

Effect of processing parameters on the shrinkage behaviour of injection moulded polypropylene gear

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Abstract. The polymer gears are widely used as basic motion transfer elements in many industries. Continuous improvement on the quality performance of polymer gears is very important for their ability to meet present demand. So that, controlling the parameters setting in polymers gears are very importance in order to get the best gears quality. In this study, the influences of injection moulding processing parameters on shrinkage of polypropylene gears was investigated by using Taguchi approach. It was found that the optimal processing parameters for addendum circle shrinkage, dedendum circle shrinkage and tooth thickness shrinkage are A1B1C3D3E1F2G3, A3B1C3D3E3F1G3, and A1B3C3D2E3F2G1 respectively. This results showed that pattern of fluctuation showed either an improvement or reduction in quality characteristics upon the change of process parameters setting.

1. Introduction

An increasing demand of polymer gears used as a basic and motion transfer components make it is widely used in many industries starting from lightweight industries such as copy machine, printers and facsimiles until to heavyweight industries such as automotive, robotics and starter motors manufacturing [1]. The light weight, noise reduction, anti-corrosion, oil free condition as well as low materials and manufacturing cost advantages that owned by polymers gear have contribute to their increasing of application compare to metal gears [2]. Nowadays, an injection moulding process offer the shorts product cycle, excellent aesthetics appearance and high flexibility of part geometry for polymer gears production with low cost and high productivity rate. Although injection moulding is the most widely used process in polymers gear manufacturing, there are still needs tremendous efforts to solve the problems especially regarding to shrinkage in polymer gears. Over the past few decades, a lot of studies are conducted with purpose to enhance the performance and durability of polymer gears by means of internal structure enhancement [3], [4] and design modification [5], [6]. Apart of material enhancement, another consideration for the possibility of optimizing the injection moulding process from the manufacturing point of view should not grossly underestimated. It could be an appealing approach to enhance the polymer gear's quality especially when it relates to shrinkage problem, considering no extra processing cost is required. Generally, there are numerous processing parameters that need to be controlled during injection moulding which can be classified into four namely, temperature, pressure, time, and distance [7]. With plastic materials exhibiting extremely convoluted properties, and the intricacy of the moulding process, attaining the desired final moulded gear quality particularly when it comes into shrinkage, is a very challenging task. Thus, the aim of this study is to investigate the impact



of variation in processing parameters on shrinkage behaviour in moulded polymer gears as well as to determine the optimal processing parameters that can minimize the shrinkage problem in polymer gear. Seven processing parameters including melting temperature, mould temperature, injection pressure, injection time, packing pressure, packing time and cooling time with three levels of each was systematically analysed and investigated in this study via the Taguchi method.

2. Methodology

Polypropylene (PP) was used as gear material in this study, denoted as Titanpro Polypropylene 6331 by Titan Chemicals. Prior to injection moulding process, the PP was dried at 80 °C for 2 hours to remove moisture for better moulding quality. The spur gear with module 1.5, pressure angle 20°, 20 teeth and 10mm thickness compliance with American Gears Manufacturers Association (AGMA) was the part studied (Figure 1).



Figure 1. Spur Gear

2.1. Design of experiment

The experiment was conducted by using Taguchi method approach in order to study the influences of processing parameters on polymer gears shrinkage. Seven parameters of melting temperature, mould temperature, injection pressure, injection time, packing pressure, packing time and cooling time with three levels of each factor was selected, as shown in Table 1. Shrinkage in addendum circle, dedendum circle and tooth thickness of the gear were studied. The orthogonal array (OA) L_{18} , as tabulated in Table 2 are used in designing the experiments. All the trials in L_{18} OA was conducted by using Battenfeld TM750/210 injection moulding machine with five repetitions of each trial.

Table 1. Factors and levels selected in experiments

Column	Parameters	Level 1	Level 2	Level 3
A	Melting temperature (°C)	220	230	240
B	Mould temperature (°C)	40	50	60
C	Injection pressure (bar)	80	90	100
D	Injection time (s)	1	2	3
E	Packing pressure (%)	70	80	90
F	Packing time (s)	5	10	15
G	Cooling time (s)	50	60	70

2.2. Shrinkage Measurement.

Rax Vision DC 3000 Mitutoyo profile projector was used to measure the shrinkage rate of moulded gear addendum and dedendum circle as well as tooth thickness by measuring their two dimensional contours. To reduce the variance in measurement, five samples of each injected gear are measured and their relative shrinkage rate are calculated based on following equation:

$$S = (D - D_m)/D_m \times 100\% \quad (1)$$

Where S = shrinkage, D = injected gear dimension and D_m = mould dimension

Table 2. L₁₈ OA of experimental study

Trials	A	B	C	D	E	F	G
1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2
3	1	3	3	3	3	3	3
4	2	1	1	2	2	3	3
5	2	2	2	3	3	1	1
6	2	3	3	1	1	2	2
7	3	1	2	1	3	2	3
8	3	2	3	2	1	3	1
9	3	3	1	3	2	1	2
10	1	1	3	3	2	2	1
11	1	2	1	1	3	3	2
12	1	3	2	2	1	1	3
13	2	1	2	3	1	3	2
14	2	2	3	1	2	1	3
15	2	3	1	2	3	2	1
16	3	1	3	2	3	1	2
17	3	2	1	3	1	2	3
18	3	3	2	1	2	3	1

3. Results and Discussion

3.1 Signal-to-Noise Ratio (S/N)

Taguchi method introduced the S/N ratio approach in order to measure the deviation of quality characteristics from their target value. The higher value of S/N ratio indicate the minimization of noise sensitivity of any process. The S/N ratio can be divided into three stages: the-lower-the-better, the-nominal-the-better and the-bigger-the-better. The objective of this study is to minimize the value of shrinkage in addendum and dedendum circle, as well as in tooth thickness of the PP injected moulded gears. The S/N ratio for all 18 trials are reported in Table 3.

Table 3. The S/N ratio of quality characteristics

Trials	Addendum circle (dB)	Dedendum circle (dB)	Tooth thickness (dB)
1	33.800	32.821	25.347
2	34.258	33.043	25.783
3	34.659	33.900	26.577
4	33.741	32.753	22.275
5	34.511	33.176	25.398
6	34.740	33.559	25.955
7	34.398	33.287	22.150
8	34.882	33.506	22.286
9	34.227	33.038	22.298
10	34.327	33.659	22.550
11	33.825	32.649	25.906
12	34.166	33.059	26.595
13	34.636	33.463	22.529
14	35.217	33.983	22.258
15	34.020	32.831	25.636
16	31.803	34.140	22.639
17	34.626	33.491	22.142
18	33.627	32.845	21.837

3.2 The effects of processing parameter on PP gears shrinkage

For better interpretation of the S/N results tabulated in Table 3 in determining the optimal levels of each processing parameters studied in this research, the results in Table 3 can be presented graphically. Figure 3 demonstrates the impact of variation in melting temperature (A), mould temperature (B), injection pressure (C), injection time (D), packing pressure (E), packing time (F) and cooling time (G) on the shrinkage behaviour in addendum and dedendum circle as well as in tooth thickness of the PP gears.

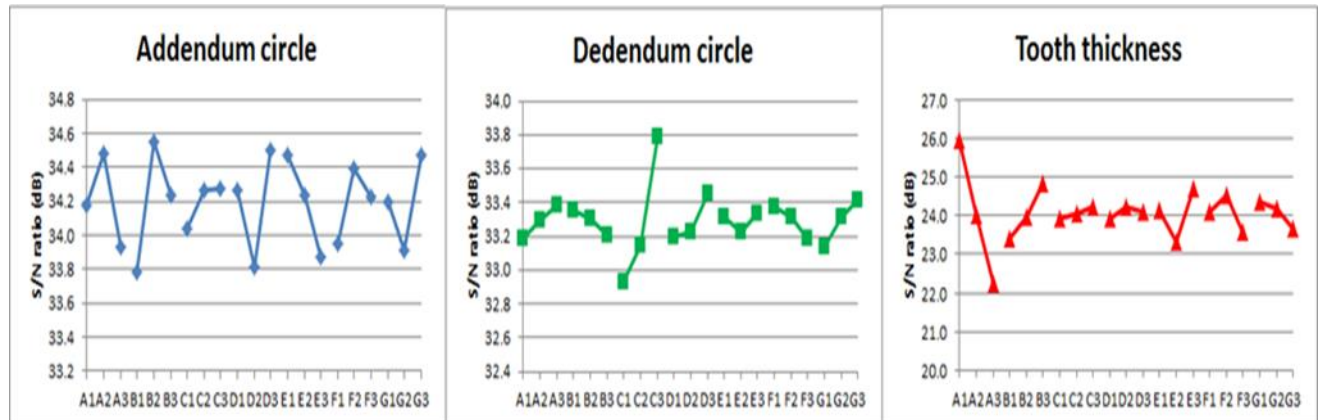


Figure 2. Shrinkage S/N Ratio Response Plot

From Figure 2, it is clearly shown that shrinkage behaviour in addendum and dedendum circle as well as in tooth thickness of the injected PP gears, which in this case, are presented by the S/N ratio, are affected significantly by variations in processing parameters. It can be observed that for the shrinkage in addendum circle of the moulded PP gear, the increment of melting temperature, mould temperature, injection pressure and packing time levels, the shrinkage rate has been minimized. However, the shrinkage rate seen to be increased upon the increment of injection time, packing pressure and cooling time levels. For shrinkage in dedendum circle of the moulded PP gear, the increasing of melting temperature, injection pressure, injection time and cooling time is observed in minimizing the shrinkage rate. Otherwise, the increasing of mould temperature, packing pressure and packing time levels have increased the shrinkage rate. Meanwhile, for the case of tooth thickness, the increment of mould temperature, injection pressure, injection time and packing time levels has reduced the shrinkage rate of tooth thickness. In contrary, the increment of melting temperature, packing pressure and cooling time is observed to increase the tooth thickness shrinkage.

The best combination of processing parameters and levels can be easily obtained from Figure 2 by selecting the level of each parameters with the highest value of S/N response. For addendum circle shrinkage minimization, A1B1C3D3E1F2G3 is identified as an optimal parameters combination, represent 220°C melting temperature, 40°C mould temperature, 100bar injection pressure, 3s injection time, 70% packing pressure, 10s packing time and 70s cooling. Meanwhile, A3B1C3D3E3F1G3 is identified as an optimal parameters combination in minimizing the shrinkage in dedendum circle represent 240 °C melting temperature, 40 °C mould temperature, 100 bar injection pressure, 3 s injection time, 90 % packing pressure, 5 s packing time and 70 s cooling time. On the other hand, A1B3C3D2E3F2G1 is identified as optimal processing parameters in minimizing the tooth thickness shrinkage of the moulded PP gear. The parameters setting are melting temperature of 220 °C, mould temperature of 60 °C, injection pressure of 100 bar, injection time of 2s, packing pressure of 90 %, packing time of 10s and cooling time of 50s.

3.3 Analysis of Variance (ANOVA)

To examine the extent to which processing parameters affects the shrinkage in addendum and dedendum circle as well as in tooth thickness of the moulded PP gear, ANOVA of the Taguchi method for the S/N ratios (Table 3) is performed. ANOVA enables engineers to quantitatively estimate the relative contribution of each processing parameter to the overall measured quality characteristics. Table 4

presents a summary of percentage contribution, denoted as “P” of all seven parameters on shrinkage in addendum and dedendum circle as well as in tooth thickness of the moulded PP gear. Roy [8] suggested of using the 10% rule, where, a parameter is considered insignificant when its influence is less than 10% of the highest parameter influence.

Table 4. ANOVA of percentage contribution

Parameters	Addendum circle	Dedendum circle	Tooth thickness
	P	P	P
Melting temperature (°C)	9.960	3.440	69.549
Mould temperature (°C)	19.612	1.985	9.941
Injection pressure (bar)	2.293	70.533	0.385
Injection time (s)	16.002	7.238	0.434
Packing pressure (%)	12.202	1.230	9.639
Packing time (s)	6.503	3.050	4.675
Cooling time (s)	10.029	6.628	2.495

From the results of percentage contribution (P) in Table 4, the mould temperature appears to be the most decisive processing parameter in reducing the shrinkage in addendum circle of the moulded PP gear. The percentage contribution of the mould temperature is 19.612%, outweighing the other processing parameters followed by injection time, packing pressure, cooling time, melting temperature, packing time and injection pressure for the case of addendum circle. For dedendum circle, only two out of seven processing parameters, namely injection pressure and injection time, are considered to be significant, following the 10% rule. Meanwhile for tooth thickness, the most decisive processing parameter in reducing the shrinkage is found to be melting temperature with the percentage of contribution (P) of 69.549 %. By using 10% rule, the second significant parameter is mould temperature followed by packing pressure.

4. Conclusion

In this study, the influence of processing parameters on shrinkage in addendum and dedendum circle as well as in tooth thickness of PP injection moulded gears was investigated by using Taguchi approach. The findings from the analysis of the results, obviously showed that the variation in parameters setting have significant impact in minimizing the shrinkage in addendum and dedendum circle as well as in tooth thickness of the moulded PP gear. The set of optimal processing parameters that predicted in minimizing the shrinkage in addendum circle is identified as melting temperature of 220 °C, mould temperature of 40 °C, injection pressure 100 bar, injection time 3 s, packing pressure of 70%, packing time of 10s and cooling time of 70s. For the shrinkage in dedendum circle, the set of optimal processing parameters is predicted to be melting temperature of 240 °C, mould temperature of 40 °C, injection pressure 100 bar, injection time 3 s, packing pressure of 90%, packing time of 5s and cooling time of 70s. As for tooth thickness, the set of optimal processing parameters that predicted in minimizing the shrinkage is identified as melting temperature of 220 °C, mould temperature of 60 °C, injection pressure 100 bar, injection time 2 s, packing pressure of 90%, packing time of 10s and cooling time of 50s.

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