Optimization of Shrinkage and Strength of the Molded Part Produced using LDPE (Virgin and Recycled) material: A Review

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Abstract. The injection molding process is seen to be one of a versatile and important manufacturing process. This is due to its ability in producing product with complicated design and producing part in large quantity. The advantages of this process had caused an active research on its quality improvement and process. This paper reviews the part quality issues happened in the processes. Along with the reviews of the parameters which affects the defects occurrences. Besides that, recycled plastic application in injection molding process was also reviewed. At the end, it is seen that as compared to other thermoplastic materials, LDPE is least popular and discussed as a subject of research. This paper organizes past research studies in few categories firstly the defects occurrences in plastic injection molding, followed by application of recycled material in molding plastic part, application of optimization method in injection molding, next the application of LDPE material in molding plastic part. Lastly, this paper ends with a brief summary and future work.

1. Introduction

Plastic materials have a wide range of ability in producing part with various shapes and complex design. Things such as water bottles, food container which comes in various shapes, color and sizes are made possible with the plastic injection process. Hence causing the products made of plastic to be high in demands. Since the plastic injection molding involves manufacturing part in mass quantity, thus the amount of part rejected and go to waste is abundance in a day. The discard of part can cause waste in money, time and also effort in the improvement of the part. Hence, a simple definition to the quality improvement is the ability to reduce the amount of waste.

Besides quality improvement, the recycling of plastic may also help in reducing the waste. As mentioned previously, the discard of part can cause loss in money, hence it is seen that the ability in reusing this unwanted part may become a big advantage to the manufactured. However plastic recycling was restricted by restrictions of standards, specifications and trust issues on the use of recycled plastic. Most of this happened because of perception that recycled plastic produce a really bad quality of part as compared to the use of virgin material.
Although the use of recycles raises a lot of doubt to the consumer and manufacturer, researchers on the other hand show interest in studying its potential. Besides that, it is seen that many researches focus on the improvement of the recycles plastic properties in material perspective when applied the additives. The cost of applying additives to recycled materials however become a main considerations as the manufacturer had to paid more for the manufacturing cost even though the recycles improves due to the additives help [1]. Thus, another alternative arises from the manufacturing perspectives, where process parameters settings control involves.

There are numbers of factor that can affect a quality performance of a molded part as shown in Figure1 below. This includes factors such as the mold design, material selection, machine parameters and operator and working parameters. These variables in the process can easily results in waste due to not fulfilling the quality specification [2-5].

![Fishbone diagram on parameter affecting the defects of part](Image)

In practice, when the part mold is secure to the machine, the molding engineer has to set the parameters of the machine as refer to the material specifications provided by the material’s supplier, sometimes lead to the extent based on the mold designer and also his experience. Next, the engineer needs to performed mold trial procedure where the tested parts were produced and the machine parameters were adjusted. This trial and error continue until the design specifications of the molded part fulfilled. Such procedure does not only require long time but also has to be repeated for different materials, machine and mold specifications. However, these steps are necessary in order to achieve a quality part. Hence it is seen that due to its complex manufacturing process, the trial and error process that is costly and yet time consuming was not suitable to be applied. Besides that, trial and error is seen to be impossible in verifying the real optimal processing settings [7].

2. Defect Occurrences in Plastic Injection Molding Process

As the mold was fully filled by the injected plastic, the screw stays stationary in a while in order to keep the plastic inside the mold under pressure (holding time). In this stage additional plastic material was injected into the mold, thus compensate for shrinkages happened which caused by the cooling effects. Hence it is seen that parameters involved in injection molding process can potentially effect in shrinkage occurrences. All of these factors are worth to pay attention to in identifying its influence on shrinkage [8].

Once most of the plastic has been injected by applying the injection pressure, next the machine will shift to inject the material by packing pressure. This pressure applied allows a final filling into the cavity by packing the molecule together. Packing pressure continue to apply until the gate freezes. A study on a casing of a cellular phone was performed by S.J. Liao et al. [9] recorded that the most influential
process parameter is the packing pressure. It is discussed in his study that as the packing pressure high, melted material can squeeze into the cavity and compensate the shrink volume as the thermoplastic resin cool down. Besides that, mold temperature also seen as one of the influential factors. The study seen that a high mold temperature results in the plastic in the cavity to cool down from a high temperature condition. Thus, the finished product has higher density and low shrinkage. A similar results was achieved by [10], a high holding pressure does seen to cause shrinkage reduction in both parallel and normal flow direction.

Another study performed by A.Wavare and S.Ubale [11] in the year of 2016, investigated the effect of applying the parameter optimization on the warpage and shrinkage of plastic part. The optimization techniques applied in the study is Taguchi. In the study it was found that the melt temperature influenced the shrinkage occurrences the most. Meanwhile for warpage, the holding pressure was the most influential parameter. Similar results was achieved by few other researchers [12-13], where the melt temperature was one of the most important factor affecting the shrinkage and warpage of part. Shrinkage of plastic part was also studied by G.J. Kang [14]. Besides that, Taguchi optimization was also applied in this study. Four parameters were selected for the study. They are the melt temperature, mold temperature, cooling time, packing time, and lastly packing pressure. In the study, it was found that the most affecting parameter for shrinkage is the injection time. While for warpage is the cooling time. By applying the optimal parameter settings, it is seen that the quality characteristic of shrinkage and warpage improved.

Not only the shrinkage, but a weld line can also affect the appearance of the molded part. Beside that the weld line also may affect the strength of the produced part. One of the advantages of the injection molding method is a multi-gated mold and insert can be designed to fit the design of the part needs and shapes. By this means that a formation of weld lines during the process of injection molding is unavoidable. When the design of the products causes the option of changing the weld lined location by changing the gates to be impossible, it can lessen the weld line visibility by adjusting the processing condition.

A study on molded plastic strength was studied B.Ozcelik [15] in year 2011. 3 parameters were studied, they are packing pressure, melt temperature and injection pressure. Properties such as the extension at break, charpy impact strength and maximum tensile load were investigated. Taguchi orthogonal array was employed and optimal conditions of each response were recorded. Based on the regression analysis, shown a linear relationship between molding parameter with the mechanical properties. It is also seen that injection pressure and melt temperature were highly affected the maximum tensile load and extension at break. While, the charpy impact strength is the melt temperature and packing pressure.

Melt temperature and packing pressure was also seen to be the an influential factors in a study conducted by Dar et al [16] on Polycarbonate. The study seeks to measure yield and post yield effect by differentiating the process parameters of injection molding. The variable studied were mold temperature, injection velocity, cooling time, melt temperature and packing pressure. It was seen that an increase in melt temperature from 533 K to 593 K caused an increased in yield stress. Besides that, this study shows that when the flow velocity increases the material viscosity reduces. In every change on the melt temperature value, the mold temperature was held constant at 303K. These differences in temperature reduce the material’s residual stress. In each test conducted, the yield stress lied in the range of 0.21 to 0.35 MPa. Upon reaches the value of 343K, the reading was constant but was increased from 343K until 413K. It was observed that, an increased in packing pressure of 30MPa, the yield stress was increased at 1.1MPa.

Based on the few mentioned researchers, it can be concluded that a different process parameter has different effect on the quality of plastic part. Therefore, achieving the suitable process parameter settings is seen to be an important task in the molding industries. Trial and error method had been a popular applied to find a suitable molding condition. Even though this method has been applied for many years, however this method depends on the operator experience and time consuming. Achieving an optimal process condition for a part is a major advantage since it can improve not only the quality but also reducing the amount of waste. In the industries, lesser waste means the manufacturer can save money on
producing new quality part. It is seen that, not only by maintaining good quality, ability to fully utilizing
the material can also be an advantage to the manufacturer.

3. Application of Recycled Material in Molding Plastic Part

Thermomechanical degradation affects the chain breakage of the material’s polymeric chains. This
happens due to the radical chain reaction which leads to a series of changes in the structural properties
of the polymers. Changes on the material’s structural properties worry the manufacturer to apply the
recycled plastic in molding new part. This due to the reason that, quality of the molded part might
reduce.

A research conducted by Aurrekoetxea et al [17] investigate Recycled Polypropylene (PP) fracture
behavior on injection molding induced morphology. The material used was Polypropylene (PP). The
steps of recycling were conducted up to six times in simulating the recycling process. The specimens
were tested on its microhardness, and hardness. Besides that, fracture test was also conducted and
fracture surface was also been analyzed. The test revealed a higher elongation caused the core breaks,
while at small elongation level the skin layer of the specimen broke. Besides that, it was also seen that
first recycled PP to six times recycled PP specimens fractured brittle. Charpy specimens broke
immediately as the maximum load was achieved and at small deflections. As compared to recycled,
virgin shown higher plastically deformed zone at crack tip and micro-hardness values. Otherwise, in
both materials, skin layer has shown lower micro-hardness values and smaller plastic zone extension
than the core region.

Another study on reprocessing cycle of recycled material was performed by R. Scaffaro et al. [18]. In
rheological test conducted, it was determined that viscosity of ABS compared to the virgin material until
two processing cycle was not substantially different. However, in the third cycle, it was seen that the
viscosity was reduced slightly. In the first reprocessing, the material tensile decreased. Although the
amount of pc-ABS added increased it did not have any significant changes. In contrast, the materials
flexural properties were slightly affected by the recycling operations, and were almost did not influenced
by the amount pc-ABS added. Meanwhile, there was decreased in the impact resistance when the
reprocessing cycles increased and by increasing the amount of pc-ABS. The worsening of the property
was related with the degradation of the PB phase, likely due to thermo-mechanical stresses.

Based on the study, it is seen that degradation of plastic does highly affected by the number of
reprocessing operations. Thus, further affect the recycle plastic’s rheological and also mechanical
properties of the molded part. Although it is proven by few researches that reprocessing the plastic few
times affect the part quality, the research of plastic recycle ability doesn’t stop there. Other research
found that applying an ideal recycle to virgin ratio is acceptable and safe depending on its application. In
some company they completely ban the use of recycled material or placing a maximum limit of recycled
material added to the raw material.

In 2008, C. Meran et al. [19] conducted a study on the recycling possibility and using recycled
polypropylene (PP), high-density polyethylene (HDPE) and low-density polyethylene (LDPE) in
relation to the tensile strength exchange ratio. The test specimen in this study is shown in the Figure 2.17
below. The recycled material used was mixed with the virgin materials in different proportions and were
examined by using the tensile test. In the experiment, the test specimens of each mixture were broken and
the average values were the recorded. Besides that, the material usability was observed and its
optimal points were searched. The tensile strength decreases to 15% as the mixture proportions of LDPE
decreases. While for HDPE, as the mixture proportion decrease, the tensile strength decreases to 5%.
Lastly, high and low density polyethylene mixture decreases, the tensile strength decreases to 3%.

C. Javierre et al. [20] conducted a study on the effect of percentages of the recycled material on
mechanical behavior and the safety factor of the part. The HDPE recycled material was sorted into
different percentages of 20%, 40%, 60%, 80% and 100%. The characteristic of the formed specimen
from raw and recycled were both tested using tensile machine. CAE tool was utilized in studying the
effect of the recycled percentage on mechanical tests. Simulation analysis was performed with the FEM
model of the container’s part, with fully recycled material and also with raw material. The addition of
different recycled material percentage during injection molding processes implies an important change in the stiffness and safety factor. 100% recycled HDPE blend decreases strength up to 40% in regard to raw HDPE. An important factor to be remembered was there must be an increase in 20% of material strength for it to perform its functionality well with fully made of recycled material. Lastly, with 40% of recycled material, minimum effect was achieved on safety factor in regard to stress.

In 2014, D.Bhattacharya and B.Bepari [21] conducted a study on the feasibility and recyclability of polypropylene (PP) in injection molding based on grey relational analysis. The parameters studied were the ratio of virgin to recycled, injection temperature, injection pressure and injection speed. To obtain the elongation at break and tensile strength value, universal Testing Machine was used. VSP (Vicat Softening Point) was determined by using microprocessor controlled HDT/VSP apparatus. While, the density of PP sample was measured by using Dhona. In this research, the number of experiments conducted was reduced by using the box-behnken model. While, in order to obtain the response’s weight, a grey entropy method was used. It is seen that, the most contributing factor is the injection speed, while the least contributing factor is the injection temperature. Up to 5% of adulteration the product maintains the properties tantamount to the virgin one. Lower level of injection temperature and lower level for injection pressure and higher level of injection speed must be selected with a virgin to recycled ratio of 95:05.

The addition of recycled material percentage to raw causes change in the mechanical [20] and also the material rheological behavior [22]. It is seen that the utilization of a certain recycled material gave a minimum influenced to the safety factor or sometimes gave a less significant influence on the material’s behavior. However, it is also seen that when a percentage of recycled was applied along with a specific parameter setting can also produce a good property as the raw material.

4. Application of Optimization Method in Plastic Injection Molding

Optimization of injection molding parameters has proven to be effective in many studies conducted in improving the quality appearance of product. Warpage and shrinkage had seen to be reducing when applying the optimization method. The optimization method was not only limited to the use of Taguchi even though it is popularly applied. However, the introduction of other optimization method was seen to achieve even a better part quality.

A study was conducted by Chen et al. [23] on the warpage analysis of plastic spur gear. Five processing parameters, the holding pressure, injection pressure, holding time, plastic temperature and mold temperature were studied. In this study the Taguchi and RSM optimization method were implemented. Taguchi concluded the holding time as the most influenced factor. By comparing both method results, it is seen that RSM produced the best optimal combination. They were packing time of 19s, packing pressure of 70MPa, injection pressure of 105s, plastic temperature of 190°C and lastly mold temperature of 60 °C. In measuring the accuracy between the experimental and simulation, the error count was only 2.7% difference.

GA optimization was performed by S.Yoewono and A.Kaswadi [12] in producing the optimum plastic injection process cycle time. Full factorial design was used with 4 factors and 2 levels. The factors were melting temperature, holding pressure, injection pressure, and holding. While the responses studied were cycle time, wall shear stress and volume shrinkage. Moldflow simulation was used in running all 16 run orders and the response was produced. In order to produce the relation between factors with cycle time, a linear regression analysis was conducted of the cycle time responses. The optimum parameters were determined by optimizing linear regression equation in GA. The result for both simulated and experiment were compared. The best parameter settings determined by GA were holding pressure of 16MPa, injection pressure of 20MPa, melt temperature of 180°C and holding time of 8s, with 14.11 of the cycle time. By simulation both wall shear stress and shrinkage did not change significantly and stay below allowed maximum limit.

S.Sudsawat and W.Sriseubsai [24] performed an optimization method in minimizing the shrinkage of wrench specimen and also the warpage. In the study, Response Surface methodology (RSM), Genetic Algorithm (GA) and Firefly Algorithm (FFA) was applied. 7 parameters were studied, they are mold
temperature, injection pressure, melt temperature, packing pressure, packing time, flow rate profile and cooling time. RSM was applied in stabilizing the experimental run. Meanwhile, the GA and FFA were applied in minimizing the volume shrinkage as well as the warpage. It is seen that cooling time and melt temperature is the most influenced factor for both shrinkage and warpage. At the end of the study, it is concluded that FFA optimization produced better results than the GA method.

Referring to the previous section, it is seen that most research on the plastic recycling focused on improvement of the recycled plastic properties from material perspectives. Hence another alternative from manufacturing perspective arises. In few, process optimization was seen to have a decisive influence on quality improvement of molded part, but its influence is underestimated. Few studies were performed in investigating the influence of the injection parameters on mechanical properties and on the defect occurrence [25-26].

In 2011, N.M. Mehat and S.Kamaruddin [13] employed the Taguchi method in enhancing the mechanical properties of recycled plastic. By applying L9 Taguchi Orthogonal Array, the trials were reduced to nine trials with five repetitions. Four parameters for this study were, packing pressure, packing time, injection time and melt temperature. The material used in this research was the Polypropylene (PP), injected by a Battenfeld TM750/210 molding machine. In obtaining the influential processing parameter on the quality of product and the optimal process parameters, the S/N ratio and ANOVA was conducted. The outcome of this study shows that, a 75% to 25% of recycled to virgin polypropylene product has better flexural modulus as compared to the virgin polypropylene. While the same product decreases 3.4% in flexural strength. Thus, shows that by optimizing the processing parameter can elevate the degradation in the mechanical properties of recycled plastic.

Another study on PP was performed by F.Gu et al [27]. The influence of recycled plastic proportion and processing parameters on the mechanical characteristic was investigated. Four factors were studied in this research, they were mold temperature, packing pressure, melt temperature and injection speed. The L9(34) orthogonal array was applied which further reduce the amount of experiment conducted from 81 to 9. It was observed that, lower melt temperature achieved a good flexural result and achieved a good outcome in most mechanical performance and a good result obtained with higher packing pressure. On the other hand, better result was obtained for tensile properties when a lower packing pressure was used. From the experiment indicate that, the best blending composition for adapting to recycled plastic content was PP90. Which, shown to be an improvement on 100% virgin PP. Besides that, tensile and flexural properties improved from 0.36% to 2.66% as 10% recycled PP was added, without significantly deteriorated the impact properties (loss about 2.06%). This study shows that, if the controlled variable changed, the mechanical properties or improvement on the specimen may also be changed.

J. Abdullaha et al. [28], studied the effect of process setting on the quality characteristics of plastic tray. This study employed the Taguchi orthogonal array. The quality characteristic tested was the tensile strength, flexural strength and shrinkage. Results optimal process settings in optimizing shrinkage were packing pressure of 70%, melting temperature of 513.15 K, injection pressure of 15 MPa and packing time of 30 s. Next in optimizing tensile strength the optimal settings were, packing pressure of 85%, injection pressure of 15 MPa, melting temperature of 518.15 K and packing time of 30 s. Lastly, the optimal settings for flexural strength were, packing pressure of 80%, injection pressure of 14 MPa, melting temperature of 518.15 K and packing time of 10 s. It was determined that, the most significant parameter that effect the mechanical properties and shrinkage were the packing time. Lastly, for the tensile strength, the top contributor determined was the melting temperature. Through confirmation seen that the quality characteristic of the material has almost similar behavior with expected performance and the percentages of errors are less than 10%.

Taguchi optimization had been used as one of the statistical tools that helps to find the suitable parameters condition as seen in few mentioned researches. The application of this method had attracted the attention of many researcher in the past 20 years, and in recent years it has been vastly applied in various field such as in mechanical component design [29], process optimization [30-31] and also in manufacturing system [32]. This popularity was gained due to its practicality in developing a
high-quality system which provides less experimental run with an optimal process setting of the control parameters. Thus, prove the points that statistical tools are suitable and efficient to be applied in improving the molded part quality. Not only even though Taguchi able to provide optimal settings, few researches show a better optimization results by other statistical tools. Such as the artificial intelligence method of Particle swarm optimization and Firefly Algorithm (FFA). These tools which adopt the natural behavior have slowly gaining its reputation in parameter optimization study. However, the application of the artificial intelligence tool was hardly found in optimizing the parameter for a recycled material.

5. Application of the LDPE Material in Molding Plastic Part

Polyolefins (PP, HDPE, LDPE) are massively used thermoplastic material through the world. Due to its various applications in producing many types of product. Data from 2003 recorded approximately 21.37 million tones consumed the three polymers in Western Europe alone. Which constitute about 56% of total thermoplastic[33]. Since the three thermoplastics are applied in various amount of application, thus clearly show how important and valuable study on these materials.

Study on Low Density Polyethylene (LDPE) was performed by S.K. Lal and H. Vasudevan [34] which optimized the injection molding process parameters of low density polyethylene(LDPE). Taguchi method is used to investigate the effects of melting temperature, injection pressure , refilling pressure and cooling time on the shrinkage of LDPE. Signal to noise ratios were used for determining the optimum combinations of the process conditions for shrinkage. The result showed that melting temperature of 190 °C, injection pressure of 55 MPa, refilling pressure of 85 MPa and cooling time of 11 s. gave minimum shrinkage for LDPE. Cooling time was found to be most effective factor for LDPE followed by refilling pressure. Injection pressure was found to be the least effective factor. From the findings, it can be stated that Taguchi method is a powerful tool for evaluating the defect of shrinkage in the plastic injection molding.

The study on LDPE material doesn’t stop there, the potential of recycled plastic applied in manufacturing part was studied by many researchers. Their shows the ability of the recycled and most of study was conducted on evaluating the recycle material’s mechanical ability.

In 2008, C. Meran et al. [19] conducted a study on the recycling possibility and using recycled polypropylene (PP), high-density polyethylene (HDPE) and low-density polyethylene (LDPE) in relation to the tensile strength exchange ratio. The recycled material used was mixed with the virgin materials in different proportions and were examined by using the tensile test. In the experiment, the test specimens of each mixture were broken and the average values were the recorded. Besides that, the material usability was observed and its optimal points were searched. Based on the experimental results, it is seen that, the recycled material of all three material are 100% usable. PP was seen to be the most succeed to be fully recycled. This because the tensile strength for PP decreases to only 15% as compared to the virgin. While for HDPE, tensile strength decreases to 24%. Lastly for LDPE, the tensile strength decreases to 36%. The result also recorded that all three material doesn’t have problems during pressing and it even achieved to 100% of the pressing level.

Similar study was performed by Bajracharya and Manalo [35] in 2014 where the mechanical properties of recycled material was studied. The recycles plastics used in this study were recycled low density polyethylene (rLDPE), recycled high density polyethylene (rHDPE), recycled polypropylene (rPP) and other propriety additives. The variables for this study were the temperature across the barrel and also melt temperature. The plastic pallets were injected with barrel temperature of 220°C, 210°C and 205°C for front, mixing and feeding temperature. The temperature of melt was set for 23°C, 30°C, 40°C, 60°C, 80°C and 100°C. It is seen that the thermal stability of mixed recycled plastic is similar to virgin plastic. It is also seen that there was reduction of tensile strength for PP as compared to MRP when the temperature as around 60°C. It was seen that, an increased in temperature from 23°C to 100°C caused the modulus and tensile strength reduced at a significant amount of 75% and 80%. Besides that, there is a higher reduction of the tensile modulus than tensile strength at elevated temperature.
Even though the addition of additives able to improve a certain wanted properties of the recycled, and few researches had been performed on the addition of fillers, however there is an increase in cost [22]. In addition, a complex relationship between processing parameters needed numerous repeated experiments, which is seen to be time consuming and costly. Thus, it seen that the statistical methods are efficient to be apply in finding an optimal processing condition and shorten the time consumed. Most of the research on recycled which applied the optimization method used the Taguchi [13-28]. Indeed the Taguchi able to lessen the trials numbers in experiments. However, in many studies on processing condition optimization of the virgin material, artificial intelligence had started to be applied. Its ability had been proved by many optimization study [36-37]. However, for LDPE material, the study performed by using artificial intelligence is hardly found for both virgin and recycled material.

6 Summary and Future Works
Plastic materials have wide range of usability, hence causing its application to increase in demands year by year. This past decade had witnessed the injection molding fields continue to grow and more developed. Thus, it is seen that a review on the field would help researchers to have ideas on identifying the path to further improve the injection molding.

The review highlights the effects of injection molding parameters on the part quality. Although it can be solved by finding a suitable parameter setting, however the trial and error method which based on the molder’s experience is costly and time consuming. In order to overcome the effect on cost, few researchers investigate the potential of using the recycle material. The usage of recycled material derived from rejected parts and gating system is seen to be cost efficient. However, the reprocess of this recycled plastic is seen to have an issue to its mechanical properties. Few companies set a specific limit on recycled percentage. Few of the reviewed study also highlight a safe recycle percentage can be achieve depending on its application. Where it seen that for different material, shape of design and application the recycle percentage has to be adjusted. Hence finding the efficient way of achieving the right percentage is beneficial. Similar to virgin, process parameter on recycled material such as melt temperature also affect the manufactured part quality.

In order to overcome the appearance as well the recyclability issues, the optimization tools is seem to be one of the best solutions. Not only it able to improve the shrinkage happen on the molded part, but in certain cases also help on achieving a safe molding setting by using the recycled material. However, most optimization method applied on recycled was the Taguchi. Which in most studies it delivers a really good results, unlike the virgin material, the application of Artificial intelligence (AI) is hardly found on recycled material. Although Polyolefins (PP, HDPE, LDPE) are studied in many researches. However, among the three materials, study on LDPE is hardly found. Hence it is seen that. LDPE material can also be studied in future works. Also, the potential of AI on recycled material should also be studied, so it can be applied in the manufacturing field.

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