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MOULDABILITY OF WOOD FILLER REINFORCED POLYPROPYLENE COMPOSITE FOR INJECTION MOULDED ENGINE COVER USING MOULD FILING SIMULATION

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Abstract

Feasibility studies about processing lignocellulosic reinforced polymer composites by injection moulding have been receiving widespread attention nowadays. The aim of this research was to identify the optimal selection of parameters, significant parameters, and effects of the injection-moulding parameters during the post filling-stage. In this simulation study, the modelling of an automotive component, namely the Proton Waja CAMPRO car engine cover, required a 3-D model and mesh generation to obtain the mouldability of its composite material using the injection moulding process. Autodesk Moldflow Insight® was used to simulate and analyse the injection-moulding process. Therefore, 60 wt% of wood filler reinforced polypropylene was evaluated under optimised injection parameters (injection temperature, mould temperature, injection pressure and flow rate) during the post-filling stage simulation (filling time, average velocity, volumetric shrinkage, sink marks, and shear stress). In addition, numerical simulation by the Taguchi method consisting of S/N ratio and ANOVA were used in this research to determine which significant factors would affect all responses. Based on the numerical simulation results, the flow rate shows the most significant parameter for the reduction of filling time, volumetric shrinkage, sink marks, and shear stress while also enhancing the average velocity on the car engine cover.

Keywords: Wood reinforced composite; car engine cover; injection moulding; numerical simulation; optimisation

Abstrak

Kajian pemprosesan polimer komposit diperkuat serat lignoselulosa melalui proses pengacuanan suntikan telah mendapat perhatian meluas pada masa kini. Tujuan kajian ini adalah untuk mengenal pasti pemilihan parameter yang optimum, sumbangan terbesar, dan kesan terhadap suntikan acuan semasa peringkat pengisian bahan. Dalam kajian simulasi ini, 3D model dan penjanaan jejaring komponen automotif iaitu penutup enjin kereta Proton Waja CAMPRO diperlukan untuk mendapatkan kebolehacuan bahan komposit menggunakan proses penyuntikan. Oleh itu, 60 wt. % serat pengisi kayu bertetulang polipropilena telah diuji di bawah parameter suntikan yang optimum (suhu suntikan, suhu acuan, tekanan suntikan dan kadar aliran) semasa peringkat pasca pengisian simulasi (masa pengisian, halaju purata, pengecutan isipadu, tanda lekuk, dan tekanan ricih). Di samping itu, simulasi berangka melalui kaedah Taguchi yang terdiri daripada nisbah S/N dan ANOVA digunakan dalam kajian ini untuk menentukan faktor-faktor yang memberi kesan terhadap tindak balas. Simulasi berangka menunjukkan, keputusan kadar aliran adalah parameter yang paling penting bagi pengurangan masa pengisian, pengecutan isipadu, tanda lekuk, dan tegasan ricih di samping untuk meningkatkan halaju purata penutup enjin kereta.

Kata kunci: Pengisi kayu bertetulang polipropilena, penutup engin kereta, pengacuanan suntikan; simulasi berangka; pengoptimuman.

1.0 INTRODUCTION

Nowadays, specification properties are emphasised to produce high performance engineering products that show feasibility in exhibiting sustainable and renewable applications in various industries. Products with weight reduction, small thickness or dimension, and are environment friendly are considered to have met the required efforts for cost saving evaluation. In addition to decreasing overall weight and improving both driving stability and fuel efficiency, automotive component manufacturers have recently realised the importance of using renewable resources, namely natural filler reinforced polymer composites, rather than heavy weight materials such as sheets of metal, aluminium and alloy, in the fabrication of parts around the car engine.

The idea of using natural lignocellulosic fillers in composite applications has been embraced by European car manufacturers and there has been growing interest as this provides many advantages over synthetic fibre, such as low-density, low cost and biodegradability. Natural plants most commonly used in these applications are bast fibres such as hemp, jute, flax, kenaf, and sisal. One of the reasons for the increase in such usage is due to its higher specific strength and certain similar modulus compared to fibre glass [1]. Its initial stages were recorded by Germany's automotive manufacturers where Daimler-Benz replaced the glass fibre in one of their car components (i.e., door trim) with wood filler reinforced polymer composites [2]. However, the major concern of using lignocellulosic fibre is that its usage is mostly limited to degradation temperatures below 230°C. Higher temperatures might lead to thermal degradation for the polymer composites, while lower temperatures make the flow of polymer melt unable to fulfil the mould cavities [3].

Thus, by using the injection moulding process, critical parameters such as injection temperature, injection pressure, packing time, and flow rate that have caused major defects must be included and considered for the process's precautions. Azaman *et al.* [4] reported that the three major challenges in injection moulding are influenced by the inconsistent distribution at the cavity filling stage, leading to residual stresses, volumetric shrinkage [5], and warping [6] defects in moulded products, particularly for parts with complex geometries, thin-walled parts, micro-parts, and certain materials [4]. Due to these inappropriate setting parameters, the application of the Taguchi method within signal-to-noise (S/N) and the analysis of variance (ANOVA) was used by most researchers as a practical approach for optimisation. This method was developed by systematically allocating factors and levels to suitable orthogonal arrays to identify the optimal and significant combinations of the parameters to obtain validated results that affect the quality of the parts [7-10].

Wu *et al.* [6] investigated the effects of processing parameters, which covered melt temperature, packing pressure, injection time, and cooling time, on warpage problems for truck bumpers. The results revealed that the warpage parts were reduced with increase in injection time, cooling time, and packing pressure. This warping defect was worse when the packing pressure reached 45MPa. The numerical simulation work conducted by Azaman *et al.* for moulded thin-walled parts using wood-filled polypropylene composites found that the packing pressure and mould temperature were significant parameters in the reduction of residual stresses and volumetric shrinkage, while the packing pressure, packing time, and cooling time were most influenced by the reduction of warpage [11]. Moreover, as previously proven by Azaman *et al.* [12], shallow thin-walled parts are suitable for moulding lignocellulosic composite materials, where they exhibited lower residual stress and warpage compared to flat thin-walled parts.

This review investigated the limitations of numerical simulation research conducted on automotive components under the hood cover. Furthermore, the materials applied were not natural resources that were fully utilised, thus requiring extensive studies to implement the challenge of natural polymer composites which needed sustainable defences towards higher temperature, and impact. Through this work, the modelling of an automotive component, namely the Proton Waja CAMPRO car engine cover, was simulated by Moldflow software based on optimised injection moulding parameters. 60 wt% of wood filler reinforced polypropylene was utilised in order to investigate the effect of optimum injection moulding parameters (injection temperature, mould temperature, injection pressure, and flow rate) during the post-filling stage (filling time, average velocity, volumetric shrinkage, sink marks, and shear stress) of mouldability. Numerical simulation consisting of the Taguchi method, S/N ratio and ANOVA were used in this work.

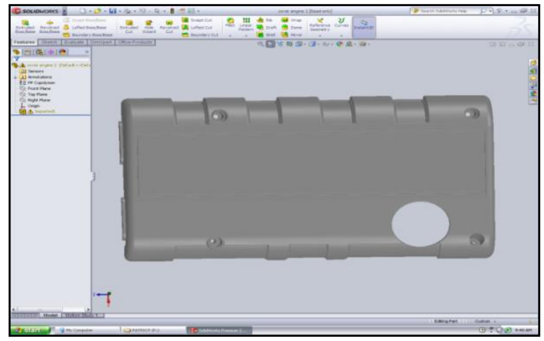
2.0 METHODOLOGY

SolidWork Premium 2012 was used to model the car engine cover of the Proton Waja CAMPRO, and a 3D design component was created following the actual dimensions of the parts as shown in Figure 1.

The simulation and analysis of the injection moulding process were done using Autodesk Moldflow Insight®. The materials and injection moulding machine used in the simulation were chosen and described based on the following specifications: 60wt% wood filler + PP, (WPC-2-mv; Fraunhofer Institute), and HUSKEY Modiline G-series RS 100/100 injection moulding machine.

Table 1 summarises the material properties of the filler reinforced polymer composite. The simulation was performed using a set analysis (Fill + Pack) for these models. Table 2 shows the post-filling processing parameters used for the simulation. The results regarding fill time, average velocity, volumetric shrinkage, sink marks and shear stress were then analysed.

(a) Actual parts of Proton Waja CAMPRO car engine cover



(b) A 3D model in SolidWork Premium software

Figure 1 Component parts

Table 1 Material properties of filler reinforced polymer composite

	PP60 wt% wood filler + PP
Trade name	WPC-2-mv
Filler content (wt%)	60
Material structure	Semi-crystalline
Melt flow rate (g/10min)	3.81
Melt temperature (°C)	190
Mould temperature (°C)	50
Aspect ratio (L/D) of fillers	1

Table 2 Post-filling processing parameters

Parameters	Values
Injection temperature	250 - 270°C
Mould temperature	40 - 60°C
Injection pressure	50 - 70cm^3/s
Flow rate	300 - 350MPa

During the process, Taguchi orthogonal arrays comprising nine experiments with three levels were applied, and four processing parameters were used in the analysis. Table 3 and Table 4 show the list of processing parameters and levels, and the detailed arrangement of the orthogonal arrays respectively. Based on the simulation observation, the significant results will be analysed and discussed further.

Table 3 Parameters and levels of process

Factors	Description (unit)	Levels		
		1	2	3
A	Injection temperature (°C)	250	260	270
B	Mould temperature (°C)	40	50	60
C	Injection pressure (MPa)	300	325	350
D	Flow rate (cm^3/s)	50	60	70

The signal-to-noise (S/N) analysis of the smaller-is-better quality characteristic has been selected for each response: filling time, sink marks, volumetric shrinkage, and shear stress. Meanwhile, the Taguchi signal-to-noise (S/N) analysis of bigger-is-better was chosen to obtain the optimum parameters for the average velocity results. Moreover, ANOVA was also used to analyse the collected data to investigate which significant factors would affect all responses [11].

Table 4 Combination of parameters in the orthogonal array $L_9 4^3$

No. trial	Parameters			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3.0 RESULTS AND DISCUSSION

3.1 Analysis of S/N Ratio for Optimisation of Moulding Parameters and ANOVA

The S/N ratio was used in the Taguchi method to analyse the collected data to obtain the optimal combination of parameters and also to predict the optimum value. A smaller-is-better and a bigger-is-better of the S/N ratio were selected from the results of the highest S/N ratio responses as shown in Table 5. This value gives the optimum combination of the processing conditions for the minimisation of the four chosen responses (filling time, volumetric shrinkage, sink marks, and shear stress), which can also be used for the enhancement of other responses (i.e., average velocity).

Meanwhile, in the ANOVA analysis, the most effective parameters can be obtained with either the highest F-ratio value or P less than 0.05 value recorded. This study found that flow rate was the most important parameter that influenced the filling time, volumetric shrinkage, sink marks, shear stress and average velocity on the car engine cover. This was proven by the ANOVA analysis results, where the highest values of F-ratio for filling time, volumetric shrinkage, sink marks, shear stress and average velocity were 444.33, 2.80, 5.31, 669.46, and 580.77 respectively, hence representing the most significant parameter (refer Table 6).

Table 5 Responses of S/N ratio for filling time, volumetric shrinkage, sink marks, average velocity and shear stress

	Level	*Injection temperature*	*Mould temperature*	*Flow rate*	*Injection pressure*
Filling time	*1*	***27.28***	*27.34*	*28.81*	***27.29***
	2	*27.29*	*27.30*	*27.22*	*27.30*
	3	*27.31*	***27.24***	***25.86***	*27.29*
	Variance	*0.03*	*0.10*	*2.96*	*0.1*
Volumetric shrinkage	*1*	*24.10*	*24.64*	***25.25***	*24.62*
	2	***25.22***	***24.96***	*24.44*	*24.52*
	3	*24.57*	*24.29*	*24.21*	***24.76***
	Variance	*1.12*	*0.67*	*1.04*	*0.24*
Sink marks	*1*	***-17.88***	*-18.36*	*-19.48*	***-18.30***
	2	*-19.23*	*-19.30*	*-18.66*	*-18.54*
	3	*-18.43*	***-17.88***	***-17.40***	*-18.70*
	Variance	*1.35*	*1.41*	*2.08*	*0.40*
Average velocity	*1*	***52.62***	***52.79***	*51.47*	*52.45*
	2	*52.55*	*52.56*	*52.60*	***52.57***
	3	*52.39*	*52.21*	***53.50***	*52.54*
	Variance	*0.23*	*0.58*	*2.03*	*0.13*
Shear stress	*1*	*86.07*	*86.23*	***84.90***	***85.89***
	2	*85.99*	*86.00*	*86.04*	*86.01*
	3	***85.83***	***85.65***	*86.95*	*85.99*
	Variance	*0.23*	*0.58*	*2.04*	*0.12*

3.2 Filing Simulation

Table 5 highlighted the highest S/N ratio for each processing parameter which shows the optimum combination of the processing conditions, while the difference between the maximum and minimum values of the S/N ratio would be used to make an initial prediction regarding the parameters that significantly influence the responses.

The results of the filling simulation for the Proton Waja CAMPRO car engine cover design highlighted that the parts required 19.47s to fill. The fastest filling time was achieved using the optimum injection temperature, mould temperature, flow rate, and injection pressure which were 250°C, 40°C, 70cm^3/s, and 300MPa respectively.

Meanwhile, the volumetric shrinkage of the significant parameters in order to reduce shrinkage defects was simulated at injection temperature (250 °C), mould temperature (60°C), flow rate (70cm^3/s), and injection pressure (325MPa).

The highest average velocity at 483.7cm/s was reached when applied with the optimum parameters which were injection temperature (250°C), mould temperature (40°C), flow rate (70cm^3/s), and injection pressure (325MPa).

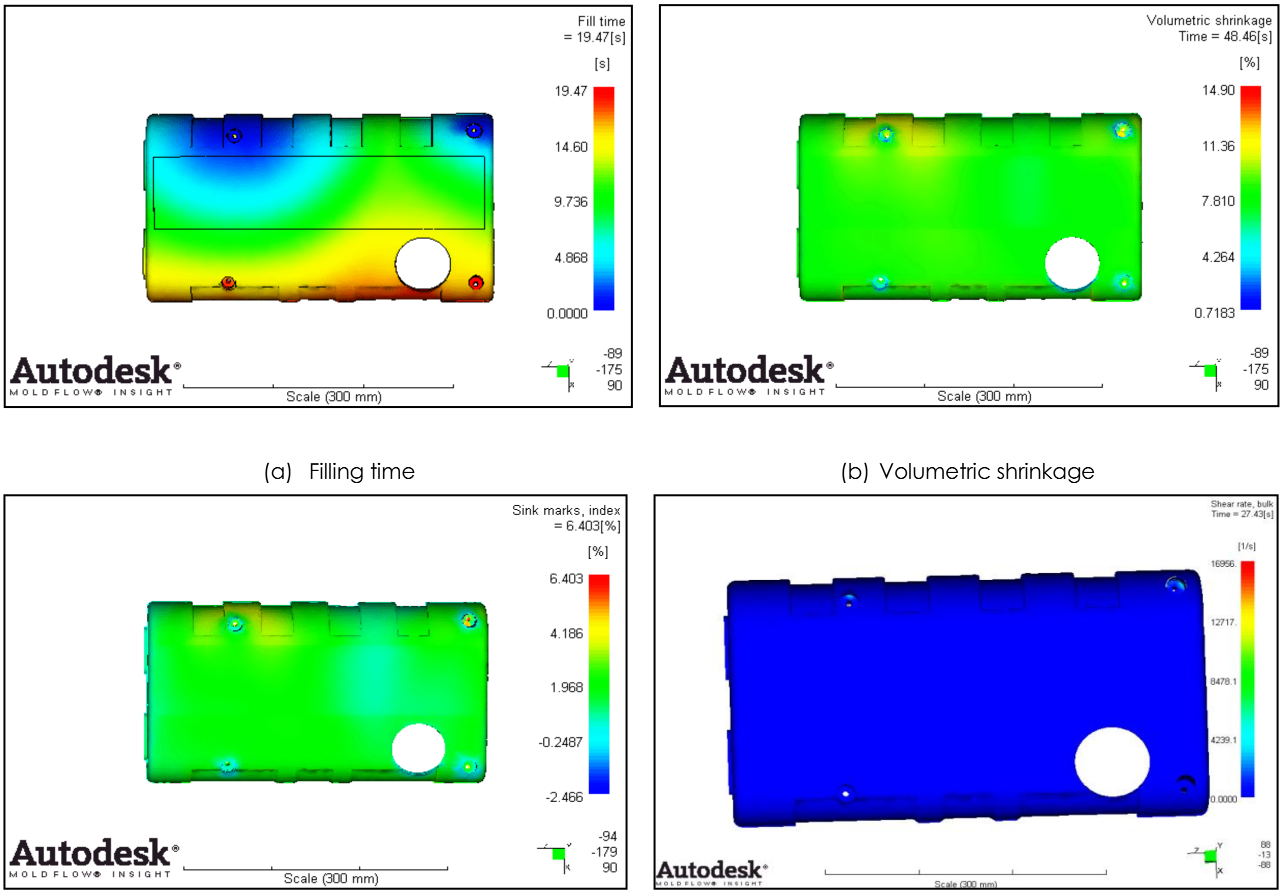
Sink mark defects were minimised until 6.403% by using the effective parameters selected which were injection temperature (250°C), mould temperature (60°C), flow rate (70cm^3/s), and injection pressure (300MPa).

Shear stress defects were simulated and obtained the best parameters for less defects which were injection temperature (270°C), mould temperature (60°C), flow rate (50cm^3/s), and injection pressure (300MPa).

Figure 2 illustrates all post-filling stage simulation in the Moldflow analysis. Although the values applied for the processing parameters were the same, the optimum parameters evaluated to affect each response (filling time, volumetric shrinkage, average velocity, sink marks and shear stress) were different. These differences occurred due to the contribution of lignocellulosic (wood filler) polymer composites with the highest loading and viscosity, thus affecting post-filling stage behaviours [11].

Table 6 ANOVA for filling time, volumetric shrinkage, sink marks, shear stress and average velocity

Factors	DOF	Seq SS	Adj MS	F-ration	P
Filling time					
Injection temperature	1	0.004	0.004	0.02	0.895
Mould temperature	1	0.101	0.101	0.47	0.529
Flow rate	1	95.042	95.042	**444.33**	0.000
Injection pressure	1	0.000	0.000	0.000	0.980
Error	4	0.856	0.214		
Total	8	96.004			
Volumetric shrinkage					
Injection temperature	1	1.288	1.288	0.59	0.487
Mould temperature	1	0.589	0.589	0.27	0.632
Flow rate	1	6.161	6.161	**2.80**	0.169
Injection pressure	1	0.177	0.177	0.08	0.791
Error	4	8.794	2.198		
Total	8	17.009			
Sink marks					
Injection temperature	1	0.475	0.475	0.42	0.552
Mould temperature	1	0.233	0.233	0.21	0.673
Flow rate	1	6.004	6.004	**5.31**	0.082
Injection pressure	1	0.443	0.443	0.39	0.565
Error	4	4.520	1.130		
Total	8	11.676			
Shear stress					
Injection temperature	1	329941	329941	6.78	0.060
Mould temperature	1	2562373	2562373	52.63	0.002
Flow rate	1	32596704	32596704	**669.46**	0.000
Injection pressure	1	88088	88088	1.81	0.250
Error	4	194763	48691		
Total	8	35771870			
Average velocity					
Injection temperature	1	138.2	138.2	5.50	0.079
Mould temperature	1	1170.4	1170.4	46.58	0.002
Flow rate	1	14592.8	14592.8	**580.77**	0.000
Injection pressure	1	34.6	34.6	1.38	0.306
Error	4	100.5	25.1		
Total	8	16036.5			



(a) Filling time

(b) Volumetric shrinkage

(c) Sink marks

(d) Shear stress

Figure 2 Post-filling stage simulation

4.0 CONCLUSION

In conclusion, the optimisation of injection moulding parameters was required in order to investigate the effects of optimum parameters (injection temperature, mould temperature, injection pressure, and flow rate) regarding the post-filling stage (filling time, average velocity, volumetric shrinkage, sink marks, and shear stress) of mouldability. In this study, the Proton Waja CAMPRO car engine cover was simulated by Moldflow software, using 60wt% of the wood filler reinforced polypropylene composite. The ANOVA analysis ascertained that flow rate was the most significant parameter for the reduction of filling time, volumetric shrinkage, sink marks, and shear stress, as well as for the enhancement of the average velocity on the car engine cover. Besides that, to minimise the degradation of lignocellulosic wood fibre, the processing should be limited to temperatures below 230°C which can affect the strength, shrinkage, and warpage in the injection moulding of high-temperature natural fibre reinforced composite automotive parts.

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