Research Article

Effects of Plastic Injection Moulding Process Parameters on Material Elastic Modulus on Complex Geometry and Parameter Optimization for Getting Maximum Stiffness in Washing Machine Tubs

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Abstract

Plastic injection is widely used in white goods sector in case of highly production rates, low transformation costs and recyclability of products. There are many parameters affecting on the quality, dimensional stability and mechanical strength in plastic injection process. In washing machine tubs which are exposed to dynamic loads during spinning, it is necessary to optimize process parameters. In this research; packing pressure, packing transition point, packing time and injection time is optimized by using Box Behnken methodology via Moldlfow elastic modulus outputs and structural analyses results. Optimum process parameters are obtained to achieve best material orientation.

Keywords: *Plastik Injection, Moulding, Process, Tubs, Washing Machine*

1. Introduction

Plastic Injectıon Moulding which is also called PIM process is widely used in almost all industries especially thanks to its production rate and manufactured complex shapes with lower costs. Material and geometry flexibility, low transformation costs, recyclability of products and also improved strength of the geometry are fundamental advantages of PIM process. However, mould design based on geometry and material choice (including cooling features) and also process parameters are directly related with getting optimum shape and stiffness.

In white goods sector especially laundry side, tub groups produced by plastic injection are constantly exposed to dynamic loads due to the unbalanced load created by the laundry and must withstand this load at spinning cycle. Although the material selection is critical for product strength in tub groups, which determined in the structural analysis processes, process parameters have a significant impact on the material mechanical properties. Distribution of elastic modulus and Poisson ratio are the key parameters for design of the tub.

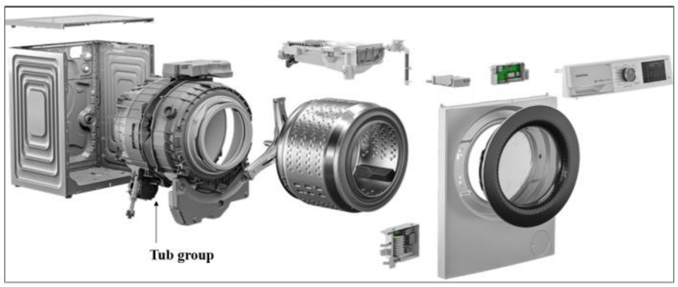

Figure 1: Exploded view of washing machine.

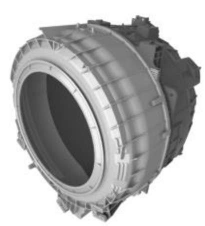

Figure 2: Tub group.

2. Materials and Methods

In washing machines, approximately 20% of materials are made of plastics in total. Different types of plastics (calcite filled polymers, PET additive polymers and glass fiber reinforced polymers) are used in tub groups to achieve proper strength in the products. Many of investigations have been focused on process parameter optimization with using statistical tools such as; Minitab. Many designs of experiment (DOE) approaches (Taguchi, full factorial, response surface method, Box Behnken, central composite design and Doehlert Design) are used to optimize the parameters. In this research, Box Behnken design were used for optimization. Box Behnken design is strongest approach than other theories such as; central composite design, Doehlert design and three level full factorial [1].

2.1. Process Parameters & Optimization

Plastic injected tub group is optimized with four different process parameters. Packing pressure helps to control the compression of the melt of flow path. Improper packing pressure values can cause the porosity, shrinkage, warpage and short shots in samples [11]. Packing transition point is another optimization parameter that; in this point, velocity control switches from packing control. Generally, this point ranges 90-99 % of full part injection. Packing time is a factor that; it allows to plastic to fill the entire cavity and obtains the good surface finish and less visual defects. The last one is the injection time which depends on shot size and machine power. PIM process scheme is shown below:

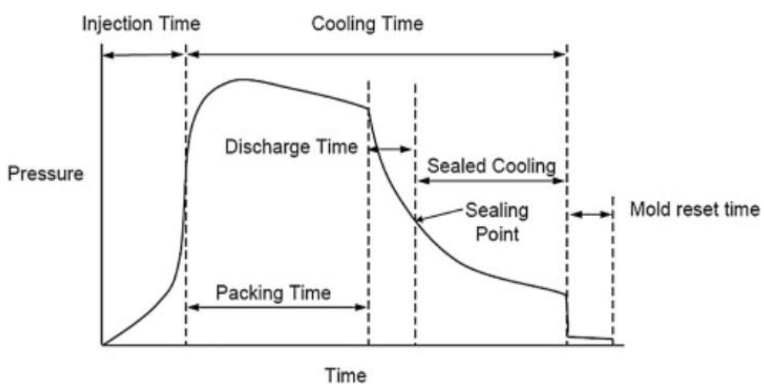

Figure 3: PIM process [12].

Four critical process parameters and their ranges are given in Table 1.

Table 1: Process parameter ranges in Box Behnken method.

Parameters	Minimum	Center	Maximum
Packing time (s)	8	14	20
Packing pressure (bar)	30	35	40
PTP*	93	96	99
Injection time (s)	5	7	9

*Packing transition point

Table 2: Box Behnken method DOE setup.

#	Injection time (s)	PTP	Packing pressure (bar)	Packing time (s)
1	5	93	35	14
2	9	93	35	14
3	5	99	35	14
4	9	99	35	14
5	7	96	30	8
6	7	96	40	8
7	7	96	30	20
8	7	96	40	20
9	7	96	35	14
10	5	96	35	8
11	9	96	35	8
12	5	96	35	20
13	9	96	35	20
14	7	93	30	14
15	7	99	30	14
16	7	93	40	14
17	7	99	40	14
18	7	96	35	14
19	5	96	30	14
20	9	96	30	14
21	5	96	40	14
22	9	96	40	14
23	7	93	35	8
24	7	99	35	8
25	7	93	35	20
26	7	99	35	20
27	7	96	35	14

Totally 27 different scenarios have been analysed using Moldflow which is shown in Table 2. Glass fiber reinforced polymer has been used in process optimization and injection samples. Besides; only modulus of elasticity at different critical regions in tub group has been obtained each step. Main technical characteristics of material are revealed below:

Table 3: Material specifications.

Specs	Values
Density (g/cm^3)	1,12
Elastic Modulus (fiber) (MPa)	24700
Elastic Modulus (matrix) (MPa)	2700
Poisson Ration (v12)	0,401
Poisson Ration (v23)	0,472

Optimization flowchart are shown in Figure 4. In this process, Moldflow simulations are performed for each step and modulus of elasticity for each critical region in tub group are obtained. After finished all injection simulations, optimum process parameters are defined by using Box Behnken method (including Stepwise elimination) with 95% confidence interval.

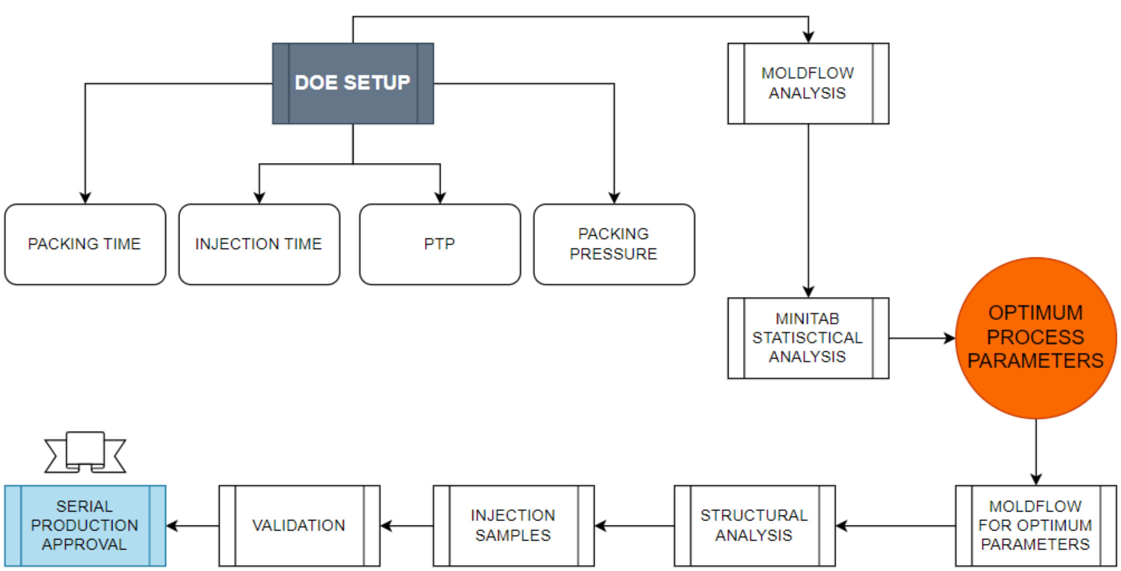

Figure 4: Optimization flowchart.

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3. Results

There are many critical regions in the tub group geometry that affects the service call rate (SCR) directly. Firstly, washing machine dynamic systems are needed to extra weights to keep stable the oscillations during washing and spinning cycles. Oscillation orbit behaviour increases the stress concentration on connected regions between tub and counterweights. Secondly, transportation safety is critical before customer experience and design of transport safety bosses in tub group is determinant of SCR. Thirdly, Insert radial ribs are responsible for distributing centrifugal forces and bending moments to the all system in a homogenous manner. Radial ribs on the insert are crucial to estimate the reliability of the product. All these of three points on the tub group have a roughly 80% on determining product life. Here critical regions are shown below in Figure 5:

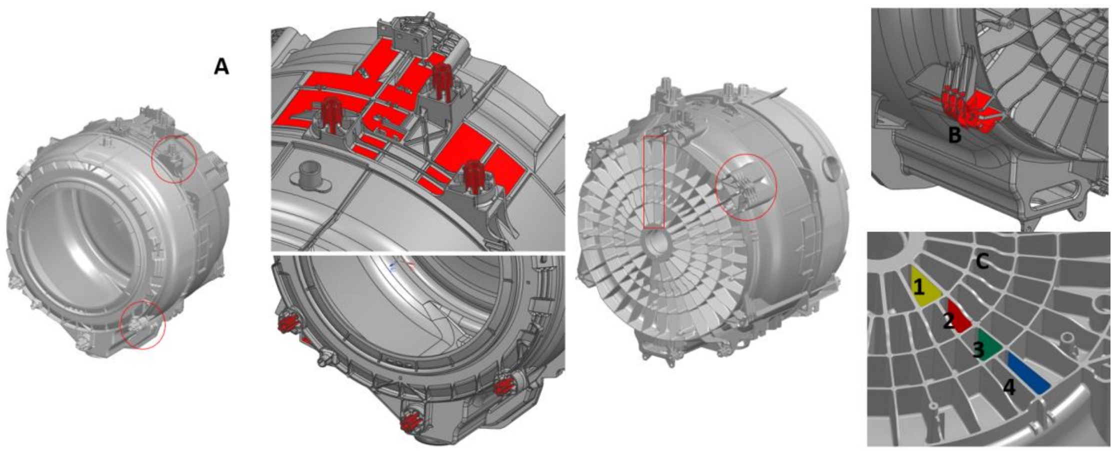


Figure 5: A (counterweight bosses), B (transport safety bosses), C (insert ribs).

Table 4: DOE results.

#	INPUTS				OUTPUTS						
	Injection time (s)	PTP	Packing pressure (bar)	Packing time (s)	S1	S2	S3	S4	Transport Boss	CTW_Boss _Front	CTW_Boss_ Top
1	5	93	35	14	6971	8131	8550	8564	8918	8740	6279
2	9	93	35	14	6946	8105	8518	8599	8955	8680	6398
3	5	99	35	14	6843	8108	8526	8202	8911	8802	6281
4	9	99	35	14	7129	8309	8527	8228	8956	8713	6470
5	7	96	30	8	7944	8191	8484	8173	8973	8658	6420
6	7	96	40	8	7436	8154	8566	8395	8960	8645	6319
7	7	96	30	20	7031	8187	8504	8316	8924	8800	6414
8	7	96	40	20	7107	8236	8606	8320	8959	8819	6382
9	7	96	35	14	6192	8338	8572	8165	8954	8680	6429
10	5	96	35	8	7082	8442	8563	8260	8958	8648	6296
11	9	96	35	8	7338	8432	8543	8266	8966	8731	6548
12	5	96	35	20	7440	8508	8538	8528	8964	8847	6318
13	9	96	35	20	7337	8512	8546	8352	8935	8776	6404
14	7	93	30	14	7114	8500	8604	8504	8946	8855	6411
15	7	99	30	14	6999	8330	8644	8419	8942	8669	6517
16	7	93	40	14	7045	8227	8595	8362	8958	8836	6376
17	7	99	40	14	6864	8423	8548	8576	8934	8844	6488
18	7	96	35	14	6885	8318	8535	8507	8951	8842	6419
19	5	96	30	14	6914	8353	8593	8472	8932	8827	6297
20	9	96	30	14	6700	8537	8575	8329	8937	8737	6421
21	5	96	40	14	6613	8465	8636	8457	8958	8828	6300
22	9	96	40	14	6930	8549	8444	8652	8968	8763	6383
23	7	93	35	8	6978	8455	8648	8602	8959	8693	6354
24	7	99	35	8	6976	8205	8605	8433	8948	8744	6423
25	7	93	35	20	6711	8515	8576	8580	8958	8830	6401
26	7	99	35	20	6883	8495	8627	8568	8968	8791	6419
27	7	96	35	14	6742	8541	8627	8568	8962	8785	6429

All output elastic modulus values are obtained from Moldflow for each step shown in Table 4. In each step, elastic modulus values are taken as an average for critical regions. Using Minitab and Box Behnken method with Stepwise elimination, optimum process parameters to achieve maximum elastic modulus on critical areas are obtained. In this optimization, 95% confidence interval are assumed in the formulas.

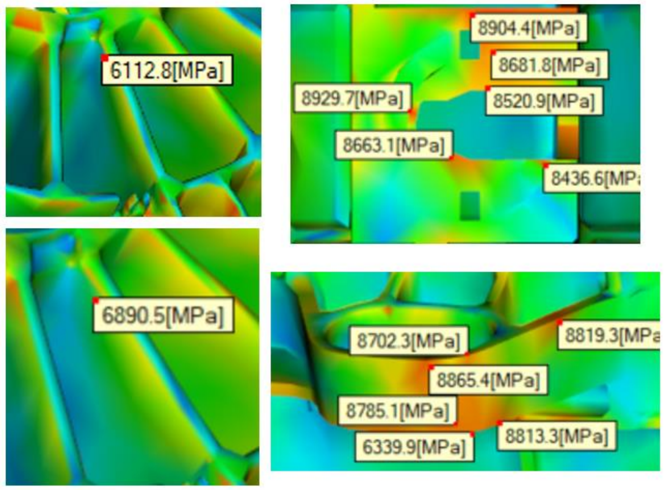
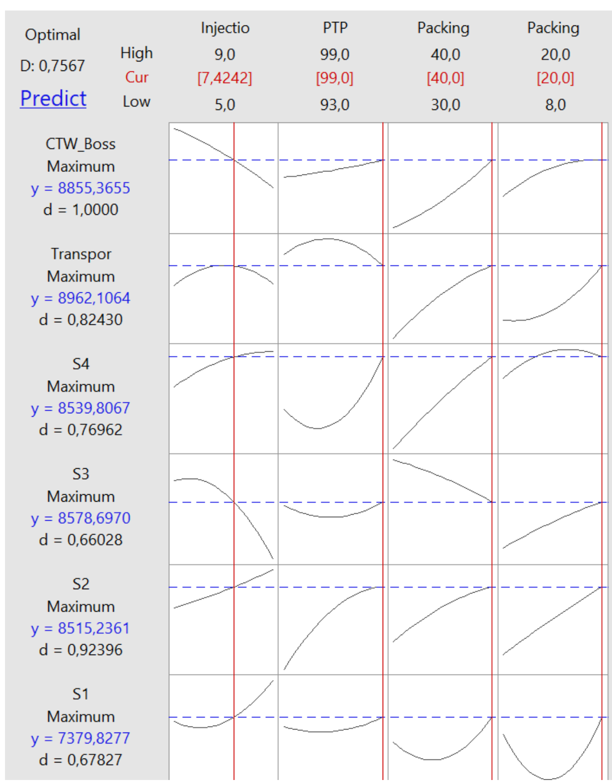


Figure 6: Elastic modulus in critical areas obtained from Moldflow.

In statistical analysis, CTW_Boss_front, CTW_Boss_Top, S3 and S4 have a normal distribution. Other results have been transformed using Box-Cox transformation. Optimum process parameters are found using response optimizer in Minitab. In here, composite desirability combines individual desirability all response variables and calculated as 0,7567. This should be 1 if it is needed to have ideal case.

Table 5: Process optimization results.



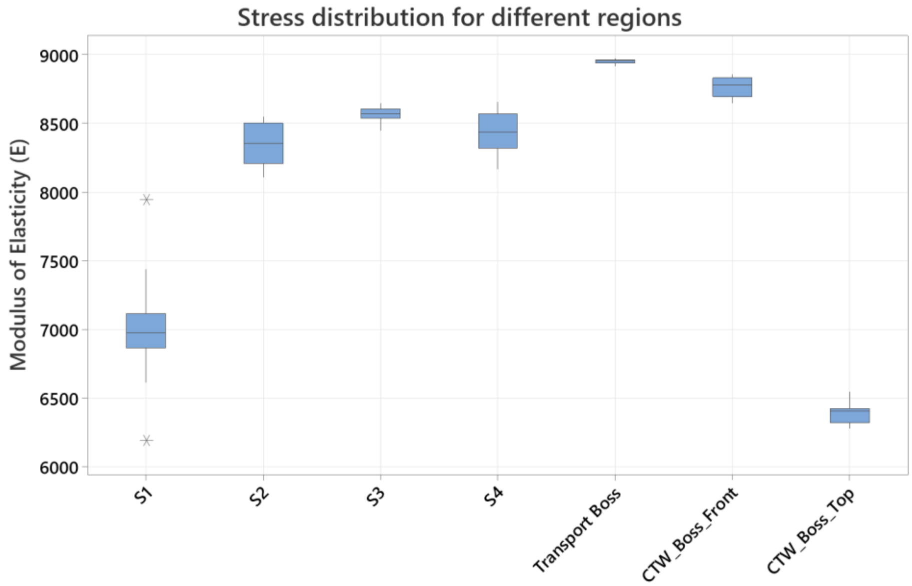
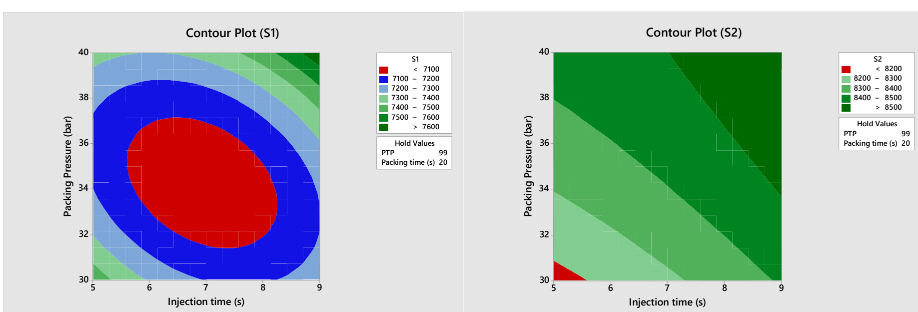


Figure 7: Stress distribution for different regions.

In Figure 7, stress distributions for each DOE step are shown. According to this graph, it is concluded that; S3, Transport Boss and CTW_Boss_Top are not affected from parameter changes. The worst case for the tub group is CTW_Boss_Top since the minimum elastic modulus is obtained during injection analyses. Insert ribs are critical especially at the spinning cycle because; loads caused by unbalance mass at high spin speeds are carried by them. In Figure 8, contour plots for insert ribs at optimum process parameter conditions obtained in Table 5 are shown:



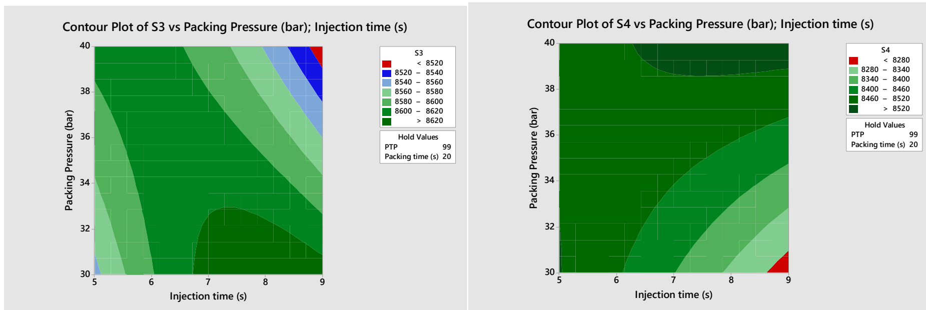


Figure 8: Contour plots for different insert ribs.

According to the optimization, optimum process parameters are obtained; 7,4242 s as injection time, 99 as PTP, 40bar as packing pressure and 20 s as packing time. In below, overall process scheme (plastic injection optimization using Minitab & Moldflow◎ structural analysis check with optimum process parameters ◎ sample production and laboratory test for validation) is given:

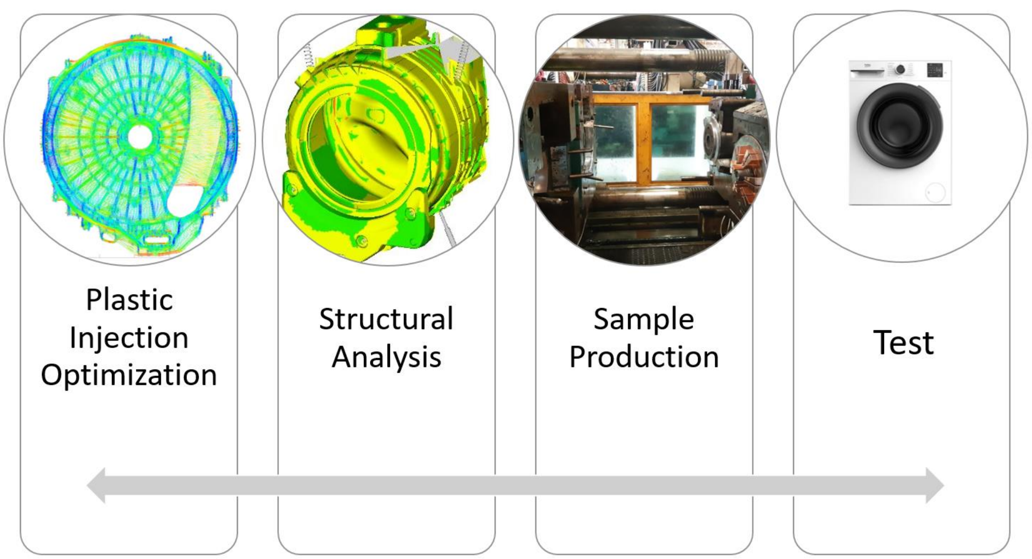


Figure 9: Overall process scheme.

4. Discussion and Conclusion

WeiTai Huang et al. [2] examined the impacts of process parameters and mould design on the shrinkage of auto-lock designs by using Taguchi's approach and Grey Relation Analysis technique. Relation between process parameters and shrinkage were reported. Ashwani Kapoor et al. [3] performed test for optimizing process parameters to achieve minimum shrinkage with using material as Nylon 66 40% GF. Genetic algorithm was used to optimize process conditions. Meant NM. et al. [4] investigated the relation of multiple mechanical properties by changing process parameters using Taguchi's method. Shi et al. [5] obtained optimum process parameters which affects the maximum shear stress of the butter container lid by integrating genetic algorithm and neural network. In this research optimum parameter set were found where the maximum shear stress was minimum. Gou et al. [6] examined the process parameters acting the warpage behaviour in thickness of 2mm standard piece of PP by using DOE methodologies. Davide Masato et al. [7] explained that; main injection process parameters which affects the shrinkage behaviour are cooling time, packing pressure, melt temperature and injection speed. Although these parameters are highly important for shrinkage, material properties and geometry features are also critical. Adhikary et al. [8] focused on the microstructure of the composite by adding MAPP, stability and mechanical properties by changing parameters. Mehdi Moayyedian et al [9] reported that; size and geometry of the runner and gate is critical for quality of injection. Bigger gates have a positive impact on residual stresses. Improper gate location causes short shot, preliminary failure and increasing shrinkage. Oktem et al [10] obtained best parameters for decreasing shrinkage and warpage behavior after injection process by using Taguchi's method.

5. Acknowledge

In plastic injection production, there are many parameters affecting on quality, dimension and perception of the geometry. In this research effects of injection time, PTP, packing pressure and packing time on elastic modulus of glass fiber reinforced polymer in washing machine tub groups are examined by using Box Behnken design. According to the optimization, optimum process parameters for achieving best elastic modulus and strength of the tub group is obtained as 7,4242 s as injection time, 99 as PTP, 40bar as packing pressure and 20 s as packing time. It is concluded that; S3, Transport Boss and CTW_Boss_Top are not affected from parameter changes. Structural analysis and sample productions for validation tests are completed with best parameter set.

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