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Assessment of Porosity Defects in Sand Metal Casting Process A Case Study at Tanzania Automotive Technology Centre.

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Abstract: Porosity defects reduce mechanical performance and cause much reject in TATC. The purpose of this paper was to identify the porosity causes at the TATC and examine effects of pouring temperature, permeability of sand and rate of solidification through sequential mixed-methods and ANSYS numerical simulation approach.

Porosity was reduced from 6.8% at 1200 °C to a minimum of 3.4% at 1440 °C before increasing back to 5.2% at 1600 °C. A range of sand permeability from 80 to 140 lowered porosity from 5.1% to 2.2%. Increasing the solidification rate from 0.8 °C /sec to 2.0 °C /sec resulted in a reduction from 5.5% to 1.9% porosity.

The study selects at approx. 1440 °C as the best pouring temperature. To reduce defect, the suggestions are controlling temperature, making higher sand permeability, strengthening solidification, and using more simulation, and it needs further experiment to verify these ideas.

KEY WORDS: Sand casting; porosity defects; cast iron; pouring temperature; sand permeability; ANSYS; TATC.

I. INTRODUCTION

Sand casting is a fundamental and widely used metal-manufacturing process in which molten metal is poured into a mould cavity that reproduces the desired geometry of a component and is subsequently allowed to solidify. The process remains important because of its relatively low tooling and production costs, flexibility in producing components over a wide range of sizes and materials and capability to manufacture components with complex geometries, including internal cavities formed using sand cores (Saikaew and Wiengwiset, 2012; Kleinhans et al., 2025).

Regardless of their widespread use, casting processes are prone to defects, which can lead to reduced structural integrity and mechanical properties of the final product. Among the most common defects are gas porosity and shrinkage, which typically arise due to improper solidification, trapped gases or inadequate feeding during cooling. Porosity is the presence of voids or holes in cast metal and may reduce strength, fatigue resistance and product reliability while increasing scrap rates and production costs (Sertucha and Lacaze, 2022; Sahoo and Goswami, 2023).

Traditionally, predicting the formation of porosity defects in casting has relied largely on trial-and-error methods and operator experience. Such approaches can be time-consuming and costly, particularly for complex geometries. Numerical modelling and computer simulation have therefore increasingly been adopted to predict solidification patterns, temperature gradients, mould filling and potential defect formation before physical production (Patwari et al., 2024; Chen et al., 2023).

At the Tanzania Automotive Technology Centre (TATC), research and manufacturing activities in automotive engineering components and foundry technology are conducted, with various engineering components produced using sand casting. However, the sand-casting process is associated with defects such as porosity and shrinkage, which can increase production costs and rejection rates and compromise the dimensional integrity, mechanical performance and reliability of manufactured components. Previous work also indicates that parameters such as sand permeability, pouring temperature and sand moisture content influence porosity formation (Malek Ali et al., 2022; Sertucha and Lacaze, 2022). Therefore, this study aimed to assess the causes of porosity formation in sand-metal casting at TATC and to evaluate selected process conditions using numerical simulation. The study focused on identifying the major porosity defects and

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their causes, determining the effects of pouring temperature, sand permeability and solidification rate on predicted porosity, and recommending appropriate measures for reducing porosity defects.

II. RELATED WORK

Research on sand-casting quality has examined the influence of mould composition and permeability on defect formation. Saikaew and Wiengwiset (2012) investigated moulding-sand composition for improving the quality of iron castings, highlighting the importance of controlling mould properties. Malek Ali et al. (2022) reviewed how ceramic sand particles and related mould characteristics affect casting defects. These studies provide a basis for considering sand permeability as one of the process variables associated with gas evacuation and porosity in sand moulds.

Casting literature also identifies the interaction between pouring temperature, metal fluidity, feeding and solidification as important to defect formation. Campbell (2015) describes the relationships among casting design, melt behaviour and defect prevention, while Sertucha and Lacaze (2022) review defects in sand-mould cast irons and discuss mechanisms that include gas-related and shrinkage defects. The implication for the present study is that pouring temperature should not be considered independently of mould venting, feeding design and the thermal conditions during solidification.

Numerical simulation has increasingly been used to examine mould filling, heat transfer and casting quality before physical production. Chen et al. (2023) studied optimization of casting-system structure for A356 casting-quality prediction, while Patwari et al. (2024) reviewed approaches combining manual and digital techniques for casting-defect reduction. Muzaqqi et al. (2024) examined sand-casting parameter design for minimizing shrinkage, porosity and incomplete defects. Baitiang et al. (2024) further demonstrated data-driven process analysis in iron foundries using automatic sand moulding. Together, these studies support the use of modelling and process-data analysis to investigate casting quality.

Despite this body of work, the available literature cited here does not establish the actual response of the selected Tanzania Automotive Technology Centre (TATC) casting to the specific parameter ranges assessed in this paper. This study therefore applies an ANSYS-based numerical assessment to the selected TATC casting and examines predicted porosity in relation to pouring temperature, sand permeability and solidification rate. Because the reported validation is based on comparison with published trends rather than a direct experimental validation at TATC, the numerical results should be interpreted as model predictions requiring further experimental confirmation.

III. MATERIALS AND METHODS

A) Study Design and Data

A mixed-methods research design was adopted. The qualitative component focused on identifying the causes of porosity defects through observations, interviews and document reviews, while the quantitative component involved numerical simulation and assessment of process parameters influencing porosity formation. The research was conducted at the Tanzania Automotive Technology Centre (TATC), where sand casting is used to manufacture engineering components. The study population included sand-cast products, production and quality inspection records, and foundry engineers, technicians, quality-control personnel and production supervisors.

Purposive sampling was used to select cast products exhibiting porosity defects and personnel directly involved in mould preparation, melting, pouring and inspection. Visual examination, questionnaires, interviews, production records and quality inspection information were used to identify defects and their causes. The major defects identified were gas porosity, blowholes, pinholes and shrinkage porosity.

B) Numerical Simulation and Parameter Assessment

A three-dimensional model of the selected TATC casting, including the gating and feeding systems, was developed using SolidWorks and simulated in ANSYS. The simulation evaluated mould filling, heat transfer, solidification behaviour and predicted porosity. The investigated input parameters were molten-metal pouring temperature, sand permeability and solidification rate. The selected ranges were 1200-1600°C, permeability numbers of 80-140, and solidification rates of 0.8–2.0 °C/s, respectively.

The casting model considered the relevant thermal and flow conditions, including pouring temperature, initial mould condition, ambient temperature, gravity, heat transfer between metal and mould, heat transfer to surrounding air and atmospheric pressure at the vent or riser outlet. Cast iron was selected as the investigated metal and silica sand as the moulding material. Predicted porosity percentage was used as the primary response for evaluating the effect of the selected process parameters.

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C) Model Validation

Validation was performed by comparing the simulated trends and predicted porosity behaviour with findings reported in previous experimental and numerical studies on sand casting. Particular attention was given to the effects of pouring temperature, sand permeability and solidification behaviour on gas entrapment and shrinkage porosity. The comparison was used as a consistency check for the simulation results and the identified favourable process conditions.

IV. RESULTS AND DISCUSSION

A) Porosity Defects Identified at TATC

The investigation identified gas porosity, shrinkage porosity, blowholes and pinholes among the major defects observed in TATC sand-cast products. The findings indicate that porosity is multifactorial and is associated with gas entrapment, inadequate gas evacuation, inappropriate pouring temperature, poor sand permeability, inadequate feeding and uneven cooling. The primary defect frequencies reported in the study are summarized below.

Table1 Frequency of major casting defects reported at TATC

Sn	Defect	Average weekly occurrence
1	Blowholes	4
2	Pinholes	2
3	Shrinkage porosity	2
4	Misrun	1

B) Effect of Pouring Temperature on Porosity

The simulations showed that predicted porosity initially decreased as pouring temperature increased and then increased at the highest temperatures. At 1200 °C, predicted porosity was 6.8%, which was associated with inadequate fluidity, early solidification and insufficient feeding. Increasing the temperature to 1350 °C reduced porosity to 5.4%. The lowest predicted porosity, 3.4%, occurred at approximately 1440 °C, indicating favourable fluidity and feeding conditions.

Further increases in temperature resulted in higher predicted porosity, reaching 4.1% at 1550 °C and 5.2% at 1600 °C. The increase at high temperature was associated in the study with greater gas absorption and less favourable casting conditions. Thus, approximately 1440°C was identified as the most favourable pouring temperature among the investigated conditions.

Table2 Effect of pouring temperature on predicted porosity

Sn	Pouring temperature (°C)	Predicted porosity (%)	Observed effect
1	1200	6.8	Poor fluidity, early solidification, insufficient feeding
2	1350	5.4	Improved filling and reduced shrinkage defects
3	1440	3.4	Optimum fluidity and controlled solidification
4	1550	4.1	Improved filling but increased gas-related porosity
5	1600	5.2	High fluidity with increased predicted porosity

C) Effect of Sand Permeability on Porosity

Increasing sand permeability progressively reduced predicted porosity. At a permeability number of 80, predicted porosity was 5.1%, indicating poor gas extraction from the mould cavity. Increasing permeability to 100, 120 and 140 reduced predicted porosity to 3.8%, 2.4% and 2.2%, respectively. The trend indicates that adequate permeability improves gas evacuation and reduces the likelihood of blowholes and gas porosity.

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Table3 Effect of sand permeability on predicted porosity

Sn	Permeability number	Predicted porosity (%)
1	80	5.1
2	100	3.8
3	120	2.4
4	140	2.2

D) Effect of Solidification Rate on Porosity

Solidification rate showed a strong relationship with porosity formation. At a slow solidification rate of 0.8 °C/s, predicted porosity was 5.5%. Increasing the rate to 1.2 °C/s reduced porosity to 4.0%, while rates of 1.6 °C/s and 2.0 °C/s produced 2.7% and 1.9%, respectively. The results indicate that faster heat extraction and more favourable directional solidification reduce regions susceptible to shrinkage and gas-related defects.

Table4 Effect of solidification rate on predicted porosity

Sn	Solidification rate (°C/s)	Predicted porosity (%)
1	0.8	5.5
2	1.2	4.0
3	1.6	2.7
4	2.0	1.9

E) Validation and Discussion

The simulation results were consistent with the general mechanisms reported in the reviewed literature. The reduction in porosity at moderate pouring temperature is consistent with the balance between molten-metal fluidity, feeding and gas absorption described in casting literature (Campbell, 2015; Sertucha and Lacaze, 2022). The progressive reduction in porosity with increasing sand permeability is also consistent with the role of permeability in gas evacuation and the prevention of gas-related defects (Malek Ali et al., 2022; Sahoo and Goswami, 2023).

The solidification results further indicate that cooling and feeding conditions are important in controlling shrinkage-related porosity. The reduction from 5.5% at 0.8 °C/s to 1.9% at 2.0 °C/s suggests that faster solidification under the investigated conditions reduced the formation of regions prone to shrinkage. Overall, the three investigated parameters interacted through molten-metal fluidity, gas evacuation, heat transfer, feeding and solidification behaviour. The combined results support the use of simulation to identify favourable process conditions before production.

V. CONCLUSION

The study assessed porosity defects in sand-metal casting at the Tanzania Automotive Technology Centre and evaluated the influence of pouring temperature, sand permeability and solidification rate using ANSYS simulation. The major defects identified were gas porosity, shrinkage porosity, blowholes and pinholes, with their occurrence associated with gas entrapment, inadequate gas evacuation, inappropriate pouring temperature, poor permeability, inadequate feeding and uneven solidification.

Among the investigated pouring temperatures, approximately 1440 °C produced the lowest predicted porosity of 3.4%. Increasing sand permeability from 80 to 140 reduced predicted porosity from 5.1% to 2.2%, while increasing solidification rate from 0.8 to 2.0 °C/s reduced predicted porosity from 5.5% to 1.9%. These results indicate that appropriate control of pouring temperature, adequate mould permeability and favourable solidification and feeding conditions can substantially reduce predicted porosity.

The study recommends maintaining pouring temperature at approximately 1440 °C, routinely testing and controlling mould-sand permeability, improving cooling and feeding conditions, and increasing the use of casting simulation during process design. Future research should experimentally validate the simulation results and investigate additional parameters including moisture content, mould hardness, pouring rate, gating and riser configuration, as well as different casting materials.

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BIOGRAPHY



Eng. **Rogasian J. Kijuu** is a Tanzanian Mechanical Engineering professional with approximately ten years of experience in mechanical engineering, automotive technology, quality assurance and research and development. He currently serves at the Tanzania Automotive Technology Centre (TATC-NYUMBU) as Quality Assurance Engineer, where he contributes by ensuring the quality, reliability, compliance and performance of automotive and mechanical engineering processes.

His professional expertise covers mechanical and automotive engineering, quality assurance, engineering inspection, preventive maintenance, equipment reliability, technical evaluation and engineering standards and compliance. Through his role at Nyumbu, he has gained extensive practical exposure to automotive technology development, inspection and testing, quality verification, engineering documentation, process improvement and evaluation of mechanical and vehicle systems. His experience combines practical engineering knowledge with quality assurance practices aimed at improving the reliability, safety, performance and conformity of automotive technologies and mechanical systems.

He holds a Bachelor's degree in Mechanical Engineering and is currently pursuing a Master of Mechanical Engineering with Transportation Machinery at the National Institute of Transport (NIT), Tanzania. His postgraduate studies further strengthen his expertise in transportation machinery, mechanical systems, maintenance and reliability, and automotive technology. With extensive professional experience and advanced academic training, Eng. Rogasian Kijuu brings a strong combination of mechanical engineering, quality assurance, automotive technology and transportation machinery expertise to engineering research, innovation and technology development in Tanzania.