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Multi performance characteristic optimization of shot peening process for AISI 304 austenitic stainless steel using grey relational analysis with principal component analysis and Taguchi method

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Abstract: - Shot peening is a cold working process. It impact on thin surface layer of the material and is used to enhance the mechanical and surface properties. The manufacturer is in demand to reduce the cost and improve the process productivity. He is always in search of an optimization technique which involves multiple performance characteristics. From this work, an optimal combination of shot peening parameters is generated by using a Grey relational analysis (GRA) with Principal component analysis (PCA) and Taguchi method. The present study shows that there are many factors that affect the properties of the AISI 304 austenitic stainless steel. Mechanisms to compensate for surface tractions and further enhancement of mechanical properties are described. The shot peening is discussed to enhance the mechanical and surface properties of AISI 304 austenitic stainless steel. The optimization of shot pening process is done by including multi performance characteristics i.e. tensile strength, surface hardness an fatigue strengths. The analysis includes pressure, shot size, exposure time, nozzle distance and nozzle angle as process parameters. The complete analysis will be helpful to the manufacturer in deciding the shot peening parameters for required performance characteristics.

Keywords: - *ANOVA, Austenitic stainless steel, Gray relational analysis (GRA), optimization, shot peening.*

I. INTRODUCTION

The austenitic stainless steel is used in verity of applications due to its corrosion resistance, ductility, good weldability and resistance to high and low operating temperatures [1].The main constituents for austenitic stainless steel are chromium, nickel, molybdenum, and aluminium. Chromium makes the surface passive by forming a surface oxide film [2, 3], which protects the underlying metal from corrosion. This is because when the metal is scratched; the oxide layer re-forms quickly, hence protecting it from corrosion. However, chromium is a ferrite stabilizer. To counteract this, nickel is added as an austenite stabilizer, so that the microstructure at ambient temperature remains as austenitic [4].The heat treatment processes make austenitic stainless steel soften. Further the addition of carbon results in sensitization. Austenitic stainless steel is usually cold worked to enhance the mechanical properties [5, 6, 7]. Kirk and Payne [5] concluded in their work that martensite formation was easily induced by plastic deformation in austenitic stainless steel.

Many researchers found that shot peening can improve the mechanical properties the material [6, 7]. Shot peening is one of the most versatile tool to strengthen the metal parts against tensile strength, impact strength, surface hardness, compressive residual stress, damping, surface roughness, fatigue failure and corrosion. The induction of compressive residual stress in the thin skin layer of the surface results in the improvement of mechanical and surface properties. Shot peening is used now days in hundreds of different components of automobiles, aircraft and marine industries like railway and automobile leaf spring, helical spring, gears, axle bearing, crankshafts, milling cutters, connecting rod, cylinder block, valve springs, washers etc.

The controlled shot peening parameters helps in enhancing the surface and mechanical properties of the material. T. Dorr et. al. and M. Obata et. al. discussed the increase in surface hardness and surface roughness with increase in shot size and the peening intensity [8, 9]. K.B. Prakash et. al. have made study on shot peening for precision-machined steels with high strength to weight ratio [10]. As per the guidelines given by Champaine [11], the exposure time is an important factor to achieve desired peening coverage for the material. Sharma and Mubeen [12] investigated the effect of shot size on peening intensity. They guided the selection of correct size for shots to obtain desired intensity of shot peening. Sharma et. al. [13] presented a detailed discussion on development of various methods of controlling shot peening parameters. Schulze [14] discussed the characteristics of surface layer produced by shot peening.

Only a few authors have used the design of experiment (DoE) technique with a specialized single-ball controlled shot peening machine. The Taguchi method [15, 16] is a systematic tool for designing and analyzing the experiments for improving product quality. However, it is found that with Taguchi Method only a single performance characteristic is optimized. Phadke et. al. [17] suggested that the optimization of multi performance characteristics became difficult by Taguchi method. Deng [18, 19] proposed that grey relational analysis (GRA) is a part of grey system theory for the optimization of multi performance characteristics. Jeyapaul et al. suggested several modifications to the original Taguchi method for multi performance characteristic's optimization such as principal component analysis (PCA), data envelopment analysis (DEA) and GRA [20]. In recent years, GRA has become a powerful tool to analyze the processes with multiple performance characteristics. Chen et. al. [21], Bin et. al. [22] and Hsiao et. al. [23] are making use of GRA in many applications. Hence in view of all, it is necessary to perform a comprehensive investigations using GRA so as to evaluate the effect of shot peening parameters on surface integrity aspects such as tensile strength, surface hardness and fatigue strength of the material.

This paper proposes a novel design concept evaluation method based on GRA including Taguchi analysis and PCA to optimize the shot peening process for AISI 304 austenitic stainless steel. Effects of process parameters such as pressure, shot size, exposure time, nozzle distance and nozzle angle on tensile strength, surface hardness and fatigue strength were investigated and then process is optimized by using the approach. The performance characteristics considered for material are as tensile strength, surface hardness, and fatigue strength. The investigation is helpful to the manufacturers for reduction of cost, performance variation and scrap to increase productivity.

II. EXPERIMENTAL SET UP

The material AISI 304 austenitic stainless steel was used for various tests. The composition of the material is shown in Table 1. A flat plate having thickness of 10mm was used for making the specimens for various tests. The mechanical properties of the material were: tensile strength 617MPa, fatigue strength 228MPa and surface hardness 271VHN.

Table 1: Chemical composition (wt %) of AISI 304 austenitic stainless steel.

Austenitic stainless steel	C	Si	Mn	P	S	Ni	Cr	Mo	V
AISI 304	0.08	0.57	1.6	0.021	0.02	9.83	18.78	0.25	0.07

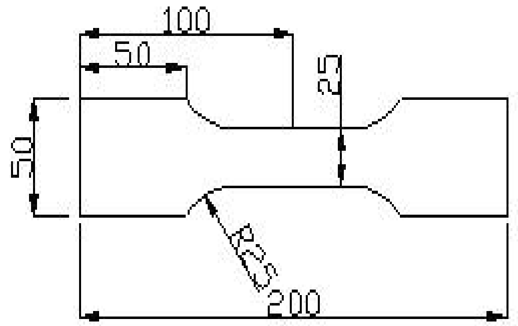
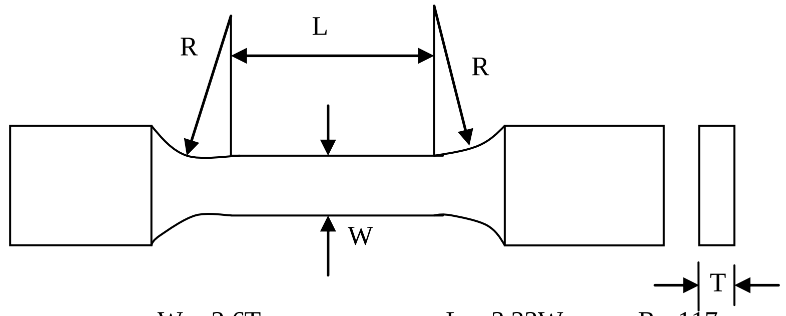


Fig. 1: Specimen for tensile test (all dimensions in mm).



T = 5mm W = 2.6T L = 3.23W R= 117 mm

Fig. 2: ASTM flat specimen for fatigue strength.

The dimension of specimen for tensile strength test is shown in Fig. 1. These specimens were required to perform the tensile test at different process parameter levels. Tensile testing was carried out at room temperature using a universal testing machine of type HEICO HL 590.15 having capacity 400kN with 5mm/min cross-head speed.

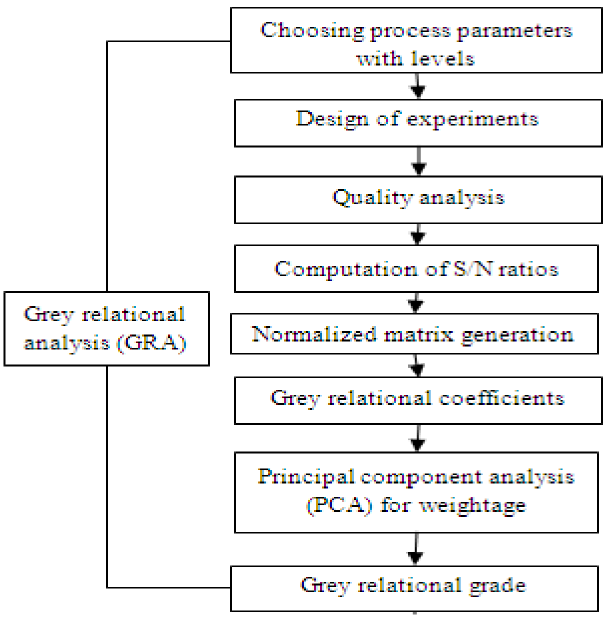
Vickers hardness test was carried on the surface of specimens. The hardness measurements were performed on specimens of 20mm by 60mm by 10mm thickness using WOLPERT universal hardness testing machine dia tester – 2, model 2RC. The average values of three readings of surface hardness were taken for different peening parameters.

The fatigue life of the shot peened specimens was tested by an axial fatigue-testing machine. Stress ratio (R) equal to 0.1 was used during fatigue testing. The dimension of specimen for plotting S-N curve is shown in Fig. 2. The dimensions of the specimens were according to the ASTM standards. Fifteen specimens were tested in order to plot an S/N curve. Only the average points were presented for each level. The specimens were testing in axial fatigue testing machine MTS model 810, at a frequency 30Hz, at room temperature. The other specifications of the machine are:

Type	: Servo hydraulic system
Force Capacity	: $\pm$ 285 kN
Column space	: 460 mm
Test space	: 978 mm

III. ANALYSIS PROCEDURE

In modern industry the goal of an engineer is to manufacture low cost, high quality products in short duration of time. It is always necessary to produce a component with higher stress to weight ratio. Shot peening is a low cost cold working process used to enhance the mechanical and surface properties of AISI 304 austenitic stainless steel. Moreover, in order to produce any product with desired performance characteristics by shot peening process, the shot peening parameters should be selected properly.



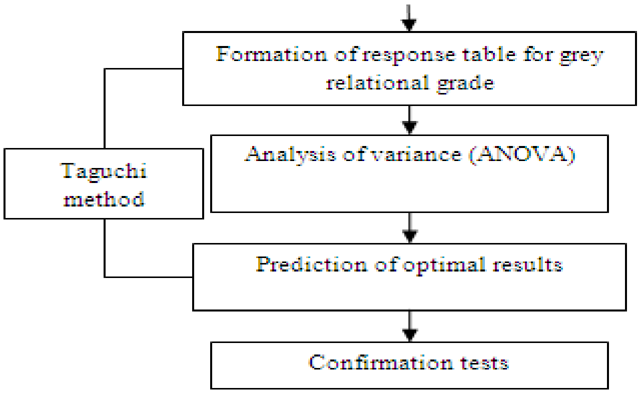


Fig. 3: Flow chart for analyzing process parameters of shot peening process for multi performance characteristics.

The present analysis proposes a novel design method based on GRA with PCA and Taguchi method to select the best combination of shot peening parameters to optimize the performance characteristics of AISI 304 austenitic stainless steel. The optimization of process parameters such as pressure, shot size, exposure time, nozzle distance and nozzle angle for performance characteristics are investigated by using the approach. The flow chart for analyzing and modeling of performance characteristics is shown in Fig. 3. The results of this analysis can be used by the engineers who are willing to search for an optimal solution of shot peening process of AISI 304 austenitic stainless steel.

IV. SELECTION OF SHOT PEENING PARAMETERS

It is viewed that the parameters like coverage, shot velocity, shot intensity etc. are controlled by the air pressure, type of nozzle, exposure time, nozzle distance and feed rate. Therefore with reference to literature [24] and basic experimental results the present investigation involves pressure, shot size, exposure time, nozzle distance and nozzle angle the process parameters which are considerably affecting the shot peening process. In shot peening process the parameters are divided into two categories one is controlled before the start of the process i.e. shot size and nozzle angle and the remaining are evaluated after shot peening process i.e. intensity, saturation, coverage etc. The desired magnitude of intensity, saturation, velocity and coverage are controlled by the air pressure, shot mass flow rate, nozzle type, feed rate of the nozzle along the work piece, nozzle distance from the work piece, and the work piece table speed. Therefore in the present investigation pressure, shot size, exposure time, nozzle distance and nozzle angle are the controllable influential process parameters under consideration. These shot peening parameters along with their levels are shown in Table 2.

Table 2: Process parameter and their levels.

Process Parameter	Parameter Designation	Levels		
		L1	L2	L3
Pressure (MPa)	P	0.196	0.392	0.588
Shot Size (mm)	S	0.85	1.00	1.85
Exposure Time (Sec)	T	80	120	160
Nozzle Distance (mm)	D	80	100	120
Nozzle Angle	E	60^0	75^0	90^0

An air-blast shot peening machine was used for shot peening of the specimens. Spherical cast steel shots were used as a shot peening media. The hardness of shots was 56HRC to 60HRC.

Design of experiments (DoE)

The design of experiment was based on full factorial design considering five factors each at three levels. An orthogonal array is a fractional factorial matrix that ensures a balanced comparison of levels of any parameter. In the present analysis a L27 orthogonal array is used. For three levels of each five factors there are 27 runs. The experimental results for tensile strength (TS), surface hardness (VHN) and fatigue strength (FS) are depicted in Table 3 for different 27 runs.

Signal-to-noise (S/N) ratio

Taguchi method is used to determine signal-to-noise (S/N) ratio. It is used to represent a performance characteristic and the largest value of S/N ratio is always desired. In this method, there are three types of S/N ratios i.e. the lower-the-better, the higher-the-better, and the nominal-the-better.
In the present analysis S/N ratio with a higher-the-better characteristic is used, that can be expressed as:

$$(S/N)_{HB} = -10 \text{ Log} \frac{1}{r}\left[\sum_{i=1}^{r}\frac{1}{y_i^2}\right] \quad (1)$$

where:
y_i = value of the performance characteristic in observation i
r = number of repetitions in a trial
The results of S/N ratios for different performance characteristics are shown in Table 4.

Grey relational analysis (GRA) with Principal component analysis (PCA)

7.1 Grey relational coefficients

The GRA is employed to analyze the complicated inter-relationships between the S/N ratios of performance characteristics. A linear normalization of the S/N ratio is performed in the range between zero and unity. The normalized S/N ratio y_{ij} for the i^{th} performance characteristic in the j^{th} experiment can be expressed by equation (2). The normalized matrix is represented in Table 5.

Table 3: Experimental results for different shot peening parameters.

Exp. No.	P	S	T	D	E	TS	VHN	FS
1	1	1	1	1	1	760.8	361.2	270.5
2	1	1	1	1	2	778.4	381.4	281.3
3	1	1	1	1	3	793.5	390.6	295.6
4	1	2	2	2	1	790.4	370.1	292.4
5	1	2	2	2	2	802.5	382.7	301.8
6	1	2	2	2	3	815.6	395.4	315.2
7	1	3	3	3	1	799.1	360.4	282.6
8	1	3	3	3	2	825.1	381.1	291.3
9	1	3	3	3	3	840.7	395.7	305.1
10	2	1	2	3	1	722.5	370.5	267.3
11	2	1	2	3	2	738.3	386.4	278.2
12	2	1	2	3	3	750.4	397.6	289.6
13	2	2	3	1	1	805.7	391.2	295.6
14	2	2	3	1	2	815.8	403.1	318.2
15	2	2	3	1	3	826.9	415.2	310.3
16	2	3	1	2	1	685.8	355.9	245.7
17	2	3	1	2	2	698.3	375.8	258.4
18	2	3	1	2	3	720.6	381.3	264.6
19	3	1	3	2	1	788.6	390.8	280.8
20	3	1	3	2	2	800.1	412.3	320.5
21	3	1	3	2	3	835.7	419.8	308.2
22	3	2	1	3	1	670.5	362.4	239.1
23	3	2	1	3	2	681.4	377.2	252.4
24	3	2	1	3	3	695.3	389.7	261.3
25	3	3	2	1	1	740.8	399.1	258.1
26	3	3	2	1	2	750.3	416.2	272.6
27	3	3	2	1	3	758.8	426.8	283.8

Larger-the-better

$$x'_i(j) = \frac{y_{ij} - \min_j y_{ij}}{\max_j y_{ij} - \min_j y_{ij}} \quad (2)$$

Now from the normalized matrix a reference value is determined as the largest value of normalized value for each criterion.

$$x'_0(j) = \max_{i=1}^{n} x'_i(j) \tag{3}$$

The next step is to construct the difference matrix by taking the difference between the normalized entity and reference value.

$$\Delta_{oi}(j) = |x'_o(j) - x'_i(j)| \tag{4}$$

Afterwards the grey relational coefficients are determined by using equation (5) and they are presented in Table 6. It represents the relationship between the desired and actual experimental results.

$$\delta_{oi}(j) = \frac{\min_{i=1}^{n} \min_{j=1}^{m} \Delta_{oi}(j) + \zeta \times \max_{i=1}^{n} \max_{j=1}^{m} \Delta_{oi}(j)}{\Delta_{oi}(j) + \zeta \times \max_{i=1}^{n} \max_{j=1}^{m} \Delta_{oi}(j)} \tag{5}$$

where ζ ($0 \le \zeta \le 1$) is the distinguishing coefficient or the index for distinguishability and ζ takes the value of 0.5 because this value usually provides moderate distinguishing effects and good stability.

Table 4: Data for S/N ratios of performance characteristics.

Exp. No.	S/N_{TS}	S/N_{VHV}	S/N_{FS}
1	57.6254	51.1550	48.6433
2	57.8241	51.6276	48.9834
3	57.9909	51.8346	49.4141
4	57.9569	51.3664	49.3195
5	58.0889	51.6572	49.5944
6	58.2295	51.9407	49.9717
7	58.0520	51.1357	49.0234
8	58.3301	51.6208	49.2868
9	58.4928	51.9473	49.6888
10	57.1768	51.3758	48.5400
11	57.3647	51.7407	48.8871
12	57.5059	51.9889	49.2360
13	58.1235	51.8480	49.4141
14	58.2317	52.1083	50.0540
15	58.3491	52.3651	49.8356
16	56.7239	51.0266	47.8081
17	56.8808	51.4991	48.2459
18	57.1539	51.6253	48.4518
19	57.9371	51.8391	48.9679
20	58.0629	52.3043	50.1166
21	58.4410	52.4608	49.7767
22	56.5280	51.1838	47.5716
23	56.6680	51.5314	48.0418
24	56.8434	51.8146	48.3428
25	57.3940	52.0216	48.2358
26	57.5047	52.3860	48.7105
27	57.6025	52.6045	49.0602

7.2 Principal component analysis (PCA)

In the next stage a weightage method is used to analyze the weightage of each performance characteristic. The weightage assigned to the performance characteristics is either decided by the manufacturer or determined by using PCA.
The elements of Table 6 represent the grey relational coefficients for the multi performance characteristics of shot peened AISI 304 austenitic stainless steel. This data is used to evaluate the correlation coefficient matrix and further it is used to evaluate the corresponding eigenvalues and eigenvectors from the following equation:

$$[(CC)_{jk} - \beta_l I_m]\, E_{il} = 0 \qquad (6)$$

where β_l represents the eigenvalues; $\sum_{l=1}^{n} \beta_l = n$, l = 1, 2, 3,……..n; and

$E_{il} = [a_{li}\ a_{l2}\ a_{l3}\ \ldots\ldots.. a_{ln}]^T$ is the eigenvector corresponding to the eigenvalue β_l.

The eigenvalues are shown in Table 7 and the eigenvector corresponding to each eigenvalue is listed in Table 8. The results are obtained by using statistical software MINITAB 14. Hence, for this study, the squares of corresponding eigenvector of first principal component is selected as the weighting values of the related performance characteristic, represented by ω_{TS}, ω_{VHN} and ω_{FS} in Table 9.

Table 5: Normalized matrix elements.

Exp. No.	TS	VHN	FS
1	0.5585	0.0814	0.4211
2	0.6597	0.3809	0.5547
3	0.7446	0.5121	0.7240
4	0.7272	0.2153	0.6868
5	0.7944	0.3996	0.7948
6	0.8660	0.5793	0.9431
7	0.7757	0.0691	0.5705
8	0.9172	0.3766	0.6739
9	1.0000	0.5835	0.8319
10	0.3302	0.2213	0.3805
11	0.4258	0.4526	0.5169
12	0.4977	0.6099	0.6540
13	0.8120	0.5206	0.7240
14	0.8671	0.6855	0.9754
15	0.9269	0.8483	0.8896
16	0.0997	0.0000	0.0929
17	0.1796	0.2994	0.2650
18	0.3186	0.3794	0.3459
19	0.7172	0.5149	0.5486
20	0.7812	0.8097	1.0000
21	0.9736	0.9089	0.8664
22	0.0000	0.0996	0.0000
23	0.0713	0.3199	0.1848
24	0.1605	0.4994	0.3030
25	0.4408	0.6306	0.2610
26	0.4971	0.8615	0.4475
27	0.5469	1.0000	0.5849

7.3 Grey relational grade

In the next step grey relational grades are calculated based on equation (7) from data listed in Table 6. Thus, the optimization design is performed with respect to a single grey relational grade rather than complicated performance characteristics. This grey relational grade is a single numerical value which represents the optimization of multi performance characteristics. The grey relational grade is determined from following equation:

$$\gamma_{oi} = \sum_{i=1}^{m} \delta_{oi}(j)\omega_i \qquad (7)$$

The grey relational grade is calculated by using equation (7). In this equation m is the number of performance characteristics, $\delta_{oi}(j)$ are the grey relational coefficients and ω_i is the weightage assigned to the performance characteristics. The results of grey relational grade are represented in Table 10. Table 10 and Fig. 4 shows the shot peening parameters setting of experiment no. 21 has the highest grey relational grade (0.8590). Thus, the experiment no. 21 gives the best combination of process parameters among the twenty seven experiments for shot peened AISI 304 austenitic stainless steel.

V. ANALYSIS OF EXPERIMENTAL RESULTS

Further ANOVA and Taguchi method are performed on grey relational grade by using statistical software MINITAB 14 to determine the significant process parameter. They help in predicting the best combination of process parameters for optimal performance characteristics.

8.1 Taguchi analysis

Taguchi analysis is performed to generate the response table i.e. the average grey relational grade for each factor level, by using statistical software MINITAB 14. It helps to determine the significant process parameter. The procedure was to group the grey relational grades firstly by factor level for each column in the orthogonal array,

Table 6: Grey relational coefficients for performance characteristics.

Exp. No.	**$\square_{oi}$(TS)**	**$\square_{oi}$(VHN)**	**$\square_{oi}$(FS)**
1	0.5311	0.3525	0.4634
2	0.5950	0.4468	0.5290
3	0.6619	0.5061	0.6443
4	0.6470	0.3892	0.6149
5	0.7086	0.4544	0.7090
6	0.7886	0.5431	0.8978
7	0.6903	0.3494	0.5379
8	0.8579	0.4451	0.6053
9	1.0000	0.5456	0.7484
10	0.4274	0.3910	0.4466
11	0.4655	0.4774	0.5086
12	0.4989	0.5617	0.5910
13	0.7268	0.5105	0.6443
14	0.7900	0.6139	0.9531
15	0.8724	0.7672	0.8191
16	0.3571	0.3333	0.3553
17	0.3787	0.4165	0.4048
18	0.4232	0.4462	0.4332
19	0.6387	0.5076	0.5256
20	0.6956	0.7244	1.0000
21	0.9499	0.8459	0.7892
22	0.3333	0.3570	0.3333
23	0.3500	0.4237	0.3802
24	0.3733	0.4997	0.4177
25	0.4720	0.5751	0.4035
26	0.4986	0.7831	0.4751
27	0.5246	1.0000	0.5464

Table 7: The eigenvalues and proportions for principal components.

Principal Component	Eigenvalue	Proportion (%)
First	2.1202	70.7
Second	0.7004	23.3
Third	0.1794	06.0

Table 8: The Eigenvectors for principal components.

Performance characteristics	First principal component	Second principal component	Third principal component
TS	-0.613	0.419	0.670
VHN	-0.465	-0.877	0.123
FS	-0.639	0.236	-0.732

Table 9: The weightage of each performance characteristic.

Performance Characteristics	Weightage
ω_{TS}	0.3758
ω_{VHN}	0.2162
ω_{IS}	0.4083

Table 10: Grey relational grade.

Exp. No.	Grey relational grade
1	0.4637
2	0.5346
3	0.6194
4	0.5769
5	0.6524
6	0.7784
7	0.5533
8	0.6642
9	0.7974
10	0.4261
11	0.4841
12	0.5482
13	0.6447
14	0.8166
15	0.8254
16	0.3501
17	0.3961
18	0.4308
19	0.5625
20	0.8237
21	0.8590
22	0.3373
23	0.3768
24	0.4171
25	0.4644
26	0.5478
27	0.6328

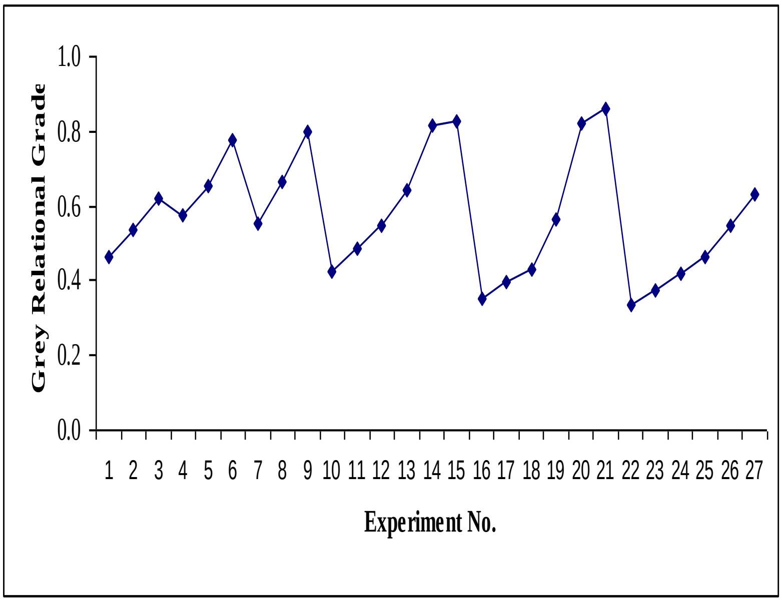


Fig. 4: Graph of grey relational grade.

Table 11: Response table for the grey relational grade.

Level	P	S	T	D	E
1	0.6267	0.5913	0.4362	0.6166	0.4866
2	0.5469	0.6028	0.5679	0.6033	0.5885
3	0.5579	0.5374	0.7274	0.5116	0.6565
Delta	0.0798	0.0654	0.2912	0.1050	0.1699
Rank	4	5	1	3	2

and then to average them. For example, the grey relational grades for factors P at level 1 and 2 can be calculated as follows:

$$P1 = \frac{1}{9}(0.4637 + 0.5346 + 0.6194 + 0.5769 + 0.6542 + 0.7784 + 0.5533 + 0.6642 + 0.7974)$$

$$= 0.6267$$

$$P2 = \frac{1}{9}(0.4261 + 0.4841 + 0.5482 + 0.6447 + 0.8166 + 0.8254 + 0.3501 + 0.3961 + 0.4308)$$

$$= 0.5469$$

The generated response tables are shown in Table 11 for each factor level. The grey relational grades represent the level of correlation between the reference and the comparability sequences. Larger value of grey relational grade shows that the comparability sequence exhibits a stronger correlation with the reference sequence. On the bases of this statement this analysis helps to select the level of process parameters that provides the largest performance characteristics. In Table 11, P1, S2, T3, D1 and E3 have largest value of average grey relational grade for factors P, S, T, D and E respectively. Hence P1S2T3D1E3 is the best combination of shot peening parameters for optimal performance characteristics of AISI 304 austenitic stainless steel. It is restated that for AISI 304 austenitic stainless steel the best combination of shot peening process are as: pressure 0.196 MPa, shot size 1mm, exposure time 160 sec, nozzle distance 80 mm and nozzle angle is 90^0. The impact of each shot peening parameter can be presented clearly by means of the response graphs. These graphs shows the change in the response, when the parameters changes their level from 1 to level 3. The response graphs for shot peening parameters are presented in Fig. 5. In these figures, the higher value of response gives the high value of performance characteristics.

Fig. 5: Response graphs of shot peening parameters.

The order of importance is also observed from Table 11 i.e. by calculating the difference between the maximum and minimum value of the average grey relational grade for each factor. The last row of response tables indicates that the exposure time has stronger effect on the multi-performance characteristics than other parameters.

8.2 ANOVA

The purpose of the ANOVA is to investigate which parameters of shot peening process affect significantly the performance characteristics. This is achieved by separating the total variability of the grey relational grades. To evaluate the impact of each process parameters on performance characteristics, the total sum of the squared deviations can be utilized. Table 12 gives the results of the ANOVA for performance characteristic using the calculated values of grey relational grade in Table 10. According to Table 12, the exposure time with 57.88% of contribution, is the most significant controlled parameters. It is also found that the p-value of all the factors is less than 0.05 that represents significant effect on the performance characteristics.

Table 12: ANOVA results of grey relational grade.

Source	DF	Seq SS	Adj MS	P	Contribution (%)
P	2	0.033656	0.016828	0.003	5.09
S	2	0.021929	0.010965	0.016	3.32
T	2	0.382780	0.191390	0.000	57.88
D	2	0.058830	0.029415	0.000	8.90
E	2	0.131689	0.065844	0.000	19.91
Error	16	0.032389	0.002024		4.89
Total	26	0.661272			
S = 0.0449923 R-Sq = 95.10% R-Sq(adj) = 92.04%					

VI. CONFIRMING EXPERIMENTAL DESIGN

After identifying the most of influential parameters, the final phase is to verify the performance characteristics by conducting the confirmation experiments. The GRA with PCA and Taguchi method gives the optimal parameters combination as P1S2T3D1E3 for shot peening process of AISI 304 austenitic stainless steel. Hence this combination of shot peening parameters is used for confirmation tests. With these optimal settings for AISI 304 austenitic stainless steel, the specimens give the tensile strength of 832.8 MPa, surface hardness of 403.8 VHN and fatigue strength of 318.6 MPa. The optimal grey relational grade (γ_{opt}) is predicted by using the following equation:

$$\gamma_{opt} = \gamma_m + \sum_{i=1}^{n} (\gamma_i - \gamma_m) \quad (8)$$

Where γ_m is the average of grey relational grade, γ_i is the average of grey relational grade at optimum level and n is the number of significantly affecting process parameters. Pressure, shot size, exposure time, nozzle distance and nozzle angle are all the significant parameters used for predicting the optimal grey relational grade. The predicted value of optimal grey relational grade is expressed as:

$$\gamma_{opt} = \gamma_m + \sum_{i=1}^{5} (\gamma_i - \gamma_m)$$

The predicted value of optimal grey relational grade is calculated as:

= 0.5772+(0.7274-0.5772)+(0.6565-0.5772)+(0.6166-0.5772)+(0.6267-0.5772)+(0.6028-0.5772) = 0.9212

Table 13: Experimental and predicted values of grey relational grade.

Performance characteristics	Predicted value	Experimental value
Optimal parameters	P1S2T3D1E3	P1S2T3D1E3
Tensile Strength		832.8 MPa
Surface Hardness		403.8 VHN
Fatigue Strength		318.6 MPa
Grey relational grade	0.9212	0.8713

It is found that calculated grey relational grade for these optimal values of performance characteristics is higher from the grey relational grade among the 27 experiments as shown in Table 13. This table also represents that the grey relational grade for optimal parameters is near to the predicted value of optimal grey relational grade. Hence using the present approach, shot peening of AISI 304 austenitic stainless steel is successfully optimized.

VII. CONCLUSION

The response table and ANOVA presented in Table 11 and 12 shows that pressure, shot size, exposure time, nozzle distance and nozzle angle are the process parameters which significantly affecting the performance characteristics. All parameters affecting the performance characteristics are at 95% confidence level. The GRA with PCA and Taguchi analysis gives the optimal process parameters as P1S2T3D1E3. At this optimal condition the process parameters are set as: pressure 0.196 MPa, shot size 1.00 mm, exposure time 160 sec, nozzle distance 80 mm and nozzle angle 90^0. At this condition of process parameters the confirmatory experiments are performed and the average value of tensile strength, surface hardness and fatigue strength are as 832.8 MPa, 403.8 VHN and 318.6MPa respectively. Hence these are the proposed process parameter levels for the optimal performance characteristics of shot peened AISI 304 austenitic stainless steel.

The maximum grey relational grade for the material is 0.8590 among the 27 experiments. The conformation experiments at optimal process parameters give a grey relation grade of 0.8713. It is higher than the grey relational grade among 27 experiments and near to the predicted value of optimal grey relational grade i.e. 0.9212. Hence it optimizes the shot peening process for AISI 304 austenitic stainless steel. It seems that GRA with PCA and Taguchi analysis is a straight forwarded method for optimizing multi performance characteristic problems in shot peening.

REFERENCES

[1] A. Kyröläinen, M. Vilpas and H. Hänninen, Use of stainless steels in bus coach structures, *Journal of Materials Engineering and Performance. Vol. 9(6)*, 2000, 669-677.

[2] R.W.K. Honeycombe and H.K.D.H. Bhadeshia, *Steels - Microstructure and Properties*, (Second Edition, Edward Arnold, 1995).

[3] P.J. Cunat, A New Structural Material for Passenger Cars: Stainless Steel, *Auto Technology*, 2002, 40-42.

[4] T. Oshima, Y. Habarai and K. Kuroda, Efforts to save nickel in austenitic stainless steels, *ISIJ International. Vol. 47, No. 3*, 2007, 359-364.

[5] D. Kirk and N.J. Payne, Transformation induced in austenitic stainless steels by shot peening, *ICSP-7, Warsaw, Poland*, 1999, 15-22.

[6] M. Milad, N. Zreiba, F. Elhalouani and C. Baradai, The effect of cold work on structure and properties of AISI 304 stainless steel, *Journal of Materials Processing Technolog,. 203*, 2008, 80-85.

[7] A. Hedayati, A. Najafizadeh, A. Kermanpur and F. Forouzan, The effect of cold rolling regime on microstructure and mechanical properties of AISI 304L stainless steel, *Journal of Materials Processing Technology, 210*, 2010, 1017-1022.

[8] T. Dorr, M. Hilpert, P. Beckmerhagan, A. Kiefer and L. Wagner, Influence of shot peening on fatigue performance of high-strength aluminum-and magnesium alloys, *Proceedings of the ICSP-7 conference, Warsaw, Poland*, 1999.

[9] M. Obata and A. Sudo, Effect of shot peening on residual stress and stress corrosion cracking for cold worked austenitic stainless steel, *Proceedings of the ICSP-5 conference, Oxford, UK*, 1993.

[10] K.B. Prakash, B.M. Sunil and Y.S. Chandrakant, Shot peening: state of-the-art, *Proceedings of the ICAMMP Conference, IIT Kharagpur*, 2006, pp 296–303.

[11] J. Champaigne, *Controlled shot peening*, (2nd ed., The Shot Peener, Mishawaka, USA, 1989).

[12] M.C. Sharma and A. Mubeen, Effect of shot size on peening intensity for local peening, *Journal of Mechanical Working Technology, 8,* 1983, 155-160.

[13] M.C. Sharma, H. Deo, S.C. Modi and R.G. Bosshard, *Virtues & limitations of Almen round shot peening*, (Wiley-VCH Verlag GmbH & Co. KgaA, 2006).

[14] V. Schulze, Characteristics of surface layers produced by shot peening, *ICSP-8, Garmisch-Partenkirchen, Germany*, 2002, 145-160.

[15] P.J. Ross, *Taguchi Techniques for Quality Engineering*, (McGraw-Hill, New York, 1988).

[16] R.K. Roy, Design of Experiments using the Taguchi approach: 16 steps to Product and Process, Improvement, *Wiley-Inter science, New York*, 2001, 179-186.

[17] S.M. Phadke, *Quality Engineering Using Robust Design*, (Englewood Cliffs, NJ: Prentice Hall, 1989).

[18] J.L. Deng, *Basic methods of Grey System*, (1st edition Press of Huazhong University of Science and Technology, Wuhan, China, 1987).

[19] J.L. Deng, Introduction to grey system theory, *Journal of Grey Syst., 1*, 1989, 1-24.

[20] R. Jeyapaul, P. Shahabudeen and K. Krishnaiah, Quality management research by considering multi-response problems in the Taguchi method-a review, *International Journal of Advance Manufacturing Technology, 26*, 2005, 1331–1337.

[21] F.S. Chen, T.C. Chang and H.H. Liao, The application of grey relation analysis on teacher appraisa, *IE Times New Roman EE International conference on Systems Man and Cybernetics, 5*, 2000, 6-10.

[22] S. Bin, Y. Ping, L. Yunbai and W. Xishan, Study on the fault diagnosis of transformer based on the grey relation analysis, *International Conference Power System Technology, China, 4,* 2002, 2231-2234.

[23] Y.F. Hsiao, Y.S. Tarng and W.J. Huang, Optimization of plasma arc welding parameters by using the Taguchi method with grey relational analysis, *Material and Manufacturing Processes, 23*,2008, 51-58.

[24] Lakhwinder Singh, R.A. Khan and M.L. Aggarwal, Empirical modeling of shot peening parameters for welded austenitic stainless steel using grey relational analysis, *Journal of Mechanical Science and Technology, 26(6)*, 2012, 1731-1739.