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# Evaluation of Surface Roughness of Medium Carbon Low Alloy Forged Steels Quenched in Polymer

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**Abstract:** ***Medium carbon steels are similar to low carbon steels except that the carbon ranges from 0.30 to 0.50% and manganese from 0.60 to 1.65% [1]. The uses of medium carbon steels include shafts, axles, gears, crankshafts, couplings and forgings. Steels of 0.40 to 0.60% C range are used for rails, railway wheels and rail axles. Therefore, medium carbon low Alloy steels have found enormous application aerospace, structural in automotive, engineering, agricultural engineering, railways, marine and power sectors due to high strength and specific mechanical properties. EN18 (AISI 5140), EN19 (AISI 4140), EN 24 (AISI 4340) and EN25 (AISI 3430) are MCLA steels under High Strength Low Alloy (HSLA) category. In some applications, there is a need to increase the strength along with the high ductility. In practice, heat treatment is the process by which changes in mechanical properties can be achieved. It mainly depends on the microstructural transformation, the microstructural changes occurring at different heat treatment conditions [2] with varying holding time and varying tempering temperature. The final end structure of the heat-treated components decides the applications where it can be used with the environmental conditions. The synthetic polymer quenchant, polyethylene glycol (PEG) [3]. has the advantages of lesser risk of cracking and less distortion, resulting in better mechanical properties compared to untreated samples.***

**Keywords:** EN Steels, Heat Treatment, Polymer Quenching, Forged Steels, Surface Roughness

## 1. Materials and Methods

Four steels, viz., EN 18, EN19, EN 24, and EN25 in the normalized condition were procured and the compositions were analysed for confirmation and table 2.1. gives the results of the composition check.

**Table 2.1:** Chemical Composition of Steels Studied

| Element | EN18 | EN19 | EN24 | EN25 |
|---|---|---|---|---|
| C | 0.380 | 0.393 | 0.431 | 0.350 |
| Mn | 0.700 | 0.660 | 0.605 | 0.700 |
| P | 0.012 | 0.014 | 0.023 | 0.04 |
| S | 0.012 | 0.019 | 0.030 | 0.04 |
| Si | 0.192 | 0.253 | 0.283 | 0.40 |
| Ni | -- | -- | 1.395 | 2.80 |
| Cr | 0.70 | 1.043 | 0.978 | 0.80 |
| Mo | -- | 0.202 | 0.207 | 0.65 |
| Fe | bal | bal | bal | bal |

{Polyethylene glycol, H−(O−CH2−CH2) n−O H [where n represent the average number of oxyethylene groups]} from Bangalore market to serve as quenchant.

### 1.1 Test specimen preparation

A set of specimens was prepared for fatigue and Micro structural analyses. The standard used for samples to carry out the fatigue tests is ASTME466. **Fig.2.1** shows the geometry of rotating beam sample.

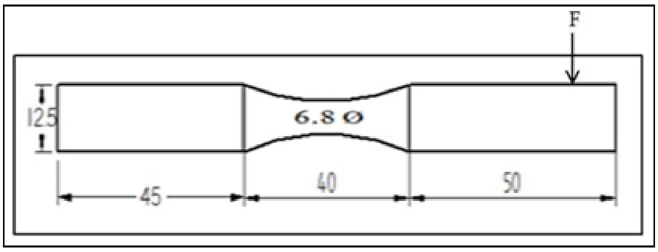


**Figure 2.1:** Geometry of Rotating Beam Sample

### 1.2 Heat Treatment/ Quenching and Step Tempering

An electric furnace with maximum temperature of 1200°C was used for both solutionizing and step tempering. The heat treat temperatures were kept same for all four steels studied, as shown in **Table 2.**

**Table 2.2:** Temperature and soaking time

| Process | Temp °C | Soaking time |
|---|---|---|
| Hardening | 855 | 60 Min |
| Tempering I | 575 | 60 Min |
| Tempering II | 220 | Min |

## 2. Mechanical Tests

Fatigue tests were carried out for MCLA steels in forged and polymer quenched conditions using a horizontal rotating bending fatigue testing machine **[3].** The selected steels were tested for forged and polymer quenched (10% and 30%) conditions separately. Tests were conducted at loads of 10 to 90% of UTS with increments of 10% (total 10 loads).

### 2.1 Surface Roughness for EN18

The experimental layout for the process parameters levels using an $L_9$ OA for EN18, 30% polymer heat treated samples are shown in **Table 3.1** also, the total mean surface roughness for nine experiments is also calculated. The surface roughness for each level is summarized in the response **Table 3.2** The experimental layout for the process parameters levels using an $L_9$ OA for EN18, 30% polymer heat treated samples are shown in **Table 3.2** also, the total mean surface roughness for nine experiments is also calculated. The surface roughness for each level is summarized in the response **Table 4.**

**Table 3.1:** Experimental Layout using an L9 Orthogonal Array of Ra for EN18

| Sl. No. | Speed, rpm | Feed, mm/rev | Depth of cut, mm | Ra | Ra-avg | (Ra-avg)2 |
|---|---|---|---|---|---|---|
| 1 | 150 | 0.05 | 0.5 | 5.25 | -1.14 | 1.29 |
| 2 | 150 | 0.11 | 0.75 | 6.03 | -0.36 | 0.13 |
| 3 | 150 | 0.22 | 1 | 6.13 | -0.26 | 0.07 |
| 4 | 250 | 0.05 | 0.75 | 5.13 | -1.26 | 1.58 |
| 5 | 250 | 0.11 | 1 | 7.01 | 0.62 | 0.39 |
| 6 | 250 | 0.22 | 0.5 | 6.08 | -0.31 | 0.09 |
| 7 | 420 | 0.05 | 1 | 7.65 | 1.26 | 1.60 |
| 8 | 420 | 0.11 | 0.5 | 7.03 | 0.64 | 0.41 |
| 9 | 420 | 0.22 | 0.75 | 7.17 | 0.78 | 0.61 |
| | | | **Average (T) =** | **6.387** | | **6.17** |

**Table 3.2:** Response Table of Mean for Ra and Significant Interaction for EN18

| Symbol | Process parameters | Level 1 | Level 2 | Level 3 | Optimum level |
|---|---|---|---|---|---|
| A | Speed | 5.80 | 6.07 | 7.28 | A1 |
| B | Feed | 6.01 | 6.69 | 6.46 | B1 |
| C | DOC | 6.12 | 6.11 | 6.96 | C2 |

The total mean surface roughness = 6.387. A response graph is drawn using the values from the response table. The Fig.2 shows the response curve surface roughness.

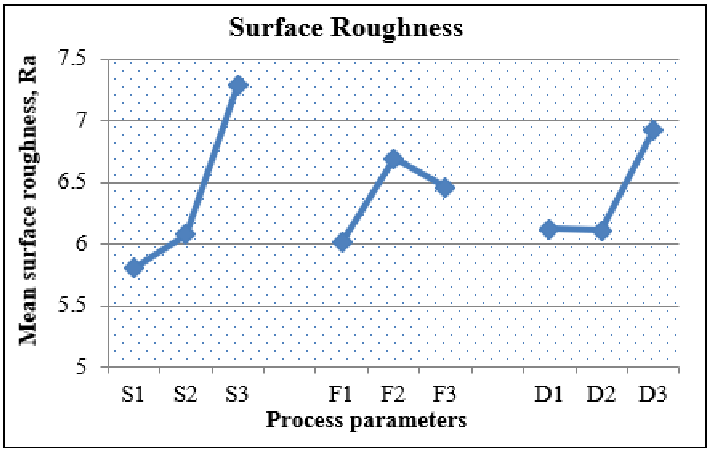


**Figure 3.1:** Response Graph of Surface Roughness for EN18

From the response graph, the optimal parameters for minimum surface roughness are;

- Speed at level 1, A1 = 150 rpm
- Feed at level 1, B1 = 0.11 mm/rev
- Depth of cut at level 2, C2 = 0.75 mm

## 3. Analysis of Variance (ANOVA)

The contributing ratio of the control factors in getting the minimum surface finish as brought by ANOVA is shown in the Table 4.1 And the corresponding Pareto ANOVA diagram is shown in Fig.4.2. It is concluded that the speed is the major contributing factor (60.40%), depth of cut is the second influencing factor (21.53%) followed by the feed has less influence (11.63%) on the surface roughness.

**Table 4.1:** Results of Analysis of Variance for EN18

| Source of variation | Degrees of freedom | Sum of squares | Variance | True variation | F-ratio | C | Contribution, % |
|---|---|---|---|---|---|---|---|
| Speed | 2 | 3.7274 | 1.8637 | 3.3308 | 9.3984 | 0.604 | 60.408 |
| Feed | 2 | 0.7178 | 0.3589 | 0.3212 | 1.8099 | 0.116 | 11.633 |
| DOC | 2 | 1.3286 | 0.6643 | 0.932 | 3.35 | 0.215 | 21.532 |
| Error | 2 | 0.3966 | 0.1983 | | | 0.064 | 6.427 |
| Total | 8 | 6.1704 | 3.0852 | | | | 100.000 |

- Sum of squares for Speed = $(L_1 - L_2)^2 + (L_2 - L_3)^2 + (L_3 - L_1)^2$
  $= (5.80 - 6.07)^2 + (6.07 – 7.28)^2 + (7.28 – 5.80)^2 = 3.7274$
- Sum of squares for Feed= $(L_1 - L_2)^2 + (L_2 - L_3)^2 + (L_3 - L_1)^2$
  $= (6.01 - 6.69)^2 + (6.69 – 6.46)^2 + (6.46 – 6.01)^2 = 0.7178$
- Sum of squares for DOC= $(L_1 - L_2)^2 + (L_2 - L_3)^2 + (L_3 - L_1)^2$
  $= (6.12 - 6.11)^2 + (6.11 – 6.93)^2 + (6.93 – 6.12)^2 = 1.386$
- Error= Avg (Ra- Avg) $^2$ – (SOS, Speed + Feed + DOC)

= 6.17 – (3.7274 + 0.7178 + 1.386)
= 0.3966

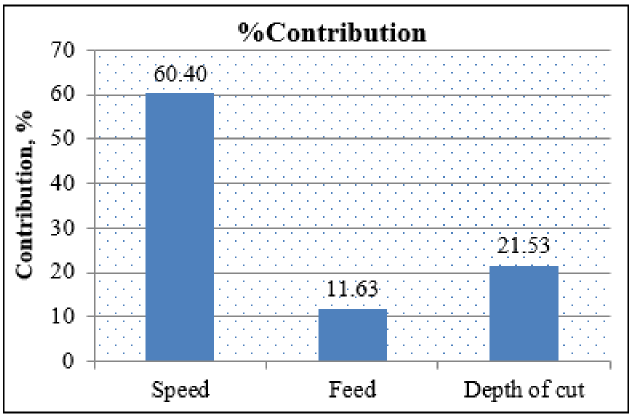


**Figure 4.1:** Process Parameters and % Contribution for EN18

### 3.1 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness is estimated as follows:
Predicted optimal surface roughness = $(A_1 + B_1 + C_2 - 2T)$

Where $A_1$, B1 and $C_2$ are the average surface roughness value for the first and second level and T is the mean surface roughness value of all experimenting data. In calculating the estimate, we use only strong effects.

Predicted optimum value of surface roughness
= (5.80) + (6.01) + (6.11) - (2×6.387)
**= 5.15 Ra**

### 3.2. Confidence Interval

A random sample that will produce an interval for which the experimental value must lie is the confidence interval.

Confidence interval, CI = $\sqrt{F(\alpha\,;v1;v2) \times (\frac{Ve}{neff})}$

F (α ; 1; v2) = F-distribution with V1 and V2 degrees of freedom
α = risk (90%)
Confidence = 1-risk =1-0.90 = 0.10, $v_1$=1

$v_2$= degrees of freedom for pooled error

$$Ve = \frac{\text{Pooled variation of non-significant sources}}{\text{Pooled degrees of freedom of non-significant sources}}$$

$$= \frac{0.3589+0.6643+0.1983}{6} = 0.2035$$

$$neff = \frac{\text{Number of experiments}}{1+\text{Total degrees of freedom in items used in } \mu \text{ estimate}}$$

$= \frac{9}{7} = 1.2857$
F (0.10, 1, 6) = 3.776 (from the F- distribution table)
CI = $(3.776 * (0.20 / 1.29))^{0.5}$
**CI = 0.77**

From the equation the confidence interval of the above predicted estimate at (90%) significance = ± 0.77 i.e., the experimental values should lie within the predicted range of 5.15 ± 0.77 = 4.38 Ra to 5.92 Ra.

### 3.3 Confirmation

A confirmation test was carried out at the optimum settings of the process parameters recommended by the investigation, i.e., 150 rpm, 0.05 mm/rev and 0.5 mm, which gives a surface roughness of 5.25 Ra which was found to be falling within the predicted range.

### 3.4 Verification using Minitab for EN18

The experimental results were fed to Minitab and that response curves as well as predicted values verifying that the calculations made are correct.

**Factor Information**

| Factor | Type | Levels | Values |
|---|---|---|---|
| Speed | Fixed | 3 | 150, 250, 420 |
| Feed | Fixed | 3 | 0.05, 0.11, 0.22 |
| Depth of cut | Fixed | 3 | 0.50, 0.75, 1.00 |

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Speed | 2 | 3.7274 | 1.8637 | 9.40 | 0.096 |
| Feed | 2 | 0.7178 | 0.3589 | 1.81 | 0.356 |
| Depth of cut | 2 | 1.3286 | 0.6643 | 3.35 | 0.230 |
| Error | 2 | 0.3966 | 0.1983 | | |
| Total | 8 | 6.1704 | | | |

**Design Summary**

Taguchi Array L9(3^3)
Factors: 3
Runs: 9

Columns of L9(3^4) array: 1 2 3

**Taguchi Analysis: RA versus Speed, Feed, Depth of cut**

Smaller is better

**Response Table for Means**

| Level | Speed | Feed | Depth of cut |
|---|---|---|---|
| 1 | 5.803 | 6.010 | 6.120 |
| 2 | 6.073 | 6.690 | 6.110 |
| 3 | 7.283 | 6.460 | 6.930 |
| Delta | 1.480 | 0.680 | 0.820 |
| Rank | 1 | 3 | 2 |

**Figure 4.2:** Experimental Layout of Taguchi Analysis for EN18

```
L9 (3^3)

Factors: 3
Runs:    9

Columns of L9 (3^4)

1 2 3

Display Units: Uncoded

Factors and Their Uncoded Levels

Factor  Name           Levels
A       Speed          150 250 420
B       Feed           0.05 0.11 0.22
C       Depth of cut   0.50 0.75 1.00
```

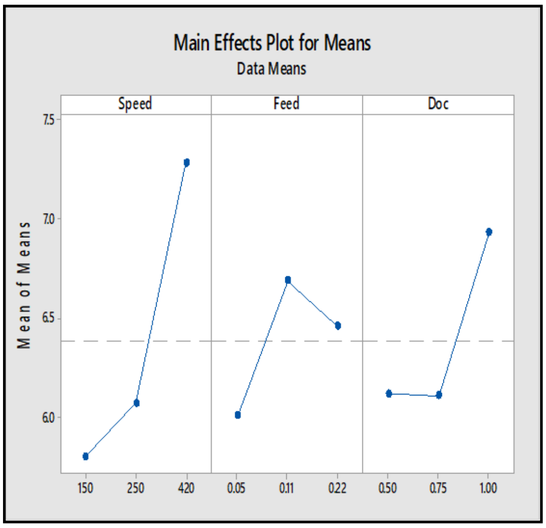


**Figure 4.3:** Taguchi Design and Mean Effect Plot of Surface Roughness for EN18

### 3.1.5 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness is estimated and the optimum predicted optimal surface roughness for EN18.

| Predicted values | | Settings | |
|---|---|---|---|
| Prediction | Speed | Feed | Depth of cut |
| Mean 5.16 | 150 | 0.05 | 0.5 |

**Figure 4.4:** Predicted Optimal Surface Roughness for EN18

### 3.2 Surface Roughness for EN 19

The experimental layout for the process parameters levels using an $L_9$ OA for EN19, 30% polymer heat treated samples is shown in Table 5.40, also the total mean surface roughness for nine experiments is also calculated. The surface roughness for each level is summarized in the response Table 4.2.

**Table 4.2:** Experimental Layout using an L9 Orthogonal Array of Ra for EN19

| Sl. No. | Speed, rpm | Feed, mm/rev | Depth of Cut, mm | Ra, µm | Ra - avg | (Ra - avg)2 |
|---|---|---|---|---|---|---|
| 1 | 150 | 0.05 | 0.5 | 5.38 | -1.10 | 1.21 |
| 2 | 150 | 0.11 | 0.75 | 6.24 | -0.24 | 0.06 |
| 3 | 150 | 0.22 | 1 | 6.3 | -0.18 | 0.03 |
| 4 | 250 | 0.05 | 0.75 | 5.15 | -1.33 | 1.77 |
| 5 | 250 | 0.11 | 1 | 6.89 | 0.41 | 0.17 |
| 6 | 250 | 0.22 | 0.5 | 6.18 | -0.30 | 0.09 |
| 7 | 420 | 0.05 | 1 | 7.69 | 1.21 | 1.46 |
| 8 | 420 | 0.11 | 0.5 | 7.22 | 0.74 | 0.55 |
| 9 | 420 | 0.22 | 0.75 | 7.28 | 0.80 | 0.64 |
| Average (T) = | | | | 6.48 | | 5.98 |

**Table 4.3:** Response Table of Mean for Ra and Significant Interaction for EN19

| Symbol | Process parameters | Level 1 | Level 2 | Level 3 | Optimum level |
|---|---|---|---|---|---|
| A | Speed | 5.97 | 6.07 | 7.40 | A1 |
| B | Feed | 6.07 | 6.78 | 6.59 | B1 |
| C | DOC | 6.26 | 6.22 | 6.96 | C2 |

### 3.2.1 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness is estimated as follows:

Predicted optimal surface roughness = $(A_1 + B_1 + C_2 - 2T)$,

Where $A_1$, B1 and $C_2$ are the average surface roughness value for the first level and T is the mean surface roughness value of all experimenting data. In calculating the estimate, we use only strong effects.

Predicted optimum value of surface roughness
= (5.97) + (6.07) + (6.22) - (2×6.48)
= **5.31 Ra**

### 3.2.2 Confidence Interval

A random sample that will produce an interval for which the experimental value must lie is the confidence interval.

Confidence interval, $CI = \sqrt{F(\alpha\,; v1; v2) \times \left(\frac{Ve}{neff}\right)}$

$F\ (\alpha\,; 1; v2)$ = F-distribution with V1 and V2 degrees of freedom

$\alpha$ = risk (90%)

Confidence = 1-risk =1-0.90 = 0.10

$v_1$=1

$v_2$= degrees of freedom for pooled error

$$Ve = \frac{\text{Pooled variation of non-significant sources}}{\text{Pooled degrees of freedom of non-significant sources}}$$

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$= \frac{0.40+0.52+0.18}{6}$

$= 0.18$

$$neff = \frac{\text{Number of experiments}}{1+\text{Total degrees of freedom in items used in }\mu\text{ estimate}}$$

$= \frac{9}{7} = 1.29$

F (0.10, 1, 6) = 3.776

CI = $(3.776 * (0.18/ 1.29))^{0.5}$

**CI = 0.73**

From the equation the confidence interval of the above predicted estimate at (90%) significance = ± 0.73 i.e., the experimental values should lie within the predicted range of 5.31 ± 0.73 = 4.58 Ra to 6.04 Ra.

### 3.2.3 Confirmation

A confirmation test was carried out at the optimum settings of the process parameters recommended by the investigation, i.e., 150 rpm, 0.05 mm/rev and 0.5 mm, which gives a surface roughness of 5.38 Ra which was found to be falling within the predicted range.

### 3.2.4 Verification using Minitab for EN19

The experimental results were fed to Minitab and that response curves as well as predicted values verifying that the calculations made are correct.

**Design Summary**

| | |
|---|---|
| Taguchi Array | L9(3^3) |
| Factors: | 3 |
| Runs: | 9 |

Columns of L9(3^4) array: 1 2 3

**Taguchi Analysis: ra versus Speed, Feed, Depth of cut**

Smaller is better

**Response Table for Means**

| Level | Speed | Feed | Depth of cut |
|---|---|---|---|
| 1 | 5.973 | 6.073 | 6.260 |
| 2 | 6.073 | 6.783 | 6.223 |
| 3 | 7.397 | 6.587 | 6.960 |
| Delta | 1.423 | 0.710 | 0.737 |
| Rank | 1 | 3 | 2 |

**Factor Information**

| Factor | Type | Levels | Values |
|---|---|---|---|
| Speed | Fixed | 3 | 150, 250, 420 |
| Feed | Fixed | 3 | 0.05, 0.11, 0.22 |
| Depth of cut | Fixed | 3 | 0.50, 0.75, 1.00 |

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Speed | 2 | 3.7871 | 1.8935 | 10.78 | 0.085 |
| Feed | 2 | 0.8063 | 0.4031 | 2.30 | 0.303 |
| Depth of cut | 2 | 1.0340 | 0.5170 | 2.94 | 0.254 |
| Error | 2 | 0.3513 | 0.1756 | | |
| Total | 8 | 5.9787 | | | |

**Figure 4.5:** Experimental Layout of Taguchi Analysis for EN19

```
L9 (3^3)

Factors: 3
Runs:    9

Columns of L9 (3^4)

1 2 3

Display Units: Uncoded

Factors and Their Uncoded Levels

Factor  Name          Levels
A       Speed         150 250 420
B       Feed          0.05 0.11 0.22
C       Depth of cut  0.50 0.75 1.00
```

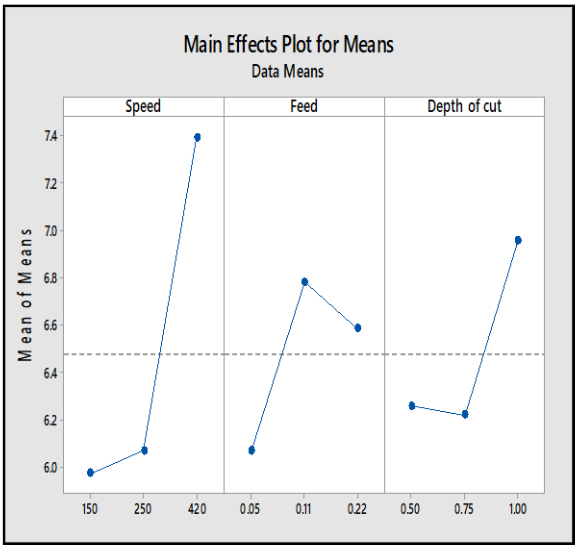


**Figure 4.6:** Taguchi Design and Mean Effect Plot of Surface Roughness for EN19

### 3.2.5 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness are estimated and the optimum predicted optimal surface roughness for EN19 is 5.34444

**Predicted values**

| Prediction | Settings | | |
|---|---|---|---|
| Mean | Speed | Feed | Depth of cut |
| 5.34444 | 150 | 0.05 | 0.5 |

**Figure 4.7:** Predicted Optimal Surface Roughness for EN19

### 3.3 Surface Roughness for EN24

The experimental layout for the process parameters levels using an $L_9$ OA for EN24, 30% polymer heat treated samples is shown in Table 4.3, also the total mean surface roughness for nine experiments is also calculated. The surface roughness for each level is summarized in the response Table 4.4.

**Table 4.3:** Experimental Layout using an L9 Orthogonal Array of Ra for EN24

| S. No. | Speed, rpm | Feed, mm/rev | Depth of Cut, mm | Ra, µm | Ra-avg | (Ra-avg)2 |
|---|---|---|---|---|---|---|
| 1 | 150 | 0.05 | 0.5 | 4.15 | -3.08 | 9.50 |
| 2 | 150 | 0.11 | 0.75 | 6.53 | -0.70 | 0.49 |
| 3 | 150 | 0.22 | 1 | 6.71 | -0.52 | 0.27 |
| 4 | 250 | 0.05 | 0.75 | 5.23 | -2.00 | 4.01 |
| 5 | 250 | 0.11 | 1 | 8.12 | 0.89 | 0.79 |
| 6 | 250 | 0.22 | 0.5 | 6.88 | -0.35 | 0.12 |
| 7 | 420 | 0.05 | 1 | 9.1 | 1.87 | 3.49 |
| 8 | 420 | 0.11 | 0.5 | 8.92 | 1.69 | 2.85 |
| 9 | 420 | 0.22 | 0.75 | 9.45 | 2.22 | 4.92 |
| Average (T) = | | | | 7.23 | | 26.44 |

**Table 4.4:** Response Table of Mean for Ra and Significant Interaction

| Symbol | Process parameters | Level 1 | Level 2 | Level 3 | Optimum level |
|---|---|---|---|---|---|
| A | Speed | 5.80 | 6.74 | 9.16 | A1 |
| B | Feed | 6.16 | 7.86 | 7.68 | B1 |
| C | DOC | 6.65 | 7.07 | 7.98 | C1 |

#### 3.3.1 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness is estimated as follows:

Predicted optimal surface roughness = ($A_1$ + $B_1$ + $C_2$ - 2T), Where $A_1$, B1 and $C_2$ are the average surface roughness value for the first level and T is the mean surface roughness value of all experimenting data. In calculating the estimate, we use only strong effects.

Predicted optimum value of surface roughness
= (5.80) + (6.16) + (6.65) - (2×7.23)
**= 4.15 Ra**

#### 3.3.2 Confidence Interval

A random sample that will produce an interval for which the experimental value must lie is the confidence interval.

Confidence interval, $CI = \sqrt{F(\alpha\,;v1;v2) \times (\frac{Ve}{neff})}$

$F\ (\alpha\,;1;v2)$ = F-distribution with V1 and V2 degrees of freedom

α = risk (90%)

Confidence = 1-risk =1-0.90 = 0.10

$v_1$=1

$v_2$= degrees of freedom for pooled error

$$Ve = \frac{\text{Pooled variation of non-significant sources}}{\text{Pooled degrees of freedom of non-significant sources}}$$

$$= \frac{2.61+1.38+0.23}{6}$$

= 0.70

$$neff = \frac{\text{Number of experiments}}{1+\text{ Total degrees of freedom in items used in } \mu \text{ estimate}}$$

$= \frac{9}{7} = 1.29$

F (0.10, 1, 6) = 3.776

CI = (3.776 * (0.70/ 1.29)) $^{0.5}$

**CI = 1.43**

From the equation the confidence interval of the above predicted estimate at (90%) significance = ± 1.43 i.e., the experimental values should lie within the predicted range of 4.15 ± 1.43 = 2.72 Ra to 5.58 Ra.

#### 3.3.3 Confirmation

A confirmation test was carried out at the optimum settings of the process parameters recommended by the investigation, i.e., 150 rpm, 0.05 mm/rev and 0.5 mm, which gives a surface roughness of 4.15 Ra which was found to be falling within the predicted range.

#### 3.3.4 Verification using Minitab for EN24

The experimental results were fed to Minitab and that response curves as well as predicted values verifying that the calculations made are correct.

**Design Summary**

| | |
|---|---|
| Taguchi Array | L9(3^3) |
| Factors: | 3 |
| Runs: | 9 |

Columns of L9(3^4) array: 1 2 3

**Taguchi Analysis: Ra versus Speed, Feed, DOC**

Smaller is better

**Response Table for Means**

| Level | Speed | Feed | DOC |
|---|---|---|---|
| 1 | 5.797 | 6.160 | 6.650 |
| 2 | 6.743 | 7.857 | 7.070 |
| 3 | 9.157 | 7.680 | 7.977 |
| Delta | 3.360 | 1.697 | 1.327 |
| Rank | 1 | 2 | 3 |

**Factor Information**

| Factor | Type | Levels | Values |
|---|---|---|---|
| Speed | Fixed | 3 | 150, 250, 420 |
| Feed | Fixed | 3 | 0.05, 0.11, 0.22 |
| DOC | Fixed | 3 | 0.50, 0.75, 1.00 |

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Speed | 2 | 18.0100 | 9.0050 | 39.67 | 0.025 |
| Feed | 2 | 5.2203 | 2.6101 | 11.50 | 0.080 |
| DOC | 2 | 2.7585 | 1.3792 | 6.08 | 0.141 |
| Error | 2 | 0.4540 | 0.2270 | | |
| Total | 8 | 26.4428 | | | |

**Figure 4.8:** Experimental Layout of Taguchi Analysis for EN24

```
L9 (3^3)

Factors: 3
Runs:    9

Columns of L9 (3^4)

1 2 3

Display Units: Uncoded

Factors and Their Uncoded Levels

Factor    Name    Levels
A         Speed   150 250 420
B         Feed    0.05 0.11 0.22
C         Doc     0.5 0.75 1

Responses:  Ra
```

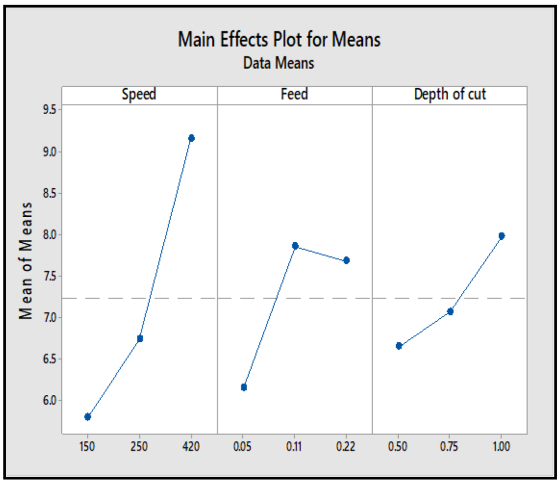


**Figure 4.9:** Taguchi Design and Mean Effect Plot of Surface Roughness for EN24

### 3.3.5 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness are estimated and the optimum predicted optimal surface roughness for EN24 is 4.14222

**Predicted values**

**Prediction Settings**

| Mean | Speed | Feed | DOC |
|---|---|---|---|
| 4.14222 | 150 | 0.05 | 0.5 |

**Figure 4.10:** Predicted Optimal Surface Roughness for EN24

### 3.4 Surface Roughness for EN25

The experimental layout for the process parameters levels using an $L_9$ OA for EN24, 30% polymer heat treated samples is shown in Table 4.6, also the total mean surface roughness for nine experiments is also calculated. The surface roughness for each level is summarized in the response Table 4.6.

**Table 4.5:** Experimental Layout using an L9 Orthogonal Array of Ra for EN25

| S. No. | Speed, rpm | Feed, mm/rev | Depth of Cut, mm | Ra | Ra-avg | (Ra-avg)2 |
|---|---|---|---|---|---|---|
| 1 | 150 | 0.05 | 0.5 | 5.25 | -2.63 | 6.92 |
| 2 | 150 | 0.11 | 0.75 | 7.33 | -0.55 | 0.30 |
| 3 | 150 | 0.22 | 1 | 7.51 | -0.37 | 0.14 |
| 4 | 250 | 0.05 | 0.75 | 6.13 | -1.75 | 3.06 |
| 5 | 250 | 0.11 | 1 | 9.02 | 1.14 | 1.30 |
| 6 | 250 | 0.22 | 0.5 | 7.08 | -0.8 | 0.64 |
| 7 | 420 | 0.05 | 1 | 9.2 | 1.32 | 1.74 |
| 8 | 420 | 0.11 | 0.5 | 9.92 | 2.04 | 4.16 |
| 9 | 420 | 0.22 | 0.75 | 9.48 | 1.6 | 2.56 |
| Average (T) = | | | | 7.88 | | 20.82 |

**Table 4.6:** Response Table of Mean for Ra and Significant Interaction for EN25

| Symbol | Process parameters | Level 1 | Level 2 | Level 3 | Optimum level |
|---|---|---|---|---|---|
| A | Speed | 6.70 | 7.41 | 9.53 | A1 |
| B | Feed | 6.86 | 8.76 | 8.02 | B1 |
| C | DOC | 7.42 | 7.65 | 8.58 | C1 |

### 3.4.1 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness is estimated as follows

Predicted optimal surface roughness = ($A_1 + B_1 + C_1$ - 2T), Where $A_1$, B1 and $C_1$ are the average surface roughness value for the first level and T is the mean surface roughness value from all experimenting data. In calculating the estimate, we use only strong effects.

Predicted optimum value of surface roughness
= (6.70) + (6.86) + (7.42) - (2×7.88)
**= 5.21 Ra**

### 3.4.2 Confidence Interval

A random sample that will produce an interval for which the experimental value must lie is the confidence interval.

Confidence interval CI = $\sqrt{F(\alpha\,; v1; v2) \times (\frac{Ve}{neff})}$

F $(\alpha\,; 1; v2)$ = F-distribution with V1 and V2 degrees of freedom
A = risk (90%)
Confidence = 1-risk =1-0.90 = 0.10
$v_1$=1
$v_2$= degrees of freedom for pooled error

$$Ve = \frac{\text{Pooled variation of non-significant sources}}{\text{Pooled degrees of freedom of non-significant sources}}$$

$$= \frac{2.74+1.13+0.00}{6}$$

= 0.647

$$neff = \frac{\text{Number of experiments}}{1+\text{Total degrees of freedom in items used in } \mu \text{ estimate}} = \frac{9}{7}$$

= 1.29
F (0.10, 1, 6) = 3.776
CI = $(3.776 * (0.647/ 1.29))^{0.5}$
**CI = 1.38**

From the equation the confidence interval of the above predicted estimate at (90%) significance = ± 1.38 i.e., the experimental values should lie within the predicted range of 5.21 ± 1.38 = 3.84 Ra to 6.59 Ra.

### 3.4.3 Confirmation

A confirmation test was carried out at the optimum settings of the process parameters recommended by the investigation, i.e., 150 rpm, 0.05 mm/rev and 0.5 mm, which gives a surface roughness of 5.25 Ra which was found to be falling within the predicted range.

### 3.4.4 Verification using Minitab for EN25

The experimental results were fed to Minitab and that response curves as well as predicted values verifying that the calculations made are correct.

**Design Summary**

Taguchi Array L9(3^3)
Factors: 3
Runs: 9

Columns of L9(3^4) array: 1 2 3

**Taguchi Analysis: Ra versus Speed, Feed, Doc**

Smaller is better

**Response Table for Means**

| Level | Speed | Feed | Doc |
|---|---|---|---|
| 1 | 6.697 | 6.860 | 7.417 |
| 2 | 7.410 | 8.757 | 7.647 |
| 3 | 9.533 | 8.023 | 8.577 |
| Delta | 2.837 | 1.897 | 1.160 |
| Rank | 1 | 2 | 3 |

**Factor Information**

| Factor | Type | Levels | Values |
|---|---|---|---|
| Speed | Fixed | 3 | 150, 250, 420 |
| Feed | Fixed | 3 | 0.05, 0.11, 0.22 |
| Doc | Fixed | 3 | 0.50, 0.75, 1.00 |

**Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Speed | 2 | 13.0641 | 6.53203 | 2020.22 | 0.000 |
| Feed | 2 | 5.4885 | 2.74423 | 848.73 | 0.001 |
| Doc | 2 | 2.2634 | 1.13170 | 350.01 | 0.003 |
| Error | 2 | 0.0065 | 0.00323 | | |
| Total | 8 | 20.8224 | | | |

**Figure 4.11:** Experimental Layout of Taguchi Analysis for EN25

```
L9 (3^3)

Factors: 3
Runs:    9

Columns of L9 (3^4)

1 2 3

Display Units: Uncoded

Factors and Their Uncoded Levels

Factor  Name   Levels
A       Speed  150 250 420
B       Feed   0.05 0.11 0.22
C       Doc    0.5 0.75 1

Responses:  Ra
```

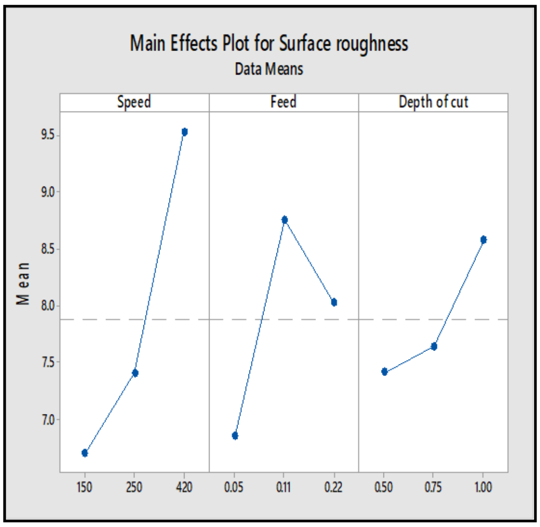


**Figure 4.12:** Taguchi Design and Mean Effect Plot of Surface Roughness for EN25

### 3.4.5 Prediction of Optimum Performance

At the optimum setting condition, the optimum surface roughness are estimated and the optimum predicted optimal surface roughness for EN25 is 5.2133

**Predicted values**

**Prediction Settings**

| Mean | Speed | Feed | Doc |
|---|---|---|---|
| 5.21333 | 150 | 0.05 | 0.5 |

**Figure 4.13:** Predicted Optimal Surface Roughness for EN25

## 4. Conclusion

For obtaining the optimum surface roughness, the cutting parameters for all the four steels studied were found to be the same, viz., Speed 150 rpm, feed 0.05 mm/rev, Doc 0.5mm.

A comparison of the optimum surface roughness of the four steels is shown in Fig. 4.14. It is seen that all the four steels have surface roughness of about 5 Ra.

The surface finish for selected MCLA steels was investigated, and the optimum settings of the process parameters obtained during analysis were, 150 rpm, 0.05 mm/rev for obtaining a surface finish of about 5 Ra

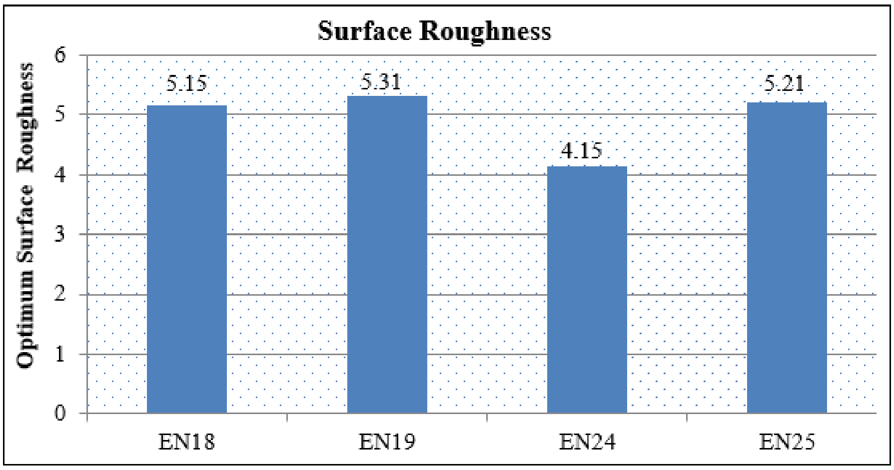


**Figure 4.14:** Comparison of Optimum Surface Roughness for MCLA Steels

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