Surface roughness prediction and parametric optimization of shot blasting of Al7068 using RSM

D Pritima1*, V Dhinakaran2, B Stalin3, M Ravichandran4, M Balasubramanian5, C Anand Chairman4

1Department of Mechatronics Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu, India.
2Centre for Applied Research, Department of Mechanical Engineering, Chennai Institute of Technology, Kundrathur, Chennai-600 069, Tamil Nadu, India.
3Department of Mechanical Engineering, Anna University, Regional Campus Madurai, Madurai - 625 019, Tamil Nadu, India.
4Department of Mechanical Engineering, K.Ramakrishnan College of Engineering, Tiruchirappalli - 621112, Tamil Nadu, India.
5Department of Mechanical Engineering, University College of Engineering, Ramanathapuram Campus, Anna University, Ramanathapuram -623 513, Tamil Nadu, India.

* Corresponding author: pritimid@skcet.ac.in

Abstract. The mechanical based shot blasting was used to remove the oxides and scales from the surface of the materials. It was used to enhance the surface properties. In this work, aluminium 7068 alloy was involved in the shot blasting process. The particle velocity, standoff distance (SOD) and impact angles were included as input factors. These factors were mainly affects the Surface Roughness (SR). The round steel balls with diameter with 2 mm diameter were used for the shot blasting process. In addition to that, the elliptic and square shape of glass beads particles were used to enhance the surface finish. The parametric effect and surface roughness optimization was achieved through Response Surface Methodology (RSM). The role of factors has been analyzed through the variance test.

1. Introduction
Shot blasting process was used in aerospace, automotive, foundry and railways. The surface of the material was cleaned without any defects and strengthened through the process. No chemicals and acids were used to clean the work piece. The shot blasting experimentation was conducted on a solar heater absorber plate and its plate surface was improved [1]. The developed surface through water and steel shots were compared [2]. Shot peening experimental investigation was made on hardened gear steel and its hardness was determined [3]. The fatigue behavior was found in aluminium, magnesium during the shot blasting process [4]. The coated and non coated cutting tools were strengthened though shot blasting process [5]. The surface roughness of aluminum alloy were investigated through a sand blasting process [6]. The aircraft components were polished through the air blasting process and its appearance was better [7]. The fatigue behavior and surface finish were discussed in forged steel [8]. The cutting tool and tips was improved through micro blasting process [9]. The alumina grit blasting
behavior was studied in mild steel [10]. Many studies are based on the RSM, Taguchi approach and the variance analysis to predict the optimum performance of the mechanical, wear, corrosion behaviour of composites and the structural analysis of mechanical system components in the automotive, aerospace industry [11-43].

The present work deals with Surface roughness prediction and parametric optimization of shot blasting of Al7068. The shot blasting factors were optimized through response surface methodology.

2. Experimental method
The gun type of shot blasting machine was used. The combination of steel balls and glass beads were forced to the workpiece through compressed air. The inner part of the gun has mixing chamber. Steel balls and glass beads were continuously fed into the chamber and it was the impact to the work piece with the help of compressed air (1MPa). The surface roughness was depends on the impact of abrasives and steel balls. The aluminium 7068 alloy was cut into required size (30x20x5mm). The Mitutoyo portable tester was used to measure the surface roughness. The experimental arrangement was shown in Fig.1. The experimental outcomes for shot blasting process were shown in Table 1.

![Figure 1. Experimental set up for shot blasting process](image)

Table 1. Experimental outcomes for shot blasting process

| Run | A: Particle velocity (m/s) | B: SOD (mm) | C: Impact angle (°) | Surface roughness (μm) |
|-----|---------------------------|-------------|---------------------|-----------------------|
| 1   | 20                        | 40          | 60                  | 3.2                   |
| 2   | 20                        | 30          | 60                  | 3.1                   |
| 3   | 10                        | 40          | 90                  | 2.4                   |
| 4   | 20                        | 30          | 60                  | 3.6                   |
| 5   | 30                        | 40          | 90                  | 4.1                   |
| 6   | 20                        | 30          | 60                  | 3.3                   |
| 7   | 10                        | 40          | 30                  | 2.1                   |
| 8   | 30                        | 20          | 30                  | 2.6                   |
| 9   | 30                        | 30          | 60                  | 4.7                   |
| 10  | 20                        | 30          | 60                  | 4.8                   |
| 11  | 20                        | 30          | 60                  | 3.8                   |
| 12  | 10                        | 30          | 60                  | 1.4                   |
| 13  | 20                        | 20          | 60                  | 2.8                   |
| 14  | 20                        | 30          | 30                  | 3.4                   |
| 15  | 20                        | 30          | 30                  | 4.2                   |
| 16  | 30                        | 40          | 30                  | 4.5                   |
| 17  | 10                        | 20          | 30                  | 2.9                   |
| 18  | 10                        | 20          | 90                  | 4.3                   |
| 19  | 30                        | 20          | 90                  | 5.2                   |
| 20  | 20                        | 30          | 60                  | 1.9                   |

3. Response Surface Methodology
The response surface methodology was used to optimize the shot blasting parameters. The design of expert 12 version was used to analyze the factors. The sequential model was attained based on the
experimental results and it was shown in Table 2. The linear model was suggested which provides the F and P values were 3.14 and 0.0543 respectively. From the table, quadratic and cubic model was also intercepted. The linear and mean has provided the influential effect on the sequential model. It was concluded that based on the F value as 3.14.

**Table 2.** Sequential model based on experiments

| Resource                  | SS    | DF | MS   | F-value | P-value | Suggested |
|---------------------------|-------|----|------|---------|---------|-----------|
| Mean and Total            | 233.24| 1  | 233.24|
| Linear and Mean           | 7.62  | 3  | 2.54  | 3.14    | 0.0543  |
| 2FI and Linear            | 3.66  | 3  | 1.22  | 3.14    | 0.0543  |
| Quadratic and 2FI         | 1.88  | 3  | 0.6283| 0.8500  | 0.4977  |
| Cubic and Quadratic       | 2.56  | 4  | 0.6409| 0.7965  | 0.5686  |
| Residual                  | 4.83  | 6  | 0.8047|
| Total                     | 253.81| 20 | 12.69 |

The variance test was exposed in Table 3. From the table, the developed model was significant because of the obtained P value was smaller than 0.05. Hence, the developed model was fit to the experimental investigations. The surface roughness was depends on many factors, including abrasive particle size, velocity of the abrasives, standoff distance between the nozzle and work piece, impact angle and coverage of area of the workpiece. However, the particle velocity was produced the maximum effect on surface roughness for this experiment work.

**Table 3.** Variance test for surface roughness

| Source             | SS    | DF  | MS   | F-value | P-value | Significant |
|--------------------|-------|-----|------|---------|---------|-------------|
| Model              | 7.62  | 3   | 2.54 | 3.14    | 0.0443  | Significant |
| A-Particle velocity| 6.40  | 1   | 6.40 | 7.91    | 0.0125  |
| B-SOD              | 0.2250| 1   | 0.2250| 0.2782  | 0.0651  |
| C-Impact angle     | 0.9997| 1   | 0.9997| 1.24    | 0.2827  |
| Residual           | 12.94 | 16  | 0.8088|         |         |
| Lack of Fit        | 8.11  | 10  | 0.8112| 1.01    | 0.0404  |
| Pure Error         | 4.83  | 6   | 0.8047|         |         |
| Cor. Total         | 20.57 | 19  |      |         |         |

![Figure 2. Actual and predicted values for SR](image)
The deviation between actual and predicted values was shown in Fig. 2. The graph was drawn between residuals and normal percentage of probability. All the values were lies in a straight line. Only few values were slightly deviated from the straight line. The linear model and predicted values were confirmed through lack of fit and it was illustrated in Table 4. The desirability of result was indicated the optimal solutions and is shown in Table 5. The optimal surface roughness of 3.4 μm was attained at a velocity of 20 m/s, standoff distance of 30mm and impact angle of 60°.

**Table 4. Investigation of lack of fit for linear developed model**

| Resource   | SS   | DF  | MS     | F-value | P-value |
|------------|------|-----|--------|---------|---------|
| Linear     | 8.11 | 10  | 0.8112 | 1.01    | 0.5204  |
| 2FI        | 4.45 | 7   | 0.6355 | 0.7898  | 0.6216  |
| Quadratic  | 2.56 | 4   | 0.6409 | 0.7965  | 0.5686  |
| Pure Error | 4.83 | 6   | 0.8047 |         |         |

**Table 5. Optimal solutions for shot blasting process**

| S.No | A: Particle velocity (m/s) | B: SOD (mm) | C: Impact angle (º) | Surface roughness (μm) |
|------|---------------------------|-------------|---------------------|------------------------|
| 1    | 20                        | 30          | 60                  | 3.4                    |

4. **Three-dimensional surface plot analysis**

The 3D surface plot was used to analyze the parametric causes and interactions. It was shown in Fig.3 (a-c). The Fig.3 (a) shown that the surface roughness was constantly up to particle velocity of 10 m/s. After that it has been gradually increased. Fig. 3 (b) shown that the impact angle and velocity has produced the correct fluctuations on surface roughness. Fig. 3 (c) shown that the surface roughness has been increased when the standoff distance between 20– 30 mm. After that it has been decreased. The wave form fluctuations have been produced by the impact angle on SR.

![Figure 3](image-url)
5. Conclusions
The following conclusions are drawn from the above experimental study:

- The SR was predicted on Al 7068 through the shot blasting process.
- The steel balls and glass beads were used as the abrasives in the present experimental work.
- The scales and oxides were removed from the material surface.
- The surface roughness was measured for each experiment.
- The RSM was used to optimize the SR factors. The optimal surface roughness of 3.4 μm was attained at a velocity of 20 m/s, standoff distance of 30mm and impact angle of 60º.
- The particle velocity has occupied the maximum role on SR. It was validated through the variance test.

6. References
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