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Achieving Environmental Sustainability in Shell Mould Foundry through Thermal Reclamation

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ACHIEVING ENVIRONMENTAL SUSTAINABILITY IN SHELL MOULD FOUNDRY THROUGH THERMAL RECLAMATION

ABSTRACT

Shell moulding is a process for producing simple or complex near net shape castings and maintaining tight tolerances with a high degree of dimensional stability. The main objective of the present research is to achieve environmental sustainability by thermal reclamation of the used shell mould foundry sand and present the results of achieving environmental sustainability. The investigations indicate that the thermal reclamation of the used foundry sand helps in achieving sustainability and the selection of process parameters like percentage of resin, catalyst and fresh silica sand addition are very important in the shell mould foundry.

Keywords: green manufacturing, sand testing, thermal reclamation, used foundry sand, environmental sustainability

1. INTRODUCTION

Environmental issue of foundry industry should be addressed both as a local issue and global issue. Local issues include air, water, noise, land degradation, loss of natural resources, etc. Whereas global issues are climate change due to green house effect, depletion of ozone layer, acid rain, etc.

Sand reclamation is a physical or chemical or thermal treatment process of reconditioning of used sand in a foundry by removing the adhesive binder coatings from sand grains without lowering its original properties, which are particularly required for foundry applications. As reclaimed sand regains its original condition, it can be reused again and again, with minimum addition of new sand.

In the thermal reclamation process, used sand from a *'Shell Mould Foundry'* is passed into lump reducer as shown in Fig.1. Vibratory unit fitted in the lump reducer breaks sand lumps into sand grains then deliver in to return sand storage silo through pneumatic transporter. From the sand storage, the sand is fed into sand preheating unit through screw feeder. In the pre-heater, the shell mould sand grains are preheated to a temperature of 600°C and fed into the specially designed '*Fluidised Bed Combustor'* where the sand grains are fluidised by precisely controlled air flow at a pressure of 0.02 MPa and also heated to a temperature of about 700°C (Lucarz 2015) by Liquefied Petroleum Gas (LPG) at controlled rate which burns with oxygen available in the fluidised bed. The organic binder in the mould sand is burnt and nearly complete removal of organic binders from sand grain surfaces is realised (Lucarz 2015).

The hot reclaimed sand at the outlet of the combustor is passed into a fluidised bed cooler to cool the hot reclaimed sand to a temperature of 40°C by using fluidised air at room temperature and water pipes beneth then it is stored in the reclaimed storage silo for future usage in the foundry. The thermal reclaimed sand is a better usage than new sand, as new sand is in a *'Wet Condition'*.

2. LITERATURE REVIEW ON THERMAL RECLAMATION

In this section, the literature review carried out during the research work is reported. The following papers published in the area of thermal reclamation were collected.

Danko et al. (2003) investigated factors and conditions allowing the replacement of fresh silica sand in foundry by the recovered moulding sand. The researchers found that the range of temperature 750 to 800°C is the main factor for thermal reclamation. The researchers also claimed that the reclamation of moulding sand is a best way of saving and protecting natural silica sand deposit.

Danko (2011) presented innovative developments in sand reclamation technologies like mechanical-cryogenic and thermal reclamation. The researcher found that the core sand-to-core sand reclamation creates a lot of technical problems. To perform this process, the researchers recommended the thermal reclamation process. The “Loss On Ignition” (LOI) and bending strength of a specimen are used as output parameters.

Lucarz (2014) investigated the thermal reclamation of spent core sands at various temperatures with gas consumption and reclamation process time. The researcher found that the sample derived from the 700°C reclamation process temperature has low ignition loss percentage and higher bending strength.

Fan Zitian et al. (2014) investigated the possibility of reusing the mixed resin bonded sand and clay bonded sand after wet-thermal composition reclamation process. They found that this composite process reduces the cost of reclamation process and improves the reclaimed sand quality.

Lucarz (2015) analysed the thermal reclamation of the spent moulding sand process with the use of a range of criteria, e.g., loss of ignition percentage, bending strength and the acidic reaction (pH). The researcher found that temperature range from 600 to 700° C should be sufficient for the thermal reclamation.

Lucarz (2015) carried out the thermogravimetric analysis for three different binders like urea-formaldehyde resin, urea-furfuryl resin and alkyd resin. The researcher found that the urea-formaldehyde resin was completely burned at temperature above 800°C, urea–furfuryl resin at a temperature of 700°C and alkyd resin at a temperature of 650°C. LOI was tested at 950°C for three binders and presented.

Lucarz and Drozynski (2017) selected moulding sand parameters like strength, permeability, grindability and ignition losses for moulding sand. Moulding sands were prepared on the fresh quartz matrix as well as on sand matrices obtained after reclamation methods. The result of the investigations concerning the applied sand matrix' influence on the properties of moulding sands used for production of large dimensional castings. They found that the process should be optimised in respect of the process time and temperature.

Yan-lei Li et al. (2017) systematically investigated the effects of additions of furan no-bake resin in the reclaimed sand on the microstructure characteristics, mechanical properties and fracture behaviour of within the temperature range between 25 and 600°C and found that the addition of 70 and 100% reclaimed sand exhibited relatively low tensile strength and compressive strength at both room and elevated temperatures. The researchers claimed that the mixture of reclaimed sand and new sand satisfies the moulding requirement.

Chate et al. (2017) conducted research on phenol formaldehyde resin mould sand with four input variables namely grain fineness number, setting time, percent of resin and hardener and analysed their effect on mould. They found that the grain fineness number is the most significant parameter in the mould's hardness and permeability.

Lucarz and Deren (2017) presented the result of investigations of thermal reclamation of spent moulding sand between 400 and 550°C originating from an aluminium alloy foundry plant. They found that the essential parameter for reclamation is the reclamation time. The researchers claimed that thermal reclamation is the best for removing organic binders from matrix grain surfaces.

Nancy Hanson-Rasmussen and Kristy J. Lauver (2017) found that the importance of each of these environmental sustainability practices like reducing waste, increasing environmental protection and limiting resource depletion.

3. INPUT–OUTPUT PARAMETERS FOR SHELL MOULD FOUNDRY

In the shell mould foundry, Chemical bonded resin like phenol formaldehyde sand moulding process has high dimensional accuracy, surface finish and sand mould properties compared to green sand mould system. Fig.2. shows input–output parameters in the shell moulding process. In the proposed process, thermal reclaimed sand is blended with ingredients like fresh silica sand, Thermal reclaimed sand, resin and hardener. The properties like Loss on Ignition (LOI), drop off percentage (or) peel back %, Mould strength (hot tensile strength and cold transverse strength) and stick point of mould and core are measured.

4. DETERMINATION OF INPUT–OUTPUT PARAMETERS

4.1. Deciding the reclaimed sand and fresh silica sand percentage

Initially the proportion of reclaimed sand and fresh silica sand is decided based on the American Foundry Society (AFS) grain fineness number. Sieve analysis is performed on a dried sand sample from which all clay substances have been removed. A set of sieves with standard sieve mesh numbers are stacked in sequence with the coarsest sieve at the top of the sieve shaker. A sample of 50 g sand is placed at the top sieve and, after 15 minutes of vibration, the weight of the sand retained in each sieve is measured and tabulated in the table 1 in the corresponding sieve mesh number. The AFS grain fineness number is determined by multiplying the weight of sand retained on each screen with a multiplier, adding the total and then dividing by the total weight of sand retained on the sieves.

AFS grain fineness number = Total product / Total weight of retained sand in sieves

AFS of fresh silica sand =3859.94/49.942=77 AFS

Similar to fresh silica sand, AFS of thermal reclaimed sand is calculated, as follows

AFS grain fineness number = Total product / Total weight of retained sand in sieves

AFS of reclaimed sand=2957.23/49.956=59 AFS

In the selected foundry, for the shell core 68 AFS is maintained and for the shell mould 64 AFS is maintained. The proportion of the thermal reclaimed sand (X) and fresh silica sand (Y) is calculated from the following formula.

(% of reclaimed sand x (AFS) reclaimed sand) + % of fresh silica sand x (AFS) fresh silica sand)

For shell core sand mixture is 50% Thermal reclaimed sand and 50% fresh silica sand.

(0.5 x 59) + (0.5 x 77) = 68 AFS

AFS for shell core sand mixture X = 50% and Y= 50%

$(X \times 59) + (Y \times 77) = 68$ AFS

For shell mould sand mixture is 70% Thermal reclaimed sand and 30% fresh silica sand.

(0.7 x 59) + (0.3 x 77) = 64 AFS

AFS for shell mould sand mixture X = 70% and Y= 30%

$(X \times 59) + (Y \times 77) = 64$ AFS

4.2. Hot tensile strength

Hot tensile tester, shown in Fig.3, is used to determine the tensile strength in MPa of shell sand in hot condition. The maximum capacity of the tester is 5.39 MPa. Two teflon coated half plates, connected with the tester is used to make a standard resin coated sand sample of 7.6 cm length and 4 cm width. Two digital temperature indicators with the range of 0 to 300°C in the tester indicate two plate temperature separately and the third digital indicator reads tensile load (MPa) applied to the sample. During testing, 230°C temperature is maintained for 3 min to complete the curing of the sample, and the tensile load is continuously applied till the sample break at neck area as shown in Fig.4 and the corresponding tensile load is marked as tensile strength of the sample. Hot tensile strength of shell core sand at different combination of fresh silica sand, thermal reclaimed sand and resin percentages are tabulated in the table 2.

4.3. Stick point

The stick point is a temperature at which the resin coated sand is sticked in the heated bar. The stick point tester as shown in Fig.5 is used to determine the stick point of resin coated sand. The major components in the tester on heated bar and temperature indicator. During testing, the heater is switched ON and the resin coated sand is distributed throughout the heated bar and allowed 1 min for curing. Then loosely sticked distributed resin coated sand is gently removed by cleaning brush. The stick point, the temperature of the resin coated sand sticked on the heated bar is measured by using thermo stick. Stick point of shell core sand at different combination of fresh silica sand, thermal reclaimed sand and resin percentages are tabulated in the table 2.

Considering hot tensile strength and stick point (low) of core 50% thermal reclaimed sand and 50% fresh silica sand with 3.3% resin mixture is selected.

4.4. Peel back

The peel back tester, shown in Fig.6, is used to determine build up or peel back property of resin coated sand. It consists of temperature controller, hot plate, funnel, handle to turn heating plate and tray.

The peel back tester is switched on, the temperature of the hot plate is set for 230°C and 450 grams resin coated sand is put into the conical funnel. Approximately 10 minutes is allowed for the hot plate to reach 230°C temperature. Then conical funnel door is opened and all the sand allowed to falling all the sands on the hot plate which is in the horizontal position. Then, 30 sec are allowed to cure the resin coated sand and hot plate is turned from horizontal to vertical position by rotating the handle. Dropout surplus sand is collect in the tray and tray is removed. The sand collected in the tray is weighted. Sand peel back on the hot plate.

$$Peel\ Back\ \% = \frac{(weight\ of\ the\ resin\ coated\ sand\ sample - weight\ of\ the\ sand\ in\ the\ tray\ A)}{weight\ of\ the\ resin\ coated\ sand\ sample} x100$$

$$= \frac{(450 - \ weight\ of\ the\ sand\ in\ the\ tray\ A)}{450} x100$$

Peel back percentage of shell core sand at different combination of fresh silica sand, thermal reclaimed sand and resin percentages are tabulated in table 3.

4.5. Cold transverse strength

The cold transverse strength tester as shown in Fig.7 is used to measure the transverse strength of resin coated sand. Two teflon coated half plates as shown in Fig.8 is used to prepare transverse specimens with the dimensions of 10 cm length, 2.5 cm width and 0.5 cm thickness. The sample is placed in the tester and the transverse load is applied till the sample is broken. The broken sand sample piece is shown in Fig.9. The cold transverse strength of the sample shown in the digital indicator is tabulated in the table 3.

4.6.Gas Evaluation

The gas evaluation tester is used to determine the rate and volume of gas evolved from a dried sample of hardened resin coated sand. One gram resin coated sand sample is propelled into the nitrogen atmosphere of silica tube furnace then the rubber sealing cork is inserted. The temperature of the furnace is controlled to 850°C. The pressure starts to rise continuously and is recorded with time from the water column height of the burette until a maximum is attained. By using a calibration chart, the pressure is converted to volumes and tabulated in table 3.

Considering peel back %, Cold Transverse Strength (high), Gas cc/gram (low) of core 50% thermal reclaimed sand, 50% fresh silica sand and 3.3% resin mixture is selected.

4.7. Loss On Ignition

Loss On Ignition is employed to determine the presence of organic and other gas forming materials present in the resin coated sand mixture. A 10 grams sample of pre-dried resin coated sand mixture is fired in a silica crucible held in a muffle furnace at different temperature for 30 min. The percentage loss in weight from the volatilisation, oxidation and decomposition of substances forming gaseous products is determined and tabulated in the table 4. These include carbonaceous additives such as resin, hardener and sand.

This study found that LOI of the shell core sand with 3.3% Phenol formaldehyde resin, 50% Thermal Reclaimed sand and 50% fresh silica sand proportion is maintained within the limit of 3.5 to 4%.

4.8. Consolidated input-output parameter for shell core

For the shell core sand, 3.3% Phenol formaldehyde resin, 50% Thermal Reclaimed sand and 50% fresh silica sand proportion is selected. Consolidated input-output parameter for shell core test results are tabulated in table 5.

4.9. Consolidated input-output parameter for shell mould

Similarly for shell mould sand, 4.2% Phenol formaldehyde resin, 70% Thermal Reclaimed sand and 30% fresh silica sand proportion is selected. Consolidated Input-Output parameter for shell mould test results are tabulated in table 6.

5. THE ENVIRONMENTAL SUSTAINABILITY ANALYSIS OF USING THERMAL RECLAIMED SAND IN THE SELECTED SHELL MOULD FOUNDRY

Businesses valuing environmental sustainability look to expand *'Environmental Protection'* along with *'Cost Saving'*. Kassins and Vafeas (2006). In the research, for core preparation 50% thermal reclaimed sand and 50% fresh silica sand is selected, for mould preparation 70% thermal reclaimed sand and 30% fresh silica sand is selected.

The environmental sustainability analysis is done in the selected foundry in two areas:

1. Total cost saving by using thermal reclaimed sand
2. Environmental protection by using thermal reclaimed sand

5.1 Total cost saving by using thermal reclaimed sand

Total cost saving includes saving from reduction in the consumption of fresh silica sand and resin for both mould and core.

5.1. 1. Fresh silica sand cost saving for mould

The cost of fresh silica is US \$0.0322/Kg which also includes cost of transporting and cost of unloading the sand. Fresh silica sand will be dried at the cost of US \$0.007/Kg before using in the foundry, as it is in wet condition. Hence total cost of fresh silica sand is US \$0.0392.

The thermal reclamation cost is US \$0.0182/Kg which includes cost of LPG, electricity and labour cost. The total cost for the 30:70 ratio of fresh silica sand to thermal reclaimed sand mixture is

$0.0392 \times 0.3 + 0.0182 \times 0.7 =$ US \$0.0245

Fresh silica sand cost saving per 1Kg = US \$0.0392-0.0245 = US \$0.0147/Kg.

% of cost saving = (Cost saving/Total cost) × 100 = (0.0147/0.0392) × 100 = 37.5 %

5.1.2. Fresh silica sand cost saving for core

In the research the ratio of fresh silica sand to thermal reclaimed sand selected is 50:50 for core.

The total cost = $0.0392 \times 0.5 + 0.0182 \times 0.5 =$ US \$0.0287

Fresh silica sand cost saving per 1Kg = US \$0.0392-0.0287 = US \$0.0105/Kg

% of cost saving = (Cost saving/Total cost) × 100 = (0.0105/0.0392) × 100 = 26.7 %

5.1.3. Resin cost saving for mould

For the capacity of a mix is 150 kg, without sand reclamation process resin addition is 7.5 kg (5 % resin addition). With sand reclamation process resin addition is 6.4 kg (4.2% resin addition).

Resin saving /Mix = 7.5-6.4 = 1.1 Kg/Mix

The cost of resin/Kg is US \$1.26

Resin cost savings /Mix = saving × cost of resin = 1.1 × 1.26 = US $1.386

$$Resin\ cost\ saving\ = \frac{5-4.2}{5}x100 = 16\%$$

5.1.4. Resin cost saving for core

For the capacity of a mix is 150 kg, without sand reclamation process resin addition is 5.25 kg (3.5% resin addition). With sand reclamation process resin addition is 4.95 kg (3.3% resin addition).

Resin saving /Mix = 5.25 - 4.95 = 0.3 Kg/Mix

Resin cost savings/Mix = Resin saving × cost of resin = 0.3 × 1.26 = US $0.378

$$Resin\ cost\ saving = \frac{3.5-3.3}{3.5}x100 = 5.7\%$$

Total cost saving per day = Fresh silica sand cost saving for mould + Fresh silica sand cost saving for core + Resin cost saving for mould + Resin cost saving for core

In the selected foundry, the capacity of a mix is 150Kg; the number of mix per shift is 37 and 3 shift per day.

Sand cost saving per day for mould making = 0.0147 × 150 × 37 × 3= US $244.755

Sand cost saving per day for core making = 0.0105 × 150 × 37 × 3= US $174.825

Resin cost saving per day for mould making =1.386 × 37 × 3 = US $153.846

Resin cost saving per day for core making =0.378 × 37 × 3 = US $41.958

Total cost saving per day = 244.755 + 174.825 +153.846 +41.958 = US $615.384

5.2. The Analysis of Environmental Protection by Using Thermal Reclaimed Sand

1. *'Land pollution'* reduction by reducing disposal of waste foundry sand in the open space
    a. 70% for shell mould making and
    b. 50% for shell core making
2. *'Air pollution'* reduction by reducing the Emissions from the foundry carrying dust and fines in to the air
    a. 70% for shell mould making and
    b. 50% for shell core making
3. *'Resource depletion'* reduction by reducing the fresh silica sand consumption
    a. 70% for shell mould making and
    b. 50% for shell core making
4. '*Resource depletion'* reduction by reducing the resin consumption
    a. 16% for shell mould making and
    b. 5.7% for shell core making

6. Conclusion

The performed Environmental Sustainability investigations indicate that using the thermal reclaimed sand for making mould and core, the selected foundry saved the cost in the following categories per day.

Percentage of fresh silica sand cost saving for mould =37.5%

Percentage of fresh silica sand cost saving for core = 26.7%

Percentage of resin cost saving for mould = 16%

Percentage of resin cost saving for core = 5.7%.

Other key benefits are

- The reduction in the manufacturing cost of mould and core and
- The reduction of casting bulging and warbage defects from 1% to 0.03%.

The analysis of the hot tensile strength, Peel back, Stick point, LOI, Cold transverse strength and Gas evaluation test are conducted for mould and core and results are presented. In addition to the reduction in waste disposal costs and fresh silica sand storage cost also reduced. Reduction in disposable waste reduces the landfill and transportation cost. This large amount of reduction in the casting cost and increase the profit. The Green environment of this technique reduces land pollution, Emissions and resource depletion and contributes to the healthy working environment.

REFERENCES

Chate, G.R., Patel, M.G.C., Parappagoundar, M.B., and Deshpande, A.S. 2017. Modeling and optimization of phenol formaldehyde resin sand mould system . Archives of Foundry Engineering. 17(2): 162-170. doi: 10.1515/afe-2017-0069.

Danko, J., Danko, R., and Holtzer, M. 2003.Reclamation of used sands in foundry production. Metalurgija. 42(3): 173-177. doi: UDC - UDK 621.742.55=20.

Danko, R. 2011.Innovative developments in sand reclamation technologies. Metalurgija. 50 (2): 93-96. doi: UDC – UDK 621.741:621.742:502.72:628.54=111.

Fan Zitian, Liu Fuchu, Long Wei, and Li Guona. 2014. A new low-cost method of reclaiming mixed foundry waste sand based on wet-thermal composite reclamation. China Foundry. 11(5): 402-407. doi: 1672-6421(2013) 05.402.06.

Kassins, G., and Vafeas, N. 2006. Stake holder pressures and environmental performance. Academy of Management Journal. 49(1): 145-159.

Lucarz, M. 2014 . Influence of the thermal reclamation of the spent core sand matrix on its reuse . Archives of Foundry Engineering 14(1): 27-30.

Lucarz, M. 2015. Setting temperature for thermal reclamation of used moulding sands on the basis of thermal analysis. Metalurgija. 54(2): 319-322. doi:UDC – UDK 621.746:621.78:621.74:621.74.04=111.

Lucarz, M. 2015. Thermal Reclamation of the used Moulding Sands. Metalurgija. 54(1): 109-112. doi:UDC – UDK 621.746:621.78:621.747:621.74.04=111.

Lucarz, M., and Deren, M. 2017 . Conditions of Thermal reclamation process realization on a sample of spent moulding sand from an aluminium alloy foundry plant. Archives of Foundry Engineering . 17(2):197-201. doi: 10.1515/afe-2017-0074.

Lucarz, M., and Drozynski, D. 2017.Influence of the reclamation method of spent moulding sands on the possibility of creating favourable conditions for gases flow in a mould. Archives of Metallurgy and Materials. 62(1): 359-364. doi: 10.1515/amm-2017-0055.

Nancy Hanson-Rasmussen, Kristy, J.,and Lauver.2017, Do Students view environmental sustainability as important in their job search? Differences and similarities across culture. International Journal of Environmental and Sustainability Development.16 (1): 80 -98.

Yan-lei Li, Guo-hua Wu, Wen-cai Liu, An-tao Chen, Liang Zhang, and Ying-xin Wang. 2017. Effect of reclaimed sand additions on mechanical properties and fracture behavior of furan no-bake resin sand.China Foundry,14(2): 128-137. doi: 10.1007/s41230-017-6024-3.

Table 1 AFS of fresh silica sand.

Sieve Mesh Number (Standard Microns Mesh No.)	Weight of retained sand in each sieve g	Multiplier factor	Weight of retained sand in each sieve x Multiplier factor
1.700	-	5	-
0.850	-	10	-
0.600	0.293	20	5.86
0.425	1.326	30	39.78
0.300	1.112	40	44.48
0.212	11.825	50	591.25
0.150	18.852	70	1319.64
0.106	12.384	100	1238.4
0.075	3.719	140	520.66
0.053	0.294	200	58.8
PAN	0.137	300	41.1
TOTAL	49.942		3859.94

Table 2 Shell core sand testing results.

Sample number	Sand combination		Resin %	Hot tensile strength MPa	Stick Point ˚C
	Thermal reclamation sand	Fresh silica sand			
1	50%	50%	2.4%	1.078	100
2	50%	50%	3.3%	1.676	99
3	-	100%	4.0%	1.755	102

Table 3 Shell Core sand testing results

Sample number	Sand combination		Resin %	Peel back %	Cold transverse strength MPa	Gas cc/gram
	Thermal reclamation sand	Fresh silica sand				
1	50%	50%	2.4%	60.9	2.951	10.8
2	50%	50%	3.3%	62.3	3.510	10.6
3	-	100%	4.0%	63	3.353	11.1

Table 4 LOI in percentage of shell core

Sample number	Temperature ˚C	Input sand weight (Grams)	Output sand weight (Grams)	LOI in %
1	500	10	9.773	2.27
2	600	10	9.752	2.48
3	700	10	9.720	2.80
4	800	10	9.715	2.85
5	900	10	9.709	2.91
6	1000	10	9.676	3.24

Table 5 Consolidated Input-Output parameter for shell core

Sand combination		Resin %	Percent age of Hardener	Hot Tensile Strength MPa	Stick Point ˚C	Peel Back %	Cold Transverse strength MPa	Gas cc/ gram	LOI in %
Thermal reclamation sand	Fresh silica sand								
50%	50%	3.3%	0.6%	1.676	99	62.3	3.510	10.6	2.91

Table 6 Consolidated input-output parameter for shell mould

Sand combination		Resin %	Percentage of Hardener	Hot Tensile Strength MPa	Stick Point ˚C	Peel Back %	Cold Transverse strength MPa	Gas cc/gram	LOI in %
Thermal reclamation sand	Fresh silica sand								
70%	30%	4.2%	0.6%	2.471	101	63.3	6.109	12.3	3.71

List of Table

Figure Title

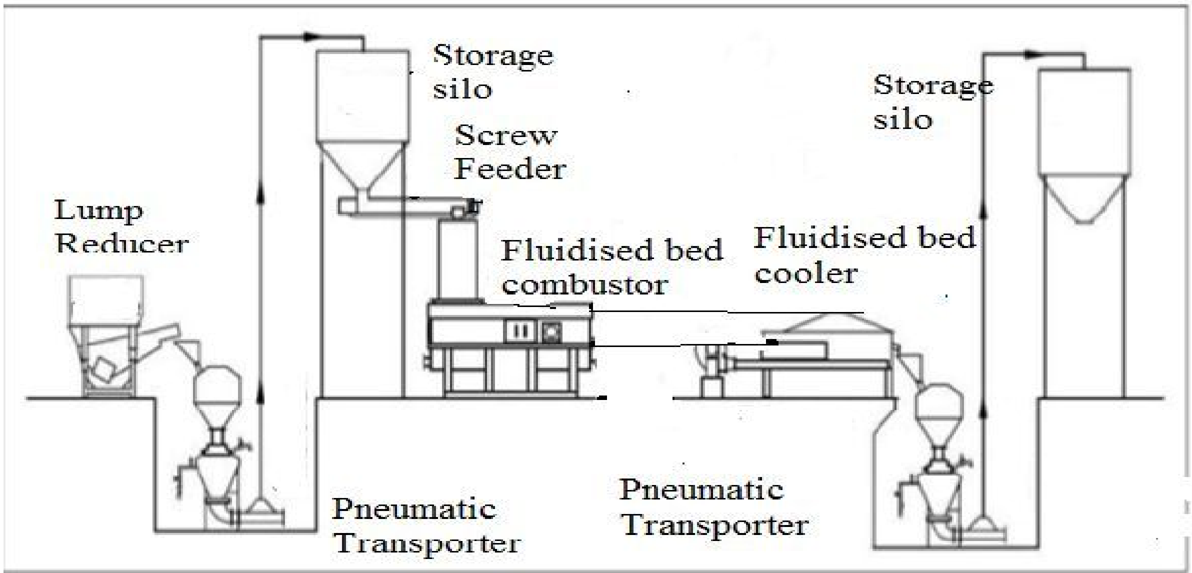

Fig. 1. Block diagram of the thermal reclamation process.

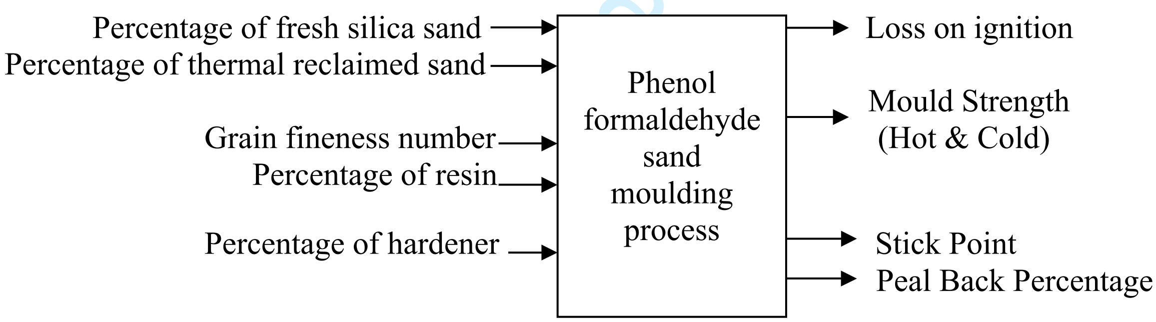

Fig. 2. Input–output model

Fig. 3. Hot tensile strength tester

Fig. 4. Standard sample after tensile strength testing.

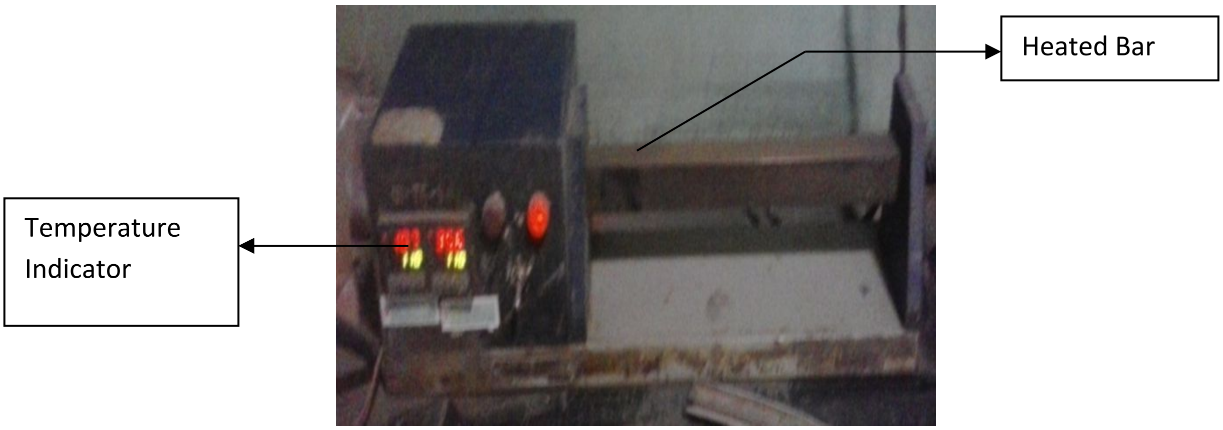

Fig. 5. Stick point tester.

Fig. 6. Peel back tester.

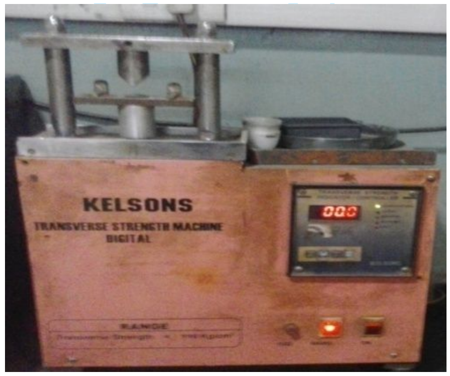

Fig. 7. Cold transverse tester.

Fig. 8. Two teflon coated half plates.

Fig. 9. Broken sand sample piece after cold transverse strength testing.