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Co-injection filling characterization of the polypropylen packaging by 3-D simulation

Polipropilen ambalajın eş-enjeksiyon dolum karakteristiğinin 3-B simülasyonu

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Abstract

Polypropylene (PP) is a crystalline thermoplastic widely used in many industrial applications such as medical devices, automotive parts, battery cases, household products, or packaging trays due to its high chemical resistance, processability and impact/stiffness balance, well barrier property, lightness and toughness respectively. However, researchers and engineers have focused on new injection methods to reduce the cost of products and production time. After doing a literature survey about the new injection methods in this study, the co-injection simulation conducted with the Moldex 3-D program using properties of both virgin PP and scrap PP. By the way, the effect of co-injection parameters such as injection pressure, closing force, mod and melt temperatures on co-injection filling characterization investigated. As a result that when the core temperature of the first injected virgin PP is higher than its nucleation temperature, the core of the wall goes on the wall with the second injection of scrap PP until cooling of nucleation temperature. End of co-injection, the second injected scrap PP after first injected virgin PP replaced the advancing virgin PP on the wall core, and a three-layered wall consisting of original PP, scrap PP, original PP obtained.

Keywords: Co-injection simulation, Injection parameters, Moldex 3-D

Öz

Polipropilen (PP), hafiflik ve tokluk, yüksek kimyasal dayanım, şekillendirilebilirlik, darbe ve rijitliği dengelenmiş iyi bariyer özelliklerinden dolayı medikal ve otomotiv parçaları, ev eşyaları ve gıda ambalajlarının imalatında yaygın kullanılan kristalin termoplastik malzemedir. Bu bağlamda, araştırmacılar ve mühendisler üretim zamanı ve ürün maliyetini azaltmak için yeni enjeksiyon metotları üzerine yoğunlaşmışlardır. Bu çalışmada yeni enjeksiyon metotlarıyla ilgili literatür araştırmasından sonra, üretim hurdası PP ve orijinal PP' nin özellikleri kullanılarak 3-B Moldex programıyla eş enjeksiyon simülasyonlar gerçekleştirilmiştir. Böylece, enjeksiyon zamanı, enjeksiyon basıncı, kapama kuvveti, kalıp ve enjeksiyon sıcaklığı gibi eş-enjeksiyon parametrelerinin dolum karakteristiğine etkisi araştırılmaya çalışılmıştır. İlk enjekte edilen orijinal PP' nin yolluk merkezindeki sıcaklığı çekirdeklenme sıcaklığından yüksek olduğunda, eş zamanlı ikinci enjekte edilen üretim hurdası PP'nin orijinal PP katılaşana kadar yolukta ilerlemekte olduğu sonucuna varılmıştır. Eş-enjeksiyon simülasyon sonunda, ilk enjekte edilen ve ilerleyen orijinal PP' nin yerini ikinci enjekte edilen üretim hurdası PP almış ve orijinal PP, hurda PP, orijinal PP' den oluşan üç katmalı cidar elde edilmiştir.

Anahtar kelimeler: Eş-enjeksiyon simülasyon, Enjeksiyon parametreleri, Moldex 3-B

1 Introduction

Polypropylene is one of the thermoplastics commonly used in automotive [1], medical, packaging [2, 3], and industrial product applications and is expected to increase its market share to 90 billion dollars in 2022, from the market share of 70 billion dollars in 2016 [3]. Besides, a wide portfolio of use in many manufacturing methods such as extrusion [4], injection molding, blow molding [5] and additive manufacturing [6] due to its lightness and low cost [7], lead to the rapid development of its market share. Injection molding process has two main units as injection and clamping given in Figure 1 [7]. Figure 1 demonstrates the all parts in this manufacturing system and its known that injection parameters affect the injection period and quality of the product significantly [8]. Therefore, machine and injection molding parameters have been special area of investigate to obtain a product with optimum quality and desired final shape [9]. Moreover, it strongly recommended that diverse factors affecting the typical plastic injection process must be analysed properly before deciding the applicability of manufacturing a product with the desired quality and complexity. By the way, these factors are classified into three categories as follows [10]:

Independent machine parameters: Barrel and nozzle temperatures, coolant temperature, packing and holding pressures, back and injection pressure, sequence and motion, injection speed, screw speed, shot volume, cushion.

Dependent injection parameters: Mold and melt temperatures, cooling temperature, melt pressure, melt-front advancement, shear stress, injection and filling times,

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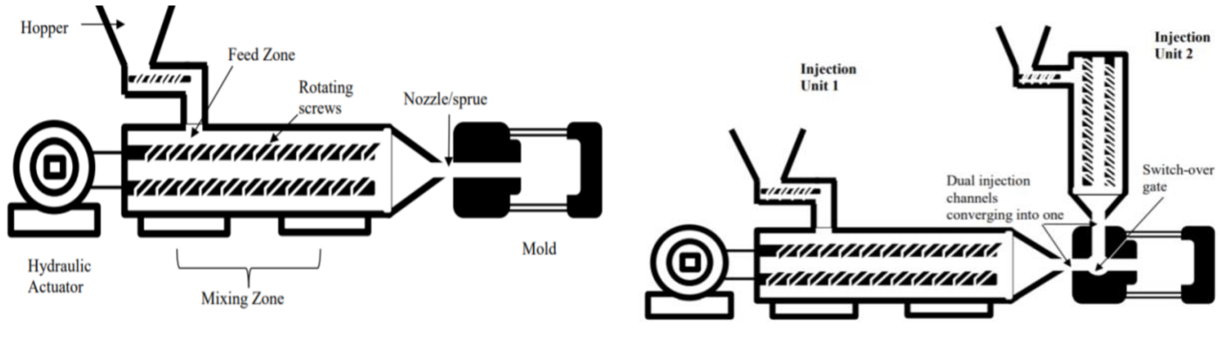


(a) (b)

Figure 1. (a) Schematic of the typical injection molding process, (b) schematic of co-injection molding process [7]

packing and holding times, cooling and mold open times, injection rate, material flow rate, rate of heat dissipation and cooling, pressure switch-over.

Final quality responses: Part dimension, shrinkage, warpage, sink marks, appearance and strength at weld lines, and other aesthetic defects such as burn marks, gate blushes, surface texture, etc. [10].

Furthermore, though machine parameters controls with using sensors in the machine or by upgrading diverse machine components, the injection parameters are mostly dependent on material properties, mold design, and process conditions. Lastly, quality indices are goals to produce desired shape and complexity [7]. Nowadays, machines with better control over parameters puts on the market. However, it is still a compelling and expensive procedure to understand the relationship between process parameters and output variables because of the necessity of quite many experiments. That is why; some important approaches like using the Taguchi method [11], artificial neural network [10], or finite element software [12] needed to minimize the number of experiments, provide self-learning, and predict the outcomes of the production respectively. It was reported that some commercial software packages were developed which use the finite element method to estimate stages of injection molding [13]. One of finite element programs: Moldflow is mainly used to determine the important parameters affecting the shrinkage of molded components [14] or estimate the injection period time easily. New co-injection molding is presented in Figure 1 in which two separate polymer materials combined to produce a sandwich structure. Co-injection molding or double action molding was originally patented in 1972 and 1973 by Garner and Oxley who worked for ICI now this method is known as a dual injection or sandwich injection or co-injection [14, 15]. Under this process, two separate polymer or polymeric materials injects into the same mold cavity in such a way that one material takes the form of the skin while the other material fills the center of the mold. The ability of co-injection molding to produce layered polymer structures leads largely with the phenomenon of parabolic flow front [7]. Moreover, a polymer consisting of a mixture of scrap and virgin polymers having different melt flow indexes can injected by the co-injected method. This innovation provides the recycling facility of valuable production scraps in the plastic injection sector. However, in order to do co-injection; different runner designs, second barrel, injection parameters, and injection period are required from typical injection molding.

Typical differences in the co-injection process schematizes in Figure 1b. As a principle of co-injection in Figure 1; one plasticized polymer from generally from virgin PP is injected from Unit I of a machine, another polymer from virgin or scrap PP is injected by Unit 2 to mold gate after then the parabolic flow is largely created due to viscosity differences in the polymer. The schematic of parabolic flow in co-injection is given in Figure 2. As the first injected polymer (virgin PP) moves farther away from the core of the melt and towards the mold wall it begins to cool down. In co-injection, the channel is created from the initially injected polymer by injecting a second polymer (scrap/recycled PP) [7].

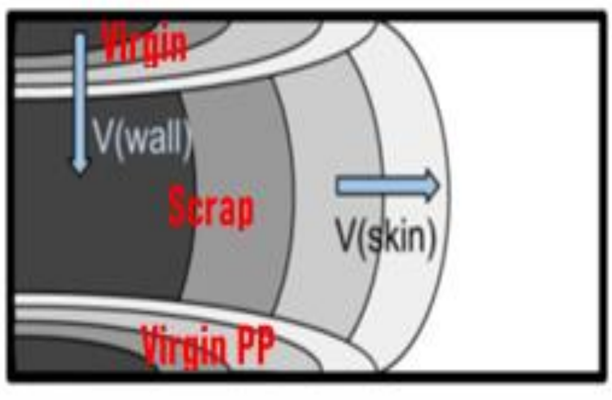


Figure 2. The schematic of parabolic flow in co-injection [7]

In this study, the effect of injection parameters on the ejection period of packaging product virgin and mixing PP materials were analysed by using the Moldflow finite element analysis program. After these co-injection 3-D simulations, the temperature distribution, glass transition temperatures and times, injection time, flow rate, scrap utilization rate on the wall of the packaging product obtained. By the related results evaluating; the amount of the valuable scrap in the product, insight for injection mold design, and information about injection period before manufacture are gained with this working.

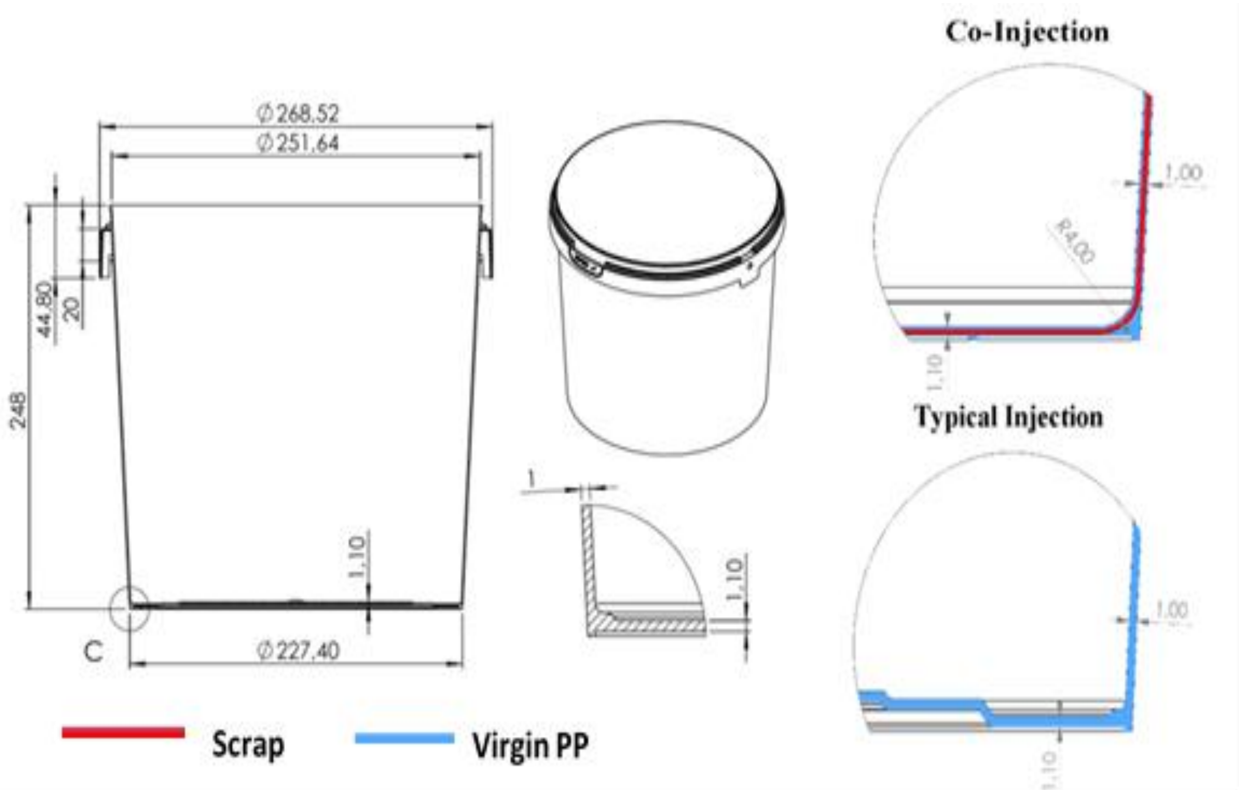
2 Material and method

After doing a literature survey about typical injection and co-injection, 3-D simulation workings focus on the packaging product having 10-liter capacity, which showed in its geometrical properties in Figure 3. This product is made from 240 g virgin PP. In Figure 3a, the wall thickness of PP packaging is mm of 1, base wall thickness is 1.1 mm, the height of the product is 248 mm and base diameter is 227.4 mm and mouth diameter is 268.52 mm. The aim of co-injection is to provide use of scrap PP together with virgin PP along the 1 mm and 1.1 mm wall and to ensure that 1 mm wall is three-layered respectively from the inside surface to outer surface: virgin PP, scrap PP, virgin PP which can be seen in Figure 4. By the Scrap PP occurs during the typical injection of various packaging from virgin PP. Material flow rate (MFR) is a property of virgin polymer, which determines injection parameters and die design. Scrap PP MFR depends on MFR values of virgin PP materials used in manufacturing. With this context, the average scrap PP material's MFR is proportionally calculated as 70 and the average virgin PP's MFR as 37 to 3-D co-injection simulations. In simulations, Properties of PP material suitable to 37 MFR and 70 MFR values defined in the Moldex program given in Table 1 and Table 2 respectively.

After doing this preparation, 3-D co-injection simulation is realized for this model, which is seen in Figure 3. According to Figure 4, virgin PP injected in the first step, and after solidification of virgin PP on mold surfaces, scrap PP was injected into the same gate in simulations. The scrap PP continues the flow and replaces the virgin PP in the channel when virgin PP has solidified at the wall, the scrap PP travels through the channel and continues to push material to the flow front. After doing polymer properties, geometrical and materials properties of mold and sample, co-injection simulations are carried out by Moldex 3D program. After then, some important results about the mold design and injection period are predicted with 3D co-injection simulation. Solid 3 layer BLM quadric element type, around 267500 element number are used in simulations.

Table 1. PP 412MN40 Polypropylene (37 MFR) some technical properties [16]

Properties	Unit (Si)	Values
Melt flow rate (MFR) at 230 ºC and 2.16 kg	dg/min	37
Density	kg/m^3	905
stress at yield	MPa	25
strain at yield	%	5
tensile modulus	MPa	1300
Izod impact notched at 23 ºC	kj/m^2	8
Izod impact notched at 0 ºC	kj/m^2	6.5
Izod impact notched at -20 ºC	kj/m^2	5
Hardness Shore D	-	63
Heat deflection temperature at 1.80 MPa (HDT/A)	ºC	55
Vicat softening temperature at 10 N (VST/A)	ºC	150
Vicat softening temperature at 50 N (VST/B)	ºC	75



(a) (b)

Figure 3. (a) Co-injection simulation applied for packaging design, (b) packaging walls by typical injection and co-injection

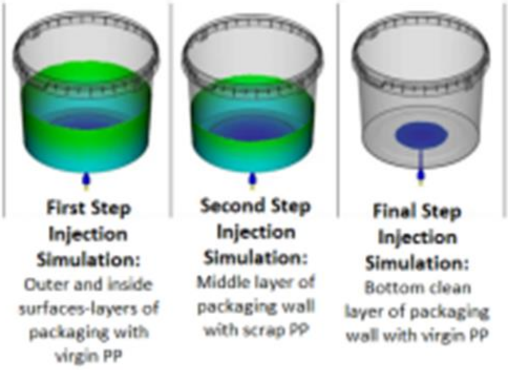


Figure 4. Co-injection simulations steps for 10 liter of packaging product

Table 2. BJ368MO Polypropylene (70 MFR) some technical properties [16]

Properties	Unit (SI)	Values
Density	kg/m^3	903
Melt flow rate at 203 ºC and 2.16 kg	dg/min	70
Hardness, Rockwell R	-	86
Tensile Strength, Yield	MPa	25
Elongation at Yield	%	4
Tensile Modulus	GPa	1.45
Charpy Impact, Notched at -20 ºC temperature	J/cm^2	0.400
Charpy Impact, Notched at 23 ºC temperature	J/cm^2	0.550
Deflection Temperatures at 0.46 MPa	ºC	102
Melt Temperature	ºC	210 - 260
Mold Temperature	ºC	10 – 30
Hold Pressure	MPa	20 – 50

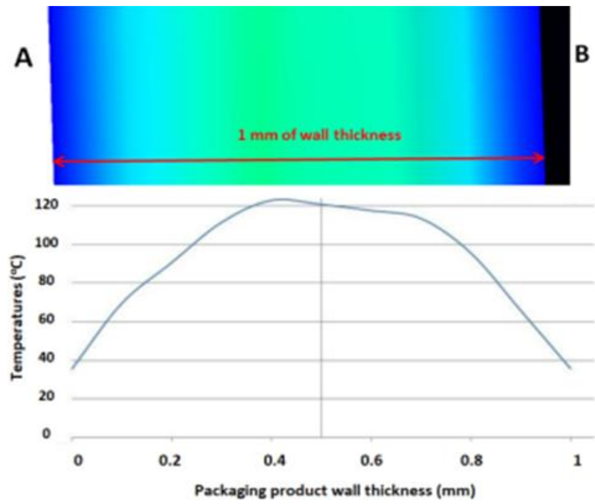
3 Results and discussion

The temperature distribution on wall thickness after the end of the first polymer injection filling is very important in co-injection. Because the initial injected virgin PP moves farther away from the core of the melt and towards the mold wall. The melt virgin PP begins to cool down when it contacts the mold surfaces close to the cooling channels.

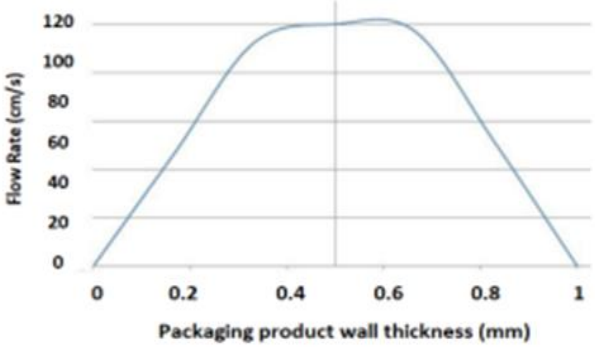
The first aim is to predict the temperature changing on the wall thickness depending on the filling time. By the way, it will be determined when the first injected virgin PP reaches the nucleation temperature on a cold mold surface where is in 60 ºC temperature. A temperature distribution result on wall thickness in the first injected virgin PP from Unit 1 during co-injection simulations is given in Figure 5a. The 1 mm wall is divided into ten equal parts, which can be seen in Figure 5a. The distance between each pint is 0.1 mm. According to Figure 5, the initial injected virgin PP temperature from cold mold surfaces (A and B) to the center of thickness varies between 35.27 ºC and 120.8 ºC after 3.06 s of filling.

According to Figure 5b, around 0.3 mm of the wall thickness is below the nucleation temperature of virgin PP. Around 0.2 mm virgin PP from the walls nucleated and it is interpreted that it solidified virgin PP tends to adhere on the wall during 3.06 s injection period. It is mentioned that the cooling rate, temperature gradient, shear condition, pressure distribution, and many other injection parameters strongly affect the distribution of crystallization behaviour of PP, frozen, and the surface quality and mechanical properties of plastic parts [17].

It is obvious that with the increase of mold cavity surface temperature, the thickness of the frozen layer gradually decreases. One research reported that when the mold cavity surface temperature is 60 °C, PP nucleation starts [18]. Another result is predicting of flow rate by 3-D simulation which was given in Figure 5b. According to Figure 5b, while the flow rate is around 25 cm/s in the first injected polymer core, it comes to standstill at the mold contact surface. Thence, the polymer velocity at the skin surface closes to zero, in the lower layer towards the center gradually increasing to the 25 cm/s during 3.06 s injection period. Lou et al. [19] studied the effect of material viscosity on core melt depth during co-injection. When the viscosity of the core is much smaller than that of the skin. It interpreted that a decrease in virgin PP temperature in the runner of die causes decreasing in its flow rate. On the other hand, as the core temperature of virgin PP in the runner increases, flows in the core go on until filling. In order to solve the defects of co-injection products, it is necessary to consider the viscosity2changes of the two polymer materials during the changes of temperature and shear rate, pressure [20].



(a)



(b)

Figure 5. The temperature distribution (a) and flow rate (b) on 1 mm of packaging product wall thickness after 3.06 s of the first virgin PP injection filling obtained from 3-D simulations

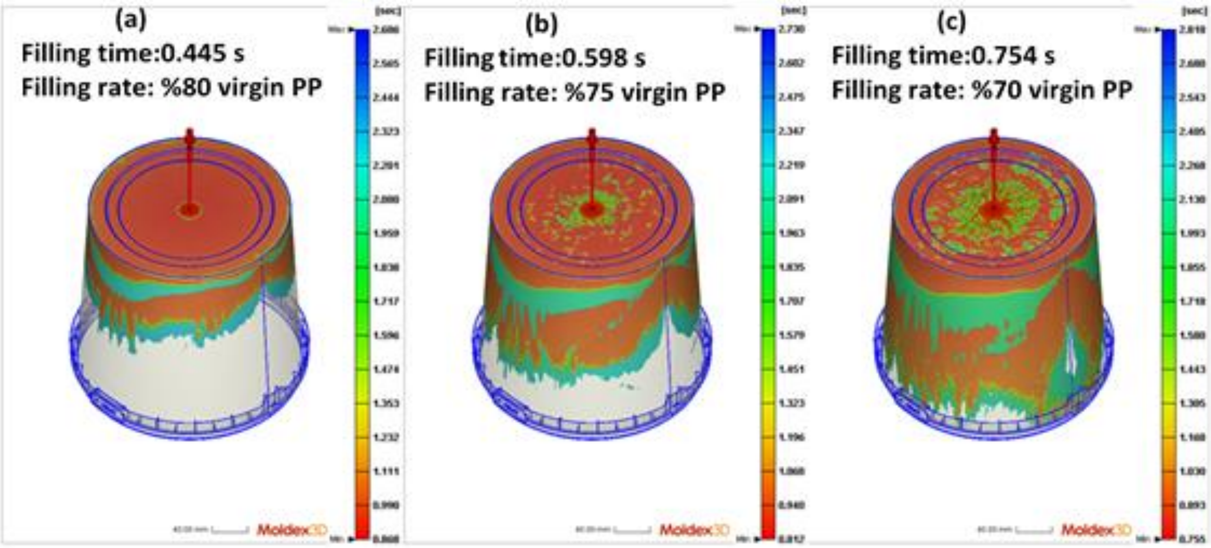


Figure 6. Simulation screens of packaging product with respect of filling time and filling ratio

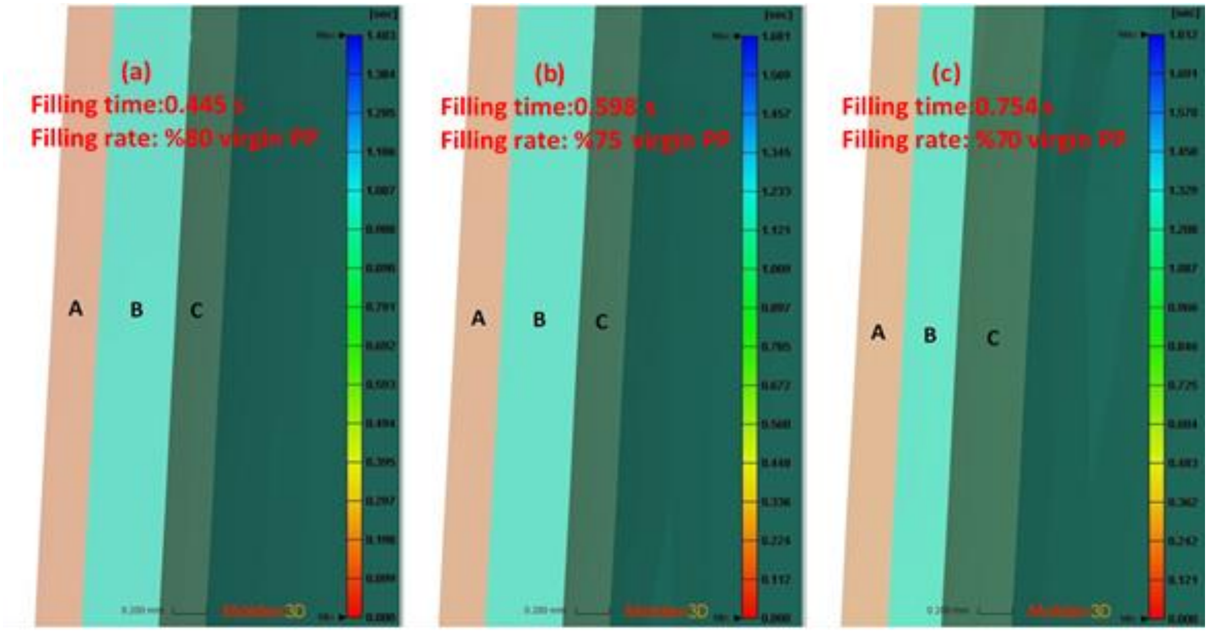


Figure 7. Virgin (A and C) and scrap (B) layer on wall of packaging product with respect of filling time and filling ratio

After the first injection filling is completed, a certain thickness/amount of virgin PP in the core of the packaging wall can progress if the second injections of scrap PP to the same die runner. For example, the level of 0.4 to 0.5 mm thickness in the core of the packaging wall seen in Figure 5 is expected to progress to filling, then it is predicted by simulation that the second injection of scrap PP replaces the advancing virgin PP. A there different co-injection simulation was realized by the Moldex 3D simulation program. In the simulation, their different filling time and filling ratio are respectively selected as 0.445 s, 0.598 s, 0.754 s and %70, %75, %80.

Virgin PP skin layers weight/thickness and core layer weight/thickness of wall thickness and total product weight, closing tonnage, injection pressure are predicted by co-injection simulations, which can see in Figure 6. Scrap PP using rate is %20 of total product weight in Figure 6a, in 6b is %25, in 6c is %30, respectively. Figure 7 shows the layers of the packaging wall concerning filling time. As can be seen, the layer thickness is changing with three different co-injection simulations. The highest thickness of the scrap layer obtained from the Figure 7b simulation screen. Therefore, co-injection simulations result in Figure 7b is important for the evaluation of scrap PP. Graphics about simulations results given in Figure 8. When evaluating Figure 8, the higher scrap PP core layers thickness values are obtained from 0.455 s and 0.598 s of filling times which can be seen in Figure 9a.

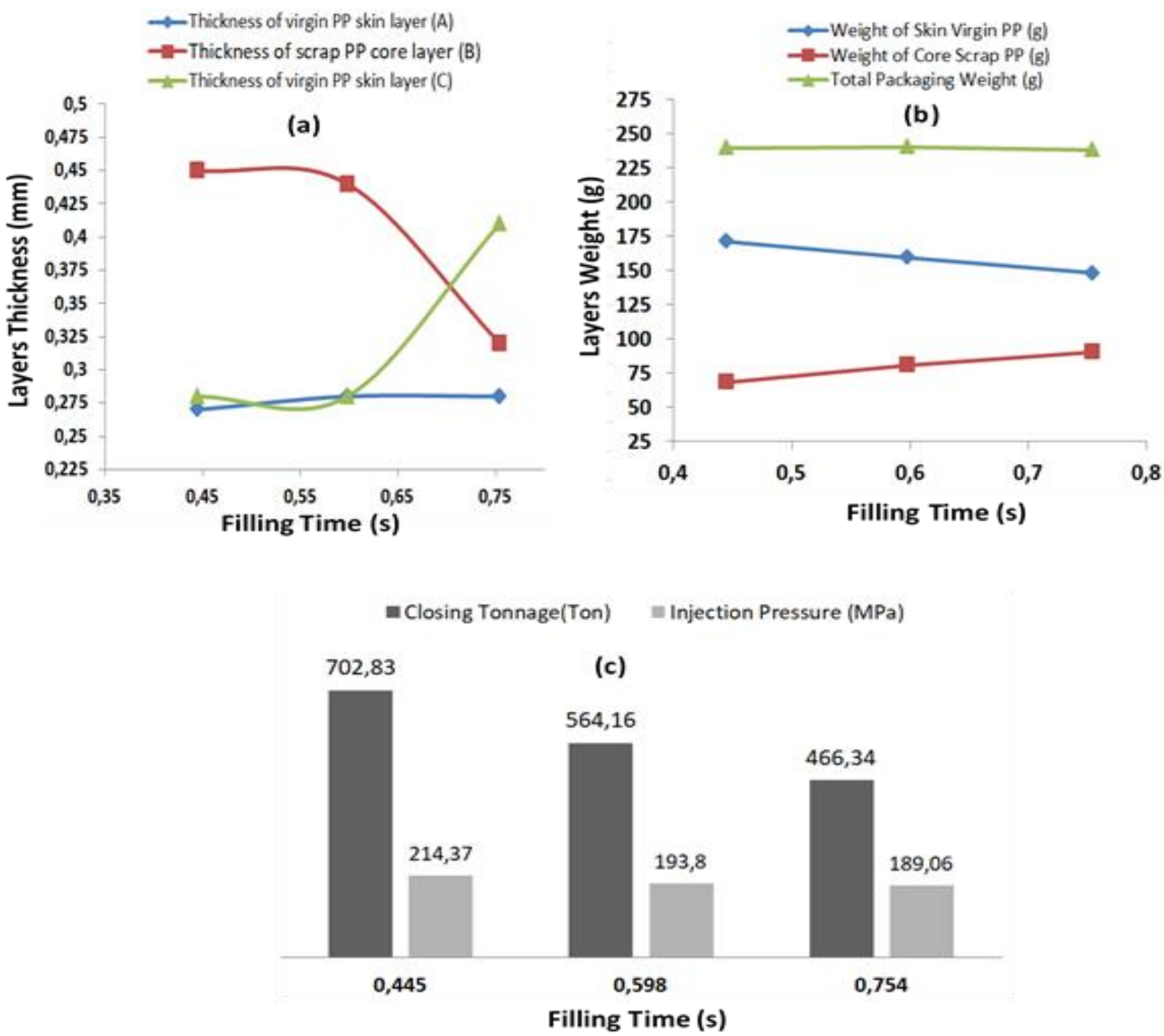


Figure 8. Co-injection simulation results about layers thickness (a), theirs weights (b), closing tonnage and pressures of injection (c)

In addition, an increase in filling time enables more scrap PP use in the packaging wall. He et al [21], the core layer distribution in the simulation results is consistent with the experimental results. As comparing Figure 8a, Figure 8b, and Figure 8c, 0.598 s of co-injection filling time, 193.8 MPa injection pressure, and 564.16 ton of injection closing are determined as the optimum condition. 0.44 mm of core thickness on packaging wall with co-injection simulation consists of scrap PP, which contributes 25% to the weight of the packaging product by this optimum condition. Thence, around 80.8 g of scrap PP will evaluate by a special co-injection method in the manufacture of a 10 liter capacity of packaging product. It will contribute to reducing the use of virgin PP.

4 Conclusion

Some following co-injection simulation results obtained from this study. By the way, these results give information about co-injection mold design and co-injection simulation parameters to be applied.

- The initial injected virgin PP temperature from cold mold surfaces to the center of packaging wall temperatures varies between 35.27 °C and 120.8 °C after 3.06 s of filling. As the core temperature of the first injected virgin PP is higher than its nucleation temperature, the core of the wall goes on the wall with the second injection of scrap PP.
- The virgin PP flow rate at the skin surface contacting the cold mold surface closes to the zero, in towards the core of wall gradually increased to the 25 cm/s in 3.06 s injection period. This means that the virgin polymer solidifies upon contacting the cold mold surfaces and the virgin polymer has the temperature and flow at the core of the wall.
- 193.8 MPa of injection pressure and 564.16 ton of injection closing force, 60 °C of mold surfaces, and 120 °C to 130 °C of first injected virgin PP core temperature

at the wall during 3.06 s of co-injection filling time are determined as an optimum co-injection condition.

- A three-layered wall consisting of original PP, scrap PP (core layer), original PP was obtained by optimum co-injection simulation. The optimum 0.44 mm of core layer thickness on packaging wall obtained from simulations.
- 25% to all weight of the packaging product consists of Scrap PP. Thence, around 80.8 g of scrap PP will be evaluated by the special co-injection method in the manufacture of a 10 liter capacity of packaging product. It will contribute to reducing use of valuable virgin PP.

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Conflicts of interest

No conflict of interest was declared by the authors.

Similarity rate (iThenticate): 12%

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