Aluminium Sand Casting in the Ghanaian Foundry Sector: Process, Practice, and Common Casting Defects in Small-Scale and Informal Production

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Abstract
Aluminium sand casting is one particular sector that stands out in the Ghanaian manufacturing sector, not because of the large-scale integrated factories, but because of the large number of small and informal production units dedicated to recycling used aluminium into cookware, corn mill plates, and light engineering parts. This paper delves into the aluminium sand casting process as practised in Ghana, following it from the preparation of the mould using the cope and drag system to pattern making and the various sand materials used for mould making, to the melting and pouring of scrap aluminium, and the shakeout and fettling processes after solidification. Special focus is placed on the informal and small-scale nature of many foundry operations in Ghana, the use of unsegregated scrap, the use of artisanal melting equipment and a lack of process instrumentation and how this influences sand casting processes and the defects most frequently observed in castings. The article is based on foundry engineering, combining general casting theory with material, technical and occupational conditions of the aluminium casting industry in Ghana, and the article ends with the quality and public-health implications and possibilities of upgrading local practice.

Keywords: casting defects, cope and drag, foundry, mould system, scrap aluminium recycling

Introduction

One of the oldest metals forming processes today still used in industry is sand casting and it is the most common form in which aluminium is formed into finished goods in much of West Africa (Osborn, 2009) [10]. It is generally observed in the small-scale and informal sector, not in the big mechanised foundries in Ghana. Informal industrial clusters in Kumasi, Ghanaians "Suame Magazine", is one of the largest clusters in West Africa, is where substantial part of the country's foundry activities takes place, in addition to the well-recognized automotive repair and light engineering activities in the city (Andrews & Gikunoo, 2011) [1] and other smaller clusters of aluminium casters are found in other cities in the country. The enterprises are mostly involved in recycling scrap aluminium from a variety of sources, such as used engine blocks, radiators, beverage cans, cookware, and electronic and electrical waste, and then casting them into new products, particularly cooking pots and utensils that are sold everywhere in the domestic and regional markets (Osborn, 2009; Weidenhamer *et a;l*., 2022) [10, 13].

Andrews and Gikunoo (2011) [1] define small-scale foundries as semi-production operations which operate with low capital investment, makes use of labour-intensive, mostly manual practices and have contributed significantly to the economic activities and informal employment in Ghana. The impact of this structure on the actual sand casting processes (pattern making, moulding, melting and pouring) is that parameters such as melt temperature, hydrogen content, sand permeability are not usually measured but rather judged by experience and visual inspection, whereas in industrial foundries they are carefully instrumented and controlled (Andrews & Gikunoo, 2011) [1].

This article gives a review of the aluminium sand casting practice in this Ghanaian environment. The book starts with an explanation of the sand and metal supplies that are available for local foundries, then follows the cope and drag mould system, mould making, melting and pouring and concludes with the shakeout and fettling operations that recover the casting. The last significant part of the book provides a discussion of the most frequently reported defects in Ghanaian and similar West African sand-cast aluminium alloys, and places them in the context of defect mechanism described in standard foundry engineering references (Beeley, 2001; Campbell, 2015; Groover, 2010; Kalpakjian & Schmid, 2014) [4, 5, 6, 7]. The issues that are considered in this discussion are the quality and public health consequences of current practice and the possibility of incremental technical upgrading.

Moulding Sand

According to the standard foundry theory, moulding sand consists of silica sand, a bonding clay, water and small number of additives, which are formulated to ensure mould has sufficient strength, permeability, and collapsibility (Groover, 2010; Kalpakjian & Schmid, 2014) [6, 7]. The small-scale foundries in Ghana typically use locally won river sand or pit sand and clays, instead of commercially graded and blended sand systems. In a study, the indigenous clay and silica were obtained from the streams around Kentinkrono village, in Ashanti Region, and it was observed that about seventy percent Mfensi clay, ten percent of the local silica sand and twenty percent water produced a good mould quality compared with the sand mixtures which have traditionally been used by artisans in Ghana, and would therefore be a low-cost method to achieve shell-mould casting for local industry (Scientific African, 2021). This discovery is a common theme in Ghanaian literature: the properties of the moulding sand used in many local practices are not systematically characterised and controlled, whilst comparatively simple moulding sand selection and proportioning can produce significant improvement in casting quality (Scientific African, 2021).

Aluminium Scrap

Much of Ghanaian casting is done with unsegregated scrap while industrial aluminium foundries melt certified ingots of known alloy composition. Historical and ethnographic literature depicts the Ghanaians and West Africans as artisans that specialise in the collection and recycling of scrap metal, using materials as diverse as the parts of a motor vehicle engine, cooking utensils and even beverage cans (Osborn, 2009) [10]. This trend is also reflected in more recent public-health studies, which report on the use of seven different group of scrap source materials from which the cookware used in Ghana was cast, including automobile radiators and blocks of engine material (Weidenhamer *et a;l.*, 2022) [13]. The resulting cast metal is metallurgically heterogeneous, as these scrap streams are not generally sorted by alloy grade, the composition of which may even vary significantly between batches and can contain high concentrations of various elements from the mixed scrap charge (Street *et a;l.*, 2020; Weidenhamer *et a;l.*, 2022) [12, 13]. This variation has implications on the mechanical strength of the castings, as will be discussed when examining casting defects, as well as its implications on the safety of cast aluminium cookware in food contact situations as will be examined in detail in the latter section.

Overview of the SandCasting Process

In general, sand casting is a process that starts with a pattern which is made larger than the actual part to account for shrinkage during solidification and then a casting sand mould is constructed of a disposable material around the pattern (Groover, 2010) [6]. The mould is made up of two parts in a flask, a sprue and runner system is used to direct the molten metal into the mould, the pattern is removed, and the mould is then remounted and the molten metal is poured, solidified, and finally the mould is broken apart to recover the casting (Kalpakjian & Schmid, 2014) [7]. The same applies to the small Ghanaian workshop that makes corn-mill plates or cooking pots as well as a fully mechanised industrial foundry, except that the amount of process control exercised at each step is different; this distinction will be followed throughout this article.

The Cope and Drag Mould System

The cope and the drag are the top and bottom portions respectively of a two-part sand mould; the flasks that hold them (Groover, 2010) [6]. Traditionally, the drag is formed by ramming around its pattern half, inverted, and the cope is placed inverted on top of the drag by its alignment pins, and the two patterns are removed and the mould is then re-assembled ready for pouring (Kalpakjian & Schmid, 2014). As noted by Andrews and Gikunoo (2011) [7, 1], the sector is generally semi-production, labour-intensive, and indeed the small-scale foundry, in Ghana, has the same two-part structure, with the exception of the mechanised jolt-squeeze equipment, which is replaced by simple wooden or fabricated metal flasks and by hand ramming (Figure 1). Indeed, the relative simplicity and low capital cost of cope-and-drag tooling has made sand casting accessible to small businesses that are otherwise unable to invest in more capital-intensive casting methods like shell-mould or permanent-mould casting, thus enabling the casting activity to persist where these other methods have been less widely used (Andrews & Gikunoo, 2011; Scientific African, 2021) [1].

Fig 1: Cope and Drag System (Fieldwork, 2026)

Making the Mould

Pattern Practice

In Ghana, they are usually very basic, often made in the small foundries from wood or metal, and developed through experience rather than formal pattern design procedures, and can be used to make a limited line of common products like corn-mill grinding plates, as well as some vehicle and machine parts (Scientific African, 2021). Like in industry, the pattern should be made larger than the casting to accommodate the linear shrinkage of aluminium as it cools, but the shrinkage allowances and the draft angles provided for artisanal pattern-making are often based on the sum of trial-and-error practice and experience rather than on the alloy's shrinkage data (Groover, 2010) [6].

The Quality of the Sand and Ramming-Gating Methods

Due to the use of local unblended sands and manual ramming for mould-making in Ghana, there is more variability in the compaction and permeability of the moulds as compared to a mechanised and quality-controlled sand system (Scientific African, 2021). The gating and risering systems for filling the cavity and feeding solidification shrinkage are also simplified compared to the calculated gating and risering system recommended in foundry engineering books (Campbell, 2015; Groover, 2010) [5, 6], and are often designed based on the practical experience of the caster with a specific pattern. This association of variable sand quality and simplified gating is very similar to a number of the defects that are commonly reported in locally produced aluminium castings, as discussed in the study.

Moulding, Melting and Pouring the Aluminium

Furnace Practice

The practices of industrial foundries typically employ gas-fired, electric resistance or induction furnaces with good control over charge cleanliness, melt temperature, and holding time. (ASM International, 2008) [3] Small-scale foundries in Ghana are usually foundries that use simpler crucible type furnace (Figure 2) that is fired by charcoal, waste engine oil or scrap wood; the temperature control in such foundries is subjectively judged by the foundry operator based on their experience (Andrews & Gikunoo, 2011) [1]. As the charge itself is a heterogeneous mix of variable composition and surface condition as described in the study, the melt is more likely to contain moisture, oil residue and surface oxide in the furnace than if the melt was made from clean certified ingot (Weidenhamer *et a;l*., 2022) [13].

Fig 2: Simpler furnaces with metal crucible for molten aluminium (Fieldwork, 2026)

Melting of Aluminium

The part of the aluminium sand casting process that will influence the quality of the casting is the melting part (Figure 3). In industrial practice, aluminium ingot or clean scrap is charged into a gas-fired, electric resistance or induction furnace and heated to about 680-750°C, which is a temperature well above the melting point of aluminium (about 660°C), to provide enough fluidity to fill the mould (Groover, 2010) [6]. In order to prevent the entry of hydrogen and oxidation of molten aluminium, the foundries usually degas the molten aluminium with an inert gas (argon or nitrogen) and remove the dross and oxide film by applying a flux before casting. (ASM International, 2008; Campbell, 2015) [3, 5]. Small-scale foundries in Ghana typically use unsegregated scrap materials, including engine components and cookware, for melting in crude crucible furnaces fueled by charcoal or waste oil, instead of certified ingot. Temperature is not always measured and is often determined by experience and formal degassing or fluxing is not always done, which may mean gas porosity and inclusions in the casting are likely to be a problem (Andrews & Gikunoo, 2011) [1].

Fig 3: Melting aluminium for casting (Fieldwork, 2026)

Spray Dyeing and Chemical Bleaching in Informal Practice

According to traditional foundry metallurgy, degassing and fluxing are important processes in preparing an aluminium melt for casting, degassing to remove dissolved hydrogen, the primary cause of gas porosity in aluminium castings, and fluxing to prevent surface oxidation of the melt and to aid in the removal of dross and non-metallic inclusions (ASM International, 2008; Campbell, 2015) [3, 5]. In order to maintain low and controlled levels of hydrogen typically an inert-gas purging system or careful control of charge moisture and melt handling, in conjunction with some form of melt quality testing prior to pouring is required, such as reduced-pressure testing (ASM International, 2008) [3]. However, this is not always practised in much of the small-scale production in Ghana and has been blamed, among other things, on the lack of capital in small enterprises in the sector and the lack of technical training (Andrews and Gikunoo (2011)) [1], an issue that will be addressed in this paper. The result, to be discussed in the following section, is a melt which is even more susceptible to hydrogen pick-up and oxide entrainment than would be acceptable in an industrial foundry and the resultant casting soundness.

Pouring

Again, in small-scale practice, the operators' judgement is relied upon to control the pouring temperature and technique, and the metal ready for pouring is usually judged visually before it is poured by hand from a crucible or ladle (Figure 4) into the mould and is often joined to the mould in the final stages of pouring without any instrumented aid. (Andrews & Gikunoo, 2011) [1] In any foundry operation, the cooling rate and pouring rate of the mould may be too fast or too slow, which can lead to insufficient filling of the mould, and the amount of turbulence during pouring can lead to oxide entrainment and gas pickup; all of these possibilities are greater in many artisanal production processes when standard pouring procedures are not followed, leading to castings that show one or more of these effects.

Fig 4: Pouring of molten aluminium into mould (Fieldwork, 2026)

7. Solidification, Shakeout, and Breaking Apart the Mould

After pouring, the casting is left to set and cool in the mould before the sand is removed, typically by hand in the small-scale, Ghanaian, castings foundries, but not on the mechanised shakeout grids found in larger foundries (Andrews & Gikunoo, 2011) [1]. The casting is then fettled and gates and risers removed, any sand that sticks to it is knocked off and rough edges are dressed, usually with simple hand tools (Figure 5), not the shot blasting and grinding equipment used in mechanised operations (Andrews & Gikunoo, 2011) [1]. In small-scale enterprises, recovered shakeout sand is generally used without any special reconditioning with limited reconditioning, and the accumulation of spent and contaminated foundry sand from many casting cycles is recognized as an environmental issue in the small-scale foundry sector, as metal leachable residues from the casting process can be left behind in the sand (Andrews & Gikunoo, 2011) [1].

Fig 5: Breaking apart the mould to reveal cast piece (Fieldwork, 2026)

Common Defects of Aluminium Products in Ghana

Although the term foundry is used to describe the factory production of aluminium alloys, the defects listed above, namely gas porosity, shrinkage related voids, misruns and cold shut, and non-metallic inclusions, are common in foundry products, many of which are more likely and difficult to prevent in much of the Ghanaian production as the small-scale and informal production conditions discussed earlier (Figure 6).

Gas Porosity

Gas porosity occurs when hydrogen dissolved in the melt or when air and moisture are included with the cast, due to rejection from the solution of the melt as it solidifies, forming voids in the metal (ASM International, 2008; Campbell, 2015) [3, 5]. Gas porosity is a defect that would be expected to be more common in artisanal castings than in industrially melted and degassed aluminium as the degassing process is not consistently followed in the small-scale Ghanaian foundries and also the moisture and oil residue are likely to be present in the scrap charge itself as discussed in the study. This is aligned with the overall description of the quality problems encountered in the small-scale foundry industry in Ghana, which are related to poor process control (Andrews & Gikunoo, 2011) [1].

Shrinkage Defects

Shrinkage voids are created due to volumetric contraction of aluminium during solidification that cannot be matched by sufficient liquid metal feed from risers (Groover, 2010) [6]. Many of the small-scale practices in Ghana do not rely on gating and risering based on the casting geometry, but on experience, therefore, the heavier or more complex portion of a casting may be at greater risk of shrinkage porosity or cavities compared to a casting that is cast using a formally designed feeding system (Campbell, 2015) [5].

Misruns and Cold Shuts

Low pouring temperatures or rates compared to the fluidity requirements of the casting geometry are thought to be the source of two defects: misruns, where metal solidifies before it fills the mould cavity, and cold shuts, where two flows of metal meet without mixing. (Groover, 2010; Kalpakjian & Schmid, 2014) [7, 6]. When the melt has cooled too much before or during pouring, it is easy to get casting defects, especially with thin sections or highly detailed designs, such as decorative or fine-featured cookware, whose production is particularly susceptible to casting defects due to the fact that pouring temperature in artisanal Ghanaian production is assessed visually and not measured.

Inclusions and Mould-Related Defects

The non-metallic inclusions occur when oxide film, dross or mould sand particles are carried into the flowing metal and become trapped on solidification of the casting (Campbell 2015) [5]. This defect category is particularly important in the small-scale practice in Ghana because of two aspects. First, the unsegregated, and sometimes visibly contaminated scrap charge described in the study contains oxide and non-metallic material at the start of the pouring independent of the pouring technique (Weidenhamer *et a;l.*, 2022) [13]. Secondly, using moulding sand sourced from the local market which may not be properly graded and bonded, as described in the study, can lead to erosion of these moulding sands and to the inclusion of sand particles in the moulding patterns, while the shell-mould study of Ghanaian indigenous materials was specifically designed to overcome this (Scientific African, 2021).

Compositional Inconsistency, as an Underlying Defect Driver

In addition to above mentioned traditional defects, the metallurgical variation in the production of aluminium castings from returned vehicles in Ghana is a unique quality issue of local importance. As the composition of the alloy used in the casting of a particular metal lot may differ due to the mix of scrap feed, the mechanical properties, fluidity and shrinkage characteristics of the casting can vary significantly from one casting production run to the next (Street *et a;l*., 2020; Weidenhamer *et a;l*., 2022) [12, 13]. Along with the classical defect risks discussed above, this compositional variability adds to the potential for the alloy to behave differently with respect to fluidity and shrinkage from the implicit assumption in the experience-based technique used to design the caster (Street *et a;l*., 2020) [12].

Fig 6: Various defects in cast piece (Fieldwork, 2026)

Discussion

The above sections indicate that the mechanisms of aluminium sand-casting defects in Ghana are similar to those found in the standard foundry engineering literature (Beeley, 2001; Campbell, 2015; Groover, 2010; Kalpakjian & Schmid, 2014) [4, 5, 6, 7] but vary in the degree of control exercised over the variables that influence the mechanisms. Andrews and Gikunoo (2011) [1] state that the small-scale foundry sector in Ghana in general is characterized by the lack of practical knowledge of management of gas porosity, shrinkage, misruns, cold shuts and inclusions through measurement and calculation.

This technical illustration also has a much deeper public health component to the artisanal, scrap-based, aluminium casting in Ghana. Many local aluminium products, such as cookware, are made from auto/electronic scraps that aren't segregated, meaning these items often contain high and variable amounts of lead, cadmium, and other metals that leach into food during cooking (Mathee & Street, 2020; Street *et a;l*., 2020; Weidenhamer *et a;l*., 2022) [8, 12, 13]. Weidenhamer *et a;l*. (2022) [13] reported that aluminium migration from the Ghanaian cookware samples collected directly from the producers was above the recommended values, with varying quantities of lead and other metals leached depending on the source of the scrap metal, with automotive radiators found to leach out the highest quantity of lead. Mathee and Street (2020) [8] place this trend into the wider public-health issue of the use of cheap, light and easy to manufacture artisanal aluminium cookware in poorly resourced nations, where its use has proliferated in recent years due to its affordability. This suggests that the defect and quality issues in aluminium casting in Ghana are not only mechanical but also for the production of cookware, relate to the safety of consumers and workers.

Parallelly, the Ghanaian literature also suggests incremental, low-cost options for quality improvement that align with the resource limitations of small-scale foundries. The results of the shell mould investigation which involved indigenous Mfensi clay and river streams silica showed that a sand mixture made with the local clay silica and sand could significantly enhance the casting surface finish and dimensional accuracy over conventional artisanal green-sand casting without the need for importation of silica and sand, which is the case for conventional artisanal green-sand casting (Scientific African, 2021). Historically, institutions have been used to provide support services to these informal clusters, for example, through the Technology Consultancy Centre and its related Intermediate Technology Transfer Unit at the Kwame Nkrumah University of Science and Technology to disseminate foundry and engineering skills to these clusters; therefore, targeted technical training in sand selection, gating design, and basic melt quality checks could have a meaningful impact on lowering the rates of defects without the capital investment that would be required for full-scale foundry equipment.

Conclusion

Despite the extensive research already conducted in the field of aluminium sand casting, the process generally takes place in Ghana within a small-scale production of informal nature that is based on scrap and has been implemented with an approach that is much less instrumented and controlled as that of production in foundries (Andrews & Gikunoo, 2011; Groover, 2010; Kalpakjian & Schmid, 2014) [1, 6, 7]. This combination of manual mould making using locally sourced sands, artisanal melting of unsegregated scrap and experience based pouring and fettling technique is responsible for the character of the sector, low capital cost, wide accessibility, strong links to informal recycling and cookware production, and the defects most commonly observed in its output: gas porosity, shrinkage voids, misruns, cold shuts, and non-metallic inclusions, compounded by the compositional variability inherent to the scrap feedstock. This very same scrap-based nature imparts public health relevance to the sector's most popular product, the cast aluminium cookware. Both local, context-sensitive research into indigenous moulding materials and institutional set-up of technical-support programmes indicate that very low-cost (and small-scale, artisanal) changes to the way sand is selected, gated, and the quality of sand-moulding materials is encouraged could make a meaningful impact on reducing the variability and safety hazards of aluminium sand casting in Ghana, without necessitating a wholesale change to large-scale, industrial production.

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