[논　문] 한국재료학회지
Korean J. Mater. Res.
Vol. 30, No. 12 (2020)
https://doi.org/10.3740/MRSK.2020.30.12.650

Effects of Injection Molding Parameters and their Interactions on Mechanical Properties of PMMA/PC Blend

Van Thanh Hoang†, Duc Binh Luu†, Le Hung Toan Do, Ngoc Hai Tran, Pham The Nhan Nguyen, Minh Sang Tran and Minh Thong Tran

Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang, Danang City, Vietnam

(Received September 8, 2020 : Revised November 5, 2020 : Accepted November 21, 2020)

Abstract A combination of Polycarbonate (PC) material and Polymethylmethacrylate (PMMA), fabricated using an injection molding machine, has been investigated to determine its advantages, as studied in Ref. 1). This paper aims to investigate the optimization of PMMA/PC blend for both tensile yield strength and impact strength. Furthermore, interaction effects of process conditions on mechanical properties including tensile yield strength and impact strength of PMMA/PC blend by injection molding process are interpreted in this study. Tensile and impact specimens are designed following ASTM, type V, and are fabricated by injection molding process. The processing conditions such as melt temperature, mold temperature, packing pressure, and cooling time are applied; each factor has three levels. As a result, in comparison with optimization of separated responses, mechanical properties of PMMA/PC are found to decrease when optimizing both tensile and impact strengths simultaneously. The melt temperature is found to be the most significant interaction parameter with the mold temperature and packing pressure. In addition, there is more interaction between the mold temperature and cooling time. This investigation provides a useful understanding of the control of injection molding processing of polymer blends in optical application.

Key words polycarbonate, polymethylmethacrylate, tensile strength, impact strength, Taguchi method.

1. Introduction

Miscibility of PMMA/PC blends was investigated by several methods including chemical solution.[2)] Kim and Burns[3)] studied that dissolution of PC in PMMA-rich phase is less than that of PMMA in PC-rich phase. In addition, effects of PC and PMMA concentrations on the glass transition temperature of PC and PMMA, respectively were explored for PMMA/PC blend. Adamove et al.[4)] investigated effect of specimen preparation methods on structures of PMMA/PC blends and the melt blending method was found to have metastable systems. Samples of PMMA/PC blend made by the screw extrusion were used to study mechanisms of tensile deformation via the dilatometric measurements.[5)] Rybnicek et al. proposed the binary and ternary blends from three materials including PMMA, PC, and Acrylonitrile butadiene styrene. To describe the relation between the deformation and fracture property, blend compositions, morphology, processing parameters were investigated.[6)]

PC and PMMA are widely used for optical secondary elements due to transparence and high refractive index which is around 1.5. PC possesses high impact strength whereas PMMA is found to have high tensile strength. A blending of PMMA and PC would be expected to obtain good mechanical properties for a wide range of applications, especially for illumination of the optical elements. In fact, as far as PMMA/PC blends are concerned, almost the works of PMMA/PC blending were performed thanks to chemical substance for dissolution. However, the PMMA/PC blend should be explored by injection molding process for practical applications. This paper aims to investigate effects of processing conditions and their interactions on mechanical properties of PMMA/PC blend with 50 % PC composition (50PMMA/50PC blend) by experimental injection molding process and optimization

†Corresponding author
E-Mail : hvthanh@dut.udn.vn (V. T. Hoang, Univ. Danang)
ldbinh@dut.udn.vn (D. B. Luu, Univ. Danang)

© Materials Research Society of Korea, All rights reserved.
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creative-commons.org/licenses/by-nc/3.0) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

of Taguchi method.[7)]

2. Experimental Set-up and Methods

2.1 Design of Experiment

There are four factors taking into account in this study such as melt temperature (A), packing pressure (B), mold temperature (C), and cooling time (D).[1)] Each factor has three levels. The factors and levels are shown in Table 1. L_9 orthogonal array[7)] was utilized to investigate effects of injection molding processing conditions to the mechanical properties, specifically tensile yield strength and impact strength. Nine treatments were carried out and there are five specimens for each treatment. The quality characteristics are tensile yield strength and impact strength. The signal-to-noise (S/N) ratio is usually used to justify the effects of the parameters. In present study, the maximum tensile yield strength and impact strength are expected. Therefore, the quality characteristics for tensile yield strength and impact strength are Larger-The-Better (LTB) expressed as (1),[7)] where η_{LTB} is the Signal-to-Noise ratio for the LTB, y_i is the experimental value of i^{th} part and n is the total number of experimental parts. This study selected the n value of five. According to the Taguchi's technique, a larger Signal-to-Noise value corresponds to the better quality characteristic. Therefore, the objective of this experiment is to maximize the Signal-to-Noise value (η_{LTB}). It means that desired values are maximum tensile yield strength and impact strength.

$$\eta_{LTB} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad (1)$$

2.2. Injection Molding Process and Materials

Polymer materials were supplied in pellet form. PMMA with type of Acryrex CM-205 produced by Chi Mei Co Ltd., and PC with type Panlite L-1225L made by Teijin Chemical Ltd were used in this experimental study. To eliminate the humidity, the PMMA and PC were dried in a vacuum hopper at 85 °C and 120 °C for 24 h, respectively before handling mixing.

For specimens preparation, the vertical injection molding machine was employed, which has maximum injection pressure of 210 MPa, injection velocity of 90 mm/s, clamping force of 25tf, and screw diameter of 22 mm.

Table 1. Factors and Levels for experimental design.

Levels	Factors			
	A (°C)	B (MPa)	C (°C)	D (s)
1	235	35	55	20
2	255	55	75	25
3	275	75	95	30

Mechanical properties including tensile yield strength and impact strength were carried out at room temperature of 23 °C. As tensile testing, speed of crosshead position used is 5 mm/min and basic pendulum impact tester was used to measure impact strength.

3. Results and Discussion

In this section, the optimization of the mechanical properties of PMMA/PC blend will be presented first. The interaction effects of the injection molding parameters on tensile yield strength and impact strength are described later.

3.1 Tensile Yield Strength and Impact Strength

Fig. 1 presents S/N ratios of tensile yield strength and impact strength. The graphs on the left hand side are S/N for tensile yield strength, whereas the S/N for impact strength are presented via the diagrams on the right hand side. (a), (c), (e), (g) are the S/N for factors of melt temperature, packing pressure, mold temperature and cooling time, respectively. (b), (d), (f), (h) for impact strength and they are melt temperature, packing pressure, mold temperature and cooling time, respectively. It can be seen that lower melt temperature leads to larger mechanical properties of tensile yield strength and impact strength. In addition, decrease degree of tensile yield

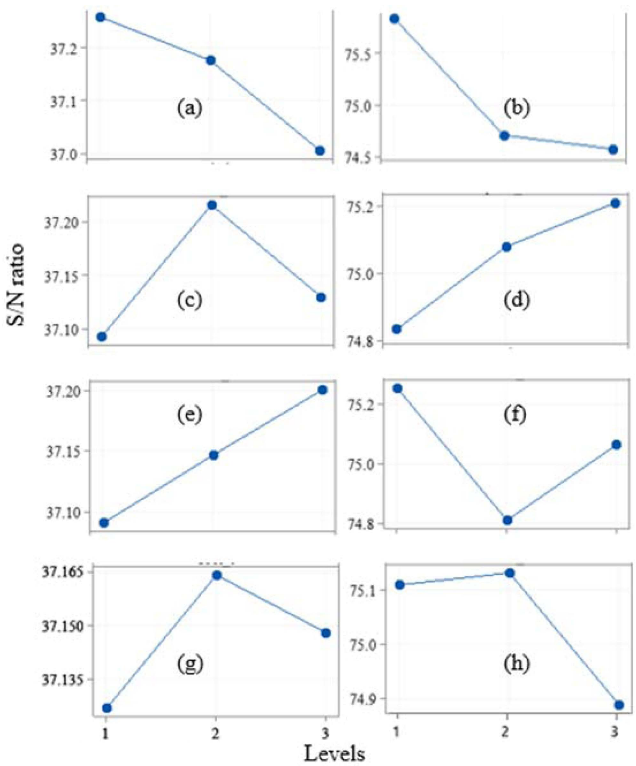

Fig. 1. S/N of tensile yield strength and impact strength

strength is greater than that of impact strength when increasing the melt temperature as shown in Fig. 1(a, b). This is due to that melt temperature of PMMA is lower than that of PC. At Fig. 1(c, d), in general, the mechanical properties raise when packing pressure is controlled from level 1 to level 2. However, as continuously increasing the packing pressure from level 2 to level 3, the tensile yield strength suddenly decreases while the impact strength slowly increases in this study. A reasonable cooling time for maximizing the mechanical properties is around level 2. According to the results from,[8] the optimal parameter settings for single response optimization of tensile yield strength and impact strength were obtained. In particular, optimal parameter setting for response of tensile yield strength is $A_1B_2C_3D_2$, whereas $A_1B_3C_1D_2$ has been found to be the optimal parameter setting for response of impact strength. Therefore, the study proposes a parameter setting for optimizing both tensile yield strength and impact strength simultaneously. The setting is A_1 (235 °C), B_{23} (65 MPa), C_{13} (75 °C) and D_2 (25s), where B_{23} was taken into account as average values between levels 2 of tensile yield response and level 3 of impact one, and it is similar to C_{13}.

Table 2 presents the experimental results of the mechanical properties optimized for each response and for both of them. In particular, (I) represents the experimental verified values when applying the optimal parameters setting for the single response of tensile yield strength, whereas the experimental verified values of tensile yield strength when using the optimal parameters setting for the both responses of tensile yield strength and impact strength are shown by (II). The experimentally verified values when using the optimal parameters setting for the impact strength are depicted by (III), while (IV) represents the experimentally verified values as employing the optimal parameters setting for the both responses of tensile yield strength and impact strength. It is obvious that the mechanical properties of PMMA/PC blend decreases when using the recommended parameters setting for both cases of tensile yield strength and impact strength (II, IV). Fig. 2 and Fig. 3 present characteristics of stress-strain curves of (I) and (II), respectively. Tensile elongation of (I) is little larger than that of (II) as well.

3.2 Interaction Effects for Tensile Yield Strength

Figs. 4 ~ 6 examine whether the levels of one factor influence performance across the levels of another for investigation of tensile yield strength. Effect of level 1 of melt temperature on mold temperature is much larger than that of the others as shown in Fig. 4. This elicits that the blend with low melt temperature needs high mold temperature for avoiding short shot during injection

Table 2. Tensile yield strength and impact strength after verification.

Rep.	1	2	3	4	5	Average
(I)	80.87	79.32	79.58	78.08	78.51	79.27
(II)	78.74	77.75	76.97	77.77	75.60	77.36
(III)	6893.38	7199.75	6433.82	7506.13	6740.20	6954.66
(IV)	5821.08	5667.89	6127.45	7046.57	6893.38	6311.27

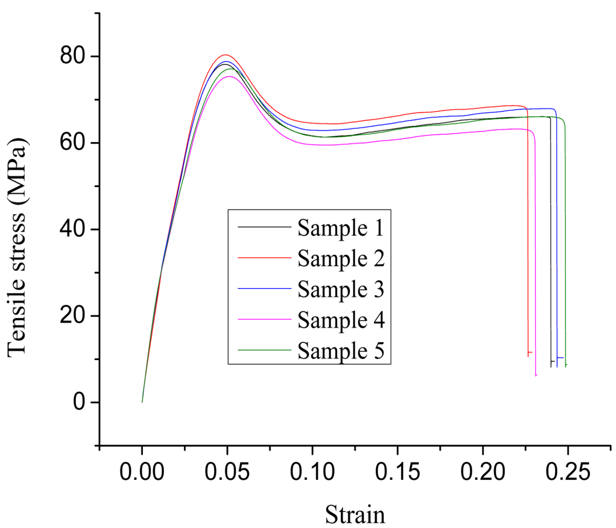

Fig. 2. Verification test of tensile stress and strain for 50PCPMMA/50PC when optimizing single tensile yield strength

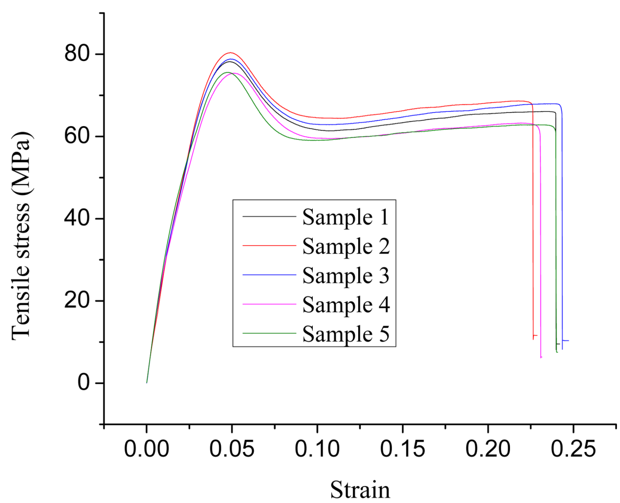

Fig. 3. Verification test of tensile stress and strain for 50PMMA/50PC when optimizing both tensile yield strength and impact strength simultaneously

molding process. Fig. 5 shows interaction effects between melt temperature and packing pressure where the level 3 is the least significant. It is not essential to provide more packing pressure as increasing melt temperature. The

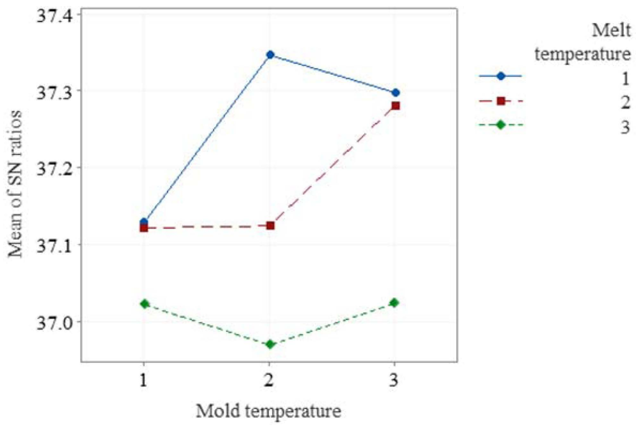

Fig. 4. The interaction effects of melt temperature to mold temperature for tensile yield strength.

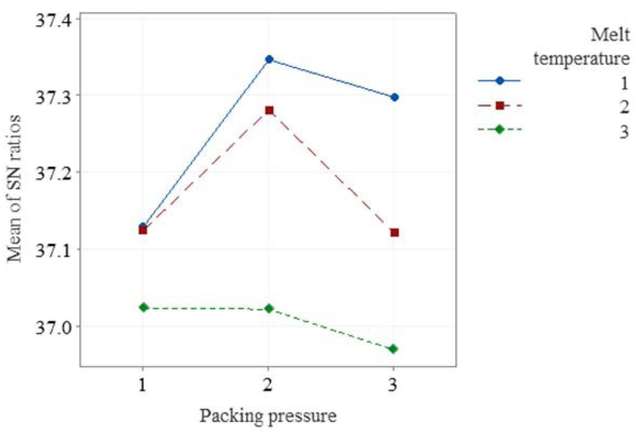

Fig. 5. The interaction effects of melt temperature to packing pressure for tensile yield strength.

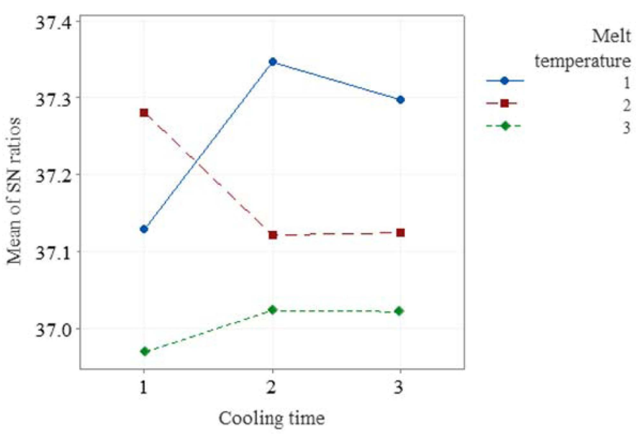

Fig. 6. The interaction effects of melt temperature to cooling time for tensile yield strength.

interaction influence of melt temperature on cooling time is plotted in Fig. 6 where level 1 of melt temperature is more significant and levels 2, 3 show the interaction happening at the range of level 1, 2 of cooling time. It is obvious that, when cooling time lasts longer, the melt temperature is independent on the cooling time for controlling tensile yield strength.

3.3 Interaction Effects for Impact Strength

Figs. 7 ~ 9 depict whether the levels of one factor influence performance across the levels of another for optimization of the impact strength. The interaction effect of melt temperature on mold temperature significantly occurs at level 2 as shown in Fig. 7. In similar for effect of melt temperature on packing pressure where the level 2 shows a more considerable influence than the others as shown in Fig. 8. In Fig. 9, there is no interactions for level 1, 3 of melt temperature across the levels of cooling time. However, the level 2 of melt temperature is significant in influencing cooling time. It can be seen

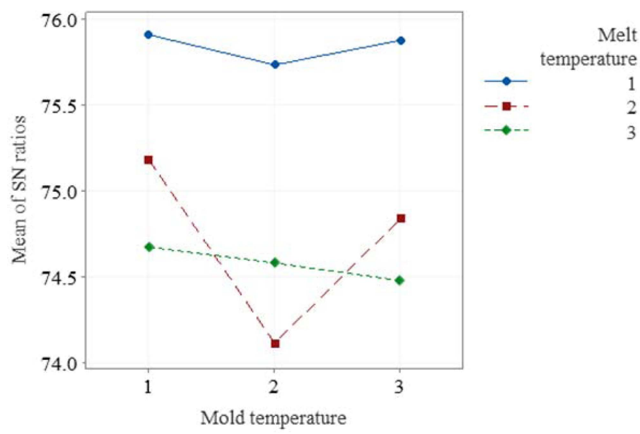

Fig. 7. The interaction effects of melt temperature to mold temperature for impact strength.

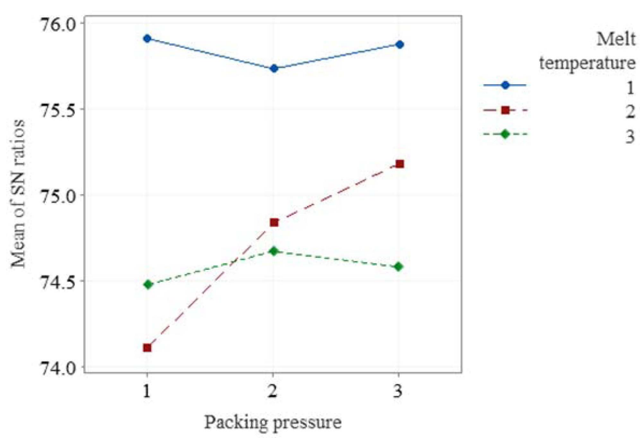

Fig. 8. The interaction effects of melt temperature to packing pressure for impact strength.

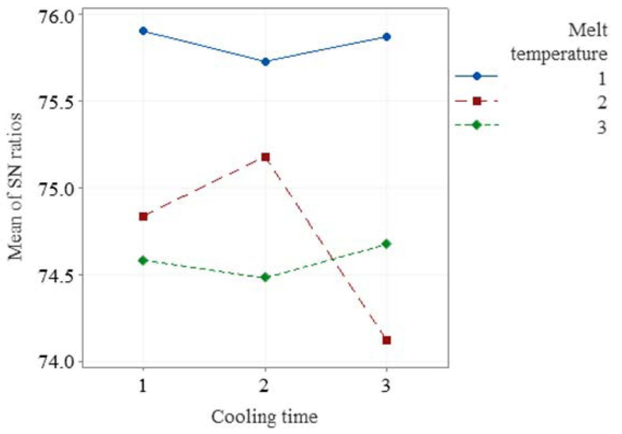

Fig. 9. The interaction of melt temperature on cooling time for impact strength.

that interaction effects of melt temperature on mold temperature, packing pressure and cooling time have been found to be remarkable at level 2 for impact strength. This is because that average melt temperature of around 255 °C is really sensitive on impact resistance via fracture toughness.[9]

4. Conclusion

Mechanical properties of PMMA/PC blend with 50% PC composition including tensile yield strength and impact strength have been investigated by injection molding process and optimization technique of Taguchi. The four factors and three levels for each of them were taken into account in this study. Nine treatments were carried out for both tensile and impact cases. The results show that the mechanical properties of PMMA/PC blend decreases when using the recommended parameters setting for simultaneously optimizing the tensile yield strength and impact strength. In addition, the melt temperature considerably influences the packing pressure and cooling time depending on levels of them when the interaction impact is taken into account. This investigation provides a clear understanding for fabricating optical molded elements for LED illumination. Furthermore, PMMA/PC blends could be applied in medical devices, appliance housings, automobile parts and protective equipment, and so on where the mechanical properties combination of PC and PMMA materials is essential.

Acknowledgement

This work was supported by The University of Danang, University of Science and Technology, code number of Project: T2020-02-30.

References

1. V. T. Hoang, C. C. A. Chen and C. H. Kuo, Adv. Mater. Res., **579**, 134 (2012).
2. J. S. Chiou, J. W. Barlow and D. R. Paul, J. Polym. Sci., Part B: Polym. Phys., **25**, 1459 (1987).
3. W. N. Kim and C. M. Burns, J. Appl. Polymer Sci., **41**, 1575 (1990).
4. L. V. Adamova, A. A. Tager, I. N. Razinskaya, V. P. Lenedev, N. T. Nerush and A. M. Kornev, Polym. Sci. U.S.S.R., **30**, 1377 (1988).
5. S. A. Xu and S. C. Tjong, Eur. Polym. J., **34**, 1143 (1998).
6. J. Rybnicek, R. Lach, M. Lapcikova, J. Steidl, Z. Krulis, W. Grellmann and M. Slouf, J. Appl. Polym. Sci., **109**, 3210 (2008).
7. P. J. Ross, Taguchi Techniques For Quality Engineering, 2nd ed., p. 71, McGraw Hill, New York (1996).
8. V. T. Hoang, D. B. Luu, Q. B. Tao and C. C. A. Chen, Key Eng. Mater., **863**, 67 (2020).
9. W. J. Cantwell and J. Morton, Composites, **22**, 347 (1991).

Author Information

Van Thanh Hoang
Lecturer at Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang

Duc Binh Luu
Lecturer at Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang

Le Hung Toan Do
Lecturer at Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang

Ngoc Hai Tran
Lecturer at Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang

Pham The Nhan Nguyen
Lecturer at Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang

Minh Sang Tran
Lecturer at Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang

Minh Thong Tran
Lecturer at Faculty of Mechanical Engineering, University of Science and Technology, The University of Danang