# Study of the Effect of Machining Parameters on Surface Finish in End Milling of Heat Treated Manganese Steel

Abubakar Buhari
School of Mechanical Engineering,
Tianjin University of Technology and Education (TUTE)
Tianjin, P.R. China.

Liu Ping (Prof.)
School of Mechanical Engineering,
Tianjin University of Technology and Education (TUTE)
Tianjin, P.R. China.

***Abstract*— Full factorial Design of experiments (DOE) was employed to analyze the effect of cutting parameters on the surface roughness of heat treated Mangalloy (45HRC). The results of the Machining experiments were used to analyze the characteristics of each factor on surface roughness by the Analysis of Variance (ANOVA). ANOVA is a statistical technique used to investigate and model the relationship between a response variable and one or more independent variable. The analysis was carried out with the aid of Origin Pro 8.0 software. The result shows that for rough cutting (high Depth of cut and low cutting speed), Depth of cut is the most significant parameter influencing the surface roughness in the end milling process of hard to cut material.**

**Keywords—Surface roughness; Full factorial DOE; ANOVA; Manganese Steel**



## I. INTRODUCTION

In today's competitive market, the requirements for minimizing cost, reduced product lead-time as well as increased quality have created a challenging environment in product development. Product Development Company has also become increasingly globalized and decentralized. The trend is towards a team effort involving various groups of designers, manufacturers, suppliers, customers, and other outsourced parties across the world.In the manufacturing sector, the trend is mostly focused on how to create a new and smaller product of higher quality, in a shorter time and at a lower cost. To achieve some of these objectives, there is the need to use hard and resistant materials. However, this type of materials is usually characterized by low machinability.

For example, the high evolutionary improvement of diesel motor is mostly due to fuel pump with working pressure of approximately 2000 bars. In this way, the diesel motor is more economical by approximately 5 litres /100 kilometre and has very high acceleration. To achieve high pressure, the tolerance is very small and material must have an elevated hardness in order to be wear resistance [1].

Similarly, the wide range of applications of hard and resistive materials like manganese steel in the aspects of general mechanical engineering, transportation, energy, hand and machine tools, surgical instruments among others necessitated for the machining of difficult to machine materials.Accordingly, milling process is one of the common metal cutting operations used for machiningparts in manufacturing industry. It is usually performed at the final stage in manufacturing aproduct. The demand for high quality and fully automated production focuses attention on thesurface condition of the product, especially the roughness of the machined surface, becauseof its effect on product appearance, function, and reliability. This paper focuses on the Experimental investigation of effect of cutting parameters (Spindle Speed, Feed Rate and Depth of Cut) in the milling operations of Manganese steel, with cemented Carbide end mill of Φ10mm, on MAKINO FNC 86 CNC Machining center.

## II. EXPERIMENTAL DETAILS

### *A. Working Material*

Manganese steel was discovered by Hadfield in 1882 and since then it has become one of the most important steels where Erosion of components takes place by continued abrasion impact. Manganese steels are universally known as the most useful abrasion resistant material. It is characterized with good metallurgical quality such as high purity and uniformity, good surface quality by strictly controlling surface defect and decarburization, good mechanical properties especially on elastic limit, strength limit and tensile ratio, as well as accurate shape and dimension. The product is a common spring steel with extensive applications. It is mainly used in the manufacture of cushion spring, clockwork spring, oil pump speed adjusting spring, plunger spring, absorber spring, clutch spring and brake spring etc. Manganese steel is classified as difficult to cut material due to the 11% to 14% manganese content. It work hardened very quickly because it's high elastic and plastic deformation property [2].

The work piece of 150mm by 80mm by 50mm was hardened to 45HRC by the use of heat treatment (heating, quenching and normalizing). The chemical composition of the work piece is as shown in table 1 below.

| **Table1: Chemical Composition of Mangalloy in Percentage (%)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Element** | *C* | *Mn* | *Si* | *S* | *P* | *Cr* | *Ni* | *Cu* |
| **Wt%** | 0.6 | 0.92 | 0.78 | 0.009 | 0.02 | 0.07 | 0.08 | 0.08 |

TABLE I.

### B. *Cutting Tool*

Carbide end mill was employed throughout the experiment. It is selected because of its suitability in machining hard materials like carbon steel and stainless steel as well as its desirability in high production line because it produces better surface finish, and allows faster machining with no or little wear. It can also withstand higher temperature when compared with standard high speed steel cutting tools. The material is usually called cemented carbide, hard metal or tungsten-carbide cobalt, because its matrix comprises of aggregate of tungsten carbide particle with metallic cobalt [2].

### C. *Experimental Procedure*

The experiment was conducted in order to analyze the effect of spindle speed, feed rate and depth of cut on the surface wrongness (Ra). These three factors were designed at four levels, as shown in Table. 2. The DOE adapted was $4^3$(=64), full factorial design with no replicate. Table 3 shows the design matrix [3].The experimental runs were carried out with each combination of the cutting parameters, using pressure air as coolant (dry cutting), on CNC vertical milling machine. The surface roughness of each combination were measured with the aid of surface roughness tester (Mitutoyo SURFTEST.500), as shown in Table 3.

TABLE II. MACHINING PARAMETERS AND LEVELS

| **Parameter** | **Unit** | **Levels** | | | |
|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** |
| *Spindle Speed(V)* | *RPM* | 600 | 700 | 800 | 900 |
| *Feed Rate(F)* | *mm/rev* | 40 | 60 | 80 | 100 |
| *Depth of Cut (D)* | *mm* | 0.1 | 0.2 | 0.3 | 0.4 |

TABLE III. DESIGN MATRIX AND EXPERIMENTAL RESULTS FOR SURFACE ROUGHNESS

| **Run No.** | **V** | **F** | **D** | **Ra(µm)** | **Run No.** | **V** | **F** | **D** | **Ra(µm)** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 600 | 40 | 0.1 | 0.2 | 33 | 600 | 40 | 0.3 | 0.18 |
| 2 | 700 | 40 | 0.1 | 0.13 | 34 | 700 | 40 | 0.3 | 0.23 |
| 3 | 800 | 40 | 0.1 | 0.12 | 35 | 800 | 40 | 0.3 | 0.19 |
| 4 | 900 | 40 | 0.1 | 0.14 | 36 | 900 | 40 | 0.3 | 0.17 |
| 5 | 600 | 60 | 0.1 | 0.17 | 37 | 600 | 60 | 0.3 | 0.2 |
| 6 | 700 | 60 | 0.1 | 0.14 | 38 | 700 | 60 | 0.3 | 0.2 |
| 7 | 800 | 60 | 0.1 | 0.19 | 39 | 800 | 60 | 0.3 | 0.22 |
| 8 | 900 | 60 | 0.1 | 0.18 | 40 | 900 | 60 | 0.3 | 0.25 |
| 9 | 600 | 80 | 0.1 | 0.17 | 41 | 600 | 80 | 0.3 | 0.26 |
| 10 | 700 | 80 | 0.1 | 0.21 | 42 | 700 | 80 | 0.3 | 0.28 |
| 11 | 800 | 80 | 0.1 | 0.22 | 43 | 800 | 80 | 0.3 | 0.3 |
| 12 | 900 | 80 | 0.1 | 0.29 | 44 | 900 | 80 | 0.3 | 0.27 |
| 13 | 600 | 100 | 0.1 | 0.26 | 45 | 600 | 100 | 0.3 | 0.28 |
| 14 | 700 | 100 | 0.1 | 0.27 | 46 | 700 | 100 | 0.3 | 0.32 |
| 15 | 800 | 100 | 0.1 | 0.35 | 47 | 800 | 100 | 0.3 | 0.35 |
| 16 | 900 | 100 | 0.1 | 0.33 | 48 | 900 | 100 | 0.3 | 0.29 |
| 17 | 600 | 40 | 0.2 | 0.2 | 49 | 600 | 40 | 0.4 | 0.45 |
| 18 | 700 | 40 | 0.2 | 0.16 | 50 | 700 | 40 | 0.4 | 0.44 |
| 19 | 800 | 40 | 0.2 | 0.21 | 51 | 800 | 40 | 0.4 | 0.35 |
| 20 | 900 | 40 | 0.2 | 0.61 | 52 | 900 | 40 | 0.4 | 0.36 |
| 21 | 600 | 60 | 0.2 | 0.39 | 53 | 600 | 60 | 0.4 | 0.41 |
| 22 | 700 | 60 | 0.2 | 0.37 | 54 | 700 | 60 | 0.4 | 0.38 |
| 23 | 800 | 60 | 0.2 | 0.48 | 55 | 800 | 60 | 0.4 | 0.47 |
| 24 | 900 | 60 | 0.2 | 0.8 | 56 | 900 | 60 | 0.4 | 0.44 |
| 25 | 600 | 80 | 0.2 | 0.93 | 57 | 600 | 80 | 0.4 | 0.63 |
| 26 | 700 | 80 | 0.2 | 0.84 | 58 | 700 | 80 | 0.4 | 0.43 |
| 27 | 800 | 80 | 0.2 | 0.48 | 59 | 800 | 80 | 0.4 | 0.39 |
| 28 | 900 | 80 | 0.2 | 0.81 | 60 | 900 | 80 | 0.4 | 0.42 |
| 29 | 600 | 100 | 0.2 | 0.75 | 61 | 600 | 100 | 0.4 | 0.38 |
| 30 | 700 | 100 | 0.2 | 0.68 | 62 | 700 | 100 | 0.4 | 0.39 |
| 31 | 800 | 100 | 0.2 | 0.49 | 63 | 800 | 100 | 0.4 | 0.4 |
| 32 | 900 | 100 | 0.2 | 0.5 | 64 | 900 | 100 | 0.4 | 0.39 |

Fig. 1. View of cutting zone

Fig. 2. Surface roughness measurement

*D. Graphical Representation of Results and Data Analysis*

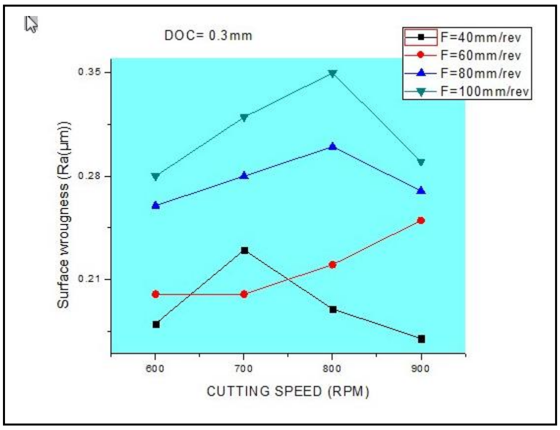


Fig. 3A. Cutting speed Vs Surface roughness

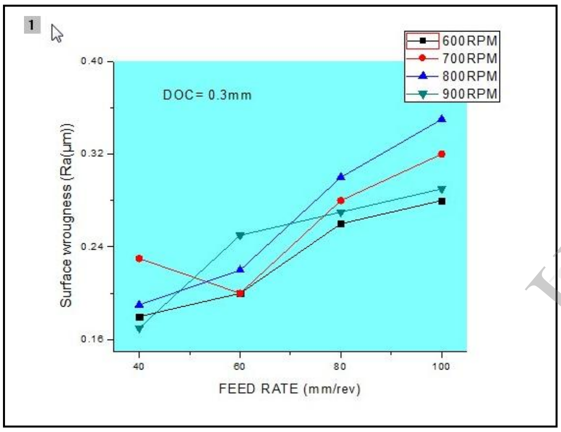


Fig.3B. Feed Rate Vs Surface Roughness

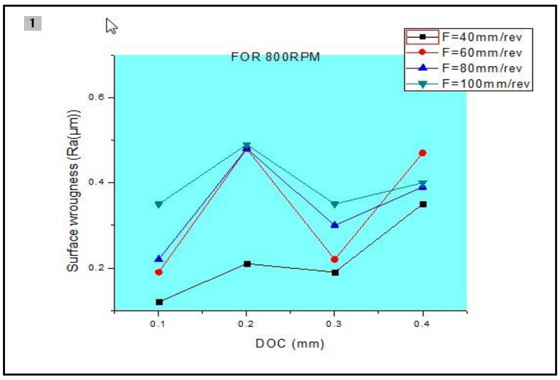


Fig. 3C. Depth of Cut vs Surface Roughness

*1) Interpretation*

Looking at Fig.3A, it can be deduced that the speed has less effect on surface roughness however, at a lower feed rate, it is observed that an increase in speed results to a better surface quality (lower surface finish).

From Fig.3B, it shows that feed rate has much effect on the surface finish, as they relates proportionally, even though high speed at high feed reduces the rate at which roughness increased.

Reading from Fig.3C, it was observed that depth of cut also affect surface quality negatively, because the combination of small depth of cut and feed rate, at a higher speed results to a better surface finish

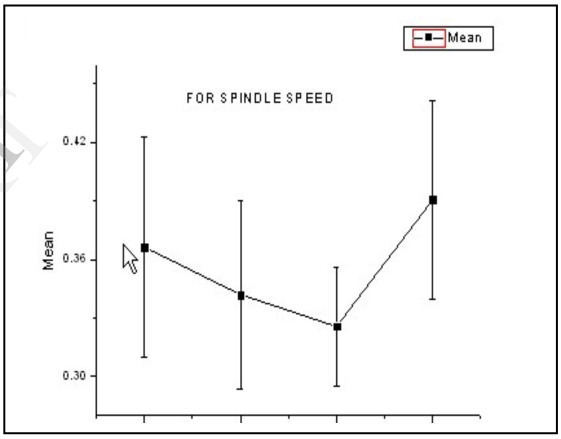


Fig. 4A. Main Effect Plot1

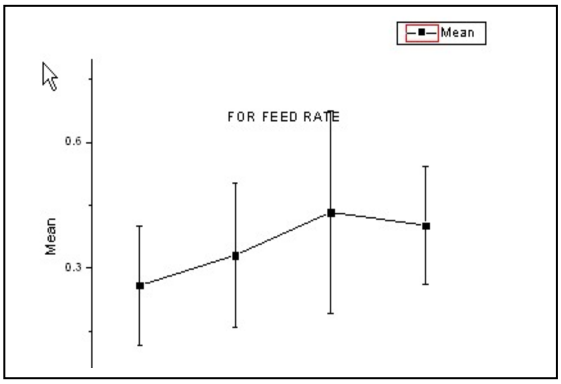


Fig. 4B. Main Effect Plot2

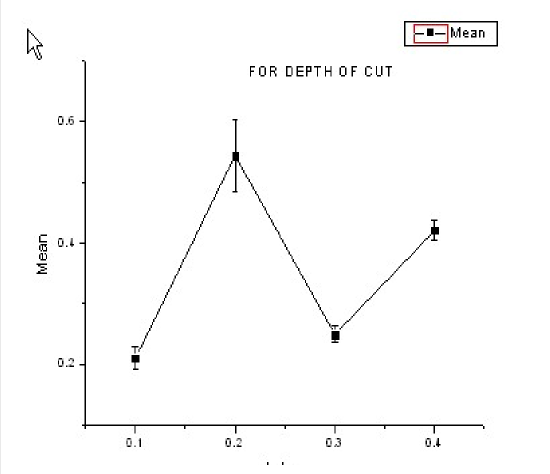


Fig. 4C. Main Effect Plot 3

*2) Interpretation*

From Fig. 4A, it can be observed that the best speed required for better surface finish is 800RPM. This is because it produces the smallest mean value of surface roughness.

Accordingly, Fig. 4B reveals that the smallest feed rate (40mm/rev) provides the smallest mean value of roughness.

Similarly, a small depth of cut of 0.1mm corresponds to the smallest mean value of surface roughness, as shown in Fig. 4C.



TABLE IV. ANALYSIS OF VARIANCE (ANOVA)

ANOVA

Overall ANOVA

| | DF | Sum of Squares | Mean Square | F Value | P Value |
|---|---|---|---|---|---|
| FactorA | 3 | 0.03882 | 0.01294 | 0.39117 | 0.7598 |
| FactorB | 3 | 0.29047 | 0.09682 | 2.9271 | 0.04135 |
| Model | 6 | 0.32928 | 0.05488 | 1.65914 | 0.14788 |
| Error | 57 | 1.88544 | 0.03308 | -- | -- |
| Corrected Total | 63 | 2.21472 | -- | -- | -- |

At the 0.05 level, the population means of Factor A are not significantly different.
At the 0.05 level, the population means of Factor B are significantly different.

Means Comparisons

Powers

CUTTING SPEED

| | Alpha | Sample Size | Power |
|---|---|---|---|
| Actual Power | 0.05 | 64 | 0.12268 |

FEED RATE

| | Alpha | Sample Size | Power |
|---|---|---|---|
| Actual Power | 0.05 | 64 | 0.66613 |

Overall ANOVA

| | DF | Sum of Squares | Mean Square | F Value | P Value |
|---|---|---|---|---|---|
| FactorA | 3 | 0.03882 | 0.01294 | 0.69229 | 0.56125 |
| FactorB | 3 | 1.15087 | 0.38362 | 20.52543 | 1.06492E-8 |
| Interaction | 9 | 0.12791 | 0.01421 | 0.76044 | 0.65263 |
| Model | 15 | 1.3176 | 0.08784 | 4.69981 | 1.98976E-5 |
| Error | 48 | 0.89713 | 0.01869 | -- | -- |
| Corrected Total | 63 | 2.21472 | -- | -- | -- |

At the 0.05 level, the population means of Factor A are not significantly different.
At the 0.05 level, the population means of Factor B are significantly different.
At the 0.05 level, the interaction between Factor A and Factor B is not significant.

Means Comparisons

Powers

CUTTING SPEED

| | Alpha | Sample Size | Power |
|---|---|---|---|
| Actual Power | 0.05 | 64 | 0.18557 |

DEPT OF CUT

| | Alpha | Sample Size | Power |
|---|---|---|---|
| Actual Power | 0.05 | 64 | 1 |

Overall ANOVA

| | DF | Sum of Squares | Mean Square | F Value | P Value |
|---|---|---|---|---|---|
| FactorA | 3 | 0.29047 | 0.09682 | 9.39026 | 5.42312E-5 |
| FactorB | 3 | 1.15087 | 0.38362 | 37.20538 | 1.41653E-12 |
| Interaction | 9 | 0.27846 | 0.03094 | 3.00074 | 0.00642 |
| Model | 15 | 1.7198 | 0.11465 | 11.11957 | 6.358E-11 |
| Error | 48 | 0.49493 | 0.01031 | -- | -- |
| Corrected Total | 63 | 2.21472 | -- | -- | -- |

At the 0.05 level, the population means of Factor A are significantly different.
At the 0.05 level, the population means of Factor B are significantly different.
At the 0.05 level, the interaction between Factor A and Factor B is significant.

Means Comparisons

Powers

FEED RATE

| | Alpha | Sample Size | Power |
|---|---|---|---|
| Actual Power | 0.05 | 64 | 0.99478 |

DEPT OF CUT

| | Alpha | Sample Size | Power |
|---|---|---|---|
| Actual Power | 0.05 | 64 | 1 |

*3) Interpretation*

Looking at the three tables, the interpretation of ANOVA shows that at 95% confidence ($\alpha$=0.05), for rough cutting, all the three factors are influential. However, Depth of cut possesses the most significant effect on the roughness, followed by the feed. Consequently, an increment in speed and decrease in feed and depth of cut results in a better surface quality.

## III. CONCLUSION

In the light of the above, the following conclusion were drawn:

Full factorial design is a good tool for the study of performance indices of cutting parameters, as it provides for all possible combination with no repetition. It also helps in determining the best combination of parameters (optimization of cutting parameters).

It can also be concluded that for the range of values selected in this test, the optimum cutting parameters are 700

RPM spindle speed, 40 mm/rev feed and 0.1mm depth of cut, respectively.

Finally, we can also say that the feed rate in machining is directly proportional to the surface finish (inversely proportional to surface quality) and has significant effect in machinability of an engineering product.

## ACKNOWLEDGMENT

The principal author will like to express his gratitude to Fari Muhammad Abubakar and Sun Baofeng, who have been supportive during the conduct of this experiment. He also wish to thank all the technical staff in the CNC workshop, Tianjin University of Technology and Education, for their assistance.

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