Research Journal of Applied Sciences, Engineering and Technology 11(8): 817-826, 2015
DOI: 10.19026/rjaset.11.2090
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: April 28, 2015 Accepted: June 14, 2015 Published: November 15, 2015

Research Article

Optimization of Process Parameters in Injection Moulding of FR Lever Using GRA and DFA and Validated by Ann

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Abstract: This study deals with the optimization of the injection moulding process parameters in the production of the FR (Forward Reverse) Lever, using the Grey Relational Analysis (GRA) and Desirability Function Approach (DFA) and the results are validated by ANN. The FR lever is used to control the direction of the rotation of spindles in conventional machines. Parameters such as injection pressure, injection speed and injection temperature, which influence the quality of the final product of the injection moulding process, are called the input parameters. Parameters such as Shrinkage and Surface Roughness, which are considered as the quality characteristics of this product, are called the output parameters. FR levers are produced using a fabricated Injection moulding tool, according to Taguchi's experimental design and the response data are recorded. The recorded experimental data are analyzed and the optimum process parameters combinations have been found, by using the GRA and DFA. An ANN has been developed using the experimental data and the responses (output data) are predicted for the corresponding optimal parameters combination. Finally, the obtained optimum parameter combinations are tested by both ANN and the experiment and the results are found to be satisfactory.

Keywords: Desirability function approach, FR lever, grey relational analysis, injection moulding

INTRODUCTION

Many Engineers and researchers have done research on the optimization of the process parameters of Plastic Injection Moulding (PIM) for various thermoplastic materials and attempted to reduce the shrinkage, surface roughness and Warpage of plastic moulded products. Some authors have presented a few case studies on improving the Quality characteristics of surface roughness, shrinkage and Warpage, by applying the Taguchi technique, Artificial Neural Network (ANN), Fuzzy logic and combination methods.

Pirc *et al*. (2008) introduced a practical methodology to optimize the position and the shape of the cooling channels in injection moulding processes and also Pirc *et al*. (2009) developed an iterative dual reciprocity boundary element method (DRBEM) to solve optimization of 3D cooling channels in injection molding. Gang *et al*. (2012) developed an experiment-based optimization system for the process parameter optimization of multiple-input multiple-output plastic injection molding process using particle swarm optimization algorithm. Huizhuo *et al*. (2010) presented a combination of artificial neural network and Design of Experiment (DOE) method is used to build an approximate function relationship between Warpage and the process parameters. Irene *et al*. (2010) presented a framework on a Multidisciplinary Design Optimization methodology, which tackles the design of an injection mold to achieve significant improvements.

In the present study, the Grey Relational Analysis and Desirability Functional Approach are applied for the optimization of the process parameters of Plastic Injection Moulding (PIM) for FR lever. The output responses are also predicted, using the developed Artificial Neural Network.

Table 1: Process parameters and their levels

S.N	Process parameters	Unit	Level 1	Level 2	Level 3
A	Injection speed	mm/s	35	40	45
B	Injection pressure	Bar	40	45	50
C	Holding pressure	Bar	25	30	35
D	Holding speed	mm/s	30	35	40
E	Clamping pressure	Bar	40	50	60
F	Clamping speed	mm/s	25	35	45
G	Injection time	Sec	1.5	2	2.5
H	Holding time	Sec	1.5	2	2.5
I	Cooling time	Sec	10	15	20
J	Nozzle temperature	°C	300	310	320

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Table 2: Experimental data

Exp. Run	A	B	C	D	E	F	G	H	I	J	Ra (μ)	Ry (μ)	Rq (μ)	Shrinkage (%)
1	1	1	1	1	1	1	1	1	1	1	5.37	27.19	6.62	2.9564
2	1	1	1	1	2	2	2	2	2	2	6.31	37.47	7.85	3.7276
3	1	1	1	1	3	3	3	3	3	3	5.45	26.84	6.49	3.8970
4	1	2	2	2	1	1	1	2	2	2	5.96	31.31	7.56	3.1178
5	1	2	2	2	2	2	2	3	3	3	5.62	29.36	6.84	4.0500
6	1	2	2	2	3	3	3	1	1	1	6.02	31.20	7.42	6.5750
7	1	3	3	3	1	1	1	3	3	3	4.39	27.89	5.69	3.3062
8	1	3	3	3	2	2	2	1	1	1	4.26	25.02	5.43	3.3394
9	1	3	3	3	3	3	3	2	2	2	6.25	33.29	7.66	3.0840
10	2	1	2	3	1	2	3	1	2	3	5.89	33.04	7.31	3.8976
11	2	1	2	3	2	3	1	2	3	1	5.41	30.66	6.92	4.4370
12	2	1	2	3	3	1	2	3	1	2	6.66	31.08	7.93	3.4214
13	2	2	3	1	1	2	3	2	3	1	4.02	25.53	5.11	3.3802
14	2	2	3	1	2	3	1	3	1	2	4.79	24.17	5.77	2.8034
15	2	2	3	1	3	1	2	1	2	3	5.74	28.90	6.87	4.7862
16	2	3	1	2	1	2	3	3	1	2	4.74	29.39	5.98	3.0748
17	2	3	1	2	2	3	1	1	2	3	5.29	29.07	6.36	2.9970
18	2	3	1	2	3	1	2	2	3	1	4.79	29.05	5.99	2.9342
19	3	1	3	2	1	3	2	1	3	2	5.26	30.93	6.58	3.2114
20	3	1	3	2	2	1	3	2	1	3	5.00	28.02	6.23	3.1674
21	3	1	3	2	3	2	1	3	2	1	5.10	28.55	6.33	3.1800
22	3	2	1	3	1	3	2	2	1	3	5.31	32.34	6.54	3.2130
23	3	2	1	3	2	1	3	3	2	1	5.72	32.74	7.25	3.6482
24	3	2	1	3	3	2	1	1	3	2	4.98	30.41	6.45	3.2053
25	3	3	2	1	1	3	2	3	2	1	5.17	26.89	6.13	3.1820
26	3	3	2	1	2	1	3	1	3	2	4.05	24.14	4.98	3.1327
27	3	3	2	1	3	2	1	2	1	3	4.87	32.97	6.25	3.1906

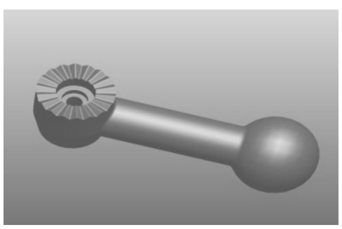

Fig. 1a: FR lever model drawing

Fig. 1b: FR lever specimen

Fig. 2a: FR levers and injection moulding tool

Fig. 2b: Talysurf meter

MATERIALS AND METHODS

An Injection moulding tool for Forward and Reverse (FR) lever has been designed and fabricated and discussed in detail in the previous research publication (Selvaraj and Venkataramaiah, 2012) of the same author. The 3D model of the FR lever is shown in Fig. 1a and the fabricated FR lever is shown in Fig. 1b. The parameters which influence the Injection moulding process and their levels, are shown in Table 1. The Taguchi experimental design L27 OA is selected, for conducting the experiments (Table 2) which are conducted as per the experimental design. Nylon-66 material is used for producing 27 FR levers, using the fabricated Injection moulding Tool (Fig. 2a). Two output parameters are measured, namely, shrinkage and surface roughness for all the 27 components of the FR lever. The shrinkages are calculated by using the procedures presented in the previous research publication (Selvaraj and Venkataramaiah, 2013) of the same author. The surface roughness values of the FR lever are measured using the Talysurf meter (Fig. 2b).

Table 3: Preprocessing data of each performance characteristic

	Grey relational generation				Quality loss estimates (Δ_{0i})			
Specimen No	Ra (μ)	Ry (μ)	Rq (μ)	Shrink-age (%)	Ra (μ)	Ry (μ)	Rq (μ)	Shrink-age (%)
1	0.4886	0.7712	0.4441	0.9594	0.5114	0.2288	0.5559	0.0406
2	0.1326	0.0000	0.0271	0.7550	0.8674	1.0000	0.9729	0.2450
3	0.4583	0.7974	0.4881	0.7100	0.5417	0.2026	0.5119	0.2900
4	0.2652	0.4621	0.1254	0.9166	0.7348	0.5379	0.8746	0.0834
5	0.3939	0.6084	0.3695	0.6695	0.6061	0.3916	0.6305	0.3305
6	0.2424	0.4704	0.1729	0.0000	0.7576	0.5296	0.8271	1.0000
7	0.8598	0.7187	0.7593	0.8667	0.1402	0.2813	0.2407	0.1333
8	0.9091	0.9340	0.8475	0.8579	0.0909	0.0660	0.1525	0.1421
9	0.1553	0.3136	0.0915	0.9256	0.8447	0.6864	0.9085	0.0744
10	0.2917	0.3323	0.2102	0.7099	0.7083	0.6677	0.7898	0.2901
11	0.4735	0.5109	0.3424	0.5669	0.5265	0.4891	0.6576	0.4331
12	0.0000	0.4794	0.0000	0.8361	1.0000	0.5206	1.0000	0.1639
13	1.0000	0.8957	0.9559	0.8471	0.0000	0.1043	0.0441	0.1529
14	0.7083	0.9977	0.7322	1.0000	0.2917	0.0023	0.2678	0.0000
15	0.3485	0.6429	0.3593	0.4743	0.6515	0.3571	0.6407	0.5257
16	0.7273	0.6062	0.6610	0.9280	0.2727	0.3938	0.3390	0.0720
17	0.5189	0.6302	0.5322	0.9487	0.4811	0.3698	0.4678	0.0513
18	0.7083	0.6317	0.6576	0.9653	0.2917	0.3683	0.3424	0.0347
19	0.5303	0.4906	0.4576	0.8918	0.4697	0.5094	0.5424	0.1082
20	0.6288	0.7089	0.5763	0.9035	0.3712	0.2911	0.4237	0.0965
21	0.5909	0.6692	0.5424	0.9001	0.4091	0.3308	0.4576	0.0999
22	0.5114	0.3848	0.4712	0.8914	0.4886	0.6152	0.5288	0.1086
23	0.3561	0.3548	0.2305	0.7760	0.6439	0.6452	0.7695	0.2240
24	0.6364	0.5296	0.5017	0.8934	0.3636	0.4704	0.4983	0.1066
25	0.5644	0.7937	0.6102	0.8996	0.4356	0.2063	0.3898	0.1004
26	0.9886	1.0000	1.0000	0.9127	0.0114	0.0000	0.0000	0.0873
27	0.6780	0.3376	0.5695	0.8973	0.3220	0.6624	0.4305	0.1027

Table 4: Individual grey relational coefficients and overall grey relational grade

Speci-men No	Grey relational coefficients of individual responses				Overall grey relational grade
	Ra(μ)	Ry(μ)	Rq(μ)	Shrinkage (%)	
1	0.4944	0.6861	0.4735	0.9250	0.6447
2	0.3657	0.3333	0.3395	0.6711	0.4274
3	0.4800	0.7117	0.4941	0.6329	0.5797
4	0.4049	0.4817	0.3637	0.8571	0.5269
5	0.4521	0.5608	0.4423	0.6020	0.5143
6	0.3976	0.4856	0.3768	0.3333	0.3983
7	0.7811	0.6399	0.6751	0.7895	0.7214
8	0.8462	0.8834	0.7662	0.7787	0.8186
9	0.3718	0.4214	0.3550	0.8705	0.5047
10	0.4138	0.4282	0.3876	0.6328	0.4656
11	0.4871	0.5055	0.4319	0.5358	0.4901
12	0.3333	0.4899	0.3333	0.7532	0.4774
13	1.0000	0.8274	0.9190	0.7658	0.8781
14	0.6316	0.9955	0.6512	1.0000	0.8196
15	0.4342	0.5834	0.4383	0.4875	0.4858
16	0.6471	0.5594	0.5960	0.8742	0.6691
17	0.5097	0.5748	0.5166	0.9069	0.6270
18	0.6316	0.5758	0.5936	0.9351	0.6840
19	0.5156	0.4954	0.4797	0.8221	0.5782
20	0.5739	0.6321	0.5413	0.8382	0.6464
21	0.5500	0.6018	0.5221	0.8335	0.6269
22	0.5057	0.4484	0.4860	0.8216	0.5654
23	0.4371	0.4366	0.3939	0.6906	0.4895
24	0.5789	0.5153	0.5008	0.8243	0.6048
25	0.5344	0.7079	0.5619	0.8328	0.6593
26	0.9778	1.0000	1.0000	0.8513	0.9573
27	0.6083	0.4301	0.5373	0.8297	0.6014

RESULTS AND DISCUSSION

Optimization study: In this study, the influential parameters are optimized using two optimization techniques, the Grey Relational Analysis and Desirability Function Approach and also the Analysis Of Variance (ANOVA) is performed to find the influence of each process parameter on the responses.

Optimization steps in grey relational analysis:

Step 1: Normalization of the responses (Quality characteristics): The quality characteristics (experimental data) of the component are normalized ranging from zero to one. There are three different types of data normalization, according to the response requirement of the LB (lower-the-better), the HB (higher-the-better) and the NB (nominal-the-best). In this study, the lower-the-better (LB) criterion is considered for normalization, since surface roughness and shrinkage should be low and the values are calculated using Eq. (1) and tabulated in Table 3.

The preprocessing data $x^*_i(k)$ can be calculated as follows:

$$x^*_i(k) = \frac{\max x^o_i(k) - x^o_i(k)}{\max x^o_i(k) - \min x^o_i(k)} \quad (1)$$

For i = 1:27, k = 1: 4, where k = number of quality characteristics and i=no of experiments:

$$x^*_1(1) = \frac{6.66-5.37}{6.66-4.02} = 0.4886$$

Similarly $(x^*_1(2) x^*_1(3) x^*_1(4))$ = (0.7712, 0.4441, 0.9594)

Step 2: Calculation of quality loss estimates (Δ_{0i}): After normalizing the experimental data, the difference of the absolute value x_0 (k) i.e., 1 and the corresponding normalized values, x_i (k) known as quality loss estimates (Δ_{0i}) are calculated and furnished in Table 3.

Δ_{0i} (k) = $\|x^*_0(k) - x^*_i(k)\|$
Δ_{01} (1) = $\|x^*_0(1) - x^*_1(1)\|$ = $|1.00 - 0.4886|$ = 0.5114
Δ_{01} (2) = $\|x^*_0(2) - x^*_1(2)\|$ = $|1.00 - 0.7712|$ = 0.2288
Similarly ($\Delta_{01}(3), \Delta_{01}(4)$) = (0.5559, 0.0406)

Similarly all calculations are performed and are shown in Table 4:

Δ_{max} = Δ_{12} (1) = Δ_2 (2) = Δ_{12} (3) = Δ_6 (4) = 1.0000;
Δ_{min} = Δ_{13} (1) = Δ_{26} (2) = Δ_{26} (3) = Δ_{14} (4) = 0.0000

Step 3: Calculation of the individual grey relational grades:

Individual grey relational coefficients: The Grey relational coefficient depends on quality loss estimates and distinguishing the coefficient ζ. Here ζ = 0.5 is considered. The grey relational coefficients are calculated by applying Eq. (2).

The greyrelation coefficient $\xi_i(k)$ for the k^{th} performance characteristic in the i^{th} experiment can be expressed as:

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \quad (2)$$

$$\xi_1(1) = \frac{0.0000 + (0.5*1.0000)}{0.5114 + (0.5*1.0000)} = 0.4944$$

($\xi_1(2)$, $\xi_1(3)$, $\xi_1(4)$) = (0.6861, 0.4735 and 0.9250)

Similarly, all the coefficients are calculated, as shown in Table 4

Overall grey relational grade: The average value of the grey relational coefficients is the overall grey relational grade (Table 4). The grey relational grade is defined as follows:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) = (0.4944+0.6861+0.4735+0.9250)/4 = 0.6447 \quad (3)$$

Similarly the grade values for all the 27 experimental runs are calculated in the same way as above and tabulated as in Table 4. Thus, the multi-response optimization problem has been transformed into a single objective optimization problem, using the combination of the Taguchi method and grey relational analysis. Higher the value of grey relational grade, the closer the corresponding factor combination towards the optimal.

Average grey relational grade: The average Grey relational grade values are calculated to determine the optimal setting of the process parameters for injection moulding, based on Taguchi's design (Table 5).
The procedure is:

Table 5: Response table for the average grey relational grade

	Average overall grey relational grade		
Process parameter	Level 1	Level 2	Level 3
Injection speed (A)	0.570667	0.62185	0.63657
Injection pressure (B)	0.548480	0.58647	0.69364
Holding pressure (C)	0.587960	0.56562	0.67552
Holding speed (D)	0.672580	0.58567	0.57083
Clamping pressure (E)	0.634300	0.64335	0.55144
Clamping speed (F)	0.625930	0.62291	0.58025
Injection time (G)	0.629200	0.57893	0.62097
Holding time (H)	0.620030	0.59160	0.61746
Cooling time (I)	0.626770	0.53479	0.66754
Nozzle temperature (J)	0.632167	0.61837	0.57855

- Group the grey relational grades by their factor level, for each column in the orthogonal array.
- Take their average. For example, the grey relational grade for factor A at level 1 can be calculated as follows:

γA1= (0.6447+0.4274+0.5797+0.5269+0.5143+0.3983+0.7214+0.8186+0.5047)/9 = 0.570667

The average grey relational grade values for each level of the process parameters were calculated, using the same method and are shown in Table 5. The optimal parametric combination is then evaluated, by maximizing the overall grey relational grade.

The optimal process parameter setting (A_3 B_3 C_3 D_1 E_1 F_1 G_1 H_3 I_3 J_1) has been found from Table 5, by choosing the higher average grade values of each parameter at different levels. Figure 3 shows the effect of the process control parameters on the multi-performance characteristics and the response graph of each level of the injection moulding parameters for the performance.

ANOVA for GRA results: The order of factors affecting the responses is determined, by performing Analysis of variance (ANOVA) as follows.

Estimation of mean overall grey relational grade: Mean overall grey relational grade:

M_g = 1/27[$gg_1+gg_2+gg_3+$ - - - - - - - - - - - $+gg_{25}+gg_{26}+gg_{27}$] =1/27(16.4619) = 0.6097

Mean grade for injection speed at level-1:

M_{gis1} = 1/9[$gg_1+gg_2+gg_3+$ $gg_4+gg_5+gg_6+$ $gg_7+gg_8+gg_9$] = 0.57067

Same procedures are used for calculating mean grade for all levels of individual parameters.

Analysis of variance for overall grey relational grade: Grand total sum of squares:

$\sum_{i=1}^{27} gg^2$ = [$gg_1^2+gg_2^2+gg_3^2+$ - - - - - - - - - $+gg_{25}^2+gg_{26}^2+gg_{27}^2$] = 10.535759

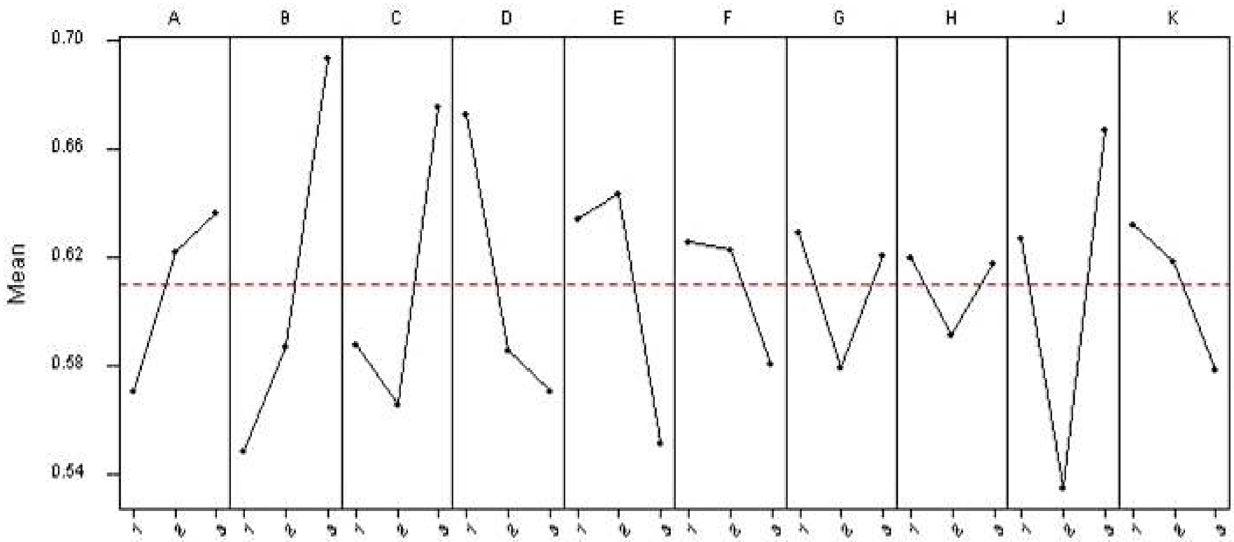

Fig. 3: Effect of injection moulding parameter levels using GRA

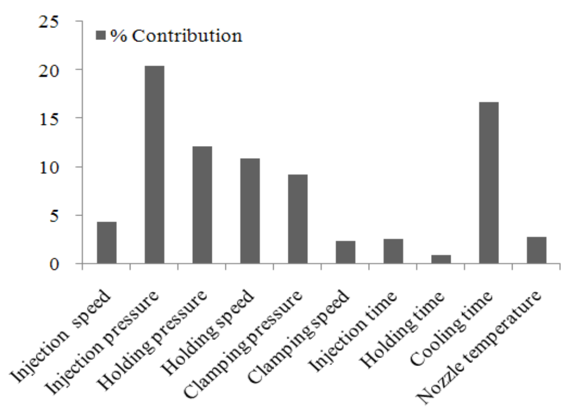

Fig. 4: Contribution of process parameters using GRA

Table 6: Analysis of variance (ANOVA) of overall grey relational grade

Parameter	DOF	SS	MS	P-value
Injection speed	2	0.021540	0.0107700	0.043170
Injection pressure	2	0.101790	0.0508950	0.204012
Holding pressure	2	0.060730	0.0303650	0.121718
Holding speed	2	0.054383	0.0271915	0.108990
Clamping pressure	2	0.046184	0.0230920	0.092564
Clamping speed	2	0.011745	0.0058725	0.023776
Injection time	2	0.013084	0.006542	0.026223
Holding time	2	0.0044806	0.0022403	0.0089802
Cooling time	2	0.083239	0.041619	0.166832
Nozzle temperature	2	0.01395	0.006975	0.027959
Error	6	0.0878134	0.0146356	0.176000
Total	26	0.498939		1.0000

Sum of squares of mean:

$$\sum M_g^{\ 2} = 27M_g^{\ 2} = 27*(0.6097)^2 = 10.036820$$

Total sum of squares: (Grand total sum of squares- Sum of squares of mean) = 0.498939

Sum of squares due to injection speed: $9 \sum_{i=1}^{3} (m_{gisi}-M_g)^2 = 0.02154$

The same procedure is used for calculating the 'sum of squares' for the remaining 9 parameters.

Sum of squares due to error, $SS_E = SS_T - SS_F$ = 0.498939-0.4111256 = 0.0878134

Mean squares: Mean squares due to injection speed = (Sum of squares due to injection speed)/(degree of freedom for injection speed) = 0.01077

The same procedure is used for calculating the 'mean of squares' for the remaining 9 parameters.

Mean squares due to error = (Sum of squares due to error)/(degree of freedom for error) = 0.0146356.

Percentage of contribution: **%** contribution for injection speed = (Sum of squares due to injection speed)/(Total sum of squares) = 0.04317

The same procedure is used for calculating '% of contribution' for the remaining 9 parameters.

% contribution for error = (Sum of squares due to error)/(Total sum of squares) = 0.176000

Figure 4 indicates that the injection pressure has the most influence on the multi performance characteristics among all the parameters and also the influence of every controllable factor over the multi-performance characteristics can be obtained by examining these values (Table 6).

Optimization steps in Desirability Function Approach (DFA): An optimal parametric combination for minimizing the surface roughness and shrinkage of the injection moulded component (FR lever) is determined, using DFA as follows.

Calculation of Individual desirability value: Calculate the individual desirability value (d_i) using

Table 7: Evaluated individual desirability values and composite desirability

Specimen No	Individual desirability (d_i) Ra (μ)	Ry (μ)	Rq (μ)	Shrinkage (%)	Composite desirability (d_c)
1	0.4886	0.7712	0.4441	0.9594	0.6330
2	0.1326	0.0000	0.0271	0.7550	0.0000
3	0.4583	0.7974	0.4881	0.7100	0.5966
4	0.2652	0.4621	0.1254	0.9166	0.3445
5	0.3939	0.6084	0.3695	0.6695	0.4934
6	0.2424	0.4704	0.1729	0.0000	0.0000
7	0.8598	0.7187	0.7593	0.8667	0.7986
8	0.9091	0.9340	0.8475	0.8579	0.8864
9	0.1553	0.3136	0.0915	0.9256	0.2534
10	0.2917	0.3323	0.2102	0.7099	0.3468
11	0.4735	0.5109	0.3424	0.5669	0.4655
12	0.0000	0.4794	0.0000	0.8361	0.0000
13	1.0000	0.8957	0.9559	0.8471	0.9228
14	0.7083	0.9977	0.7322	1.0000	0.8482
15	0.3485	0.6429	0.3593	0.4743	0.4420
16	0.7273	0.6062	0.6610	0.9280	0.7211
17	0.5189	0.6302	0.5322	0.9487	0.6374
18	0.7083	0.6317	0.6576	0.9653	0.7300
19	0.5303	0.4906	0.4576	0.8918	0.5708
20	0.6288	0.7089	0.5763	0.9035	0.6941
21	0.5909	0.6692	0.5424	0.9001	0.6629
22	0.5114	0.3848	0.4712	0.8914	0.5362
23	0.3561	0.3548	0.2305	0.7760	0.3877
24	0.6364	0.5296	0.5017	0.8934	0.6234
25	0.5644	0.7937	0.6102	0.8996	0.7042
26	0.9886	1.0000	1.0000	0.9127	0.9746
27	0.6780	0.3376	0.5695	0.8973	0.5848

Table 8: Response table for the composite desirability

Process parameter	composite desirability Level 1	Level 2	Level 3	Max-Min
Injection speed (A)	0.4451	0.5682	0.6376	0.1925
Injection pressure (B)	0.4411	0.5109	0.6989	0.2578
Holding pressure (C)	0.5406	0.4348	0.6754	0.2406
Holding speed (D)	0.6340	0.5393	0.4775	0.1565
Clamping pressure (E)	0.6197	0.5936	0.4326	0.1871
Clamping speed (F)	0.5560	0.5824	0.5124	0.0700
Injection time (G)	0.6220	0.4848	0.5440	0.1372
Holding time (H)	0.5682	0.5034	0.5791	0.0757
Cooling time (I)	0.5448	0.4198	0.6861	0.2663
Nozzle temperature (J)	0.5992	0.4818	0.5699	0.1174
Total Mean of the composite desirability = 0.5503				

Table 9: ANOVA of overall composite desirability

Parameter	DOF	SS	MS	P-value
Injection speed	2	0.1710780	0.0855390	0.092280
Injection pressure	2	0.3200304	0.1600152	0.172643
Holding pressure	2	0.2617590	0.1308795	0.141208
Holding speed	2	0.1118370	0.0559185	0.060330
Clamping pressure	2	0.1849010	0.0924505	0.099746
Clamping speed	2	0.0224938	0.0112469	0.012134
Injection time	2	0.0852372	0.0426186	0.045982
Holding time	2	0.0301451	0.0150726	0.016262
Cooling time	2	0.3195180	0.1597590	0.172367
Nozzle temperature	2	0.0672086	0.0336043	0.036256
Error	6	0.2794999	0.0465833	0.150779
Total	26	1.8537080		1.000000

Eq. (4). Here the lower-the- better is the suitable quality characteristic for both the responses.

$$\left(\frac{\hat{y}-y_{max}}{y_{min}-y_{max}}\right)^r, y_{min} \le \hat{y} \le y_{max}, r \ge 0 \quad (4)$$

For R_a, y_{min}= 4.02μ and y_{max}= 6.66 μ;
For R_y, y_{min} = 24.14μ and y_{max} = 37.47μ
For R_q, y_{min} = 4.98 μ and y_{max} = 7.85μ
For Shrinkage, y_{min} = 2.8034% and y_{max} = 6.5750%

$$d_1 = \frac{5.37-6.66}{4.02-6.66} = 0.4886 \text{ for } R_a$$

Similarly the desirability values for R_y, Rq and shrinkage are calculated (Table 7) as:

$$d_2 = 0.7712, d_3 = 0.4441 \text{ and } d_3 = 9594$$

The overall desirability is calculated for the experiment as follows:

$$d_c = (d_1 * d_2 * d_2 \ldots\ldots\ldots d_n)^{1/n} = (0.4886 * 0.7712*0.4441*0.9594)1/4 = 0.6330$$

Similarly, the remaining values are calculated using the above formulae and the values are given in Table 7.

Optimal process parameters from DFA: The optimal parameter combination is evaluated, based on the maximum composite desirability value. From Table 8 and Fig. 5, the optimal process parameters combination is A_3 B_3 C_3 D_1 E_1 F_2 G_1 H_3 I_3 J_1, by choosing the higher average composite desirability values of each parameter at different levels.

ANOVA for DFA results: The ANOVA is performed as in the following, for the Composite Desirability values to find the order of the influencing parameters and the ANOVA results are shown in Table 9.

Estimation of mean composite desirability: Mean composite desirability:

M_{cd} = 1/27[cd_1+cd_2+cd_3+ - - - - - - - - - - - +cd_{25}+cd_{26}+cd_{27}] =1/27(14.8584) = 0.5503

Mean composite desirability for injection speed at level-1

M_{dis1} = 1/9[cd_1+cd_2+cd_3+cd_4+cd_5+cd_6+cd_7+cd_8+cd_9] = 0.4451

Mean composite desirability for injection speed at level-2

M_{dis2} = 1/9[cd_{10}+cd_{11}+cd_{12}+cd_{13}+cd_{14}+cd_{15}+ cd_{16}+cd_{17}+cd_{18}] = 0.5682

Mean composite desirability for injection speed at level-3

M_{dis3} = 1/9[cd_{19}+cd_{20}+cd_{21}+cd_{22}+cd_{23}+cd_{24}+ cd_{25}+cd_{26}+cd_{27}] = 0.6376

Similarly, the 'mean composite desirability' for all levels of the individual parameters is calculated.

Analysis of variance for the composite desirability: Grand total sum of squares: $\sum_{i=1}^{27} cd^2$ = [cd_1^2+cd_2^2+cd_3^2+ - - - - - - - - -+cd_{25}^2+cd_{26}^2+cd_{27}^2] = 10.03012

Sum of squares of mean: $\sum M_{cd}^2$ = 27 M_{cd}^2 = 8.176412

Total sum of squares: (Grand total sum of squares- Sum of squares of mean) = 1.853708

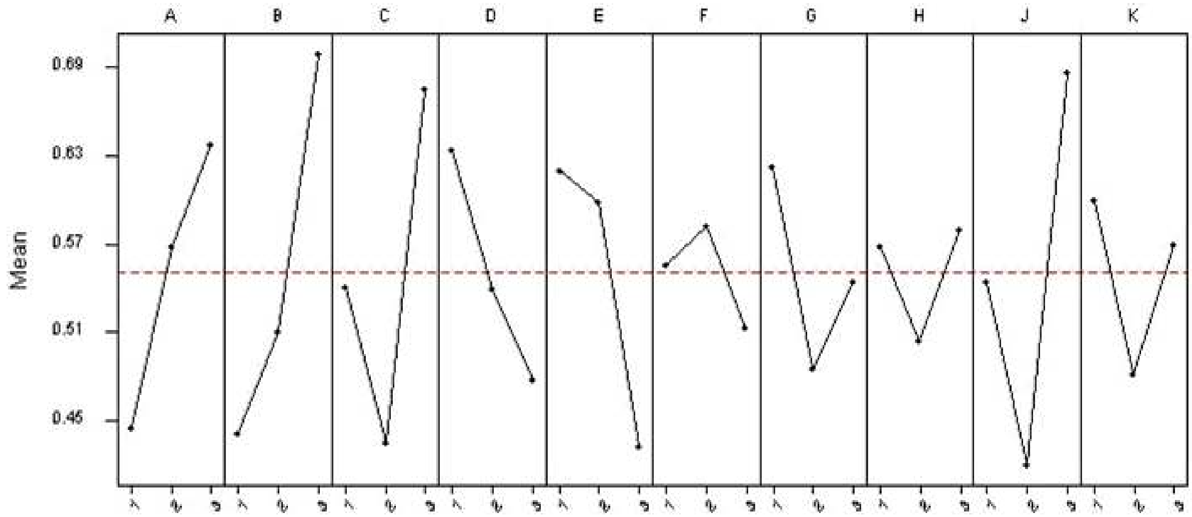

Fig. 5: Response graph for evaluation of optimal parametric combination

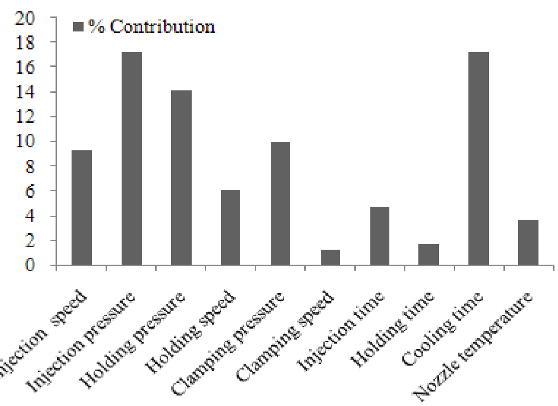

Fig. 6: Contribution of process parameters using DFA

Sum of squares due to injection speed: $9\sum^{3}_{i=1}(m_{disi}-M_{cd}) = 0.171078$.

The same procedure is used for calculating the 'sum of squares' for the remaining 9 other parameters.

Sum of squares due to error, $SS_E = SS_T-SS_F = 1.853708-1.5742081 = 0.2794999$.

Mean squares: Mean squares due to injection speed = (Sum of squares due to injection speed)/(degree of freedom for injection speed) = 0.085539.

The same procedure is used for calculating the 'mean squares' for the remaining 9 other parameters.

Mean squares due to error = (Sum of squares due to error)/(degree of freedom for error) = 0.0465833.

Percentage of contribution: % contribution for injection speed = (Sum of squares due to injection speed)/(Total sum of squares) = 0.09228.

The same procedure is used for calculating the '% of contribution' for the remaining 9 other parameters.

% contribution for error = (Sum of squares due to error)/(Total sum of squares) = 0.150779.

Figure 6 shows that the injection pressure has more influence on the multi performance characteristics, among all the considered injection moulding parameters and the least effecting parameter is the clamping speed.

DEVELOPMENT OF ANN &PREDICTION OF RESPONSES

In the present work, an ANN has been developed (Fig. 7) to predict the surface roughness and shrinkage values, for the optimal parametric combination obtained from the Grey Relational Analysis (GRA) and Desirability Function Approach (DFA). Network features such as the number of neurons and layers are very important factors that determine the functionality and generalization capability of the network. In this work, a multilayer back-propagation neural network has been developed for the prediction of the surface roughness and shrinkage of forward-reverse levers in injection moulding. The neural network has been designed using MATLAB. In order to design the best network architecture, the network is tested with different numbers of hidden layers and the number of neurons in each hidden layer with different training algorithms and transfer functions in the hidden layer. Finally, the optimal network is designed to predict the output parameters. In this method, the obtained data from the 27 experimental runs is taken and another 54 responses are calculated by taking + 5% variation to train the NN and the values are tabulated in Table 10. The Table 10 gives both the input and output data for training.

Both the approaches are for the maximization of the multi objective function, but each having its own individual objectives. The GRA leads to reduce quality loss and the DFA to attain the highest desirability. Therefore, the result of optimization i.e., the optimal

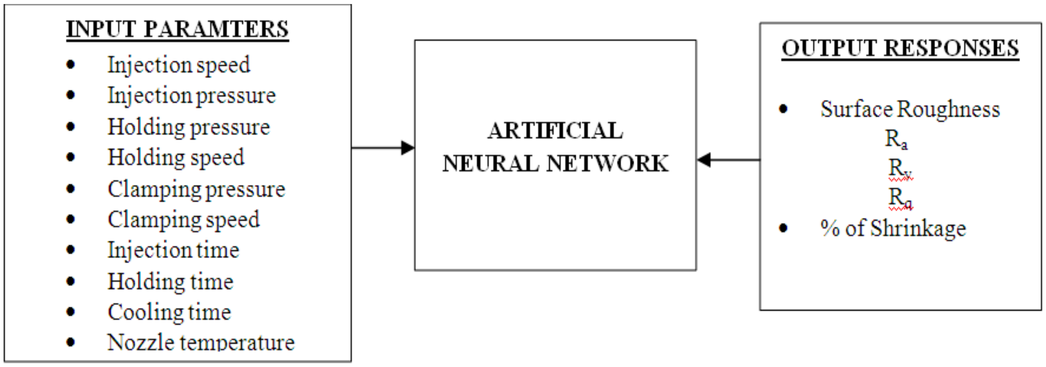

Fig. 7: Input and output parameters of the ANN model

Table 10: Input and output data for training

Input data											Output data			
Ex. run	A	B	C	D	E	F	G	H	I	J	Ra (μ)	Ry (μ)	Rq (μ)	Shrinkage (%)
1	42.66	44.44	31.35	34.64	46.96	34.04	1.92	1.95	16.40	312.50	5.32	27.14	6.57	2.906
2	43.12	45.43	29.50	37.98	43.80	41.20	2.28	2.11	13.99	311.86	6.26	37.42	7.80	3.680
3	37.51	43.47	27.87	31.76	50.76	42.65	1.60	1.80	18.05	313.68	5.41	26.80	6.45	3.855
4	42.61	43.39	29.88	38.49	46.41	34.05	2.00	2.15	14.40	310.91	5.92	31.27	7.52	3.078
5	38.11	41.95	28.03	35.63	47.91	40.47	1.62	2.03	16.79	313.20	5.57	29.31	6.79	4.004
6	35.05	43.27	25.34	36.06	55.72	44.29	1.55	2.12	13.57	300.91	5.98	31.16	7.38	6.537
7	41.56	48.55	33.08	37.72	42.91	28.33	2.43	2.35	15.67	312.70	4.35	37.85	5.65	3.267
8	39.26	48.81	33.09	34.64	50.46	27.29	2.54	2.13	15.54	305.78	4.22	24.98	5.39	3.303
9	43.15	45.23	29.63	37.86	44.01	40.81	2.25	2.10	14.06	311.75	6.22	33.26	7.63	3.051
10	35	40	25.00	30.00	40.00	25.00	1.50	1.50	10.00	300.00	5.37	27.19	6.62	2.956
11	35	40	25.00	30.00	50.00	35.00	2.00	2.00	15.00	310.00	6.31	37.47	7.85	3.728
12	35	40	25.00	30.00	60.00	45.00	2.50	2.50	20.00	320.00	5.45	26.84	6.49	3.897
13	35	45	30.00	35.00	40.00	25.00	1.50	2.00	15.00	310.00	5.96	31.31	7.56	3.118
14	35	45	30.00	35.00	50.00	35.00	2.00	2.50	20.00	320.00	5.62	29.36	6.84	4.050
15	35	45	30.00	35.00	60.00	45.00	2.50	1.50	10.00	300.00	6.02	31.20	7.42	6.575
16	35	50	35.00	40.00	40.00	25.00	1.50	2.50	20.00	320.00	4.39	27.89	5.69	3.306
17	35	50	35.00	40.00	50.00	35.00	2.00	1.50	10.00	300.00	4.26	25.02	5.43	3.339
18	35	50	35.00	40.00	60.00	45.00	2.50	2.00	15.00	310.00	6.25	33.29	7.66	3.084
19	40	40	30.00	40.00	40.00	35.00	2.50	1.50	15.00	320.00	5.89	33.04	7.31	3.898
20	40	40	30.00	40.00	50.00	45.00	1.50	2.00	20.00	300.00	5.41	30.66	6.92	4.437
21	40	40	30.00	40.00	60.00	25.00	2.00	2.50	10.00	310.00	6.66	31.08	7.93	3.421
22	40	45	35.00	30.00	40.00	35.00	2.50	2.00	20.00	300.00	4.02	25.53	6.11	3.380
23	40	45	35.00	30.00	50.00	45.00	1.50	2.50	10.00	310.00	4.79	24.17	5.77	2.803
24	40	45	35.00	30.00	60.00	25.00	2.00	1.50	15.00	320.00	5.74	28.90	6.87	4.786
25	40	50	25.00	35.00	40.00	35.00	2.50	2.50	10.00	310.00	4.74	29.39	5.98	3.075
26	40	50	25.00	35.00	50.00	45.00	1.50	1.50	15.00	320.00	5.29	29.07	6.36	2.997
27	40	50	25.00	35.00	60.00	25.00	2.00	2.00	20.00	300.00	4.79	29.05	5.99	2.934
28	45	40	35.00	35.00	40.00	45.00	2.00	1.50	20.00	310.00	5.26	30.93	6.58	3.211
29	45	40	35.00	35.00	50.00	25.00	2.50	2.00	10.00	320.00	5.00	28.02	6.23	3.167
30	45	40	35.00	35.00	60.00	35.00	1.50	2.50	15.00	300.00	5.10	28.55	6.33	3.180
31	45	45	25.00	40.00	40.00	45.00	2.00	2.00	10.00	320.00	5.31	32.34	6.54	3.213
32	45	45	25.00	40.00	50.00	25.00	2.50	2.50	15.00	300.00	5.72	32.74	7.25	3.648
33	45	45	25.00	40.00	60.00	35.00	1.50	1.50	20.00	310.00	4.98	30.41	6.45	3.205
34	35.18	40.17	25.08	39.98	42.09	25.70	1.75	1.82	10.28	300.33	5.28	30.95	6.60	3.229
35	35.28	40.03	25.09	39.97	42.67	25.36	2.02	1.87	10.51	301.43	5.01	28.03	6.24	3.179
36	35.26	40.04	25.08	39.98	42.24	25.38	1.92	1.82	10.38	300.90	5.12	28.57	6.35	3.203
37	35.14	40.27	25.10	39.97	42.64	26.03	1.82	1.75	10.23	300.19	5.33	32.36	6.56	3.229
38	35.59	40.30	26.85	39.84	49.21	27.27	1.60	1.77	10.25	300.24	5.74	32.76	7.27	3.668
39	35.12	40.08	25.05	39.96	42.00	25.81	1.84	2.00	10.50	300.59	4.99	30.42	6.46	3.219
40	35.50	40.03	25.13	39.98	43.08	25.19	2.09	1.70	10.30	301.45	5.20	26.92	6.16	3.207
41	36.11	40.07	25.04	39.77	47.29	25.62	2.26	2.08	10.53	313.56	4.07	24.16	5.00	3.148
42	35.03	40.27	25.02	39.93	42.44	26.67	2.03	2.06	10.46	300.22	4.89	32.99	6.27	3.208
43	35.72	40.09	25.12	39.98	42.57	25.27	1.73	1.83	10.49	300.96	5.42	27.24	6.67	3.006
44	35.32	40.45	32.83	36.65	55.90	29.26	1.52	2.32	10.15	300.02	6.36	37.52	7.90	3.776
45	35.36	40.04	25.21	39.97	42.41	25.37	1.72	1.69	10.17	300.75	5.49	26.88	6.53	3.939

Table 10: Continue

46	36.43	40.45	25.99	39.93	46.96	26.16	1.55	1.98	10.53	300.39	6.00	31.25	7.60	3.158
47	35.27	40.11	25.72	39.93	44.77	26.30	1.67	1.65	10.12	300.27	5.67	29.41	6.89	4.096
48	35.00	40.01	29.53	37.42	58.76	31.38	1.57	1.94	10.31	300.02	6.06	31.24	7.46	6.613
49	35.21	40.02	25.04	39.79	46.15	25.47	2.22	2.24	11.35	305.02	4.43	27.93	5.73	3.345
50	35.70	40.03	25.06	39.79	46.16	25.41	2.17	2.12	10.72	310.41	4.30	25.06	5.47	3.375
51	36.23	40.57	29.56	39.69	49.86	27.99	1.56	1.97	10.19	300.11	6.28	33.32	7.69	3.117
52	35.56	40.29	29.33	39.63	52.75	28.43	1.61	1.73	10.17	300.16	5.93	33.08	7.35	3.933
53	35.10	40.06	26.21	39.85	45.18	27.83	1.71	1.62	10.08	300.18	5.45	30.70	6.96	4.478
54	36.29	40.49	31.35	39.30	51.77	27.83	1.53	2.07	10.10	300.08	6.69	31.11	7.96	3.448
55	35.83	40.07	25.04	39.62	47.00	25.63	2.18	2.20	10.61	313.28	4.05	25.56	5.14	3.410
56	35.75	40.01	25.17	39.97	45.24	25.19	2.35	1.76	10.74	304.21	4.82	24.20	5.80	2.831
57	35.11	40.06	27.46	39.81	47.54	28.73	1.78	1.57	10.06	300.14	5.76	28.92	6.89	4.808
58	38.44	48.73	32.71	36.11	47.87	28.47	2.40	2.24	14.93	306.13	3.99	25.50	5.08	3.350
59	44.07	49.13	34.18	30.96	47.32	27.06	2.33	1.84	18.28	314.18	4.76	24.14	5.74	2.806
60	35.97	42.26	26.76	33.37	51.15	43.30	1.57	1.92	17.07	310.53	5.72	28.88	6.85	4.764
61	43.5	48.73	32.52	37.90	41.64	32.61	2.46	2.33	15.95	316.06	4.72	29.37	5.96	3.051
62	42.36	46.16	29.73	36.34	43.04	41.85	2.24	2.11	15.86	315.03	5.27	29.05	6.34	2.980
63	43.88	48.76	32.86	37.51	41.63	32.28	2.46	2.30	15.89	315.88	4.78	29.04	5.98	2.924
64	44.05	47.72	31.19	37.32	42.38	40.60	2.43	2.11	13.99	312.49	5.24	30.91	6.56	2.193
65	42.26	46.15	31.70	36.14	44.06	33.41	2.19	2.16	16.42	314.25	4.99	28.01	6.22	3.155
66	41.86	45.53	30.65	36.55	44.07	36.79	2.14	2.15	16.21	314.40	5.08	28.53	6.31	3.157
67	41.88	46.64	28.20	38.05	42.69	43.50	2.33	2.20	14.94	314.89	5.29	32.32	6.52	3.197
68	41.78	42.88	29.37	38.80	46.55	33.64	1.93	2.21	14.60	311.35	5.70	32.72	7.23	3.628
69	41.77	45.65	29.91	38.48	44.02	36.09	2.24	2.26	15.10	313.33	4.97	30.40	6.44	3.191
70	42.13	46.58	31.32	33.09	43.99	38.39	2.09	2.00	17.68	316.16	5.15	26.87	6.11	3.157
71	39.76	49.28	32.93	33.25	49.03	29.41	2.40	2.09	16.49	308.73	4.04	24.13	4.97	3.118
72	41.89	48.37	28.25	38.71	41.73	43.48	2.44	2.32	15.20	316.42	4.85	32.95	6.23	3.174

Table 11: Results from ANN and confirmation experiment

	Test data	
Criteria	Grey relational analysis	Desirability function
Optimal setting	$A_3 B_3 C_3 D_1 E_1 F_2 G_1 H_3 I_3 J_1$	$A_3 B_3 C_3 D_1 E_1 F_1 G_1 H_3 I_3 J_1$
Predicted result by ANN	R_a - 5.2992 R_y - 18.1742 R_q - 5.0048 Shrinkage - 2.0484	R_a - 3.4586 R_y- 27.3714 R_q- 5.3401 Shrinkage - 1.1215
Experimental result	R_a - 5.31 R_y - 18.24 R_q - 5.07 Shrinkage - 2.1346	R_a -3.51 R_y- 27.26 R_q- 5.44 Shrinkage - 1.1033

setting determined by these two approaches differs. In the Desirability Functional Analysis (DFA), y_{max} and y_{min} are needed for each response, whereas in the Grey Relational Analysis (GRA) these are not needed. Two approaches have been found efficient. From Table 11, it is evident that the multi objectives are optimized, using both the GRA and DFA for surface roughness and shrinkage and efficiently minimized by Desirability Function Approach.

CONCLUSION

In the present work, two optimization techniques, the Grey Relational Analysis and the Desirability Function (DF) Approaches have been applied, for solving the multi-response optimization problem in Plastic Injection Moulding (PIM) and the optimum parameter combinations are determined. The Analysis of variance (ANOVA) is also performed on the overall grey relational grade, the composite desirability obtained from the GRA and DRA and it is revealed that injection pressure is the most influencing parameter. The developed ANN can predict the response (output) parameters reliably. Finally, it is found that the Desirability Function Approach (DFA) can effectively analyze the data in the determination of the optimal parameter setting.

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