Gating Practices in Nigerian Research and Training Institutes: Case Study of Lagos State

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Abstract
Foundry practice have existed in Nigeria for centuries. However, for the development of the practice, know-how and skills must be developed. Personnel must be trained at all levels. In this study, the practices in foundries of research and academic institutions involved in foundry within Lagos state were investigated. Investigations were carried out by on-site study of the foundries and also by means of questionnaires investigating various aspects of foundry practice. From responses obtained, it was shown that the capacity of foundries to produce technically sound castings is very low. Simple steps capable of increasing the quality and reproducibility of the castings were suggested. It was concluded that students’ learning and local foundry practice can be enhanced by upgrading foundries in research and educational institutions to current global best practices.

Keywords: Casting; foundry; research and academic institutions; gating system design; Nigeria.

1. Introduction
Foundry practice in Nigeria has been dated back to several centuries. Bronze casting was introduced to the Benin kingdom in the thirteenth century by practitioners from Ife kingdom ([1]. Iron smelting and casting which has flourished in the middle belt of Nigeria is part of the inheritance from the Nok culture. The Ugbo-Ukwu bronze casting has also been practiced for over a century [2]. Casting of aluminium which consists mainly of casting aluminium pots, began in the twentieth century [3] which is rather late when compared with the art of bronze castings. It is noteworthy that bronze castings were produced through a crude version of the very sophisticated lost wax process.

Studies carried out on indigenous castings have concluded that they are worthy bases on which to build the technology of Nigeria. This is particularly beneficial to small and medium enterprises [4]. Despite the potentials of the indigenous bronze castings, the art is approaching extinction. In Ife, there is only one renowned metal caster with a similar situation in Benin where 96% of the bronze casters are from a particular family. Bronze castings are mainly religious artefacts and bust, or head, of royalties.

Aluminium casting, on the other hand, was started by Nigerians repatriated from Ghana. They were uneducated and basically stuck to the production of pots and serving spoons (ladles). Recently, simple items such as stove grate, small religious artefacts such as crosses have been produced. However, due to the level of education of majority of the casters, innovation is almost non-existent. Survival of the art is due to lack of competition and substitutes for the products. These indigenous foundries as discussed above produce mainly nontechnical products or at best castings on which the technical demand in service is minimal and they satisfy the market
demand. The casters only have knowledge of the know-how but not of the know-why of the casting processes and, consequently, lack innovation.

The Nigerian economy has a huge dependence on castings [5]. Independent studies of National Committee on Foundry Development, the Federal Office of Statistics and the National Committee on Industrial Development (NCID) under the auspices of United Nations Industrial Development (UNIDO) revealed that national demand of castings increased steadily from 292,000 tons in 1985 to 425,000 tons in 1990s and 794,000 tons in 2000. The National Committee on Foundry Development estimated 40% of these as automotive components [6]. It was stated that there is a wide area of application for casting, manufacturing of ferrous and non-ferrous materials such as valves, pumps, engine blocks, aerospace and different automobile parts. It was also noted that major components of machine tools, power plants, industrial equipment, agricultural machinery and textile industry are products of the foundry.

The Nigerian foundry industries, like other industries, have its own problems which tend to restrain the growth and development of the foundries [7]. However, the Nigerian government, considering the importance of the foundry industry to technological development, set up research foundries in industrial research institutes across the country. National Agency for Science and Engineering Infrastructure (NASENI), for instance, has equipped foundries with rotary furnaces and electromagnetic induction furnaces. The establishment of the Foundry Association of Nigeria also underscores this importance.

Studies carried out on different aspects of the foundry industry emphasized the importance of developing small-scale foundries to fast track technological development. In a study based on foundry activities in Katsina state [8] it was stated that there was a need to engage more workers, and particularly more educated persons, in the foundry industry. It was also observed that the educational curriculum, particularly of the technical and vocational institutions, needed to be upgraded to meet the current trend of modern technology. It was noted that for Nigeria to develop the know-how and skills, personnel must be trained at all levels, and educational institutions must produce knowledgeable craftsmen, qualified technicians and professional engineers. It was proposed that to produce required manpower for foundry, at least three technical colleges or trade centers, two colleges of technology or polytechnics and one university in each state should include courses in foundry technology in their curriculum. Without trained manpower at all levels, investments in foundry industry will produce little returns.

The gating system design in the casting process has been regarded as one of the crucial factors to produce good quality products [9, 10]. It was opined that for Nigeria to develop the know-how and skills, the training of personnel at all levels must be embarked upon. This entails the educational and research institutions equipping personnel at all levels with knowledge and required skills. Considering the importance of the gating system and the role of academic and technical institutions in developing a competitive foundry industry, this study intends to assess the gating practices in foundries of institutions where artisans, technicians, technologists and engineers are trained. These training institutions also include research institutes with viable foundries.

2. Gating System

In order to produce a very sound casting, the geometry of all the gating components is important as it controls the flow of metal in the mold. The basic elements of a gating system are the pouring basin, sprue, sprue base well, runner, runner extension and ingate. A gating system design should aim to provide castings free from defects. A typical gating system with its components is illustrated in Figure 1.
The first step in the conventional method of designing a gating system for a casting is to choose a suitable gating ratio that is believed to be appropriate for casting the selected alloy. The gating ratio gives the ratio of the cross-sectional areas of the sprue, the runner and the ingate. Various components such as skim bob, crocodile’s teeth or filters are provided to prevent the metallic oxide and impurities on or in the molten metal from entering the mold cavity. It was also common to have an optimally designed sprue well below the sprue. Open or blind feeders, chills and fins were also used.

Conventionally the purpose of the pouring basins (or cups), sprue, sprue well, runner and ingate is to convey the molten metal in a non-turbulent manner (as determined by Reynolds number) into all parts of the mold cavity. While feeders, fins and chills serve to compensate for the shrinkage that occurs during the phase change from liquid to solid. It was also deemed important to fill the gating system, especially the runner as quick as possible. It is generally accepted that molten metal could not be poured to fill molds in perfectly laminar manner. It is, therefore, the aim of metal casters to pour metal so that its flow lies in the transient region between perfectly laminar and turbulent flow.

Guidelines for designing gating systems abound in foundry literature[11,12,13,14,15]. These include: the size of the sprue fixes the flow rate of molten metal into the mold cavity; the sprue should be located at certain distance from the gates to minimize velocity of molten metal at ingates; sprue with rectangular cross-section sprue is better than that with circular cross-section of the same area to limit tendency of vortex; sprue should have a minimum taper of approximately 5% to avoid aspiration of air and free fall of molten metal; ingates should be located in thick regions; gates should be located to minimize agitation and prevent erosion of sand mold by molten metal stream; multiple gating is frequently desirable; runner extensions or blind ends are used in most castings to trap any dross that may occur in the molten metal stream; and a relief sprue at the end of the runner.
can be used to reduce pressure during pouring. Sama and Manogharan also presented design rules for optimal sand casting performance [16].

Ahmed and Shukri reviewed the rules of thumb for the gating system and riser configurations [17]. It was noted that geometric features of the casting such as casting boundaries, parting line, orientation of casting and flow path are essential for the design of the gating system. From the rule of thumb, the directional solidification and location of gating system are important factors of feeder design. According to Vaghasia, optimization of gating system involves maximizing yield, minimizing ingate velocity of molten metal, optimizing the ingate location and minimizing [18]. The effect of gating design on the flow pattern of melt entering the mould has been studied [9, 19,20,21,22]. The studies showed that the geometry and the size of the gate and the ratio of the gating system had great influence on the pattern of mold filling. The flexure strength and frequency of porosity defects were also affected by the geometry of the gating system. It was shown that optimum gating design could reduce the turbulence in the melt flow and minimize casting defects [23]. The main problems caused by improper gating are air entrapment, sand inclusion, entrained aluminium oxide film, cuts, washes, low casting yield and dross [23,24]. From these studies it is clear that an understanding of the gating system is essential for the production of defect free castings.

Based on researches published within the last thirty years, especially those in which real life x-ray machines were used to study the flow of molten metals inside synthetic sand molds, gating components were optimized and newly developed charts and methods were used for the calculation of the dimensions of the gates [25].

3. Methodology

Questionnaires were designed and distributed to the foundries of research and academic institutions within Lagos State, Nigeria. The institutions include Federal Institute of Industrial Research, Oshodi (FIIRO); Lagos State University, Epe campus (LASU); University of Lagos, Akoka (UNILAG); Yaba College of Technology, Yaba (YABATECH); Lagos State Polytechnic, Ikorodu campus (LASPOTECH) and Federal Science and Technical College, Yaba (FSTC). The questionnaires were designed to determine the frequency of usage of gating components by the foundries. The questionnaires inquired about the frequency of utilizing specific types of basins and not just the type of basins used. Similar set of structured questions were repeated in the questionnaire for the different types of basins such as the funnel pouring cup, pouring bush and off set step basin. For clarity and to help facilitate the understanding of the questions, sketches of the three types of basins were provided. This is because only a few foundrymen knew about the offset step basin. Table 1 below gives an analysis of the questionnaire. It shows the sections contained in the questionnaire and the number of questions asked under each topic.

Table 1: Analysis of the questionnaire showing the topics investigated.

| Section | Topic                                           | Number of questions |
|---------|-------------------------------------------------|---------------------|
| a       | Pouring basins                                  | 8                   |
| b       | Types of gating systems in general              | 3                   |
| c       | Filter types and usages                         | 5                   |
| d       | Sprue types, cross sectional shape, sprue exit and, well | 11                  |
| e       | Dross traps                                     | 3                   |
| f       | Correct pressurizing of gating systems for the alloys to be cast | 5                  |
| g       | Runners                                         | 5                   |
Besides the administration of questionnaires, the foundries were also visited and the metal casting activities in them were observed. Interactions were also carried out with the personnel engaged in the foundry practice at the listed institutions. For the questionnaires, responses were graded 1to5 in accordance with the Likert scale with each value within the range corresponding with always (frequency of 95% to 100%), often (frequency of 65% to 94%), sometimes (frequency of 35% to 64%), rarely (frequency of 5% to 34%), and never (frequency of 0% to 4%). However, when a question was left unanswered, or a foundry’s reply is ‘not applicable’ to question considered to be relevant, the answer was scored (1). This implies that the response carries the weight score of 1, the least score, but the parenthesis implies the foundry has no knowledge of what was asked. After the responses to the questionnaires were received, the scores to the questions were compiled and analyzed.

4. Results and Discussion

Although, six institutions were contacted, responses were obtained from all except one of the institutions. The foundries are reported here as Foundries A to E without naming the institutions of domain. A summary of responses and section averages are presented in Table 2. The detailed responses with the questionnaire are presented in the appendix.

Table 2: Scores of the different foundries on the topics investigated.

| Section | Topic                                      | Total score | Average (%) |
|---------|--------------------------------------------|-------------|-------------|
| a       | Pouring basins (/40)                       | 12.0 17.0 22.0 12.0 21.0 | 42.0 |
| b       | Types of gating systems in general(/15)    | 7.0 13.0 10.0 7.0 9.0 | 61.3 |
| c       | Filter types and usages (/25)              | 11.0 9.0 11.5 10.0 11.0 | 42.0 |
| d       | Sprue details (/55)                        | 30.0 19.0 31.0 30.0 22.0 | 48.0 |
| e       | Dross traps(/15)                           | 9.5 7.0 9.0 10.0 10.0 | 60.7 |
| f       | Correct pressurizing of gating systems for the alloys to be cast(/25) | 18.5 5.0 14.0 11.0 15.0 | 50.8 |
| g       | Runners (/25)                              | 19.0 6.0 11.0 20.0 11.0 | 53.6 |
| h       | Ingate (/25)                               | 13.0 8.0 16.0 11.0 9.0 | 45.6 |
| i       | Flow criterion (/14)                       | 2.0 1.0 1.0 1.0 1.0 | 8.6 |
| j       | Prevention of shrinkage porosity (/5)      | 5.0 (1.0) 5.0 5.0 5.0 | 84.0 |
| k       | Prevention of flow stoppage on horizontal wide plane. (/5) | 1.0 1.0 1.0 1.0 5.0 | 36.0 |
| l       | Application of critical velocity (/10)      | 7.0 2.0 2.0 2.0 2.0 | 30.0 |
| m       | By flows (/10)                             | 4.0 2.0 5.0 2.0 8.0 | 42.0 |
The pouring basin provides an opening for the introduction of metal into the mold from a pouring device [26]. On how frequently the foundries use pouring basins, the respondents admitted to using pouring basins quite often but one foundry stated that it used pouring basin only when the casting is a highly technical job. Ensuring the use pouring basin during casting is good practice. Its use not only enhances the quality of the casting, but also prevents hazards due to spilling of molten metal on the mold boxes and the foundry floor which may occur if the pourer misses the sprue entrance or pours too fast. Pouring basins contributes to allowing clean molten metal enter the mold cavity [26]. The pouring basin also separates dross and slag from molten metal [17]. From Table 2, it is indicated that, on the topic bothering on pouring basins, the average score of responses was about 42% which is rather poor. This proves that although most of the foundries use pouring basins quite often, they use the wrong type of basins. The offset step basin is virtually unknown and the idea of using a stopper is still strange to the foundries. All respondents mainly cut in the pouring basin or cup being used and the funnel or conical cup which in itself acts as an air pump destroys the molten metal.

From the responses, it was discovered that the foundries use tapered sprues quite often which is a good practice. However, when it comes to the details of the sprue such as shape of the cross-section, the amount of taper, usage of sprue well, the performance of the foundries is not good enough with average score of 48%. The general type of gating system used had average score of 63% which is fair and implies that bottom gating is used more often than the side or top gating. It has been stated that bottom gating is the preferred gating system. The science of casting currently indicates that if a casting with very good property is desired repeatedly, the mold cavity has to be filled counter gravity, that is from bottom to top. This casting process, being repeatable, has made it possible to produce train wheels which are stronger than those produced by forging [15]. It has also been noted that for bottom gating, the mold gets filled up gradually with minimal disturbances [26].

Filters are very important features in the gating system usually placed between the runner and ingate to act as slag trap) [26,17]. Apart from its ability to separate dross or oxides and other solid impurities from the molten metal, it also slows down the metal to achieve a uniform front with velocity below the critical velocity. The critical velocity is the velocity below which surface turbulence and associated entrainment of oxide films does not occur. Although, there are many types of filter, only the ceramic foam filters are recommended for this purpose. A score of 42% in this vital aspect of the gating system was returned by the foundries. This is not good enough and would have resulted in invisible defects (as bifilms are not detected even by x-ray machines) of many castings that cause them to fail in service.

Dross traps are used a lot by the foundries and it results in the 60.7% score they obtained. The bitter fact is that dross traps work poorly because their design assumed that once the metal fills the cavity then there is no more movement of the molten metal. It is known that currents exist in the liquid even after the mold cavity is filled and these often cause the dross to go to the mold cavity and the dross traps and blind ends are filled with the best metal. The filter seems to be more efficient than dross traps. The foundries scored 50.8% in the usage of pressurised gating system. Many of the foundries still practice the old principle of using pressurised system for the heavier metals (such as copper alloys and iron alloys) and unpressurised system for the light metals (such as aluminium alloys and zinc alloys). The recommended practice is to use unpressurised gating system for all metals and their alloys.

With respect to the foundries practice on the use of runners, the foundries score 53.6%. This is also not satisfactory. The concept of the slot runner is not known to all foundries and the thickness
of the runners they employ will cause entrainment of bifilms. Bifilms are double layered oxide films folded dry side to dry side, essentially constituting a crack. The slot runner will have a thickness just below the size of the sessile drop of the molten metal. The practice is not near uniform across the foundries in some of the questions as the standard deviation of the foundries response is over 80%. On this topic the worst performance is obtained for the geometry of runners, and specifically on position of the widest cross-sectional area. The mean score is 1.4 out of 5. The runner should have the widest cross-sectional area close to the ingate. The cross-sectional area of should be getting bigger away from the sprue exit and closer to the ingate. This will ensure correct pressurising of the molten metal [26]). This result also agrees with the result on the correct pressurisation of the molten metal by the gating system. Also there must be sufficient pressure differential to cause the feed material to flow in the right direction [17].

For responses relating to ingates, the foundries scored a mean of 45.6% which is a rather poor average. The molten metal goes into the mold cavity immediately it leaves the ingate. It is therefore compulsory that the critical velocity is achieved by the time the molten metal leaves the ingate. The transverse velocities must also be less than the critical velocity. The geometry of the ingate must also satisfy the junction criteria in order to avoid hot spots.

The performance of the foundries on flow criteria is really very poor, all responding foundries, except one, consider Reynolds number only and it, states that the Weber number quantifies the surface turbulence [26]. Traditionally, Reynolds number is one of the important parameters to consider in gating of castings. It is, however, now known that consideration of Weber number is more important. Once the Weber number criterion is met, the Reynolds number criterion will be satisfied. Also, returning or reflected waves and entrainment of bifilms as well as casting modulus should be considered when designing gating systems. The foundries made good use of feeders and chills in preference to fins. This is not really bad considering they are not high volume producers of castings.

Only one of the foundries knew how to properly prevent stoppage of flow of molten metal along a wide horizontal plane. Also, only one foundry applies the concept of critical velocity in its gating design others do not. The foundries scored 42% on questions relating to by flows. By flows are necessary in order to prevent returning waves, which apart from increasing surface turbulence (thereby encouraging entrainment of oxide films), will also encourage the filling of the mold cavity prior to the time the runner is filled. This causes entrainment of mold gases.

In order to produce a top quality casting, all the thirteen aspects specified in Table 1 should be properly attended to. Failure in any one of them will either reduce the quality of the casting or destroy the casting. It was also observed that none of the foundries produces, or uses, boxless molds. This is partly due to the type of binders, mainly clay or Bentonite, being used in the foundries. There are some inherent advantages in boxless molds as the molds achieve strengths and permeabilities that are impossible to match using the best type of Bentonite. Also it allows molds to be made with vertical parting plane like dies unlike the horizontal parting plane in the typical cope and drag used by our foundries. The usage of vertical parting plane simplifies mold production for many complex geometries of castings.

5. Conclusion
Although, it is expected that the most modern practice in casting technology should be available in training and research institutions, results of this investigation show that foundries in institutions in Lagos State, Nigeria still engage in practices that are totally outdated and not in line with the
current global best practices. Hence, foundries are limited in the production of castings for high technical demands. Usage of the funnel pouring cup (also known as conical pouring cup), whether molded or cut in, is prevalent in the foundries but this practice destroys the molten metal by filling it with gases. The use of the offset step pouring basin with stopper has been recommended. Evident from this study is the lack of knowledge on the critical velocity which is very important for the design and dimensions of the gating systems. This has resulted in the use of top and side gating systems, pressurised gating systems and dross traps in the foundries. In order to increase the quality of castings the bottom gating is preferred. It is recommended that the gating system should not be pressurised and ceramic foam filters must be used. Although filters may be expensive, it is a critical component of the gating system. It is necessary to ensure that the right types of filters are consistently used. Other recommendations, to minimize the effects of returning waves, are to utilize slot runners and bye flows. Upgrading foundries in research and educational institutions to current global best practices will have positive impact on students’ learning and enhancement of local foundries.

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Appendix

Table A1: Responses Score from the Various Foundries
| S/N | Question | A | B | C | D | E | AV | SD |
|-----|----------|---|---|---|---|---|----|----|
| 1   | 5        | 4 | 4 | 5 | 1 |    | 3.8| 1.64|
| 2   | 1        | 1 | 2 | 1 | 2 |    | 1.4| 0.55|
| 3   | 1        | 2 | 2 | 1 | 1 |    | 1.4| 0.55|
| 4   | (1)      | (1)| (1)| (1)| 5 |    | 1.8| 1.79|
| 5   | 1        | 2 | 3 | 1 | 3 |    | 2  | 1.00|
| 6   | 1        | 3 | 3.5|(1) | 3 |    | 2.3| 1.20|
| 7   | 1        | 1 | 3 | (1)| 3 |    | 1.8| 1.10|
| 8   | 1        | 3 | 3.5|(1) | 3 |    | 2.3| 1.20|
| 9   | 1        | 2 | 4 | 1 | 3 |    | 2.2| 1.30|
| 10  | 3        | 3 | 4 | 3 | 3 |    | 3.2| 0.45|
| 11  | 3        | 3 | 2 | 3 | 3 |    | 2.8| 0.45|
| 12  | 1        | 5 | 3.5| 5 | 2 |    | 3.3| 1.79|
| 13  | (1)      | (1)| 2 | 1 | 2 |    | 1.2| 0.45|
| 14  | 5        | (1)| 3 | (1)|(1) |    | 2.2| 1.79|
| 15  | 3        | (1)| (1)| (1)| 3 |    | 1.8| 1.10|
| 16  | (1)      | 3 | (1)| 4 | 2 |    | 1.4| 1.41|
| 17  | 3        | 5 | 5 | 5 | 3 |    | 4.2| 1.10|
| 18  | 4        | (1)| 1 | 3 | 2 |    | 2.2| 1.30|
| 19  | 3        | (1)| 4 | 3 | 2 |    | 2.6| 1.14|
| 20  | 3        | 1 | 1 | 1 | 2 |    | 1.6| 0.89|
| 21  | 1        | (1)| 2 | 3 | 2 |    | 1.8| 0.84|
| 22  | 1        | (1)| 3 | 2 | 2 |    | 1.8| 0.84|
| 23  | 1        | (1)| 1 | 1 | 1 |    | 1  | 0.00|
| 24  | 1        | 5 | 5 | 5 | 1 |    | 3.4| 2.19|
| 25  | 3        | 1 | 1 | 3 | 3 |    | 2.2| 1.10|
| 26  | 5        | 1 | 3 | 3 | 3 |    | 3  | 1.41|
| 27  | 4        | (1)| 5 | (1)|(1) |    | 2.4| 1.95|
| 28  | 1        | 5 | 3 | (1)| 4 |    | 2.8| 1.79|
| 29  | 5        | 1 | 3 | 4 | 3 |    | 3.2| 1.48|
| 30  | 3.5      | (1)| 3 | 5 | 3 |    | 3.1| 1.43|
| 31  | 5        | (1)| 3 | 5 | 3 |    | 3.4| 1.67|
| 32  | 2        | (1)| 2 | 3 | 3 |    | 2.2| 0.84|
| 33  | 3        | (1)| 3 | (1)| 3 |    | 2.2| 1.10|
| 34  | 3.5      | (1)| 3 | (1)| 3 |    | 2.3| 1.20|
| 35  | 3        | (1)| 3 | (1)| 3 |    | 2.2| 1.10|
| 36  | 1        | (1)| 3 | 1 | 1 |    | 1.4| 0.89|
| 37  | 3        | 2 | 3 | 5 | 3 |    | 3.2| 1.10|
| 38  | 5        | 1 | 3 | 5 | 3 |    | 3.4| 1.67|
| 39  | 5        | 1 | (1)| 5 | 3 |    | 3  | 2.00|
| 40  | 5        | (1)| 4 | 1 | 1 |    | 2.4| 1.95|
| 41  | 1        | 2 | 4 | 1 | 1 |    | 1.8| 1.30|
| 42  | 3        | (1)| 3 | 3 | 1 |    | 2.2| 1.10|
| 43  | 3        | (1)| 4 | 1 | 1 |    | 2  | 1.41|
| 44  | 3        | (1)| 4 | 3 | 1 |    | 2.4| 1.34|
| 45  | 3        | 3 | 1 | 3 | 5 |    | 3  | 1.41|
|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 46 | 2 | 1 | 1 | 1 | 1.2 | 0.45 |
| 47 | 5 | (1) | 5 | 5 | 5 | 1.4 | 0.55 |
| 48 | 1 | (1) | 1 | (1) | 5 | 1.8 | 1.79 |
| 49 | 4 | (1) | (1) | (1) | (1) | 1.6 | 1.34 |
| 50 | 3 | (1) | (1) | (1) | (1) | 1.4 | 0.89 |
| 51 | 3 | (1) | 4 | (1) | 3 | 2.4 | 1.34 |
| 52 | 1 | (1) | 1 | (1) | 5 | 1.8 | 1.79 |

AV=average or mean; SD= standard deviation