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ORIGINAL ARTICLE

Effect of Plunger Speed and Solid Fraction on Automotive Component by Thixoforming Simulation

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ABSTRACT – Thixoforming is a promising metal forming process to produce near net-shape components with high casting quality. Thixoforming of metallic alloy utilizes the thixotropic behaviour of the material with near globular or globular microstructure in the semi-solid condition. The solid content is between 50% to 70% before forming. In this paper, the effect of plunger speed and a solid fraction on an alternator housing was investigated by advance casting simulation software. The 3D CAD model of the alternator housing was created using SolidWorks software and AnyCasting software is utilized for the simulation of the thixoforming parameter and magnesium alloy (AZ91D) is the material used. The simulation had been done by varying the plunger speed, temperature (solid fraction) of the material, and both Power Law and Bingham Viscosity model are used in the simulation to identify the defect prediction at the end. The simulation result shows that laminar filling in semi-solid slurry able to achieved by controlling the plunger speed and temperature. Slower speed and lower melt temperatures are preferable in thixoforming. Therefore, a solid fraction of the material, plunger speed, and solidification rate do influence the filling behaviour of the casting of semi-solid metal.

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KEYWORDS
Thixoforming; AZ91D;
Plunger speed;
Defect prediction;
Solid fraction

INTRODUCTION

Thixoforming processes are developed by Professor Fleming and his co-workers in the 1970s when they studied the behaviour of solidifying metallic melt under conditions in which they are forming a suspension of globular solid particles in a liquid melt [1]. The industrial importance of this technology was recognised immediately, and two feasible processing routes were demonstrated as rheocasting and thixocasting [2]. These and other related processes are now known as thixoforming.

Thixoforming or commonly known as semi-solid metal processing, is a new metal forming of engineering parts [3]. It is an advantageous technology developed based on conventional metal casting and gradually becoming a near-net-shape component forming. It is usually used to cast component that requires higher mechanical properties with a lower density such as for aerospace and automotive part. Compared to conventional die casting, the thixoforming process deals with semi-solid slurries instead of molten metal alloy. Thixoforming depends on a particular material characteristic that can be an exhibit by some semi-solid metallic alloys, which is the thixotropic behaviour itself [4]. Magnesium alloy with low density as well as high specific strength, is becoming more important in engineering sectors, especially in automotive and aerospace areas. Currently, most of the magnesium alloy component is produced by high pressure die casting (HPDC). However, magnesium alloy is difficult to deform at a liquid state as it oxidises easily at a higher temperature. This conventional forming method also has difficulties in producing a high-quality casting with high complexity shape. Therefore, to countermeasure this problem, thixoforming is a better choice to cast the magnesium alloy as the process of rheological behaviour of semi-solid forming of Magnesium alloy is very contributive to eliminate the defects created and improving the die casting quality [5].

Models and software based on CFD result from generic software or more specific codes dedicated to liquid casting or foundry. They use the finite volume or difference method and the Eulerian representation. The mesh used to spatially discretie the system is attached to space volume elements. It is fixed in space. Mesh distortions are thus avoided, and the flow behaviour is much easier to obtain than using the Lagrangian representation [2, 6, 7]. Many researchers focus on the liquid state forming such as die-casting [8],[9],[10] in the numerical method. Analysis of differential equation in the semi-solid state is limited, [11] in comparison to the filling processes with three model, Newtonian model, Carreau-Yasuda model and Power law Cut-off model. Rheocasting is one of the processes resulting from a metal slurry, which most of researchers take advantage to do simulations of this process to explore the different modellings on semi-solid processing

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[12], [13]. [14] applying a finite difference method (FDM) to the semi-solid processing, in which the flow modelling is coupled with the heat transfer by continuity equation of Navier Stokes and the energy equation. On the other hand, [15] work on the thixoforming process and numerical analysis by FEM in plastic deformation stages of AZ91D magnesium.

The numerical simulation for the die filling process and solidification pattern helps in the prediction of defects that might occur in the casting. The position, size, and time occurrence of the defect can be traced effectively before the actual production, so that modification can be made to improve the quality and avoid future problems. In this work, thixoforming technology is studied, the 3D modelling of the alternator housing is created, and simulation on filling behaviour of semi-solid magnesium alloy AZ91D is completed via AnyCasting software which provides flow behaviour and defects prediction. Finite Difference Method (FDM) was used in the simulation couple with both Power law and Bingham viscosity model. The defect prediction differences on both models are compared, which, contributed to the new approach of semi-solid forming by FDM governance with both models and heat transfer models.

SIMULATION PROCEDURE

To control the forming process of semi-solid AZ91D and producing a high-quality casting part, it is very important to understand about the rheological behaviour of AZ91D in a semi-solid state. Previous researchers, Yan Hong et al. [5], had investigated the rheological behaviour of semi-solid AZ91D magnesium alloy in steady-state and the parameter used such as apparent viscosity, material temperature based on the solid fraction in this simulation is referred to the data established by the previous researcher.

3D CAD Modelling

The product chosen in this work is alternator housing and the main reason for selecting this part is because of the noncomplex overall geometry. By referring to the thixoforming die design principle, alternator mould consist of a gating system is designed by using SolidWorks software. The gating system design for thixoforming mould is simpler than the conventional die casting [16]. The overflow designs no need to be complex as die-casting because of there are some of the solid fractions in the flow and the solidification is fast compare to the conventional die-casting which completely liquid state while entering to the gating and runner.

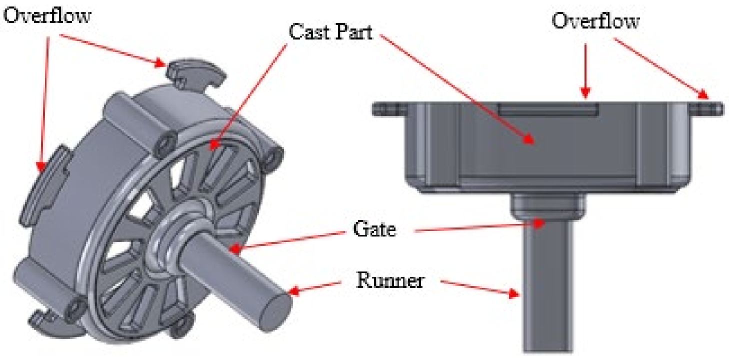


Figure 1: 3D Modeling of Thixoforming mould with a gating system

Modelling the Thixoforming Process

Considering the results are accurate, the following assumptions are to simplify the simulation process of the thixoforming process:

i. Semi-solid AZ91D is assumed as a one-phase continuous and incompressible fluid, and the flow is characterised by apparent viscosity [17].
ii. Semi-solid temperature is isothermal throughout the casting process since only small changes in temperature is occurred in thixoforming.
iii. Power Law and Bingham Viscosity model is employed to model the viscosity of semi-solid AZ91D
iv. The semi-solid flow should behave in a laminar manner.

The power law model is not only simple mathematically but also in good agreement with the experimental data in the shear rate range for semi-solid die-casting [18]. The power law model is as follows:

$$\eta = \tau/\dot{\gamma} = k\dot{\gamma}^{n-1} \tag{1}$$

where, η = apparent viscosity (Pa.s), k = consistency factor, $\dot{\gamma}$ = shear rate, τ = shear stress, and n= flow exponent (n=1 for Newtonian Fluid). For the Bingham viscosity model, semi-solid melts are flexible only shear rate exceeds the yield strength, and it will become elastic solid if the shear stress is lower than yield strength [17].

$$\eta = \eta0 + \tau s\ /\dot{\gamma}av \tag{2}$$

where τs = yield strength (shear stress at $\gamma\dot{\alpha}\, v = 0$), η0 = slurry viscosity (Pa.s) and $\dot{\gamma}$av= shear rate. Numerical simulation of thixoforming process parameter was referred to [5] as in Table 1 and Table 2 show the material properties of magnesium alloy AZ91D.

Table 1: Parameter used in modelling semi-solid AZ91D using power law viscosity model [5].

Temperature (°C)	Solid fraction (%)	Viscosity (Pa.s)	Shear Rate	K	N
580	29	1.0	30	2.7	-0.51
570	41	2.5	30	15.8	-0.58
560	48	11.7	30	137.0	-0.73
550	58	45.0	30	383.7	-0.63

Table 2: Material Properties of AZ91D

No	Property Name	Value	Unit
1.	Density	1.81	g/cm3
2.	Specific heat	Variable	cal/g*C
3.	Thermal conductivity	Variable	cal/s*cm*C
4.	Liquidus temperature	595	C
5.	Solidus temperature	470	C
6.	Latent heat	89.0853	cal/g
7.	Dynamic viscosity	0.01264	P(g/cm.s)
8.	Thermal expansion coefficient	2.5e-5	/C
9.	Solidification shrinkage	4.1	%
10.	Feedability	0.3	-
11.	Surface tension	550	dyne/cm

The standard k-ε turbulence model, which consists of two differential and one equation on the turbulence viscosity was used in this simulation where the detail of these models is in [19].

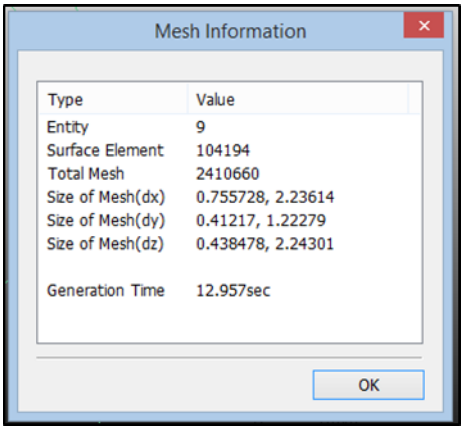
$$\begin{gathered}\frac{\partial k}{\partial t}+u_j\frac{\partial k}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\nu+\frac{\nu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k-\varepsilon\\ \frac{\partial \varepsilon}{\partial t}+u_j\frac{\partial \varepsilon}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\nu+\frac{\nu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_{\varepsilon 1}P_k\frac{\varepsilon}{k}-C_{\varepsilon 2}\frac{\varepsilon^2}{k}\end{gathered} \tag{3}$$

Initial Condition and Mesh Generation

Table 3 shows the initial condition or boundary condition for the simulation. The initial condition for the simulation can be set up appropriate to the analysis needed. The heat transfer model between moulds is 0.0239 Cal/cm².°C, between mould and material 0.0025 Cal/cm².°C and between air and another entity: 0.001 Cal/cm².°C. On the other hand, the total mesh is 2410660 unit and the generation time is 12.957 s as in Figure 2. The initial analysis type in this simulation is mould filling and heat/solidification during and after filling completed.

Table 3: Input parameter of the initial condition of the simulation

Parameter	Input value
Pouring temperature	550°C-580°C (according to the type of analysis)
Gate velocity	0.1-1.0 m/s (according to type of analysis)
Material	Cavity: AZ91D Magnesium Alloy Mould: Cast Steel
Initial mould temperature	280° C
Heat transfer model	Between mould and mould: 0.0239 Cal/cm².°C Between mould and material: 0.0025 Cal/cm².°C Between air and another entity: 0.001 Cal/cm².°C


Mesh Information

Type	Value
Entity	9
Surface Element	104194
Total Mesh	2410660
Size of Mesh(dx)	0.755728, 2.23614
Size of Mesh(dy)	0.41217, 1.22279
Size of Mesh(dz)	0.438478, 2.24301
Generation Time	12.957sec

Figure 2: Mesh information.

SIMULATION RESULTS

To observe the filling process, the plunger speed and temperature (solid fraction), which are factors that will influence the filling process are varied. The plunger speed observed are 0.1m/s, 0.2m/s, 0.3m/s, 0.4m/s,0.5m/s, and 1.0m/s and the temperature observed are 580°C, 570°C, 560°C, and 550°C corresponds to solid fraction of 29%, 41%, 48%, and 58% respectively.

Effect of Plunger Speed on Filling Process

Figure 3 shows the filling time vs plunger speed of 0.1 m/s, 0.2 m/s, 0.3 m/s, 0.4 m/s, 0.5 m/s and 1.0 m/s are 2.75 s, 1.3750 s, 0.9169 s, 0.6875 s, 0.05501 s and 0.2750 s respectively. It shows that increases in plunger speed decreasing the filling time of the cavity. Figure 4 shows the filling sequence of casting for different plunger speed. When the plunger speed drops to a very low plunger velocity (0.1 m/s), the semi-solid slurry passes through the ingate with smoother, laminar filling manner and flows steadily to fill up the cavity layer by layer. Such a condition is useful to avoid air entrapment in the casting, and when the plunger speed is 0.4 m/s or 0.5 m/s, the semi-solid slurry passes through the ingate quicker, and the die cavity is filled upwards. When the plunger speed is 1.0 m/s, the figure shows that some uneven filling of slurry and has the possibility for turbulence flow in the cavity. This type of flow is not preferable for the semi-solid die casting. Based on the simulation in figure 5 f, there are risks to air entrapment when the velocity is too high, which will affect the casting quality. Therefore, the flow behaviour of the slurry can be changed by controlling the plunger speed and size of the gate. Figure 4 shows the 70% filling rate when the plunger speed are at 0.1m/s, 0.2m/s, 0.3m/s, 0.4m/s, 0.5m/s and 1.0 m/s.

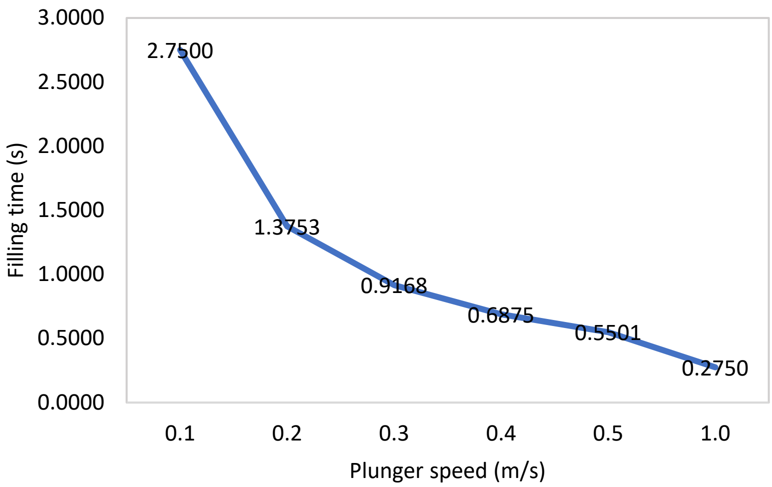
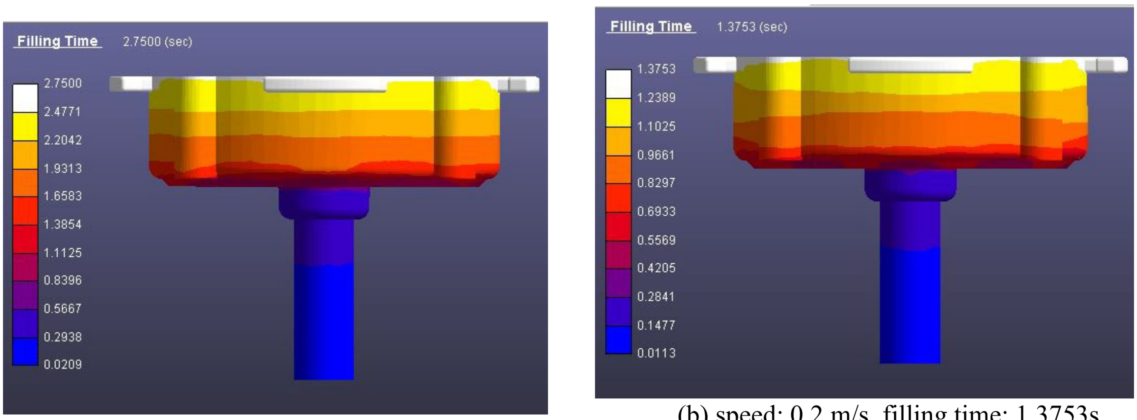
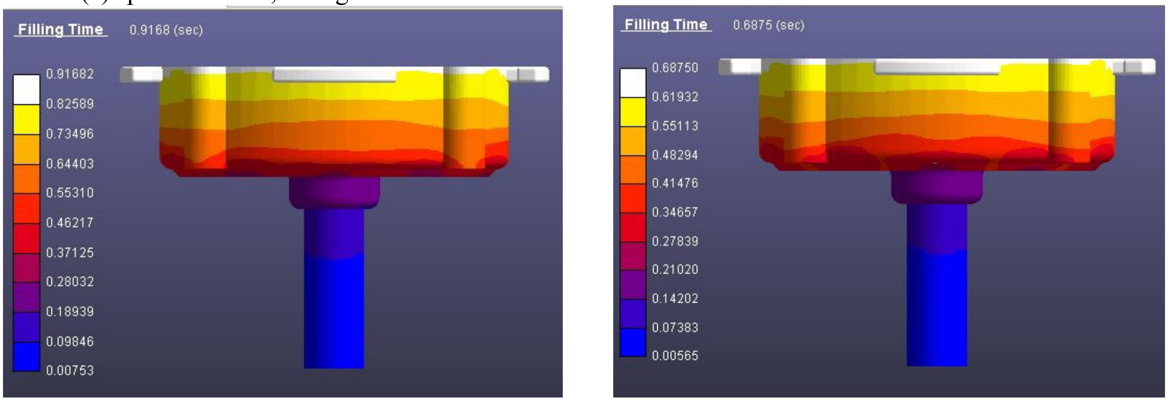


Figure 3: Graph of filling time vs plunger speed.



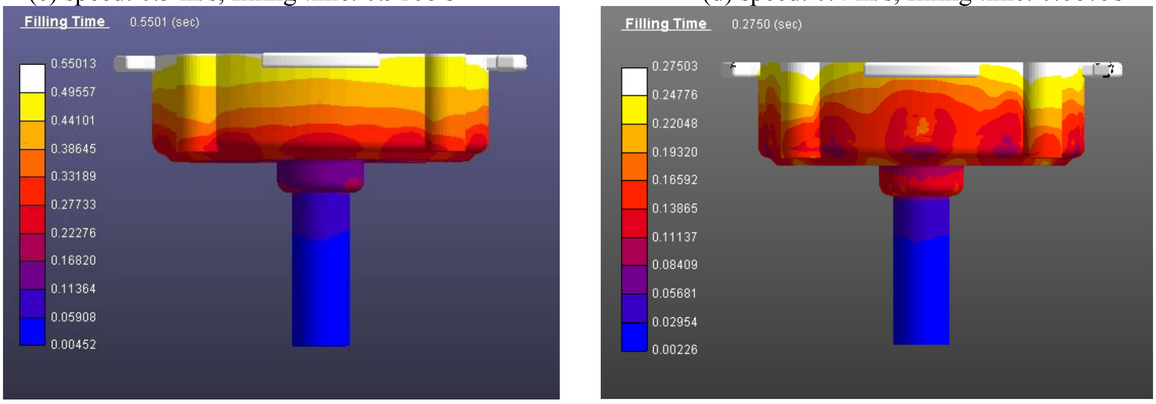
(a) speed: 0.1 m/s, filling time: 2.7500 s

(b) speed: 0.2 m/s, filling time: 1.3753s



(c) speed: 0.3 m/s, filling time: 0.9168 s

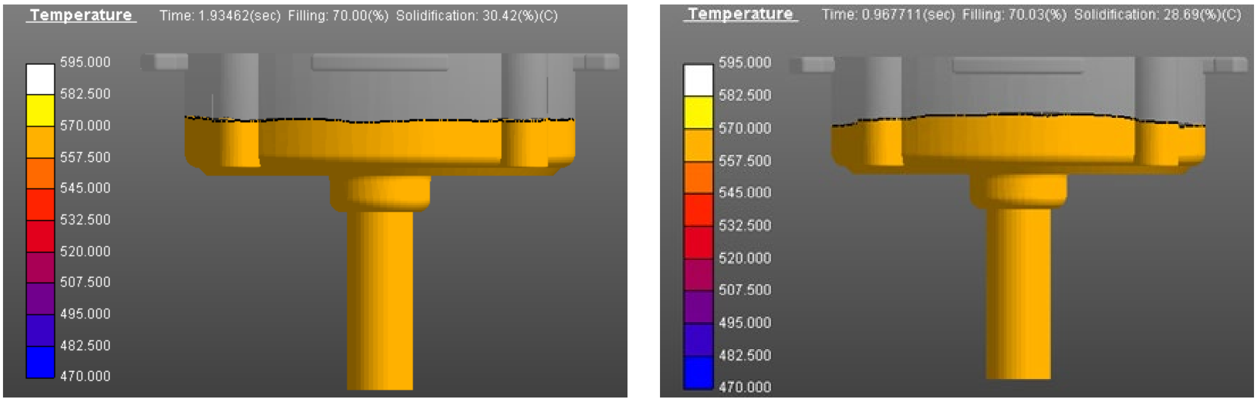
(d) speed: 0.4 m/s, filling time: 0.6875s



(e) speed: 0.5 m/s, filling time: 0.5501s

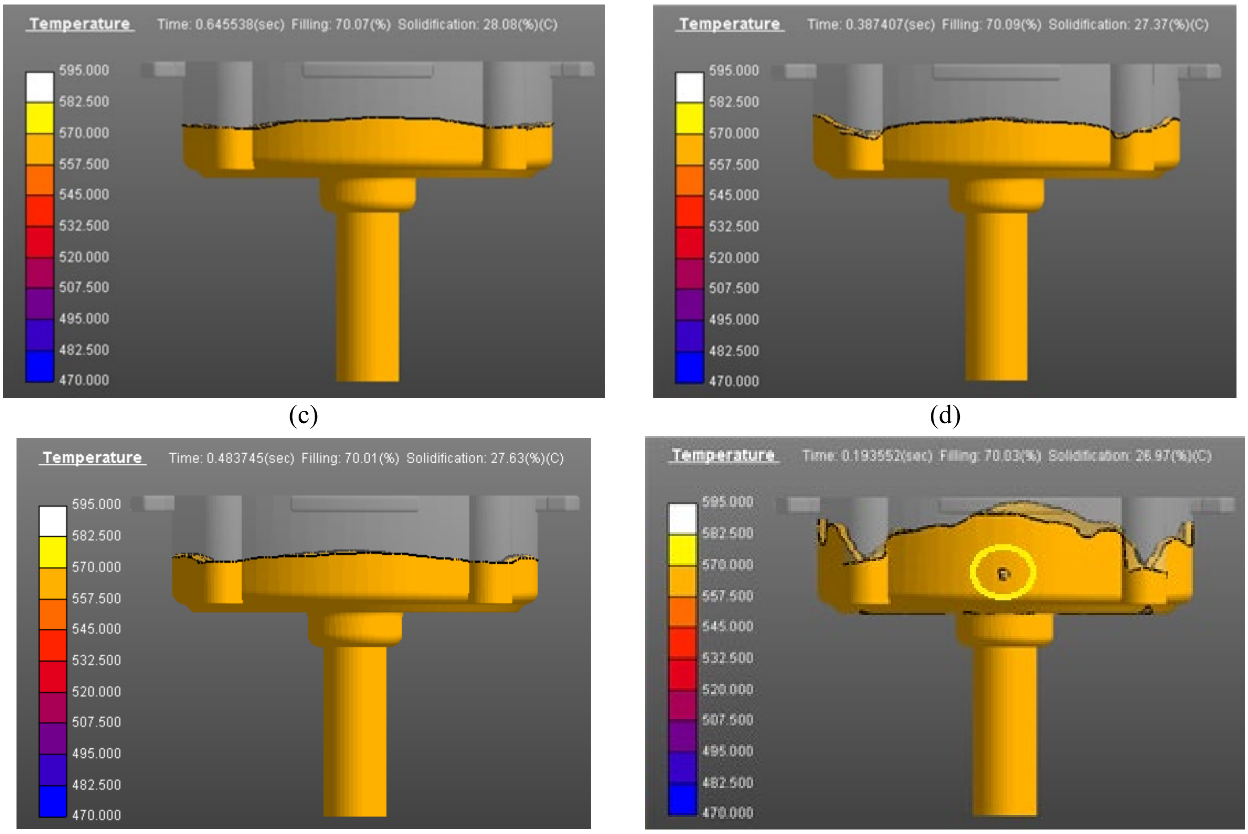
(f) speed: 1.0 m/s, filling time: 0.2750s

Figure 4: Filling time when plunger speed is at (a) 0.1m/s (b) 0.2m/s (c) 0.3m/s (d) 0.4m/s (e) 0.5m/s and (f) 1.0 m/s.



(a)

(b)



(c) (d)

(e) (f)

Figure 5: 70% Filling rate when plunger speed is at (a) 1.0 m/s, (b) 0.2m/s (c) 0.3m/s (d) 0.4m/s (e) 0.5m/s and (f) 1.0 m/s.

Effect of Temperature (Solid Fraction) on Solidification Time

Referring to Figure 6, when the temperature is 580° C (29% solid fraction), the time taken for the slurry to solidify is 64.7442s which is the last to solidify. The fastest slurry to solidify is when the temperature is 550°C (58% solid fraction), in which the solidification time is 48.3916s, follows up by the temperature of 560°C and 570°C with solidification time of 52.6509s and 60.0849s respectively. The last area for the slurry to solidify is at the centre of the runner. It can be concluded that the lower the temperature (higher solid fraction), the faster the slurry will solidify. But it is important to select the solid fraction carefully. Even though lower temperature makes the casting solidify faster, it does have an impact on the viscosity. Lower temperature (higher solid fraction) will result in higher viscosity. Therefore, temperature affects material fluidity and mostly, a lower temperature will have bad material fluidity. Besides, the material will have a longer fill time to fill up the cavity. Incomplete die filling might happen as the slurry might solidify before it can fill up the whole area of the cavity.

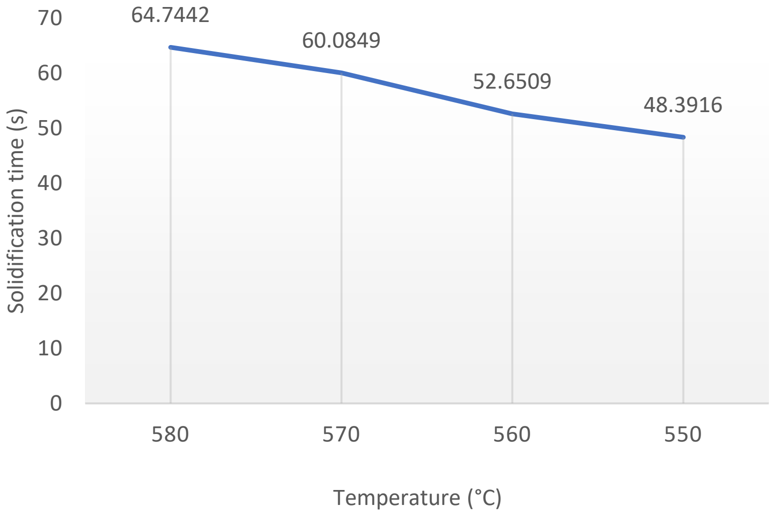
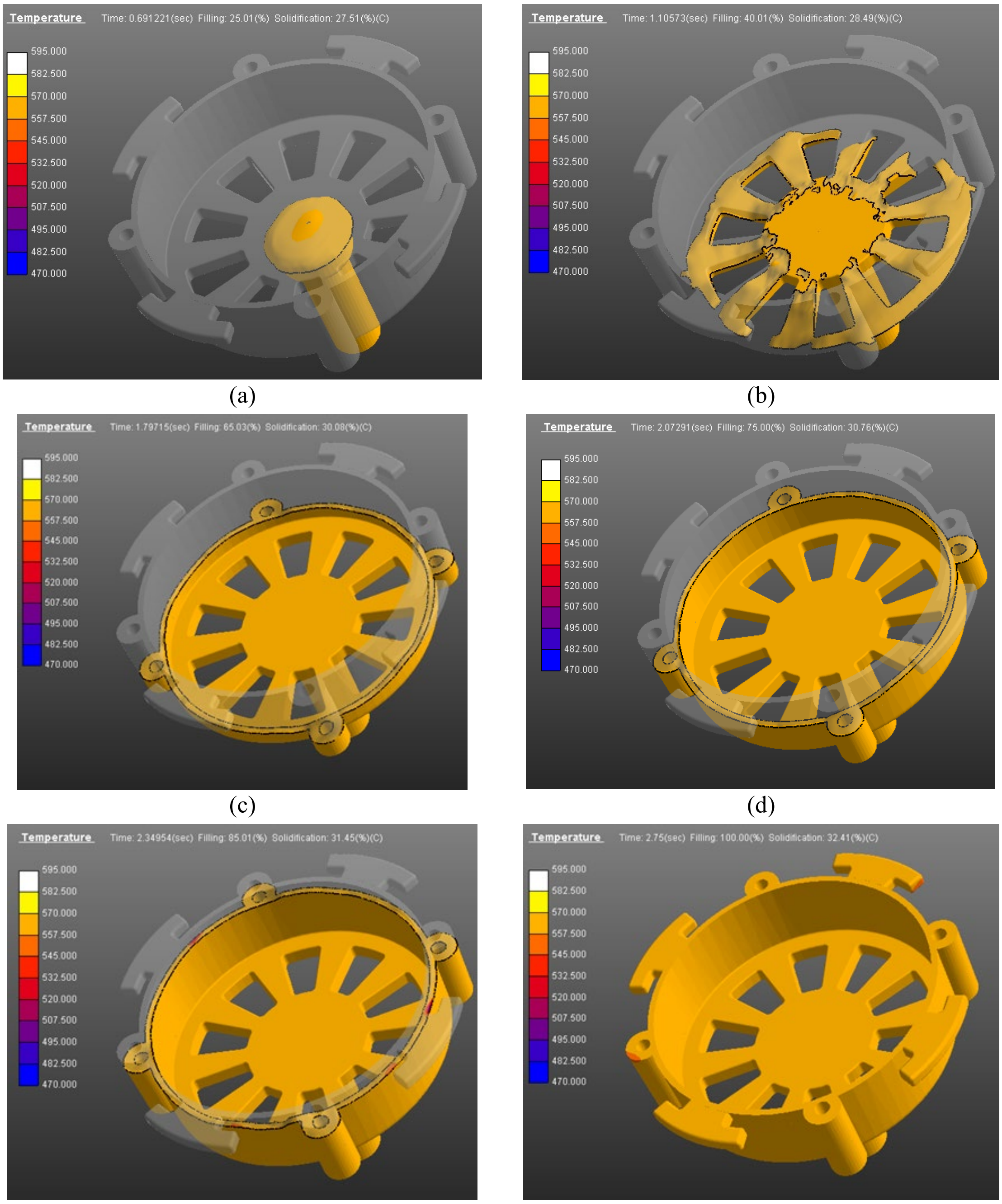


Figure 6: Graph of solidification time vs temperature.

Analysis at 570 °C Temperature (41% Solid Fraction) and Plunger Speed of 0.1 m/s.

Figure 7 shows the slurry plunger through the runner and at 25% of the cavity. The slurry begins to fill up the upper part of the cavity. The slurry moves upward to fill up the cavity since the casting process simulated is vertically plunged according to the vertical thixocasting machine. The slurry behaves in a laminar way, without splash or jet and fills up the cavity uniformly, sequentially and stable from the runner to all the cavity. This type of filling enabled air to be removed smoothly from the die layer by layer, bypassing the backflow of the semi-solid slurry and reducing the risk of air entrapment and casting defects. This result is confirmed with previous work [20] at the almost same temperature but different wall thickness. The total time taken in the die filling process to fill up the cavity completely is 2.740s.



(a) (b)

(c) (d)

(e) (f)

Figure 7: Filling process when temperature is 570°C (41% solid fraction) with plunger speed of 0.1m/s at (a) 25% (b) 40% (c) 65% (d) 75% (e) 85% and (f) 100% cavity filling rate.

The laminar flow manner for semi-solid die casting is easy to achieve with the correct selection of plunger speed and temperature. This is because the viscosity depends on the solid fraction contained in the metal slurry. The temperature for semi-solid die casting is lower compared to the molten metal die casting resulting in higher solid fraction and higher viscosity. It is important to make sure that the viscosity of the slurry is not too much to avoid unfilled or incomplete filling of the cavity.

Plunger speed can be controlled to obtain a better filling manner. For semi-solid die casting, the preferable plunger speed ranges from 0.1 m/ s to 0.5 m/s. A high plunger may cause turbulence and splashing which will give impact to the casting quality such as porosity. If the plunger speed is too low, it will take up too much time to fill up and may cause the slurry to solidify before it finishes filling up the whole cavity. In this study, the most suitable parameter for semi-solid die casting is the plunger speed of 0.1 m/s, and the temperature of semi-solid AZ91D slurry of 570 °C contains 41% solid fraction.

Analysis of Particle Tracing

In this simulation, the direction of the flow is influenced by the overflow design. The quality of casting is also affected by turbulence flow in the mould region. Therefore, to achieve high strength of the casting, turbulence flow in the casting must be reduced. The modification can be made, for example, the addition of overflow or enlarge the gate and runner in the gating system design so that, turbulence flow can be avoided, and more laminar flow can be achieved as in Figure 8. The two-equation model Reynolds-Stress model k-ε standard and other was investigated by [21] and find out that, velocity and volume fraction distribution of liquid and solid phase reveal that the higher the velocity gradient, the narrower the phase segregation width at the region adjacent to the wall [21].

Figure 9 shows the possibility of vortex flow occurrence at the end of the runner in which the melts starting to flow into the cavity. The melts flow revolves around the end of the runner. Figure 10 shows the possibility of turbulence flow occurrence at the cavity casting part when the filling rate is about 80%. Turbulence flow might happen because of inconsistent and irregular variations in the speed and the direction of the flow throughout the slurry as it travels through the casting. Turbulence flow is bad for casting quality because it can trap gases contained in the casting material resulting in mould erosion. The result contradicted with a previous work [22], it was done the design by bottleneck analysis and the result obtained was smooth laminar flow compared vortex flow in Figure 9.

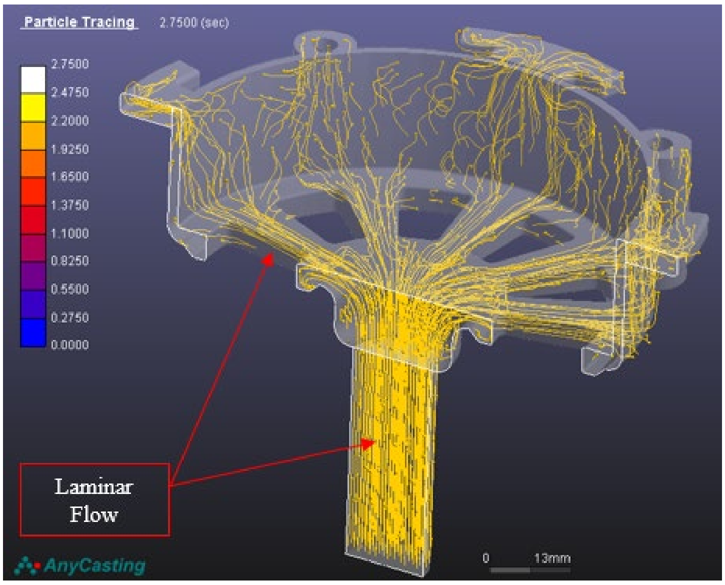


Figure 8: Cross-sectional view of particle tracing.

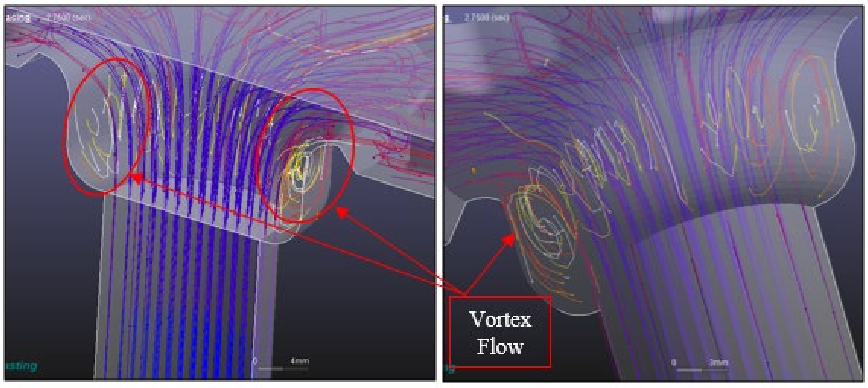


Figure 9: Vortex flow in particle tracing analysis.

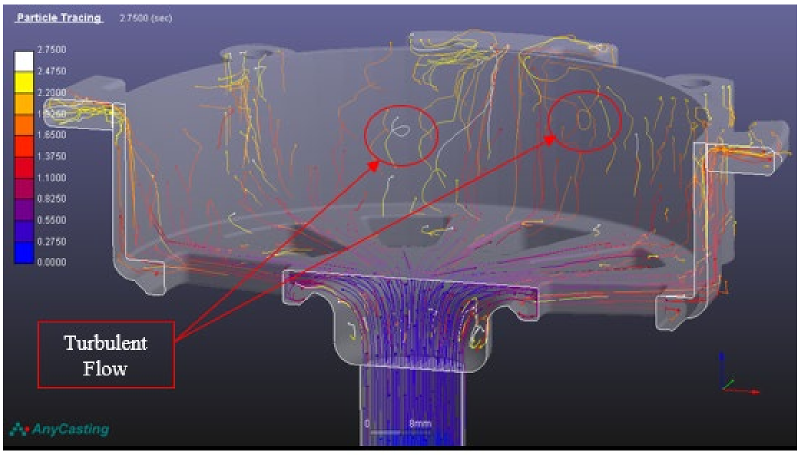


Figure 10: Turbulence flow in particle tracing analysis

Solidification of Casting Part

Figure 11 shows the solidification for the casting of semi-solid AZ91D containing 41% of the solid fraction at a plunger speed of 0.1 m/s. The solidification process is illustrated by colour contour to show the transition of the solidification time of the casting part. Based on table 4, it shows that the casting part took approximately 60.08s to solidify completely and the slowest solidification time is at 1.0m/s approximately 57.19s

Figure 11 shows the solidification sequence of semi-solid AZ91D. The last area to solidify is the central region of the runner which shown by the white colour contour. Referring to Figure 14, it is shown that a shrink in porosity during solidification occurs in that area. The filling capability of semi-solid slurry mainly depends on the pouring temperature. Higher pouring temperature induces good material fluidity and fine capability, but it has a bad impact on part quality since higher temperature leads to lower viscosity, causing turbulence filling. The casting part might have defects such as air entrapment. In contrast, too low pouring temperature induces a high viscosity and bad fluidity that might lead to incomplete filling defects. From the simulation, the solidification distribution can be predicted, and it is important to note that most of the defects in casting can be occurred and observed in the last region of solidification

Table 4: Comparison of solidification time for different plunger speed.

Filling rate (%)	Solidification time (s)					
	0.1 m/s	0.2 m/s	0.3 m/s	0.4 m/s	0.5 m/s	0.6 m/s
10	n/a	n/a	n/a	n/a	n/a	n/a
15	n/a	n/a	n/a	n/a	n/a	n/a
20	n/a	n/a	n/a	n/a	n/a	n/a
25	0.0113	0.0056	0.0038	0.0028	0.0023	0.0110
30	1.7665	1.3820	0.9383	1.0547	1.3235	0.9395
35	3.7534	3.5064	3.5486	3.8139	4.0774	3.6975
40	6.4327	6.1829	6.2368	6.5026	6.7394	6.3860
45	9.0642	8.8345	8.879	9.1454	9.3782	9.0078
50	11.670	11.4411	11.4785	11.7441	11.973	11.6288
55	14.2747	14.0434	14.0954	14.3416	14.5667	14.2066
60	16.8501	16.6198	16.6782	16.9215	17.1425	16.7938
65	19.4368	19.2091	19.2734	19.4648	19.7121	19.3746
70	22.0358	21.8116	21.862	22.082	22.2959	21.9691
75	24.6421	24.4193	24.4533	24.6971	24.904	24.5635
80	27.292	27.0519	27.4533	27.3063	27.5366	27.1986
85	30.1495	29.8917	29.9259	30.1454	30.3741	30.0018
90	33.3474	33.0177	33.0104	33.2303	33.4923	33.033
95	40.2393	39.2993	39.0782	39.3157	39.8626	38.4796
100	60.0849	58.6651	58.4332	58.6363	59.5226	57.1929

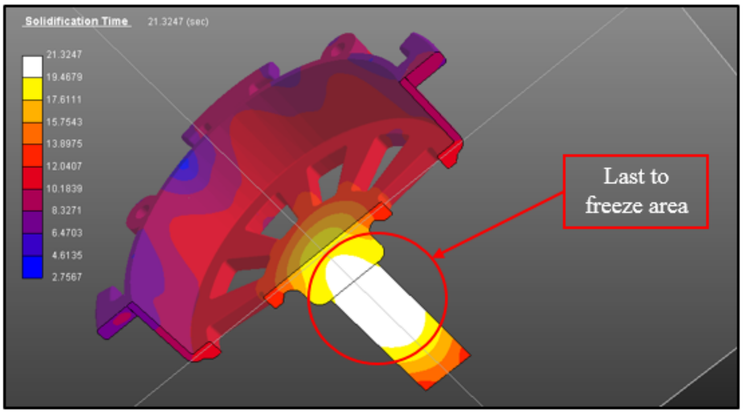


Figure 11: Solidification of casting part.

Effect of Solid Fraction to Solidification Time (Power Law)

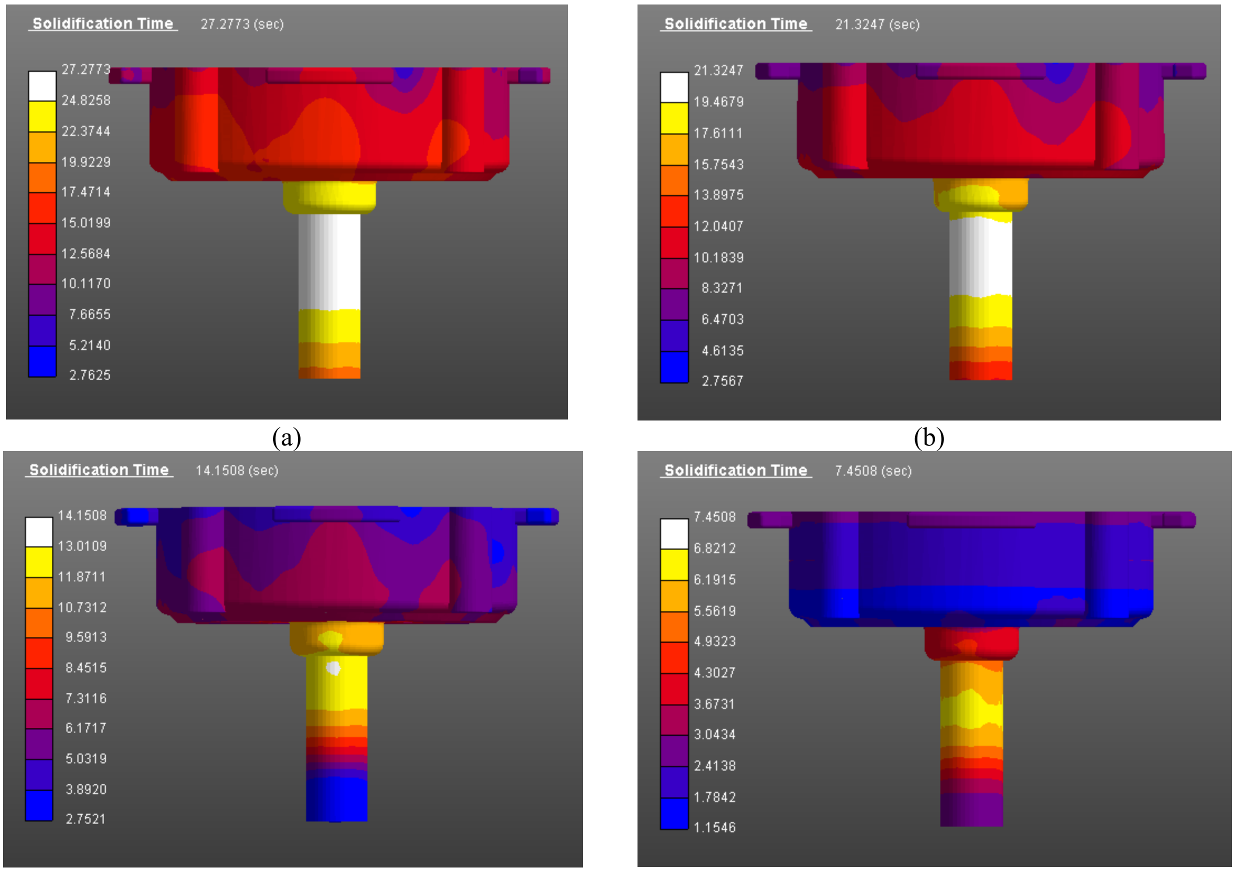
Rapid solidification achieved in the die cavity process imparts distinct characteristics to the metal. Grain structure is much finer, and porosity distribution is different from molten metal which solidifies much more slowly than thixoforming. The finer the grain structure and the more absent the porosity give the skin of the metal superior mechanical properties. Table 5 shows the time taken for the AZ91D slurry to solidify completely. Figure 12 shows the image of the solidified casting part.

Table 5: Comparison of solidification time for a different solid fraction.

Filling rate	Solidification time (s)			
(%)	SF-29%	SF-41%	SF-48%	SF-58%
10	N/A	N/A	N/A	N/A
15	0.0113	N/A	N/A	N/A
20	1.7509	N/A	N/A	N/A
25	3.441	0.0113	N/A	N/A
30	6.0338	1.7665	N/A	N/A
35	8.6033	3.7534	0.0113	N/A
40	11.1294	6.4327	2.0713	N/A
45	13.6566	9.0642	3.8712	0.0113
50	16.171	11.6717	6.6354	2.7244
55	18.6581	14.2747	9.3699	4.8267
60	21.1723	16.8501	12.0765	7.6744
65	23.6841	19.4368	14.7575	10.4946
70	26.1945	22.0358	17.4417	13.2861
75	28.7567	24.6421	20.115	16.0664
80	31.3996	27.292	22.8105	18.8463
85	34.2347	30.1495	25.6368	21.6611
90	37.5327	33.3474	28.7069	24.7522
95	44.9912	40.2393	34.0016	29.4467
100	64.7442	60.0849	52.6509	48.3916

Referring to Table 5, when the initial billet temperature is 580° C (0.29% solid fraction), the time taken for the slurry to solidify is 64.7442 s which is the last to solidify. The fastest slurry to solidify is when the temperature is 550°C (0.58% solid fraction) which the solidification time is 48.3916 s follow up by the temperature of 560°C and 570°C with solidification time of 52.6509 s and 60.0849 s respectively. The last area for the slurry to solidify is at the centre of the runner.

It can be concluded that the lower the temperature (higher solid fraction), the faster the slurry will solidify. But it is important to select the solid fraction carefully. Even though lower temperature makes the casting to solidify faster, but it does have an impact on the viscosity. A lower temperature results in higher viscosity. Therefore, it affects material fluidity, and mostly, a lower temperature will have bad material fluidity. Besides, the material will have a longer fill time to fill up the cavity. Incomplete die filling might happen as the slurry might solidify before it can fill up the whole area of the cavity.



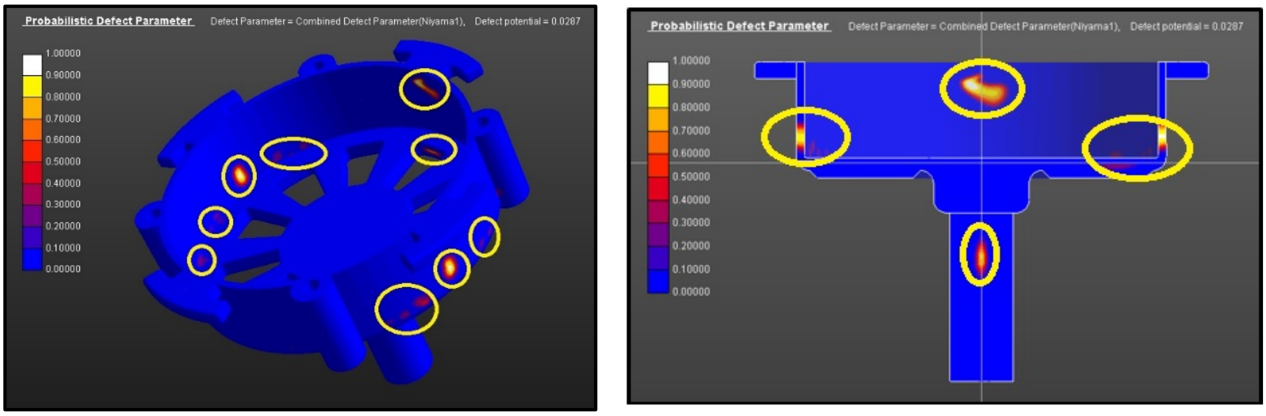
(a) (b)

(c) (d)

Figure 12: Solidification time of casting when solid fraction at (a) 29%, (b) 41%, (c) 48% and (d) 58%.

Defects Prediction (Power Law)

Figure 13(a) shows the occurrence of defects in the casting part. It can be seen that the casting part has a shrinkage defect and have defects potential of 2.87%. Figure 13(b) shows the cross-section of the defect occurring in the part. Most of the shrinkage defects occur at the thin parts caused by the turbulence flow as in Figure 10 and Figure 5(f). Other than that, shrinkage defects probably occur because of insufficient heating of the mould and a smaller average of the wall thickness of the casting part. However, several factors might increase the possibility of shrinkage occurring. Therefore, all factor that causes shrinkage defects must be optimised to prevent critical shrinkage defects which can lead to porosity at the casting part internally. Some modification is needed for this alternator housing to eliminate the possibility of defects occurrence. On the other hand, [20] tested the modelling using power law viscosity model and received the result of unfilled defects in the thin section of the turbocharger fin. The same prediction of potential defects can be analysed to detect the unfilled defects on the turbocharge by [23]. With this result, the validity of this simulation is accepted, furthermore, the combining defect with several parameters such as cooling rate and temperature gradient results in less error.



(a) (b)

Figure 13: (a) Defects prediction using probabilistic defect parameter. (b) The cross-sectional view of probabilistic defect parameter

Analysis of Filling and Solidification Time for Bingham Viscosity Model

Table 6 shows the result obtained by using the Bingham Viscosity Model. It shows that the result is quite similar to the result obtained by using the Power Law Viscosity Model. The time for 100% filling rate is about 2.75 s and the solidification time is 59.45s

Table 6: Filling time and solidification time analysis for the Bingham model

Filling rate (%)	Filling time (s)	Solidification time (s)
5	0.1391	n/a
10	0.2775	n/a
15	0.4157	n/a
20	0.5528	n/a
25	0.6914	0.0113
30	0.8299	1.7725
35	0.9674	3.2972
40	1.1059	5.9997
45	1.2443	8.6342
50	1.3823	11.2608
55	1.5205	13.8499
60	1.6594	16.4501
65	1.7725	19.0408
70	1.797	21.6239
75	1.9353	24.2315
80	2.0738	26.8816
85	2.2111	29.7376
90	2.3498	32.8936
95	2.6259	39.624
100	2.7503	59.4585

Figure 14(a) and 14(b) show the filling and solidification time analysis by using Bingham Viscosity Model. By simulating the viscosity model with a plunger speed of 0.1 m/s at a temperature of 570ºC, the result obtained is quite similar to Power Law Viscosity Model, in which the filling time is 2.7503 seconds and solidification time is 60.08 second.

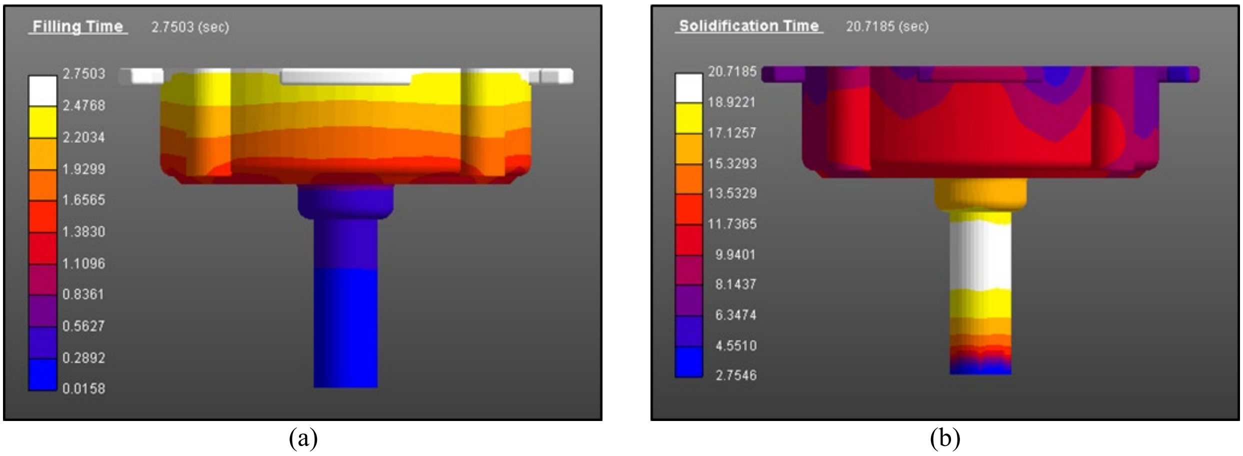


Figure 14. (a) Filling time of casting using the Bingham viscosity model. (b) Solidification time of casting using Bingham viscosity model.

Figure 15 shows the defects predicted by the simulation when it is simulated by using Bingham Viscosity Model. It shows that the location of the predicted defects which appears to be similar to the defects predicted by Power Law Model. Bingham Viscosity Model gives out the defects prediction similar to the Power Law model and it can be concluded that Bingham Viscosity Model is capable to show the defects occur on the casting. Both the viscosity model can be used to model the non-newtonian characteristic of semi-solid AZ91D.

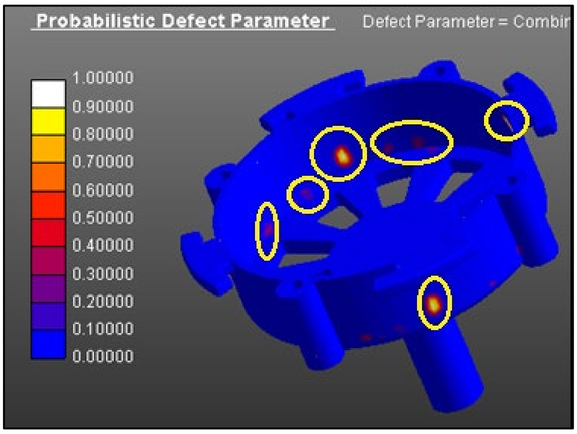


Figure 15. Analysis of combined defect parameter for Bingham viscosity model.

CONCLUSION

The simulation of the automotive component (alternator housing) has been successfully achieved through the use of AnyCasting simulation software. The following conclusion can be made: -

i. The simulation result shows that laminar filling of the semi-solid slurry can be achieved by controlling the plunger speed and temperature. The range of the plunger speed is between 0.1m/s to 1 m/s.
ii. Slower plunger speed (0.1 m/s, 0.2m/s, 0.3m/s and 0.4m/s) and high solid fraction between 48% and 58% are preferable in thixoforming.
iii. From the defect prediction results, the potential defect of the overall part is approximately 2.87% which is acceptable in the die-casting industry.
iv. Both the viscosity model used in the simulation gives a similar result. Bingham Viscosity Model gives out the defects prediction similar to the Power Law model and it can be concluded that Bingham Viscosity Model is capable to show the defects occurring on the casting.
v. The solidification time for 29%, 41%, 48% and 58% solid fraction is 64.74s, 60.08s, 52.65s and 58.39s. The higher the solid fraction gives the lowest solidification time.

For future works, it is recommended to conduct an experimental of thixoforming to validate the numerical simulation result and modification of the mould designed to reduce the possibility of defects occurrence at the casting part to improve the study of a simulation model.

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