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Application of Taguchi Robust Design for Optimization Cutting Forces and Machining Parameters

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Abstract*— The influence of cutting parameters on machining operations is essential because they influence the cutting tool life and the quality of the machined parts' surface finish. The influence of, depth of cut, cutting speed, and feed rate on cutting force during steel 204machining, aluminum 514, and cast iron alloy for two types of tool, coated carbide and Hss cutting tools with a rake angle of 10 0 was investigated in this study. Cutting parameters included spindle speeds of 180, 260, and 370 (rev/min) and feed rates of 0.2, 0.3, and 0.4 (mm/rev) with.0.1, 0.2, and 0.3mm depths of cut in 54 distinct trials. and each experiment was repeated three times in accordance, with studying the response variation by using the Taguchi robust design which is an important tool for design, this work used three factors at three levels, and an L9 Orthogonal array was used for this signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variations. There is a positive correlation between the cutting force and increasing cut depth, then feed rate. Yet, this correlation is negative with cutting speed. Also, the effect of the HSS tool is greater on the cutting force of the carbide tool. This work can be suitable to determine the optimum cutting parameters for better machinability of the selected materials.

Keyword: cutting force ,feedrate ,depthofcut

I. INTRODUCTION

Many studies found it important for the analysis of the effects of cutting parameters on machining operations. M. N. O. Stru et. al. used a Taguchi L9 orthogonal array to arrange their experiments on the turning of an AISI 1050 steel bar to examine the influence of speed of cutting, cutting depth, and feed rate on the cutting force. For the different performance factors of turning operations, the Grey-based Taguchi approach was used in this research. [1]. In the existing emulative and dynamic marketplace climate, major and tiny industrialized enterprises are further devoted to Optimization and economic machining [2 Khan, M. A ct.al have analyzed the influence of Spindle Speed, Feeding and angle of Rake on Tool enforces during turning of the AISI 1045 steel. They conclude that magnitude of cutting forces increases with rise in rate of feeding , while other factors such as cut depth are held constant and the simulation of orthogonal turning was a powerful tool for design and optimization of cutting parameters [2]. Jha, S. K. et.al have implemented Taguchi method and found out that the cutting parameter optimal levels of speed of cutting, feed rate and depth cut of aluminum, The L9 orthogonal array has been constructed for experimental planning in pocket and CNC turning machining [3]. Satyanarayana Kosaraju et.al have applied Taguchi analysis to examine the cutting factors namely , feed rate, cutting speed and cut depth on cutting force and Temperature in turning of titanium. They were able to decrease the cutting forces and hence improve the machinability of the material [4].G. Bhanodaya et.al Parametric have performed of turning operation on Al-7075 alloy by using High Speed Steel (HSS) cutting tool. Cutting force, surface roughness and temperature are considered as responses, for optimization process [5]. Hair Singh et al. optimized cutting force while turning En24 steel turned parts with titanium carbide coated carbide inserts. They found that the selected process parameters of cutting speed, feed, and depth of cut, as well as the interplay among cutting speed and depth of cut, all have a important effect on the mean and variance of cutting force. [6]. Adesta, E. Y. T et.al reported that the study uses a Taguchi design of experiment to examine how cutting parameters influence cutting forces and temperature for AISI H13 machine operation for different pocket shapes[7]. Haris Rachmat et.al have investigated of Parametric Optimization on Turning Process Using UVAT Holder of Tool Based on Taguchi Method 3 levels of speed, feed and depth of cut are evaluated. It showed the smaller was better used for the calculation of the S/Nratio for cutting forces and temperatures based on the equation[8] Ranganath, M. S et.al have employed Taguchi method for optimization of Process Parameters in Turning Operation. They found out that cutting speed must be the highest. However, depth of cut rate of feed should remain at the lowest level [9]. Krishankant et.al applied Taguchi Method for Turning Process by the effects of Machining Parameters on EN24 steel. With the concept of "the larger-the-better," metal removal rate was considered a quality characteristic. [10].] METODO, O. S. O. S. T.et.al detect the turning parameter impacts such inclduing feed rate, cutting speed and tools on the key cutting force and surface roughness by the use of Taguchi examination. The results revealed that there is a psotive correlation between main cutting force with the cutting speed. Yet, the cutting force rose at higher feed rates and the effect of the cutting speeds was not important [11]. Cutting parameters are important in process of machining since they offer information on deformations along the cutting line, stresses produced at each node/point, and temperature distribution in the tool and work element thfoU shout the machining operation. Turning is an important machining technique that eliminates material out of the surface of a spinning cylindrical workpiece making use of a single-point cutting tool. The cutting tool is fed in a straight line corresponding to the rotation axis [12].

Leksycki et al. presented for the 3 components of cutting forces, stainless steel turning is used. Both the feed rate and the depth of cut have an effect, and increasing either of them raises the responses immediately. The study's significance is that an increased feed rate and depth of cut, regardless of cooling conditions, increases each cutting force component[13].

Laghari et al. used RSM for parametric optimization to turning parameters for composite materials. Based on the the findings, the first level of cutting speed and depth, and of cut is indicated as the ideal value providing the highest desirability value among the four levels. The article demonstrated RSM's effectiveness in optimizing three cutting force components[14].

Aslan BY Using RSM, find the best conditions for all cutting force components in turning operations. Except for the radial component, two cutting force elements, based on the author's conclusions, can be lowered with great desirability. The outcomes of Taguchi and RSM's performance in optimizing cutting forces while turning a variety of materials are similar in all of the publications mentioned. Some of the publications looked at the effects of different parameters and written or measured the best solutions without using an optimization approach. Consider the following illustration[15]

According to Zerti et al., an AISI 420 turning operation is perdofmed through RSM, the cutting force and cutting power were reduced for the maximization of productivity. The significant point was that for optimal reactions, the maximum cutting speeds, the cut minimum depth and feed rate [16].

Kuntoglu and Saglam obtained, in a turning AISI 1050 steel with S/N ratios, the ideal speed of cutting and rate of feed values were obtained. The results showed the minimum tangential cutting force by using a higher cutting speed and a low feed rate[17].

Toulfatzis et al. looked into the machinability of brass alloy in order to determine the optimum option for turning. For the reduction of the cutting force, Taguchi's S/N ratio was utilized to recommend the maximization of the cutting speed and minimization of feed rate, and cut depth [18].

II. EXPRIMENTAL WORK

The materials used for this study are three different types of materials, the steel bar 204 with (5cm) diameter and (30cm) length ,the aluminum bar 514, with (3.5 cm) diameter and (30cm) length, and the bar of cast iron alloy,(5cm) diameter and (25cm)length as shown in Fig.1 The experiments were done about 54 different trial's , with cutting parameters ,spindle speed of 180, 260 and 370 (rev/min), feed rate of 0.2, 0.3 and 0.4(mm/rev). and depth of cut .0.1, 0.2and 0.3 for the two types of tool. coated carbide and Hss cutting **tools** with 10 ^{0} rake angle and each experiment was repeated three times in accordance,of studying the response variation by using of the Taguchi robust design which is an important tool for design. This work used three parameters each at three levels and L9 Orthogonal array for the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation .

Fig.(1) Steel (pin 204), Al (pin 514) , Cast iron (alloy)samples

The chemical compositions and mechanical properties of the the aluminum, steel and cast iron are presents tables from 1 to 6 respectively

Table (1) chemical composition (wt.%) of steel

Steel 204	C r	Mn	Ni	N	Fe
balance	16- 18	6.80-8.50	2-5	0.0-0.25	balance

Table (2) mechanical properties of steel

Density	7.80 g/cm^3
Thermal Expansion	17*10^{-6}
Modulus of Elasticity	200 Gpa
Thermal conductivity	15 W/m.k

Table (3) chemical composition (wt.%) of AL

AL(514)	Silicon	iron	copper
balance	0.35	0.5	0.15
Magnesium	titanium	zinc	manganese
4.5	0.25	0.15	0.35

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Table (4) mechanical properties of AL

Density	$2.65*10^3$
Tensile strength	170 Mpa
Brinell Hardness	50
Yield strength	80 Mpa

Table (5). mechanical properties of C.I

Cast iron	C	Si	Mn	S	Fe	Mo
balance	2.51	0.49	0.15	0.03	3.52	0.31

Table (6) mechanical properties of C.I

Density	7.000–7.400 g/m^3
Coefficient of thermal expansion a	9.9–12 $*10^{-6}$°C
Modulus of elasticity E	83–170 Gpa
Poisson's ratio	0.2–0.3

The material used as a cutting tool for this research work was coated carbide (2020 K12)with tool height 20mm and HSS tool (3/8x8) as shown in Fig.2and 3 respectively

Fig. (2) coated carbide cutting tools

Fig.(3). HSS (3/8x8) cutting tools

High speed lathe Marrison (M 300) with dynamometer device (Ieicos mul ticomponent digital foce indicator model 625) and senser were used for machining experiments as shown in Fig.4,5,6,

Fig.(4) high speed lathe Marrison (M 300) with dynamometer

Fig (5) dynamometer device(model 652)

Fig.(6) sensor device

III. RESULTS AND DISCUSSION

The parameters of cutting such as cutting speeds , feed rate and depth of cut on work pieces of steel, aluminum, and cast iron using a carbide tool and HSS, are shown in table 7.

The Signal / Noise Ratio was employed to examine the experimental data with the minimize the cutting force good criteria like specified by the equation (1) and is illustrated in Table 8. the S/N ratio is determined employing the MINITAB software

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$$S/N = -10\log_{10} \frac{1}{n}\sum_{i=1}^{n} y_i^2 \qquad (1)$$

Table 7 parameters and their levels

Factor/Level	1	2	3
Spindle speed (r.p.m)	180	360	370
Feed rate(mm/rev)	0.2	0.3	0.4
Depth of cut (mm)	0.1	0.2	0.4

The cutting force is clearly influenced by feed rate, cut depth, and cutting speed, as shown by the results. The cutting force is greatly increased when the feed rate is increased at any level of cutting speed. However, even at increased feed rates, there is a negative correlation between this rate with cutting speed. The cutting force also demonstrates a more complex relationship, as shown in the figuers.

In addition, when the depth of the cut increased, the force cutting increases. However, as cutting speed and depth of cut increase, a smoother surface is produced.

Figures (7- 12) and table 8 shows the main effect plot main and main effect plot of S/N ratio for the cutting force of spindle speeds and feed rate with depth. It is seen from the plot that lowest cutting force for steel is obtained at the process settings, spindle speed 370 r.pm, Feed 0.2 mm/rev and cut depth 0.1 mm. and for aluminum the at spindle speed 370 r.pm, Feed 0.2 mm/rev and depth of cut 0.1 mm. Also at cast iron the cutting force at spindle speed 370 r.pm, Feed 0.2 mm/rev and depth of cut 0.1 mm.

Table(8) cutting parameters with cutting force of carbide tool

No	Speed (r.p.m)	Feed (mm/re)	Depeth of cut (mm)	Fc(N) steel	Fc(N) AL	Fc(N) C.I	S/N (steel)	Mean steel	S/N (AL)	Mean AL	S/N (CI)	Mean C.I
1	180	0.2	0.1	147	49	88.2	-43.346	147.0	-33.80	49.0	-38.9	88.2
2	180	0.3	0.2	235.2	78.4	147	-47.428	235.2	-37.886	78.4	3.346	147.
3	180	0.4	0.3	411.6	137.2	246.9	-52.289	411.6	-42.747	137.	-7.85	247.
4	260	0.2	0.2	132	65.2	79.5	-42.411	132.0	-36.285	65.2	-8.00	79.5
5	260	0.3	0.3	264.6	88	186	-48.451	264.6	-38.890	88.0	45.39	186.
6	260	0.4	0.1	235.2	78.4	141	-47.428	235.2	-37.886	78.4	-42.9	141.
7	370	0.2	0.3	220.5	58.8	132	-46.868	220.5	-35.388	58.8	42.41	132.
8	370	0.3	0.1	147	59.6	89.4	-43.346	147.0	-35.505	59.6	39.02	89.4
9	370	0.4	0.2	235.2	88	144	-47.428	235.2	-38.890	88.0	43.16	144.

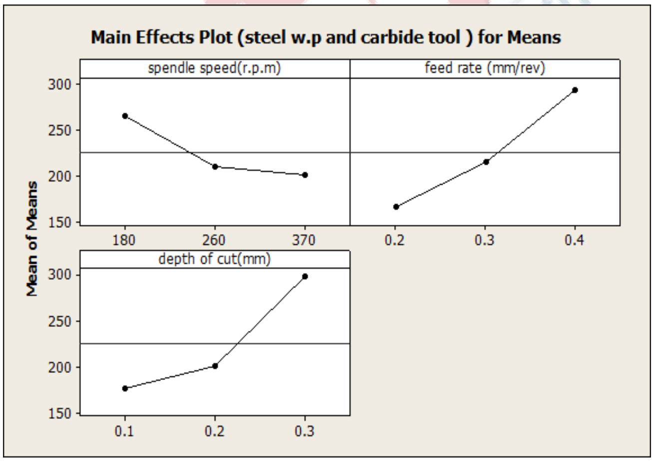

Fig (7) Main cutting parameter influence on force of cutting for Steel .W.P. .and carbide tool

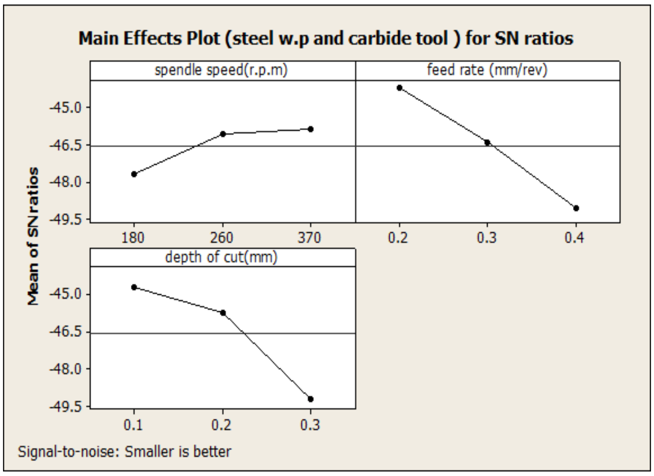

Fig (8) The cutting parameter influences on force of cutting for Steel .w.p. .and carbide tool with S/N ratio

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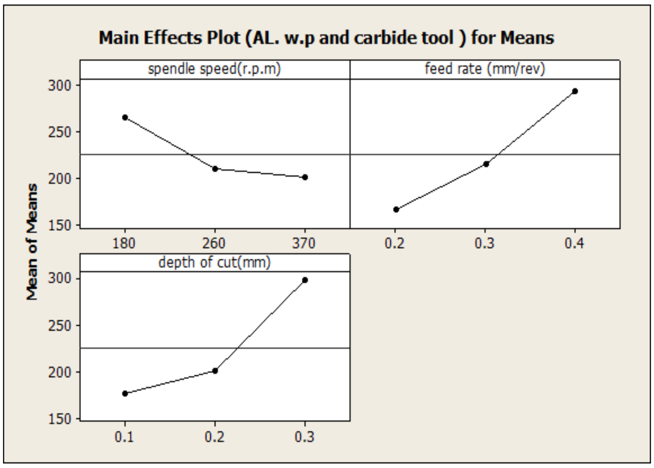

Fig (9) Main cutting parameter influence on cutting force for Steel .w.p. .and carbide tool

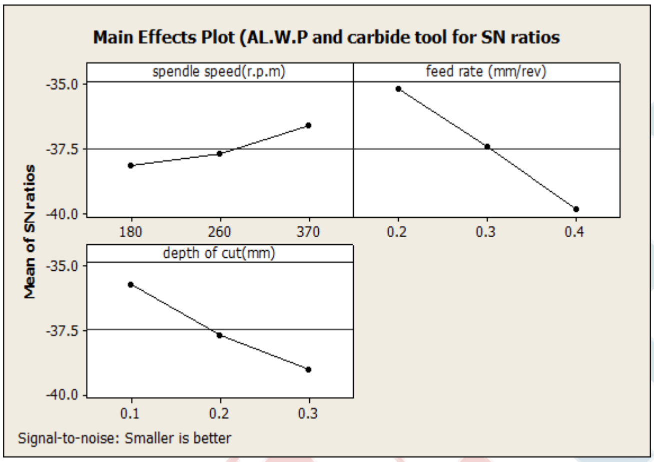

Fig (10) The cutting parameter effect on cutting force for AL.w.p. .and carbide tool with S/N ratio

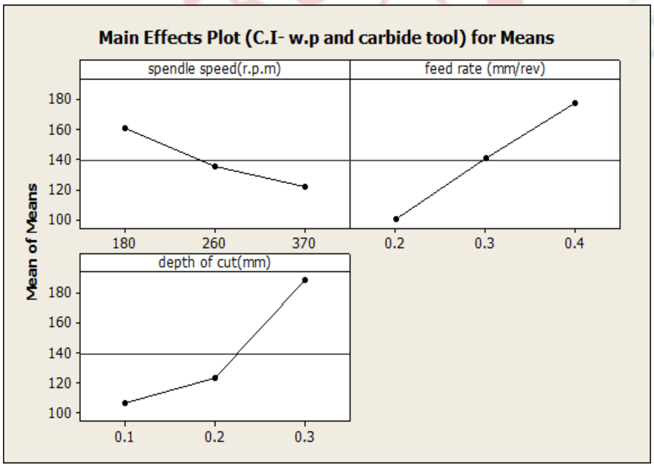

Fig (11) Key cutting parameter effect on cutting force for C.I-w.p.and carbide tool

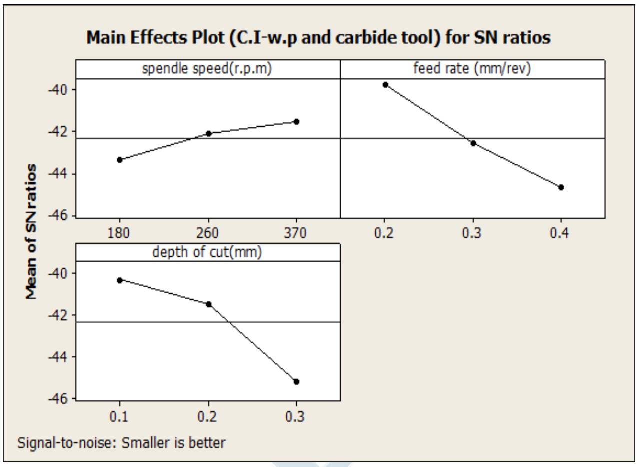

Fig (12) The cutting parameter influences on cutting force for C .L-.w.p. .and carbide tool with S/N ratio

Figure13-18 with table 9 shows the main effect plot mean and the main effect of SN percentage for the cutting force as response for Steel , aluminum and .cast iron with HSS tool. The plot is lowest cutting force for steel obtained at the process settings, spindle speed 370 r.pm, Feed 0.2 mm/rev and depth of cut 0.1 mm. and for AL cutting force at spindle speed 370 r.pm, feed 0.2 mm/rev and cut depth 0.1 mm. while at C.I at spindle speed 260 r.pm, feed 0.2 mm/rev and depth of cut 0.2mm. As a result of this combination of process parameters, the SN ratio is maximized, and the settings are considered optimal.

Table(9) cutting parameters with cutting force of HSS tool.

No	Speed (r.p.m)	Feed (mm/ rev)	Depeth of cut (mm)	Fc(N) steel	Fc(N) AL	Fc(N) C.I	S/N (steel)	Mean steel	S/N (Al)	Mean AL	S/N (C.I)	Mean C.I
1	180	0.2	0.1	196.0	73.5	117.6	-45.8	196.0	-37.32	73.5	-41.40	117.6
2	180	0.3	0.2	314.6	117.6	196.0	-49.95	314.6	-41.40	117.6	-45.84	196
3	180	0.4	0.3	548.8	205.8	329.2	-54.78	548.8	-46.26	205.8	-50.34	329
4	260	0.2	0.2	176.0	97.8	106.0	-44.91	176.0	39.80	97.8	-40.50	106
5	260	0.3	0.3	352.8	132.0	248.0	-50.95	352.8	-42.41	132.0	-47.88	248
6	260	0.4	0.1	312.6	117.6	188.0	-49.92	312.6	-41.40	117.6	-45.48	188
7	370	0.2	0.3	294.0	88.2	176.0	-49.36	294.0	-38.90	88.2	-44.91	176
8	370	0.3	0.1	195.0	89.4	119.2	-5.841	195.0	-39.02	89.4	-41.52	119
9	370	0.4	0.2	319.6	132.0	192.0	-49.92	319.6	-42.41	132.0	-45.66	192.

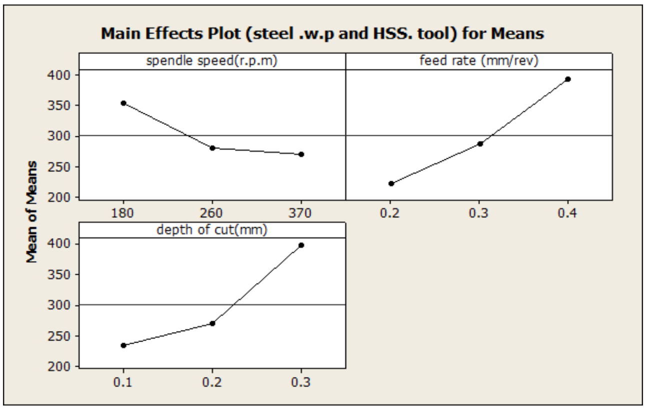

Fig (13) Key cutting parameters impacts on cutting force for steel. w.p .and HSS tool by Mean plot

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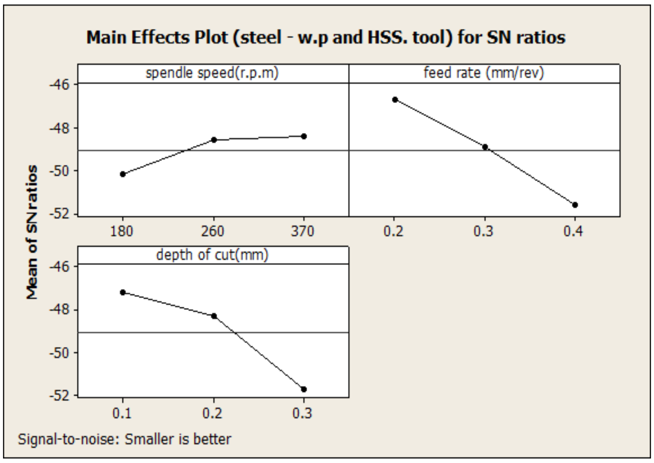

Fig (14) Key cutting parameter impacts on cutting force for Steel-.w.p. .and HSS . tool with S/N ratio

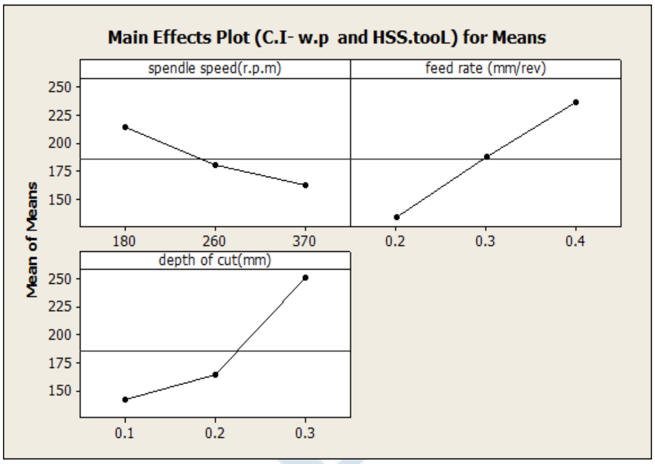

Fig (17) Main cutting parameters effects on cutting force for C.I-. w.p .and HSS tool by mean plot

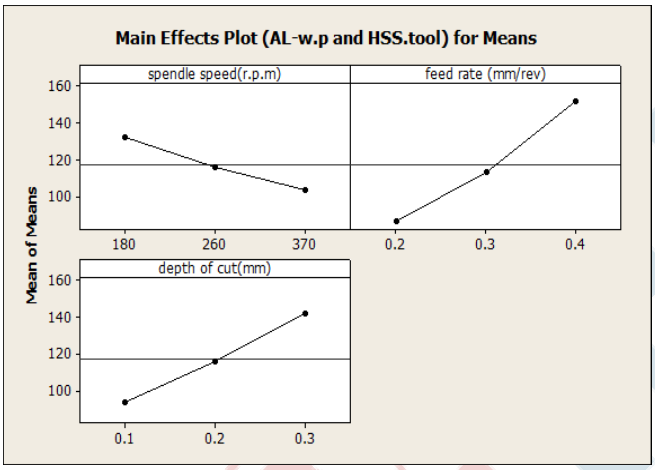

Fig (15) Key cutting parameter impacts on cutting force for AL. W.P.and HSS tool by mean plot

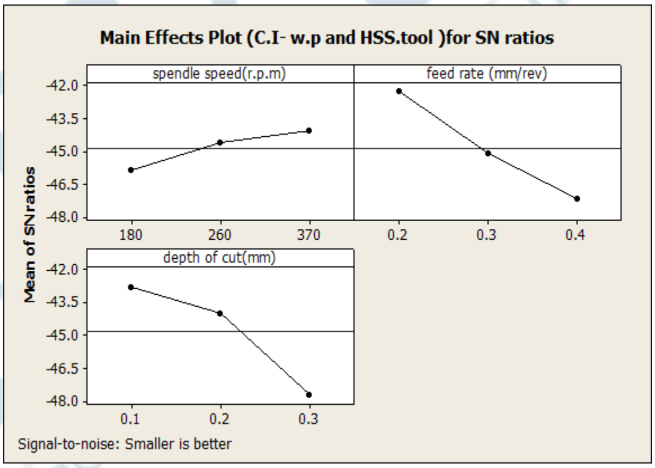

Fig (18) Cutting parameters impacts on cutting force for C.I.--.w.p. .and HSS. tool with S/N ratio

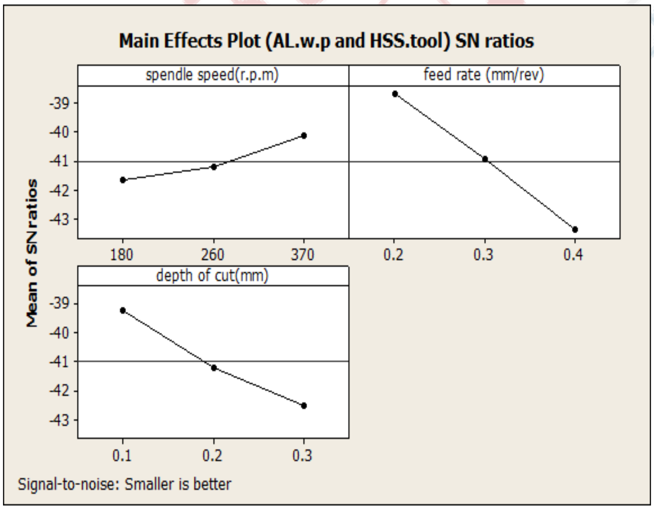

Fig (16) The cutting parameters impacts on cutting force for AL-.w.p. .and HSS. tool with S/N ratio

IV. CONCLUSION

- The effects of cutting speed, feeding, cutting depth, and tool materials on cutting forces can be evaluated during the cutting process of turning with the Taguchi robust design L9 Orthogonal array, and the following conclusion can be obtained from the present work.
- The cutting force increased with increasing cut depth, followed by feed rate, and decreased with cutting speed increase**.**
- The effect of the HSS tool is greater on the cutting force of the carbide tool**.**
- Increasing the feed rate at all cutting speed settings is seen to significantly increase the cutting force.
- It is also seen from the figures that the cutting force has a more complicated relationship in terms of cutting depth and cutting speed, in addition to the force cutting increases steadily with the increase in cutting depth**.**

- The main effect plots and interaction effects between parameters were analyzed using the MINITAB 14 data and drawn. Analysis demonstrates that the effect of cut depth in more on cu

V. ACKNOWLEDGMENT

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