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*Research Article*

# Invesitgation of Drilling Parameters on Thrust Force on AZ91 Magnesium Alloy by Genetic Expression Programming

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## ABSTRACT

This paper is presented a new theoretical model basis on experimental to predict the thrust force on AZ91magnesium alloy in drilling process depend on the various machining parameters. The experiments for modeling were conducted in dry cutting conditions and designed as full factorial using the spindle speed and feed rate with four different kinds of drill bits. The results were modeled with Genetic Expression Programming and the thrust force formulation was obtained. Considering the formulation, the factors effects were analyzed on thrust force for AZ91.

**Keywords:** *AZ91 magnesium alloys, drilling, thrust force, genetic expression programming, spindle speed, feed rate*

# AZ91 Magnezyum Alaşımının Delinmesinde İşleme Parametrelerinin Kesme Kuvveti Üzerine Etkisinin Genetic Expression Modellemesi ile İncelenmesi

## ÖZET

Bu çalışmada AZ91 magnezyum alaşımının farklı parametreler altında işlenmesi ile oluşan kesme kuvvetlerinin deneysel tabanlı teorik bir model ile tahmin edilmesi sunulmuştur. Modelleme için gerekli deneyler kuru işleme ortamında ve işleme devri ilerleme hızı ve 4 farklı matkap ucunun tam faktöriyel deney tasarımı kullanarak gerçekleştirilmiştir. Deneyler sonucunca elde edilen veriler Genetic Expression yazılımı ile modellenerek kesme kuvveti tahmini için formulasyon oluşturulmuştur. Bu formulasyon kullanılarak deneyde kullanılan parametrelerin kesme kuvveti üzerindeki etkileri detaylı olarak analiz edilmiştir.

***Anahtar Kelimeler:*** *AZ91 Magnezyum alaşımı, delme, kesme kuvveti, genetic expression modelleme, kesme hızı, ilerleme hızı*

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# I. Introduction

THE lightweight magnesium alloys, (1.7g/cm$^3$) have been developing as for many kind of industrial sector because of high mechanical properties regarding density [1-4]. Beside on that magnesium alloy is replacing the plastics, especially in computer industries [5]. However they have poor workability because of their hexagonal structure and the degradation of mechanical properties at elevated temperatures [6,7].

AZ91 alloy is the most widely used die casting magnesium alloy, with high castability [8-11]. However, this popular alloy has not much study on machinability properties. Therefore this study focused on machining parameters influence on drilling for AZ91 magnesium alloy. The experimental results are analyzed with Genetic Expression Programming (GEP).

# II. Material and Experimental Methods

In experiments, a die cast AZ91 magnesium alloy was used. The chemical compositions of alloy were given in Table 1. The work piece thickness was defined as 17 mm and prepared suitable clamping fixture for fix to dynamometer (Figure 1.) AZ91 alloys were received as 57 mm diameter a cylindrical bar. The sides of work pieces weremachined as flat for clamping.

***Table 1.*** *AZ91 magnesium alloy chemical compositions wt.%*

| %Al | %Zn | %Mn | %Fe | %Si | %Mg |
|---|---|---|---|---|---|
| 3.07 | 0.81 | 0.31 | 0.002 | 0.015 | Balanced |

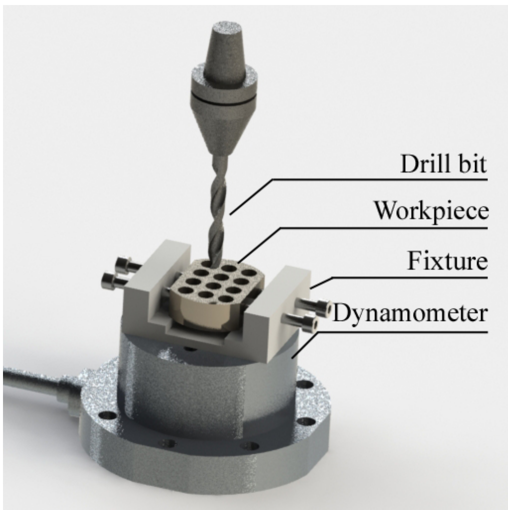


***Figure 1.*** *Experimental setup*

Four different types unused Ø 8mm drill bits were used in experiments. The drill bits were chosen as follows; uncoated HSS, HSS-TiAl coated, uncoated carbide and TiAl coated carbide drill bit. Drilling process were conducted at a numerical controlled (CNC) vertical machining center (VMC-550 Johnford Fanuc Series O-M) having the capacity of 15 kW in an ambient atmosphere at dry cutting conditions. The tests in experiments were two times operated for reliability of the results. A KISTLER 9272 type dynamometer was used to measure the thrust force during the drilling process. The thrust force data has recorded to computer environment with KISTLER DynoWare software. For machining process, the spindle speed and the feed rate used machining parameters. Three and four different parameters were selected for the feed rate and the spindle speed, respectively. The factors and levels used for tests were given in Table 2.

***Table 2.*** *Factors and levels for drilling process*

| **Control parameters** | **Levels** | | | |
|---|---|---|---|---|
| | **1** | **2** | **3** | **4** |
| Feed rate (A) (mm/rev) | 0.1 | 0.2 | 0.3 | - |
| Spindle speed (B) (rpm) | 1500 | 2000 | 2500 | 3000 |
| Drill material (C) | Uncoated HSS | HSS-TiAl coated | Uncoated carbide | TiAl coated carbide |

## III. MODELING WITH GENETIC PROGRAMMING

Genetic Expression Programming was first described by Ferreira [12]. GEP algorithm is able to provide a global function for problems, developed as a resultant of genetic programming algorithms and genetic algorithm [13]. The GEP structure is established on five units. These are terminal set, function set, control parameters, fitness function and termination conditions [14]. GEP evaluation system of any data approach is similar with biological evaluation. The system uses two components as chromosomes that coded some information using special language with gene(s) and the expression trees that reflection of translated chromosomes [15]. The first step in GEP modelling problem definition which is also the most difficult step is problem definition the encoding of the candidate solution and the definition of the fitness function. The fitness and the encoding are defined separately for each problem. To achieve the successful results of the algorithm should be applied the appropriate choices with dominating the problem and expected results. GEP algorithm begins to generate randomly with a mathematical function that chromosome. In following, it converts the function a expression tree (Figure 2.) Program controls the model and target values till desired predefined error criteria [15].

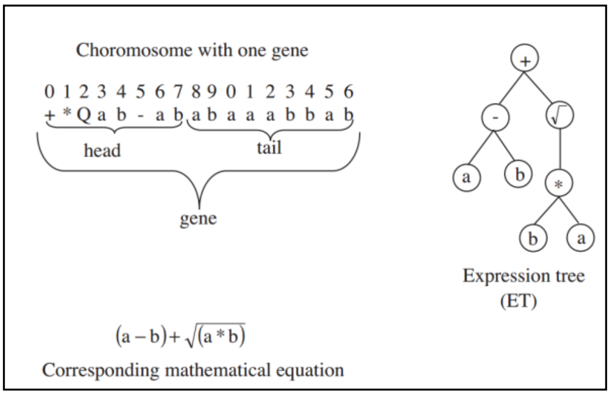


***Figure 2.*** *Schematic indication of a chromosome with one gene and its expression tree and corresponding mathematical equation [15]*

## A. GEP FORMULATIONS

The purpose of this study is to get the thrust force formulation effected by machining parameters and kind of drill bits in drilling process. GEP presents the user very kind of options to set configuration. The GEP options for this modeling were shown in Table 3.

***Table 3.*** *The GEP models parameters*

| | | |
|---|---|---|
| P1 | Function set | +, -, *, /, Pow, Sqrt, Exp, Pow10, Ln, Log, Inv, X^2, X^3 |
| P2 | Chromosomes | 15-45 |
| P3 | Head size | 10-20 |
| P4 | Number of genes | 4-12 |
| P5 | Linking function | Addition, multiplication |
| P6 | Mutation rate | 0.044 |
| P7 | Inversion rate | 0.1 |
| P8 | One-point recombination rate | 0.3 |
| P9 | Two-point recombination rate | 0.3 |
| P10 | Gene recombination Rate | 0.1 |
| P11 | Gene transposition rate | 0.1 |

The GEP was obtained following function in Matlab language for thrust force with *0.97* training R-square and *0.96* testing R-square values. The comparative table of the model and the test results are presented in Table 4 and 5.

```
function result = gepModel(d)
varTemp = 0.0;
varTemp = (((1/(=7.477295))^(((1/((d(3)*((1/((4.321777*2.845063)))-d(2)))))+d(2))* -7.845368))-d(1));
varTemp = varTemp + exp(((2.267792*(10^d(2)))-(log(((d(2)/((d(1)/ 1.513519)^ 0.4823))*(d(1)^3)))^2)));
varTemp = varTemp + ((4.718384+((1/(d(3)))^((log(((d(3)^3)-(d(3)* -9.33789)))*d(2))-log10((4.718384^3)))))^3);
varTemp = varTemp + ((4.316101-(log(3.204467)*(exp(((((d(1)/ 9.964905)/d(1))-d(2))*d(3)))-( 0.533997^3))))^3);
varTemp = varTemp + exp(((log10(((d(1)+(log(d(1))^2))-(( -3.613526+(d(1)* 0.999146))/( 0.999146^d(3)))))-(10^d(2)))^2));
varTemp = varTemp + ((4.329468-((d(1)*(d(2)-(1/((d(3)-((( 7.338318^2)+( -1.101654+d(1)))*(d(1)^d(1))))))))^3))^3);
result = varTemp;
```
(1)

***Table 4.*** *Results of GP formulation versus Test results*

| Drill bit Type | Feed rate (mm/rev) | Spindle speed (RPM) | Thrust Force (N) | | Residual |
|---|---|---|---|---|---|
| | | | Expr. Results | Gep Model | (N) |
| 4 | 0.2 | 2500 | 320 | 274 | 46 |
| 3 | 0.2 | 3000 | 327 | 292 | 35 |
| 3 | 0.3 | 3000 | 377 | 357 | 20 |
| 4 | 0.2 | 2000 | 260 | 273 | 13 |
| 2 | 0.3 | 1500 | 441 | 428 | 13 |
| 4 | 0.1 | 3000 | 208 | 195 | 13 |
| 2 | 0.3 | 2500 | 438 | 429 | 9 |
| 1 | 0.2 | 2500 | 310 | 304 | 6 |
| 2 | 0.1 | 1500 | 227 | 239 | 12 |
| 1 | 0.1 | 2000 | 207 | 209 | 2 |

*Table 5. Results of GP formulation versus training results*

| Drill bit Type | Feed rate (mm/rev) | Spindle speed (RPM) | Thrust Force (N) *Results* | | Residual |
|---|---|---|---|---|---|
| | | | Exp. | Gep | (N) |
| 3 | 0.3 | 1500 | 296 | 311 | 15 |
| 4 | 0.2 | 1500 | 258 | 272 | 14 |
| 4 | 0.1 | 1500 | 214 | 221 | 7 |
| 2 | 0.2 | 1500 | 335 | 327 | 8 |
| 4 | 0.3 | 1500 | 318 | 324 | 6 |
| 1 | 0.2 | 1500 | 300 | 303 | 3 |
| 1 | 0.1 | 1500 | 227 | 225 | 2 |
| 1 | 0.3 | 1500 | 417 | 419 | 2 |
| 3 | 0.1 | 1500 | 202 | 202 | 0 |
| 3 | 0.2 | 1500 | 249 | 242 | 7 |
| 3 | 0.1 | 2000 | 249 | 217 | 32 |
| 3 | 0.3 | 2000 | 388 | 357 | 31 |
| 3 | 0.2 | 2000 | 319 | 292 | 27 |
| 1 | 0.3 | 2000 | 407 | 420 | 13 |
| 2 | 0.3 | 2000 | 423 | 429 | 6 |
| 2 | 0.2 | 2000 | 336 | 327 | 9 |
| 4 | 0.3 | 2000 | 334 | 327 | 7 |
| 2 | 0.1 | 2000 | 222 | 223 | 1 |
| 1 | 0.2 | 2000 | 311 | 304 | 7 |
| 4 | 0.1 | 2000 | 204 | 205 | 1 |
| 1 | 0.3 | 2500 | 460 | 420 | 40 |
| 3 | 0.2 | 2500 | 267 | 292 | 25 |
| 3 | 0.3 | 2500 | 330 | 357 | 27 |
| 3 | 0.1 | 2500 | 190 | 208 | 18 |
| 1 | 0.1 | 2500 | 184 | 200 | 16 |
| 4 | 0.1 | 2500 | 196 | 197 | 1 |
| 2 | 0.2 | 2500 | 323 | 327 | 4 |
| 4 | 0.3 | 2500 | 326 | 332 | 6 |
| 2 | 0.1 | 2500 | 207 | 214 | 7 |
| 1 | 0.2 | 3000 | 286 | 304 | 18 |
| 1 | 0.3 | 3000 | 404 | 420 | 16 |
| 2 | 0.2 | 3000 | 313 | 327 | 14 |
| 4 | 0.2 | 3000 | 274 | 284 | 10 |
| 2 | 0.3 | 3000 | 422 | 429 | 7 |
| 3 | 0.1 | 3000 | 199 | 202 | 3 |
| 4 | 0.3 | 3000 | 382 | 379 | 3 |
| 2 | 0.1 | 3000 | 202 | 208 | 6 |
| 1 | 0.1 | 3000 | 192 | 195 | 3 |

# IV. RESULTS & DISCUSSION

The formulation that obtained from GEP, was utilized for analyze of the thrusts force relations between machining parameters. The plots were generated for each parameter. These plots were shown in Figure 3-9.

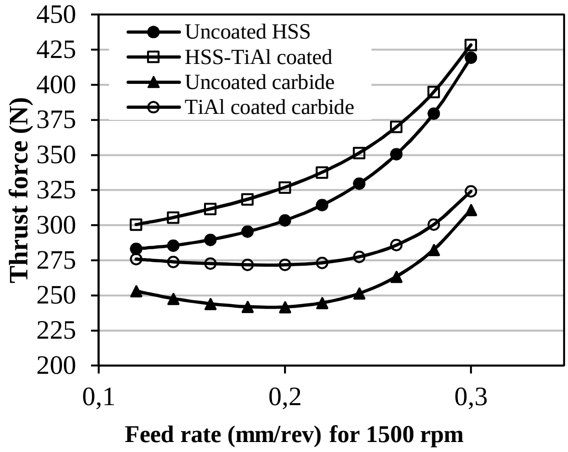


***Figure 3.*** *Feed rate effects on thrust force analyze for 1500 rpm spindle speed*

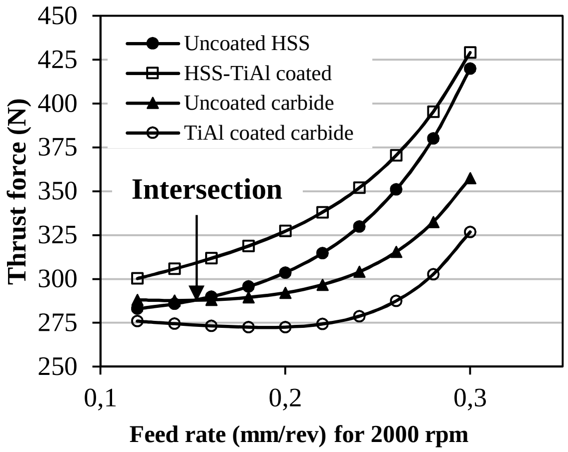


***Figure 4.****Feed rate effects on thrust force analyze for 2000 rpm spindle speed*

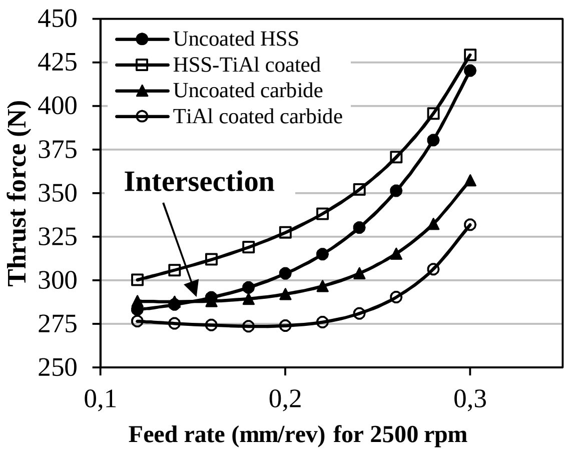


***Figure 5****.Feed rate effects on thrust force analyze for 2500 rpm spindle speed*

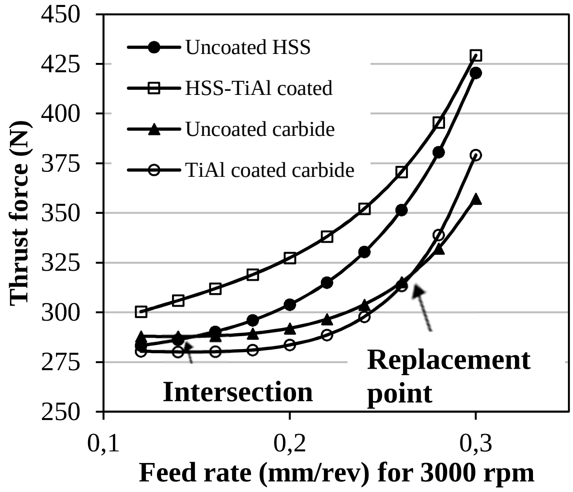


***Figure 6.****Feed rate effects on thrust force analyze for 3000 rpm spindle speed*

Even the plots seem extremely similar, there are some differences in Fig. 3-6. Ti-Al coated HSS drill bits were generated the highest thrust force in plots. The uncoated HSS was shown a same tendency with uncoated drill bit but with lower levels. A close resemblance is also valid for uncoated and coated carbide drill bits. But in Fig. 3 uncoated carbide drill bit showed better performance at a plot for 1500 rpm comparing to Fig. 4, 5 and 6.In carbide drill bit the coat performance increasing in high spindle speeds. In generally increasing the feed rate value the thrust force increases proportionally. Increasing the spindle speed was not much affected the uncoated HSS and coated HSS thrust force. However, raising the spindle speed higher, uncoated carbide drill bits showed worse performance and its thrust force level increased as approximately 15%. The coated carbide drill bit was performed more stable operation considering the other drill bits with 2% changes. In Fig. 4, 5 and 6 plots the intersection at 0.14 mm/rev uncoated HSS and uncoated carbide drill bit achieved the same force for 2000 rpm and 2500 rpm. The major differences were occurred in Fig. 6. The carbide drill bits performance levels were changed at 0.26 mm/rev for 3000 rpm spindle speed. However in general view of the plots, the thrust force values at lower feed rate get very close levels especially 0.1-0.15 mm/rev. The ductile structure of the material at high feed rates was proved with an increase of around 35% at cutting force.

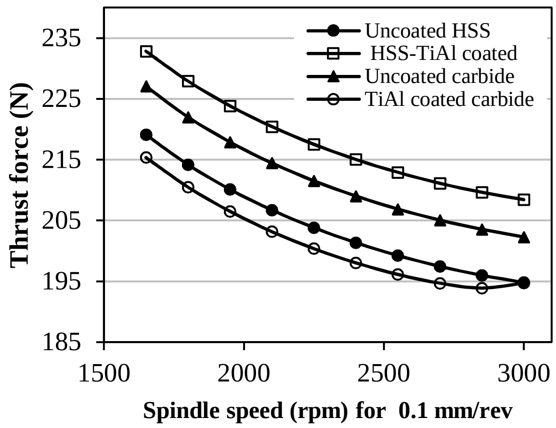


***Figure 7.*** *Spindle speed effects on thrust force analyze for 0.1 mm/rev*

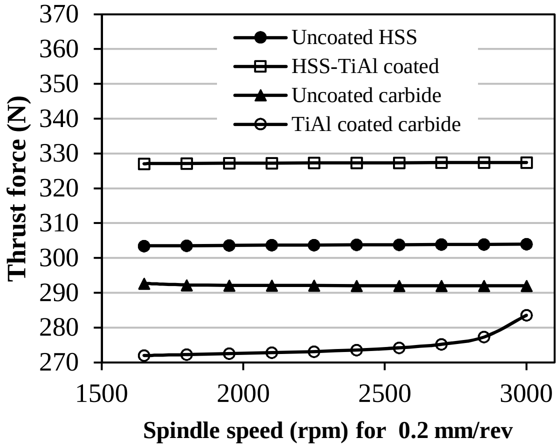


***Figure 8.****Spindle speed effects on thrust force analyze for 0.2 mm/rev*

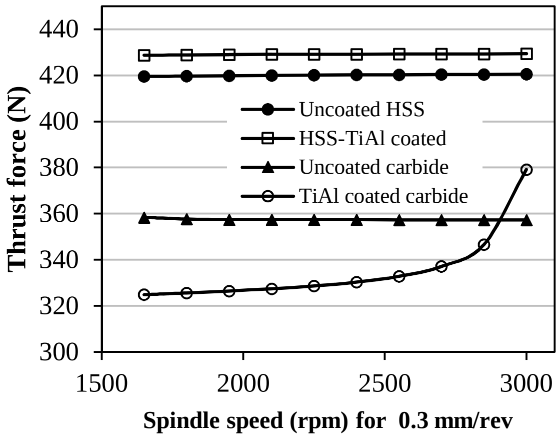


***Figure 9.****Spindle speed effects on thrust force analyze for 0.3 mm/rev*

Different tendencies were observed between Fig. 7 and Fig. 9. The spindle speed increment made lower thrust force levels in Fig. 7. However, this increment does not show same effects on Fig. 8 and Fig. 9. Both plots performed better stable behavior against increment. 1.5mm/rev feeding rate is acting as transition speed for achieve to regime zone. This can be explaining with the drill bit geometry that forced material at lower speeds. In Fig. 7, the uncoated HSS drill bit and TiAl coated carbide drill bit achieved same level at 3000 rpm for 0.1mm/rev. TiAl coated drill bit trend changes to un-stable position at 2850 rpm breaking point. For Fig. 8 and 9 the TiAl coated drill bit showed positive tendency against the increment of spindle speed, regarding the other drill bits. The reason of this tendency can be explain with continuous chip with built up edge (BUE) problem that encountered with increasing feeding rate in high spindle speeds in machining. Also this problem was observed in the experiments. But angle of inclination in plots is not significant except Fig. 7. In lower feed rate, the chip flow is being sufficient against the increment of spindle speed and that make easier machinability for AZ91 alloy. However in medium and high level of feed rate ( 0.2 and 0.3 mm/rev) this chip flow showed sustain more stable structure for each drill bits except TiAl coated drill bit in Fig. 8 and 9.

## V. Conclusion

The thrust force is one of the major factors for the defining the machinability of any materials. In this study, influence of various machining parameters on thrust force with drilling the AZ91 alloy was investigated. The full factorial experiments were conducted for different type drill bits and different spindle speed and feed rates values. Thrust force formulation was obtained based experiments test results with GEP software. The formulation was utilized to generate the plots in respect to the factors used in experiments. In plots the highest thrust forces were obtained with HSS TiAl. Generally the lowest point was observed for TiAl coated drill bits. The feed rate increment thrust force values were increased proportionally. However that situation was not observed for spindle speed. The thrust force values were deducted with increment of spindle speed at 0.1mm/rev feed rate. Nevertheless, thrust force was shown stable tendency in the other plots at 0.2 mm/rev and 0.3 mm/rev except for TiAl coated carbide drill bit.

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