Design, Fabrication and Testing of Standard Sand Rammer

K. C. Bala
Mechanical Engineering Department, Federal University of Technology, Minna, Niger State (Nigeria)

Abstract

A Standard Sand Rammer was designed, fabricated and its performance compared with an imported one by producing standard specimens from it. The rammer was designed to help foundry industries in Nigeria as well as small-scale foundries acquire basic foundry equipment to test and control raw materials in order to improve castings quality. In designing the standard rammer, standard specification of the American Foundry Society (AFS) was taken into consideration and it followed a systematic design analysis of the basic theories required to make it functional. The standard rammer was fabricated from locally sourced materials, tested and found to produce a cylindrical specimen of 50mm by 50mm after three rams. Flowability and Permeability tests were carried out on specimens produced from the Rammer. These shows similar results compared with an imported rammer.

Keywords

Standard Sand Rammer, Flowability, Permeability, Plunger/Piston, Rammer rod

Glossary

Casting:	The production of shaped- articles by pouring molten metal into moulds.
Dwell angle:	An angular rest interval on the profile of a cam where there is no rise or fall of the cam follower.
Fineness sieve number:	A measure of grain size distribution in moulding sand.

Lathe machine:	A machine tool used to produce cylindrical, flat and conical surfaces by generating process and the use of single-point tool.
Naira (₦):	Nigerian currency.
Plunger:	A rammer attachment to the lower end of the ramming rod, which fits into the specimen tube.
Ramming:	The act of compacting moulding sand to a uniform density.

1. Introduction

Foundry practice is an important facet in all engineering activities, and the development of any nation's technology depends greatly on the development of its foundries. The poor development of foundries in Nigeria today reported in Bala (1998), extend to the fact that science and engineering infrastructures were not provided at the beginning of its national independence.

The need for systematic evaluation of the working conditions and quality of moulding materials like sand under foundry conditions has led to the development of a wide range of tests and test equipment. Most of the moulding property requirements (Orumwense 2002) are determined by standard tests carried out on standard samples that are representatives of the bulk sand. This is because bulk properties of moulding sand are sensitive to small variations in mixing conditions and specimen preparation.

It is therefore a standard practice to subject all initial materials delivered to the foundry for testing (Strobl and Silsby 2001) towards meeting the quality requirements. Many of these tests utilize the standard cylindrical specimen of 50 mm diameter by 50 mm height (Heine *et al*. 1967).

Foundry industries have much to gain in processing moulding sands so as to improve casting's quality (Harding 1995), increase production and lower total production costs. The foundries find it difficult to purchase or acquire this basic equipment to test the properties of materials, which are vital to the production of sound, dimensionally accurate castings.

In Nigeria, founding and metallurgical practices have been known and practised long before the advent of European civilization. The industry has not developed tremendously. Beyond artifacts, Nigeria has a total of 160 foundries (Foundry chronicle 1995) of which only five are commercial in contrast with India, which has 9000, registered foundries. Also a recent study by National Agency for Science and Engineering Infrastructure, (NASENI) shows that the foundries located around the country have an average capacity utilization of 33%.

This low capacity utilization is also attributed to lack of appropriate foundry equipment. The need to locally redesign and develop the standard rammer according to international specification will go a long way to helping in the research and development of foundries, use in schools laboratories, to provide for both routine foundry control and development of new materials.

There are three principal requirements that indicate whether sand rams well. These are flowability, rammability and permeability.

Flowability measures whether moulding sand rams firmly against the pattern and into restricted pockets without showing any voids (Khan *et al* 1972) that are larger than those the sand grains will normally form. Flowability is recognised by AFS sand committee (Dietert, 1954) because low flowability allows molten metal to flow into false voids or open pockets of the mould surface, causing roughness on the casting surface.

1.1 Standard Sand Rammer

The standard sand rammer figure 1 consists of a known cylindrical weight supported by a vertical shaft - the ramming rod, which has the ramming piston or plunger attached at the lower end, fits into the specimen tube. The ramming device is manually operated by the use of two cams. The smaller cam enables the weight to be lifted through a height of 50mm, and then dropped suddenly. The bigger cam is provided as a means to support the weight and the vertical rod, and to allow the removal of the specimen tube. The cylindrical weight slides along the shaft and engages a collar by impact, which provides the ramming pressure.

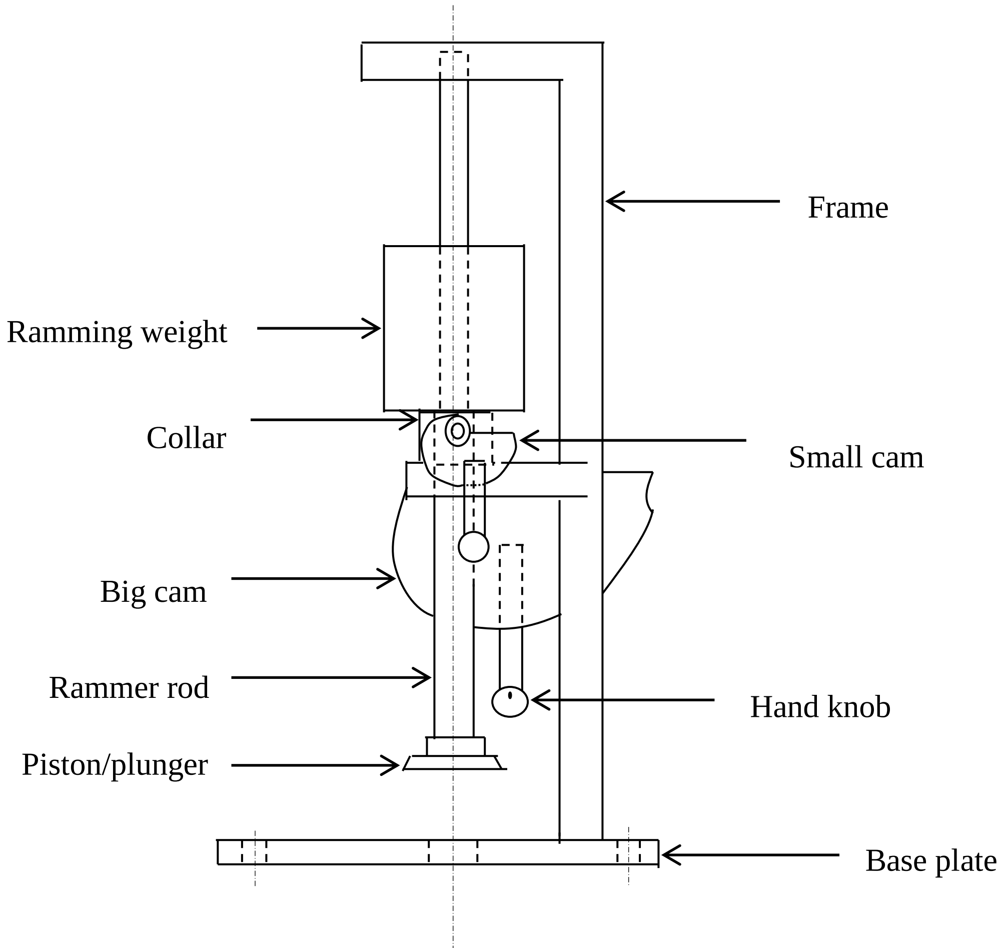

Figure 1: The Standard Sand Rammer

2. Design Considerations and Analysis

The design consideration of the standard sand rammer is based on the standard parameters of AFS for obtaining the standard specimen. These include:

Diameter of specimen = 50.0 ± 0.02 mm;

Height of specimen = 50.0 ± 0.02 mm;

Ramming mass = 6.35 kg;

Height of drop of ramming mass = 50.0 mm.

2.1 Design Analysis

2.1.1 Specimen Tube

This holds the moulding sand and subsequently the specimen. The volume of moulding sand required to produce standard specimen is given by:

$$V_s = \frac{M_{st}}{\rho_s} = \frac{\pi d_t^2 h_t}{4} \qquad 1$$

where, M_{st} = mass of sand required for specimen production (kg);

ρ_s = density of moulding sand (kg/m^3);

d_t = diameter of specimen tube (m);

h_t = height of specimen tube (m).

Therefore,

$$h_t = \frac{4M_{st}}{\pi \rho_s d_t} \qquad 2$$

2.1.2 Ramming Weight

The ramming weight has a mass of 6.35 kg and is cylindrical in shape with a hole drilled into the central axis to allow for ramming rod passage. Assuming a ram height – diameter ratio of 1.5, we obtain:

$$H_w = 1.5 D_w \qquad 3$$

where, H_w = height of ramming weight (m);

D_w = diameter of ramming weight (m).

Similarly, if the diameter of hole for rammer rod is d_h , then the volume of ramming weight is given by:

$$V_w = \frac{\pi (D_w^2 - d_h^2) H_w}{4} \qquad 4$$

Substituting equation (3) in equation (4) gives,

$$V_w = \frac{1.5\pi D_w (D_w^2 - d_h)}{4} \qquad 5$$

Also,

$$V_w = \frac{M_w}{\rho_w} \qquad 6$$

where, M_w = mass of ramming weight (kg);

ρ_w = density of weight material (kg/m^3).

Substituting equation (6) into equation (5) gives,

$$D_w^3 - D_w d_h - \frac{4M_w}{1.5\pi\rho_w} = 0 \qquad 7$$

Equation (7) is a third degree polynomial with second terms absent. The solution (Eugene and Theodore, 1987) follows:

$$D_w = 3\sqrt{\frac{4M_w}{3\pi\rho_w} + \sqrt{\frac{16M_w^2}{9\pi^2\rho_w^2} - \frac{d_h^6}{27}}} + 3\sqrt{\frac{4M_w}{3\pi\rho_w} - \sqrt{\frac{16M_w^2}{9\pi^2\rho_w^2} - \frac{d_h^6}{27}}} \qquad 8$$

2.1.3 Dynamic Force under Impact

The velocity of fall of weight under gravity is given by:

$$v = \sqrt{2gh} \qquad 9$$

where, h = height of drop of ramming weight (m);

g = acceleration due to gravity (m/s^2).

To determine the force responsible for the impact action, the law of conservation of energy is employed. Therefore, equating kinetic energy of falling body to potential strain energy of the bar, work done by falling weight is:

$$W_w = M_w g(h + \Delta l_d) \qquad 10$$

where, Δl_d =dynamic deformation (shortening of the bar).

Potential energy of strain in compression is:

$$P_e = \frac{\Delta l_d^2 EA}{2l} \qquad 11$$

where, E = modulus of elasticity (N/m^2);

A = cross sectional area of ramming rod (m^2);

l = length of rod under compression (m).

Therefore,

$$M_w g(h + \Delta l_d) = \frac{\Delta l_d^2 EA}{2l} \qquad 12$$

Expanding and dividing through by EA gives:

$$\Delta l_d^2 - \frac{M_w g l 2\Delta l_d}{EA} - \frac{2M_w ghl}{EA} = 0 \qquad 13$$

For statically applied load, static deformation is given by:

$$\Delta l_s = \frac{4M_w gl}{\pi E d_r^2} \qquad 14$$

where, d_r = diameter of rod (m).

Therefore,

$$\Delta l_d^2 - 2\Delta l_s \Delta l_d - 2\Delta l_s h = 0 \qquad 15$$

Hence,

$$\Delta l_d = \Delta l_s \pm \sqrt{\Delta l_s^2 + 2h\Delta l_s} \qquad 16$$

And since a solution with the minus sign before the radical is contrary to the physical meaning of the problem, we obtain:

$$\Delta l_d = \Delta l_s (1 + \sqrt{1 + \frac{2h}{\Delta l_s}}) \qquad 17$$

$$= \Delta l_s K_d \qquad 18$$

where, K_d = dynamic load factor = $\frac{\Delta l_d}{\Delta l_s}$

This implies that the dynamic effect of the falling weight is K_d times its static effect.

Dynamic force is

$$F_d = F_s \times K_d = K_d M_w g \qquad 19$$

2.1.4 Ramming Plunger / Piston

Ramming plunger is required to fit into the specimen without squeeze out of sand mixture. Therefore, for fit and standard, the diameter of the plunger is made to 49.95 ± 0.03 mm.

2.1.5 Collar and Shaft

The collar, which receives the impact, is supported on the vertical plunger with the latter step-turned. A small pin fixes the collar to the shaft to prevent movement.

2.1.6 Small Cam for Weight Lifting

This rotates clockwise, and lifts the weight through a height of 50 mm and drops suddenly. The following specifications are given:

Type of cam: Plate cam

Minimum diameter = 24 mm;

Maximum diameter = 74 mm;

Cam shaft diameter = 12 mm;

Dwell angle = 0° to 180°;

Lift angle with uniform acceleration = 180° to 360°.

2.1.7 Big Cam for Lifting Weight and Rod

This is to lift and suspend both the ramming weight and the ramming rod, to enable the placing and removal of the specimen tube. The following cam specifications are given:

Type of cam: Plate cam

Minimum diameter = 41 mm;

Maximum diameter = 131 mm;

Cam shaft diameter = 12 mm;

Dwell angle = 0° to 180°;

Lift angle with uniform acceleration = 180° to 360°;

External diameter of ball bearing follower = 28 mm.

3. Fabrication

The sand rammer was fabricated from various locally sourced materials, which include mild steel shaft (Φ95 x 150) mm for the ramming weight. Mild steel rod (Φ22 x 600) mm for ramming rod; mild steel shaft (Φ70 x 200) mm for specimen tube base; mild steel plate (290 x 255 x 10) mm for frame base and square steel section (900 x 40 x 4) mm for frame. Turning operations on the lathe machine produced the ramming weight, shaft, collar, and specimen tube. The frame was constructed by marking out, notch cutting and bending. The frame was then welded to the base plate by carefully aligning the plunger's axis of movement to fit into the specimen tube. Figure 1 shows the basic components of the rammer.

4. Testing

In testing the sand rammer, flowability and permeability tests were carried out on standard specimens produced from the fabricated rammer as well as an imported rammer and the results compared. Sand mix of various compositions was weighed to the amount required to form a standard AFS specimen (0.145kg to 0.175kg) and filled into the specimen tube, which was fabricated along with the rammer. The specimens were transferred to the flowability tube and three blows (Beeley 1982) were applied using the foreign and the indigenous rammers. Percentage flowability was calculated for the rammers.

Similarly, the green permeability (Plain 1986) was determined using a permeability meter. Figures 2 and 3 show the variation of percentage flowability and green permeability with fineness sieve numbers obtained from a sand mix of 75% silica, 20% clay content and 7% moisture content.

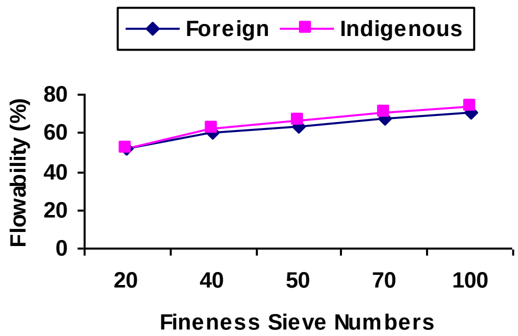

Figure 2: Variation of Flowability with Sand Fineness

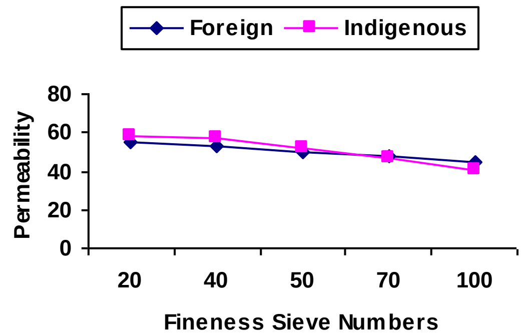

Figure 3: Variation of Green Permeability with Sand Fineness

Similarly, figures 4 and 5 show the variations of percentage flowability and green permeability with moisture content for a sand mix of 6% clay content.

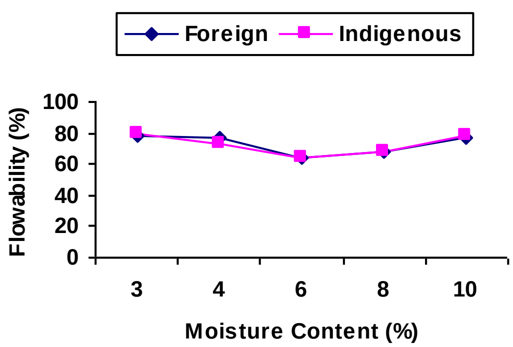

Figure 4; Variation of Flowability with moisture

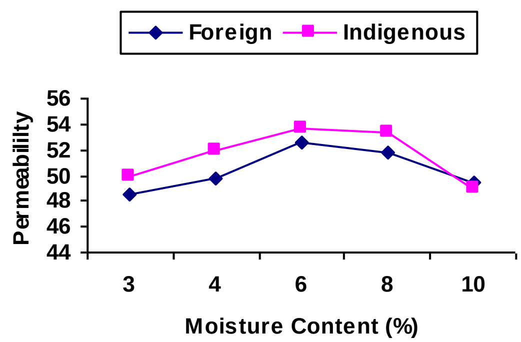

Figure 5: Variation of Permeability with Moisture

5. Discussion of Results

From the results obtained, figure 2 shows that there is much closeness in the results of flowability for the indigenous rammer when compared with that obtained from the foreign rammer. The graph is almost linear with a standard deviation of 0.954 and 0.947

for the foreign and indigenous rammer respectively. Coarser sand grains have a lower flowability than do the finer grains (Abubakar 2001). This is because greater force is required to rearrange the larger sand grains. The smaller grains flow together more readily.

Similarly figure 3 the comparison of the indigenous and the foreign rammers in terms of green permeability after ramming. While the indigenous has a standard deviation of 0.966, the foreign has 0.995. This indicates that the indigenous rammer has more voids due to low impact force.

Flowability and permeability of moulding sand are also influenced by moisture content. Figure 4 indicates that at low and high moisture content, flowability is low than at the temper moisture content of 6%. This is because the clay swells most at or near temper moisture. However, there is a close conformity between the values for indigenous and the foreign rammers when their trend lines are examined.

Figure 5 shows a much more clear difference of the results for the two rammers, although the pattern of variation is similar.

6. Conclusion

The redesigning of the Standard Rammer presented in this work was to enhance indigenous development of Nigeria foundry industries by providing test equipment at minimal cost. The total cos of production amounted to ₦175, 600.00 ($1,300.74) compared to that of Georg Fischer Disa Ltd. (Price list 1998), Switzerland of ₦ 601,897.50 ($4,458.5).

From the results, it can be concluded that there is a close agreement between the flowability and green permeability values obtained from the foreign and indigenous rammers, within the limits of experimental errors, and fabrication defects, although several other tests could be carried out to test its validity. It can therefore, be concluded that the locally fabricated rammer is of good standard and can be used for various foundry tests. It is pertinent to bring therefore the design of this rammer to foundry industries for mass production and commercialization.

References

1. H. W. Dietert, "Processing moulding sand," *Paper presented at the Annual Meeting of the American Foundrymen's Society,* Cleveland, Ohio, pp 1- 32, May 12, 1954.
2. A. A. Eugene, and B. III. Theodore, "Standard handbook for mechanical engineers," McGraw-Hill, Inc.; New York. 1987.
3. Foundry Association of Nigeria; "Foundry chronicle," vol. 1, no. 7, pp.5 – 6, 1995.
4. R. W. Heine, C. R. (JR). Loper, P. C. Rosenthal, "Principles of Metal Casting," McGraw-Hill, Inc., New York, 1967.
5. K. C. Bala, "Design and development of sand muller and standard sand rammer," *M. Eng. Thesis, Mechanical Engineering Department, Federal University of Technology, Minna,* 1998.
6. Price list, "Testing equipment for moulding and core sands," Goerg Fischer Disa Ltd., Switzerland, 1998.
7. R. H. Khan, N. S. Mahadevan, M. R. Seshadri, "Some studies on the flowability of moulding sand," *Journal of the Indian Institute of Science,* vol. 54, no. 4, pp. 194 – 210, 1972.
8. P. R. Beeley, "Foundry technology," Butterworth scientific, London, 1982.
9. P. L. Jain, "Foundry technology," Tata McGraw-Hill company, New Delhi, 1986.
10. F. F. O. Orumwense, "Moulding properties of synthetic sand mixtures – a comparative study," *Scandinavian Journal of Metallurgy*, vol. 31, no. 2 , pp. 100 2002.
11. R. A. Harding, "Towards the production of high performance castings,' Foundry International, vol. 18, no. 1, pp. 22-26, 1995.
12. S. M. Strobl and D. V. Silsby, "Controlling hot sand to ensure mold, casting quality," *Modern Casting*, pp. 42-44, Feb., 2001.
13. M. H. Abubakar, "Investigation on rammability of moulding sand using locally fabricated sand rammer," *PGD thesis, Mechanical Engineering Department, Federal University of Technology, Minna,* 2001.

Acknowledgement: The author is expressing his thanks to Prof. R.H. Khan of the Mechanical Engineering Department, Federal University of Technology, Minna, Nigeria for supervising this work.