Special Issue of the 7th International Advances in Applied Physics and Materials Science (APMAS 2017)

Optimization of the Effects of Machining Parameters in Turning on Hastelloy C22 Composition through Taguchi Response Surface Methodology

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In this study, the effects of cutting parameters (cutting depth, cutting speed, cutting tip radius, feed rate, cooling liquid flowrate, rake angle, approach angle) on cutting forces, temperatures and surface roughness were compared by using dry turning and minimum quantity lubrication turning methods. With this in mind, in order to determine the effects of cutting parameters in turning, L_{36} hybrid experimental design was established through Taguchi experimental method. Mathematical models were obtained by employing this design.

DOI: 10.12693/APhysPolA.134.28

PACS/topics: turning, hastelloy C22, Taguchi, response surface methodology, optimization

1. Introduction

In metal cutting industry, during metal cutting process the stress, the high-temperature and the friction between the cutting tools and the workpiece cause abrasion of cutting tools, an increase in the cutting force and a decrease in the surface quality. The disposal of the excess heat by the turnings in a cutting process is something desired. Certain cooling liquids are used in order for the heat occurring during metal cutting to be decreased [1, 2]. When cooling liquids are employed, it is easier to dispose of the heat forming between the turnings and the tools [3]. Therefore, cutting fluids are of great significance in terms of raising productivity in metal cutting [4, 5].

Because oiling, cooling and preventing functions of cutting fluids will reduce the friction and the temperature occurring in the cutting zone, tool life and surface quality will improve and cutting force will decrease [6–10]. In addition, the fact that cutting fluids temporarily protect the workpiece against oxidation and corrosion adds to their importance in terms of engineering.

Hastelloy C22 is nickel based, corrosion resistant face centered cubic nickel, chromium, molybdenum alloy [11]. During the machining of superalloys, many problems occur because of heat formation and the resulting high temperatures [12]. An increase in the cutting force, overwearing of tools, low finish surface quality, low measurement stability are side effects dependent on temperature. These are regarded as basic parameters interdependent on each other [13]. These alloys are extensively used for rocket caps because of keeping their strength at high temperatures and ensuring high erosion resistance [14]. On account of their high temperature resistance, these alloys are preferred in the manufacture of aviation turbine engines and super turbo loaders [15]. These alloys are in great demand in the manufacturing of gas turbines and in defense industry [16].

In this study, the work piece was of ASTM B574 (Hastelloy C-22) alloy and the entering angles of cutting tools were 55°, 75° and 90° and three different tool holders were used. The insert radius of the replaceable inserts was 0.4 and 0.8, the rake angles were 15° and 16°. The bits had duromatic plating.

Cutting tests were conducted on a CNC turning machine for different cutting speeds, progressions and depth of cut under dry conditions and then the same procedure was applied under minimum quantity lubrication (MQL).

Cutting forces were measured with a Kistler dynamometer during the cutting process, temperature of the cutting zone was measured and the turnings produced were taken into account too. Through MQL and cooling techniques, progress was made towards eliminating such problems as temperature at the cutting zone, turnings-tool interaction and turnings-machine interaction, tool wear and surface roughness. Efforts were made in order to obtain a high quality product by reducing the friction between the cutter and workpiece and thus consuming less energy and as a result doing less harm to the environment.

This method contributes to the efficiency of the production process, preservation of the labor force and the working environment and reducing the costs.

2. Materials and methods

2.1. Experimental specimens and equipment

The workpiece was a 200×50 mm ASTM B574 (Hastelloy C-22). The chemical composition of the specimen is given in Table I and the mechanical properties are given in Table II.

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TABLE I

Chemical properties of the ASTM B574 (Hastelloy C-22).

C	0.004	Al	0.18
Si	<0.05	Ti	<0.02
Mn	<0.02	V	0.08
P	<0.005	W	3.01
S	<0.0003	Co	0.13
Cr	22.07	Nb	< 0.02
Ni	56.4	Fe	5.2
Mo	12.8	Ta	< 0.02

TABLE II

Mechanical properties of the ASTM B574 (Hastelloy C-22) material.

Yield strength [N/mm^2]	Tensile strength [N/mm^2]	Elongation [%]	Hardness (Rockwell)	Density [g/cm^3]
449	832	60	95	8.69

During the machining, high abrasive resistant and edge strong CCMT 09T304, CCMT 09T308, CVD Ti(C,N) + Al_2O_3 insert cutting tools were used. For oiling, Lubrioil (acid based ester) and MQL system was used. SKF trademark Vario model metal body mechanism with 1.8 liter capacity and three terminals at most was employed.

A Johnford x-y axial TC 35 CNC Fanuc OT machine was used in the experiments. A perthometer M1 type surface roughness measurement machine produced by Mahr was employed in the experiment. In the experiments, a KISTLER 9121 force sensor was used for force measurements, a KISTLER 5019b load amplifier and DynoWare analysis program were used.

3. Experimental design

Turning parameters and levels are given Table III. The experimental design was carried out by using Taguchi L_{36} combine design technique. Taguchi L_{36} combine design is given in Table IV. Therefore, more wide-ranging results were obtained with fewer experiments by means of which we have saved time and money. Because the smallest values of surface roughness, cutting force and temperature ratios are desired while determining the quality characteristic, among the quality values expected to be obtained in the experiments, the smallest ones were taken.

4. Results and discussion

When the surface roughness, the cutting force and temperatures obtained in the experiments were studied at the end of the 36 conducted experiments, it was seen that the results obtained under MQL are superior to those obtained under dry conditions. The surface roughness, cutting force and temperatures obtained in the experiments are comparatively presented in Figs. 1–3. When

TABLE III

Turning parameters and levels.

Nr	Factors	Unit	Levels		
1	Radius	mm	0.4	0.8	...
2	Rake angle	degrees	15	16	...
3	Cutting speed	m/min.	60	80	100
4	Progression	mm/dev.	0.1	0.2	0.3
5	Cutting depth	mm	0.1	0.3	0.5
6	Flow rate	ml/h	40	50	60
7	Enterring angle	degrees	55	75	90

TABLE IV

Cutting conditions according to Taguchi experimental design L_{36} orthogonal index.

No.	Radius [mm]	Rake angle [deg.]	Cutting speed [m/min]	Progres-sion [mm/dev]	Cutting depth [mm]	Flow rate [ml/h]	Entering angle [deg.]
1	0.4	15	60	0.1	0.1	40	55
2	0.4	15	80	0.2	0.3	50	75
3	0.4	15	100	0.3	0.5	60	90
4	0.4	15	60	0.1	0.1	40	75
5	0.4	15	80	0.2	0.3	50	90
6	0.4	15	100	0.3	0.5	60	55
7	0.4	15	60	0.1	0.3	60	55
8	0.4	15	80	0.2	0.5	40	75
9	0.4	15	100	0.3	0.1	50	90
10	0.4	16	60	0.1	0.5	50	55
11	0.4	16	80	0.2	0.1	60	75
12	0.4	16	100	0.3	0.3	40	90
13	0.4	16	60	0.2	0.5	40	90
14	0.4	16	80	0.3	0.1	50	55
15	0.4	16	100	0.1	0.3	60	75
16	0.4	16	60	0.2	0.5	50	55
17	0.4	16	80	0.3	0.1	60	75
18	0.4	16	100	0.1	0.3	40	90
19	0.8	15	60	0.2	0.1	60	90
20	0.8	15	80	0.3	0.3	40	55
21	0.8	15	100	0.1	0.5	50	75
22	0.8	15	60	0.2	0.3	60	90
23	0.8	15	80	0.3	0.5	40	55
24	0.8	15	100	0.1	0.1	50	75
25	0.8	15	60	0.3	0.3	40	75
26	0.8	15	80	0.1	0.5	50	90
27	0.8	15	100	0.2	0.1	60	55
28	0.8	16	60	0.3	0.3	50	75
29	0.8	16	80	0.1	0.5	60	90
30	0.8	16	100	0.2	0.1	40	55
31	0.8	16	60	0.3	0.5	60	75
32	0.8	16	80	0.1	0.1	40	90
33	0.8	16	100	0.2	0.3	50	55
34	0.8	16	60	0.3	0.1	50	90

the graphs are studied, it is seen that MQL positively contributes to surface roughness, cutting force and temperature values.

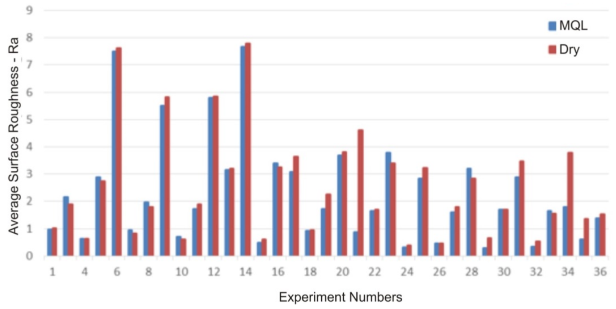

Fig. 1. Comparison of MQL and dry cutting in terms of average surface roughness.

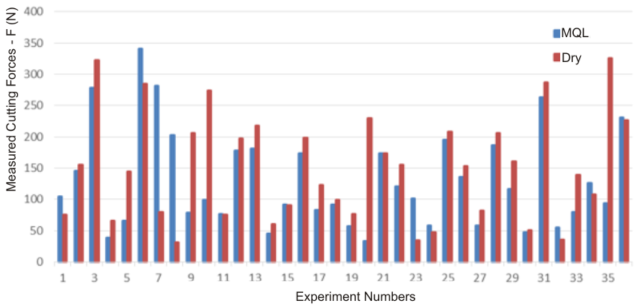

Fig. 2. Comparison of MQL and dry cutting in terms of cutting forces.

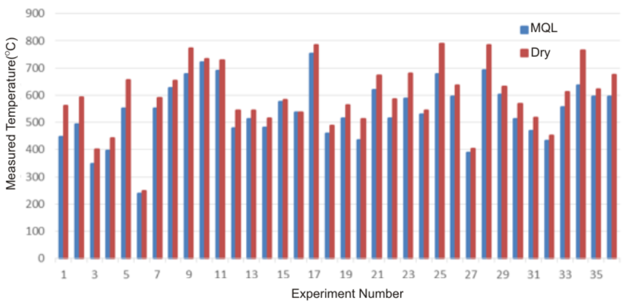

Fig. 3. Comparison of MQL and dry cutting in terms of temperature.

4.1. Mathematical model for average surface roughness

A mathematical model was obtained for the average surface roughness R_a which had occurred after the machining (material removal) experiments, depending on the cutting tool bit radius r, rake angle α, cutting speed v, progression per cycle f, depth of cut a, flow rate d, entering angle q. The second degree regression model was stated as:

$$R_a = k_0 + k_1 r + k_2\alpha + k_3 v + k_4 f + k_5 a + k_6 d + k_7 q$$
$$+ k_8 v^2 + k_9 f^2 + k_{10} a^2 + k_{11} d^2 + k_{12} q^2 + k_{13} r\alpha$$
$$+ k_{14} rv + k_{15} rf + k_{16} ra + k_{17} rd + k_{18} rq + k_{19}\alpha v$$
$$+ k_{20}\alpha f + k_{21}\alpha a + k_{22}\alpha d + k_{23}\alpha q + k_{24} vf + k_{25} va$$
$$+ k_{26} vd + k_{27} vq + k_{28} fa + k_{29} fd + k_{30} fq + k_{31} ad$$
$$+ k_{32} aq + k_{33} dq. \qquad (1)$$

Coefficient of correlation for the model is 99.77%, which shows that the obtained model is quite suitable. It is shown in Fig. 4.

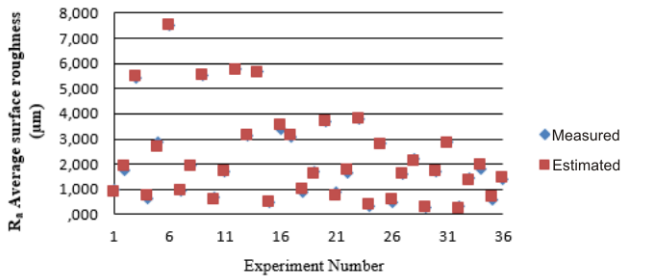

Fig. 4. Mathematical model and experimental data for the average surface roughness.

4.2. Mathematical model for average cutting force

A mathematical model was obtained for the force F, which was formed as a result of the machining (material removal) experiments. Depending on the cutting tool bit radius r, rake angle α, cutting speed v, progression per cycle f, depth of cut a, flow rate d, entering angle q, the second degree regression model was stated as:

$$F = k_0 + k_1 r + k_2\alpha + k_3 v + k_4 f + k_5 a + k_6 d + k_7 q$$
$$+ k_8 v^2 + k_9 f^2 + k_{10} a^2 + k_{11} d^2 + k_{12} q^2 + k_{13} r\alpha$$
$$+ k_{14} rv + k_{15} rf + k_{16} ra + k_{17} rd + k_{18} rq + k_{19}\alpha v$$
$$+ k_{20}\alpha f + k_{21}\alpha a + k_{22}\alpha d + k_{23}\alpha q + k_{24} vf$$
$$+ k_{25} va + k_{26} vd + k_{27} vq + k_{28} fa + k_{29} fd + k_{30} fq$$
$$+ k_{31} ad + k_{32} aq + k_{33} dq. \qquad (2)$$

Coefficient of correlation for the model is 99.89%, which shows that the obtained model is quite suitable. It is shown in Fig. 5.

4.3. Mathematical modelling for temperature data

A mathematical model was obtained for the temperature (°C) which formed as a result of the machining (material removal) experiments. Depending on the cutting tool bit radius r, rake angle α, cutting speed v, progression per cycle f, depth of cut a, flow rate d and entering angle q the second degree regression modelling was stated

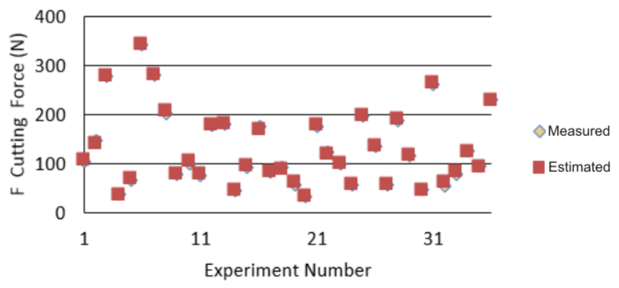

Fig. 5. Comparison of the experimental and modeled data for cutting force.

as:

$$T = k_0 + k_1 r + k_2 \alpha + k_3 v + k_4 f + k_5 a + k_6 d + k_7 q$$
$$+ k_8 v^2 + k_9 f^2 + k_{10} a^2 + k_{11} d^2 + k_{12} q^2 + k_{13} r\alpha$$
$$+ k_{14} rv + k_{15} rf + k_{16} ra + k_{17} rd + k_{18} rq + k_{19} \alpha v$$
$$+ k_{20} \alpha f + k_{21} \alpha a + k_{22} \alpha d + k_{23} \alpha q + k_{24} vf + k_{25} va$$
$$+ k_{26} vd + k_{27} vq + k_{28} fa + k_{29} fd + k_{30} fq + k_{31} ad$$
$$+ k_{32} aq + k_{33} dq. \quad (3)$$

Coefficient of correlation for the model is 96.25%, which shows that the obtained model is quite suitable. It is shown in Fig. 6.

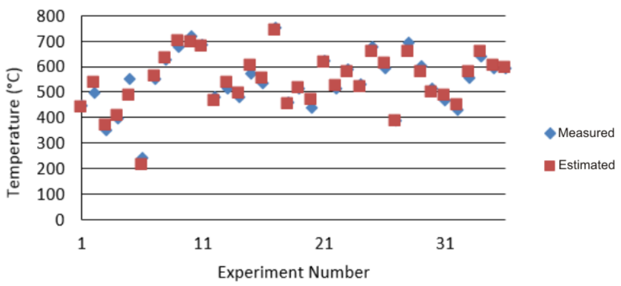

Fig. 6. Comparison of the experimental and modelled data for temperature.

5. Conclusions

In this study, the effects of MQL on the tool and on the workpiece during machining as well as the effective parameters were studied using experimental, analytical, and numerical methods. The effective parameters for increasing the efficiency of machining (material removal) were determined.

By employing response surface method, estimated models were formed for the obtained temperature, cutting forces and surface roughness. When these models were studied it was seen that the coefficients of correlation were over 85%. When the models were examined, it was seen that:

- The coefficient of correlation for the cutting force was 99.89%
- The coefficient of correlation for the temperature was 96.25%
- The coefficient of correlation for the average surface roughness was 99.77%.

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