# Effect of Turning Parameters on Power Consumption in EN 24 Alloy Steel using Different Cutting Tools

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**Abstract**— In this paper the effect of machining parameters (cutting speed, feed rate, depth of cut) on power consumption of the tool during turning of EN-24 alloy steel was studied. Tools considered in this experimental work are HSS and tungsten carbide tool. Comparison of power consumed by the tools was done. Mathematical models for power consumption of the tools was created by using SPSS software from the experimentally measured power readings. The $R^2$ value obtained from the regression is around 95 percentage for carbide tool and 93 percentage for HSS tool which indicates that the model developed is good fit. The power consumed by both tools are measured by measuring the forces acting on the cutting tool using a lathe tool dynamometer with a digital display for measuring the forces acting on three axis. From the model it was found that cutting speed is the most important factor that influences power consumed by the tool and feed rate has less influence.

**Keywords**— Force measurement, Tool power prediction model, Comparison of tools.

## INTRODUCTION

Power consumed by a single point cutting tool is an important factor to be considered in turning operation. The study of power consumed by the tool helps to find out the life of the tool for maximum productivity, helps to select the capacity of the motor required for the machine and it also helps for designing machine components. Power consumed by the tool can be measured by using two methods. First method of measuring power consumed by the tool is by using a watt meter connected to the motor of the lathe tool. In this method during machining operation the watt meter shows power consumed by the tool at different cutting condition. This method has some drawbacks that certain amount of work done by the motor is wasted in the form of mechanical losses in the transmission system so using this method for power consumption we can't create a universal model for power consumption of the tool. Second method is by measuring the cutting forces acting on the tool during turning operation. For measuring the forces a lathe tool dynamometer is used. A lathe tool dynamometer is a device that can measure forces acting on cutting tool in 3 axis ($F_{X,}$ $F_Y$, and $F_Z$) axis. Among these forces the component of force which has highest value is used to calculate the power consumption of the tool. Power consumed by the tool is a function of cutting force and cutting velocity. The power consumed is given by P = F * V. where P is power in kilowatts, F is force in newton and V is cutting speed in meter per minute. Experiments are conducted using Box-Behnken design. Experimentally obtained data's are used to create mathematical models for power consumption for both tools.

## EXPERIMENTATION

In this experimental work the power consumed by the tool was measured during turning of EN 24 steel alloy by HSS tool and with tungsten carbide inserts by measuring the force acting on the tool using a lathe tool dynamometer. Turning was performed on a precision lathe (NAGMATI-175) in Mechanical Engineering Department.

### *A PROCESS VARIABLES AND THEIR LEVELS*

Turning operation was conducted on a sample EN 24 work piece of 60 mm diameter and 40 mm length using precision lathe in order to find out the maximum allowable range of cutting parameters (cutting speed, feed rate, and depth of cut) that can be used. Cutting parameters are classified in to three levels.

Table: 1 Cutting parameters and their levels

| NO | PARAMETERS | SYMBOLS | LEVEL -1 | LEVEL 0 | LEVEL 1 |
|---|---|---|---|---|---|
| 1 | Cutting speed (rpm) | v | 54 | 135 | 215 |
| 2 | Feed rate(mm\rev) | f | 1 | 1.5 | 2 |
| 3 | Depth of cut (mm) | d | 0.5 | 0.75 | 1 |

### *B DESIGN OF EXPERIMENT*

Experiments have been carried out using Box-Behnken design which was found by devised by George E. P. Box and Donald Behnken. The Box-Behnken design does not contain an embedded factorial design it is an independent quadratic design. In this design the treatment combinations are at the corners of the process space, face centre and at the body centre. These designs require 3 levels of each factor and are rotatable (or near rotatable). Compared to the central composite designs these designs have limited capability for orthogonal blocking [3].

Table: 2 Factorial combinations

| SL. NO | Factorial combination | | |
|---|---|---|---|
| | (V) | (F) | (D) |
| 1 | 0 | 0 | -1 |
| 2 | 0 | 0 | 1 |
| 3 | 0 | -1 | 0 |
| 4 | 0 | 1 | 0 |
| 5 | 1 | 0 | 0 |
| 6 | -1 | 0 | 0 |
| 7 | 1 | 1 | -1 |
| 8 | -1 | 1 | -1 |
| 9 | 1 | -1 | -1 |
| 10 | -1 | -1 | -1 |
| 11 | 1 | 1 | 1 |
| 12 | 1 | -1 | 1 |
| 13 | -1 | -1 | 1 |
| 14 | -1 | 1 | 1 |
| 15 | 0 | 0 | 0 |

### *C TOOL FORCE AND POWER CONSUMPTION MEASUREMENTS*

The forces acting on the tool is measured during turning of EN 24 steel alloy with HSS tool and tungsten carbide inserts using a lathe tool dynamometer with digital display unit. Among all forces main the main force is identified and is used to calculate the power required to perform the machining operation. Power is the function of main cutting force and the cutting velocity. The equation for the power is: P = F * V. Where P is the power in watt, V is the cutting speed in m/min and F is the main cutting force in N.

### *D CARBIDE TOOL FORCE AND POWER CONSUMPTION READINGS*

Table 3 Carbide tool force and power consumption readings

| Exp NO | Cutting speed(rpm) | Feed rate(mm/rev) | Depth of cut(mm) | Velocity (m/min) | MRR | Force Z (N) | Power (KW) | Model power(kw) | % Error |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 54 | 2 | 1 | 10.1736 | 339.12 | 421.4 | 4.28715504 | 4.352 | 1.490004 |
| 2 | 54 | 2 | 0.5 | 10.1736 | 169.56 | 333.2 | 3.38984352 | 3.18 | -6.59885 |
| 3 | 215 | 2 | 0.5 | 40.506 | 675.1 | 539 | 21.832734 | 22.661 | 3.655028 |
| 4 | 215 | 2 | 1 | 40.506 | 1350.2 | 735 | 29.77191 | 23.833 | -24.9189 |
| 5 | 54 | 1 | 1 | 10.1736 | 169.56 | 343 | 3.4895448 | 3.138 | -11.2028 |
| 6 | 54 | 1 | 0.5 | 10.1736 | 84.78 | 264.6 | 2.69193456 | 2.1936 | -22.7177 |
| 7 | 215 | 1 | 0.5 | 40.506 | 337.55 | 411.6 | 16.6722696 | 20.698 | 19.44985 |
| 8 | 215 | 1 | 1 | 40.506 | 675.1 | 558.6 | 22.6266516 | 21.87 | -3.45977 |
| 9 | 54 | 1.5 | 0.75 | 10.1736 | 190.755 | 372.4 | 3.78864864 | 2.7845 | -36.0621 |
| 10 | 135 | 2 | 0.75 | 25.434 | 635.85 | 480.2 | 12.2134068 | 13.567 | 9.9771 |
| 11 | 135 | 1.5 | 0.5 | 25.434 | 317.925 | 392 | 9.970128 | 11.9995 | 16.91214 |
| 12 | 215 | 1.5 | 0.75 | 40.506 | 759.4875 | 588 | 23.817528 | 22.2655 | -6.97055 |
| 13 | 135 | 1 | 0.75 | 25.434 | 317.925 | 401.8 | 10.2193812 | 11.604 | 11.93225 |
| 14 | 135 | 1.5 | 1 | 25.434 | 635.85 | 499.8 | 12.7119132 | 13.1715 | 3.489252 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 135 | 1.5 | 0.75 | 25.434 | 476.8875 | 460.6 | 11.7149004 | 12.5855 | 6.917481 |

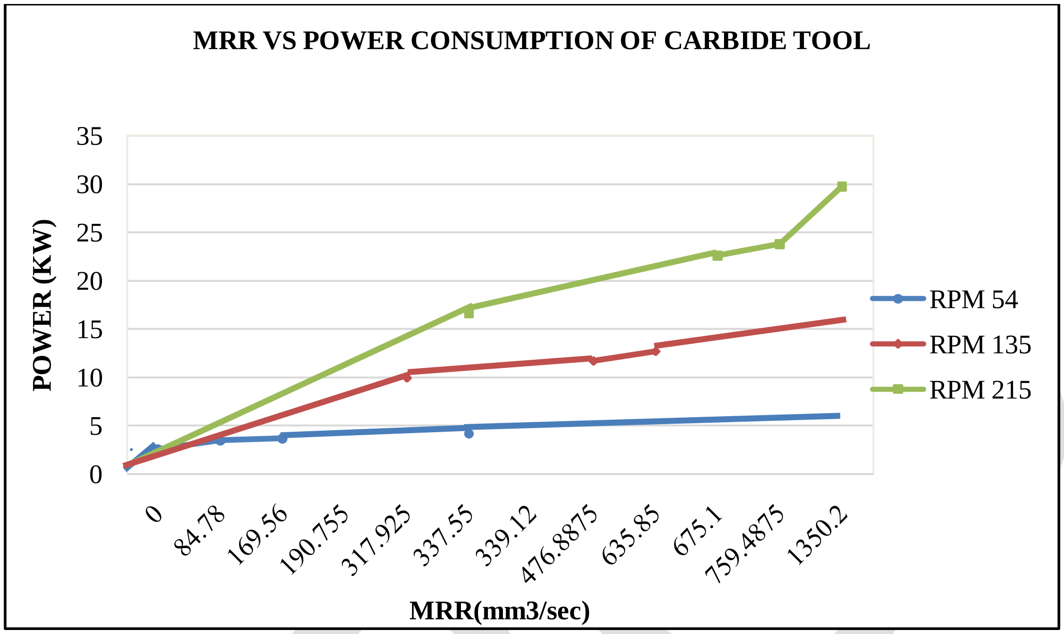


Figure No: 1 MRR vs. power consumption of carbide tool

The experimentally measured power consumption readings is used to plot the graph between material removal rate and power consumed by the tool. From the graph it was found that as the MRR increases power consumption values also increases. Thus it is noticed that the power consumed is a function of MRR and thus the value of MRR can be used to predict the value of power consumed.

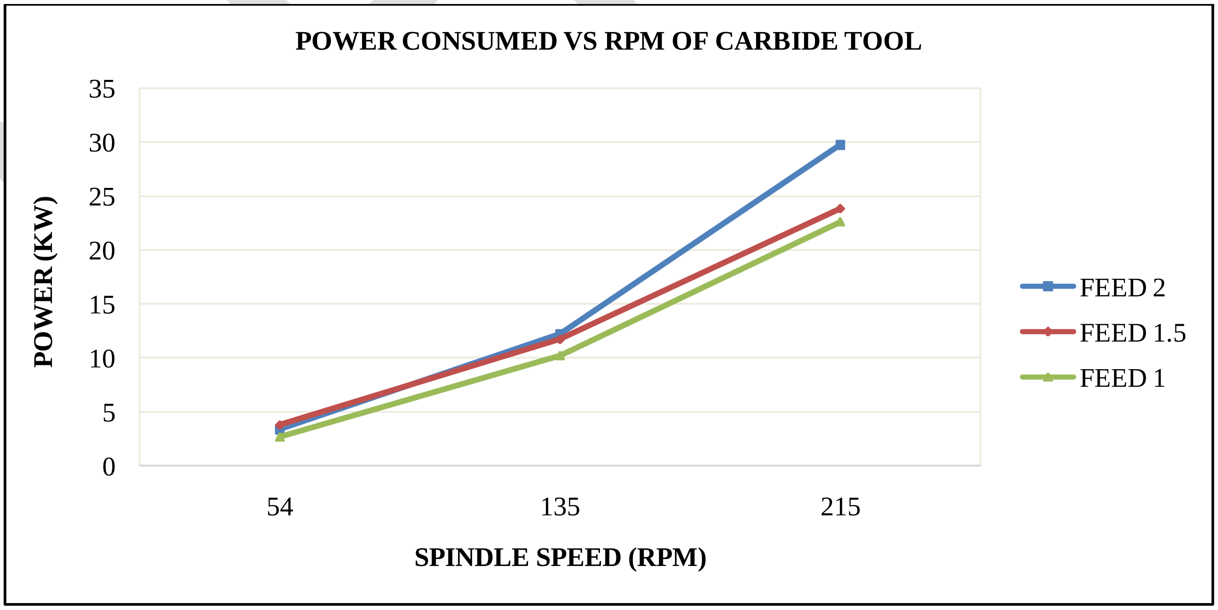


Figure No: 2 RPM vs. power consumption of carbide tool

The experimentally measured power consumed readings is used to plot power consumption vs rpm graph at three separate feed levels. Comparing the slop of lines of various feed parameters it was found that power consumed by the tool increases with increase in rpm. It was also found that at constant rpm highest power consumption was observed for highest value of feed rate.

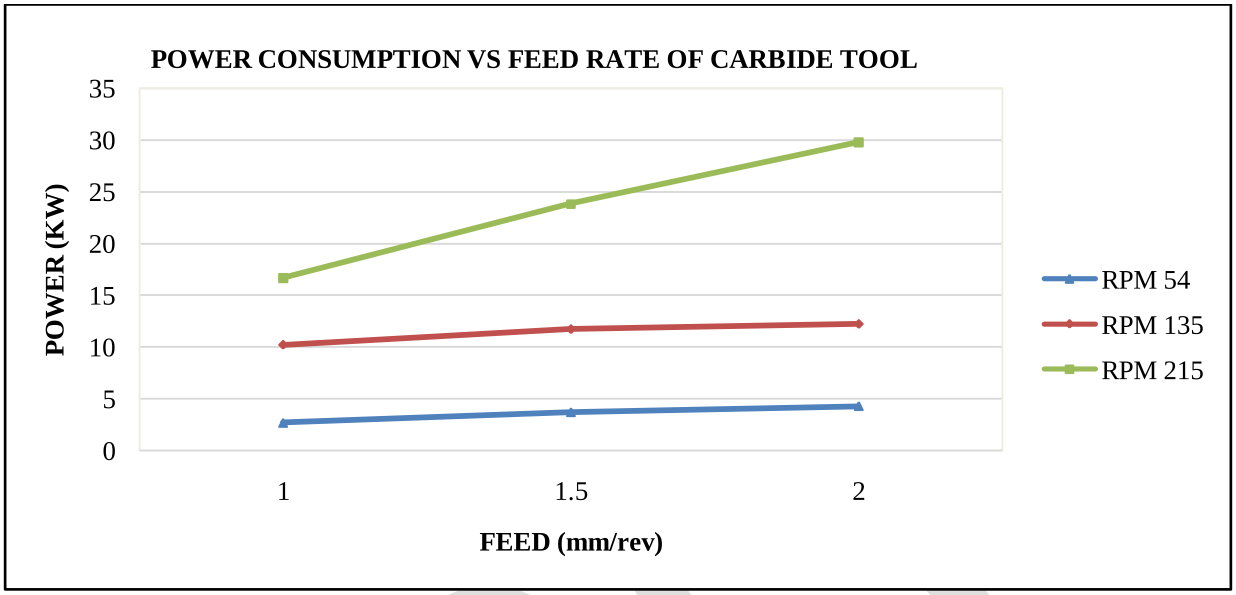


Figure No: 3 Feed vs. power consumption of carbide tool

The experimentally measured power consumed readings is used to plot power consumed vs feed graph at three separate rpm levels. Comparing the slop of lines of various rpm parameters it was found that power consumed by tool increases with the increase in feed rate. It was also found that at constant feed rate highest power consumption was observed for highest value of rpm.

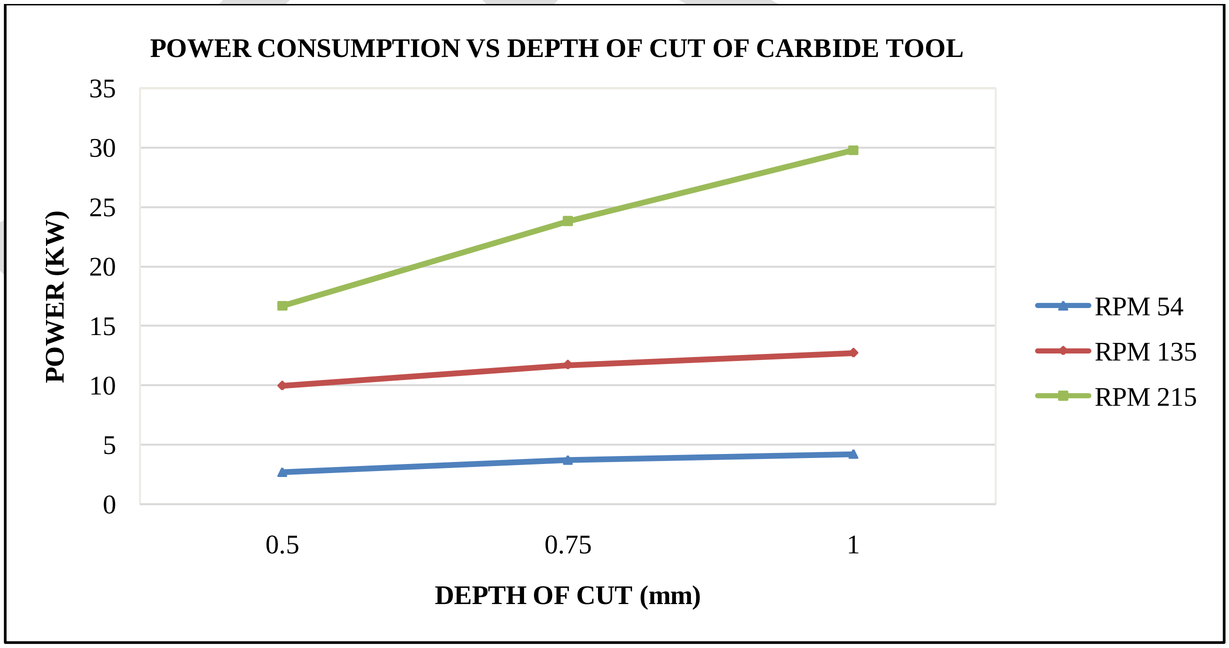


Figure No: 4 Depth of cut vs. power consumption of carbide tool

The experimentally measured power consumed readings is used to plot power consumed vs depth of cut graph at three separate rpm levels. Comparing the slop of lines of various rpm parameters it was found that power consumed by tool increases with the increase in depth of cut. It was also found that at constant depth of cut rate highest power consumption was observed for highest value of rpm.

Multiple regression analysis was conducted on experimentally measured power values using SPSS software. Mathematical models are developed in terms of machining parameters. The values of cutting parameters are substituted in the mathematical model and corresponding power values are noted. Percentage error was calculated using experimental values and model values in order to find out the variation.

Table: 4 Regression analysis of Carbide tool power consumption

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .976 | .953 | .940 | 2.11518922 |

**ANOVA**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1000.120 | 3 | 333.373 | 74.513 | .000 |
| | Residual | 49.214 | 11 | 4.474 | | |
| | Total | 1049.335 | 14 | | | |

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -13.857 | 3.099 | | -4.472 | .001 |
| | Cutting speed(rpm) | .121 | .008 | .947 | 14.507 | .000 |
| | Feed rate(mm/rev) | 3.159 | 1.338 | .154 | 2.361 | .038 |
| | Depth of cut(mm) | 7.332 | 2.676 | .179 | 2.740 | .019 |

Multiple regression coefficient of the first order power prediction model is approximately 0.95 ($R^2$ = 95%) indicates a good model fit. ANOVA was performed to find the statistical significance of process. ANOVA table also gives values of sum of squares, mean squares, degree of freedom and F values. Examination of t values in this table indicates that the variables, cutting speed, feed rate, depth of cut are significant at 95% confidence level. From the result it was found that power consumed by carbide tool increases with increase in RPM, feed rate and depth of cut. However the most important factor that effects power consumed is cutting speed then second important factor is depth of cut followed by feed rate. The experimental results were used to develop the mathematical models.

Mathematical model of power consumed by carbide tool,

$P_{CARBIDE} = -13.857 - A*0.121 + B*3.159 + C*7.332$

Where A= RPM, B= Feed rate (mm\rev), C= Depth of cut (mm)

### *E HSS TOOL FORCE AND POWER CONSUMPTION READINGS*

Table No: 5 HSS tool force and power consumption readings

| Exp NO | Cutting speed(rpm) | Feed rate(mm/rev) | Depth of cut(mm) | Force Z (N) | Velocity (m/min) | Power (KW) | Model power(KW) | MRR | % Error |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 54 | 2 | 1 | 352.8 | 10.1736 | 3.589246 | 4.507 | 339.12 | 20.36286 |
| 2 | 54 | 2 | 0.5 | 284.2 | 10.1736 | 2.891337 | 2.615 | 169.56 | -10.5674 |
| 3 | 215 | 2 | 0.5 | 588 | 40.506 | 23.81753 | 20.647 | 675.1 | -15.3559 |
| 4 | 215 | 2 | 1 | 803.6 | 40.506 | 32.55062 | 29.34 | 1350.2 | -10.9428 |
| 5 | 54 | 1 | 1 | 303.8 | 10.1736 | 3.09074 | 2.856 | 169.56 | -8.21918 |
| 6 | 54 | 1 | 0.5 | 176.4 | 10.1736 | 1.794623 | 1.9648 | 84.78 | 8.661287 |
| 7 | 215 | 1 | 0.5 | 352.8 | 40.506 | 14.29052 | 18.996 | 337.55 | 24.77092 |
| 8 | 215 | 1 | 1 | 637 | 40.506 | 25.80232 | 20.888 | 675.1 | -23.527 |
| 9 | 54 | 1.5 | 0.75 | 323.4 | 10.1736 | 3.290142 | 2.7355 | 190.755 | -20.2757 |
| 10 | 135 | 2 | 0.75 | 509.6 | 25.434 | 12.96117 | 12.633 | 635.85 | -2.59769 |
| 11 | 135 | 1.5 | 0.5 | 431.2 | 25.434 | 10.96714 | 10.8615 | 317.925 | -0.97262 |
| 12 | 215 | 1.5 | 0.75 | 588 | 40.506 | 23.81753 | 20.7675 | 759.4875 | -14.6865 |
| 13 | 135 | 1 | 0.75 | 460.6 | 25.434 | 11.7149 | 10.982 | 317.925 | -6.67365 |
| 14 | 135 | 1.5 | 1 | 529.2 | 25.434 | 13.45967 | 12.7535 | 635.85 | -5.53709 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 135 | 1.5 | 0.75 | 441 | 25.434 | 11.21639 | 11.8075 | 476.8875 | 5.006191 |

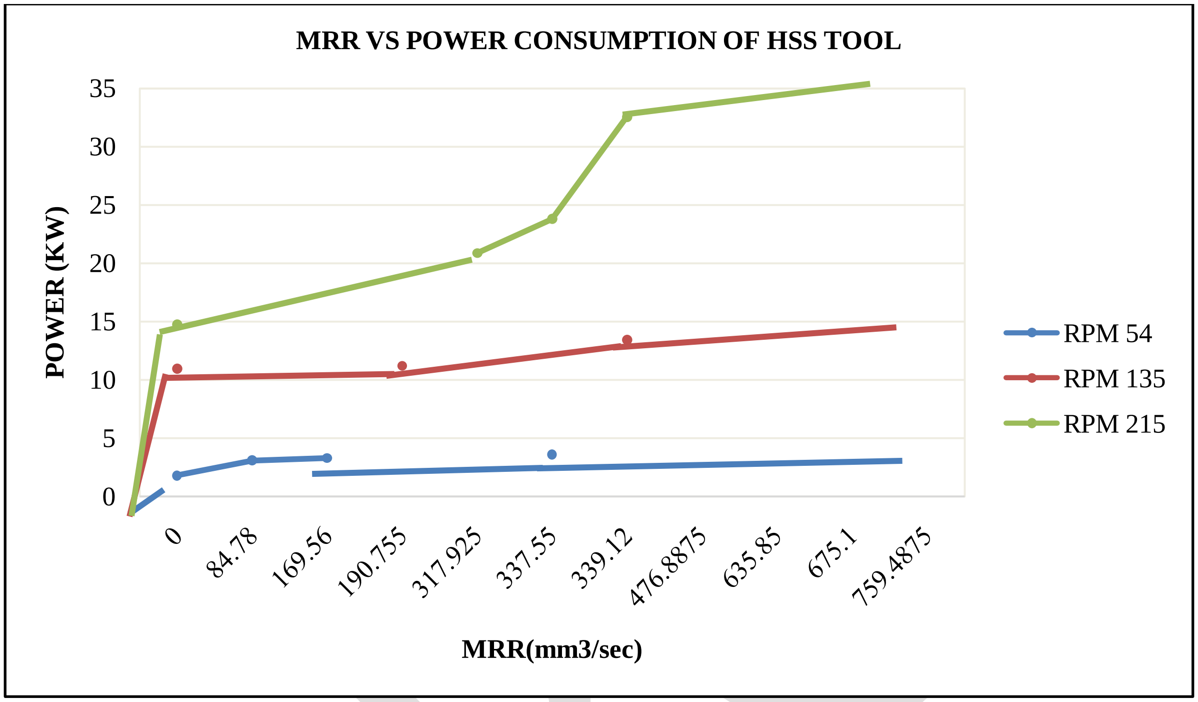


Figure No: 5 MRR vs. power consumption of HSS tool

The experimentally measured power consumption readings is used to plot the graph between material removal rate and power consumed by the tool. From the graph it was found that as the MRR increases power consumption values also increases. Thus it is noticed that the power consumed is a function of MRR and thus the value of MRR can be used to predict the value of power consumed.

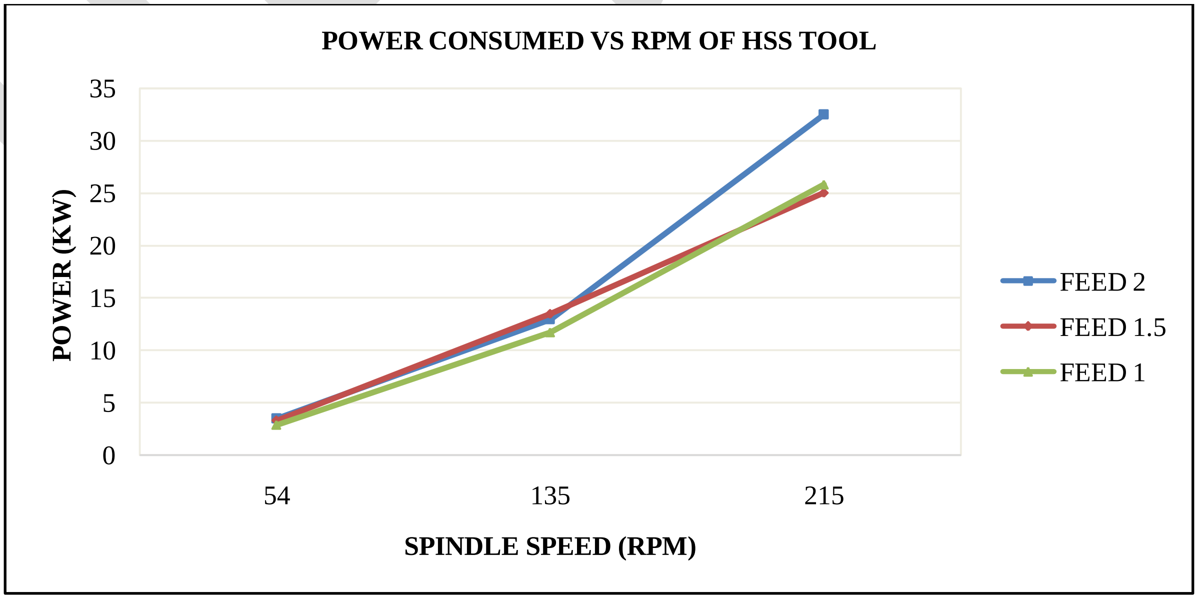


Figure No: 6 RPM vs. power consumption of HSS tool

The experimentally measured power consumed readings is used to plot power consumption vs rpm graph at three separate feed levels. Comparing the slop of lines of various feed parameters it was found that power consumed by the tool increases with increase in rpm. It was also found that at constant rpm highest power consumption was observed for highest value of feed rate.

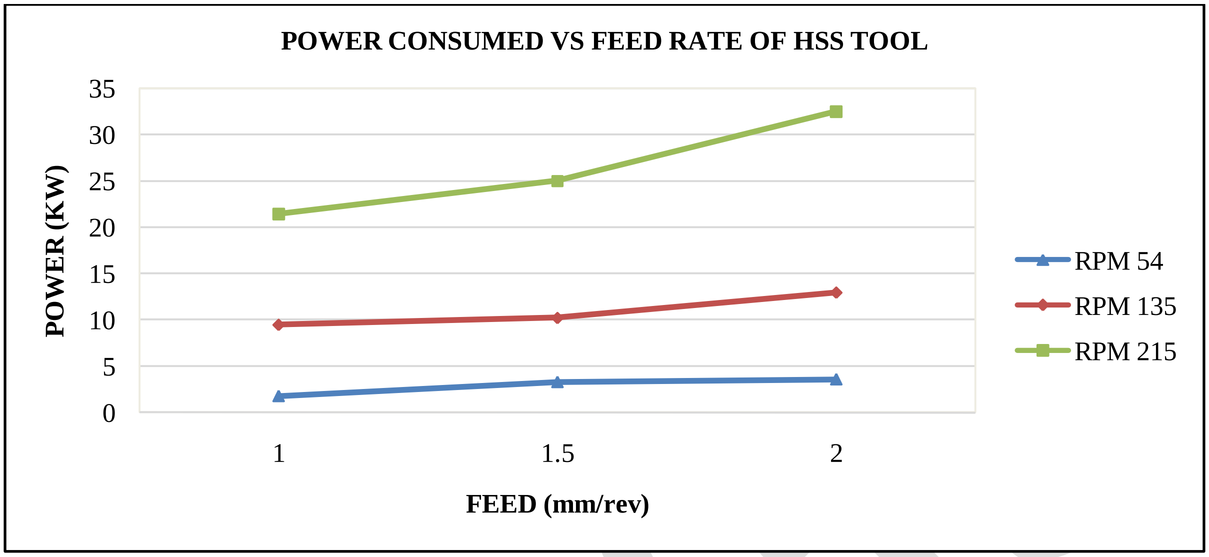


Figure No: 7 Feed vs. power consumption of HSS tool

The experimentally measured power consumed readings is used to plot power consumed vs feed graph at three separate rpm levels. Comparing the slop of lines of various rpm parameters it was found that power consumed by tool increases with the increase in feed rate. It was also found that at constant feed rate highest power consumption was observed for highest value of rpm.

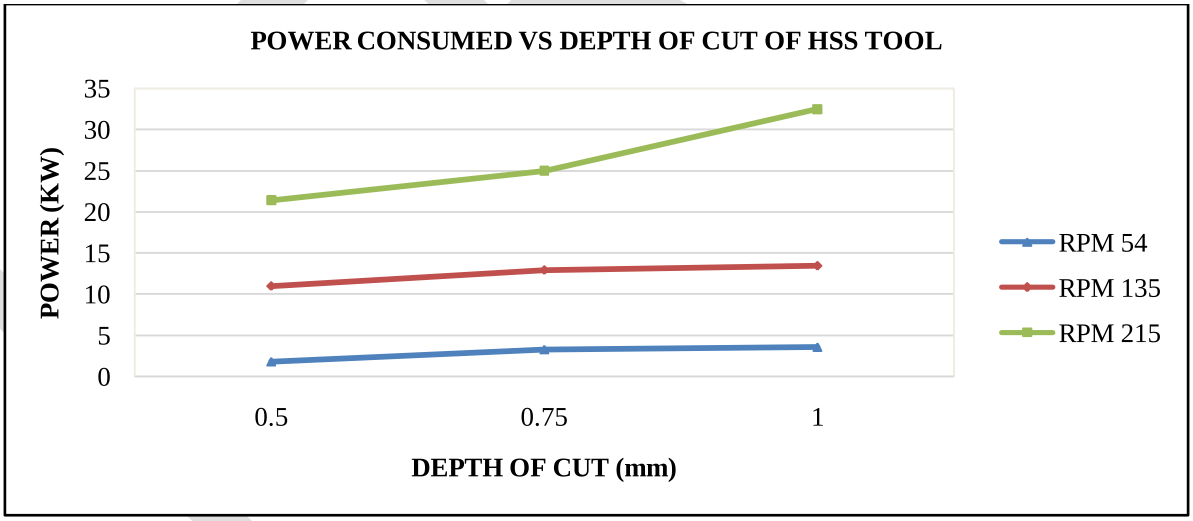


Figure No: 8 Depth of cut vs. power consumption of HSS tool

The experimentally measured power consumed readings is used to plot power consumed vs depth of cut graph at three separate rpm levels. Comparing the slop of lines of various rpm parameters it was found that power consumed by tool increases with the increase in depth of cut. It was also found that at constant depth of cut rate highest power consumption was observed for highest value of rpm.

Multiple regression analysis was conducted on experimentally measured power values using SPSS software. Mathematical models are developed in terms of machining parameters. The values of cutting parameters are substituted in the mathematical model and corresponding power values are noted. Percentage error was calculated using experimental values and model values in order to find out the variation.

Table No: 6 Regression analysis of HSS tool power consumption

| **Model Summary** | | | | |
|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | .966 | .933 | .915 | 2.8140226 |

| **ANOVA** | | | | | | |
|---|---|---|---|---|---|---|
| Model | | Sum of Squares | df | Mean Square | F | Sig. |
| 1 | Regression | 1212.680 | 3 | 404.227 | 51.047 | .000 |
| | Residual | 87.106 | 11 | 7.919 | | |
| | Total | 1299.786 | 14 | | | |

| **Coefficients** | | | | | | |
|---|---|---|---|---|---|---|
| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -17.802 | 4.123 | | -4.318 | .001 |
| | Cutting speed(rpm) | .131 | .011 | .926 | 11.866 | .000 |
| | Feed rate(mm/rev) | 3.823 | 1.780 | .168 | 2.148 | .055 |
| | Depth of cut(mm) | 9.893 | 3.559 | .217 | 2.779 | .018 |

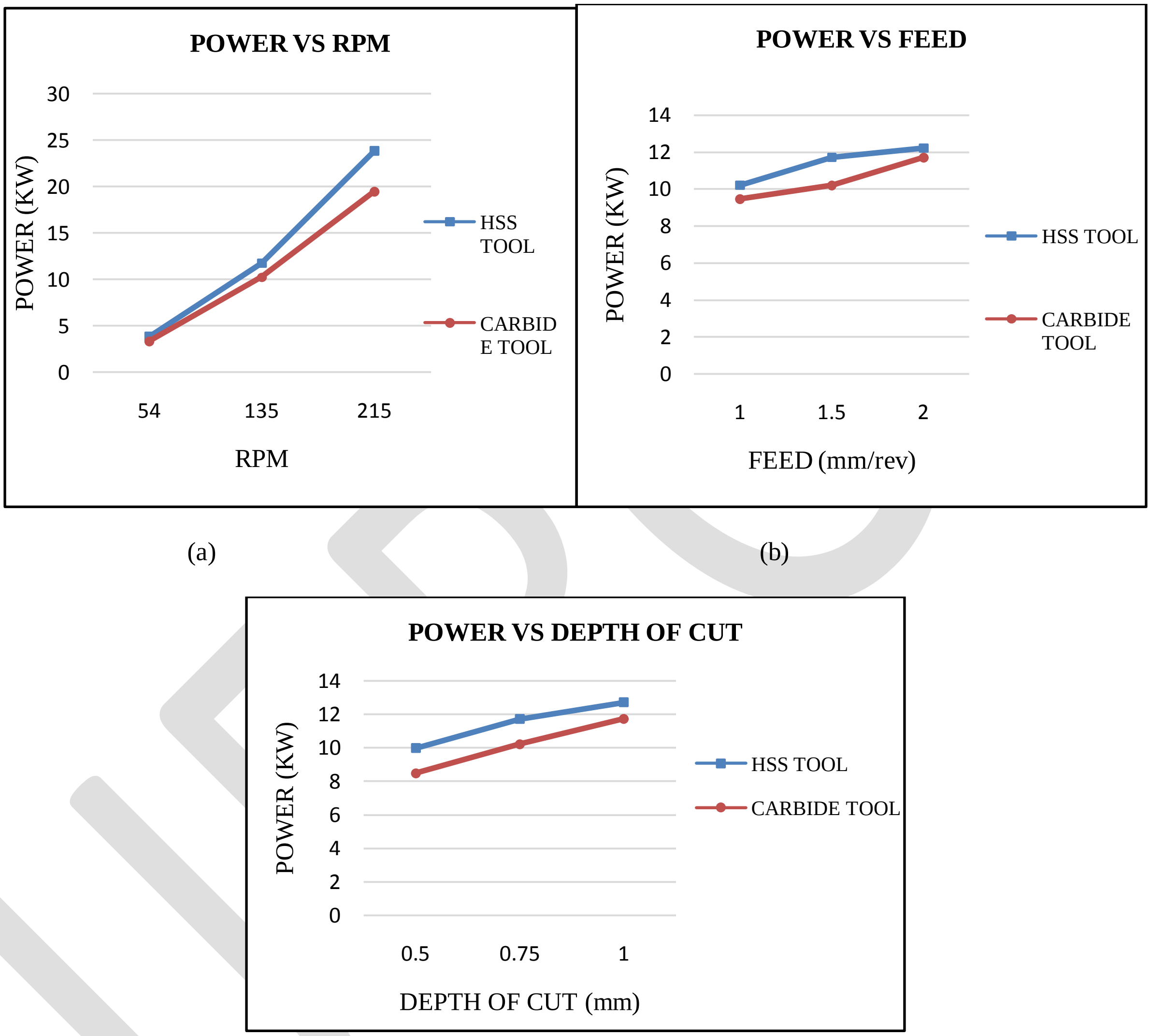
Multiple regression coefficient of the first order power prediction model is approximately 0.93 ($R^2 = 93\%$) indicates a good model fit. ANOVA was performed to find the statistical significance of process. ANOVA table also gives values of sum of squares, mean squares, degree of freedom and F values. Examination of t values in this table indicates that the variables, cutting speed, feed rate, depth of cut are significant at 95% confidence level. From the result it was found that power consumed by HSS tool increases with increase in RPM, feed rate and depth of cut. However the most important factor that effects power consumed is cutting speed then second important factor is depth of cut followed by feed rate. The experimental results were used to develop the mathematical models.

Mathematical model of power consumed by HSS tool,

$$P_{HSS} = -17.802 - A*0.131 + B*3.823 + C*9.893$$

Where A= RPM, B= Feed rate (mm\rev), C= Depth of cut (mm)

### *E COMPARISON OF POWER CONSUMED BY TOOLS*



(a) (b)

(c)

Figure No: 9 Average power consumed with varying (a) cutting speed, (b) feed and (c) depth of cut

From the graph it can be seen that the average power consumed is lower for carbide tool in comparison to HSS tool during turning of EN- 24 alloy steel. It can be seen that the average power consumed get affected mostly by cutting speed followed by depth of cut.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the support provided by SCMS College who helped us for completing this work into a success.

## CONCLUSION

In this experimental work the power consumed by the HSS tool and tungsten carbide tool during turning of EN- 24 alloy steel was studied. Based on the experimental data mathematical models are developed by multiple regression model using SPSS software.

The model developed for power prediction produces smaller errors and it shows good results, since multiple regression coefficient of the first order power prediction model of carbide tool is approximately 0.95 ($R^2$= 95%) and first order power prediction model of HSS tool is approximately 0.93 ($R^2$ = 93%) .Therefore the proposed model can be utilized to predict the corresponding power consumed by HSS and Carbide tool during machining EN-24 steel rod at different parameters in turning. The established equation clearly revealed that the rpm is the main influencing factor power consumption of tool and feed rate has the lowest influencing parameter. From the comparison of the tools it was found that during turning of EN- 24 steel rod with both tools the HSS tool consumes more power than the carbide tool.

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