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Theoretical determination of voltage arise in machining of gray cast irons

A. Yardimeden [a,*], A. İnan [b], M. Aksoy [c]
[a] Department of Mechanical Engineering, Dicle University, 21280 Diyarbakir, Turkey
[b] Faculty of Engineering, Department of Mechanical Engineering, University of Fírat, Elazig 23119, Turkey
[c] Faculty of Engineering, Department of Metallurgical Engineering, University of Fírat, Elazig 23119, Turkey
* Corresponding author: E-mail address: ayardim@dicle.edu.tr

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Analysis and modelling

ABSTRACT

Purpose: Machining conditions should be well determined in order to increase production speed and minimize machining cost. However, it is difficult to produce all information for optimum machining conditions. Therefore it is generally accepted provide the most influential factors for determination of optimum machining conditions. The optimum machining conditions would provide longer tool life and better surface finish quality.

Design/methodology/approach: Taylor mentioned a relative between cutting speed and tool life and developed model from consecutive experimental studies completed under invariable machining conditions. Recently the factorial regression analysis has been extensively applied for providing optimum machining conditions for expected tool life and surface roughness. In the present study, voltage differences between workpiece and cutting tool were also taken consideration for theoretical determination of machining conditions. The results of experimental study carried out for machining of gray cast irons (at different chemical compositions) were modeled by using regression analysis method.

Findings: The influence of cutting speed, feed rate, diameter and depth of cut on the voltage difference were investigated. Consequently theoretical values obtained from the equation were similar to the experimental values.

Practical implications: The results of experimental study carried out for machining of gray cast irons (at different chemical compositions) were modeled by using regression analysis method.

Originality/value: In the present study, a mathematical model was improved using regression analysis method of potential differences between workpiece and cutting tool and, machining on the lathe which is made different chemical compositions of gray cast iron.

Keywords: Numerical techniques; Voltage difference; Cast iron; Machining

1. Introduction

Gray cast iron is one of most widely used engineering materials in cast alloys in the world. Low tensile strength, especially low ductility caused by the thick graphite flakes with random orientation has limited its application for many years. Many methods to control the morphology, size and distribution of graphite phase were used to improve the mechanical properties of GCI, such as modification, spheroiding and alloying, etc. [1–7].

Cutting conditions should be well determined in order to increase the speed of production and minimize costs in machining. However it is difficult to determine all the cutting conditions together. From this point of view, the cutting conditions (depth of cut, feed rate, cutting speed, cutting tool material etc.) are affecting on tool life and surface roughness should be well determined and, the usable equations of surface roughness and tool life have also will be known. Taylor obtained a relationship between the cutting speed and tool life, and developed a model from consecutive experimental studies which done under invariable cutting conditions [8]. In the most used model of $V*T^n=C$ a relationship was established between cutting speed and tool life keeping pair of cutting tool and workpiece. The model of Taylor is not useful model in all machining processes in case of various influential machining parameters occurred in cutting conditions. Therefore lots of experiments should be run under variable cutting conditions to obtain an optimum tool life equation. Since this process will take too much time and will require many workpieces, it is hard to proceed it. The model, developed by Gilbert and complement of Taylor's model, depth of cut and feed rate have been taken into the consideration as main parameters. Tool life was defined as $T= C*V*S*t$ in this model.

The most utilised method of obtaining an equation for tool life and surface roughness is the factorial regression analysis. This method has been used successfully by many researchers [9-12]. Wo used factorial regression analysis for the first time to obtain tool life equations for machining [13]. Ozel, regression analysis method based on GA for the determination of cutting parameters in machining operations was proposed [14]. In hot machining the method was also used by Mutherrjee and Lo [15,16].

In the present study, a mathematical model was improved using regression analysis method of potential differences between workpiece and cutting tool and, machining on the lathe which is made different chemical compositions of gray cast iron.

2. Regression analysis

Regression analysis consists of three types; simple linear, multiple linear and nonlinear regression. The following equation can be written generally using least square method for each regression types.

$$Y=a_0.z_0+a_1.z_1+a_2.z_2+.................a_m.z_m \quad (1)$$

Here, z0, z1,……zm are different functions of m+1. It' s clear that Z0=1, Z1=X1,….,Zm=Zm in simple and multiple linear regression. Z0=X0,……Zm=Xm in nonlinear regression. The equation (1) can be written in matrix form as ;

$$\{Y\}=[z].\{a\}+\{E\} \quad (2)$$

Z, is the matrix form of independent variables and can be written as ;

$$[z]=\begin{bmatrix} z_{01} & z_{11} & ....z_{m1} \\ z_{02} & z_{12} & ....z_{m2} \\ z_{03} & z_{13} & ....z_{m3} \\ . & . & . \\ . & . & . \\ . & . & . \\ z_{0n} & z_{1n} & ....z_{mn} \end{bmatrix} \quad (3)$$

m is the number of variables and n is the number of data. Y is a column vector and defines visible value of dependent variables, and written as;

$$\{Y\}^T=[Y_1,Y_2,Y_3,........,Y_n] \quad (4)$$

In the equation (4), a refers to unknown coefficients and e is column vector of errors, and written as;

$$\{a\}^T=[a_0,a_1,a_2,..........,a_m] \quad (5)$$

$$\{e\}^T=[e_0,e_1,e_2,..........,e_n]$$

As stated before; sum of the square root of errors for this model can be described as;

$$S_e=\sum_{i=1}^{n}(Y_i-\sum_{j=1}^{m+1}a_j.z_{ji})^2 \quad (6)$$

It's possible to obtain the ideal equations minimizing square root of errors with respect to each coefficient that is, taking partial derivatives of them and equating to zero. This equations can be written in matrix notations as follow:

$$[[z]^T[z]].\{a\}=[z]^T.\{Y\} \quad (7)$$

It's possible to solve the equation by inverting the matrix, and vector (a) can be written as;

$$\{a\}=[[z]^T[z]]^{-1}[z]^T.\{Y\} \quad (8)$$

3. Mathematical model

To allow generalizing of the results obtained from various studies, a mathematical method is developed applying polynomial regression analysis method taking into the consideration the results of highest value of the first sample. Experimental data cannot be represented by linear or logarithmic curves all the time. In this case, the relationship between independent variable x and independent variable y, can be adopted only to the third degree polynomials. There exists the peak and depression value of those curves which are less then number of highest power of independent variable.

To determine the functional relationship between the dependent and the independent variables a second order polynomial multi-regression model could be utilized. According to this model; the equation could be expressed as shown below.

$$Y=a_0+\sum_{i=1}^{n}a_i.x_i+\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}a_{ij}.x_i.x_j+\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ij}.x_i.x_j \quad (9)$$

n is the number of independent variable. Unknown coefficients are obtained minimizing sum of square of errors as in multiple regression.

a_0,a_i and a_{ij} are constants and known as independent variable coefficients. Those coefficients are obtained using equation of (8) which is assigned for multiple linear regression. In order to solve polynomial regression, the independent variables has been defined as following. This solution is made by means of computer.

Here are the dependent and independent variables used in the equation;

Y=V (Voltage difference, mV)
x1=t (depth of cut, mm)
x2=d (diameter, mm)
x3=s (feed rate, mm/rev)
x4=n (spindle speed, rpm)
and independent variables of regression are;
Z0=1, Z1=x1,
Z2=x2, Z3=x3,
Z4=x4, Z5=$(x1)^2$,
Z6=$(x2)^2$, Z7=$(x3)^2$,
Z8=$(x4)^2$, Z9=x1.x2,
Z10=x1.x3, Z11=x1.x4,
Z12=x2.x3, Z13=x2.x4,
Z14=x3.x4
which transformation was carried out.

If the regression is applied step by step; since it hasn't single solution, Z5 variable was ignored, and coefficients of independent variables were obtained by using Matlab as;

a0=273.7540 a1=-140.7660
a2=-6.8174 a3=128.8497
a4=0.0883 a5=0.0420
a6=-87.8906 a7=-0.0001
a8= 2.8551 a9=-25.5063
a10=0.0077 a11=-1.5455
a12=-0.0007 a13=0.0691

By placing these coefficients into the equation (9), theoretical average voltage difference could be expressed as shown below was obtained.

$$Y=a0+a1.t+a2.d+a3.s+a4.n+a5.d^2+a6.s^2+a7.n^2+a8.t.d+a9.t.s+a10.t.n+a11.d.s+a12.d.n+a13.s.n$$

$$Y=273,7540 - 140.7660.t - 6,8174.d + 128,8497.s + 0,0883.n + 0,0420.d^2 - 87,8906.s^2 - 0,0001.n^2 + 2,8551.t.d - 25,5063.t.s + 0,0077.t.n - 1,5455.d.s - 0,0007.d.n + 0,0691.s.n$$

4. Results

Experimental values and estimated voltage differences are shown in Table 1. For the first sample which the best result was obtained. Experimental and estimated values are compared with the values of t=0,5 mm, t=1mm and t=1,5mm for s=0,48 mm/rev and shown in Table 2-4 and as graphically in Fig 1-3.

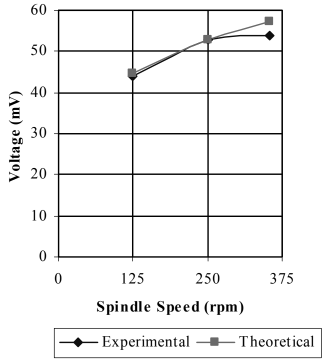

Fig. 1. Relationship between experimental and theoretical voltage difference – spindle speed (s=0,48mm/rev)

Table 1.
Comparison of experimental and theoretical voltage differences

Exp. No	$V_{Exp.}$	$V_{Teo.}$	Exp. No	$V_{Exp.}$	$V_{Teo.}$
1	35	34.5250	17	53	53.8107
2	48	43.3045	18	54	55.5792
3	51	48.2192	19	44	44.8723
4	42	41.6028	20	52	51.2877
5	50	48.4964	21	53	54.2166
6	54	51.8270	22	47	49.1034
7	44	44.5467	23	52	53.3239
8	53	52.8217	24	54	54.4092
9	55	57.3127	25	48	47.9056
10	43	42.9905	26	54	53.5077
11	53	52.6470	27	55	55.7534
12	56	58.2985	28	42	42.2079
13	48	48.1813	29	52	49.1914
14	53	51.8337	30	54	52.5975
15	54	52.4418	31	50	47.2542
16	50	48.7768	32	52	52.0429
Exp. No	$V_{Exp.}$	$V_{Teo.}$	Exp. No	$V_{Exp.}$	$V_{Teo.}$
33	53	53.6053	44	49	47.4745
34	47	44.2633	45	52	50.4921
35	51	50.4334	46	33	34.4518
36	52	53.1563	47	40	42.3542
37	35	36.7724	48	44	46.5322
38	41	44.3239	49	36	38.0830
39	51	48.2073	50	42	44.0995
40	43	42.9554	51	47	46.6933
41	46	48.0949	52	39	38.5540
42	51	49.9520	53	44	45.9520
43	42	40.9536	54	49	49.7063

Table 2.
Experimental and theoretical voltage difference and variation of spindle speed (n) for the first sample (t=0.5 mm, d=50 mm)

Spindle Speed (rpm)	Voltage difference (mV) s=0,48 (mm/rev)	
	Experimental	Theoretical
125	44	44,5467
250	53	52,8217
355	54	57,3127

Table 3.
Experimental and theoretical voltage difference and variation of spindle speed (n) for the first sample (t=1 mm, d=50 mm)

Spindle Speed (rpm)	Voltage difference (mV) s=0,48 (mm/rev)	
	Experimental	Theoretical
125	44	44,5467
250	53	52,8217
355	54	57,3127

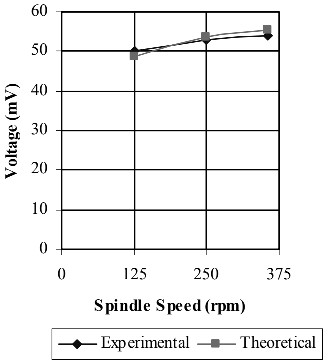

Fig. 2. Relationship between experimental and theoretical voltage difference – spindle speed (s=0,48mm/rev)

Table 4.
Experimental and theoretical voltage difference and variation of spindle speed (n) for the first sample (t=1,5 mm, d=50 mm)

Spindle Speed (rpm)	Voltage difference (mV) s=0,48 (mm/rev)	
	Experimental	Theoretical
125	48	47,9056
250	54	53,5077
355	55	55,7534

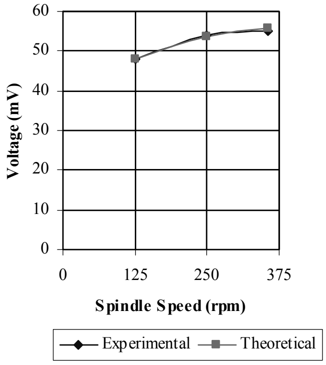

Fig. 3. Relationship between experimental and theoretical voltage difference – spindle speed (s=0,48mm/rev)

In order to generalize the result of researches, taking the results of first sample which gave the highest value, a mathematical method was developed by applying regression analysis method. By this model, comparing theoretical and experimental values variations of both are plotted together (Figure 1, 2 and 3) While studying on these graphics, it has observed that theoretical experimental values are coincided with a little bit difference at 125 rev/min, 250 rev/min and 355 rev/min. But it has observed that experimental values with respect to increased depth of cut took away from theoretical values from 0,01 to 0,06 at 355 rev/min.

By assuming that much of deviation is acceptable, the studies were completed as obtained mathematical formula can represent experimental researches.

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