Warpage optimisation using virgin and recycled polycarbonates: a case study of front panel housing

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Abstract: Plastic product are commonly produced using an injection molding process. A large amount of product can produce within a very short time. One of the defect that often being encountered in the production is warpage. By determine the appropriate parameter setting by using optimisation method, the quality of the moulded part can be improve. The warpage can be minimise but difficult to eliminate. The part can be smaller than the actual size cause by the warpage. Due to this defect will cause the plastic part difficult to be assembled. Considering the increasing application of these thermoplastic materials, the use of recycled polymers has increased too. Environmental issues, the subsequent tendency to save resources and the high costs of polymers have made the recycling an inevitable option. This study provides a scientific knowledge that will be useful to plastic manufacturing industries in injection moulding process especially by using virgin and recycle material. The parameter that being significant from the studied that been review were mostly melt temperature, packing time, cooling time and packing pressure.

1. Introduction

Plastic product produce by using an injection moulding process which is categorise as one of the manufacturing process in the industry. This study presents about the injection moulding defect of warpage as their output response. In addition, the warpage defect was highlighted because this defect can reduce the quality of the part and affect the assembly process of the product [1, 2]. Plastic housing components are widely used in many assembly manufacturing processes to produce a final product [3]. The major quality characteristics of concern such as weight, dimension and thickness for the plastic housing components are need to be taken care as to pass the quality control [4, 13]. In the other hand, mould quality significantly affects the injection moulding procedure by affecting the material quality of the product.

Many of the children’s toys and automobile parts made from this injection moulding process. Most of thermoplastic product has specified such as complex dimension, tight tolerance and high production volume. Therefore, the materials used as to make the part also examine from the reviewed journal. The
simulation analysis or experimental were also examined by review the method of the researcher used in their studies. The simulation were studied by observing the method that had been used as the optimisation method. In industry, there are many types of process other than injection moulding such as blow moulding, compression moulding and rotational moulding. Each type of them brings their own advantages but the most preferable in industry is injection moulding.

Plastic products commonly produce by using injection moulding. Within a very short time, it can produce a large amount of product with low production cost. By comparing than previously thought, plastic injection moulding is more complex. A significant economies of mass production gain as a benefit of this process [5]. The plastic parts produce defects cause by the parameter settings, inappropriate mould design and material used. Warpage, shrinkage, sink marks, short shot and so on are the defects found by many researchers [3-4, 6-8]. The quality of plastic parts produced by injection moulding can be affected by the process parameters, material of the part and part design [10]. Geometric reduction on size should be controlled as to define shrinkage, because warpage are the problem effect of the variation in shrinkage [11]. Warpage is considered as one of the most difficult defect to control and it caused by a non-uniform change of internal stress [12].

2. Injection Moulding Process
A plastic part produces by injecting the raw molten plastic material into a mould and it is called an injection moulding process. In addition, the hydraulic system is used as to run the machine. The main unit that was used in injection moulding processes were driven unit, plasticising unit and clamping unit. The clamping unit is used as to open and close the mould. This part also will move and the plate will be fixed as the mechanism has been clamped.

The plasticising unit will heat the raw plastic material until it melts. Then the molten plastic will inject into the mould by the injection unit. The drive unit provides the power for this unit. Within a very short time, it can produce a large amount of product with low production cost. Moreover, Short cycle time production, the light weight of products, and high surface quality are their several advantages and solution for plastic injection moulding industries (PIM). By comparing than previously thought, plastic injection moulding is more complex. The plastic parts produce defects cause by the parameter settings, inappropriate mould design and material used. Sink marks, warpage, short shot, shrinkage and so on are the defects found by many researchers [3-5, 6-9, 13].

The process will become more difficult in plastic injection moulding difficult when the plastic part was very thin. Besides that, a thin plastic part was a demand in the industry features [14-16]. Plastic injection, packing, cooling, ejection and process part quality control applications describe the procedure of injection moulding. The plastic product was ejected after stable of the interior cavity had achieved. This case of a defect will affect the accuracy of plastic part and quality [18]. A minimum warpage of a thin shell plastic part resulted can be accepted by an important factor which is dimensional stability. As to improve the injection moulding’s quality, warpage need to be reduced [19-24].

At the first stage of plastic injection moulding, a closed mould is injected with granular plastic resin which are melted in the barrel machine. The mould needs to be opened first so that the melted material that has been solidified in the mould can be ejected out. In order to produce higher quality of the moulded parts, an appropriate setting of injection moulding machine required and also the old design need to be reconsidered. So that the part defect can be minimised as examples shrinkage, warpage and so on. Geometric reduction on size should be controlled as to define shrinkage, because warpage are the problem effect of the variation in shrinkage [11].

3. Important Parameter in Injection Moulding Process
A thin shell is commonly used in industrial production of injection moulding. The parameters condition takes place in determining the level of warpage. As to minimise the warpage until reach the acceptable stage, the warpage need to be reconsidered in more proper way [17]. Many studied had been done over this year as to handle the warpage of a thin shell plastic products [21-22, 25-27]. There are a few parameters need to be considered in injection moulding.
Plastic parts that produce by using an injection moulding process was one of the important methods in polymer processing [10]. Another method as to reduce defects can be done by controlling the parameter settings. Previously, the trial and error approach is used onto the process parameter in PIM process relied but eventually for the complex manufacturing processes is not suitable and effective to use this approach [28-29].

Parameters such as injection pressure, mould temperature, melt temperature and injection time are taken into consideration that effecting minimum warpage. In terms of critical process parameters, Response surface methodology software can create a predictive model for warpage. In order to find the optimum process parameter values, response surface model coupled with a more efficient of genetic algorithm [10].

4. Material Used In Injection Moulding Process
Considering the increasing application of these thermoplastic materials, the use of recycled polymers has increased too. Environmental issues, the subsequent tendency to save resources and the high costs of polymers have made the recycling an inevitable option [25-27,29-30]). In order to achieve ‘go green environment’, many waste plastic part need to be recycle but the defect was hardly to be diminish. Many researcher have study about virgin-recycle blend ratio material but focus into mechanical properties as the output [31-33] and one of them use Polycarbonate as the material of the study but focus on tensile stress as the output response [34]. There are two recycled polymer that can be differentiate. First recycled polymer are come from the materials of a plastic waste that lead biological and environmental problem and second is the plastic waste that comes from the manufacturing process in a factory known as the scrap materials. Examples of the scrap materials generated by the factory were gates and runners which are discarded from a part and have a noticeable weight regarding the weight of the main part [30].

5. Optimisation in Injection Moulding Process
The most important factor contribute in warpage was shown that packing pressure factor was the result. The result also shown that filling time and gate location gave a small impact toward warpage [35]. GA also was a technique as to obtain optimal conditions. Taguchi methods [36, 37], hybrid optimisation [31], and DOE [18] show a numerical simulation on shrinkage by several of researches and the result shown that packing time as a critical factor. Packing pressure also shown as more significance other than packing time that contributes toward shrinkage of the moulded [38, 39]. For Error! Reference source not found. shows the optimisation made by using RSM, GA, PSO and Taguchi methods.
| Title | Method                                                                 | Part | Result                                                                                                                                 |
|-------|------------------------------------------------------------------------|------|---------------------------------------------------------------------------------------------------------------------------------------|
| Huang *et al.* [20] | Taguchi, response surface methodology, neural network, and genetic algorithm | ![Part Image] | Compared to the traditional methods, there exists advantages and shortness of the three models, but all of them can effectively find out the settings of manufacturing parameters through experimental designs, which dramatically reduce the number of experiments |
| Kurtaran and Erzurumlu [10] | Response surface methodology and genetic algorithm | ![Part Image] | GA has reduced the warpage of the initial model significantly. Warpage is improved by about 46%. |
| Ozelik and Erzurumlu [40] | Response surface method and genetic algorithm | ![Part Image] | Seen that maximum warpage on the thin shell plastic parts model, 0.0977 mm before the optimisation, is reduced to 0.0582 mm by 40.4% after optimisation |
| Sun and Wu [39] | Response Surface Methodology and Genetic Algorithm | ![Part Image] | Warpage has been improved by about 30%. The optimisation process reduced the warpage of the initial model significantly. |
### Table 1. The optimisation made by using RSM, GA, PSO and Taguchi method.

| Title                  | Method                                           | Part | Result                                                                                                                                 |
|------------------------|--------------------------------------------------|------|-----------------------------------------------------------------------------------------------------------------------------------------|
| Türköz et al. [41]     | Response Surface methodology and Genetic Algorithm |      | At the optimal conditions, the dimension shrinkage variation of thin-wall moulded plate has been improved about 85% and 63% in the transversal direction and the longitudinal direction, respectively. |
| Nasir et al. [42]      | Response Surface methodology                     |      | This study has applied the RSM method to estimate the optimal solutions of injection moulding process that lead to minimise shrinkage. The mathematical model of the shrinkage has been carried out to correlate the dominant injection moulding parameters of the plastic injection moulding process thick plate using ABS material. |
| Yin et al. [43]        | Neural Network Model and Genetic Algorithm        |      | For its efficiency and flexibility, the proposed BP/GA optimisation method can be used generally to optimise defects of plastic as well as other considerations such as production cycle, cost and so on during PIM. |
| Chen et al. [44]       | Response Surface Methodology                      |      | The minimum values of dimension shrinkage variation obtained at the optimal condition in both transverse and longitudinal direction were 0.081 and 0.286 mm, |


6. Summary and future works

Plastic have been widely used in industrial as to produce many parts in especially in automotive, spacecraft and other industrial products. Other than increasing of oil price, the industrial also demand in the usage of recycled plastic as to reduce cost of the production. When examining the mechanical and rheological properties of the recycle plastic, it tends to have less desirable properties compare to virgin plastic and lead to defects. Warpage hold the highest rank of factor that form warpage in plastic geometry part. Therefore, to overcome this a further study need to be done.

Other than that, an injection moulded thermoplastic part with a thin-shell feature need important procedures in injection moulding processes in industry. Then, the major factors that affect quality of thermoplastic found that machining parameters in addition to moulding material, part and mould designs produce by injection moulding. The numerous mathematical model has been proposed due to the complexity of injection moulding and many analysis studies of different stages of the injection moulding process were done [45].

Most of the researchers used RSM and GA as the optimisation method in order to minimise the warpage nor shrinkage for the plastic part. Therefore, these two optimisation methods which were RSM and GA were choose as the optimisation method in this study and it also had been used by many researchers in their studies. Less time will be spent as to find the most appropriate and optimal solution to more complex engineering problems when this GA method was applied to the neural network optimisation. This method also will help the engineering designer in reducing the cost and time spent in trial and error in the experiment and analysis. By reducing the defects occurrence to the plastic parts, the quality of the product can be increase. Therefore, optimisation needs to be determined precisely in injection moulding processes as to give a better result in producing plastic part.

In conclusion, by introduced the RSM and genetic algorithm can resulted in generate the efficient optimisation methodology in minimised a recycled plastic parts in warpage aspect. The plastic part made by using injection moulding. The successful optimisation parameters resulted in plastic part will reduce warpage defect and minimise the cost by using recycled plastic materials.

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