Experimental Study of Packing Time and Melt Temperature Effects on Shrinkage of a Thin Sheet Made of Wood-HDPE Composite

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Abstract
Injection molding is one of the most common processes which are used for manufacturing different plastic parts. This method includes 3 continuous steps: filling of the mold, cooling and driving the part out. A wide range of plastic and Non-Plastic materials can be used as raw material in this process. One of the most important advantages of this way of production is that it is very economic. In this study packing time & melt temperature effects on shrinkage of a thin sheet made of wood-HDPE composite has been investigated. Based on previous works, defining a thin sheet means the ratio of length to thickness of it should be at least 100. The results were obtained after manufacturing of different pieces and 3D scanning using CATIA software package. Finally the results were represented and compared using EXCEL. Main parameters such as packing time and melt temperature were studied in 4 levels. The method used for designing of experiments is full factorial. The main goals in this study were to reduce the number of defected parts and recommend appropriate process parameters to producethin sheetsmade of wood-HDPE composite. Having this information will result in saving time and reducing the production costs. It has been seen that by increasing the packing time and lowering the temperature, the shrinkage was reduced.

Keywords
Injection Molding, Shrinkage, Wood-HDPE Composite, Melt Temperature, Packing Time

1. Introduction

Since 90 years ago wood particles have been used as filler in polymer composites. Nowadays wood and plastics are taken into account more and more. More than 85% of market for wood-plastic composites (WPC) belongs to North America and Europe is the second consumer of it [1]. WPC as a modern concept witnessed a renaissance in Italy in 1970s. In that time, wood-plastic composite with 50% wood was used in specific cases such as door panels in automotive industry and other similar fields. It was after a while when it entered to North America, in 1990s. At the beginning of the current century, many other countries such as India, Singapore, Malaysia, Japan and China began to use it [2]. One of the other goals in this study is to investigate the possibility of using wood wastes in the shape of powder resulting from sanding process of MDF, in this composite. Based on the low price of this kind of wood particles, using it can lead us to a very cost effective material. Another purpose of this study is doing more investigation on physical characteristics of wood-plastic composite.

One of the most important production processesfor polymers is injection molding. This technique is useful for producing parts with complex design and one of its advantages is the high variety of parts which can be produced in this process. Other merits are easy automation, brief manufacturing and manufacturing parts with high accuracy. In some cases, selecting the right volume percentagefor materials and additives in wood-plastic composition in order tocompletely fill the cavity is the main

problem. To solve it, wood filler percentage and consequently the viscosity should be reduced. The differences between part dimensions and cavity dimension cannot be prevented if plastics are used in the injection molding process. These differences are defined as shrinkage. During injection of plastic into mold, it has a high temperature and brief cooling eventuates in thermal residual stress that results in change of part after ejecting from mold. The ratio of difference between a specific dimension in cavity and the same dimensionon part to that specific dimension in cavity itself is defined as shrinkage. It can be written as follow [3]:

$$S = \left(\frac{L_{cavity} - L_{part}}{L_{cavity}}\right) * 100 \quad (1)$$

In whichL_{cavity} is cavity length andL_{part}means the longer length of the part.
The main reasons for excessive shrinkage are low injection pressure, low cooling time, high melting temperature, high mold temperature or low secondary pressure [3].
Also using the results of this study can help selecting better values for parameters such as melt temperature, packing time and etc. in manufacturing of this kind of composite which can end to minimum shrinkage in final products. Some previous studies reported that by changing the process conditions, the final characteristics of the wood-plastic composite can be improved. They examined injection-molded polypropylene (PP)-based wood–plastic composites and investigatedhow the rate of moisture absorption can be reducedby changing extruder operating conditions [1]. In another study Adhikary et al. showed that dimensionalstability and strength properties of the composites can be improved by increasing the polymer content or by addition of coupling agent.This study shows that the composites treated with coupling agents will be properfor using as building materials due to their improvedstability and strength properties [2]. In 2009, Soury et al. presented the application of an innovative method of optimization to the design of an I-shaped profile used in a wood–plastic composite pallet. The pallet was made via assembling three WPCextruded profiles manufactured in the extrusion process. The middle profile was considered to beI-shaped which believes to have a high load bearing capability.The comparison of simulations and experimental results showed that the givendesign method is reasonably reliable. The final mass of the produced pallet was less than 20 kg whereasits strength against bending and distributed smooth restraint loading were greater than 500 kg and2000 kg, respectively [4]. In another study Pei-Yu Kuo et al. investigated the effects of material compositions on the mechanicalproperties of wood-plastic composites manufactured by injection molding process.In comparison to the mechanical properties of RPP (recycled polypropylene) itself, themodulus of rupture(MOR) increasedand the tensile strength decreased for WPCs manufactured with RPP.The tensile strength, MOR, and storage modulus of WPCs made from PP mixed with 47% wood flours(<180 lm) and 3–4.5% MAPP were larger than those of the other WPCs manufactured in this study. However, the polymer damping peaks showed a contrary result [5]. 3 years later Hancic et al. studied the mechanical response of wood and cellulose-filled polymers and compare it with analytical models. The comparison of results showed that both methods canaccurately predict the response of the composite in the elastic area; however Mori–Tanaka Methodcan achieve better results for predicting plastic deformations of wood-plastic composites [6]. At the same year, AlMaadeed et al. showed that an increase in wood particle content in the PP results in a decrease in the degree of crystallinity of the polymer. The tensile strength of the composites increased with growth in the percentage of crystallinity by adding the glass fiber. The improvementin the mechanical properties with the increase in crystallinity percentage (and with the decreaseof the lamellar thicknesses) can be attributed to the constrained region between the lamellae becausethe agglomeration is absent in this case [7]. In addition, in 2013 Azaman et al. designed flat or shallow thin-walled parts to compare the advantages and

disadvantages of lignocellulosic polymer composites (PP + 50 wt% wood) in terms of process ability. That study focused on the filling of cavity, in-cavityresidual stresses and warpage parameters associated with both types of thin-walled molded parts.Thin-walled parts with 0.7 mm thickness were suitably molded using lignocellulosic composite materials to determine the effects of filling. The analysis showed the shallow thin-walled part is preferable inmolding lignocellulosic polymer composite material due to the low residual stress and warpage measured.The results also indicated that the shallow thin-walled part is structurally rigid, so that it canbe used in applications involving small shell parts, and can be processed more economically using lessmaterial than the flat thin-walled part [8]. Furthermore, they presenteda numerical analysis of in-cavity residual stress formation in the thin-walled parts of injection-molded parts by considering the residual stresses produced during the post-fillingstage.The analysis showed that the cooling times and packingtimes had a less significant effect; nevertheless, the optimal levels that are required to be used in themolding process for thin-walled parts yielded better results. The in-cavity residual stress results showthat the stress variation across the thickness exhibits a high tensile stress at the part surface, whichchanges to a low tensile stress peak value close to the surface, with the core region experiencing a parabolictensile stress peak [9]. Aside from these efforts, the injection molding of shallow, thin-walledparts (thickness 0.7 mm), composed of lignocellulosic polymer composites (polypropylene(PP) + 50 wt% wood) was simulated.The analysis showed that the cooling time and packing time had less effect on the shrinkage and warpage; however the optimal levels for both factors are required in the molding process in order to achieve best results.The volumetric shrinkage was lower near the gate than at the end-of-fill location along the flow path. Theresults also showed that the volumetric shrinkage correlates with the warpage measured on the moldedpart [10]. In 2014, in a study which was conducted by Kaymakci & Ayrilmis, The relationship between Brinell hardness and tensile strength of wood plastic composites was investigated as afunction of wood filler content. The sawdust flour was compounded with polypropyleneat 30%, 40% and 50% (weight percentage) content with and without coupling agent, maleic grafted polypropylenewith anhydride, in a twin screw co-rotating extruder. Test specimens were produced by injection moldingprocess from the pellets dried to moisture content of 1%. The relationship between Brinell hardnessand tensile strength for all the filler loading levels was studied using linear regression method. The strongcorrelation was found between the Brinell hardness and tensile hardness of the WPCs as the filler contentwas between 30 and 40 wt%. This correlation showed that the Brinell hardness could be a goodindicator for tensile strength for WPCs [11]. Aside from previously mentioned studies, in 2009, Jam et al. represented an experimental investigation on the flowbehavior of the composites of high density polyethylene (HDPE) and very finewood particles (smaller than 50 μm).Complex modulus, melt flow index (MFI), and flow length are measured forcomposites containing 40–70wt% wood particles. The results indicate that noticeableincrease is observed for all measured properties upon increasing the woodcontent; however this change is very significant for MFI. Thus, for this study, composites having fine wood particles content above 60wt% can be considered as the highly filled composites [12]. Also in another study the same authors have represented another experimental investigation on injection molding of woodplasticcomposites with the same material. Moisture andwater absorption, MFI values, and shrinkage values were also measured for various wood contentsfrom 40% to 70%. The results indicated that the moisture content is highly increased when addingwood content to 70%. MFI measurement also exhibited a very large drop by increasing woodcontent from 60% to 70%. The prediction was that the conventional injection molding of thecomposites with 70% content of very fine wood particles would be highly challenging. Theexperiments in molding process revealed that while modification of sprue design and increasing moldtemperature can enhance mold filling for

wood contents up to 60%, but for the composite of 70%wood content, the mold filling was incomplete [13].

2. Materials and methods

2.1. High density polyethylene:

High density polyethylene (HDPE), grade I3, with MFI of 8.23 g/10min (190ºC / 2.16 kg) produced by Kermanshah Petrochemical Co. was used as the polymeric material. Detail specifications of this polymeric matrix are shown in Table1.

Table1. Typical properties of HDPE, grade I3 [14]

Property	Unit	Typical value	Test method
Physical			
Melt Flow Rate(MFR)(190 °C /2.16 Kg) Density	g/10min g/cm^3	8.23 0.957	ISO 1133 ISO1183
Mechanical			
Tensile strength@ yield	MPa	29	ISO 527
Tensile strength@ break	MPa	30	ISO 527
Elongation@ break	%	>1000	ISO527
Hardness shore D	---	64	ISO 868
ESCR (FNCT)@2.5MPa	h	1.5	ISO CD 16770
Charpy notch Impact Strength	Kj/m2	3	ISO 179
Thermal			
Vicat softening Temperature	°C	72	ISO 306
Melting point	°C	138	ISO 3146

2.2. Wood powder

Wood component material in this study which is in the shape of flour is a byproduct of sanding process in particle board manufacturing shop and from Oak tree with the particle size of less than 250 micron.

2.3. Additives

MAPE as coupling agent and PEWAX as lubricant were utilized in the final composition with polymer matrix and wood particles (Figure1). The weight percentage of MAPE, PEWAX, HDPE and wood content are 1%, 5%, 44% and 50% respectively.

Figure1. Wood-plastic mixed with additives

A co-rotating twin-screw extruder was employed for compounding. A perforated die was used to produce granules with 50% wood contents. The barrel and die temperatures were set below 170°C to prevent wood burning.

2.4. Design of experiments

The resulted granules were injected to the mold via the injection molding machine. Melt temperaturewas adjusted to 4 different levels in design of experiments as shown in Table2. Selecting these temperatures was done based onthe result of some primary tests which were conducted on the mold. It showed that the mold couldn't be filled using melt temperature less than 140°C so the lower temperature limit was set to 140°C. Also, temperature shigher than 170°Cwill affect the composite color which is caused bywood degradation. So this temperature has been selected as the upper temperature limit in the experiments.

Table2. Details for design of experiments

Variable	Levels
Melt Temperature, °C	140,150,160,170
Packing Time, sec	1,2,3,4
Total Experiments	16

The schematic design of the part is shown in Figure 2.

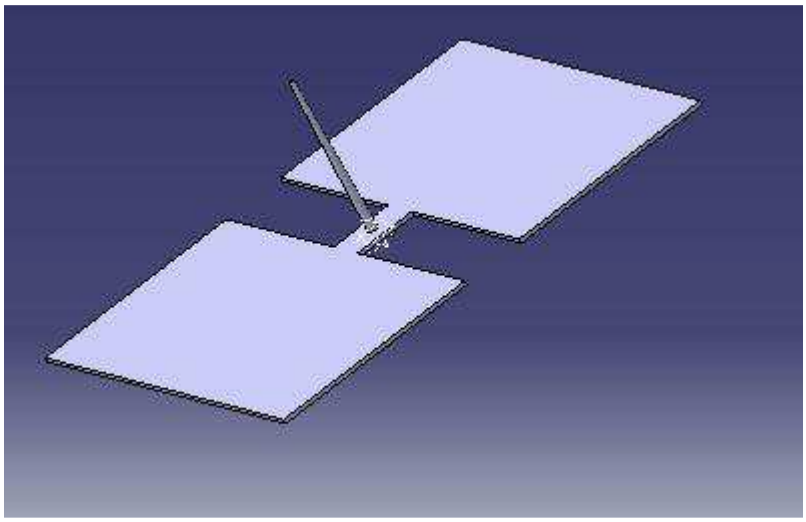

Figure2. Schematic design of the part

Using a 120 ton injectionmolding machine, the granules were injected into the mold to produce parts. In production of these specimens theother parameters including injection pressure (85 MPA), mold secondary pressure (60 MPA), cooling time (15 seconds) and clamping pressure (60 bars) wereset to mentioned values. One of the manufactured specimens is shown in Figure 3.

Figure3. A sample manufactured specimen

Table 3 shows the coding system used for categorizing different experiments.

Table3. Coding system used for different experiments

Experiment Number	Melt Temperature (°C)	Packing Time (s)	Code
1	140	1	A1B1
2	140	2	A1B2
3	140	3	A1B3
4	140	4	A1B4
5	150	1	A2B1
6	150	2	A2B2
7	150	3	A2B3
8	150	4	A2B4
9	160	1	A3B1
10	160	2	A3B2
11	160	3	A3B3
12	160	4	A3B4
13	170	1	A4B1
14	170	2	A4B2
15	170	3	A4B3
16	170	4	A4B4
Total Experiments			16

In which, A is melt temperature and B is packing time. Furthermore, the numbers (1-4) shows that each parameter has 4 different levels. After preparingthese specimens, they were taken to measurement laboratory and laser photos were taken. The photos were imported to CATIA software package to produce desired surfaces. Finally shrinkage values were calculated from these data.

2.5. Experimental tests

In order to 3D scanning, the specimens were placed on a white surface (white color is for better accuracy). Then some round tags were stuck on the specimens. Finally the specimens were covered by dioxide titanium spray. To make communications between the cameras and tags, the tags should be cleaned. Figure4 shows the 3D scanner which has been used for scanning the specimens. This machine was made by Solution Company and the model number is rexcancs+. The scanner uses two industrial cameras and one light source which can scan the specimens from different views. Figure5 shows the specimens which were prepared for 3D scanning.Then the cloud of points was exported to a CAD drawing file and the values and dimensions were measured. Figure6 shows the 3D scanning of the specimens.

Figure4. 3D Scanner used for scanning the specimens

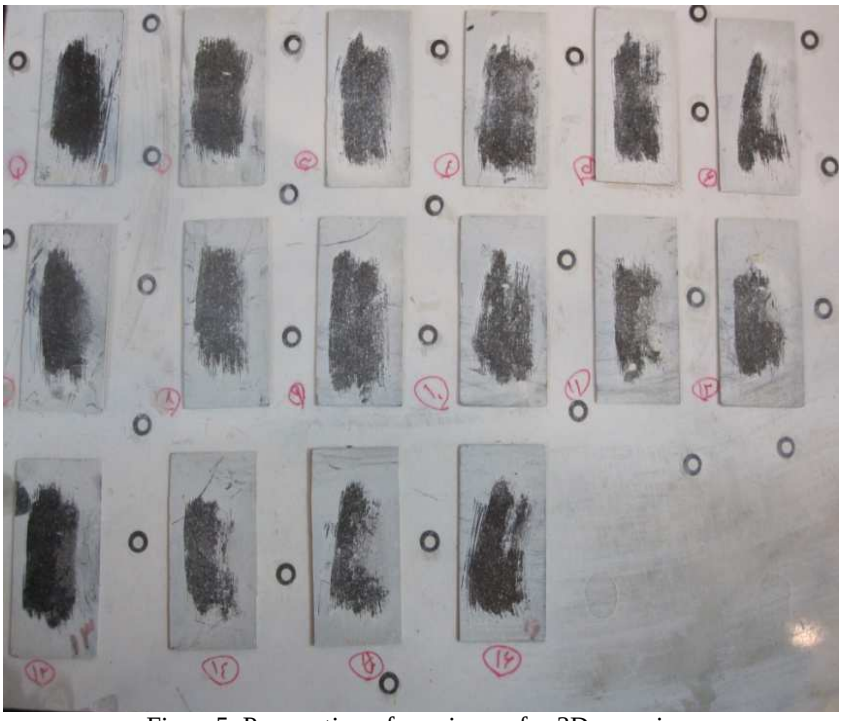

Figure5. Preparation of specimens for 3D scanning

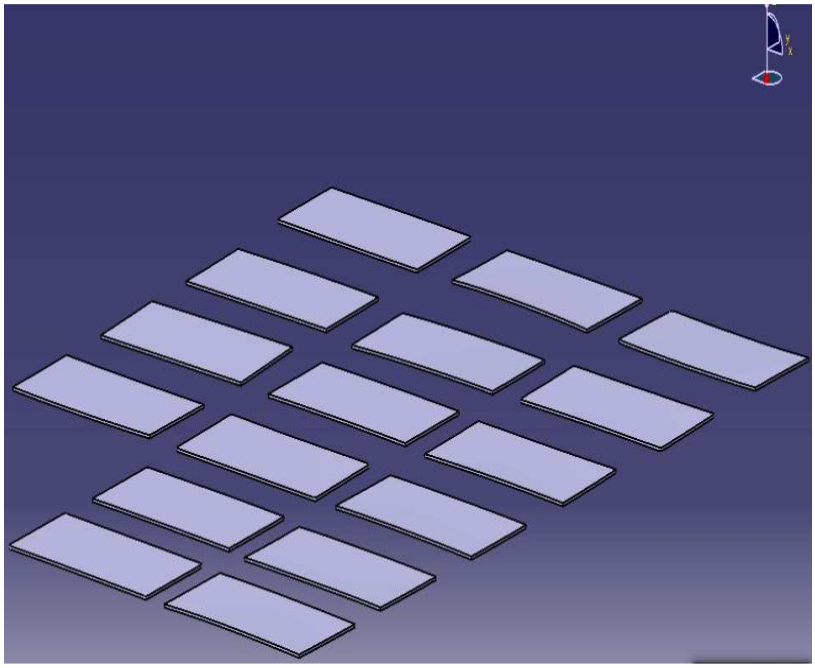

Figure6. Exported CAD file showing the 3D scanning of the specimens

3. Result and discussion

The shrinkage values are calculated with the mentioned method in section 2-5 for each specimen. As it can be seen in Figure 7, by increasing the packing time shrinkage was considerably reduced. The most and the least amount of shrinkage variations occur in 170°C and 140°C respectively. So increasing the packing time more than 4 seconds, especially for low temperatures, may not be very helpful. Also in can be seen in Figure 6 that by increasing the packing time from 1 sec to 2 sec, the final shrinkage in the specimen coded A4B1, will decrease 18.5% while decreasing the temperature

from 170°C to 160°C will decrease it 22.7%. Similar trend can be seen in other specimens too. Unfortunately in most injection molding processes, the range of melt temperature can't vary too much.

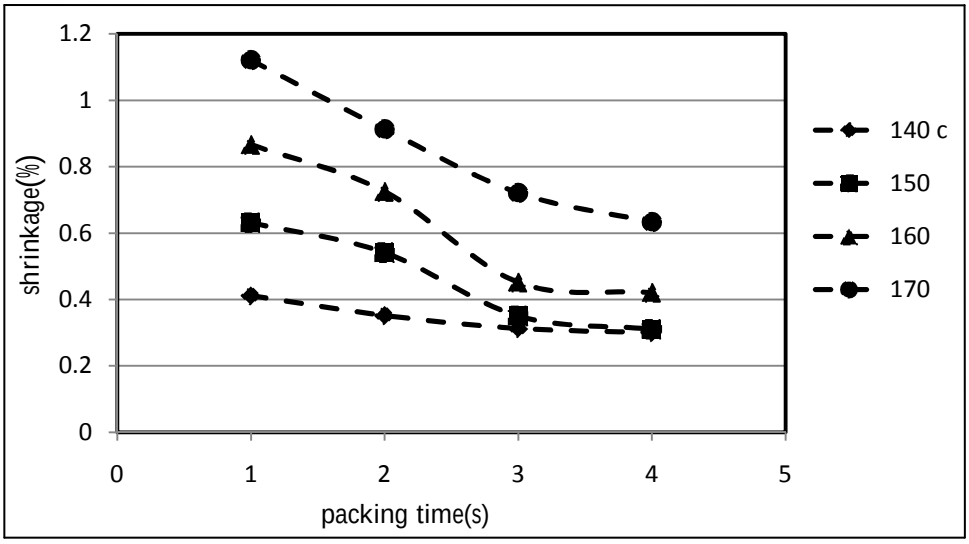

Figure7. Shrinkage versus packing time for different melting temperatures (140-170°C)

As it is shown in Figure 8, by increasing melt temperature, shrinkage will increase too. It is also can be found that the increasing rate for the packing times of 1 and 2 sec, are obviously more rapid than the packing times of 3 and 4 sec. Considering this graph, someone can say that a packing time of 3 or 4 sec for low melt temperatures such as 140-150°C will decrease the shrinkage to its minimum value while such packing times although will decrease the shrinkage percentage in higher melt temperatures like as 160-170°C, but seems to be insufficient for them.

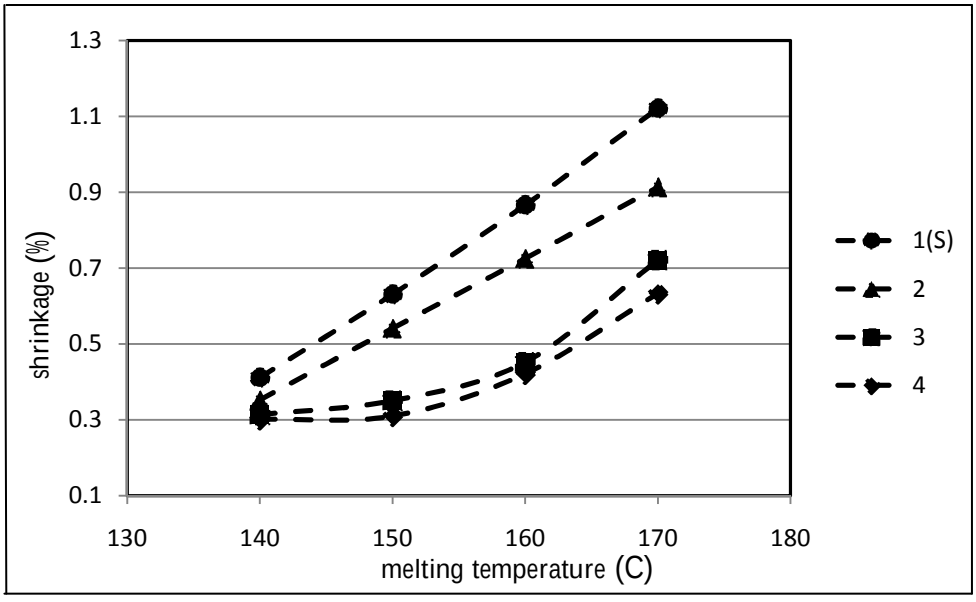

Figure8. Shrinkage versus melting temperature for different packing times (1-4 s)

4. Conclusion

As it mentioned in previous sections, 16 different wood plastic composite thin sheet specimens were produced via injection molding process in 4 levels of different packing times and melt temperatures and shrinkage percentage in each of them were calculated using Equation 1.The results can be simply concluded as follow:

- Either by increasing the packing time or reducing the melt temperature, the final shrinkage will significantly decreased.
- Decreasing 10°C in melt temperature normally has more significant effect on decreasing the shrinkage than increasing 1 sec in packing time.
- Packing time of 3 or 4 sec for low melt temperatures such as 140-150°C will decrease the shrinkage to its minimum value while such packing times although will decrease the shrinkage percentage in higher melt temperatures like as 160-170°C, but seems to be insufficient for them.
- Considering the above mentioned issues, it can be concluded that for decreasing the shrinkage to its minimum value, first of all it is better to set the melt temperature to its minimum possible degree and after that by increasing the packing time, we should find the least acceptable time. In this way of selecting parameters, the energy saving issue has been considered too.

5. References

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