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Influence of Injection Molding Parameters on the Mechanical Properties of Injected PC/ABS Parts

Fatma Hentati and Neila Masmoudi

Abstract

This study optimized the influence of process parameters on the mechanical properties during injection molding (IM) of PC/ABS blend. The Taguchi method of design of experiments (DOE) was employed to optimize the process parameters and to increase the tensile strength and the elasticity module. Taguchi's L9 (3^4) orthogonal array design was employed for the experimental plan. Process parameters of the injection molding such as material temperature, injection pressure, holding time, and mold temperature were studied with three levels. The Signal to noise (S/N) ratio for mechanical properties of PC/ABS blend using the Taguchi method was calculated. Taguchi's results proposed two sets of optimal injection parameters conditions to achieve the best mechanical characteristics (σ , E). The (S/N) ratio results proved that the injection pressure was the more prominent than the other IM process parameters for the tensile strength, and the material temperature was the more prominent for the elasticity module.

Keywords: PC/ABS parts, injection molding parameters, Taguchi method, mechanical properties

1. Introduction

Plastic injection molding (IM) is one of the most important polymer processing operations in the plastic industry nowadays. The application of this process is increasing significantly in many fields, especially in the automotive parts. The most process injection molding parameters that analyze the mechanical properties are pressure, temperature, and time.

Experimental and-error approach to control the process parameters for injection molding is no longer effective. Wrong selection of these parameters induces a drop in the mechanical properties of injected molded parts [1–6].

Such problems can be solved by first developing optimization models correlating the responses and the process parameters. Optimizing these parameters requires a careful endeavor. Besides, the method of varying one parameter while keeping the others constant contains limitations such as the long time experience and the large number of experiments which raise its cost in order to get an important quality of the parts. Hence, a suitable optimization technique using design of experiment DOE

by Taguchi approach is then applied to search for fine tuning of parameter values to obtain the desired responses. The Taguchi method introduces an integrated approach that is simple and efficient for finding the best range of designs for quality, performance, and computational cost [7–9]. Taguchi method is a useful methodology for analyzing the variation using the signal-to noise (S/N) ratio. The Taguchi analysis of the S/N ratio specifies three situations of quality characteristics, as well as the-larger-the-better (LB), the nominal-the-better (NB) and the-smaller-the-better (SB).

A great deal of research used this approach is being carried out to understand, identify critical factors and to optimize the molding process. For example, Wegrzyn et al. conducted a study to investigate the impact of injection speed and melt temperature on electrical conductivity and dynamic mechanical properties of PC/ABS-MWCNT Nano composites [10]. These authors figured out that the injected molded specimens recover conductivity. In addition, Wang et al. elaborated experimentally the compression behavior of PC/ABS during monotonic and cyclic loading over a wide-ranging of temperatures (up to 373 K) and strain rates (up to 5000 s⁻¹) [11]. In parallel, Li et al. analyzed effect of process parameters namely, melt temperatures, injection speed and injection pressure to determine the influence of weld lines on appearance of PP products using Taguchi experimental design method [12].

Rafizadeh et al. showed that when fixing the mixing time and temperature, temperature and pressure of injection, mold temperature, and blend composition in mixing through the Taguchi orthogonal array, the impact strength of PC/ABS blend could be optimized [13]. Equally, Ozcelik studied the influence of the injection parameters and weld line on the mechanical properties of polypropylene (PP) during IM process via the design of experiment (DOE). Mechanical properties such as maximum tensile load, extension at break and charpy impact strength (notched) of the specimens were measured [14]. Furthermore, Kuram et al. discussed the tensile and the flexural strength during injection molding of virgin and recycled PBT/PC/ABS blends using Taguchi experimental design. The results showed the impact of injection pressure, holding pressure, and injection temperature on the mechanical properties of the molded parts [15]. Aditya M. Darekar used the Taguchi approach and found that quality and mechanical properties parts are mainly caused due to improper selection of the processing conditions during production [16].

In this study, the effect of the injection molding process on the mechanical properties of the injected PC/ABS parts was investigated. The Taguchi method was used to find out the optimal combinations of the injection molding (IM) parameters that provide better mechanical properties. These results are considered interesting especially in the automotive industries. We intend to reduce the rejection rate caused by the surface quality of some injected PC/ABS parts.

2. Material and methods

2.1 Industrial context

SKG Company recognized by the injection and metallization of the PC/ABS automotive parts, discovered the occurrence of some defects in the surfaces of the injected parts. These defects caused a high rejection rate [17].

2.2 Material elaboration

The commercial PC/ABS blend used in this investigation was the T45 PG. This blend was proximately oven dried at 120°C for 4 h [17]. Its mechanical and thermal properties are exhibited in **Table 1**.

Properties	Method	PC/ABS
MVR (260°C/5 kg)	ISO 1133	12 cm ³ /10 min
Melt viscosity(1000 s ⁻¹ /260°C)	ISO 11443	200 Pa.s
Vicat softening temperature	ISO 306	112°C
Tensile strength (50 mm/min)	ISO 527	49 MPa
Izod notched impact strength (23°C)°	ISO 180	40 kJ/m ²

Table 1.
Characteristics data of PC/ABS blend [13].

2.3 Injection machine and molded part description

As illustrated in **Figure 1(a)**, a horizontal injection molding machine “FCSHN 125SV” was used to elaborate the PC/ABS parts. Their maximum injection pressure and clamping force were 217 MPa and 125 kN, respectively. Its screw’s diameter was 34 mm.

The injection mold forms three imprints presented in **Figure 1(b)**. Imprint A was the tensile specimen. Imprint B was the dynamic tensile specimen. Imprint C was the torsion specimen [17].

This study is an alternate to investigate the impact of the injection process on the mechanical properties of injected PC/ABS parts.

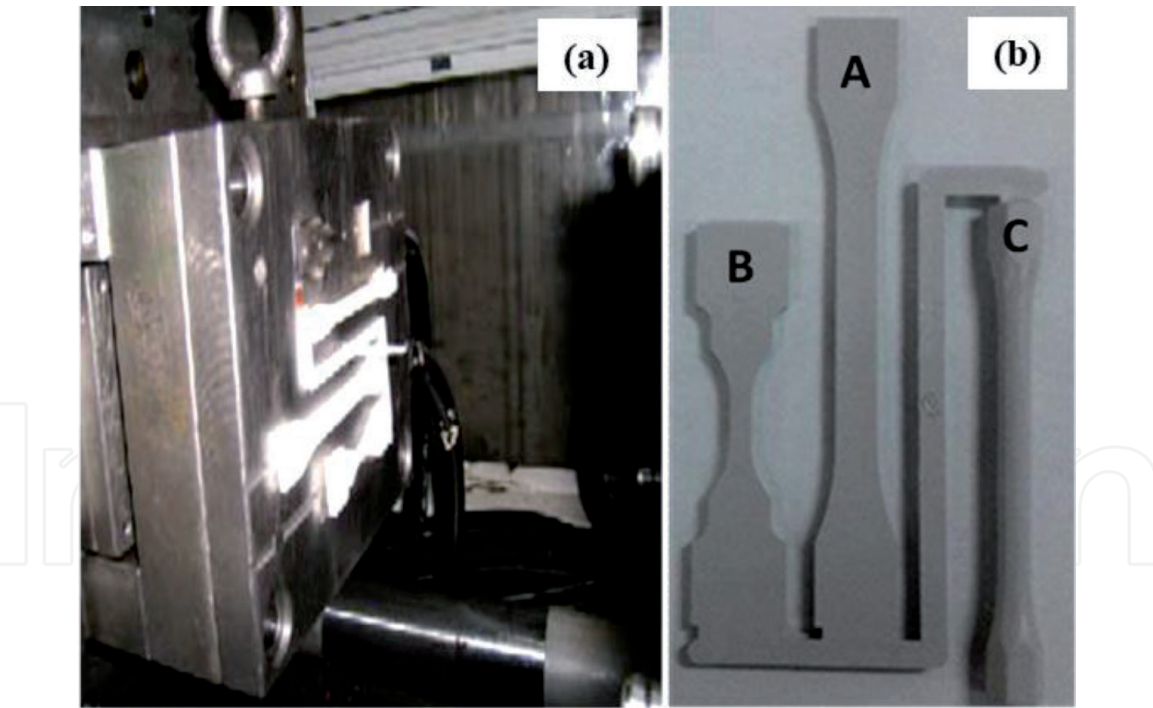


Figure 1.
(a) Injection molding machine, (b) obtained specimens [17].

2.4 Design of Experiment (DOE): Taguchi method

The developed Taguchi method goal is to determine the set of parameters which leads to the best mechanical properties of the PC/ABS injected part.

MINITAB 18 statistical software was used to find out the optimal processing conditions. A confirmation test was performed in order to guarantee the validity of the optimal experimental conditions considered from the design of the parameters.

Following preliminary tests carried out within the SKG Company, the choice of the factors and their levels was made as illustrated in **Table 2**.

The impact of the injection molding parameters on the mechanical characteristics are evaluated through the S/N ratio obtained in the Taguchi experimental plan. The S/N ratio was calculated by the larger is better quality characteristic for determining the effect of each process IM factor. The responses required are the tensile strength and the elasticity module.

Index	Factors	Unit	Level 1	Level 2	Level 3
A	Material Temperature	°C	240	250	260
B	Injection Pressure	bar	30	40	50
C	Holding Time	sec	4	8	14
D	Temperature Mold	°C	40	50	60

Table 2.
Geometric and process factors in three levels.

2.5 Tensile tests

The tensile tests were carried out, with imposed displacement, on a machine of the LLYOD INSTRUMENT type equipped with a 5 kN load cell.

All tests were achieved at ambient temperature and for a strain rate of 5 mm/min. The local deformation of the specimens during these tests was measured using an extensometer having an initial length of 25 mm and an elongation of ±1 mm.

The measurement was repeated at least 4 times for the samples and the average of three sample readings was taken for accurate results. The specimens used for the simple tensile test are taken from the ISO 527-2 standard. Its geometry is illustrated in **Figure 2**.

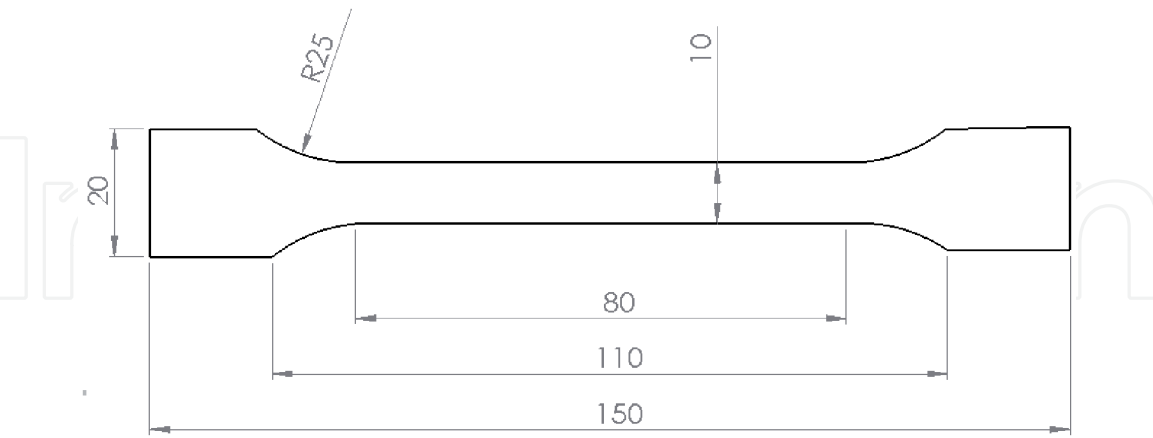


Figure 2.
Tensile specimen geometry (in mm).

2.6 Experimental

The injection molding (IM) process parameters considered in this study were: material temperature (A), injection pressure (B), holding time (C) and mold temperature (D).

In order to optimize these parameters, the famous optimization approach Taguchi was adopted. One main reason for using Taguchi is the low number of experiments. The

number of experiments required could be reduced to nine, instead of 81 (3^4) experiments to find out the parameters that influence on the mechanical properties.

As depicted in **Table 3**, an orthogonal array (OA) L9 was involved to investigate the effect of the process IM parameters. Three levels for each factor were studied. The DOF for the three levels was 2 (DOF = number of levels–1).

The elaboration of the injected PC/ABS parts was done within the SKG factory. Each combination was iterated 5 times ($9 \times 5 = 45$). The tensile strength and the elasticity module of the injected PC/ABS parts were regarded as the desired responses.

Test Number	Material Temperature (°C)	Injection Pressure (bar)	Holding Time (sec)	Mold Temperature (°C)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3.
Experimental layout using an L₉ orthogonal array.

3. Results and discussion

3.1 Mechanical test results

Figure 3 shows only the standard deviations of the tensile strength and elasticity module as a function of each experiment number. The mechanical

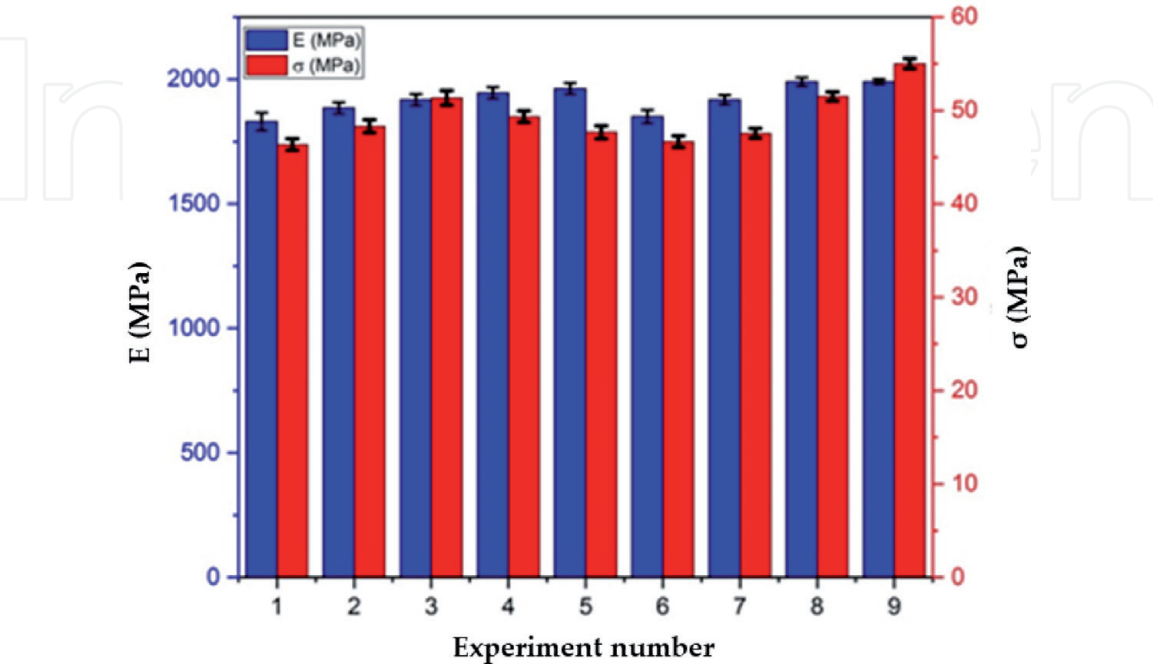


Figure 3.
Variation of the tensile strength and the elasticity module.

properties measured of each test performed were extracted. These values were introduced in the MINITAB 18 statistical software in order to optimize the injection parameters.

3.2 Taguchi results

3.2.1 Analysis of mean

The S/N ratios were calculated for each of the nine conditions of the test. All the details: the values, the average of each parameter at different levels, and the standard deviation of each test were depicted in **Table 4**.

The responses studied are the tensile strength and the elasticity module. **Tables 5** and **6** represented the average values of mean response relative to the four control parameters (factors) studied. **Figures 4** and **5** illustrated these values.

The optimum conditions corresponded to the maximum tensile strength and the elasticity module. These conditions illustrated the levels of the highest mean responses values chosen for each IM process parameter.

The averages values of the tensile strength (σ) and the elasticity module (E) were depicted in **Figures 4** and **5**. Hence, the optimum condition levels corresponding to the maximum tensile strength of the injection molding process of the PC/ABS blend was A3, B3, C2, and D3. That is to say, in the third level, at the material temperature of 260°C, represented by parameter A; an injection pressure of 50 bar, represented by parameter B; a mold temperature of 60°C represented by parameter D; and in

Test Number	A	B	C	D	σ (MPa)	S/N	E(MPa)	S/N
1	1	1	1	1	46.46	33.34	1830	65.24
2	1	2	2	2	48.3	33.67	1885	65.5
3	1	3	3	3	51.38	34.21	1918	65.65
4	2	1	2	3	49.33	33.86	1946	65.78
5	2	2	3	1	47.66	33.56	1962.67	65.85
6	2	3	1	2	46.66	33.37	1850	65.34
7	3	1	3	2	47.53	33.53	1917.67	65.65
8	3	2	1	3	57.5	34.23	1989.67	65.97
9	3	3	2	1	55	34.81	1990	65.97

$\bar{\sigma}$: Overall mean of tensile strength = 49.31 MPa.
 \bar{E} : Overall mean of elasticity module = 1921 MPa.

Table 4.
Experimental results of mechanical properties for T45PG.

Parameter	Level 1	Level 2	Level 3	Max-Min	Rank
A	48.72	47.89	51.36	3.47	1
B	47.78	49.16	51	3.25	2
C	48.21	50.89	48.86	2.68	4
D	49.72	47.5	50.74	3.24	3

Table 5.
Average values of the tensile strength (σ) at the different levels and their main effects.

Parameter	Level 1	Level 2	Level 3	Max-Min	Rank
A	1878	1920	1966	88	1
B	1898	1946	1919	48	4
C	1890	1940	1933	50	3
D	1928	1884	1951	67	2

Table 6.
Average values of the elasticity module (E) at the different levels and their main effects.

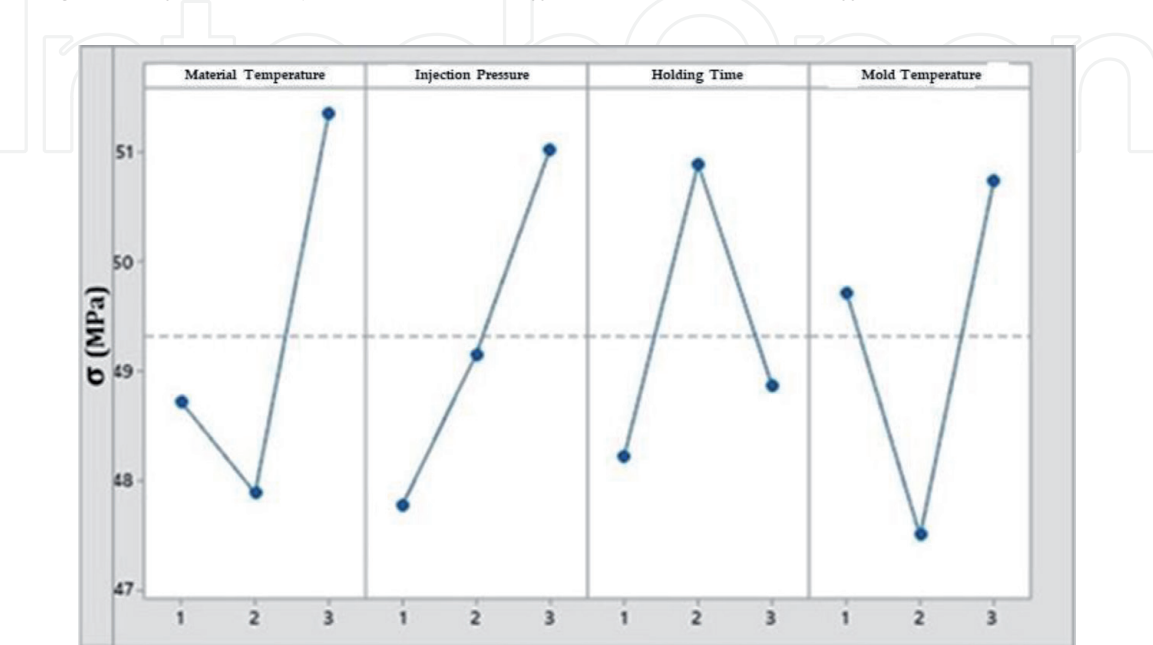


Figure 4.
Average values of tensile strength (σ) for each parameter at levels 1–3.

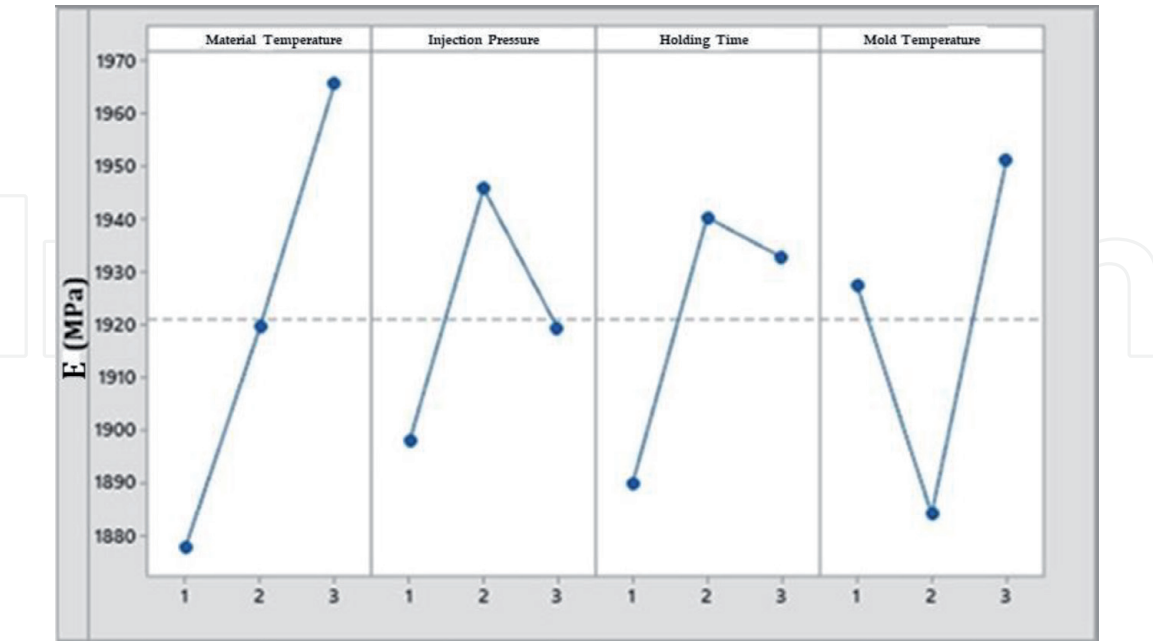


Figure 5.
Average values of elasticity module (E) for each parameter at levels 1–3.

the second level at a holding time of 8 sec, represented by parameter C. In parallel, the injection pressure was considered the more prominent than the other IM process parameters for the tensile strength.

Figure 5 shows that the material temperature represented by parameter A was more prominent than the other IM process parameters for the elasticity module. Moreover, the maximum elasticity module was recorded in the third level, at the material temperature of 260°C, represented by parameter A; a mold temperature of 60°C, represented by parameter D; and in the second level at; an injection pressure of 40 bar, represented by parameter B; a holding time of 8 sec, represented by parameter C.

The average values of S/N ratios of various parameters at different levels are shown in **Tables 7** and **8**. These values are plotted in **Figures 6** and **7**.

The S/N ratio analysis of the tensile strength plotted in **Figure 6** provides in to the same levels of the parameters as depicted in **Figure 4**. Therefore, A3, B3, C2, and D3 were the best levels for reducing the variability of the injection molding process of the PC/ABS blend.

Parameter	Level 1	Level 2	Level 3	Max-Min	Rang
A	33.74	33.6	34.2	0.59	1
B	33.58	33.82	34.13	0.55	3
C	33.65	34.12	33.77	0.46	4
D	33.91	33.53	34.1	0.57	2

Table 7.
Average values (σ) of S/N ratios at the different levels and their main effects.

Parameter	Level 1	Level 2	Level 3	Max-Min	Rang
A	65.47	65.66	65.87	0.4	1
B	65.56	65.78	65.66	0.22	4
C	65.52	65.75	65.72	0.23	3
D	65.69	65.5	65.8	0.3	2

Table 8.
Average values (E) of S/N ratios at the different levels and their main effects.

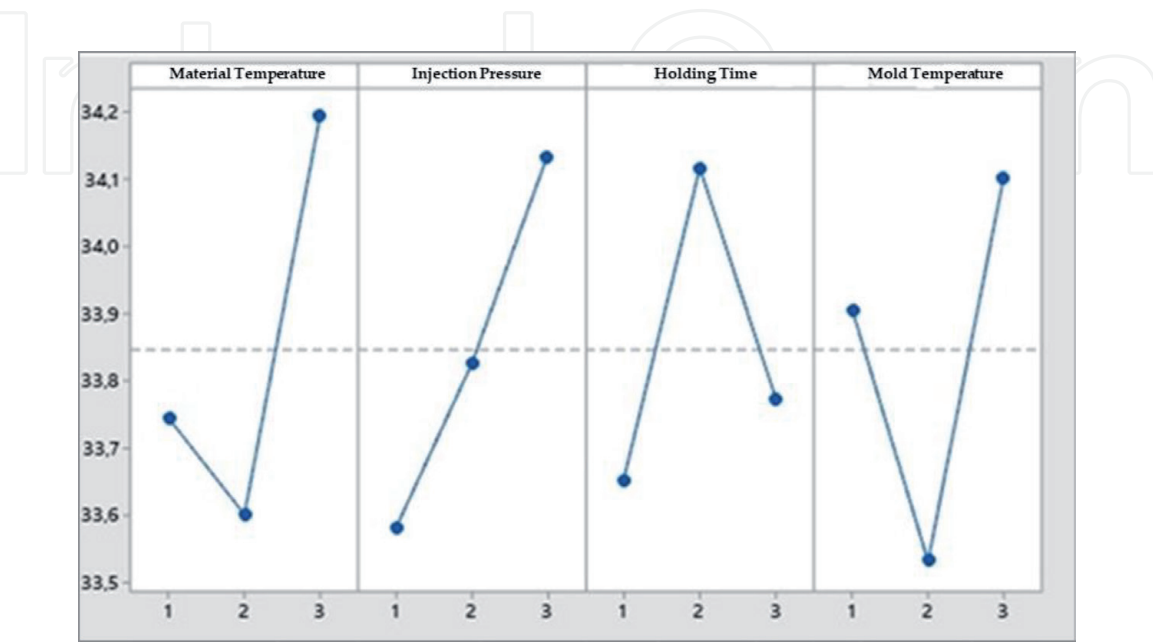


Figure 6.
Average values (σ) of S/N ratio for each parameter at levels 1–3.

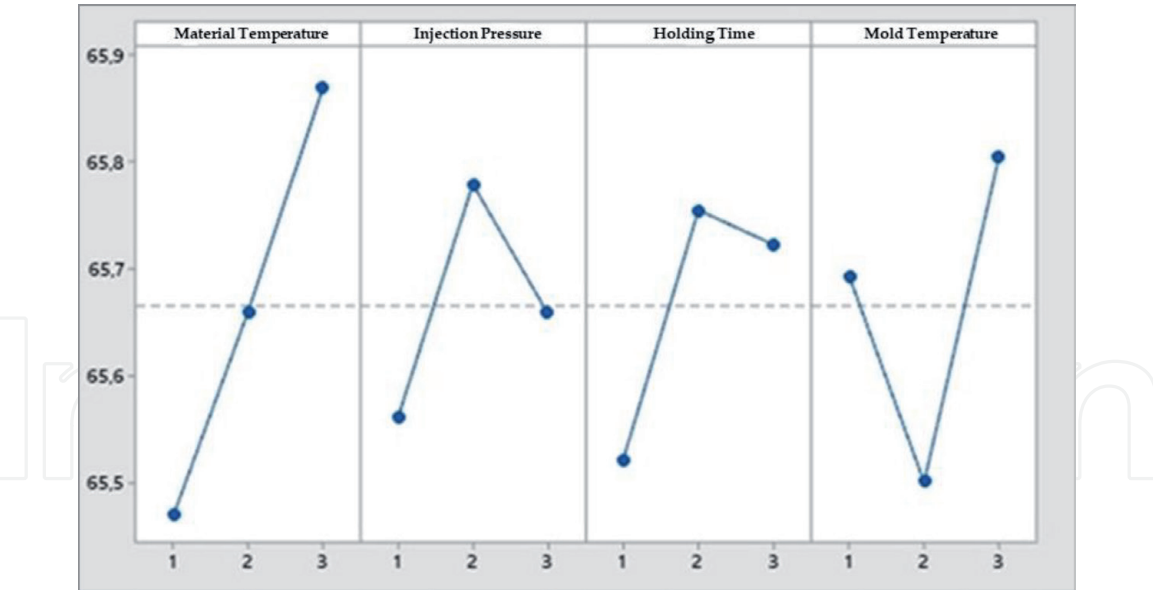


Figure 7.
 Average values (E) of S/N ratio for each parameter at levels 1–3.

The S/N ratio analysis of the elasticity module depicted in **Figure 7** offers in to the same levels of the parameters as shown in **Figure 5**. So, A3, B2, C2, and D3 were the best levels for reducing the variability of the injection molding process of the PC/ABS blend.

Table 3 shows the combinations of factor levels (3, 3, 2, 3) and (3, 2, 2, 3) were not among the obtained combinations within the tested experiment. Thus, it was necessary to verify the optimum injection molding conditions via confirmation tests of the experimental design.

3.2.2 Estimation of predicted mean

The optimum levels of the control parameters of the tensile strength (μ_1) and the elasticity module (μ_2) are determined as A3, B3, C2, D3 and A3, B2, C2, D3 respectively [18, 19]:

$$\begin{aligned} \mu_1 &= \bar{\sigma} + (\bar{A}_3 - \bar{\sigma}) + (\bar{B}_3 - \bar{\sigma}) + (\bar{C}_2 - \bar{\sigma}) + (\bar{D}_3 - \bar{\sigma}) \\ &= 51.36 + 51 + 50.89 + 50.74 - (3 \times 49.31) = 56.06 \text{ MPa.} \end{aligned} \tag{1}$$

Where \bar{A}_3 is the average tensile strength at the third level of material temperature, 260°C, \bar{B}_3 is the average tensile strength at the third level of injection pressure, 50 MPa, \bar{C}_2 is the average tensile strength at the third level of holding time, 8 sec, \bar{D}_3 is the average tensile strength at the third level of mold temperature, 60°C and $\bar{\sigma}$ is the mean of tensile strength obtained from **Table 4**.

$$\begin{aligned} \mu_2 &= \bar{E} + (\bar{A}_3 - \bar{E}) + (\bar{B}_2 - \bar{E}) + (\bar{C}_2 - \bar{E}) + (\bar{D}_3 - \bar{E}) \\ &= 1966 + 1946 + 1940 + 1951 - (3 \times 1921) = 2040 \text{ MPa.} \end{aligned} \tag{2}$$

Where \bar{A}_3 is the average elasticity module at the third level of material temperature, 260°C; \bar{B}_2 is the average elasticity module at the second level of injection pressure, 40 MPa, \bar{C}_2 is the average elasticity module at the second level of holding

time, 8 sec, \bar{D}_3 is the average elasticity module at the third level of mold temperature, 60°C and \bar{E} is the mean of elasticity module obtained from **Table 4**.

3.2.3 Confirmation tests

Three confirmation experiments were conducted at the optimum settings of the process parameters recommended by the investigation. The average tensile strength and the elasticity module obtained at the optimal level of the process parameters were 56.28 MPa and 1983 MPa.

Obviously, there was a difference between the computed and the experimental results. However, this difference can be considered not significant. Therefore, the confirmation tests indicate that the optimal conditions obtained above produced the best mechanical properties (σ , E) of the PC/ABS blend (**Table 9**).

	Experimental value	Measured value	Error
Tensile Strength (σ)	56.06 MPa	56.28 MPa	0.39%
Elasticity module (E)	2040 MPa	1983 MPa	2.28%

Table 9.
Confirmation test results.

4. Conclusion

This work focused on Taguchi experimental method for investigating the influence of the injection parameters on the mechanical properties of PC/ABS during injection molding. Taguchi’s results proposed two sets of optimal injection parameters conditions to achieve the best mechanical characteristics (σ , E). A first series: a material temperature of 260°C, an injection pressure of 50 bars, a holding time of 8 sec and a mold temperature of 60°C. A second series: a material temperature of 260°C, an injection pressure of 40 bar, a holding time of 8 seconds and a mold temperature of 60°C. All mechanical properties measurements matched very well with the experimental data. The most important parameter affecting the maximum tensile strength was the injection pressure. However, the material temperature was considered the most important parameter affecting the elasticity module. Consequently, it is shown clearly the above performance characteristics in the injection molding process are greatly significant through this study. So, we recommend that future works involve the impact of injection processing on the surface quality of the PC/ABS parts.

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The authors are grateful for the help of the SKG staff during the materialization of this study.

Acronyms and abbreviations

IM	Injection Molding
DOE	Design of Experiment
S/N	Signal-to-Noise ratio

OA	The Orthogonal Array
T _{ma}	The material temperature
T _{mo}	The mold temperature
P _{inj}	The injection pressure
t _h	The holding time
MPa	Mega Pascal
°C	Celsius temperature scale
bar	Bar pression scale
sec	second time scale

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