Effect of Multi-gating System on Solidification of Molten Metals in Spur Gear Casting: A Simulation Approach

Enesi Y. Salawu, Emuowhochere Oghenevwegba, Oluseyi O. Ajayi, A. O. Inegbenebor, E. T. Akinlabi and S. T. Akinlabi

Abstract Casting process is widely used in preparing spur gear blanks or in complete production of gears because of its less defect at the end of the process. The importance of the gating system in casting process lies in its ability to channel molten metal into the mould cavity within the allowable period at a controlled parameter. The study therefore investigated the effect of increasing the gating system on the solidification of molten metal during gear cast to determine the time of solidification and casting productivity. Both the top and bottom gating system were modelled in solidwork, while the simulation was done using Pro-Cast. The result revealed that for the case of two runner gating system, both the top and bottom gating system took 9.195 and 9.320 s respectively, to fill the mould cavity. However, the three-runner gating system took a shorter filling time with top gating system having 8.824 s filling time and the bottom gating system took about 9.655 s to fill the mould cavity. The outcome showed that the top gating system tends to discharge molten metal faster than the bottom gating system as seen from the filling time of both the two and the three-gating system.

Keywords Production technology · Simulation · Spur gear · Energy savings

Introduction

Development of engineering materials for efficient product manufacturing requires the need to identify some essential techniques and their impact on manufacturing. The time taken for molten metals to solidify has become a critical issue as the

E. Y. Salawu · E. Oghenevwegba · O. O. Ajayi (✉) · A. O. Inegbenebor
Department of Mechanical Engineering, Covenant University, P.M.B. 1023, Ota, Ogun State, Nigeria
e-mail: oluseyi.ajayi@covenantuniversity.edu.ng

E. T. Akinlabi · S. T. Akinlabi
Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa

The Minerals, Metals & Materials Society (ed.), *TMS 2019 148th Annual Meeting & Exhibition Supplemental Proceedings*, The Minerals, Metals & Materials Series, https://doi.org/10.1007/978-3-030-05861-6_65

formation of slag distort the process and reduce the mechanical properties of the cast [1]. Adequate solidification of molten metal in the mould cannot be achieved without an effective and efficient gating system design which enable the efficient solidification of the molten metal [2]. Based on this findings, Kwon and Kwon [3] employed a computer-aided design approach to simulate the behaviour of gate and runner in casting of an automobile component. The result revealed the presence of porosities due to longer solidification time. The rate of porosity produces scrap and reduces the quality of the cast [4].

The general agreement by industries is that filling, and solidification time is critical to casting quality. Thus, study has shown that a submerged gate technique used in casting would reduce filling difficulties and improve quality of casting [5]. However, high precision casting requires adequate design of the gating system for efficient filling and solidification [6]. In fact, the gating system design for die casting process is known with time consumption and expensive [7]. Thus, Salawu et al. [8–11] established that adequate design of engineering components with good choice of manufacturing method will give a better product performance, reduce failure and losses and increase productivity.

Additionally, Hsu et al. [12] investigated the accuracy of solidification during gravity casting by varying the number of the gating system using a computational technique. The result revealed a uniform distribution of molten metal. It was also discovered that some percentage of frictional loss affected the filling of the mould. Based on this study, it was established that Parameters such as filling, and solidification time are essential to achieving casting quality [13]. Moreso, thickness, width and shape are geometrical factors which affects the filling behaviour of the gating system [14].

From literature, it is obvious that several studies related casting quality problems to filling time and design of the gating system without considering the solidification time especially in complex structures like gear. Also, variation in filling time to reduce slag formation using various design of gating system is also helpful, however it has its limitations. Therefore, the study employed a simulation approach via PRO-CAST to investigate the effect of introducing multi-gating system on the filling time and solidification time during the casting of a spur gear in order to get a quality cast, prevent surface inclusions and turbulence.

Materials and Method

Both the top and bottom gating system were modelled in solidworks as well as the pattern design of the spur gear, while the simulation was done using Pro-Cast. Bernoulli's equation and continuity equations were equally employed to analyse the time taken to fill both the top and bottom gating system.

Design Analysis of Top Gating System

Consider Fig. 1. Point 3 is datum, $h_3 = 0$.

From Bernoulli's equation

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 : [15] \quad (1)$$

$$P_1 = P_2 = P_{atm} = 0$$

$$V_1 = 0$$

$$Z_1 \text{(with respect to datum)} = hc + hs$$

$$Z_2 = h_s$$

Substituting into Eq. (1)

$$hc + hs = \frac{v_2^2}{2g} + hs \quad (2)$$

$$V_2 = \sqrt{2ghc}$$

from continuity equations

$$Q = A_1V_1 = A_2V_2 : [15] \quad (3)$$

$$Q = A_2V_2 \quad \text{Since } V_1 = 0$$

$$Q = A_2\sqrt{2ghc} \quad (4)$$

Applying Bernoulli's equations to point 2 and 3

$$\frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 = \frac{P_3}{\rho g} + \frac{v_3^2}{2g} + z_3 \quad (5)$$

$$P_1 = P_2 = P_{atm} = 0$$

$$V_2 = \sqrt{2ghc}$$

$$Z_2 \text{(with respect to datum)} = hs$$

$$z_3 = 0$$

$$hc + hs = \frac{v_3^2}{2\boldsymbol{g}}$$

let, $hc + hs = ht$

$$\mathrm{V}_3 = \sqrt{2\boldsymbol{g}ht} \quad (6)$$

$$\mathrm{Q} = \mathrm{A}_3\mathrm{V}_3$$

$$\mathrm{Q} = \mathrm{A}_3\sqrt{2\boldsymbol{g}ht}$$

Choke area: this is the smallest area of the ingate.

To determine the filling time from the discharge equation, choke area equals A_3

$$\mathrm{Ac} = \mathrm{A}_3$$

$$\mathrm{Q} = \mathrm{A}_\mathrm{c}\sqrt{2\boldsymbol{g}ht}$$

Discharge equation is the same as the continuity equation, $Q = A_c\ V_{max}$. The discharge equation

$$\mathrm{Q} = \mathrm{A}_\mathrm{c}\mathrm{V}_\mathrm{max} = \text{rate of change of volume of casting}$$

differentiating height with respect to time to make the units in the LHS equal RHS and also to determine the filling time of the mould cavity;

$$\mathrm{A}_\mathrm{c}\mathrm{V}_\mathrm{max} = \mathrm{A}_\mathrm{m} \times \frac{dh_m}{dt}$$

$$\mathrm{dh}_\mathrm{m} = \frac{A_c}{A_m} \times \mathrm{V}_\mathrm{max}\mathrm{d}_\mathrm{t}$$

integrate both side, taking the area ratio and velocity as constant.

$$\int_0^{hm} dh = \frac{A_c}{A_m} \times \mathrm{Vmax} \int_0^{t} dt^{|\text{when t=0;h=0}|\text{when t=t;h=hm}}$$

$$\mathrm{hm} = \frac{A_c}{A_m} \times \mathrm{Vmax} \times \mathrm{t}$$

filling time t,

$$t = \frac{Am\,hm}{Ac\,Vmax} = \frac{vm}{Ac\,Vmax} \quad (8)$$

similarly, the bottom gating system was analysed using the same principles to arrive at the time required for filling the mould cavity given as

$$t = \frac{2 \cdot Vm}{Ac\sqrt{2ght}} \tag{9}$$

Results and Discussion

Figure 1 presents the sketch of the gating system while Fig. 2 presents the pattern design of the gear in Solidwork as well. Also, Figs. 3 and 4 present the simulation result of using two (2) runners for both top and bottom gating system in order to determine the filling time and the solidification behavior of the molten metal in the mould cavity as represented by Figs. 5 and 6. It can be depicted from Figs. 5 and 6 that both the top and bottom gating system filled the mould cavity at 9.195 s and 9.320 s, respectively. The variation in filling time can be attributed to the increase in height of the sprue for the bottom gating system thus making the top gating system to fill faster.

Figures 7 and 8 showed the behavior of the molten metal for both gating system during solidification. It was observed that the solidification of molten metal at the top gating system started from 640 °C and decreases gradually to 525 °C at 305 s. Similarly, the bottom gating system started at a temperature of 678 °C to about 532.5 °C with a total solidification time of 335 s. Thus, it is important to note that the solidification time at each of the gating system depends on the filling time of the molten metal into the cavity which also depend on the sprue design.

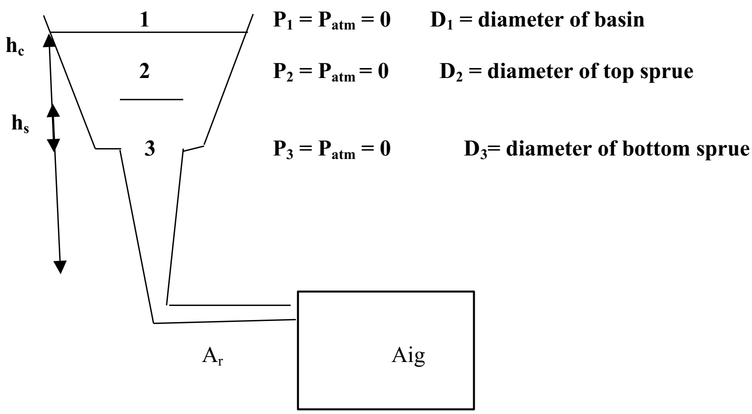

Fig. 1 Schematic view of the gating system

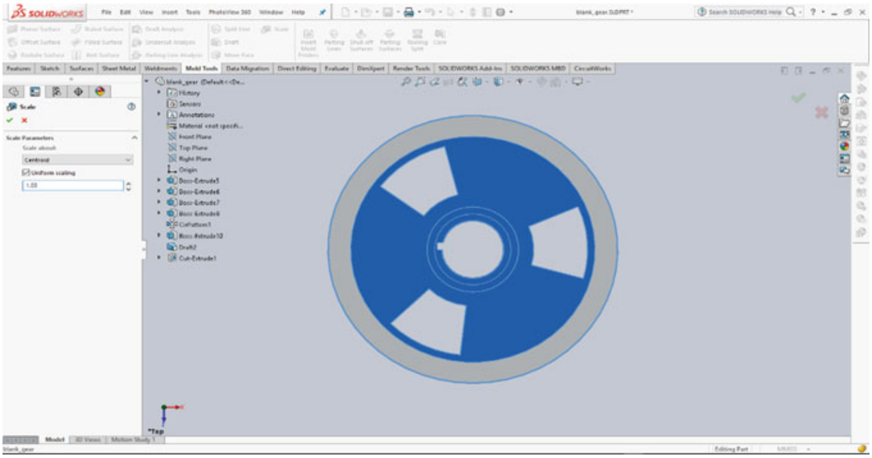

Fig. 2 Pattern design of spur gear in solidwork

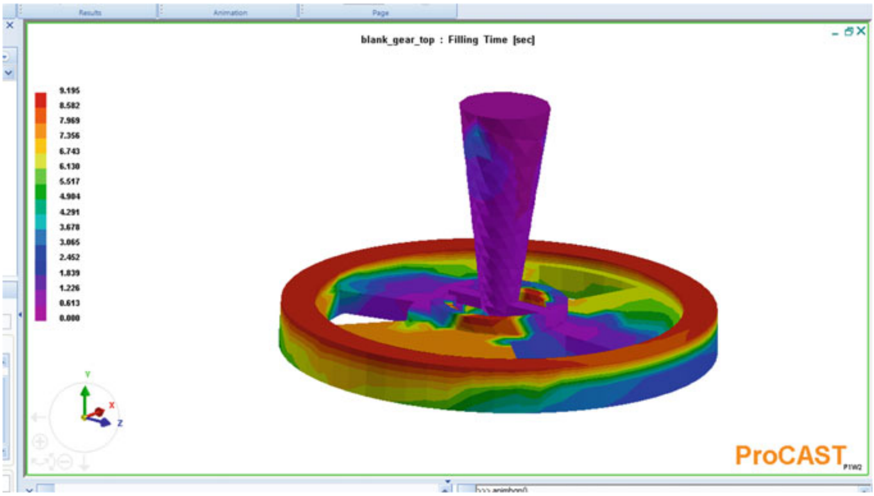

Fig. 3 Effect of using 2-runners for top gating system

More so, Figs. 9 and 10 illustrate the effect of using 3-runner attached to both the top and bottom gating system in order to increase the flow rate and reduce the filling time of the cavity. From the result of the simulation, it was observed that the top gating system took 8.824 s to fill the mould cavity against 9.195 s when 2-runner was attached to the gating system. Also, it took 9.655 s for the bottom gating system to fill the mould cavity against the 9.320 s for the 2-runner attached to the gating system.

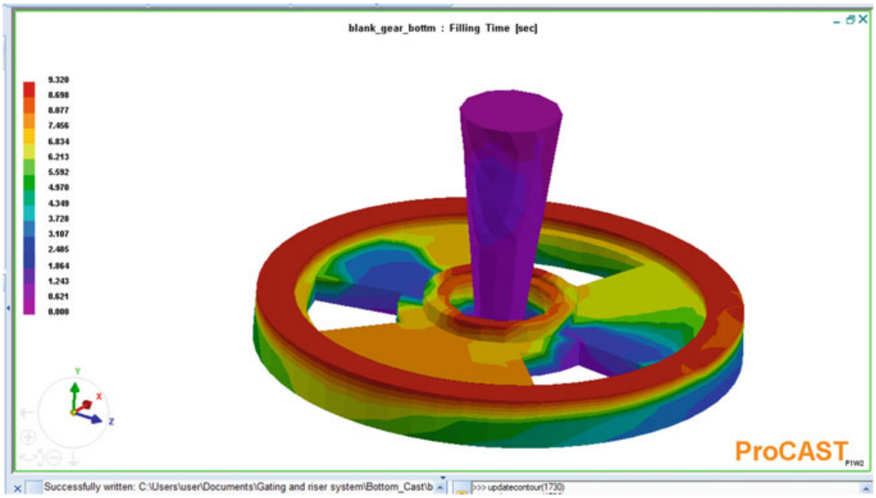

Fig. 4 Effect of using 2-runners for bottom gating system

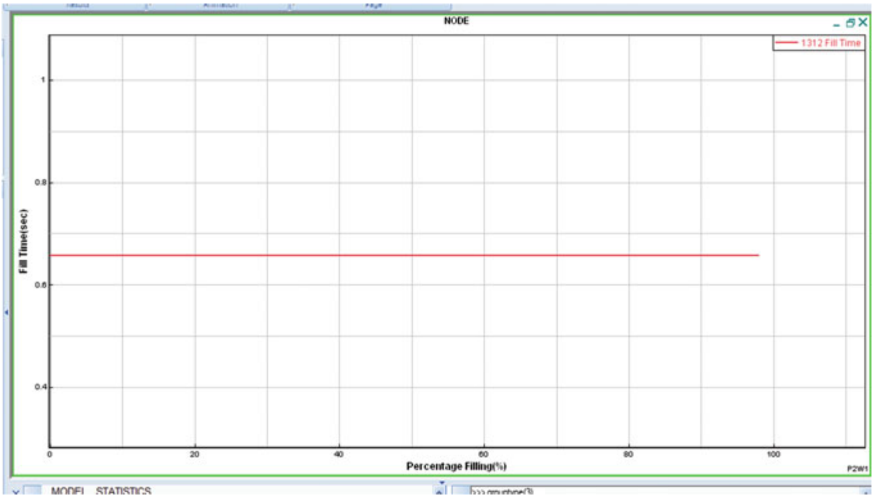

Fig. 5 Filling time plot for the top gating system

Conclusion

Filling and solidification of molten metal into mould cavity through the application of multi-gating system during casting process have been simulated using Pro-Cast. Based on the outcome of the simulation, it was observed that the top gating system

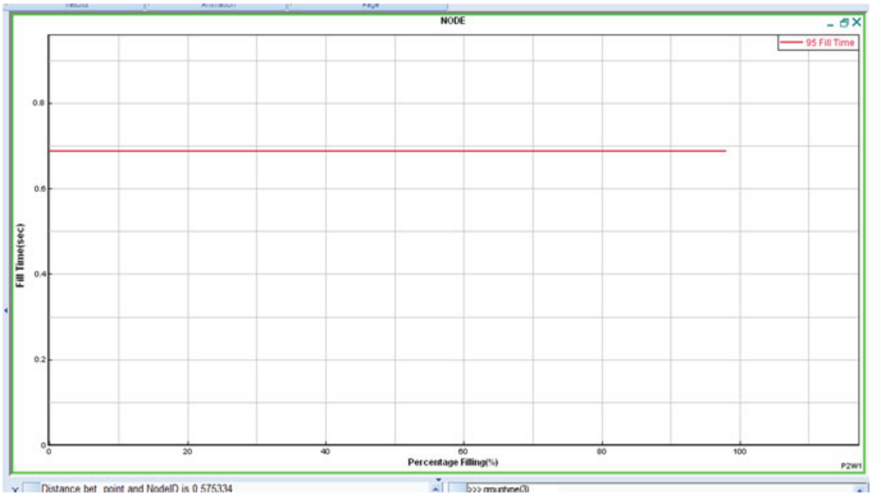

Fig. 6 Filling time plot for the bottom gating system

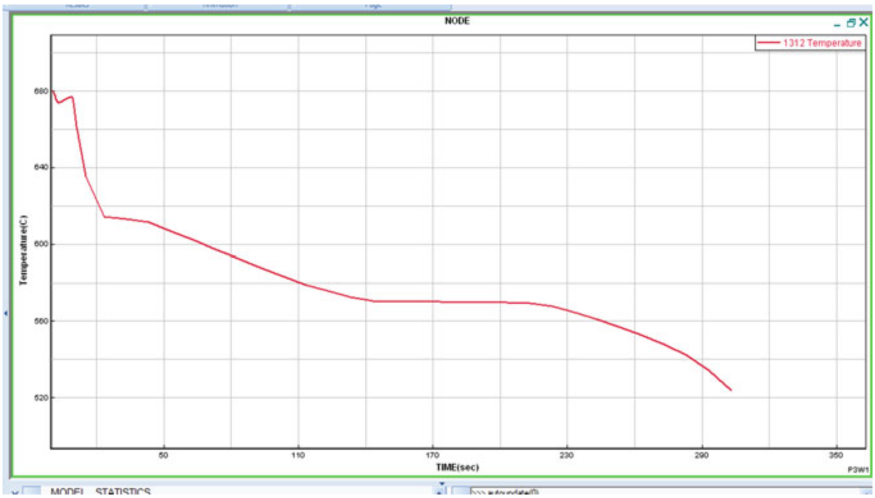

Fig. 7 Solidification behaviour of the top gating system

design gave a better filling and solidification efficiency. The simulation approach showed that multi-gating system has the advantage of preventing turbulent flow since many runners were attached. Thus making it impossible to have erosion of the mould. Also, smooth flow of molten metal would be achieved using multi-gating system.

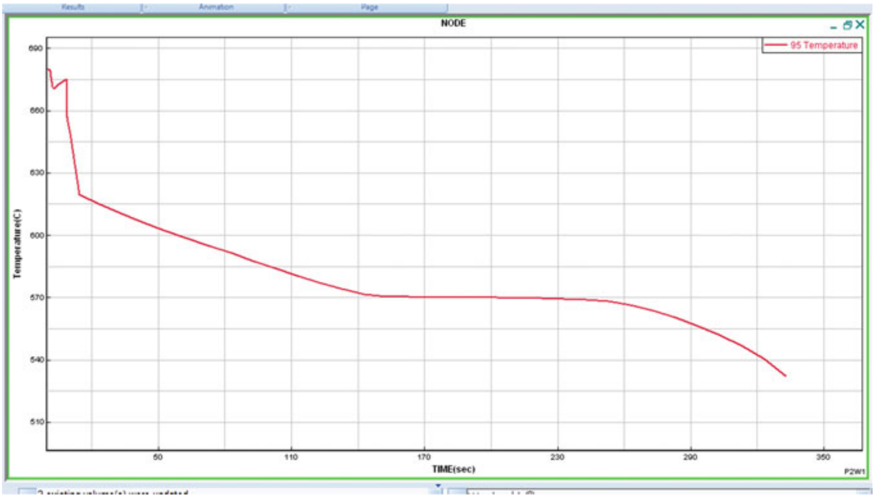

Fig. 8 Solidification behaviour of the bottom gating system

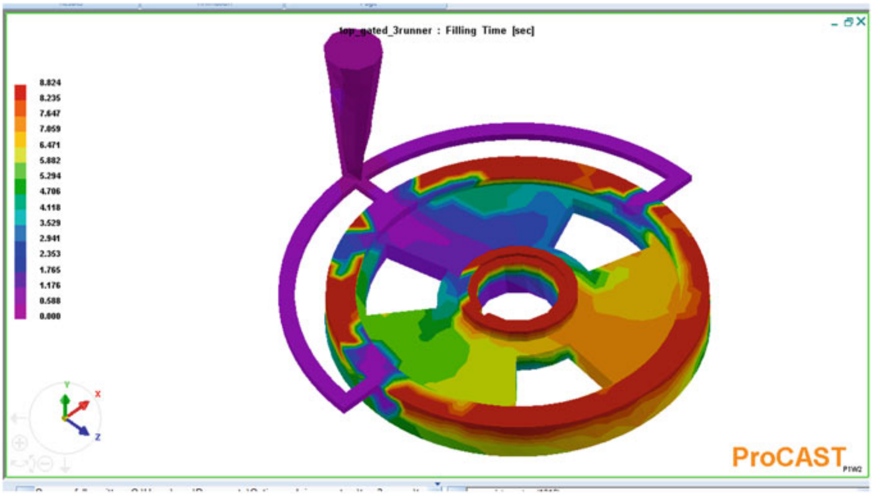

Fig. 9 Effect of using 3-runners for top gating system

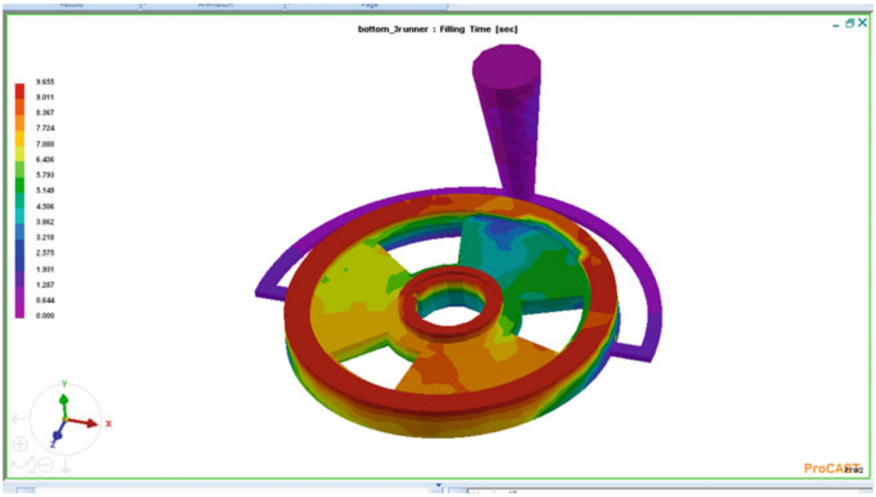

Fig. 10 Effect of using 3-runner for bottom gating system

Acknowledgements The authors appreciate the management of Covenant University for support in making this research a success.

References

1. Wang T, Yao S, Tong Q, Sui L (2017) Improved filling condition to reduce casting inclusions using the submerged gate method. J Manuf Process 27:108–113
2. Ingle PD, Narkhede BE (2018) A Literature survey of methods to study and analyze the gating system design for its effect on casting quality. Mater Today Proc 5(2):5421–5429
3. Kwon HJ, Kwon HK (2018) Computer aided engineering (CAE) simulation for the design optimization of gate system on high pressure die casting (HPDC) process. Robot Comput-Integr Manuf
4. Nimbulkar SL, Dalu RS (2016) Design optimization of gating and feeding system through simulation technique for sand casting of wear plate. Perspect Sci 8:39–42
5. Wang T, Yao S, Shen W (2015) A submerged-gate casting method. J Mater Process Technol 222:21–26
6. Salonitis K, Zeng B, Mehrabi HA, Jolly MR (2016) The challenges for energy efficient casting processes
7. Salawu EY, Ajayi OO, Olatunji OO (2015) Theoretical modelling of thermal-hoop stress around the tooth of a spur gear in a filler machine. J Multidiscip Eng Sci Technol (JMEST) 2(2):1635–1640
8. Wu SH, Fuh JY, Lee KS (2007) Semi-automated parametric design of gating systems for die-casting die. Comput Ind Eng 53(2):222–232
9. Salawu EY, Okokpujie IP, Ajayi OO, Agarana MC (2018) Analytical technique for the determination of hoop stress and radial stress on the tooth spur gear under vertical loading in a food packaging machine

10. Salawu EY, Okokpujie IP, Ajayi OO, Afolalu SA, Agarana MC (2018) Numerical modeling and evaluation of involute curve length of a spur gear tooth to maintain constant velocity ratio while in motion
11. Salawu EY, Okokpujie IP, Afolalu SA, Ajayi OO, Azeta J (2018) Investigation of production output for improvement. Int J Mech Prod Eng Res Dev 8(1):915–922
12. Hsu FY, Jolly MR, Campbell J (2009) A multiple-gate runner system for gravity casting. J Mater Process Technol 209(17):5736–5750
13. Sun Z, Hu H, Chen X (2008) Numerical optimization of gating system parameters for a magnesium alloy casting with multiple performance characteristics. J Mater Process Technol 199(1–3):256–264
14. Seo PK, Kim DU, Kang CG (2007) The effect of the gate shape on the microstructural characteristic of the grain size of Al–Si alloy in the semi-solid die casting process. Mater Sci Eng A 445:20–30
15. Al-Shemmeri T (2012) Engineering fluid mechanics. Bookboon