EXPERIMENTAL EVALUATION AND DETERMINATION OF OPTIMUM PARAMETERS FOR MULTI-PERFORMANCE CHARACTERISTICS IN SHOT PEENING

A. Dounde[1], V. S. Jadhav[2]

[1,] PG Student, [2,] Associate Professor, Department of Mechanical Engineering, Government College of Engineering, Karad, (India)

ABSTRACT

Fatigue is the main reason for failure of connecting rods and which mainly due to tensile residual stresses at the surface of connecting rod. To improve mechanical properties of metal we should try to avoid tensile mean stress and have compressive mean stress. Shot peening is the cold working process that introduce residual compressive stress on the surface of components and modify its mechanical properties, which depends on correct choice of peening parameters. The manufacturer is always in demand to improve productivity and reduce its cost. He is in search of an optimization technique which involves multiple performance characteristics. The attempt of this paper is to optimize the multi performance characteristics of shot peening process using Grey relational analysis (GRA) method. The optimization of shot peening process is done by including multi performance characteristics i.e. compressive residual stresses and surface roughness. The analysis includes shot flow rate, shot mix, exposure time as process parameters. In the present study, the introduced compressive residual stresses measured by XRD technique. The complete analysis will be helpful to the manufacturer in deciding the shot peening parameters for best combination of performance characteristics.

Keywords: ***Residual Compressive Stress, Grey Relational Analysis, DOE, ANOVA, Shot Peening Parameters.***

I INTRODUCTION

Shot peening (SP) is an effective surface method, which is widely used to improve the fatigue resistance and damage tolerance of components in industry. The process of shot peening involves the bombardment of the treated surface with a stream of small hard spherical media called shots. As a result, elastic and plastic deformation is induced in near surface layer of the treated sample, since the plastically stretched surface layer wants to expand and the adjacent elastically responding material around and below the impact restrains the expansion; therefore, a compressive residual stress field is generated in near surface layer which improve the performance and extend the life of critical components viz. connecting rods, gears.

Connecting rod is subjected to millions of repetitive cyclic loadings. It should be strong enough to remain rigid under loading. The connecting rod failure reasons are: fatigue failure (crack initiation); lubrication failure in a bearing due to faulty maintenance; failure of the rod bolts from improper tightening; over-revving of the engine etc. Fatigue is the main reason for failure of the connecting rods and which mainly depend on surface residual stresses. Residual stress is crucial in ensuring the integrity of engineering component and shot peening can be used to introduce the beneficial compressive residual stress levels [1]. Residual stresses are those internal stresses left after permanent deformation. Residual stress can be either tensile or compressive. Failures are often related to residual tensile stress induced during manufacturing procedures like grinding, milling and bending. On contrary compressive residual stress induced over the surface of connecting rod leads to improving the fatigue resistance. It can reduce the effective applied stresses of the component during application, which results in delayed crack initiation and retarded crack propagation from the surface. Beneficial manufacturing processes include surface hardening, burnishing and surface rolling as it induces residual compressive stress into the surface. These processes primarily limited to cylindrical geometries. Shot peening has no geometry limitations and produces results that is usually the most economical. Compared with the other advanced mechanical treatment technology like laser shot peening (LSP) and low plasticity burnishing (LPB), which are more expensive and time consuming [2,3].

Most authors have used standard specimens for the shot peening study [4][5][6][7]. It is noted that hardly any shot peening studies have been made on actual component [8] like connecting rod. Further few authors have used design of experiment (DOE) technique with a specialized shot peening machine powered by centrifugal force. Therefore present study focuses on shot peening of specialized connecting rods using centrifugal type shot peening machine.

II EXPERIMENTAL PROCEDURE

2.1 Material

Forged Connecting rods of material AISI 4140H used in experiments. These connecting rods are being used in Cummins Engines. The connecting rod material composition is given in Table 1. The initial compressive residual stress on surface of connecting rod was in the range of 240-245 Mpa. Cast steel shots were used as a peening media having hardness of 44-52 HRC.

Element	C	Cr	Mn	Si	S	P
% Wt	0.4	0.8	0.68	0.18	0.04	0.035

Table 1: Chemical composition of AISI 4140H steel connecting rod

2.2 Machine Setup

The entire experimental work is carried out in the premises of Bharat Forge Ltd. Pune. Shot peening machine specification shown in Table 2. Response parameters such as compressive residual stress and surface roughness were measured by Residual Stress analyser (Stresstech X-stress 3000) and surface roughness tester (Mahr Perthometer) respectively.

1	Equipment	Automatic Shot flow by centrifugal force
2	Number of Impeller	2 (Two)
3	Size of Impeller	Diameter 380 mm
4	Impeller speed in RPM	2900 rpm
5	Impeller Motor Current	22-24 Amps
6	Peening Media	Cast steel shots
7	Stand off Distance (fixed)	350 mm

Table 2: Shot peening machine Specifications

Fig (1): Shows shot peening machine; Blasting Cabinet; Connecting rod mounted in cabinet

Fig (2): X-stress analyzer (XRD); Measurement of residual compressive stress by XRD; Measurement of Surface roughness.

2.3 Experimental parameters and their levels

Shot size, shot flow rate, intensity, saturation, shot velocity, distance between nozzle to work piece and work piece table speed, exposure time coverage are the various input parameters. Since some parameters such as velocity, intensity, and coverage are difficult to control, controllable influential parameters such as shot mix, shot flow rate and exposure time factors were considered in the present investigation. Levels of these parameters were determined by one factor at a time experiments. These shot peening parameters along with their levels are shown in Table 3. Shot mix 60: 40 (S 330) indicates that S330 (diameter=0.838mm) shot grade used during experimentation in which 60% of shot have diameter equal to 0.838mm and remaining 40% of shots have diameter less than 0.838 mm. The ratio of such shot mix was calculated by sieve analysis before the experimentation.

Process Parameter	Level 1	Level 2	Level 3
Shot Size (mix)	60:40 (S 330)	75:25 (S 330)	-
Shot Flow in terms of Assembly current. (Amp))	18	21	24
Exposure Time (Sec)	60	90	120

Table 3: Parameter levels and their values

2.4 Design of Experiments

The design of experiment (DOE) was based on full factorial design considering two factors each at three levels and one factor at two levels. In the present analysis total number of runs = $L^F = 3^2 \times 2^1 = 18$ have been taken. The experimental results for compressive residual stress (CRS) and surface roughness (SR) are depicted in Table 4 for different 18 runs. Both compressive residual stress and surface roughness were measured at centre of parting line of a connecting rod as shown in Fig. 2

Exp. No	Shot Mix	Shot Flow Rate (Amp)	Exposure Time (Sec)	Compressive Residual Stress (Mpa)	Surface roughness-Ra value (µm)
1	60:40	18	60	349.6	4.09
2	60:40	18	90	351.5	4.14
3	60:40	18	120	353.6	4.18
4	60:40	21	60	370.3	4.6
5	60:40	21	90	376.8	4.66
6	60:40	21	120	380.2	4.53
7	60:40	24	60	400.1	5.15
8	60:40	24	90	404.3	5.18
9	60:40	24	120	418.9	5.22
10	75:25	18	60	360.2	5.35
11	75:25	18	90	379.7	5.28
12	75:25	18	120	397.6	5.24
13	75:25	21	60	382.2	6.38
14	75:25	21	90	398.5	6.3
15	75:25	21	120	420.6	6.2
16	75:25	24	60	417.4	5.19
17	75:25	24	90	416.2	5.1
18	75:25	24	120	456.4	5.26

Table 4: Experimental results for different shot peening parameters

III GREY RELATIONAL ANALYSIS

Grey relational analysis (GRA) is suitable for solving problems with complicated interrelationships between multiple factors and variables. GRA solves multiple attribute decision making (MADM) problems by combining all performance values of every alternative into one, single value. This reduces the original problem to a single attribute decision making problem. Therefore, alternatives with multiple attributes can be compared easily after the GRA process [9]. In the present investigation, GRA was used for finding the best combination of input parameters among eighteen alternatives by considering two performance attributes. The procedures of grey relational analysis are shown in Fig. 3.

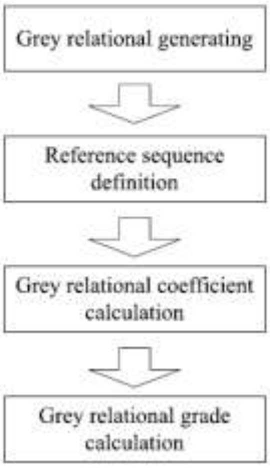


Fig.3: Procedure of grey relation analysis.

3.1 Grey relational generating

This process is analogous to normalization. For a MADM problem, if there are m alternatives and n attributes, the ith alternative can be expressed as $Y_i = (y_{i1}, y_{i2}, \ldots, y_{ij}, \ldots, y_{in})$, where y_{ij} is the performance value of attribute j of alternative i. The term Y_i can be translated into the comparability sequence $X_i = (x_{i1}, x_{i2}, \ldots, x_{ij}, \ldots, x_{in})$ by use of one of Eq. 1 or 2.

$$x_{ij} = \frac{y_{ij} - Min(y_{ij}, i=1,2,\ldots,m)}{Max(y_{ij}, i=1,2,\ldots,m) - Min(y_{ij}, i=1,2,\ldots,m)} \qquad for\ i = 1,2,\ldots,m\ j = 1,2,\ldots,n \qquad (1)$$

$$x_{ij} = \frac{Max(y_{ij}, i=1,2,\ldots,m) - y_{ij}}{Max(y_{ij}, i=1,2,\ldots,m) - Min(y_{ij}, i=1,2,\ldots,m)} \qquad for\ i = 1,2,\ldots,m\ j = 1,2,\ldots,n \qquad (2)$$

Eq. (1) is used for the-larger-the-better attributes; Eq. (2) is used for the-smaller-the-better attributes.

The main purpose of grey relational generating is transferring the original data into comparability sequences. Compressive residual stress is a larger-the-better attribute, and surface roughness is smaller-the-better attributes, The grey relational generating process adopts Eq. (1) for compressive residual stress, Eq. (2) for the data of performance values of surface roughness. For example, in the case of the compressive residual stress, the maximum value is 456.4 from alternative No. 18 and the minimum value is 349.6 from alternative No. 1. Using

Eq. (1) the results of grey relational generating of alternative No. 1 is equal to (349.6-349.6)/(456.4-349.6) = 0. The entire results of grey relational generating are shown in Table 5.

Exp. No	Shot Mix	Shot Flow Rate (Amp)	Exposure Time (Sec)	Grey Relation Generating for CRS	Grey Relation Generating for Ra value
1	60:40	18	60	0	1
2	60:40	18	90	0.017790262	0.978165939
3	60:40	18	120	0.037453184	0.96069869
4	60:40	21	60	0.193820225	0.777292576
5	60:40	21	90	0.254681648	0.751091703
6	60:40	21	120	0.286516854	0.807860262
7	60:40	24	60	0.472846442	0.537117904
8	60:40	24	90	0.512172285	0.524017467
9	60:40	24	120	0.648876404	0.506550218
10	75:25	18	60	0.099250936	0.449781659
11	75:25	18	90	0.281835206	0.480349345
12	75:25	18	120	0.449438202	0.497816594
13	75:25	21	60	0.305243446	0
14	75:25	21	90	0.457865169	0.034934498
15	75:25	21	120	0.664794007	0.07860262
16	75:25	24	60	0.634831461	0.519650655
17	75:25	24	90	0.623595506	0.558951965
18	75:25	24	120	1	0.489082969

Table 5: Result of grey relational generating

3.2 Grey relational coefficient calculation

Grey relational coefficient is used for determining how close x_{ij} is to x_{0j}. The larger the grey relational coefficient, the closer x_{ij} and x_{0j} are. The grey relational coefficient can be calculated by Eq. (3).

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{min}+\zeta\Delta_{max}}{\Delta_{ij}+\zeta\Delta_{max}} \quad for\ i = 1,2,\dots,m \quad j = 1,2,\dots\dots,n \tag{3}$$

Where,

$\Delta_{ij} = |x_{0j} - x_{ij}|$

$\Delta_{max} = \max\{ \Delta_{ij}, \quad i = 1,2,\dots,m \quad j = 1,2,\dots\dots,n\}$

$\Delta_{min} = \min\{ \Delta_{ij}, \quad i = 1,2,\dots,m \quad j = 1,2,\dots\dots,n\}$

ζ is distinguishing or identification coefficient: $\zeta \in [0,1]$ (the value may be adjusted based on the actual system requirements). A value of ζ is the smaller and the distinguished ability is the larger. ζ=0.5 is generally used.

After calculating Δ_{ij}, Δ_{max} and Δ_{min} all grey relational coefficients can be calculated by Eq. (3). For example, Δ_{11} = |1- 0|= 1, Δ_{max} = 1 and Δ_{min}= 0, if ζ = 0.5, then $\gamma(x_{01}, x_{11})$ = (0 + 0.5 ×1)/(1 + 0.5 × 1) = 0.33333. The entire results for the grey relational coefficient are shown in Table 6.

Expt. No	Grey relational coefficient for CSR	Grey relational coefficient for Ra value
1	0.333333333	1
2	0.337334176	0.958158996
3	0.341869398	0.927125506
4	0.382795699	0.6918429
5	0.401503759	0.667638484
6	0.412037037	0.722397476
7	0.486782133	0.519274376
8	0.506161137	0.512304251
9	0.587458746	0.503296703
10	0.356951872	0.476091476
11	0.410453497	0.490364026
12	0.475935829	0.498910675
13	0.418495298	0.333333333
14	0.479784367	0.341281669
15	0.598654709	0.351766513
16	0.577922078	0.510022272
17	0.570512821	0.531322506
18	1	0.494600432

Table 6: Result of grey relational coefficient

3.3 Grey relational grade calculation

After calculating the entire grey relational coefficient γ (x_{0j}, x_{ij}), the grey relational grade can be then calculated using Eq. (4).

$$\Upsilon(Xo,Xi) = \sum_{j=1}^{n} w_j \gamma(\text{x0j,xij}) \qquad i = 1, 2, \ldots, m \tag{4}$$

In Eq. (4), ϒ(X0, Xi) makers judgment or the structure of the proposed problem. In this case, the importance of both performance-attributes such as compressive residua) is the grey relational grade between Xi and X0. w_j is the weight of attribute j and usually depends on decisional stress and surface roughness was assumed to be equal. Thus the weights of the two performance attributes were the same (50% each). By using Eq. (4), the grey relational grade can be calculated and is shown in column 2 of Table 7.

Expt. No.	Grey Relational Grade	Ranking
1	0.666666667	2
2	0.647746586	3
3	0.634497452	4
4	0.5373193	9
5	0.534571122	10
6	0.567217257	5
7	0.503028255	12
8	0.509232694	11
9	0.545377725	7
10	0.416521674	16
11	0.450408762	15
12	0.487423252	13
13	0.375914316	18
14	0.410533018	17
15	0.475210611	14
16	0.543972175	8
17	0.550917663	6
18	0.747300216	1

Table 7: Result of grey relational grade

IV RESULTS

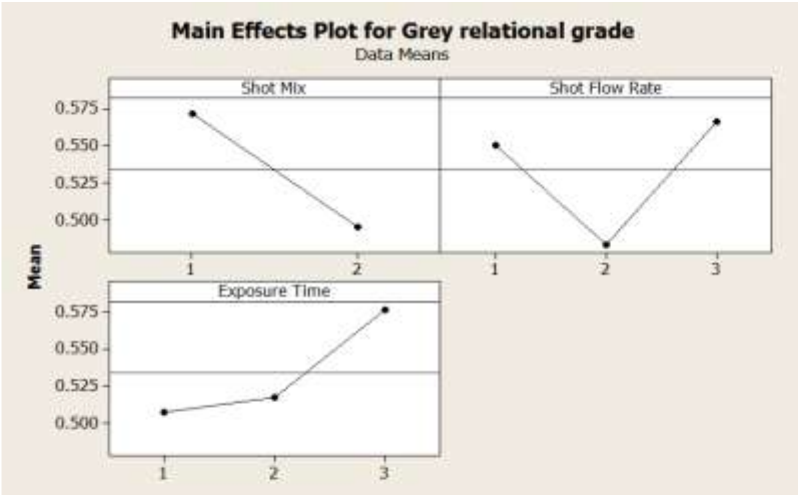
The ranking results of GRA are shown in column 3 of Table 7. GRA procedure would suggest alternative No. 18 has the highest grey relational grade. Thus experiment no. 18 gives the best multi-performance characteristics among the 18 experiments. Hence, according to GRA for better performance characteristic optimal settings should be set like shot mix of 75:25, shot flow rate of 24 Amp and exposure time of 120 sec by this setting we get maximum value of residual compressive stress and minimum value of surface roughness.

Further ANOVA is performed on grey relational grade by using statistical software MINITAB 15 to determine the significant process parameter. It helps in predicting the best combination of process parameters for optimal performance characteristics. 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 is utilized. Table 8 gives the results of the ANOVA for performance characteristic using the values of grey relational grade.

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Shot mix	1	0.026255	0.026255	0.026255	41.07	0.003
Shot flow rate	2	0.023355	0.023355	0.011678	18.27	0.01
Time	2	0.016651	0.16651	0.008325	13.02	0.018
Shot mix * shot Flow	2	0.069901	0.069901	0.034950	54.67	0.001

Shot mix * time	2	0.009904	0.009904	0.004952	7.75	0.042
Shot flow *time	4	0.007361	0.007361	0.001840	2.88	0.165
Error	4	0.002557	0.002557	0.000639		
S = 0.0.252840 R-Sq = 98.36% R-Sq(adj.) = 93.03%						

Table 8: ANNOVA results for grey relational grade



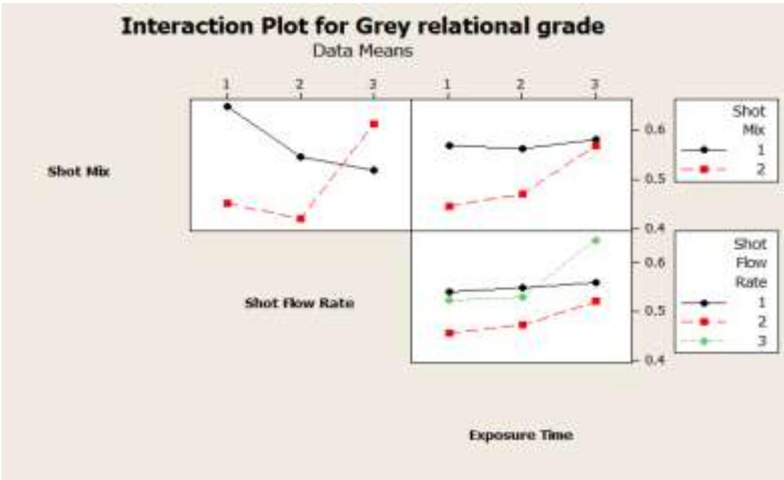


Fig.3 Response Graphs of Shot Peening Parameters

Table 8 indicates that the p-value of all the factors is less than 0.05 that represents significant effect on the performance characteristics of each parameter. Interaction between shot mix - shot flow and shot mix – time have significant effect on performance characteristics.

V CONCLUSION

The grey-relation analysis in shot peening suggests the optimum setting of peening parameters at shot mix of 75:25, shot flow rate of 24 Amp and exposure time of 120 sec with equal weights for compressive residual stress and surface roughness for multi-performance. At this optimal condition the process parameters were set and the confirmatory experiments performed. The average values of compressive residual stress and surface roughness measured as 561.1 Mpa and 5.13 µm respectively.

ANOVA presented in Table 8 shows that shot mix, exposure time, shot flow rate nozzle distance are the process parameters which significantly affecting the performance characteristics. All parameters affecting the performance characteristics are at 95% confidence level.

It seems that GRA is a straight forwarded method for optimizing performance characteristic problems in shot peening.

REFERENCES

[1] Baskaran Bhuvaraghana, Sivakumar M.Srinivasanb, Bob Maffeoc, "*Optimization of the fatigue strength of materials due to shot peening: A Survey*", International Journal of Structural Changes in Solids, Vol. 2, 2010, pp 33-63.

[2] J. Aylott, D. Lassithiotakis,*"Optimising Shot Peening Parameters Using DOE",* 9th International Conference on Shot Peening, 2005, pp. 406-412.

[3] S. B. Mahagaonkar, P. K. Brahmankar, C. Y. Seemikeri, "*Effect of shot peening parameters on microhardness of AISI 1045 and 316L material: an analysis using design of experiment",* International Journal of Advanced Manufacturing Technology, Vol. 38, 2008, pp. 563-574.

[4] S. B. Mahagaonkar, P. K. Brahmankar, C. Y. Seemikeri, "*Effect on fatigue performance of shot peened components: An analysis using DOE technique",* International Journal of Fatigue, Vol. 31, 2009, pp.693-702.

[5] E.V. Ramana, P. Ravinder Reddy, "*Optimization of Shot Peening Process Parameters Using Taguchi Approach And Validation by Data Mining",* International Journal of Engineering Science and Technology, Vol. 5, 2013, pp. 1471-1475.

[6] P.M. George, Nisha Pillai, Nisha Shah, *"Optimization of shot peening parameters using Taguchi technique"*, Journal of Materials Processing Technology, Vol. 153-154, 2004, pp. 925–930.

[7] L. Singh, R. Khan, M. Aggarwal *"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",* American Journal of Engineering Research, 2013, pp. 160-412-172.

[8] Benudhar Sahooa, *"Effect of Shot Peening on Low Cycle Fatigue Life of Compressor Disc of a Typical Fighter Class Aero-Engine",* 6th International Conference on Creep- Fatigue Interaction, Vol. 55, 2013, pp. 144-148.

[9] Yiyo Kuo, Taho Yang, Guan-Wei Huang, *"*The use of grey relational analysis in solving multiple attribute decision-making problems*",* Computers & Industrial Engineering Vol. 55, 2008, pp.80‑93.