

CHAPTER-7

CASE STUDY

The study was conducted at a manufacturing facility specializing in plastic products. The particular plant is a part of the “parag group” of its parent company, which is made up of three divisions: filter, hygiene/medical, and plastics. This company’s vision, which is to be innovative and quality-driven in its technically demanding applications, is determined by its guiding principles of continuous improvement, leadership, and commitment to anticipate and understand their customer’s needs and expectations. Seventy percent of the plant’s revenue comes from the plastic moulded parts, it produces for the automotive industry.

The proposed DAURR (Diagnose, Analyze, Upgrade, Regulate and Review) principle along with various statistical tools of six sigma was applied to improve the quality of nylon-6 bush (KAMANI BUSH) produced by plastic injection moulding process. The production equipment employed in this study was a precision injection machine, model: PPU7690TV40G, over all dimensions 856×1500×2480 mm manufactured by the Targor Corporation. This machine was installed at Central Institute of Plastic Engineering and Technology (CIPET) Lucknow.

7.1. MODIFIED METHODOLOGY FOR SMALL ENTERPRISES

Having arisen in large corporations, Six Sigma is surely one of the most comprehensive approaches for company development and performance

improvement of products and processes. Nevertheless, it appears that the majority of small and medium sized enterprises (SMEs) either does not know the six sigma approach, or find its organization not suitable to meet their specific requirements. In the SME environment, there is little spare resource; every employee has a key role and usually several [Ryan's, 1995, cited by Macadam, 2000].

The challenges of smaller companies are “funding and logistics”, a “limited talent pool”, “multi-hat roles”, and “less exposure to management innovations in other industries”.

However the other side of the coin is that it is easier to implement TQM in SMEs because the power of decision making does not depend on extensive hierarchies but lies within the owner managers.

Since the SMEs have a much closer proximity to the customers and this proximity is coupled with a larger number of SME employees having direct customer contact and knowledge “therefore, the customer voice can be incorporated within SME operations without prolonged and formalized approaches” [Hale and Cragg, 1996, cited by McAdam, 2000].

Traditional loyalty to specific customers ,support improvement efforts, which are visible to the customers. Six Sigma depends on reliable ways of collecting the voices of the customer and translating these into critical-to-quality requirements of products and services. This close relationship and the high degree of communication with key customers appear to be significant advantages of SMEs in opposition to large corporations.

The review of published literature on general QM and the cultural requirements that build the basis for any Six Sigma program, combined with the survey

responses, suggest that several factors have to be represented in a Six Sigma initiative within an SME context. These are

(1) The Six Sigma roles should be restricted to the project leaders in the SME organisation (e.g. an “SME black belt”). The rest of the workforce and management staff should only participate in the awareness training.

(2) A general six sigma concept for SMEs needs to be adjusted to the core requirements of ISO 9000 to enable a certification, which represents a major difference to Six Sigma programs in large corporations.

(3) A training program has to be employed which is significantly shorter than in large corporations, but is still based on the well-proven methods and tools of QM adjusted to specific SME needs.

(4) SMEs require consulting services which differ significantly from those usually found in the Market place working for larger corporations. SMEs require consultants and trainers offering modular services, which allow the addition or subtraction of elements without compromising the entirety of the concept and without risking the success for their target group.

Keeping in mind the above problems and specific requirements of SMEs ,especially the plastic injection moulding industry, the DMAIC procedure of six sigma can be moulded into a cycle with slight modification.

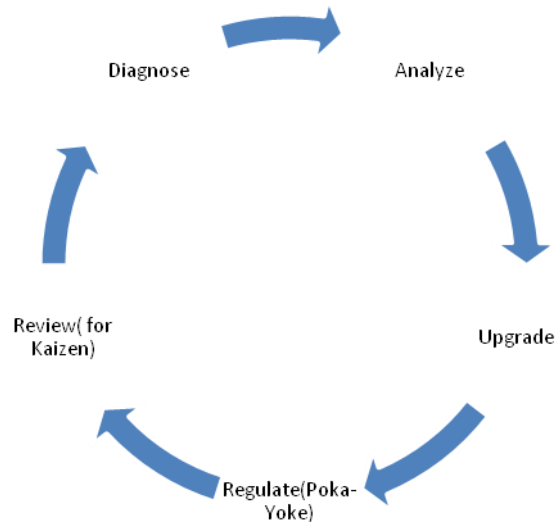


Fig.7.1 Modified approach in a cycle

The road map of this new proposed method is given in the Table 7.1. Based on this modified methodology a case study was carried in a small enterprise consisting of one expert (Black Belt) and few trained personnel. The results of this case study are discussed further in the article which are quite satisfactory.

This modified approach will not put a large financial burden on small scale industries having, limited talent pool and less exposure to management innovations. The approach will help them to upgrade their existing system in a slow but steady manner. The experimental work was done at Central Institute of Plastic Engineering and Technology (CIPET), Lucknow.

Table-7.1 Road map for the proposed methodology

THE MODIFIED ROAD MAP FOR SMEs		
Phases	Breakthrough Strategy	Phase Objectives
DIAGNOSE	Define and Measure	Define inputs to defining customer expectations. Measure variability and current capability.
ANALYZE	Analyze	Modeling of the problem
UPGRADE	Improve	Optimize the process to attain “Six Sigma” ,Define capability and control process variation to maintain the desired capability level.
REGULATE/POKAYOKE	Control	Transform corporate Culture.
REVIEW	Benchmarking for KAIZEN	Find out further improvement needed to achieve six sigma standard, sort out the areas of

		improvement whether Man,Machine,Material or Method, Switch to diagnose stage.
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Nylon-6 bush (KAMANI BUSH) produced by plastic injection moulding process has following specifications.

Length- 44.4mm, internal diameter-16.1mm, Outer diameter-22mm.

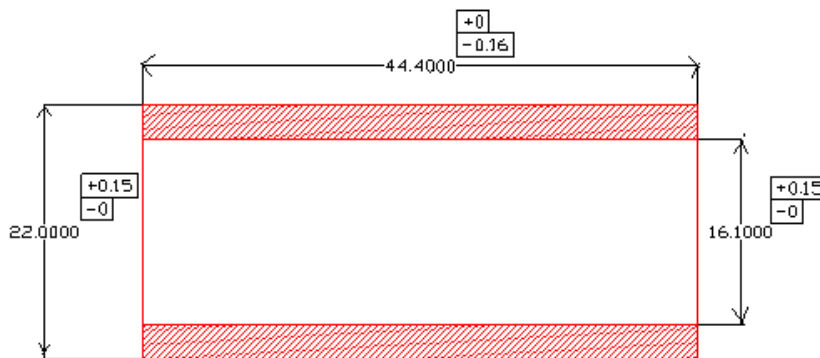


Fig.7.2 Drawing of nylon-6 bush

Application of modified methodology at manufacturing facility is described below

7.2 DIAGNOSE

The first step in modified procedures is to define and measure the problems so that possible confusion in targets for improvement due to differences in cognition among project staff can be avoided. In this phase, the reasons for rejection and failure of nylon-6 bush were investigated by the management techniques like voice of customer and brain storming of production manager, quality engineer on the shop floor, as well as workers concerned with the production of the above product. After voice of customer and brain storming we

concluded that following four defects were playing important role in rejection and failure of the bush.

1. Sink marks
2. Stress cracking
3. Bulging defect (over shrinkage)
4. Low value of hardness

After doing Pareto analysis we decided that bulging defect and low value of hardness are responsible for 80% of the failures and rejection.

To measure the problem, the process capability index was used to illustrate the most efficient way to circumvent the problems defined in the previous steps (bulging defect and hardness in this case). For the nylon-6 bush moulded in this study, the process capability index is measured based upon the data obtained from the bulging and hardness measurements (For the bulging measurement we used a dial gauge attached with a V shaped anvil placed over a surface plate while for the hardness measurement we used core hardness indenter).

In general, the upper process capability index CPU is defined by the following equation.

$$CPU = \frac{USL - \mu}{3\sigma}$$

Where USL is the upper specification limit, μ is the mean of all measured values, and σ is the standard deviation.

Similarly the lower process capability index CPL is defined by the following equation.

$$CPL = \frac{\mu - LSL}{3\sigma}$$

Where LSL is the lower specification limit. The higher value of CPU or CPL is known as C_{pk} .

Before implementation of six sigma projects hundred random samples were taken from production line at ten different occasions in a week and over shrinkage in samples was measured, using dial gauge attached with a V shaped anvil, placed over a surface plate. SPC software was used to analyze the process.

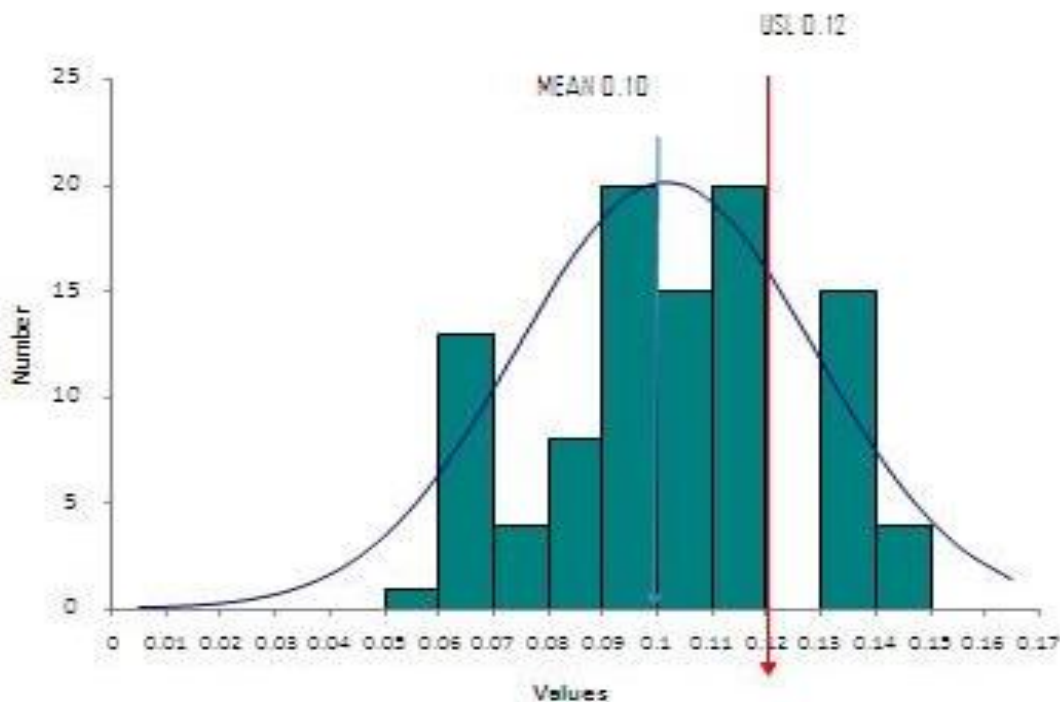


Fig.7.3 Histogram for hundred random samples taken from production line at ten different occasions in a week (over shrinkage measurements shown on x-axis).

Value of CPL calculated from hundred random samples for over shrinkage was 0.24 and production was of 2.38 sigma standard and the process mean was 0.1015. Analysis indicates that 19% defects are expected. This is obvious from the Fig.7.3 and Table-7.2.

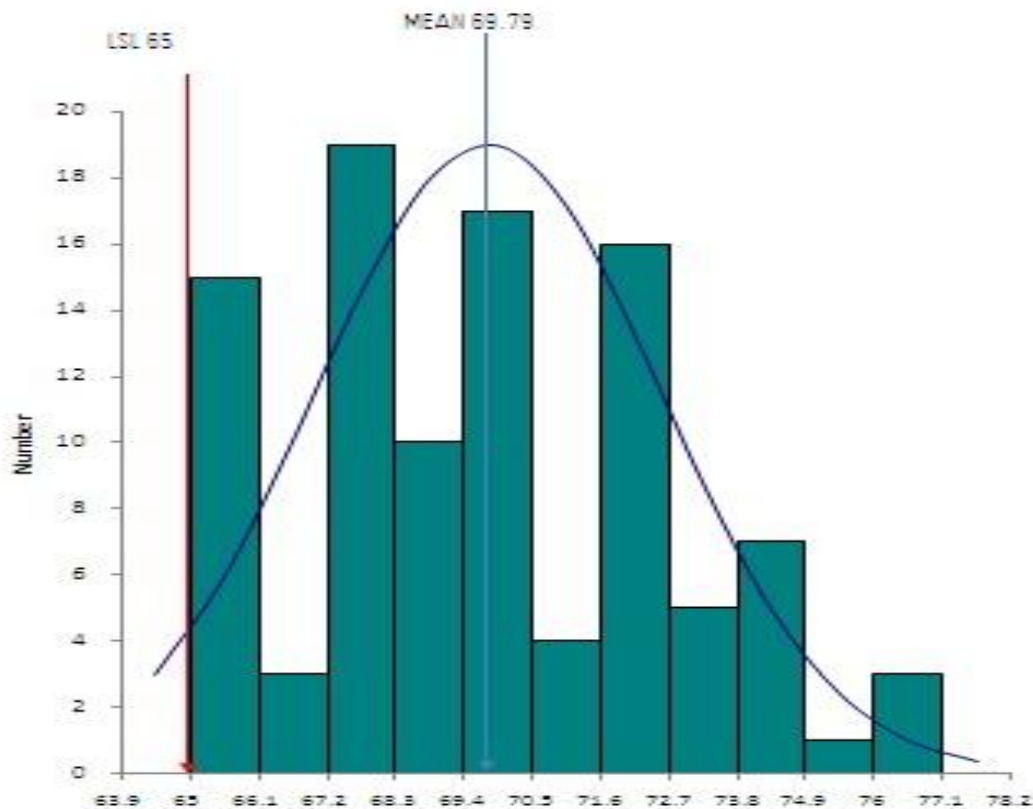
Similarly SPC analysis for hardness was carried out with the help of hundred samples taken from production line at ten different occasions in a week. The histogram for these measurements is shown in Fig.7.4.

Value of CPU calculated from hundred random samples for hardness was 0.56 and production is of 3.19 sigma standard and the process mean was 69.79. This is obvious from the Fig.7.4 and Table-7.3.

Table-7.2 SPC software analysis for over shrinkage (bulging defect) in selected samples

Cp	values	Decimal Points	2.00
Cpk	0.24	Number of Entries	100
CpU	0.24	Average	0.1015
Ppk	0.23	Stdev	0.03
Min	0.05	Median	0.1
Max	0.15	Mode	0.12
Z Bench	0.71	Minimum Value	0.05
% Defects	19.0%	Maximum Value	0.15
PPM	190000.00	Range	0.1
Expected	238713.25	USL	0.12
Sigma	2.38		
	Observed	Expected	Z
PPM<LSL	*	*	*
PPM>USL	190000.0	238713.2	0.71
PPM	190000.0	238713.2	

SPC analysis for hardness was carried out with the help of hundred samples taken from production line at ten different occasions in a week. The histogram for these measurements is shown in Fig. 7.4.



Hardness values

Fig.-7.4 Histogram for hardness of hundred samples (horizontal axis shows hardness, vertical axis shows number of samples)

Table-7.3 SPC analysis for hardness in selected samples (for hardness measurements)

Cp	*	Number of Entries	100
Cpk	0.56	Average	69.79
CpU	*	Stdev	2.77
CpL	0.56	Median	70
ZTarget/DZ	1.27	Mode	68
Pp	*	Minimum Value	65

Ppk	0.58	Maximum Value	76
		Range	11
PpL	0.58	LSL	65
Skewness	0.19	USL	FALSE
Stdev	2.771773	Number of Bars	10.00
Min	65	Number of Classes	10.00
Max	76	Class Width	1.10
Z Bench	1.69	Beginning Point	63.9
% Defects	0.0%	Stdev Est	2.84
PPM	0.00	d2/c4	0.97
Expected	45568.98	Target	73.31532
Sigma	3.19		
	Observed	Expected	Z
PPM<LSL	0.0	45569.0	-1.69
PPM>USL	*	*	*
PPM	0.0	45569.0	
% Defects	0.0	0.0	

7.3 ANALYZE

In the analysis step, the data collected from the process is analyzed in accordance with the CTQ (critical to quality) factors. The literature review suggests that to have better surface quality of moulded part, it is important to

correctly tune the settings of process parameters in injection moulding ,as well as precision machining of mould.

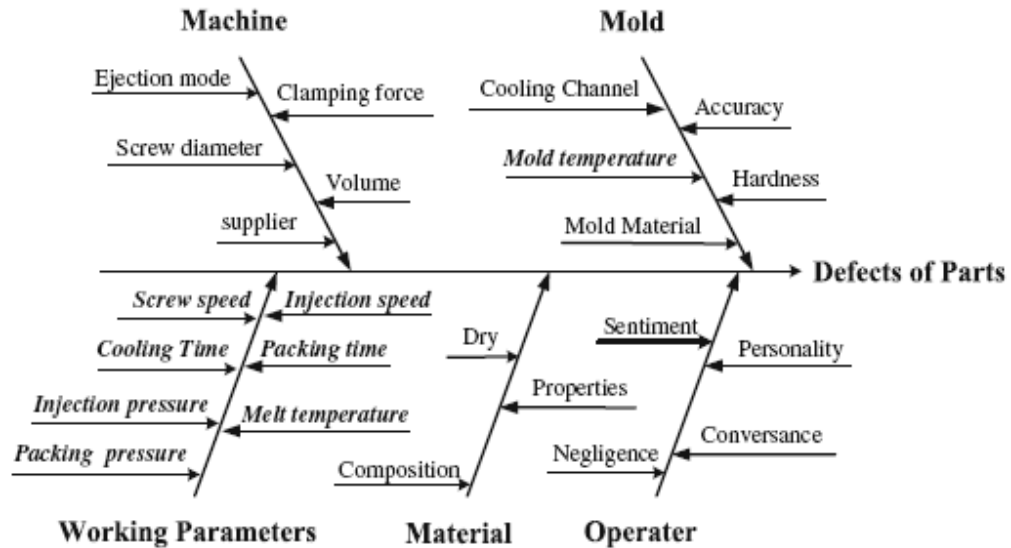


Fig. 7.5 Cause-and-effect diagram shown in fishbone schematics for the moulded bush.

There are many factors that influence the quality of the moulded bush but eight factors are selected here as shown in bold italic type.

According to the literature and with the cause-and-effect diagram shown in Fig.7.5, the most significant processing parameters selected were melt temperature(A), injection pressure(B) injection speed(C), mold temperature(D), packing pressure(E), packing time(F) , cooling time(G) and screw speed(H).

Using Taguchi method L27 orthogonal experiment was performed setting above eight parameters at three different levels.

Table-7.4 Different parameters and their levels

Parameter	Symbol	Values at different levels
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		Level-1	Level-2	Level-3
Melting temperature	A	260 ⁰ C	275 ⁰ C	290 ⁰ C
Injection pressure	B	60 M Pa	75 M Pa	90 M Pa
Injection speed	C	40 Cm ³ /Sec	50 Cm ³ /Sec	60 Cm ³ /Sec
Mold temperature	D	40 ⁰ C	60 ⁰ C	80 ⁰ C
Packing pressure	E	70 M Pa	75 M Pa	80 M Pa
Packing time	F	3 Sec	4 Sec	5 Sec
Cooling time	G	20 Sec	30 Sec	40 Sec
Screw speed	H	50 rpm	65 rpm	80 rpm

S/N (signal to noise) ratio in Taguchi method is helpful in the selection of process parameters at better levels. A large number of different S/N ratios have been defined for a variety of problems, though in this work we have used larger the better characteristic for hardness and smaller the better characteristic for over shrinkage (bulging defect). The method used to calculate S/N ratio for both the types is as follows:

7.3.1 Larger – the – better

$$S/N \text{ ratio } (\eta) = -10 \log_{10}(1/n \sum 1/y_i^2) \quad [i=1 \text{ to } n]$$

Where n = number of replications.

This is applied for problems where maximization of the quality characteristic of interest is sought. This is referred to as the larger-the-better type problem.

7.3.2 Smaller – the – better

$$S/N \text{ ratio } (\eta) = -10 \log_{10}(1/n \sum y_i^2) \quad [i=1 \text{ to } n]$$

This is termed as smaller-the-better type problem where minimization of the characteristic is intended.

Table-7.5 Average value of hardness (for three sample pieces) and S/N(signal to noise) ratio in 27 experiments performed at three different levels of parameters A, B, C, D, E, F, G, and H.

S.No.	A	B	C	D	E	F	G	H	Hardness	S/N ratio
1	1	1	1	1	1	1	1	1	75	37.5
2	1	1	1	1	2	2	2	2	77	37.73
3	1	1	1	1	3	3	3	3	76	37.62
4	1	2	2	2	1	1	1	2	74.5	37.44
5	1	2	2	2	2	2	2	3	78	37.84
6	1	2	2	2	3	3	3	1	76	37.62
7	1	3	3	3	1	1	1	3	80	38.06
8	1	3	3	3	2	2	2	1	81.33	38.21
9	1	3	3	3	3	3	3	2	80.5	38.12
10	2	1	2	3	1	2	3	1	80.5	38.12
11	2	1	2	3	2	3	1	2	83.66	38.45
12	2	1	2	3	3	1	2	3	81.66	38.24
13	2	2	3	1	1	2	3	2	81.5	38.22

14	2	2	3	1	2	3	1	3	84.66	38.55
15	2	2	3	1	3	1	2	1	83.66	38.45
16	2	3	1	2	1	2	3	3	79.66	38.02
17	2	3	1	2	2	3	1	1	82.66	38.35
18	2	3	1	2	3	1	2	2	81.5	38.22
19	3	1	3	2	1	3	2	1	82.66	38.35
20	3	1	3	2	2	1	3	2	84	38.49
21	3	1	3	2	3	2	1	3	84.33	38.52
22	3	2	1	3	1	3	2	2	82	38.28
23	3	2	1	3	2	1	3	3	83.66	38.45
24	3	2	1	3	3	2	1	1	81	38.17
25	3	3	2	1	1	3	2	3	78	37.84
26	3	3	2	1	2	1	3	1	80	38.06
27	3	3	2	1	3	2	1	2	79	37.95

Using Taguchi method, L27 orthogonal experiment was performed setting the above eight parameters at three different levels for bulging (over shrinkage). The S/N ratio for the experiment is shown in Table-7.6.

Table -7.6 Average value of bulging or over shrinkage (for three sample pieces) and S/N ratio in 27 experiments performed at three different levels of parameters A, B, C, D, E, F, G, and H

									Avg.	S/N
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S. No.	A	B	C	D	E	F	G	H	Bulging	
1	1	1	1	1	1	1	1	1	0.116667	18.661
2	1	1	1	1	2	2	2	2	0.086667	21.243
3	1	1	1	1	3	3	3	3	0.135	17.39
4	1	2	2	2	1	1	1	2	0.142	16.95
5	1	2	2	2	2	2	2	3	0.083333	21.58
6	1	2	2	2	3	3	3	1	0.136667	17.29
7	1	3	3	3	1	1	1	3	0.1193	18.47
8	1	3	3	3	2	2	2	1	0.072	22.85
9	1	3	3	3	3	3	3	2	0.113333	18.91
10	2	1	2	3	1	2	3	1	0.106667	19.44
11	2	1	2	3	2	3	1	2	0.05	26.02
12	2	1	2	3	3	1	2	3	0.093333	20.59
13	2	2	3	1	1	2	3	2	0.18	14.89
14	2	2	3	1	2	3	1	3	0.106667	19.44
15	2	2	3	1	3	1	2	1	0.246	12.18
16	2	3	1	2	1	2	3	3	0.38	8.4
17	2	3	1	2	2	3	1	1	0.316667	9.9
18	2	3	1	2	3	1	2	2	0.38	8.4
19	3	1	3	2	1	3	2	1	0.362	8.82

20	3	1	3	2	2	1	3	2	0.303333	10.36
21	3	1	3	2	3	2	1	3	0.345	9.24
22	3	2	1	3	1	3	2	2	0.283333	10.95
23	3	2	1	3	2	1	3	3	0.234	12.61
24	3	2	1	3	3	2	1	1	0.28	11.05
25	3	3	2	1	1	3	2	3	0.182	14.79
26	3	3	2	1	2	1	3	1	0.13	17.72
27	3	3	2	1	3	2	1	2	0.175	15.14

Table-7.7 Average values of S/N ratio at different parameter levels

S. NO.	Parameter Levels	Avg. S/N ratio (Bulging)	Parameter Levels	Avg. S/N ratio (Hardness)
1	A1	19.26	A1	37.7933
2	A2	15.47	A2	38.2911
3	A3	12.3	A3	38.2344
4	B1	16.86	B1	38.11333
5	B2	16.66	B2	38.11333
6	B3	14.95	B3	38.09222
7	C1	13.18	C1	38.03778
8	C2	18.84	C2	37.95111

9	C3	15.02	C3	38.33
10	D1	16.83	D1	37.9911
11	D2	12.33	D2	38.0944
12	D3	17.88	D3	38.2333
13	E1	14.59	E1	37.9811
14	E2	17.96	E2	38.2366
15	E3	14.47	E3	38.10111
16	F1	15.11	F1	38.10111
17	F2	15.98	F2	38.08667
18	F3	15.94	F3	38.1311
19	G1	16.09	G1	38.11
20	G2	15.71	G2	38.12889
21	G3	15.22	G3	38.08
22	H1	15.32	H1	38.0922
23	H2	15.87	H2	38.1
24	H3	15.83	H3	38.12667

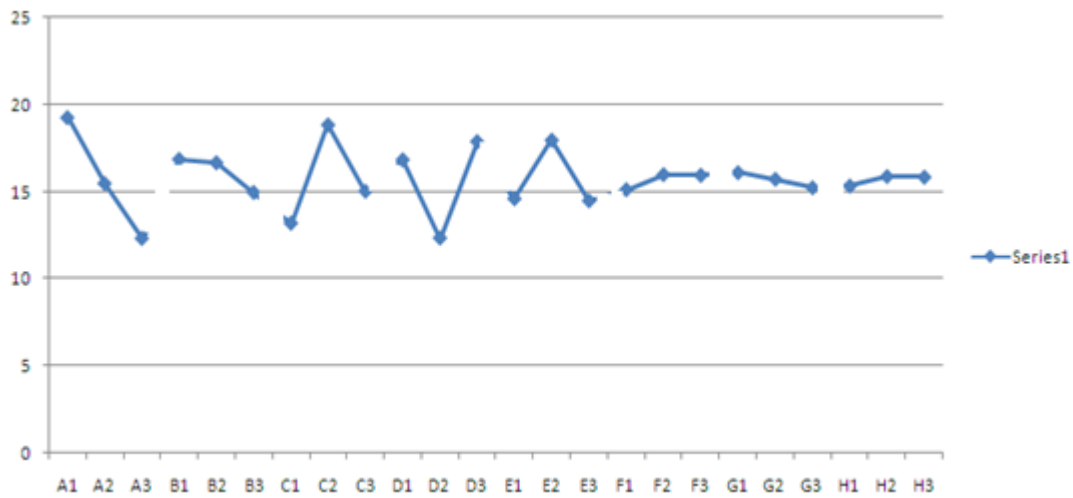


Fig.7.6 Variation in S/N ratio (vertical axis) because of change in parameter levels (for bulging)

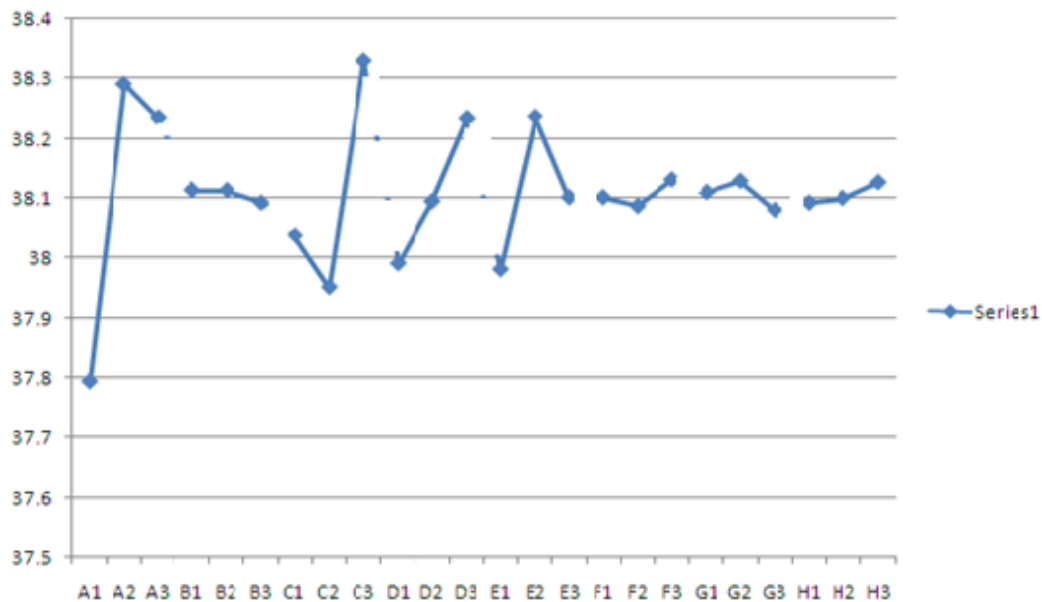


Fig.7.7 Variation in S/N ratio (vertical axis) because of change in parameter levels (for hardness)

From Fig.7.6 it is obvious that parameters affecting bulging in order of preference are A, C, D E, B, F, G, and H. The parameters A, C, D and E has

larger impact on the bulging defect therefore these parameters were selected to make regression and neural network models.

While Fig.7.7 depicts that parameters affecting hardness in order of preference are A, C, E, D, G, F, H, B. The parameters A, C, E and D have larger impact on the hardness therefore these parameters were selected to make regression and neural network models.

Both the properties hardness and bulging are affected the most by the parameters A, C, D and E therefore these will be considered for further analysis.

The first order regression equation with the above variables did not give better results; therefore we opted for second order regression analysis.

With the help of the above data we formed a second order regression equation for hardness as below

$$\begin{aligned} \text{HARD} = & 6.3732839507248 A + 0.012305555556039 D - 2.0035555555469 C \\ & + 10.93255555366 E - 0.011343209876806 A^2 + 0.00034861111110563 D^2 \\ & + 0.021377777777698C^2 - 0.072155555545211 E^2 - 1182.3028394404 + e \\ & \dots\dots\dots (1) \end{aligned}$$

Where 'e' is an error term

The regression statics for this model is depicted in Table-7.8

Table-7.8 Regression statistics for equation one

<u>Multiple Linear Regression - Regression Statistics</u>	
Multiple R	0.985151
R-squared	0.970523
Adjusted R-squared	0.957422
F-TEST	74.079898
Observations	27
Degrees of Freedom	18
<u>Multiple Linear Regression - Residual Statistics</u>	
Standard Error	0.606962
Sum Squared Errors	6.631244

Table-7.9 Regression statistics (Analysis of Variance) for equation (1)

Multiple Linear Regression - Analysis of Variance			
ANOVA	DF	Sum of Squares	Mean Square
Regression	8	218.329741	27.291218
Residual	18	6.631244	0.368402
Total	26	224.960985	8.6523455840456
F-TEST	74.079898		

Table-7.10 Regression statistics (Student Distribution Probability) for equation (1)

Student (mathematical equation plotter)	Distribution	Probability
T-Test	10.5206	
D.F.	18	

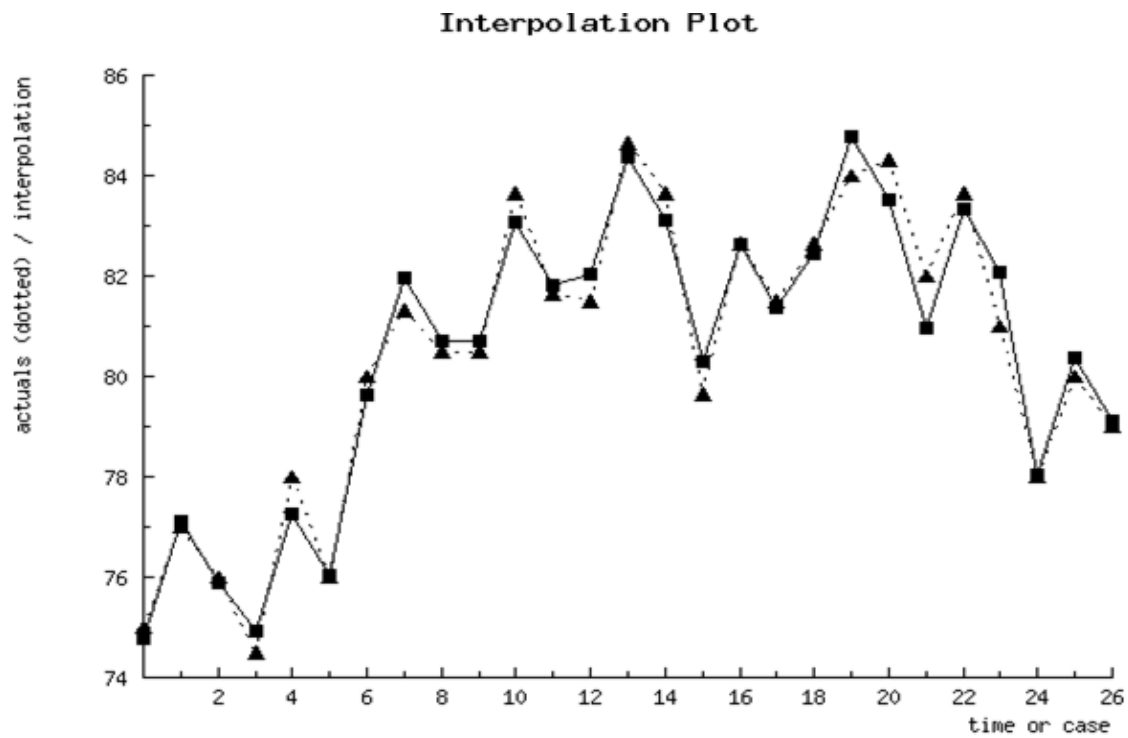


Fig.7.8 Comparison between actual hardness values (dotted) and predicted hardness values (from equation one) for twenty seven experimental samples.

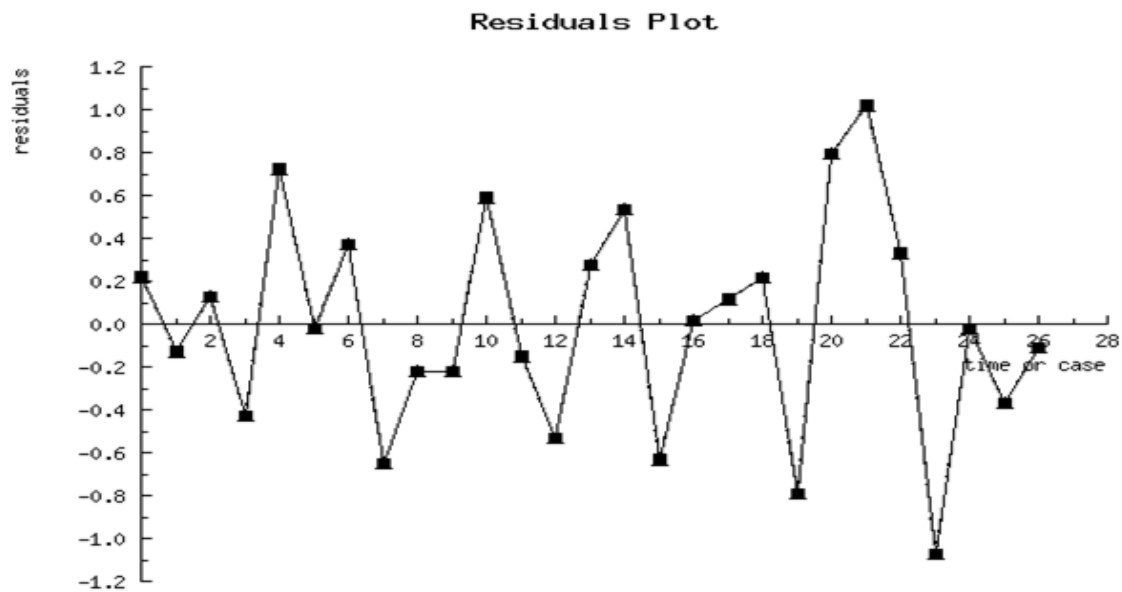


Fig.7.9 Residuals plot for twenty seven experimental samples.

Similarly the second order regression equation for bulging was formed as below

$$\text{BULGING} = 0.061682428194518 A + 0.0364504629528 D - 0.10546870372806 C - 0.33662925904979 E - 0.0001034650209666 A^2 - 0.00030389351847241 D^2 + 0.001034425926114 C^2 + 0.0022465925911414 E^2 + 5.2475707471113 + e \dots \dots \dots (2)$$

The Regression Statistics of this model is shown in table-7.11.

Table-7.11 Regression statistics for bulging model shown in equation (2)

<u>Multiple Linear Regression - Regression Statistics</u>	
Multiple R	0.984221
R-squared	0.968691
Adjusted R-squared	0.954776
F-TEST	69.614348
Observations	27
Degrees of Freedom	18
<u>Multiple Linear Regression - Residual Statistics</u>	
Standard Error	0.022217

Table-7.12 Analysis of Variance for bulging model shown by equation (2)

Multiple Linear Regression - Analysis of Variance			
ANOVA	DF	Sum of Squares	Mean Square
Regression	8	0.274894	0.034362
Residual	18	0.008885	0.000494
Total	26	0.283779	0.010914588545104
F-TEST	69.614348		

Table-7.13 Student Distribution Probability for bulging model shown by equation (2)

Student (mathematical equation plotter)	Distribution	Probability
T-Test		2.7817
D.F.		18

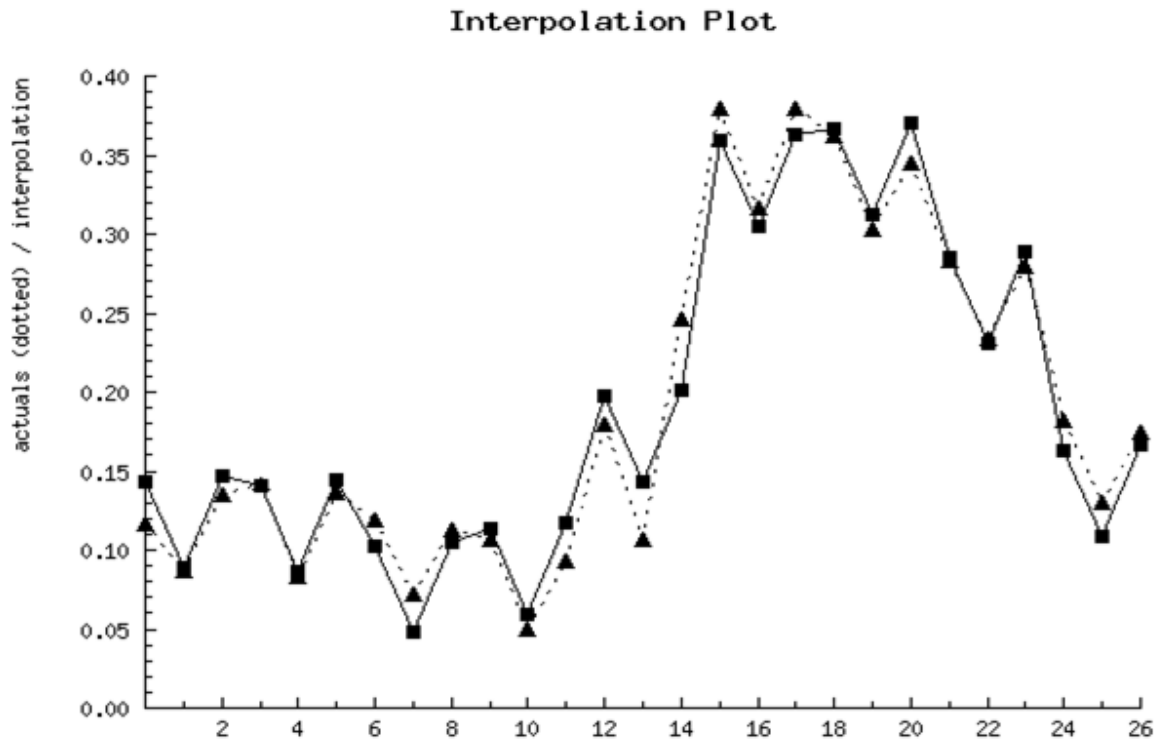


Fig.7.10 Comparison between actual shrinkage values (dotted) and predicted shrinkage values for twenty seven experimental samples.

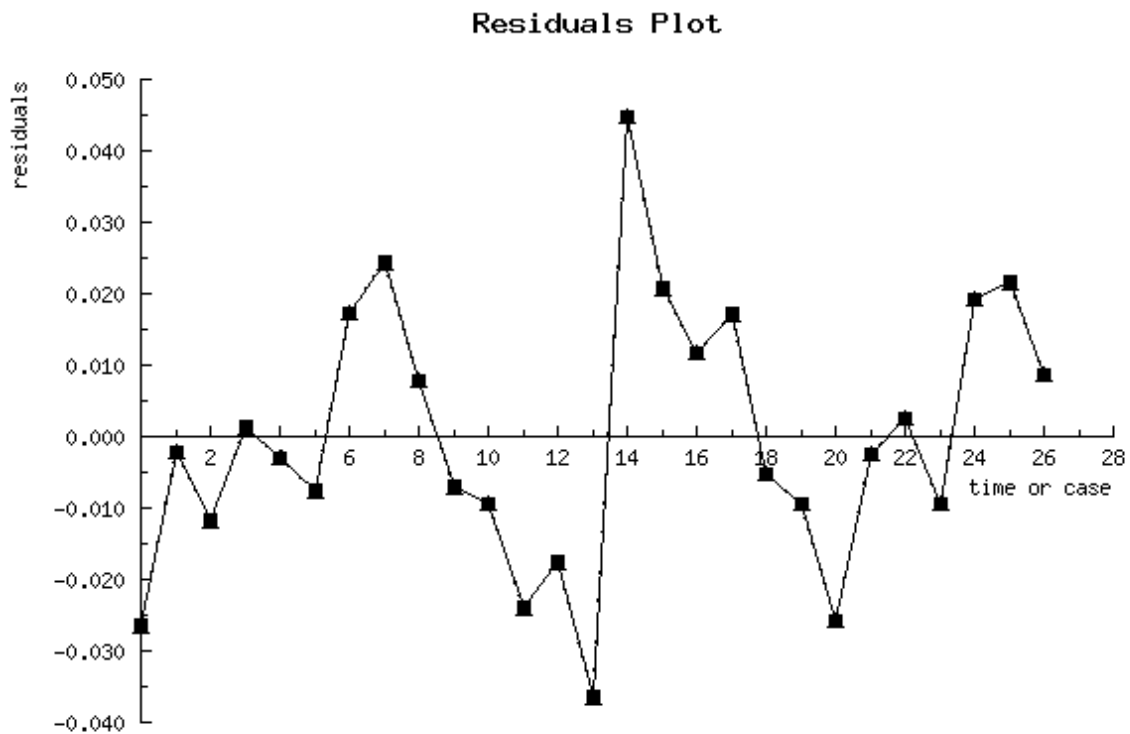


Fig.7.11 Residuals plot for twenty seven experimental samples.

These second order regression models were further validated with the help of neural network models which have been prepared separately for both hardness and bulging predictions.

The twenty seven results of Table-7.5 were used for training neural network model. We used neural net work model with following specifications for prediction of hardness value

Minimum weight-0.0001

Limit of epochs-10,000

Initial weight-0.3

Learning rate -0.3

Momentum-0.6

Activation function –Log sigmoid function with no neurons in hidden layer

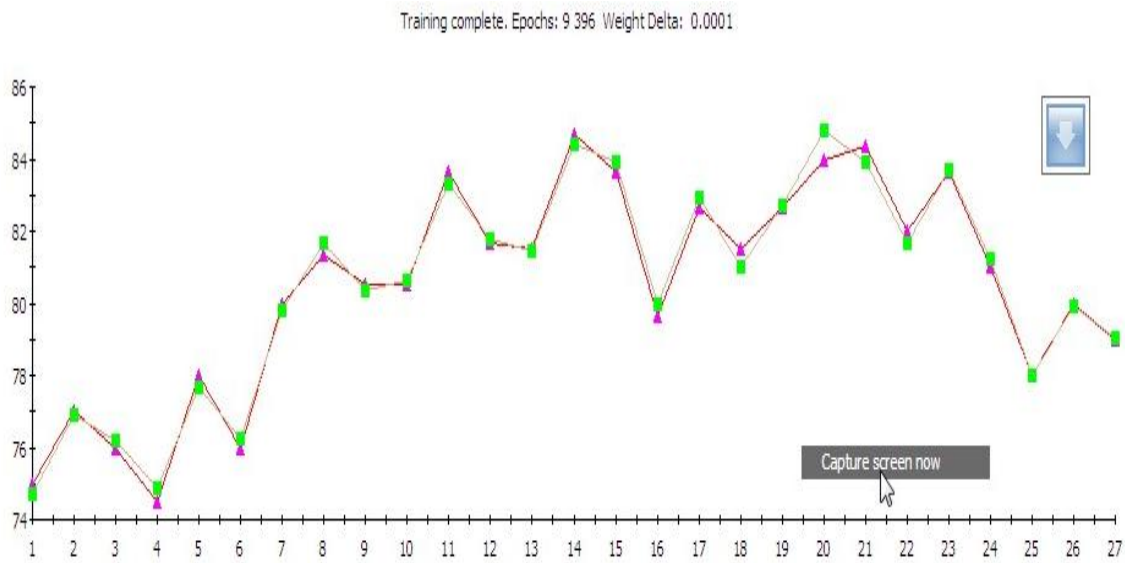


Fig.7.12 Comparison between actual hardness values (red) and predicted hardness values (green) for twenty seven experimental samples.

Similarly the twenty seven results of Table-7.6 were used for training neural network model for prediction of bulging. The model had following specifications.

Minimum weight-0.0001

Limit of epochs-10,000

Initial weight-0.3

Learning rate -0.3

Momentum-0.6

Activation function – log sigmoid function with no neurons in hidden layer

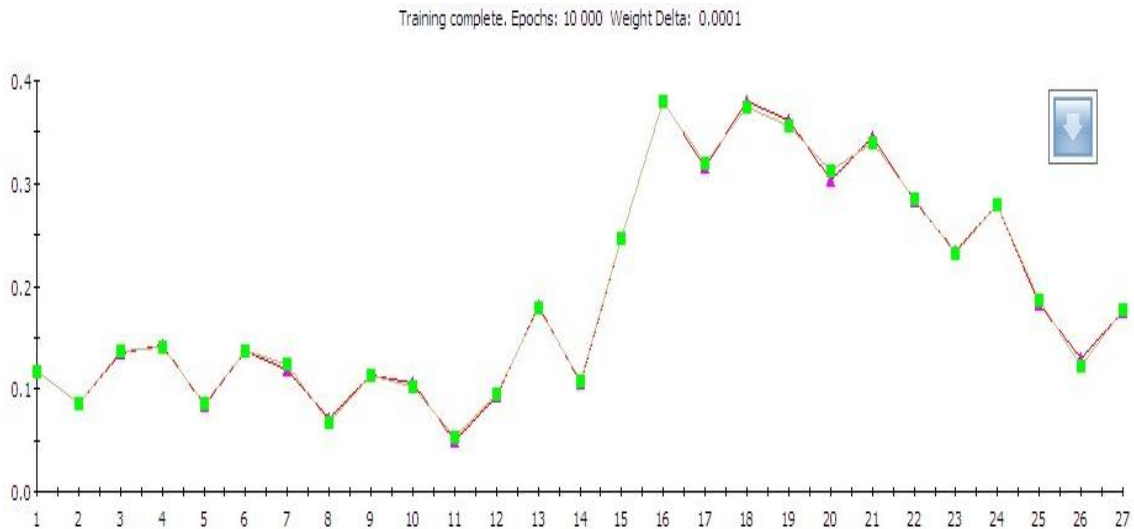


Fig.7.13 Comparison between actual shrinkage values (red) and predicted shrinkage values (green) for twenty seven experimental samples.

From Fig.7.6 and Fig.7.7 it is obvious that factors A, D, C and E has the most significant affect on both the quality characteristics i.e. over shrinkage and hardness. Taguchi design of experiment (Table-7.5 and Table-7.6) indicates that hardness is maximum when parameters are at A2, C3, D1 and E2 levels while over shrinkage is minimum when parameters are at A2, C2, D3 and E2 levels. Since the parameters A and E give optimum value of both the quality characteristics at the same level a compromise was made between parameters C and D with the help of regression and neural net work models prepared with the help of experiment.

The predicted values of hardness and over shrinkage (bulging) at different values of parameters A, C, D and E are shown in Table-7.14. After analyzing the predicted values of hardness and over shrinkage, obtained from both the models, we selected parameter A-275, D-80, C-54 and E-75, which shows best compromise between hardness and over shrinkage.

Table-7.14 Predictions made by proposed Regression and ANN models at different values of parameters D and C while parameters A and E are constant.

Table-7.14 Prediction made by both regression and ANN models

S.NO.	Parameters and their levels				Neural network model predictions		Second order regression model predictions	
	A	D	C	E	Predicted Hardness	Predicted Bulging	Predicted Hardness	Predicted Bulging
1	275	45	52	75	83.86272195	0.207976	81.4	0.11318675
2	275	50	54	75	84.28938385	0.2485	82.2190	0.1594505
3	275	55	56	75	84.47720709	0.198369	83.1596	0.198795
4	275	60	58	75	84.47592161	0.107416	84.2886	0.23122029
5	275	65	60	75	84.30075696	0.0587	85.60607	0.25672627
6	275	70	58	75	84.02592984	0.052041	84.86487	0.2006633
7	275	75	56	75	83.68894122	0.048561	84.3121	0.1376811
8	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797
9	275	75	52	75	83.70390173	0.056641	83.09114	0.11268397
10	275	65	50	75	84.10593786	0.142654	82.12607	0.17354479
11	275	60	52	75	84.26794599	0.192166	82.22	0.18131140
12	275	55	54	75	84.37414015	0.228232	82.4636	0.182158
13	275	50	56	75	84.43304319	0.229088	82.915	0.176086
14	275	45	58	75	84.45100007	0.184063	83.55497	0.16309569
15	275	40	60	75	84.43222966	0.106967	84.3833	0.143185

Confirmation experiment was done at the above setting of selected parameters i.e. melting temperature (A)-275°C, mold temperature (D)-80°C, injection speed (C)-54 cm³/sec., packing pressure (E)-75 M Pa rest of the parameters like injection pressure (B), packing time (F), cooling time (G) and screw speed (H) were taken at moderate levels of 75 M Pa, 4 second, 30 second and 65 rpm respectively.

Nine experimental runs were carried out based on the above parameter settings. The results of these runs are shown in Table 7.15.

Table-7.15 Prediction made by both regression and ANN models vs. actual values obtained in experimental run.

S.NO.	Parameters and their levels				Neural network model predictions		Second order regression model predictions		Confirmation experiment results	
	A	D	C	E	Predicted Hardness	Predicted Bulging	Predicted Hardness	Predicted Bulging	Actual Hardness	Actual shrinkage
1	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	83	0.056
2	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	82.8	0.065
3	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	84	0.068
4	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	83.6	0.07
5	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	84.2	0.075
6	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	84.2	0.050
7	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	83.8	0.060
8	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	85.4	0.052

9	275	80	54	75	83.29563224	0.04709	83.9478	0.0677797	84.6	0.062
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If we compare the predicted values of both the models as well as actual values obtained in confirmation run (Table-7.15), it becomes clear that both the models are predicting values of both the quality characteristics very close to actual value. To further consolidate results t-test was performed.

7.4 T test: For a normal population of size n with mean μ , variance σ^2 and standard deviation s, student's t is defined as

$$t = (\bar{x} - \mu) / (s / \sqrt{n}) \dots \dots \dots (3)$$

While the confidence interval of μ is given by

$$\bar{X} \pm t_{0.005} s / \sqrt{n} \dots \dots \dots (4)$$

Where $t_{0.005}$ is tabulated value of t at 99.5 percent confidence limit

Table-7.16 T test for hardness with alternative hypothesis that true mean is greater than 83 at confidence level of 99.5 percent

One Sample t-test	
H0	83
Alternative	greater
CI	0.99
Sample Mean	83.95555555555555
T-Test	3.61804719244034
DF	8
P-Value	0.00340091193327827

Since the p value is smaller than significance level and tabulated value of t (3.355) is less than calculated value (3.61804) null hypothesis that actual mean is 83 is rejected and alternate hypothesis that actual sample mean is more than 83 is accepted.

Confidence interval for hardness in the above case can be given as

$$83.95555 \pm 3.355 \times 0.792324288/3$$

i.e. the hardness value lies between 83.06 and 84.8416 can be predicted at 99.5 percent confidence limit.

Table-7.17 T test for over shrinkage with alternative hypothesis that true mean is less than 0.075 and at confidence level of 99.5 percent

One Sample t-test	
H0	0.075
Alternative	less
CI	0.99
Sample Mean	0.062
T-Test	-4.65308989292077
DF	8
P-Value	0.000819043782834587

Since the p value is smaller than significance level and tabulated value of t (3.355) is less than calculated value (4.65308) null hypothesis that actual mean

is .075 is rejected and alternate hypothesis that actual sample mean is less than .075 is accepted.

Confidence interval for over shrinkage in the above case can be given as

$$0.062 \pm 3.355 \times 0.0083815/3$$

i.e. the over shrinkage value lies between 0.053 and 0.071 can be predicted at 99.5 percent confidence limit

7.5 UPGRADE PHASE

First the optimal parameter setting decided in analyze phase such as melting temperature (A)-275°C, mold temperature (D)-80°C, injection speed (C)-54 cm³/sec., packing pressure (E)-75 M Pa were employed and rest of the parameters like injection pressure (B), packing time (F), cooling time (G) and screw speed (H) were taken at moderate levels of 75 M Pa, 4 second, 30 second and 65 rpm respectively.

The adequate number (nearly 100 to 150) of nylon-6 bushes were produced under the above setting of parameters and all the quality characteristics of bush were measured thoroughly.

To measure the improvement in shrinkage values after process improvement, we selected hundred samples from the production line at different times in a week. The process capability index for these samples was calculated. The results of process capability analysis are shown in Table-7.18 and in Fig.7.14.

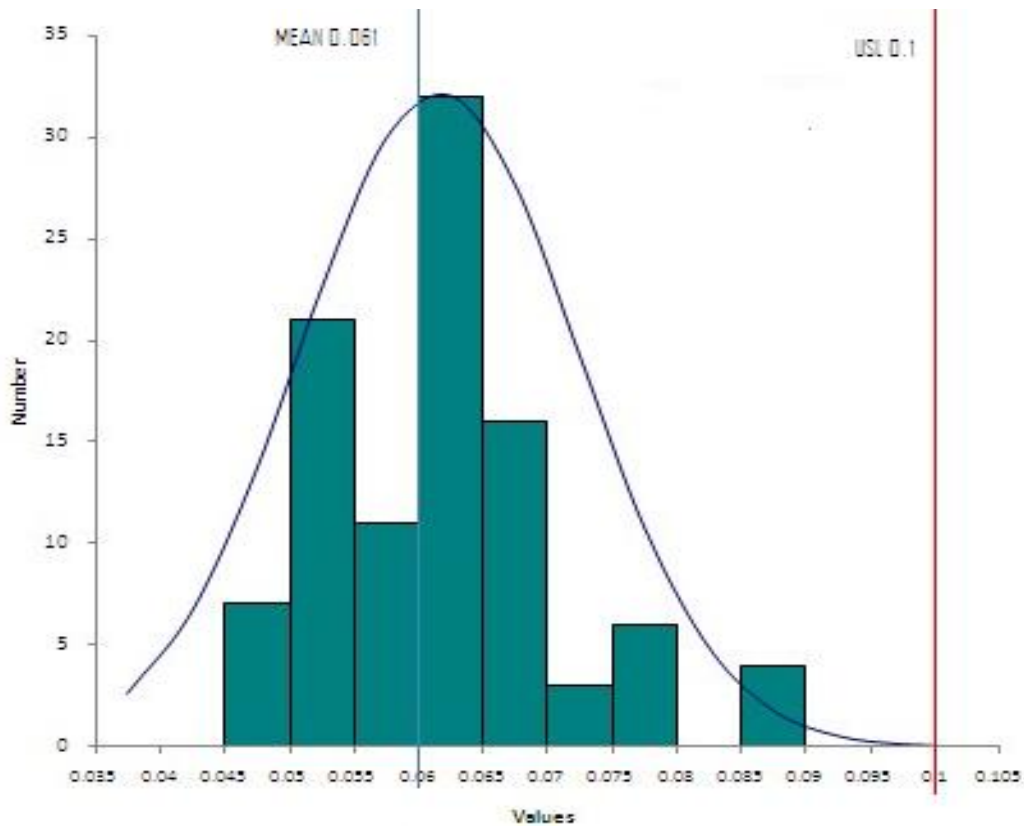


Fig.7.14 Histogram for hundred samples (over shrinkage measurement)

If we compare the histograms for over shrinkage in diagnose phase and upgrade phase (Fig.7.3 and Fig.7.14) as well as process capability analysis in both the phases (Table-7.2 and Table-7.18) we can easily draw following conclusions.

- (1) Process capability index CPU has increased from 0.24 to 1.225
- (2) Process mean has decreased from 0.1015 to 0.0615, which is very much desired.
- (3) Process has improved from 2.38σ standard to 5.18σ standard.

Table-7.18 Process capability analysis for hundred samples (for over shrinkage measurements)

Cp	values	Number of Entries	100
Cpk	1.225	Average	0.06157
CpU	1.225	Stdev	0.011
CpL	*	Median	0.06
Ppk	1.193	Mode	0.06
PpU	1.193	Minimum Value	0.045
PpL	*	Maximum Value	0.09
Min	0.045	Range	0.045
Max	0.09	LSL	FALSE
Z Bench	3.674	USL	0.1
% Defects	0.0%	Number of Bars	10.000
PPM	0.000	Number of Classes	9.000
Expected	119.555	d2/c4	0.987
Sigma	5.170	Target	0.067776
	Observed	Expected	Z
PPM<LSL	*	*	*
PPM>USL	0.0	119.6	3.674
PPM	0.0	119.6	

To measure the improvement in hardness values after process improvement, we selected hundred samples from the production line at different times in a week. The process capability index for these samples was calculated. The results of process capability analysis are shown in Table-7.19 and in Fig.7.15.

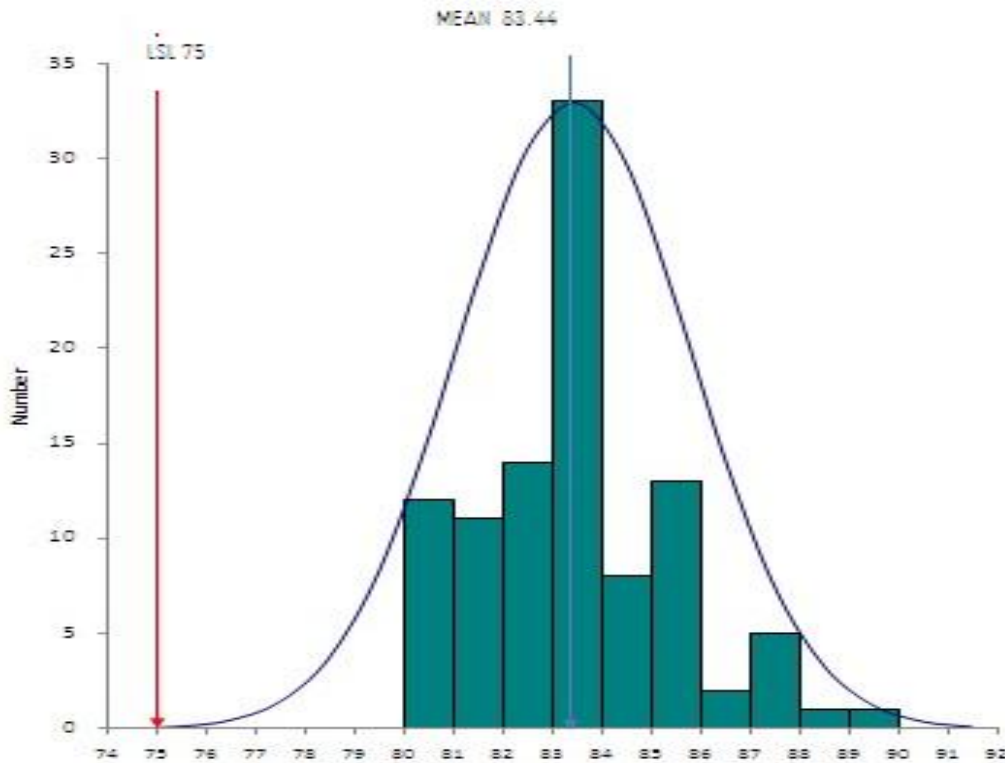


Figure-7.15 Histogram for hardness (horizontal axis)

If we compare the histograms for hardness in diagnose phase and upgrade phase (Fig.7.4 and Fig.7.15) as well as process capability analysis in both the phases (Table-7.3 and Table-7.19) we can easily draw the following conclusions.

- (1) Process capability index CPL has increased from 0.56 to 1.16.
- (2) Process mean has increased from 69.79 to 83.44, which is very much desired.

(3) Process has improved from 3.19σ standard to 4.99σ standard.

Table-7.19 Process capability analysis for hundred samples (for hardness)

Cp	*	Number of Entries	100
Cpk	1.16	Average	83.44
CpU	*	Stdev	2.36
CpL	1.16	Median	83
ZTarget/DZ	0.57	Mode	83
PpU	*	Minimum Value	80
PpL	1.19	Maximum Value	90
Skewness	0.45	Range	10
Stdev	2.362673	LSL	75
Min	80	USL	FALSE
Max	90	Number of Bars	10.00
Z Bench	3.49	Number of Classes	10.00
% Defects	0.0%	Class Width	1.00
PPM	0.00	Beginning Point	74
Expected	241.86	Stdev Est	2.42
Sigma	4.99	d2/c4	0.97
		Target	82.08802

	Observed	Expected	Z
PPM<LSL	0.0	241.9	-3.49
PPM>USL	*	*	*
PPM	0.0	241.9	
% Defects	0.0	0.0	

The above analysis shows improvement in process mean as well as process capability for both the quality characteristics therefore it was decided to control the process parameters at optimal levels as in the upgrade phase.

7.6 REGULATE PHASE (POKA YOKE)

In regulate phase of the approach, the improvement reached in upgrade phase is standardized and adopted for production management of the process. The results must be clearly defined in the control plan in order to constantly monitor its process capabilities and retaining the fruitful improvements.

The production equipment employed in this study is a precision injection moulding machine, model: PPU7690TV40G, over all dimensions 856×1500×2480 mm manufactured by the Targor Corporation. The machine is equipped with a built-in monitoring system together with a controller for the process parameters during injection moulding. Because of the built-in monitoring system it was not difficult to maintain the process parameters at the optimal levels decided in regulate phase, Poka Yoke was not needed.

7.7 REVIEW PHASE (KAIZEN)

In the review phase we compared the results obtained in upgrade phase with the six sigma standard so that further improvement (KAIZEN) can be done. As obvious in this study, process has been carried out up to 4.99σ and 5.18σ standard for the two major quality characteristics bulging and hardness respectively, but there is still scope for the improvement. After brain storming with the shop floor workers, engineers and experts, out of 4Ms (Man, Machine, Material and Method) improvement is needed in mould design (Machine) because of following reasons.

1. In built monitoring and control system of the machine leaves no scope for operator (Man) intervention after the process parameters are set.
2. The material used for molding was tested and it was meeting the quality standards.
3. Method has already been improved (process parameters were already optimized), which leaves a little scope for improvement in method.

With a vision for improvement in mould design we will switch to diagnose phase. The reasons for rejection and failure of nylon-6 bush will further be investigated. Keeping in mind the voice of customer, critical to quality factors which arise because of poor mould will be analyzed. This cycle (Diagnose, Analyse, Upgrade, Regulate and Review) will be carried out until six sigma standard is reached.