Warpage Optimisation On The Front Panel Housing Moulded By Acrylonitrile Butadiene Styrene (ABS) (Virgin and Recycle) Material: A Review

To cite this article: Nurul Hidayah Mohamad Huzaim *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **551** 012025

View the article online for updates and enhancements.

Warpage Optimisation On The Front Panel Housing Moulded By Acrylonitrile Butadiene Styrene (ABS) (Virgin and Recycle) Material: A Review

Nurul Hidayah Mohamad Huzaim[1], Shayfull Zamree Abd Rahim[2], Norshahira Roslan[3], Nur Aisyah Miza Ahmad Tamizi[4]

[1,2,3,4]School of Manufacturing Engineering, Universiti Malaysia Perlis, KampusTetapPauh Putra, 02600 Arau, Perlis, MALAYSIA.
[2]Green Design and Manufacture Research Group, Center of Excellence Geopolymer and Green Technology (CEGeoGTech), Universiti Malaysia Perlis, 01000 Kangar, Perlis, MALAYSIA.

E-mail: hidayah_huzaim@yahoo.com

Abstract. Injection molding process is well known in plastic molding industries. The development of this process had causes the materials used to mold plastic product to increase. However, this downside of this large amount of plastic consumption also leads to the fact that plastic waste fills the landfill. This cause researches on recycling plastic to increase. Even though injection molding process has many advantages, but the occurrence of defects on plastic part molded is one of the most important issues to be resolved. Warpage defect is one of the defect that normally occurred on molded part. This paper presents a review of the current research on the outlook of injection molding process and the effect of parameter processing on plastic molded part. The effect of parameter processing on mechanical properties of plastic mold parts with a mixture of virgin and recycled material has been numerously studied. However, studies on the physical appearance and quality of plastic mold parts by a mixture of virgin and recycled material have yet to be explored.

1. Introduction

Plastics industries were one of the fastest growing major industries in the world [1]. The amounts of the plastic products used are increasing every year. Meaning that, the widespread use of plastic materials has increased the quantities of plastic waste sent to landfills and raw material extracted. Thus, recycling of plastics is important to be implemented in order to reduce the waste of the plastic. However, the performance or quality of products made from recycled polymer will be differ from products made of virgin polymers, due to several reactions occur. An alternative to maintain the properties of product is to blend virgin material with recycled material [2]. There are many researcher studies on the impacts of percentage of recycled material by focusing on strength and mechanical properties of the part produced during injection molding process [3–5].

Material selection, part and mould design as well as processing parameters in the injection moulding process influence the quality of the plastic product and improper combination of it can lead to numerous production issues, reduce the competitive price advantage and also reduce the company's profitability [6–7]. One of the common thermoplastic used in industries and highly demand in the market in recent year is Acrylonitrile Butadiene Styrene (ABS). This is due to its mechanical

properties, dimensional stability and chemical resistance performance. In order to produce plastic product of low cost with high value, Recycled Acrylonitrile Butadiene Styrene (r-ABS) can be used as a mixture with virgin ABS.

The quality of the product is the concern of the manufacturers and customers, the high quality of the product and the great rate of production are the key to the success of the industry [7]. Thus, the identification of the root cause of the defects directly contributes to the elimination of part defects as well as the improvement of the quality of the moulded parts. Many researchers found that injection moulding parameters have an important impact on the quality of plastic parts. The researchers address injection moulding issues such as shrinkage, warpage, weld lines, sink marks, and residual stress caused by process parameters. Their study also shows that processing parameters that influenced the quality of the plastic parts are packing pressure, melt temperature and mould temperature [8–10].

In fact, it is noted that product defects, with process instability and so forth, are due to a combination of processing parameters that are not appropriate. To solve these problem, many researchers conducted injection moulding simulation experiments by using Computer-Aided Engineering (CAE) simulation software such as Autodesk Moldflow Insight (AMI), C-MOLD and Moldex3D and there are also used experimental design for the optimisations process and optimisation method such as Taguchi method, Response Surface methodology (RSM) and Genetic Algorithm (GA) [11–18].

In recent years, the performance of recycled ABS in injection moulding process has triggered many researchers to investigate the effects of recycling process on physical and mechanical properties of r-ABS and virgin ABS when mixed according to the loading ratio. Performing the injection moulding process is quite challenging as we have to control the processing parameter involves during the manufacturing process efficiently in order to obtain a high quality product.

2. Injection Molding Process

Injection moulding process is segmented into several levels, which are the operating cycles, including plasticisation, filling, packing, cooling and ejection. Initially, screw shearing and feed pipe heating the plastic pellets before plasticised it in to melt. Then, to fill the cavities of the mould, the melt will be injected into the runner system. Lastly, after cooling process, the product will be ejected out. The quality of final moulded parts is highly unpredictable due to it will be affected by several factors in the injection moulding process. Some of the significant impacts were the process parameter, design of the mould and the properties of plastic material [19–21].

Consequently, several process parameters which include the melt temperature, mould temperature, injection pressure, injection velocity, injection time, packing pressure, packing time, cooling temperature, and cooling time all potential effect the quality of injection-moulded plastic products [22].

3. Parameters in Injection Molding Process

Numerous researcher found that the injection moulding process parameters have crucial effects on the calibre of the plastic parts, most of researcher looked into the problems of the injection moulding part including the shrinkage warpage, weld lines, sink marks, and residual stress made by process parameters. From their studies, the main parameters regarding the quality of the plastic parts are packing pressure, packing time, cooling time, melt temperature, and mould temperature [8–10], [23–24]. When packing time was fixed, the warpage and shrinkage will be more affected by the cooling time compared to packing pressure. Thus, the quality of the warpage and shrinkage will be increased due to the cooling time increased [25]

Liao *et al.*[26] determining the most proper condition for a thin walled part according to shrinkage and warpage problems. A cell phone cover was applied to the analysis. Melt temperature, mould temperature, packing pressure and injection speed were required as the injection parameters. The experimental tests were built in Taguchi experimental method. Cyclone scanner, polycad and

polyworks were used to determine the shrinkage and warpage values. As a result of experiments packing pressure was found as the most important parameter.

Ozcelik and Sonat [27] investigated on the warpage and structural analysis of thin shell phone cover made of PC/ABS. Determination on the effect of warpage in different thickness values was used by the Taguchi method. From the analysis, the warpage values were found by Moldflow Plastic Insight (MPI) 4.0 software. Mould temperature, packing pressure, packing time and melt temperature were the parameters that involved in this analysis. Packing pressure was found as the main effect parameter on the warpage of PC/ABS material. Same goes to Chen *et al.*[28] they have performed similar research and they have found that packing pressure and melt temperature were used to be the most important parameters for thin shell parts.

Increasing in melt temperature of the material will not give improvement to the flow of molten material in the diaphragm gate of the thin section towards the mould cavity. Nevertheless, a concentric sprue will be the fed to the diaphragm to allow a uniform flow of molten material to all parts of the gate, so that it will make the maintenance of it much easier. This will improve the injection time in the cavity of the molten material.

Besides that, mechanical properties of product produced from recycled plastic also can be improved by optimizing the processing parameters in the injection molding process. Mehat and Kamaruddin [29] found that melt temperature with 43.34% of contribution is the most significant parameter in yield at stress of the recycled tool box tray that made of 100% recycled Polypropylene.

Wavare and Ubale [30] found that cooling time is the most influencing parameter in plastic injection moulding process of PP Homopolymer (1110MAS) in order to control the warpage and improve the quality of the manufactured specimen. Other than that, according to ANOVA analysis in the case study by Chen and Kurniawan [24], cooling time and packing time is the most significant processing parameter to obtain an optimal value for shrinkage and warpage on the moulded parts of optimisation on the processing parameters in an injection moulding process. Chen *et al.*[11], concluded that the packing time should be controlled earlier than the cooling time or increase at the same time in order to produce a better and lower warpage.

Other than that, Wang *et al.*[31] analyze on the optimization of processing parameter in plastic injection molding process with the used of Taguchi optimization method to obtain the strength compression of the product to be manufactured which is a brake booster valve body. The compression strength and curing percentage of the brake booster valve get a high impact from the mold temperature with 12% of improvement was obtain from the test. From the previous studies show that mold temperature affects the surface and strength of the plastic part. Mold temperature is the temperature required for the mold to maintain. When the mold temperature is increased, it will allow a slower injection rate without the plastic getting cold. Mold temperature will affect the surface quality, shrinkage and deformation. Higher elongation at break values during tensile test will be obtained when the mold temperature is low, as the temperature gradient during cooling is high and fast, thus prevent the crystallization processes [32]. These show that each of parameter processing influence the part produce by injection molding process. However, most researchers are investigating optimization of processing parameters to minimize the problems related to dimensional stability or mechanical properties of the part, which is made only from virgin materials that are scarcely found in recycled materials.

4. Recycled Material in Injection Molding Process

The use of recycled material in the market of plastic industry in Germany has been wandering by the designers as the product from recycled material can be rejected due to their surface appearance other than their physical properties. Nevertheless, in that respect are some countries in the US such as Michigan have been reached nearly to 100% of recycling rates where it turns out that there are others still have a concerned regarding the recycling plastic waste which changes in the market attitude [33]. There are various methods of polymers recycling such as mechanical recycling and chemical recycling has been used by most of the studies. Still, mechanical recycling is the most desirable from the

perspective of industrial point as it is low in price and reliability [34]. Thus, in order to reduce the cost of a production, the recycle material will blend in with virgin material to produce a new plastic product with minimum occurrence of defects. Besides processing parameter and percentage of mixture of virgin and recycled blends, the number of recycling process also give influence to the mechanical properties of plastic product. Plastic recycling and recovery are divided into four categories. First is primary recycling where involve in mechanical reprocessing into a product with equivalent properties. Next is secondary recycling which is mechanical processing into products requiring lower properties. Tertiary recycling is the recovery of chemical constituents and lastly is quaternary which is the recovery of energy [30].

Scaffaro *et al.* [4] studied on the effect of postconsumer content on ABS (pc-ABS) and of reprocessing cycles on the physical properties of virgin – recycled ABS blends and also with investigation on rheological, thermal and mechanical properties of injection-moulded samples after up to three reprocessing cycles. In this study, the material of virgin ABS was supplied by Starex that been used in the frame of this work and from ground phones the pc-ABS has been obtained by injection moulding of the same material. Evaluation on the effect of pc-ABS amount and number of the reprocessing steps on physical properties in this study has been done by recycled the ABS/pc-ABS blends up to three times. In investigation of rheological measurement, it showed that the viscosity of all the blends were slightly decreases has been influenced by the third reprocessing cycle as shown in Figure 1. While in Heat Distortion Temperature (HDT) test, the values for HDT of the materials does not influenced significantly by the presence of pc-ABS and the reprocessing steps up to two. Besides that, the effect on the reduction of the relaxation times has been proved on the orientation which with consequent more relevant decrease of HDT, especially at high pc-ABS amount in R3 blends. Addition of the smallest amount of pc-ABS in the first reprocessing does not give effect towards the decreasing of the tensile properties of ABS/pc-ABS blends as it did not cause significant changes. This can be said that crosslink of the PB phase and the opposite degradation effect of chain scission were give a balance results. For flexural properties, pc-ABS were almost not give any effect but slightly influenced by the recycling operations. This can be explained that the injection moulding operation was inciting the degree of orientation of ABS and this would make to the flexural stiffening of the structure since the bending stiffness is more affected by the degree of orientation in the surface layers of the specimens. Other than that, addition of pc-ABS and increasing the number of reprocessing steps were give effect to the impact resistance of the blends as it significantly decreased. Thus, correlated with the degradation of the PB phase will cause to the worsening of this property as in thermo-mechanical stresses undergone by the material during processing and to the photo-oxidation undergone by pc-ABS.
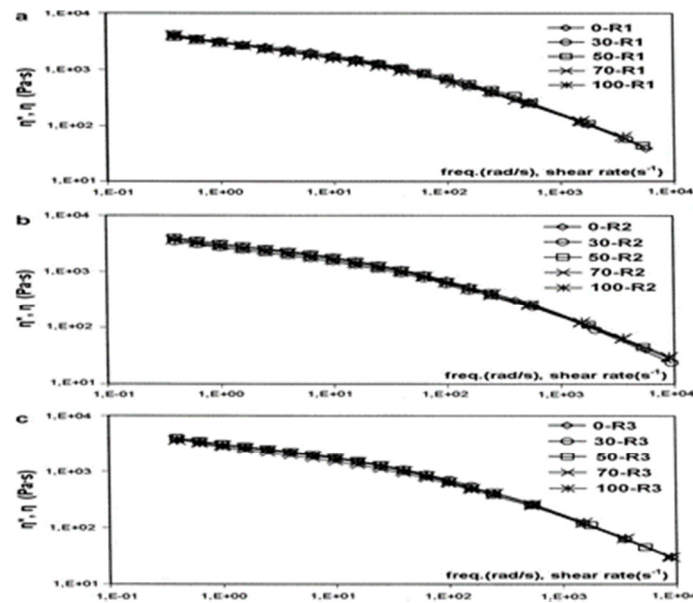
Figure 1. Viscosity curves of ABS/pc-ABS blends processed up to three times: (a) 1 reprocessing cycle; (b) 2 reprocessing cycles; 3 reprocessing cycles [4].

Kuram *et al.*[5] studied on the effect of recycling process on rheological, thermal chemical and mechanical properties on Polycarbonate/Acrylonitrile–Butadiene–Styrene (PC/ABS) and Polyamide6/PC/ABS (PA6/PC/ABS) blends. In this work, the composition of 75wt%/10wt%/10wt% was for PA6, PC and ABS, respectively, and 5wt% of compatibilier in the ternary blends of PA6/PC/ABS. The influence of the reprocessing number of the properties will be obtained by reprocessed the blends five times. After the virgin blends were moulded, only five specimens will be used for each test of the virgin samples. While the remainder of the specimen was remanufactured again as the first recycled specimen and the process were repeated to bring on other recycled specimens. From the solution obtained by the Differential Scanning Calorimetry (DSC) which been used to investigate the miscibility and melting behaviour of blends, the melting temperature and chemical structure of blends did not significantly shift. In the degradation and thermal behaviour of blends, the effects shown by Thermal Gravimetric Analysis (TGA) curves were similar to each other for virgin and recycled specimens as shown in Figure 2. From this study, it has been observed that impact strength and Melt Flow Index (MFI) of PC/ABS were decreased, while the elastic modulus increased with the recycling process. But, tensile strength and flexural properties of PC/ABS did not significantly vary by the recycling operation. Other than that, the elastic modulus and tensile strength of PA6/PC/ABS will continuous decreases as the recycling process increasing. But as the recycling process increasing, the MFI, impact strength and flexural properties of PA6/PC/ABS were increased gradually. Therefore, it can be said that recycled PC/ABS and PA6/PC/ABS can be applied as the replacement of virgin ones without a substantial alteration in the mechanical properties and it can be applied as the production in commercial functions and roles that does not need hygienic and aesthetic attributes. Lastly, it can also be concluded that the mechanical properties of PC/ABS will be improved with the addition of PA6 polymer.
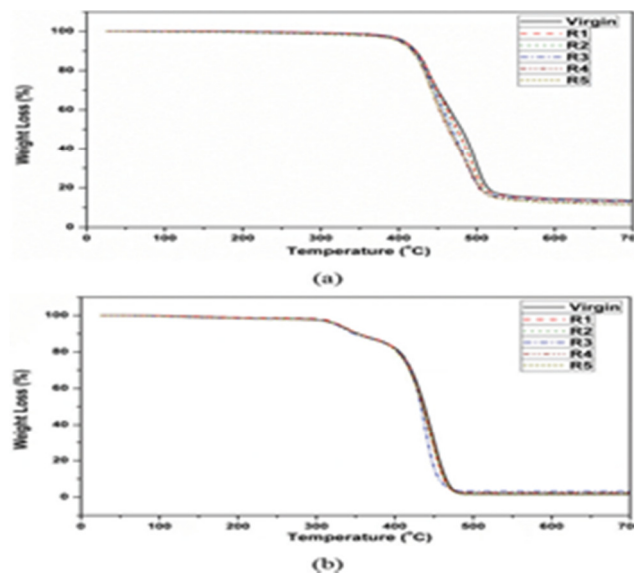
Figure 2. TGA curves for virgin and recycled specimens of (a) PC/ABS binary and (b) PA6/PC/ABS ternary blends. TGA: thermogravimetric analysis; PC: polycarbonate; ABS: acrylonitrile–butadiene–styrene; PA6: polyamide 6 [5].

From the literature review above, it is generally dependent on the purity of the recycled plastic material and the property requirements of the plastic product being produced whether or not the virgin polymer can be replaced with recycled plastic. The result obtained from most of the studies show that the impact strength and Melt Flow Index (MFI) will be decreases as the recycling process of the material increases.

5. Application of Optimization Method in Injection Molding Process

There are some researchers that have been studied on improving warpage by using different optimisation method such as Taguchi method, Design of Experiment, Artificial Neural Network, artificial intelligence, Response Surface Methodology (RSM) and mould flow analysis in order to reduce the values of warpage and the summary of the previous studies

There are numerous researchers that are using statistical method which is Taguchi method in order to improve the quality of product that been manufactured by optimising the processing parameter.

Wavare and Ubale [30] analysed on parametric of PP Homopolymer (1110MAS) in plastic injection moulding process by using Taguchi method to improve the quality of manufactured specimen which were optimising the shrinkage and warpage. The material used for the specimen was PP Homopolymer (1110MAS) with dimensions of 169×16×3.2 mm and it has been modelled in PRO/Engineer. In this study, determination of effect of injection moulding process parameters on shrinkage and warpage of the specimen will be obtained by calculating the S/N with the categories of smaller is better. The volumetric shrinkage has been minimise by 3.75% which least than experimental values. While for warpage it has been reduce to 2.54% which least than experimental value. Besides that, validation of the analysis was confirmed by the confirmatory experiment with the use of the optimal values parameter and the result obtain were close enough to the experimental values. The most influencing parameter to controlling the volumetric shrinkage was melt temperature followed by injection time, injection pressure, cooling time and holding pressure. While for controlling the warpage, the most influencing parameter was cooling time followed by melt temperature and injection time. Therefore, from the optimisation of parameters in injection moulding process by using Taguchi OA, S/N ratio and ANOVA method were very powerful tools to minimise warpage and volumetric

shrinkage and can be successfully employed to improve injection moulding of other plastic parts with complex geometry.

Nasir *et al.*[13] analysed optimisation on the processing parameters in thermoplastic processing by using RSM to obtain an optimal value of shrinkage on the moulded parts. The measurement of the shrinkage of the moulded part will be simulated by Autodesk Moldflow Insight (AMI) software and specification of injection moulding machine of Nessei NEX100 have been set in this software to get a more accurate results. The main effects of shrinkage of the moulded part will be estimated by using Design Expert 7.0 software in the process of DOE. RSM were used to define the relationship between various responses and various processing parameters. A quadratic model of the RSM will be adequate by the CCD and produced empirical model to obtain minimise shrinkage. The plastic part was used the material of ABS or called as Polylac PA-777B and the variable parameters were melt temperature, coolant inlet temperature, cooling time and packing pressure. From DOE, the main factor that contributed to the shrinkage was packing pressure, with the determination for dual and single gates as shown in

Figure 3 and Figure 4, are 0.9816 and 0.9786 respectively. While the determination coefficient, R^2 were the dual gates and single gate of 0.9854 and 0.9849, respectively. P-value were obtained from ANOVA and ensure that it was less than 0.0001 for both types of gates. Minimum value of shrinkage will be obtained from the combination software. Hence, from the investigation it can be concluded that the main factor of parameters was packing pressure and result of shrinkage of single gate were better than the dual gates.
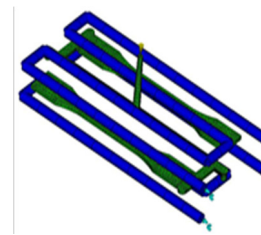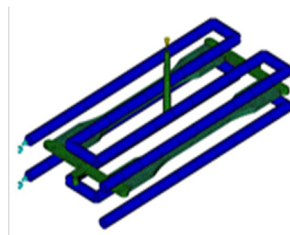

Figure 3. Mold design for dual gate [13].   **Figure 4.** Mold design for single gate [13].

Chen *et al.* [11] investigated optimisation on the processing of Plastic Injection Moulding (PIM) using Taguchi method, RSM and GA to obtain an optimal value of shrinkage and warpage on the moulded parts. Computer Aided Engineering (CAE) simulation software and DOE were used to obtain the data that can be conducted in ANOVA as the result of optimal parameter will be used in RSM. Then, by combining the GA with the regression model, the best combination of optimal process parameter will be gained. The injection moulding machine Victor Taichung VS-80 were used in this case study. The plastic part as shown in Figure 5 moulded by using PBT-2100 has been used as a case study. Length and warpage parameter combination of highest S/N ratio result for the shrinkage was 0.02% nearly closest to the target value which is 170.5. While for the Cpk, the value increased by 69.93% from 1.53 and the standard deviation decreased by 9.09% from 0.022. The average value for warpage and standard deviation were decreased by 64.3% and 38.095% respectively. Thus, this will have reduced the cost for the injection and time consuming of the mould design to the manufacturing process.

Besides that, Chen *et al.* [36] also investigated optimisation on the processing parameters in an injection moulding process using Taguchi method, RSM and hybrid GA–PSO to obtain an optimal value for shrinkage and warpage on the similar moulded parts as shown in Figure 5. Data were processed using the Backpropagation Neural Network (BPNN) combined with GA. ANOVA and DOE were used to screen the experiment setting by simulation. Then, the RSM and GA were used to determine an appropriate parameter for injection moulding process. Then, the RSM and GA were used to determine an appropriate parameter for injection moulding process. Melt temperature, injection

velocity, packing pressure, packing time and cooling time were selected as variable parameters. The closest to the target value (170.5) was the length average value of 170.483. The Cpk length value increased 67.37%, standard deviation decreased 40.91%. While for the warpage, the average value decreased 72.826% and for the standard deviation decreased 66.67%. From this result, the warpage values decrease as the length value approached the target value. Thus, the time required and injection cost to be moulded and the process of manufacturing will be reduce.
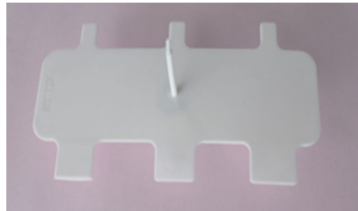
Figure 5. Plastic part [11].

Xu *et al.* [37] investigate on multi-objective optimisation of Multiple-Input Multiple-Output (MIMO) to obtain solutions for different objectives of multiobjectives of system and to find the best Pareto in injection moulding by using PSO. MIMO in plastic injection moulding process was used in optimisation process parameter to assisting engineers. The thin-walled part as in Figure 6 is use in the experiment was high density Polyethylene with dimension of 80 m length and 3 mm thickness. The parameter used in this experiment were mould temperature, injection time, injection pressure, melt temperature, cooling time, holding time and holding pressure. Hydraulic vibrating dynamic plastic injection moulding machine were used for the injection moulding process. From the results of the experiments, the optimal parameter for PSONN were maximum allowable iteration number (10K), particle population (100), parameter dimension (122), optimal value of inertia weight (0.9), error limit (0.01), ultimate value of inertia weight (0.3) and acceleration factor of 2. While for MOPSO, the acceleration factors (1.49), ultimate value of inertia weights (0.9), the population (200) and ultimate value of inertia weights 0.3. Improvement to PSONN give 32%, 43% and 14% for volume shrinkage, flash response and product weight severally. While for MOPSO, the improvement gives 42%, 30% and 21% for volume shrinkage, flash response and product weight respectively. Therefore, from this study know that PSONN model and MOPSO will provides an accurate estimations and predictions. Then PSONN will provide solution in form of Pareto-optimal with different combinations of optimal solutions. Thus, the approach that have been proposed was effective and feasible for optimisation process parameter in MMO plastic injection moulding and give advantages on costs and quality.

Figure 6. Thin walled plastic parts [37] .

Liu *et al.* [38] investigated injection conditions for a thin- walled wax pattern by using RSM to obtain an optimal value of shrinkage variation of thin walled wax in the injection process. ANOVA and DOE were used to get the mathematical model and to obtain optimal range of design space. Multiple response method was used to gain the best setting for the minimum shrink. A MPI55 injection moulding machine were used in this experimental works and to obtain the mean of the shrinkage a CMM with 0.1um resolution was used. The material that have been used as case study was

crystalline wax (KC4017B). From the experiment, the optimal value of the shrinkage was 0.98935 as melt temperature become the most significant factors with major contribution percentages 43.67% followed by the mould temperature (23.77%), holding time (16.99%) and packing pressure (11.85%). The optimal setting for mould temperature, melt temperature, packing pressure, and holding time is 74℃, 30℃ 25 bar, and 5 s, respectively were indicates from RSM analysis. Thus, from this case study it can be conclude that to reduce the shrinkage of the wax part, the relationship between the process and the shrinkage of thin walled will be describe by the mathematical regression model with the used of RSM.

Many researchers have studied on the optimization of parameter processing in plastic injection molding process, in order to reduce defects that will occur on the plastic part produce, such as warpage and shrinkage. From the studies by some researcher, it shows that by using optimization method such as RSM, PSO and GA were proven improve the quality of plastic part produced. However, most of the researchers only focused on the quality of plastic part produced by virgin material. Research on quality of plastic part produced by recycled material are still lack of supports and verifications from optimization method and real experiment data.

6. Summary and Future Works

The need of the plastic has been continuously increase together with the increases of population in worldwide which will affect the waste problem. The amount of polymer material wasted which is feed system of the part and scrap generated along the process due to quality problems is very high [39]. Thus, recycling process should be implemented for both economic and environmental reasons. To overcome these issues, there are many researcher focuses on the effect of virgin-recycled blends material and number of reprocessing cycles on mechanical properties of part produced by performing experiment [3], [29], [40–43]. While, there are only several researcher that are studied on the effect of processing parameters on the plastic part produced by virgin-recycled blends material [29], [44]. However, the effect of processing parameters and virgin-recycled blends on the quality of part (warpage) is hardly to find.

One of the most successful engineering thermoplastics is ABS [4]. ABS is widely employed in automotive industry, mobile phones, electronic equipment and other commodities[4]. Products that are made from ABS are fast moving and high demand, therefore by recycling and reuse of these blends are very important. The effect of virgin-recycled ABS blends on reprocessing cycles and mechanical properties have been extensively studied [4], [5], [43]. However, it is difficult to find a study on the effect of virgin-recycled ABS blends on warpage that affects product quality. The comparison should be done between the plastic part produced by virgin material and various combination of virgin and recycled material in term of the length, width and depth. In addition, most of them are using real experimental work without the aided of simulation software and artificial intelligence optimisation method.

The moulded plastic parts may not be functional or visually acceptable if there is warped occurred on the plastic parts [45]. It will affect the assembly process of the plastic part. The formation of warpage in plastic moulded part is influenced by the most influential processing parameter in the injection moulding process [13], [27], [45–47]. Thus, formation of warpage will affect the productivity, quality and cost of production in plastic injection moulding industry [31], [37], [47–48]. Traditionally, trial and error approach are often used in plastic injection moulding process in order to obtain an optimal combination of processing parameter. To overcome these issues, the use of artificial intelligent methods in simulation studies and experimental works will reduce both the time consuming and cost, while producing the best quality of product. Most studies based on optimization method have been concerned with optimizing processing parameters to minimise the warpage of the part produced using virgin materials only. However, there are lack of research on optimising processing parameters in order to minimising warpage compared to the mechanical properties of plastic parts produced by combination of virgin and recycled material, especially on ABS.

References

[1]   A. Mohd *et al* 2016 *Indian J. Sci. Technol.* **9** 9.
[2]   S. Chen *et al* 2011 *Polym. Plast. Technol. Eng.* **50** 306–311.
[3]   C. Meran *et al* 2008 *Mater. Des.* **29** 701–705.
[4]   R. Scaffaro *et al* 2012 *Eur. Polym. J.* **48** 637–648.
[5]   F. Kuram *et al* 2015 J. *Elastomers Plast.* **48** 164–181.
[6]   T. C. Chang *et al* 2001 *Polym. Eng. Sci.* **41** 703–710.
[7]   N. C. Fei *et al* 2013 *ISRN Ind. Eng.*
[8]   W. C. Bushko *et al* 1996 *Polym. Eng. Sci.* **36** 658–675.
[9]   K. M. B. Jansen *et al* 1998 *Polym. Eng. Sci.* **38** 5.
[10]   M. C. Huang *et al* 2001 *J. Mater. Process. Technol.* **110** 1–9.
[11]   W. C. Chen *et al* 2015 Taylor & Francis Group, London, 341-346.
[12]   W.-C. Chen *et al* 2016 *Int. J. Adv. Manuf. Technol.* **83** 1873–1886.
[13]   S. M. Nasir *et al* 2016 *Key Eng. Mater.* **700** 12–21.
[14]   Fathullah M *et al.* 2011 *International Review of Mechanical Engineering* **5(7)** 1278
[15]   Fathullah M *et al.* 2011 *International Review of Mechanical Engineering* **5(7)** 1189
[16]   Nasir S M *et al.* 2012 *International Review of Mechanical Engineering* **6(3)** 372
[17]   Nasir S M *et al.* 2013 *International Review of Mechanical Engineering* **7(5)** 977.
[18]   Isafiq M *et al.* 2016 *MATEC Web of Conferences* **78** 01084.
[19]   K. Park 2005 *Polym. Plast. Technol. Eng.* **43** 1569–1585.
[20]   H. Li *et al* 2007 *Int. J. Adv. Manuf. Technol.* **32** 927–931.
[21]   M. Kurt *et al* 2010 *Int. J. Adv. Manuf. Technol.* **46** 571–578.
[22]   H. Kurtaran *et al* 2006 *Int. J. Adv. Manuf. Technol.* **27** 468–472.
[23]   M. H. Othman *et al* 2012 *Appl. Mech. Mater.* **229–231** 2536–2540.
[24]   W. C. Chen *et al* 2014 *Int. J. Precis. Eng. Manuf.* **15** 1583–1593.
[25]   L. Balasz, I. Sors, 1989 Design of. Hungary: Elsevier Science Publishers.
[26]   S. J. Liao *et al* 2004 *Polym. Eng. Sci.* **44** 917–928.
[27]   B. Ozcelik *et al Mater. Des.* **30** 367–375.
[28]   C. P. Chen *et al* 2009 *Expert Syst. Appl.* **36** 10752–10759.
[29]   N. M. Mehat *et al* 2011 *J. Mater. Process. Technol.* **211** 1989–1994.
[30]   A. Wavare *et al* 2016 *Intro to Stats.* **4** 323–331.
[31]   Y. Q. Wang *et al* 2014 *Mater. Des.* **56** 313–317.
[32]   R. Navarro *et al* 2008 *J. Mater. Process. Technol.* **195** 110–116.
[33]   A. F. Ávila *et al* 2003 *Polym. Degrad. Stab.* **80** 373–382.
[34]   K. Hamad *et al* 2013 *Polym. Degrad. Stab.* **98** 2801–2812.
[35]   J. Hopewell *et al* 2009 *Trans. R. Soc. B Biol. Sci.* **364** 2115–2126.
[36]   W. Chen *et al* 2016 *Int J Adv Manuf. Technol.* **83** 1873–1886.
[37]   G. Xu *et al* 2012 *Int. J. Adv. Manuf. Technol.* **58** 521–531.
[38]   C. H. Liu *et al* 2014 *Appl. Mech. Mater.* **607** 185–192.
[39]   C. Javierre *et al* 2007 *Waste Manag.* **27** 656–663.
[40]   D. Bhattacharya *et al* 2014 *Procedia Eng.* **97** 186–196.
[41]   D. Marulanda *et al* 2014 *J. Elastomers Plast.* **46** 355–367.
[42]   J.Abdullaha *et al* 2016 *Int. J. Mech. Prod. Eng.* **4** 76–81.
[43]   S. D. Mancini *et al* 1999 *Mater. Res.* **2** 33–38.
[44]   F. Gu *et al* 2014 *Mater. Des.* **62** 189–198.
[45]   S. Taghizadeh *et al* 2013 *IJST, Trans. Mech. Eng.* **37** 149–160.
[46]   N. M. Mehat *et al* 2013 *ISRN Ind. Eng.*
[47]   Q. H. Sun *et al* 2013 *Appl. Mech. Mater.* **377** 133–137.
[48]   C. Chen *et al* 2009 *Int. J. Adv. Manuf. Technol.* **45** 1087–1095.