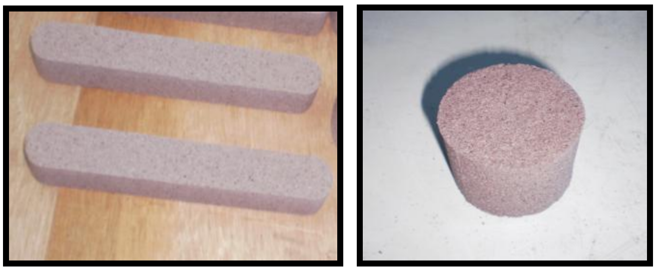


Fig. 2 A sample was clammped between the attachments of the universal sand strength machine

Using the same machine, the attachments for tensile testing were disassembled and attachments for transverse test were mounted. It consists of specimen holder and knife-edge. Transverse test was performed to measure the bending strength. The sample was placed in vertical position and the knife-edge pressed at the center until it was broken into two parts. Reading at the position of the magnet bar stopped was recorded. Transverse strength was read based on Equation 2. Figure 3 (a) shows the sample for transverse strength test.

$$\text{Transverse strength} (kgcm^{-2}) = 8.65 * \text{reading at magnet bar} \quad (2)$$

Compressive strength test was performed using a universal testing machine (UTM). Samples for the test were cylindrical shape with 50 mm diameter and 50 mm height (Figure 3(b)). The sample was placed in between a compression holder. The sample was pressed at load of 1200 N until the sample was broken. Result was displayed from the aided software.



(a) (b)

Fig. 3 Samples for (a) tranverse strength and (b) compressive strength testing

D. Loss on Ignition (LOI)

Loss on ignition was performed to test to measure amount of moisture or impurities loss when the sample was ignited. It also determines the presence of organic or other gas forming materials in the sand mixture. Sand mixture according to ratio set in Table I and II was weighted for 10 g and put into a crucible. The samples were then heated at 1000°C for 30 minutes in a port clay kiln. After the samples were taken out of the kiln or oven, they were immediately placed in desiccators. The samples were again weighted and LOI was measured according to initial weight minus final weight and divided by the initial weight in unit gram.

IV. Results and Discussion

A. Tensile, Transverse and Compressive Strength

1) Phenolic – Ester Sand Mould

Table III shows results for tensile, transverse and compressive strength for phenolic–ester bonded sand moulds. The values were averaged from 5 samples for each set of percentage ratio. It was observed that maximum tensile strength was obtained for 7.9 kg/cm^2 when resin ratio was 3.0% and hardener was 20%. Maximum transverse strength and compressive strength were obtained when resin and hardener ratio were 3.0% and 30% i.e. 6.7 kg/cm^2 and 17.8 kg/cm^2, respectively.

Minitab software was used to construct main effect plots as shown in Figure 4. The main effect plots display the responses means for each factor. Magnitudes for the main effects are shown by the differences between the means and reference line. It is clearly observed from Figure 4, effect of the resin is more significant than the hardener on the phenol-ester bonded sand moulds. This result is supported by Foseco Foundry [7] that ester catalyst is a fixed addition of 20 – 25% based on the weight of binder and between these ratios the strip time of the hardening process did not change significantly. Reaction time and speed can be altered by changing the grade of the ester solution.

From the plot, it could be observed that tensile, transverse and compressive strength of the moulds increased with the increased of phenolic resin. Brown [2] claimed that tensile strength of the phenolic resin bonded sand moulds could be ~ 9 kg/cm^2 for ratio of resin and hardener 2 – 2.5% and 20 – 25%, respectively. As for the transverse and compressive strength, review shows that maximum values could be ~ 16 and 40 kg/cm^2, respectively. Apparently, with higher ratio of resin and hardener employed in this study, the maximum tensile, transverse and compression strength obtained is low.

TABLE III. Tensile, Transverse and Compressive Streng for Phenolic – Ester Bonded Sand Casting Mould

Run	**Resin (% by weight of sand)**	**Hardener (% by weight of resin)**	**Tensile strength (kg/cm^2)**	**Transverse strength (kg/cm^2)**	**Compressive strength (kg/cm^2)**
1	3	25	7.5	6.1	14.7
2	2	20	6.0	4.8	11.1
3	3	30	7.2	6.7	17.8
4	2.5	30	6.9	5.6	16.6
5	2.5	20	5.8	4.8	16.5
6	2	30	4.3	3.2	12.6
7	2	25	0.5	4.6	12.0
8	2.5	25	2.4	4.4	13.6
9	3	20	7.9	6.3	15.5

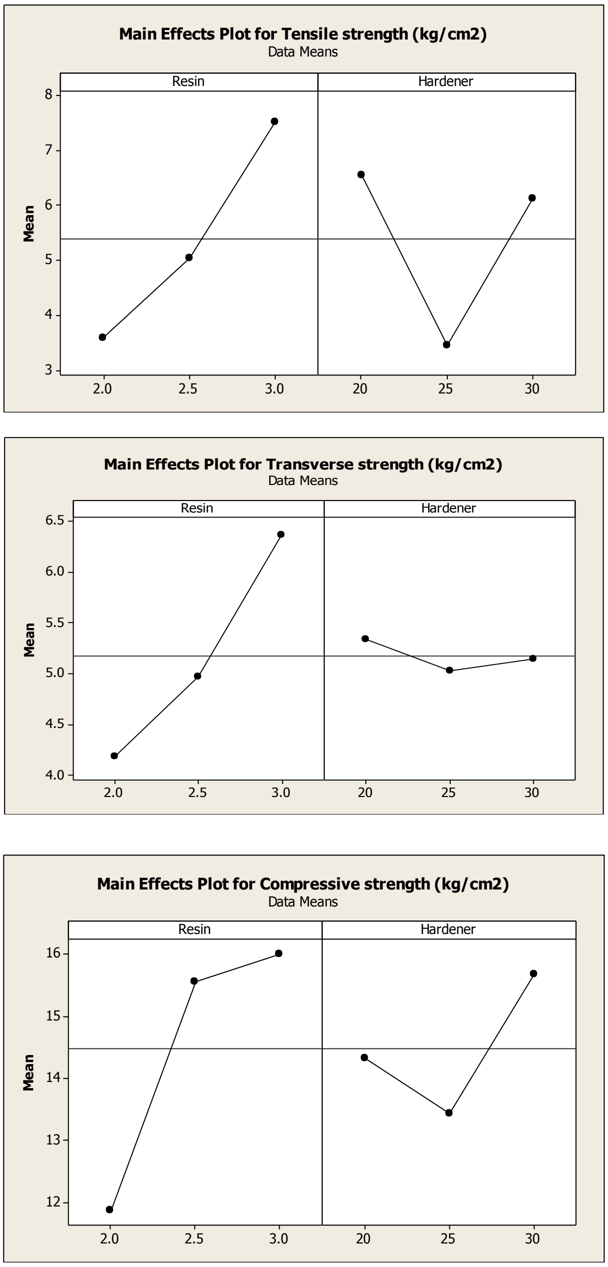


Fig. 4 Main plots effect plots for tesnsile, transverse and compressive strength results of the phenolic-ester bonded sand casting moulds.

Factors that could compromise the strength values are mixing speed and time as well as surrounding temperature [8, 9]. At higher surrounding temperature, there will be fast reactions and it will affect the mechanical properties of the material [7].

2) Furan-Sulfonic Acid Sand Mould

Table IV shows results for tensile, transverse and compression strength for furan–sulfonic acid bonded sand moulds. The values were averaged from 5 samples for each set of percentage ratio. It shows that maximum transverse strength was obtained at 4.33 kg/cm^2 when resin ratio was 2.0% and hardener was 55%. Maximum tensile strength and compressive strength were obtained when resin and hardener ratio were 2.4% and 60% i.e. 5.16 kg/cm^2 and 18.36 kg/cm^2, respectively.

Figure 5 shows the main effect plots indicating the effect of the furan resin and sulfonic acid to the sand moulds. Result shows that sulfonic acid significantly affected the tensile and transverse strength of the resin bonded sand moulds when compared to the effect of furan resin. This is supported by Foseco Foundry [7] that for furan system uses 40-60% of hardener ratio, the amount of acid catalyst used will significantly affect the strip time.

From the plots in Figure 5, it could be observed that tensile strength dropped significantly at 55% hardener ratio. The low tensile strength of the furan system is usually due the excess moisture [5]. On the other hand, transverse and compressive strength of the moulds decreased with the decreased of sulfonic acid. Brown [2] claimed that compressive strength of the furan resin bonded sand moulds could be ~ 42 kg/cm^2. Apparently, the maximum compressive strength obtained in this study is low.

Factors that could compromise the strength values are sand acid level, mixing speed and time as well as surrounding temperature [8, 9]. Since the hardener used in furan system is acidic, the sand should have lower acid content i.e. less than 6ml. In addition, cold sand could seriously affect the curing speed and final strength [2]. Curing time for furan sand moulds in this study occurred about 2 hours, in which took longer than those suggested by Brown [2] i.e. 30 minutes. Apparently, shorter curing time requires higher mixing speed. There are limited publications that reports on the strength of the furan-sulfonic acid bonded sand moulds and results obtained in this study contribute to this field of knowledge.

TABLE IV. TENSILE, TRANSVERSE AND COMPRESSIVE STRENG FOR FURAN – SULFONIC ACID BONDED SAND CASTING MOULD

Run	Furan resin (%) by weight of sand	Sulfonic acid (%) by weight of resin	Tensile strength (kg/cm^2)	Transverse strength (kg/cm^2)	Compressive strength (kg/cm^2)
1	2.2	55	4.43	3.37	8.95
2	2.2	60	3.20	2.19	5.72
3	2.4	55	3.52	3.60	7.64
4	2.4	60	5.16	3.72	18.36
5	2.0	50	2.41	2.54	13.28
6	2.2	50	4.11	2.88	7.66
7	2.0	55	3.14	4.33	16.25
8	2.4	50	3.33	3.40	16.55
9	2.0	60	4.44	1.61	16.18

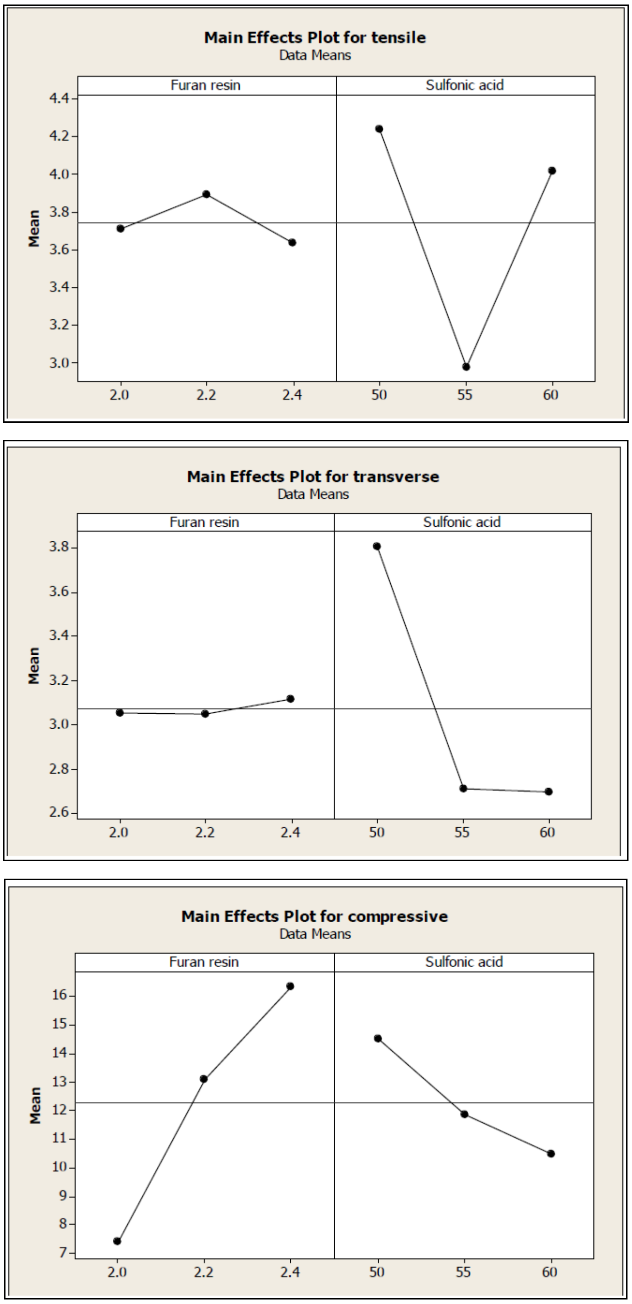


Fig. 5 Main plots effect plots for tensile, transverse and compressive strength results of the furan-sulfonic acid bonded sand casting moulds.

B. Loss on Ignition (LOI)

Table V shows the LOI results for phenolic and furan resin bonded sand moulds. LOI obtained for both set of moulds was <1.6% and vary within standard deviation of 0.3% for phenolic moulds and 0.1% for furan moulds. This results show good LOI values because according to Brown [2], LOI must be kept below 3%. Both set of moulds show that LOI increased as the ratio of resin and hardener increased.

TABLE V. TENSILE, TRANSVERSE AND COMPRESSIVE STRENG FOR PHENOLIC – ESTER BONDED SAND CASTING MOULD

Run	Phenolic Resin Ratio	Ester Ratio	LOI (%)	Furan Resin Ratio	Sulfonic Acid Ratio	LOI (%)
1	3	25	1.4	2.2	55	1.1
2	2	20	1.0	2.2	60	1.3
3	3	30	1.4	2.4	55	1.6
4	2.5	30	1.3	2.4	60	1.4
5	2.5	20	0.8	2.0	50	1.6
6	2	30	0.7	2.2	50	1.5
7	2	25	0.6	2.0	55	1.4
8	2.5	25	1.2	2.4	50	1.5
9	3	20	1.3	2.0	60	1.6

CONCLUSION

In phenolic-ester bonded sand casting mould, the effect of phenolic resin on the tensile, transverse and compression strength is significant as compared to the effect of ester hardener. Opposite results were obtained for the furan-sulfonic acid bonded sand casting mould. It is understood from this study that in different mould system, either resin or hardener could be the primary strengthening element.

In phenolic resin bonded sand moulds, with higher ratio of resin and hardener employed in this study, the maximum tensile, transverse and compression strength obtained is low. Similar results observed in the furan resin bonded sand moulds. Factors that could compromise the strength values are mixing speed and time as well as surrounding temperature.

LOI of both set of moulds is within acceptable values in which should be kept < 3.0%. Increased in combustible materials like the resin and hardener also increased the LOI value.

This preliminary study has provided significant insight to the behavior of resin and hardener towards the mechanical properties and LOI of the sand moulds that could be benefited during the development of biodegradable resin bonded sand casting mould.

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