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An Investigation of the Effect of Shot Peening On the Properties of Lm25 Aluminium Alloy and Statistical Modelling

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ABSTRACT

In this work the effect of shot peening on the tensile strength, hardness and impact strength of mild steel is studied using a compressed air shot-peening machine. This investigation examines the respective effects of influencing parameters such as pressure, angle of impingement, nozzle distance and the exposure time in enhancing micro hardness, tensile strength and average surface roughness. Further, statistical analysis software such as MINITAB is used to predict the optimal process parameters for the responses such as tensile strength, hardness and impact strength on the basis of taguchi analysis. These test results will be useful to the industries in deciding the optimal levels for the shot peening parameters.

Keywords: *shot peening, Minitab, tensile strength impact strength, hardness, taguchi analysis.*

I. INTRODUCTION

The process of shot peening and parameters of shot peening effect the micro hardness of LM25 material. Benefits obtained due to cold working include work hardening, intergranular corrosion resistance, surface texturing and closing of porosity. The quality of peening is determined by the degree of coverage, magnitude and depth of the induced residual stress. Various studies have demonstrated the improvements induced by the peening process; thus it can be widely used to enhance the life of components operating in highly stressed environments and the other critical parts such as in motor racing, aero engines and aero structures. The surface modifications produced by the shotpeening treatment are :(a) roughening of the surface,(b) an increased near surface dislocation density (strain hardening), and (c) the development of a characteristic profile of residual stresses.

II. EXPERIMENTAL ANALYSIS OF SPECIMEN AFTER SHOT PEENING

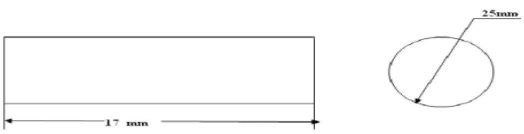


Fig 1. Testing specimen: LM 25 Aluminum Alloy

III. PHYSICAL PROPERTIES:

Coefficient of Thermal Expansion (per ^{o}C at 20 -100 ^{o}C) 0.000022
Thermal Conductivity (cal/cm^{2}/cm/^{o}C/s at 25^{o}C * 0.36
Electrical Conductivity (% copper standard at 20^{o}C) * 39
Specific Gravity 2.68
Freezing Range (^{o}C) Approx 615-550
Casting Characteristics:
FLUIDITY: Good, suitable for fairly thin castings.
PRESSURE TEST: Suitable for castings required to be leak tight.
HOT TEARING: The production of castings in this
Alloy very rarely introduces
Problems due to hot tearing.

IV. REGR ESSION ANALYSIS

Regression technique is concerned with predicting some variables by knowing others. The process of predicting variable Y using variable X. Multiple regression analysis is a simple regression analysis. In multiple regressions two or more independent

Variables are used to estimate the values of a dependent variable. The general purposes of multiple regression analysis are 1.To derive an equation which provides estimates of the dependent variable from values of the two or more independent variable. 2. To obtain a measure of the error involved in using this regression equation as a basis of estimation. 3. To obtain a measure of the proportion of variance in the dependent variable accounted for or explained by the independent variable. If there are three variable x_1, x_2 & x_3 the multiple regressions will take the following form:

$Y=ax_1 +bx_2 +cx_3$ ……………………………..…..1.

A regression equation is an equation for estimating a dependent variable, say y from the independent variables
x_1, x_2, x_3 and is called a regression equation of y on x_1, x_2, x_3 and so on. For the case of three variables the simplest regression equation of $x_1$on x_2 &x_3 has the form of equation 1, Where a, b, c are constants, the least square regression plane $x_1$on x_2 & x_3 of has the equation 1.0 where a, b and c are determined by simultaneously the normal equations.

$\sum y = a\sum x_1 + b\sum x_2 + \sum x_3$ …………...……………..2

$\sum x_1y = a\sum x_1^2 +b\sum x_1x_2 + c\sum x_3$…………………...3

$\sum x_2y = a\sum x_1x_2 + b\sum x_2^2 + c\sum x_2 x_3$ ……………….4

By solving the above equations the values of a, b, c can be obtained. On substituting the values in eqn 1.0 we get the values of 'y' for different values of x_1, x_2 & x_3. Correlation is a statistical technique used to determine the degree to which two variables are related. Simple correlation also as called Pearson's correlation or product moment correlation coefficient. It measures the nature and strength between two variables of the quantitative type. The sign of 'r' denotes the nature of association while the value of 'r' denotes the strength of association. If the sign is +ve this means the relation is direct (an increase in one variable is associated with an increase in the other variable and a decrease in one variable is associated with a decrease in the other variable).While if the sign is -ve this means an inverse or indirect relationship (which means an increase in one variable is associated with a decrease in the other). The value of r ranges between (-1) and (+1). The value of r denotes the strength of the association as illustrated

Chemical composition	cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sb	Ti	Al
Percentage	0.1	0.2-0.6	6.5-7.5	0.5	0.3	0.1	0.1	0.1	0.05	0.2	Remainder

Table 1.Chemical composition of the specimen

- If r = Zero this means no association or correlation between the two variables.
- If $0 < r < 0.25$ = weak correlation.
- If $0.25 \le r < 0.75$ = intermediate correlation.
- If $0.75 \le r < 1$ = strong correlation.
- If r = l = perfect correlation

Correlation coefficient:

$$'r' = \frac{\sum XY - \frac{\sum X \sum Y}{n}}{\sqrt{\left[\sum X2 - \frac{(\sum X)2}{n}\right]\left[\sum Y2 - \frac{(\sum Y)2}{n}\right]}}$$

Multiple regressions technique is used to predict a value using ‘n’ number of variables and Pearson’s correlation coefficient explains the strength and type of correlation between predicted values and actual values. By which we can recommend the optimum usage of input variables.

V. REGRESSION ANALYSIS USING MINITAB SOFTWARE:

Linear regression investigates and models the linear relationship between a response (Y) and predictor(s) (X). Both the response and predictors are continuous variables In particular, linear regression analysis is often used to: determine how the response variable changes as a particular predictor variable changes, predict the value of the response variable for any value of the predictor variable, or combination of values of the predictor variables , The regression equation is an algebraic representation of the regression line and is used to describe the relationship between the response and predictor variables. The regression equation takes the form of: Response = constant + coefficient (predictor) + ... + coefficient (predictor)

$$y = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k$$

Predictor variable(s) is zero. The constant is also called the intercept because it determines where the regression line intercepts (meets) the Y-axis. Predictor(s) (X) is the value of the predictor variable(s). Coefficients (b1, b2, bk) represent the estimated change in mean response for each unit change in the predictor value. In other words, it is the change in Y that occurs when X increases by one unit. P-Value The coefficient table lists the estimated coefficients for the predictors. Linear regression examines the relationship between a response and predictor(s). In order to determine whether or not the observed relationship between the response and predictors is statistically significant, you need to identify the coefficient p-values the coefficient value for P (p-value) tells you whether or not the association between the response and predictor(s) is statistically significant. Compare the coefficient p-values to your level; If the p-value is smaller than the □-level you have selected, the association is statistically significantly. A commonly used a-level is 0.05, Predicted values: Minitab displays the predicted value table when you request the calculation of the mean responses or the prediction of new response values at certain settings of the predictors. The Fit is the predicted (fitted) value for the response at the combination of predictor settings you requested. Typical values, spread or variation, and shape, unusual values in the data. This pattern indicates skewness, long tails and outlier i.e. bars away from other bars, because the appearance of the histogram can change depending on the number of intervals used to group the data, use the normal probability plot and goodness-of-fit tests to assess whether the residuals are normal. The residuals from the analysis should be normally distributed. In practice, for data with a large number of observations, moderate departures from normality do not seriously affect the results In this work, First and fore most thing is to compare the tensile strength, hardness and impact strength of peened and unpeened specimen .Secondly to find the effectiveness of impact pressure and exposure time on tensile strength, hardness and average surface roughness of the specimen. Thirdly to study the tensile strength, hardness and impact strength of Al alloy specimen at different input parameters and compare it with predicted values of tensile strength, hardness and average surface roughness from MINITAB software and by applying multiple regression technique and find the strength of correlation between experimental values and predicted values. In un- peened specimen the tensile strength for as cast LM25 Aluminium alloy is approximately 210 N/mm^2.Whereas after shot blasting the LM25 Aluminium alloy specimen the optimum tensile strength was observed as 217.98 N/mm^2. Unpeened specimen hardness for as cast LM25 Aluminium alloy specimen is approximately 83 BHN, whereas shotpeened LM25 Aluminium alloy specimen the optimum hardness was observed as 108 BHN. Unpeened specimen has an Impact strength for an as cast LM25 Aluminium alloy as approximately 4.75 µm. Whereas after shot blasting the LM25 Aluminium alloy specimen the optimum average surface roughness was observed as 7.78 µm. From the above discussion we can conclude that shot blasting of Aluminium LM25 alloy specimen increases its tensile strength,

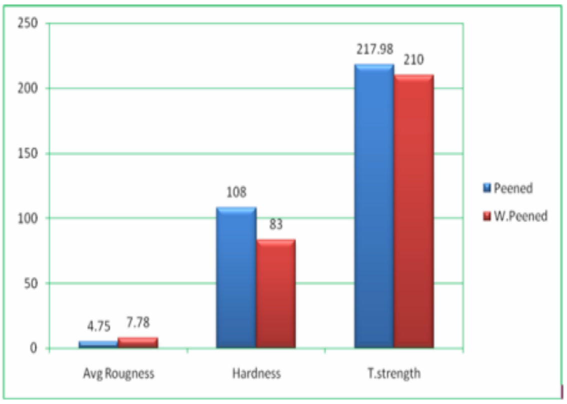


Fig 2.Graph showing properties of LM25 Aluminum alloy specimen before and after shot peening

From the readings taken from tensile test conducted on UTM we can say that with the increase in exposure time the tensile strength will increase up to a certain time after that it will decrease. This is depicted in table and graph below.

S.No	Time (min)	Pressure (bar)	Tensile strength (N/mm^2)
1	10	10	130.38
2	12	10	131.40
3	15	10	179.68
4	18	10	211.86
5	20	10	207.79
6	22	10	138.52
7	25	10	134.45

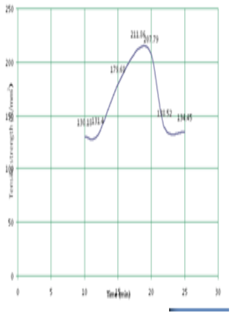


Table 2, Fig 3 Effect of exposure time on tensile strength of specimen at constant pressure

Effect of impact pressure on tensile strength of LM25 Aluminum alloy specimen at constant time
From the readings taken from tensile test conducted on UTM we can say that with the increase in the impact pressure tensile strength will decrease. This is explained in table and graph below.

S.No	Pressure(bar)	Time (min)	Tensile strength (N/mm2)
1	4	12	220
2	5	12	217.98
3	6	12	213.90
4	7	12	212.17
5	8	12	209.83
6	9	12	190.47
7	10	12	131.40

Table 3 Effect of pressure and time on tensile strength of specimen

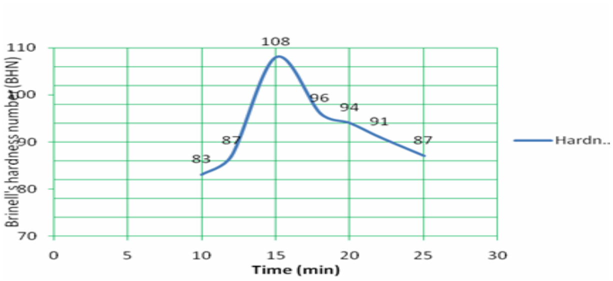
From the contour plot above we can say that the optimum tensile strength we can get when time of exposure is approximately in between 10 min and 19 min and impact pressure is approximately in between 4 bar and 7.5 bar. With the increase in exposure time the tensile strength will increase up to a certain time after that it will decrease because the specimen will undergo internal compression up to certain time and then the specimen will loose its compressive stress which is developed internally. With the increase in the impact pressure tensile strength will decrease because the specimen will loose its tendency to produce internal compressive stresses as the impact pressure increase.

VI. EFFECT OF EXPOSURE TIME ON HARDNESS OF LM25 ALUMINUM ALLOY SPECIMEN AT CONSTANT PRESSURE

From the readings taken from Hardness test conducted on Portable hardness tester we can say that with the increase in exposure time the Brinell's Hardness Number (BHN) will increase up to a certain time after that it will decrease. This is explained in table and graph below.

S.No	**Time (min)**	**Pressure (bar)**	**Hardness(BHN)**
1	**10**	**10**	**83**
2	**12**	**10**	**87**
3	**15**	**10**	**108**
4	**18**	**10**	**96**
5	**20**	**10**	**94**
6	**22**	**10**	**91**
7	**25**	**10**	**87**

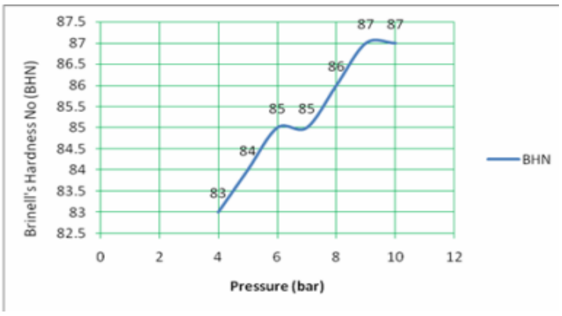
Table 4. Effect of exposure time on Hardness of specimen at constant pressure



Effect of impact pressure on Hardness of LM25 Aluminum alloy specimen at constant time: From the readings taken from Hardness test conducted on Portable hardness tester we can say that with the increase in impact pressure the Brinell's Hardness Number (BHN) will increase. This is explained in table and graph below.

S.No	Pressure(bar)	Time (min)	Hardness (BHN)
1	4	12	83
2	5	12	84
3	6	12	85
4	7	12	85
5	8	12	86
6	9	12	87
7	10	12	87

Table 5 Effect of impact pressure on Hardness of specimen at constant time



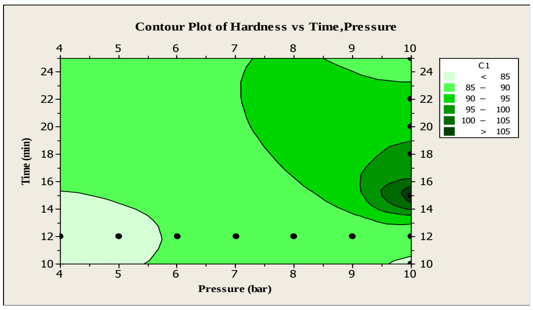


Fig 5. Effect of pressure on Hardness of specimen at constant time & plot of Hardness time and impact pressure

From the contour plot above we can say that the optimum Hardness Number we can get when time of exposure is approximately in between 14.5 min and 15.5 min and impact pressure is approximately in between 9.8 bar and 10 bar. With the increase in exposure time the Brinell's Hardness Number (BHN) will increase up to a certain time after that it will decrease because the metal will loose its strength of bonds between the atoms when it is exposed to peening for more than the required time. With the increase in impact pressure the Brinell's Hardness Number (BHN) will increase because as the impact pressure increases the strength of bonds will increase due to high compression of atoms of metal. Effect of exposure time on Average surface roughness of LM25 Aluminum alloy specimen at constant pressure From the readings taken from Average surface roughness test conducted on surface roughness tester we can say that with the increase in exposure time will decrease Average surface roughness (R_a) i.e. it will improve surface finish of specimen up to a certain period than it will become constant. This is explained in table and graph below.

S.No	Time (min)	Pressure (bar)	Average surface roughness (μ_m)
1	10	10	7.50
2	12	10	7.30
3	15	10	7.10
4	18	10	6.37
5	20	10	5.20
6	22	10	4.75
7	25	10	4.75

Table 6 Effect of exposure time on Average surface roughness (R_a) of specimen at constant pressure

Effect of impact pressure on Average surface roughness of LM25 Aluminum alloy specimen at constant time: From the readings taken from Average surface roughness test conducted on surface roughness tester we can say that with the increase in impact pressure will decrease Average surface roughness (R_a) i.e. It will decrease surface finish of specimen. This is explained in table and graph below

Table 7 Effect of exposure time on Average surface roughness (R_a) of specimen at varying pressure

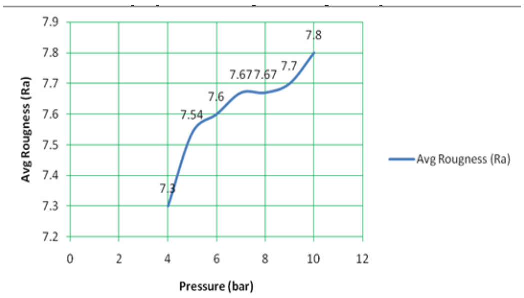


Table 8 Effect of impact pressure on Average surface roughness of specimen at constant time

S.No	Pressure(bar)	Time (min)	Average surface roughness (μ_M)
1	4	12	7.78
2	5	12	7.70
3	6	12	7.67
4	7	12	7.67
5	8	12	7.60
6	9	12	7.54
7	10	12	7.30

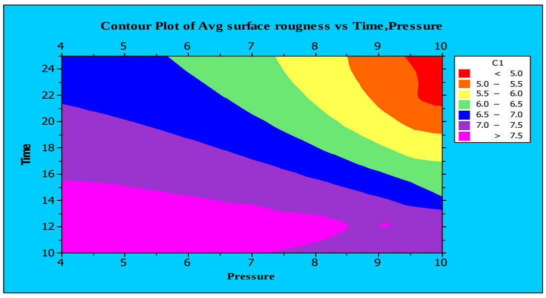


Fig 6. Effect of impact pressure on Average surface roughness of specimen at constant time & contour plot of Average surface roughness for time and impact pressure

From the contour plot above we can say that the optimum surface finish of the specimen will be when time of exposure is approximately in between 22 min and 25 min and impact pressure is approximately in between 9.5 bar and 10 bar. The increase in exposure time will decrease Average surface roughness (R_a) i.e. it will improve surface finish of specimen up to a certain period than it will become constant because the shot which is used for blasting is not in round steel balls but it is stainless steel cut wire type which is widely used for cleaning and polishing of the surface of metal parts. The impact pressure nearly will not have any effect because the amount of metal removed from the specimen is same irrespective of pressure.

VII. RESULTS AND DISCUSSION

Statistical analysis of tensile strength values using Minitab software and regression equation.

S.No	Time (min)	Pressure (bar)	Exp (N/mm2)
1	10	10	130.38
2	12	10	131.40
3	12	9	190.47
4	12	8	209.83
5	12	7	212.17
6	12	6	213.90
7	12	5	217.98
8	12	4	220.00
9	15	10	179.68
10	18	10	211.86
11	20	10	207.79
12	22	10	138.52
13	25	10	134.45

Table 9. Tensile strength of specimen at various input parameters

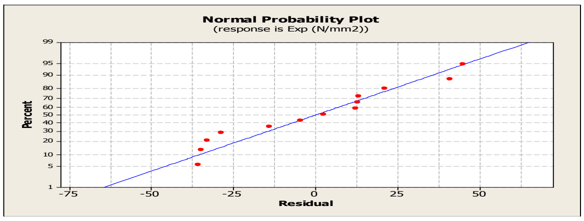
Regression Analysis: Exp (N/mm2) versus Time (min), Pressure (bar)
The regression equation is
Exp (N/mm2) = 278 + 0.10 Time (min) - 11.3 Pressure (bar)

Predictor	Coef	SE Coef	T	P
Constant	277.61	36.97	7.51	0.000
Time (min)	0.097	2.124	0.05	0.964
Pressure (bar)	-11.278	4.627	-2.44	0.035

S = 30.4014 R-Sq = 43.5% R-Sq (adj) = 32.2%

Table 10. Predicted values of tensile strength from equation and MINITAB software

S.No	Time (min)	Pressure (bar)	Exp (N/mm2)	Reg (N/mm2)	FITS1
1	10	10	130.38	166.0	165.798
2	12	10	131.40	166.2	165.992
3	12	9	190.47	177.5	177.270
4	12	8	209.83	188.8	188.548
5	12	7	212.17	200.1	199.826
6	12	6	213.90	211.4	211.104
7	12	5	217.98	222.7	222.382
8	12	4	220.00	234.0	233.661
9	15	10	179.68	166.5	166.284
10	18	10	211.86	166.8	166.575
11	20	10	207.79	167.0	166.769
12	22	10	138.52	167.2	166.964
13	25	10	134.45	167.5	167.255



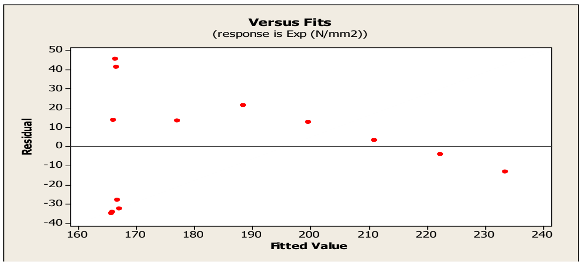


Fig 7. Normal probability plot showing distribution of residuals versus the fitted values

The interpretation of the regression equation follows: Exp (N/mm2) = 278 + 0.10 Time (min) - 11.3 Pressure (bar), the slope (b1 = 0.10) is the change in Tensile strength when time increases by 1minute. That is, when the time increases by one unit, the Tensile strength increases by 0.10 units. The slope (b2 = -11.3) is the change in Tensile strength when pressure increases by 1. That is, when the pressure increases by one unit, the Tensile strength increases by -11.3 units. The relationships between the response, Experimental Tensile strength, and the predictor, pressure (P = 0.035), is significant. The relationship between the response, Experimental Tensile strength, and the predictor, Time (P = 0.964), is not significant because the p-value is higher than the pre-selected α-level. The R^2 indicates that the predictors explain 43.5% of the variance in Tensile strength. The adjusted R^2 32.4%, which accounts for the number of predictors in the model. Both values indicate that the model fits the data not perfectly well. The Pearson correlation between experimental Tensile strength and predicted Tensile strength is 0.660 which indicates there is direct intermediate correlation between experimental values and predicted values. The histogram indicates that outliers may exist in the data, shown by a bar on the far right side of the plot. The normal probability plot shows an approximately linear pattern consistent with a normal distribution. The point in the upper-right corner of the plot may be outliers. Brushing the graph identifies these points as 41.0207.

VIII. REGRESSION EQUATION BY MINITAB SOFTWARE

S.No	Time (min)	Pressure (bar)	Exp Hardness (BHN)
1	10	10	83
2	12	10	87
3	12	9	87
4	12	8	86
5	12	7	85
6	12	6	85
7	12	5	84
8	12	4	83
9	15	10	108
10	18	10	96
11	20	10	94
12	22	10	91
13	25	10	87

Table 11. Hardness of specimen at various input parameters

Regression Analysis: Exp Hardness (BHN) versus Time (min), Pressure (bar)
The regression equation is **Exp Hardness (BHN) = 73.6 + 0.221 Time (min) + 1.43 Pressure (bar)**

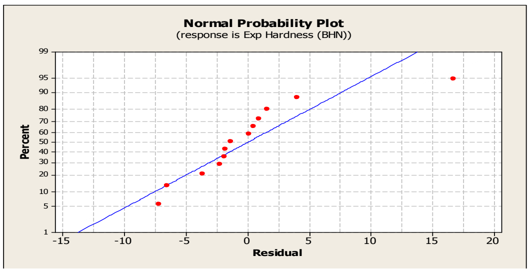
Predictor	Coef	SE Coef	T	P
Constant	73.604	7.876	9.35	0.000
Time (min)	0.2213	0.4525	0.49	0.635
Pressure (bar)	1.4332	0.9858	1.45	0.177

S = 6.47679 R-Sq = 28.8% R-Sq (adj) = 14.5%

S. No	Time (min)	Pressure (bar)	Exp Hardness (BHN)	Reg Hardness (BHN)	FITS1
1	10	10	83	90.100	90.1489
2	12	10	87	90.550	90.5914
3	12	9	87	89.122	89.1582
4	12	8	86	87.690	87.7251
5	12	7	85	86.262	86.2919
6	12	6	85	84.832	84.8587
7	12	5	84	83.402	83.4255
8	12	4	83	81.972	81.9923
9	15	10	108	91.215	91.2552
10	18	10	96	91.878	91.9191
11	20	10	94	92.320	92.3616
12	22	10	91	92.762	92.8041
13	25	10	87	93.425	93.4680

Table 12. Predicted values of Hardness from equation and MINITAB software

Correlations:
Exp Hardness (BHN), Reg Hardness (BHN)
Pearson correlation of Exp Hardness (BHN) and Reg Hardness (BHN) = 0.537
P-Value = 0.059
Exp Hardness (BHN), FITS1
Pearson correlation of Exp Hardness (BHN) and FITS1 = 0.536
P-Value = 0.059



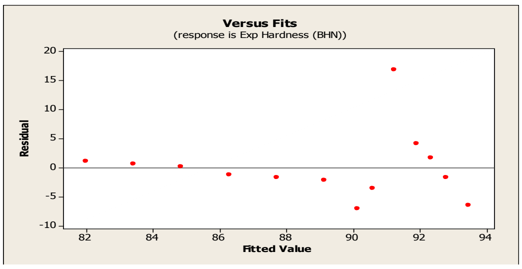


Fig 8. Normal probability plot showing distribution of residuals & Residuals versus the fitted values

The interpretation of the regression equation follows: Exp Hardness (BHN) = 73.6 + 0.221 Time (min) + 1.43 Pressure (bar) , · The slope (b1 = 0.221) is the change in Tensile strength when time increases by 1minute. That is, when the time increases by one unit, the Tensile strength increases by 0.0.221 units. The slope (b2 = 1.43) is the change in Tensile strength when pressure increases by 1. That is, when the pressure increases by one unit, the Tensile strength increases by 1.43 units. The relationships between the response, Experimental Hardness value, and the predictor, pressure (P = 0.117), is not significant because the p-value is higher than the pre-selected α-level. he relationship between the response, Experimental Hardness value, and the predictor, Time (P = 0.635), is not significant because the p-value is higher than the pre-selected α-level. The R^2 indicates that the predictors explain 28.8% of the variance in Hardness value. Both values indicate that the model fits the data not perfectly well. The Pearson correlation between experimental Average surface roughness and predicted Average surface roughness is 0.537 which indicates there is direct intermediate correlation between experimental values and predicted values. The histogram indicates that outliers may exist in the data, shown by a bar on the far right side of the plot. The normal probability plot shows an approximately linear pattern consistent with a normal distribution. The point in the upper-right corner of the plot may be outliers. Brushing the graph identifies these points as 16.748.

1. The plot of residuals versus the fitted values shows that the residuals get larger (away from the reference line) as the fitted values increase

IX. REGRESSION EQUATION BY MINITAB SOFTWARE

S.No	Time (min)	Pressure(bar)	Exp (μm)
1	10	10	7.50
2	12	10	7.30
3	12	9	7.54
4	12	8	7.60
5	12	7	7.67
6	12	6	7.67
7	12	5	7.70
8	12	4	7.78
9	15	10	7.10
10	18	10	6.37
11	20	10	5.20
12	22	10	4.75
13	25	10	4.75

Table 13. Average surface roughness of specimen at various input parameters

Regression Analysis: Exp (μm) versus Time (min), Pressure (bar)

The regression equation is

Exp (μm) = 10.8 - 0.221 Time (min) - 0.0769 Pressure (bar)

Predictor	Coef	SE Coef	T	P
Constant	10.7829	0.3398	31.73	0.000
Time (min)	-0.22093	0.01952	-11.32	0.000
Pressure (bar)	-0.07695	0.04253	-1.81	0.101

S = 0.279447 R-Sq = 95.2% R-Sq (adj) = 94.3%

X. CONCLUSION

From this work it has been observed that by varying input parameters of shot peening process there is variation in mechanical behavior of LM25 Al Alloy. The comparison between the peened and unpeened specimens shows that the earlier has better tensile strength (217.98 N/mm^2) and Hardness (108 BHN) but inferior Average surface roughness (4.75μm). Various residual plots give the value of input parameters for optimum Tensile strength, hardness and average surface roughness of best fit. Regression Analysis on various input parameters has predicted the tensile strength, Hardness and Average surface roughness at various strength of correlations enabling a reasonably good statistical model to predict the responses.

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