

## Journal of Material Sciences & Engineering

**Research Article** 

Dpen Access

# Optimization of Sustainable Cutting Conditions in Turning Carbon Steel by CNC Turning Machine

#### Mohammad HM<sup>1</sup> and Ibrahim RH<sup>2\*</sup>

<sup>1</sup>Materials Engineering Department, College of Engineering, University of Basrah, Iraq <sup>2</sup>Mechanical Engineering Department, College of Engineering, University of Basrah, Iraq

#### Abstract

The current study aims to find the optimum cutting parameters in turning process without using cutting fluids (dry cutting condition) towards sustainable manufacturing. Where the power consumption and environmental pollution increase due to increase of the machining operations in manufacturing field, so to save energy and environment and reduce cost it is important to adopt sustainability in machining processes.

The experimental work in this study involves the preparation to a number of experiments on AISI 1045 carbon steel to collect the necessary data for implementing optimization process. The experiments were conducted by changing levels of cutting parameters (spindle speed, feed rate and cutting depth) in CNC turning machine. Surface roughness of the workpiece has been depended as a quality indicator. In addition, the temperature of cutting tool has been recorded during machining the work pieces in order to control the temperature of cutting process.

Theoretically, empirical equations for temperature of cutting tool and surface roughness of the work piece have been discovered. By using Genetic Algorithm technique these equations have been used to find the optimum of cutting parameters spindle speed, feed rate and depth of cut.

The optimum values that obtained by using Genetic Algorithm which achieve sustainable cutting were spindle speed 588.96 rpm, depth of cut 0.50 mm and feed rate 64.55 mm/min in order to have the optimum of surface roughness in low cutting temperature.

**Keywords:** Surface roughness; Optimization; Sustainable manufacturing and machining

#### Introduction

Metal cutting processes comprise the biggest part of manufacturing sector that in turn represents one of the largest energy consumers in the world. As the world is moving today towards sustainable industrialization to preserve the environment of manufacturing pollutants and protects non-renewable resources of energy and production goods with high quality and low cost, the improvement of operating conditions in the machining operations like turning, milling, boring ... etc., has become an urgent need.

The cutting conditions includes cutting parameters (spindle speed, feed rate and cutting depth) and other factors related to cutting process like cutting fluids used for cooling and lubrication, cutting temperature, the type of cutting tool and its geometry specification, ...etc. Cutting parameters are the more effecting conditions on the cutting process and quality of the workpiece that is usually measured by surface roughness [1].

Surface roughness is one of the most important customer requirements where it measures the finer irregularities of the surface texture. Achieving the required surface roughness is critical for the functional behaviour of a part due to its impact on mechanical properties of the manufactured parts such as fatigue life, wearing, and light reflection, ability to distribute and hold a lubricant between contacting bodies, load bearing capacity and coatings [2,3]. Moreover, surface roughness plays a significant role on machining cost where it is related to the dimensions precision so contributes in reducing assembly time and avoiding the need for secondary operation, therefore cost will be reduced [3,4]. The value of surface roughness depends on numerous factors such as machining parameters, material of cutting tool and its geometry parameters, work piece material and its mechanical properties, generated temperature, machine vibrations and cutting conditions (wet or dry cutting). Even small changes in any of the mentioned factors may have a significant influence on the machined surface [4].

Sustainability has been applied to many fields, include engineering, manufacturing and design. In manufacturing sector, metal machining industry is under increasing pressure as a result of competition. Manufacturers are becoming increasingly concerned about the issue of sustainability because adopting sustainability in metal machining processes lead to improve their economic, environmental and social performance [5,6]. The U.S. Department of Commerce defines  $Sustainable\,manufacturing as the creation of manufactured products that$ use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound. Figure 1 shows Sustainability Elements of Manufacturing Processes [5,6]. One of the main problems in machining processes is the generated heat in the cutting zone where about 97% of the work that goes into cutting dissipated in the form of heat. The generated heat impacts on mechanical properties of the workpiece and wear rate of the cutting tool and consequently on surface

\*Corresponding author: Ibrahim RH, Mechanical Engineering Department, College of Engineering, University of Basrah, Iraq, Tel: 009647801015687; E-mail: ceo\_engg@yahoo.com

Received December 23, 2016; Accepted January 24, 2017; Published February 04, 2017

**Citation:** Mohammad HM, Ibrahim RH (2017) Optimization of Sustainable Cutting Conditions in Turning Carbon Steel by CNC Turning Machine. J Material Sci Eng 6: 319. doi: 10.4172/2169-0022.1000319

**Copyright:** © 2017 Mohammad HM, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.



roughness. To moderate the damaging effect of heat in machining processes, Cooling Lubricating Fluids (CLFs) were used. Economic and environmental troubles accompanied using conventional cutting fluids. Where cutting fluids are not naturally biodegradable, treatment of cutting fluids is required before disposal. In addition to maintenance and fluid purchase and preparation cost, this treatment estimated to be two or four times purchase price. Moreover, some of cutting fluids are a major non-sustainable factor in machining processes, which led to developed alternate cooling mechanisms [5,7].

To achieve sustainable manufacturing, alternatives to conventional fluid machining were developed such as cryogenic cooling, minimum quantity lubrication (MQL) and high pressure cooling. These new techniques contribute in reducing cost and reducing/avoiding health and environment problems that are usually caused when using oilbased CLF [1]. Towards sustainability, the complete omission of cutting fluids (dry cutting) was also used in machining materials that have relatively low hardness. Dry cutting condition was adopted in this study and measurement of the tool tip temperature was performed by infrared thermometer to control the temperatures range.

The growing demands of machining processes attract the attention of many researchers to explore the behaviour of factors on surface quality, tool wear, power consumption and ambient in machining operations especially in turning process. Yusuf Sahin [8], developed a mathematical models to predict surface roughness in terms of cutting speed, cutting depth and feed rate by using Response Surface Methodology (RSM). AISI 1040 steel was the workpiece material in the turning process with coated carbide cutting tools. The results showed that feed rate is the main influence factor. It has been seen that surface roughness increases as feed rate increases but decreases with increasing both depth of cut and cutting speed. Hasan Gokkaya [9] presented a study about the effects of various coating materials of cutting tool, coating method and cutting factors on surface roughness. Workpiece of AISI 1015 steel was turned without coolant using four types of cemented carbide cutting tools. Feed rate and cutting speed were selected as cutting parameters. According to the coating types, the results indicated that the best surface roughness was achieved when using cutting tools coated with TiN using the CVD technique. It is also noticed that surface roughness decreases when cutting speed increases while it increases when feed rate increases.

Yansong Guo [10] presented mathematical models in order to optimize energy consumption and surface quality in dry turning of steel (11SMnPb30) and aluminum (AlCuMgPb) with coated carbide cutting tool "SPUN120304". Cutting speed, feed rate and depth of cut were the input variables in the proposed models. It has been noticed that total specific energy (TSE) for both steel and aluminum decreases with increasing feed rate and depth of cut. The behaviour of total specific energy shows decreasing as cutting speed increases until a specific extent after that it begins in increasing with increasing speed. It is also obtained that surface roughness improves with increasing cutting speed and degrades with increasing feed rate and cutting depth. Ashvin J. Makadia [2] investigated the effect of cutting speed, feed rate, depth of cut and tool nose radius on the surface roughness in turning AISI 410 steel. A mathematical model was developed to predict surface roughness in terms of above parameters. Response Surface Methodology was used to find the optimum cutting parameters and study their effect on surface roughness. It has been seen that feed rate was the main factor that effects on the roughness, followed by the tool nose radius and cutting speed while depth of cut has no significant effect on the surface roughness. Murat Sarkaya [1] investigated the effect of cutting speed, feed rate, depth of cut and cooling condition on surface roughness in turning AISI 1050 steel by using CNC turning machine. The cooling condition involved dry cutting, conventional wet cooling and MQL. Taguchi design and response surface methodology were used to find optimal operating parameters and to create mathematical models for Ra and Rz. The results showed that feed rate is the most effective factor on the surface roughness and MQL is a good tool to improve surface roughness.

As there are many researchers studied the effect of cutting factors in turning, this work aims to investigate the influence of cutting parameters (spindle speed, feed rate and cutting depth) on both surface roughness and tool temperature and studies the behaviour of AISI 1045 steel under dry turning condition. The sustainable manufacture has been taken into account by identifying the optimal of these cutting parameters which achieve sustainability from economic perspective, Also, by specifying dry cutting condition sustainability can be achieved from economic, environmental and social aspects as stated in Figure 2.

### **Experimental Work**

CNC turning machine of FANUC (Series of Mate-TC) which is shown in Figure 3 was used to perform experiments, Table 1 shows machine specifications.

The choice of CNC machine is based on the high precision of the parts produced by it and as consequence, it reduces cost of machining and improves productivity. The used material in the present work was medium carbon steel of grade AISI 1045. Table 2 shows the chemical composition test that performed according to ASTM A751 standard [11]. Medium carbon steel of grade AISI 1045 has wide range applications because it machines readily.Typical applications of AISI 1045 steel are: various axles, bolts, connecting rods, hydraulic clamps and rams, various pins, various rolls, shafts, gears... etc.The specimens of carbon steel with length of 90 mm and diameter of 45 mm were cut by carbide cutting tool.

Five levels of cutting speed and three levels of both feed rate and depth of cut have been selected to conduct the experiments as shown in Table 3. As the turning process was conducted without cutting fluid, the generated heat was increasing especially at high speeds and form blue continuous chip which accumulated on tool. This type of chip which

J Material Sci Eng, an open access journal ISSN: 2169-0022



Figure 2: Dimensions of this study that lead to sustainable manufacturing system.

Equipment	Unit	Range
Chuck diameter	mm	200
Max. cutting diameter	mm	200
Max. cutting length	mm	500
Spindle bore diameter	mm	55
Spindle rotating speed	rpm	45-4000
Main motor power (AC)	kW	11
Hydraulic unit power motor	kW	1.5
Chip conveyor motor	kW	0.2
Coolant pump motor	Kw	0.55
Weight	Kg	5000

 Table 1: Specifications of FANUC Series of Mate-TC machine.

shown in Figure 4 is dangerous and may be harmful for the worker and cutting tool so when this type was produced at any level of cutting parameters the higher levels of these parameters were not conducted.

Measurement of tool tip temperature was performed by infrared thermometer deviceof type UNI-Trend (UT303) as the operation of cutting progresses as shown in Figure 5 in order to control the temperature of cutting process. Three readings have been recorded during cutting the specified length of specimen and the maximum temperature has been chosen. Measurements of the surface roughness were taken in each of the mentioned levels in Table 3. The measurements were performed by a portable-type of surface roughness



Figure 3: CNC turning machine of FANUC (Series Oi Mate-TC).

Element	Chemical composition Results %	ASTM results %[19]
Carbon	0.44	0.43-0.50
Manganese	0.52	0.60-0.90
Phosphorus	0.023	0.040 (max)
Sulfur	0.030	0.050(max)
Fe	Balance	Balance

Table 2: Chemical composition of AISI 1045 carbon steel in wt. % compared to ASTM.

Cutting parameters Units	Spindle speed (rev/min)	Feed rate (mm/min)	Depth of cut (mm)
Level-1	200	50	0.5
Level-2	300	100	1
Level-3	400	150	1.5
Level-4	500	_	_
Level-5	600	_	_

Table 3: Levels of cutting parameters that have been used in turning experiments.



tester (Qualitest TR-110, US) as shown in Figure 6. Arithmetic average height (Ra  $\mu$ m) parameter was identified to measure the surface texture according to ISO 4287:1997 standard specifications. Five measurements have been recorded after each cutting process to minimize readings error. Calibration of tester device was done before each reading.

### Optimization using genetic algorithm

Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenance of any engineering system engineers need to specify the ultimate value of a particular function [13]. The goal of optimization is either minimization or maximization of an objective function within appropriate criteria. In this study, the Genetic Algorithm (GAs) has been used to find the

Page 3 of 9



Figure 5: Measurement of tool tip temperature by Infrared Thermometer of type UNI-Trend (UT303) during cutting.



optimum values of the specified cutting parameters. Genetic algorithms (GAs) are well suited for solving such problems; they can find the global optimum solution with a high probability [13].

Genetic Algorithms are considered good search tools to find the global maxima or minima of a practical application. The idea of genetic algorithm was inspired by biological system and Darwinian Theory of natural evolution depending on the principle "survival of the fittest". Genetic algorithm is a class of stochastic search and optimization methods where it works on three basic operators selection (reproduction), crossover (recombination) and mutation.

Genetic Algorithm initiates a random population of size N say P (t), and then the fitness function (objective function) of each individual in the population will be computed. After that if a convergence is achieved by a specific criterion the GA will stop and the best solution in P(t) will be chosen as an optimum solution, if the criteria has not met the operators (selection, crossover and mutation) are applied to form P(t+1) then the termination criterion is checked and so on. This process continues until a termination criterion has met. Figure 7 shows the cycle of the simple GA.

In engineering designs and problems that require finding optimal conditions there is usually more than one objective to be optimized. In single objective optimization (SOO), there is just one optimum solution while in (MOO) there is a set of optimal solution called "*Pareto optimal set*" [14]. Although multiple objectives optimization (MOO) are difficult but they are realistic problems, where the objectives are generally conflicting preventing simultaneous optimization of each objective. The Genetic Algorithm is considered one of the most popular metaheuristic approaches that are well suited for solving multi-

Many methods were developed in order to solve multi-objective problems depending on the operators of the simple GA (selection, crossover and mutation) such as Schaffer's Vector Evaluated Genetic Algorithm (VEGA), Hajela and Lin's Weighting-based Genetic Algorithm, Fonseca and Fleming's Multi objective Genetic Algorithm (FFGA).Horn and Controlled Elitist Non-dominated Sorting Genetic Algorithms [15]. Additional operators were adopted in these methods to modify GA for implementation multi-objective optimization, to see advantages and disadvantages of these methods [16].

The aim of the current study is to find the optimum values of two objective functions in terms of their design variables. The first objective is the surface roughness of the workpiece and the second objective is the tip tool temperature. The design variables are spindle speed, feed rate and depth of cut. The optimization process has been performed by multi-objective optimizer (*gamultiobj*) in MATLAB R2010a software that optimizes the two objectives simultaneously. The *gamultiobj* uses



Page 4 of 9

a *Controlled Elitist Genetic Algorithm* (a variant of *NSGA-II*) [15]. The options in multi-objective optimizer (*gamultiobj*) in MATLAB were specified as following:

- 1. Population Size=100.
- 2. Population Initial Range=[200 0.5 50; 600 1.5 150].
- 3. Lower Bound=[200; 0.5; 50], Upper Bound=[600; 1.5; 150].
- 4. Creation Function=Feasible population.
- 5. Selection Function=Tournament, Tournament size=10.
- Crossover Function=Two point crossover, Crossover Fraction=0.7.
- 7. Mutation Function=Adaptive feasible.
- 8. Pareto Fraction=0.7.
- 9. Plot Function=Pareto front.

#### **Results and Discussion**

#### Temperature of cutting tool

In all machining processes most of the cutting energy converts to heat between tool, chip and work piece. Therefore, it is important to measure the temperature at the tip of cutting tool to control the process and avoid high temperatures of tool that may cause wearing and reduce tool hardness. By using infrared thermometer device, temperature of cutting tool was recorded at different cutting parameters. The multiple non-linear regression method has been used to predict a mathematical model for cutting tool temperature by using LAB-fit Curve Fitting software. Cutting tool temperature model is given by the equation (1) under effect of three variables spindle speed, feed rate and depth of cut with multiple correlation coefficient (R) equal to 98.83%, constants values of the equation are shown in Table 4. The predicted values of equation (1) and their errors are shown in Table 5. Figure 8 shows a

Constants	Values
A	-5.54E+01
В	3.45E-04
С	8.95E-04
D	-2.11E-01
E	8.32E-01
F	-2.18E-01
G	-8.49E+00
Н	6.20E+01

Table 4: Constants values of the equation
---

comparison between the predicted values of the tool temperature empirical model with the experimental values.

$$\boldsymbol{T} = A + B x_1^{2} + C x_2 x_3^{2} + D (x_1 - x_3) + x_1^{(E + F x_2)} + G \frac{x_1}{x_2 x_3} + H \sqrt{\frac{x_1}{x_3}}$$
(1)

The effect of spindle speed on tool temperature is shown in Figure 9. Increasing in spindle speed causes increasing in tool temperature and this can be explained as following, the total energy in cutting process can be partitioned into shear energy, friction energy, kinetic energy and surface energy. Both the kinetic energy and surface energy represent a small amount and they are usually neglected except kinetic energy that is take into consideration at high speeds (900 to 1200 m/ min) [17]. The shear energy is the largest one where more than 75% of total energy is related to shear action and all this energy transforms into heat because of plastic deformation of material in shear zone. The friction energy represent the energy dissipated in sliding the chips on the tool face and as a result, heat will generates due to friction action, this energy is sensitive to the velocity of chips as it flows over the tool. So when spindle speed increases, the cutting speed increases which cause increasing in the shear and chip velocities so the shear and friction energies that will be dissipated in the form of heat will increase and as sequences the tool temperature will increase [17,18].

Figures 9 and 10 show that tool temperature increases with increasing feed rate and depth of cut respectively. The tool temperature will increase due to increase cutting forces where the amount of heat generated during turning increases directly with the cutting forces according to André Stefenon [19] and Harinath Gowd [20]. The cutting forces increase as feed rate and/or depth of cut increase due to increasing in the shear plane area as Awadhesh Pal [18] said.





No.	Speed (rpm)	Depth (mm)	Feed (mm/min)	Tool temperature (°C) (Experimental)	Tool temperature (°C) (Theoretical)	Error %
1	300	0.5	50	39	35.64	9.41
2	500	0.5	50	50	52.44	4.66
3	400	1.5	50	75	79.72	5.92
4	500	1.5	50	105	101.46	3.48
5	300	0.5	100	52	56.03	7.2
6	500	0.5	100	98	93.85	4.41
7	200	1.5	100	47	41.47	13.33
8	300	1.5	100	53	54.9	3.49
9	200	0.5	150	50	52.88	5.44
10	300	1.5	150	70	68.22	2.6
11	500	1.5	150	102	104.34	2.24
-	-	-	-	-	-	Mean Error=5.65%

Table 5: Experimental and theoretical cutting tool temperatures at different cutting parameters.

#### Page 5 of 9

In addition, an increase in the area of contact between tool and chip yield from increasing feed rate and depth of cut that lead to a higher frictional energy [21]. In addition, some of the generated heat dissipates in conduction to work piece material and tool holder according to their properties in conduction, when feed rate increases the cutting time will decrease which means less amount of heat will conduct to work piece material and cutting tool holder and so the temperature of the tool tip will increase.

From the proceeding discussion, the temperature increases with increasing each of spindle speed, feed rate and depth of cut, and as mentioned in chapter four that chip removes 60% from heat generated in cutting, the heat removed by chip will increase as cutting parameters increase. Because of dry cutting condition during turning process, the chip will exposed to atmosphere and due to high temperatures, chip oxidation will take place producing chip with blue colour surface [22], as shown in Figure 4. This type of chip formation leads chip to accumulate on the cutting tool and welding to the edge of tool. This state was noticed at reading 4 and 11 in Table 5, so in optimization it is desirable to avoid this unfavorable chip formation by choosing temperature below 100°C.

#### Surface roughness of work piece

Surface roughness is an important requirement in turning process due to its effect on mechanical properties of worpiece as mentioned before; therefore it has been depended as quality indictor in this study. Surface roughness data was collected during experiments by using surface roughness tester in turning AISI 1045 steel work piece at



Figure 9: Effect of feed rate on tool temperature at depth of cut 0.5 mm and different cutting speed.



and different cutting speed.

different cutting conditions. Multiple linear regression analysis was used to establish the mathematical model. By using LAB-fit Curve Fitting software, an empirical equation for predication surface roughness of the work piece was obtained. Ra model is given by equation (2) which describes the behaviour of surface roughness under the effect of spindle speed, depth of cut and feed rate with multiple correlation coefficient R equal to 98.22%, constants values of the equation are shown in Table 6. The predicted values of equation (2) and their errors are shown in Table 7. Figure 11 shows the comparison between the experimental values of surface roughness with the theoretical values obtained by empirical model.

Page 6 of 9

$$SR = A + Bx_1 + Cx_2 + Dx_3 + \frac{E}{x_1^4} + F \exp\left(\frac{1}{x_2}\right) + \frac{G}{x_3^2} + H\ln(x_1) + K\ln\left(\frac{x_1}{x_3}\right)$$
(2)

Figure 12 explains the behavior of surface roughness with spindle speed at different feed rates. It is obvious that when spindle speed increases surface roughness decreases. This can be attributed to two reasons:

The first reason is that ductile materials have high coefficient of friction, so when cut starts, some of the material because of high friction coefficient, built up ahead of the cutting edge, some of the material may even weld onto the tool point, and thus known as built up edge BUE. As the cutting proceeds, the chips flow over this edge and up along the face of the tool. Periodically a small amount of this BUE separates and may be embedded in the turned surface or leaves with the chip. Some of the tool material can be torn away with chips leading to wear in tool edge or weld into the edge and alters tool's geometry leading to inaccuracy in the required dimension. Because of these actions, BUE increases surface roughness. The coefficient of friction that related to BUE is velocity dependent. With increasing speeds, temperature will increase and the coefficient of friction decreases yielding lower friction,

Constants	Values
А	1.59E+01
В	2.19E-02
С	4.26E-01
D	-2.27E-02
E	-5.70E+09
F	2.01E-01
G	3.49E+04
Н	3.43E-01
К	-1.74E+01



Table 6: Constants values of the equation.

Citation: Mohammad HM, Ibrahim RH (2017) Optimization of Sustainable Cutting Conditions in Turning Carbon Steel by CNC Turning Machine. J Material Sci Eng 6: 319. doi: 10.4172/2169-0022.1000319

No.	Speed (rpm)	Depth (mm)	Feed (mm/min)	Ra(µm) (Experimental)	Ra(µm) (Theoretical)	Error %
1	200	0.5	50	8.87	8.86	0.11
2	400	0.5	50	5.09	4.76	6.93
3	600	0.5	50	3	2.4	25
4	300	1	50	6.09	6.27	2.87
5	400	1	50	4.6	4.03	14.14
6	500	1	50	1.93	2.55	24.31
7	300	1.5	50	5.7	6.33	9.95
8	400	1.5	50	3.76	4.09	8.06
9	500	1.5	50	2.89	2.61	10.72
10	300	0.5	100	6.57	7.47	12.04
11	400	0.5	100	5.1	5.23	2.48
12	500	0.5	100	4.26	3.75	13.6
13	600	0.5	100	3.1	2.88	7.63
14	300	1	100	6.99	6.74	3.7
15	400	1	100	4.2	4.51	6.87
16	500	1.5	100	3.47	3.08	12.66
17	300	0.5	150	11.34	11.46	1.04
18	400	0.5	150	9.51	9.22	3.14
19	600	0.5	150	6.09	6.86	11.22
20	300	1	150	11.21	10.73	4.47
21	400	1	150	8.99	8.5	5.76
22	500	1	150	6.37	7.01	9.12
23	300	1.5	150	11.89	10.79	10.19
24	400	1.5	150	7.77	8.55	9.12
_	_	_	_	_	_	Mean Error=8

Table 7: Experimental and theoretical workpiece surface roughness (SR) at different cutting parameters.

and that means the size of the BUE decreases as cutting speed increases and the surface finish is improved [4,17,23].

The second reason is that when cutting speed increases the shear angle will increase resulting in shorter shear plane and hence lower shear force, so lower cutting forces are required and this mean less vibration leading to produce smoother surface roughness [24].

Figure 12 shows the effect of feed rate on surface roughness. It can be seen that surface roughness increases with increasing feed rate. This behavior can be attributed to the increasing in cutting forces due to increase the amount of material in contact with the tool. These forces cause vibration leading to a higher surface roughness according to Murat Sarıkaya [1] and M. CemalCakir [25], also more heat is generated due to these forces, this heat contributes in tool wear and thus may produce high surface roughness.

When depth of cut increases the cutting forces increase because larger material has to be removed. As mentioned before that higher cutting forces lead to a higher vibration and thus rough surface is yield, but what has been observed in this study during experiments is that as depth of cut increases from 0.5 mm to 0.7 mm the surface roughness decreases as shown in Figure 13. Suresh [24] said that effective material removal might not have taken place at lower depth of cut, mainly due to predominant rubbing and plugging actionand hence higher surface roughness is obtained. After 0.7 mm the increasing in depth of cut has no significant effect on surface roughness.

The empirical model of surface roughness was compared to surface roughness models of Young K. and Choon M [26]. In their research, they adopted MQL and wet conditions in turning AISI 1045 carbon steel as workpiece. Figure 14 shows the three models of surface roughness as dry of this work and MQL and wet of Young K. and Choon M. work at depth of cut 1mm and feed rate 0.2 mm/rev. The









Page 7 of 9

curves of dry, MQL and wet in Figure 14 show the same behaviour, where surface roughness decreases as cutting speed increases.

#### Optimization using genetic algorithm

Multi- objective optimization was performed by applying multiobjective optimizer (*gamultiobj*) of Genetic Algorithm package in MATLAB R2010a software. Two objectives were chosen, surface roughness of workpiece and tool temperature. The models of the two objectives were in terms of spindle speed, depth of cut and feed rate.



**Figure 14:** Comparison between the current work (dry condition) and Young K. et al. [26] MQL and Wet conditions for surface roughness models with cutting speed.

Figure 15 shows the result of optimization operation (Pareto optimal set). The optimal cutting parameters shown in Table 8 are chosen as compromise solution to have a low surface roughness at temperature below the values that causing continuous blue chip which is considered undesirable because of its harmful properties for machine operator and cutting tool. The optimum cutting parameters were fulfilled the sustainable manufacture conditions.

#### Conclusions

From the current study, the more important conclusions can be drawn as following:

- Sustainable manufacturing can be obtained if dry cutting condition is adopted during machining which minimizes cost, safes operators' health and eliminates environment pollutions.
- 2- Finding the optimum of cutting parameters contributes in minimizing cost of machining by specifying the desired surface roughness for customer.
- 3- From the empirical model of cutting tool temperature it has been noticed that tool temperature increases with increasing cutting parameters (spindle speed, feed rate and depth of cut).
- 4- From the surface roughness empirical model to the workpiece it has been noticed that surface roughness decreases with increasing spindle speed and depth of cut while it increases with increasing feed rate.



Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)	Surface roughness Ra (μm)	Tool temperature T (°C)
588.96	0.5	64.55	0.98	89.05

 Table 8: The optimum cutting parameters to have optimum surface roughness.

- 5- Genetic Algorithm is an active tool for optimization multiobjectives problems.
- 6- The best compromise optimum cutting parameters were spindle speed 588.96 rpm, depth of cut 0.50 mm and feed rate 64.55 mm/min that gave surface roughness (Ra) 0.98  $\mu$ m and tool temperature 89.05°C.

#### References

- Sarıkaya M, Güllü A (2014) Taguchi design and response surface methodology based analysis of machining parameters in CNC turning under MQL. J Cleaner Prod 65: 604-616.
- Makadia AJ, Nanavati JI (2013) Optimisation of machining parameters for turning operations based on response surface methodology. Measurement 46:1521-1529.
- Kumar NS, Shetty A, Shetty A, Ananth K, Shetty H (2012) Effect of spindle speed and feed rate on surface roughness of Carbon Steels in CNC turning. Procedia Engineering 38: 691-697.
- Amsted BH, Phillip FO, Myron LB (1987) Manufacturing Processes. 7<sup>th</sup> ed. John Wiley &Sons, USA.
- Janez K, Franci P (2009) Concepts of Sustainable Machining Processes. 13th International Research/Expert Conference, Trends in the Development of Machinery and Associated Technology, Tunisia.
- Rosen MA, Kishawy HA (2012) Sustainable Manufacturing and Design: Concepts, Practices and Needs. Sustainability 4: 154-174.
- Hemant S, Mahendra S (2014) Influence of Cutting Fluids on Quality and Productivity of Products in Manufacturing Industries. Int J Eng Manag Sci 1: 8-11.
- Sahin Y, Motorcu AR (2005) Surface roughness model for machining mild steel with coated carbide tool. Mat & Des 26: 321-326.
- Gökkaya H, Nalbant M (2007) The effects of cutting tool coating on the surface roughness of AISI 1015 steel depending on cutting parameters. Tur J Eng Environ Sci 30: 307-316.
- Guo Y, Loenders J, Duflou J, Lauwers B (2012) Optimization of energy consumption and surface quality in finish turning. Procedia CIRP 1: 512-517.
- 11. ASTM International (1998) Specification for Test Methods, Practices, and Terminology F or Chemical Analysis of Steel Products. ASTM SA-751.

- 12. ASTM International (1998) Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold- Finished. ASTM SA-29/SA-29M.
- 13. Rao SS (1996) Engineering Optimization. 4th ed., John Wiley & Sons, USA.
- 14. Long Q (2015) A Genetic Algorithm for Unconstrained Multi-Objective Optimization. Swarm and Evolutionary Computation 22: 1-14.
- 15. Deb K, Tushar G (2001) Controlled Elitist Non-dominated Sorting Genetic Algorithms for Better Convergence. Springer-Verlag Berlin Heidelberg, USA.
- Abdullah K, Coitb DW, Smithc AE(2006) Multi-Objective Optimization Using Genetic Algorithms: A Tutorial. Reliability Engineering and System Safety 91: 992-1007.
- 17. ASM Metals Handbook (1992) Machining processing 16.
- Awadhesh P, Choudhury SK, Chinchanikar S (2014) Machinability Assessment through Experimental Investigation during Hard and Soft Turning of Hardened Steel. Procedia Materials Science 6:80-91.
- André S (2015) A Qualitative Analysis of Cutting Parameters Influence in Temperature of Stainless Steel AISI 420C Turning. 23<sup>rd</sup> ABCM International Congress of Mechanical Engineering, Brazil.
- Hraninath G, Vali SS, Ajay V, Mahesh GG (2014) Experimental Investigations and Effects of Cutting Variables on MRR and Tool Wear For AISI S2 Tool Steel. Procedia Materials Science 5: 1398-1407.
- 21. Abhang LB, Hameedullah M (2010) Chip-Tool Interface Temperature Prediction Model for Turning Process. Int J Eng Sci & Tech 2: 382-393.
- Siow PC, Ghani JA, Tan SCV (2011) The Wear Progression of TIN Coated Carbide Insert in Turning FCD 700 Cast Iron. Regional Tribology Conference, Malaysia.
- Debnath S, Reddy MM, Yi QS (2016) Influence of cutting fluid conditions and cutting parameters on surface roughness and tool wear in turning process using Taguchi method. Measurement 78: 111-119.
- Suresh R, Basavarajappa S, Gaitonde VN, Samuel GL (2012) Machinability Investigations on Hardened AISI 4340 Steel Using Coated Carbide Insert. Int J Ref Metals & Hard Mat 33: 75-86.
- CemalCakir M, Ensarioglu C, Demiraya I (2009) Mathematical Modeling of Surface Roughness For Evaluating The Effects of Cutting Parameters and Coating Material. J Mat Proc Technology 209.
- Young K. and Choon M. (2010) Surface Roughness and Cutting Force Prediction in MQL and Wet Turning Process of AISI 1045 Using Design of Experiments. J Mech Sci Tech 24: 1669-1677.