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An Experimental Study to Reduce Double Chip Defects in the Pelletizing Process of Polyethylene Terephthalate

Irwan Wipraseno[1], Hadi Sutanto[2], Isdaryanto Iskandar[3]

[1}2}3}] Department of Mechanical Engineering, Atma Jaya Catholic University of Indonesia
Jl. Jend. Sudirman No.51, Jakarta 12930, Indonesia

Abstract

The double chip defects in pelletizing process of Polyethylene Terephthalate (PET) occurs most often compared to other defects. This defect is caused by strand polymer sticking before the cutting process. This research aims to reduce the double chip defect during pelletizing process using Automatic Maag, machine type USG 900V by controlling some operating parameters such as cooling water temperature, cooling water debit, angle slope and groove on the startup device plate polymer. This research has shown a decreasing number of double chips defect from 800 kg/day to 50 kg/day chips or reduce 94 %.

Keywords: double chip defect, polyethylene terephthalate, pelletizing, sticking

1. INTRODUCTION

The Double chip defects in pelletizing process of Polyethylene terephthalate is a dominant problem of defect compared to other defects and until recently the double chip defect is still not significant solved.

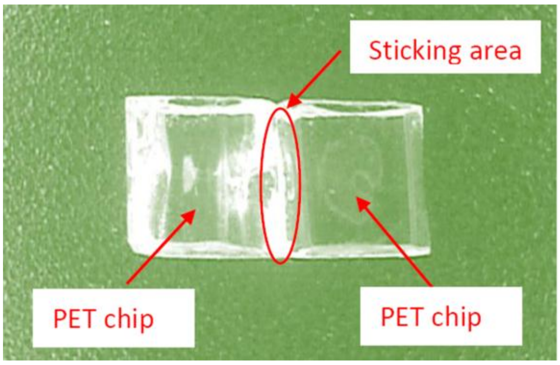


Figure 1. Double chip defect.

Double chips are two parallel plastic chips that are sticking together at one side. In processing polymer strand, if two polymer strands meet above glass temperature they will be sticking [1] [13] and both strands flow until cutting process. Sticking of two strands will produce doubles chip.

Double chip is an unexpected product due to uniformity particle size chips affect to material handling and sometimes will affect the processing characteristic [2][12].

Current condition, the pelletizing machine at PT. XXX (one of PET chips manufacturer in Indonesia) operates with capacity 260 tons/day and defective chips average are 0.6 ~ 0.8 tons/day and 60~70% of the defectives are double chips [3].

The operation of pelletizing machine is as follows [4] [5].

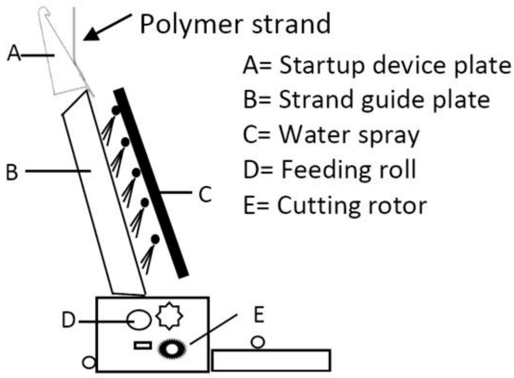


Figure 2. Main component pelletizing machine.

Figure 2 shows a melting polymer strand leave die head goes to startup device plate (A). The strand immediately receives cooling water from an overflow clearance at the upper side of startup device plate, then the strand flows to strand guide plate (B) and receives 2nd cooling from water spray nozzle(C). The strand leaves the strand guide plate and is pulled by a pair of roll/feed roll (D) and fed to the cutting rotor (E) and become polymer/plastic chips. Finally, the chips will be conveyed from the cutting area to the dryer by the 3rd cooling water. The function of 3rd cooling water beside conveys chips to dryer also functions as a chip cooling.

There are some factors that influence to double chips form [6]:

- Snaking strand movement on the die plate
- The overflow of water too much
- Uneven water flows in the strand guide section.
- Overflow water clearance at startup device plate blocked or damages.
- Die head temperature uneven
- Strand cooling before cut inadequate.

Factors mentioned above as suspected to double chip problems, but the machine maker did not clearly explain how to solve this problem. Some experiments need to be done to solve the double chips problem.

2. LITERATURE REVIEW

1. Melting polymers at low temperatures changes to dense.

During polymer chip processing, polymer leaves die head in liquid rubber form, polymer passes through mold holes at temperature 298ºC in a melted strand form. In the next process, the hot polymer strand receives cooling water and the temperature reduces until it reaches below-glass temperature (glass temperature 76 ~ 80ºC).

The first phenomenon cooling process of melted polymer is the formation of stable primary nuclei which is the result of fluctuations in density or order of supercooled melting. The rate of nucleation increases as the temperature decreases [7]

Polyethylene terephthalate is a thermoplastic polymer. A thermoplastic is a polymer in which the molecules are held together by weak secondary bonding forces that soften when it is exposed to heat and becomes dense/solid if it cooled down to room temperature [8].

2. Two polymer surfaces exposed to hot temperatures will stick.

In polymer operation, the process undergoes non-isothermal solid-to-liquid or liquid-to-solid phase changes. The hypothesis of bounding between liquid polymers and solid in non-isothermal conditions state that stickiness (tack) can occur depending on the process condition. A strong adhesion requires wetting the contact interface (and thus the creation of the surface) as a result of the contact temperature above the point of polymer solidification. It is stated that the contact temperature determines the presence or absence of a bonded surface. This statement is supported by a non-isothermal tack experiment, which shows that change from stickiness to non-stickiness is indicated by the changes in the surface temperature of a solid material [9].

3. Gradient Temperature at polymer strand section due to cooling

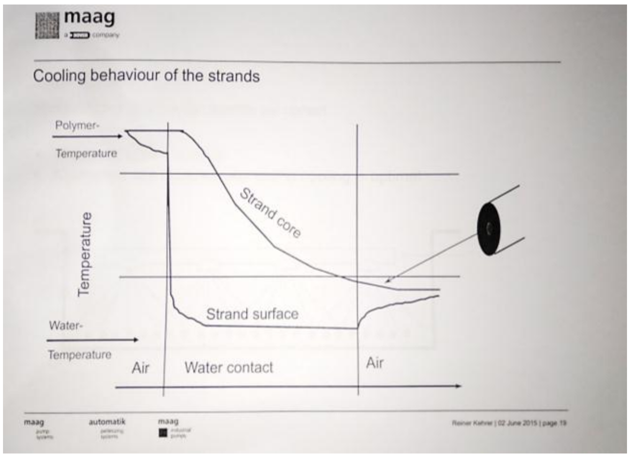


Figure 3. Gradient temperature at cross-section strand (Source: Influence to the pellet quality –maag, Reiner Kehrer,)[3].

Figure 3 shows a cooling gradient temperature at strand polymer transversely. It shows that strand surface temperature drops sharply while at the center part is still hot, hence when the cutting occurs, the surface temperature strand already below the glass temperature so the strand can be cut.

4. Glass temperature and melting temperature

PET glass temperature is between 67 to 80ºC while the melting temperature Tm is 267ºC. [10]. at these points (Tm), polymers like rubber-liquid. Polymer during a cooling process changes from liquid rubber to flexible/softened and after reaching the glass temperature polymer becomes dense/solid.

At plastic chips production, the main concern is the transition phase area between liquid-rubber to solid-state. A polymer leaves die head at liquid rubber state and receive cooling water until changes polymer phase from liquid rubber to dense/solid or ready to cut.

5. The Heat exchanger at strand polymer.

Polymer strand temperature is cooling down by chilled water. There are 3 steps of the cooling process:

a) Overflows water through a thin gap at the top of startup device plate
b) Spray water on the strands guide plate
c) Flows water to convey plastic chip from the cutting area to drying area.

Based on the first law of thermodynamics, it is required that the rate of the heat transfer from the hot fluid should be equal to the rate of the heat transferred to the cold side. [11]

$$Q = \dot{m}_c \,.\, C_{pc}(T_{c,out} - T_{c,in}) \qquad (1)$$

And $$Q = \dot{m}_h \,.\, C_{ph} (T_{h,in} - T_{h,out}) \qquad (2)$$

Q = heat transfer rate (J)

$\dot{m}_c$: water mass flow (kg/sec)

C_{pc} : water specific heat 1030 J/kg.C

$T_{c,out}$: final water temperature (ºC)

$T_{c,in}$: initial water temperature(ºC)

$\dot{m}h$: polymer water mass flow (kg/sec)

Cph : polymer specific heat (4182 J/kgC)

$T_{h,in}$: initial polymer temperature (ºC)

$T_{h,out}$: final polymer temperature (ºC)

From the equation (1) and (2), the polymer temperature will decrease until below glass temperature and the water temperature will increase. To maintain cooling water temperature stable, hot water must be cooled again by other equipment.

3. RESEARCH METHOD

The research started by collecting the initial condition process and then adjusted some parameters which have an influence on double chips form as mentioned in manual instruction [6]. The research was conducted using a pelletizing machine type USG 900 V from Automatic Maag Gmbh. The initial conditions of this research were as follows:

1) Cooling water flow is divided into 3 sections.
   a. Overflow startup device plate:10 m3/ hr.
   b. Spray nozzle: 6 m3/hr.
   c. Cooling water and chip conveying: 34 m3/ hr.
2) Cooling water temperature 20 ^oC
3) Cutting speed 256 m/sec.
4) Startup device plate angle 51 ^oC
5) Groove length of startup device plate 50 mm.
6) Deep groove 3mm.

Research is focused to some parameter which influences to double chip defect, but some parameter is keeping in the same condition to avoid complexity problem and also product quality reason, Some parameter is kept at same condition are:

1. The polymer temperature on the die head was maintained at 289^{o}C.
2. The plastic chips dimension was 2.3 mm x 2.3 mm x 1 mm with a tolerance of 0.1%.
3. Product capacity 260 ton/day with cutting speed 265m/min, roll cutter diameter 162 mm, the number of blades 40 pieces with helical degree 2^o.
4. The number of Polymer strand was 90, leaving from die head with a distance between holes/strand of 15mm and consisting of two rows, each row had 45 holes, the distance between rows was 15mm. Holes shape was square and the width was 5mm.
5. Polymer strand leave die head did not snaking/dancing.
6. Debit water flow debit was regulated by a flow meter.
7. The number of spray nozzles was 80 nozzles.
8. The grooves at a startup device plate are in line with the polymer strand flow.
9. The dropping point polymers strand are a center to the groove of a startup device plate,

Several observed parameters to this experiment were:

a. Cooling water temperature:

Cooling water was used to cool down strand polymer that has just left the die head. The strand polymer left the die head at 298^{o}C. After strand polymer met the cooling water, strand polymer temperature decreased and became solid. In this research, several cooling water temperatures are trial to reduce the double chip

b. Cooling water debit.

Debit cooling water was intended to accelerate the cooling process of strand polymer. Some water debit will be controlled to know their influence of increasing or decreasing double chip or others effects to chip product.

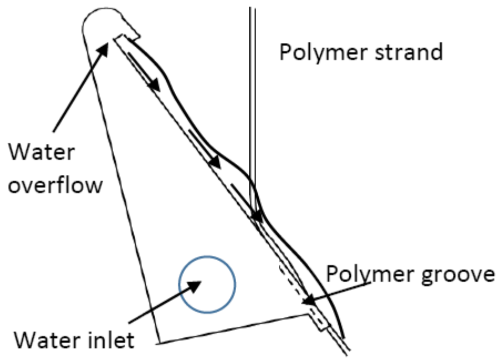


Figure 4 Startup device plate (side view).

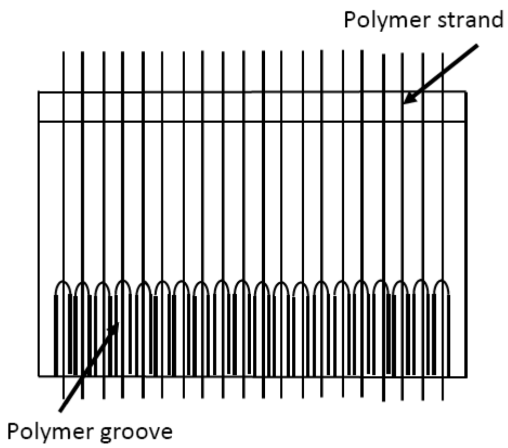


Figure 5. Startup device plate (front view).

As seen in Figures 4 and 5, the startup device plate is a place where the polymer strands meet cooling water in the beginning. In this area, the cooling water pushes polymer strands to grooves while cooling down. Often we found the strand shifts and goes to another groove which has been filled by another strand and they stick to each other. This could happen because strands are still melted.

c. The angle of the startup device plate. Changing the slope angle of startup device plate aims to achieve the right-angle plate so the double chips defect reduced. Increasing the angle to a vertical direction allows the polymer better flow but the polymer also easily switch the lanes, while reducing the angle to horizontal makes the polymer slide more difficult and could cause the polymer stuck/stop flowing, but the advantage of reducing angle to polymer is the polymer strand after enters groove, polymer strand can't shift to another groove thus protect them to meet with others strand.

d. The depth of the polymer grooves.

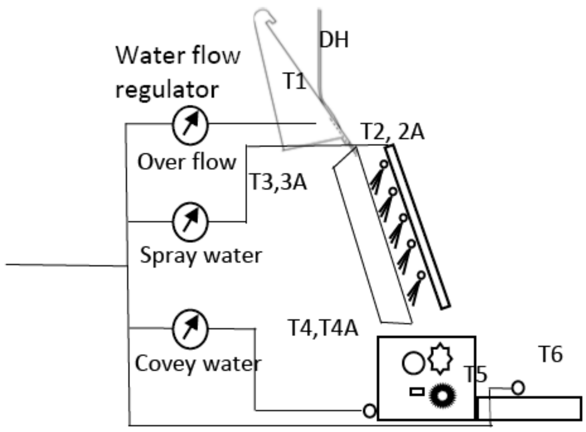
The depth of startup device plate grooves is a factor to prevent a polymer strand shifts to another groove. In this case, two depth grooves are tested to observe their influence to double chip forming, they are :

1) Depth groove 3mm (original groove).
2) Depth groove 4mm (deepening the groove).

e. Adding groove length at startup device plate. Polymer strand falls on a wide flat portion of a startup device plate. This allows the polymer strand to freely move. The cooling water flow at startup device plate is turbulent so the strand flow can easily shift and stick with other strands, by adding the groove length approaching polymer strand dropped, the strand only have a narrow space to make the strand directly move/fall to the groove and could not shift or stick with other strands.

4. RESULTS AND DISCUSSION

The experiment began with collecting the initial temperature data of the polymer strand and the cooling water from the die head until cutting.



Note:
DH : Die head polymer temperature.
T1 : Polymer temperature before meet to cooling water
T2 : Polymer temperature after leaving startup device plate
T3 : Polymer temperature at upper side strand guide.
T4 : Polymer temperature before cutting
T5 : Polymer and water temperature after cutting
T6 : Polymer and water temperature before dryer
T2A : Cooling water temperature before meet to polymer
T3A : Cooling water temperature after startup device plate
T4A : Cooling water temperature before cutting

Figure 6. Cooling Process at Polymer strand.

Table 1. Polymer and water temperature in every section at pelletizing machine

POSITION	D H	T1	T2	T3	T4	T5	T6	T2A	T3A	T4A
AVERAGE TEMPERATURE (ºC)	267	180	125	85	50	43	37	103	67	43

From Table 1. It has seen a trend of decreasing strand polymer temperature. At startup device plate area, polymer strand meet cooling water, polymer temperature reduce to 125 ºC while water temperature increase to 103 ºC, this is show polymer temperatures are still above glass temperature (Tg) and if polymer strand meet with others strand, they will sticking, while polymer temperature before cutting is 50 ºC, Polymer temperatures already below the Glass temperature Tg (Tg = 67 ~ 80 ºC), so that polymer strand surface has become solid and not sticking if they meet.

The most important thing in this process is the stage where strand polymer which has cooled can be cut. Strand polymer temperature shows 50 ºC, it means ready to cut.

There are some experiments has done to reduce double chips defect.

4.1 Regulating cooling water temperature.

Cooling water temperature is the main media to reduce polymer strand temperature. In this experiment degree of temperature will be adjusted to show the effect to double chip.

The polymer strand was cooled down in three sections, The cooling water debit set the same as the initial condition but the temperature degree will be regulated to find out the double chip effect.

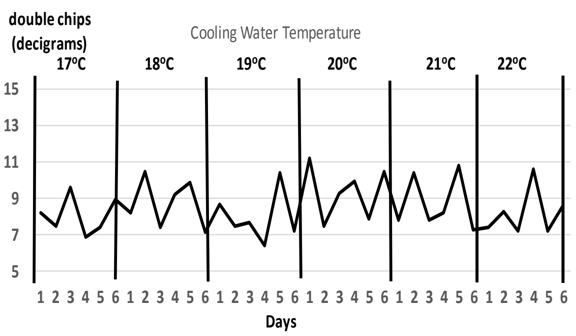


Figure 7. Graph of influence cooling water temperature to double chips.

Figure 7 shows that changing the temperature of water cooling at 17 ~ 22ºC did not have a significant effect on reducing the double chip problem. The average of double chips result at the beginning of this research (20ºC) was 8.7 decigrams/300 gram,

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trial by regulating the cooling water temperature resulting in almost the same value with the initial condition.

The experiments with cooling water temperatures below 17ºC could not be done because of limited facilities.

4.2 Regulating cooling water debit.

The second experiment was regulating cooling water debit. The regulation was divided into two different areas.

1) Regulate overflow cooling water debit at the startup device plate
2) Regulate spray debit at the strand guide plate

The purpose of regulating water debit was to make the polymer strand become cold fast so that the polymer strand will not stick when it meets another strand.

1) Regulate overflow cooling water debit at the startup device plate.

Regulating overflow cooling water debit aims to know changes in strand polymer temperature after leaving the die head. Polymer temperature becomes cold so the liquid rubber phase on strand polymer becomes solid and not sticking to another strand polymer.

The result of regulating cooling water debit to strand polymer at a startup device plate area is as follows:

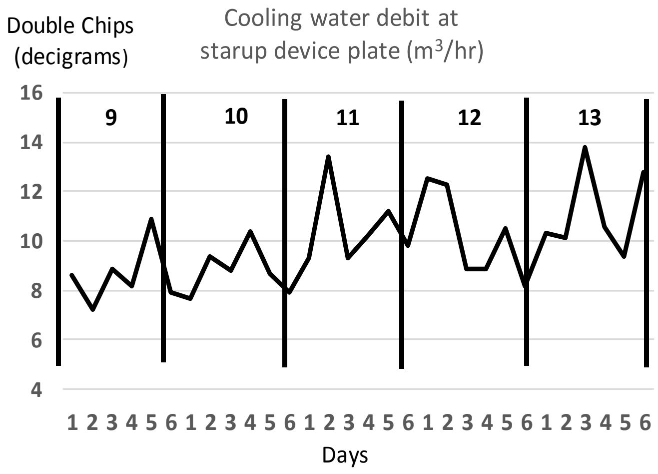

Figure 8. Graph of influence cooling water debit to double chip at startup device plate area.

Based on Figure 8, there is no significant changes/decrease in the double chip by changing the debit of cooling water at strand polymer in the startup device plate area. Reducing the cooling water debit (9 m3/hour) from the initial condition (10 m3/hour) results in the number of double chips becomes reduced, but the cooling water debit could not further reduce because the polymer strand tended to stuck, while at increasing flow (above 13 m3/min) double chips increase because movement polymer strand more random and strand easily to shift to another groove and stick with another strand.

2) Regulating spray cooling water debit at the strand guide area.

Polymer strand after pass startup device plate go to the strand guide area and get cooling by spray water cooling. This cooling to reduce strand temperature until below glass temperature (76 ~ 80 ºC). Spray cooling water divided into 10 set parallel spray and each set content 8 series spray nozzle (see figure 6)

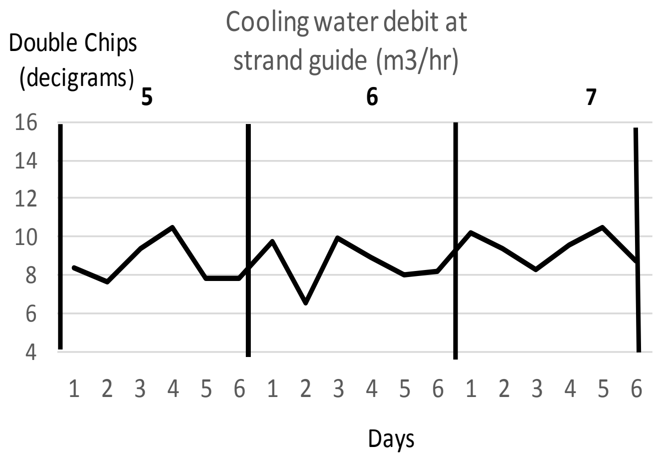

Figure 9. Graph of influence cooling water debit to double chip at strand guide area

Figure 9 shows that there are no significant changes in the number of double chips by changing the cooling water debit on the strand guide area. Changes in the cooling water debit are limited because at the debit below 5m3/hr there are many uncut chips, meanwhile, at a debit above 7m3/hr, the polymer strand tends to shift to another groove because the cooling water pushes the strand to outside.

4.3 Inclined angle degree of startup device plate.

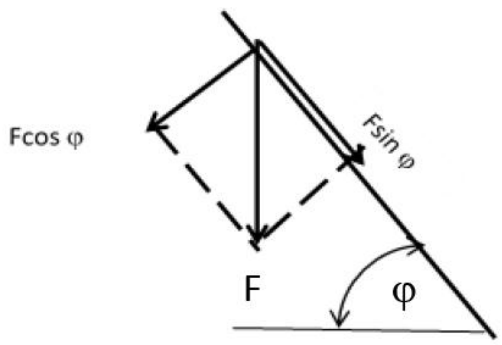

Figure 10. Force at strand polymer.

Changing the slope degree aims to find the right slope angle to reduce the occurrence of double chips. The results of the experiment are as follows:

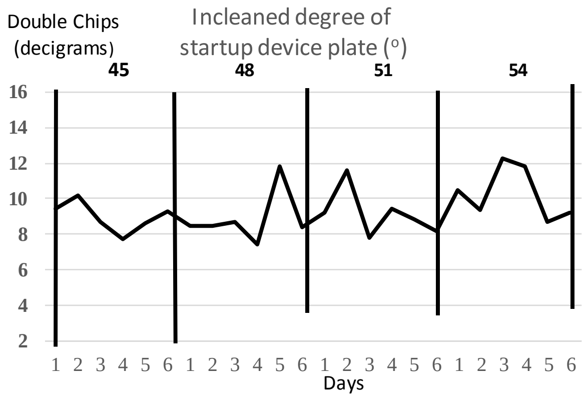

Figure 11. Graph of influence slope angle to double chips.

Figure 11 shows there is no clear sign of reducing double chip by slope angle changing. The slope angle changes are limited because for small angles (below 45°), polymer strand tends to stop/clump while large angles (above 54°) produce double chips increase and tend to vary number because of the strand easy to shift lanes.

4.4 Deepening the groove on startup device plate polymer.

Deepening the polymer groove from the original depth from 3mm to 4 mm. The objective of deepening the grooves is to make the polymer strand becomes more difficult to shift lanes so that each groove on the plate will only be filled with one polymer strand. This means that although polymer strand still melts, it doesn't meet another strand so sticking strand can be avoided.

Next, the polymer strand continues cools down to strand guide plate by receiving spray water cooling till its temperature reaches below glass temperature and the strand is ready for cutting.

The result of deepening the grooves at a startup device plate to the polymer strand is as follow:

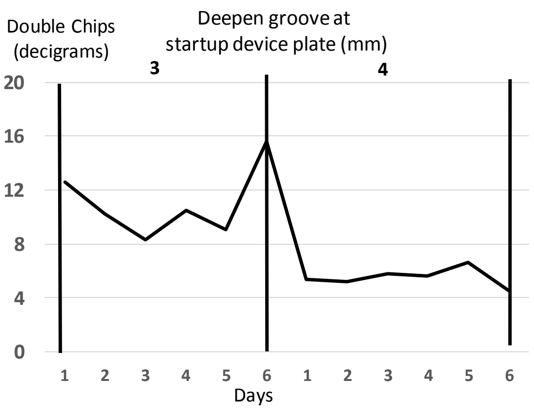

Figure 12. Graph of Deepening grooves at polymer startup device plate.

Figure 12 shows the result of addition depth groove to 4mm will reduce the number of double chips and also indicates double chips stable but still not significant. It means polymer strand tends to stable/not shifting after fall in a deep groove and strand will flow along the grooves till cut, but if the strand shifting to another groove, they will not shift again so strand becomes double and sticking. The number double chip will keep stable, reduced but not in large quantities.

4.5 Increasing length and depth of groove at the startup device plate.

The addition of groove lengths from 50mm to 75mm is the next step in this research of deepening grooves from 3 mm to 4 mm. Deepening the grooves results in a number of double chips become more stable and extending the length of the grooves provides a narrow space for the polymer strand to shift.

The polymer after leaving the die head directly went to the polymer groove. The deepen groove did not allow the strand to shift to others groove which means that every groove only filled with one polymer strand. Although the strand temperature was still high, the strand couldn't meet with other strands, so sticking polymers strand could be avoided and would result in reducing the double chip problem. The results of adding the groove length to reduce the number of double chips are as follows:

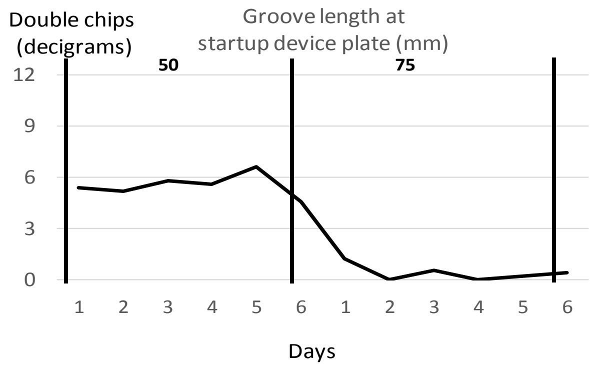

Figure 13. Graph of influence in increasing groove length to double chip on startup device plate.

Table 13 shows that there is a sharp decreasing double chip number in the experiment by adding the depth and the groove length at the startup device plate. The phenomenon i.e. polymer strand will immediately enter groove as soon as the strand touches the plate, so the strand becomes difficult to shift to another groove because it needs enough power to shift the polymer strand. Meanwhile, the strand that has entered to groove, the strand will start the cooling process until the temperature of the surface reaches below glass temperature and the polymer strand becomes solid and is ready for a cut.

5. CONCLUSIONS

The double chip defect at a Polyethylene terephthalate (PET) takes place from the effect of joining two melted polymer strands before a cut. Several important conclusions from the experiment are as follow:

1. Reducing water temperature or increasing water debit is intended to increase the cooling capacity, but the experiment proved double chips defect does not change because the strand has met with others strand at the area where the strand temperature still hot and they sticking before a cut.
2. Changing slope angle of startup device plate at a range of 45º to 54º has not clearly shown the effect to double chip defect, but reducing the angle below 45º has caused the strand to tend to clump and at above 54º the strand tended to freely move or the double chip increased.
3. Deepening the groove from 3mm to 4 mm makes strand after entering groove can't shift to others groove and increasing groove length from 50 mm to 75 mm at startup device plate makes strands approaching polymer dropped area. The polymer strand immediately enters to the closest groove, so every groove-filled only one polymer strand and can't shift, although strand temperature was still high, the strand couldn't stick, because they had their own groove and deepen groove ensured the polymer strand not to shift to another groove. This was the main solution to reduce the double chip defect.

The average of double chips defects after changing the profiles (deepen the groove and increase the groove length) at startup device plate reduced from 0.86 grams to 0.05 grams at 300 grams sample or total double defect become 0.02% from the total product.

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