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Research Article

Optimization of Sustainable Spur Gears Manufacturing

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Abstract

The machining processes represent a major manufacturing activity that contributes to the growth of the economy. In this paper, the optimum cutting parameters were determined to achieve the sustainable spur gear manufacturing and to give smooth surface and high hardness. The experimental work involves using AISI 1045 medium carbon steel to manufacture spur gears using milling machine at different Spindle speed (V) and Feed rate (f), and at constant Depth of cut (dc) which represent depth of spur gear teeth. The effect of machining parameters on surface roughness is evaluated and the effect of cutting parameters on machine efficiency was studied. The results indicated that cutting speed and feed rate has a major effect on tooth surface roughness and hardness. Also, this paper study the importance of the sustainable machining technologies in achieving sustainable development objectives.

Keywords: *Optimum cutting parameters, Sustainable manufacturing etc.*

1. Introduction

Today's, manufacturing industries are very much interested about the quality of their products. They are focused on producing at higher productivity and quality in time and at minimum cost (Domnita F. F., 2013). Gear manufacturing process has been one of the most complicated of the metal cutting processes. Spur Gears are very useful in numerous applications. They can transfer power from one shaft to another (V. Siva Prasad *et al*, 2012).

The new concept of sustainable production concerns on the creation of products and services (Pusavec F., 2010). This term was defined as the quality to sustain the environment and was mainly environmentally oriented. However, sustainability is defined with three dimensions: environmental, social and economic (Zohreh M. and Napsiah I, 2013). Surface roughness is a good predictor of the performance of a mechanical component used to determine and evaluate the quality of a product.

During machining, the surface and immediate subsurface of the material become harder due to work hardening (Goutam D.R. *et al*, 2014).

Energy efficiency is one of the key drivers for sustainability. International Energy Agency (IEA) adopted definitions of energy efficiency are: the goal of efforts to reduce the amount of energy required to provide products and services and achieving the same quality and level of some 'end use' of energy with a lower level of energy input (Konstantinos S., and Peter B, 2013). In this study tooth surface roughness, hardness and milling machine efficiency were predicted to develop and improve the surface quality of the spur gears and machine performance. The empirical model proposed in this study is a useful prediction tool to help analysis of the relationship between cutting parameters (cutting speed and feed rate) and the gears tooth roughness and hardness. Also, using multi–objective genetic algorithm optimization, optimum value of cutting speed and feed rate was found in order to find best surface properties can be obtained during machining.

2. Genetic Algorithm

An algorithm based on mechanics of natural selection and natural genetics, which are more robust and more likely to locate global optimum. GA then iteratively creates new populations from the old by ranking the strings and interbreeding the fittest to create new, and conceivably better, Populations of strings which are closer to the optimum solution to the problem at hand. So in each generation, the GA creates a set of strings from the bits and pieces of the previous strings, occasionally adding random new data to keep the population from stagnating. The end result is a search strategy that is tailored for vast, complex, multi-modal search spaces. GA is a form of randomized search, in that the way in which strings are chosen and combined is a stochastic process. The cutting parameters are encoded as genes by binary encoding to apply GA in optimization of machining parameters. Crossover and mutation are the basic mechanisms in GA (Abdelouahhab J. *et al*, 2013). Crossover is the

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operation to exchange some part of two chromosomes to generate new offspring, which is important when exploring the whole search space rapidly. Mutation is applied after crossover to provide a small randomness to the new chromosomes. To evaluate each chromosome, the encoded cutting parameters are decoded from the chromosomes and are used to predict machining performance measures. Fitness or objective function is function needed in the optimization process and selection of next generation in genetic algorithm. Optimum results of cutting parameters are obtained by comparison of values of objective functions among all individuals after a number of iterations. In this study multi- object optimization by GA used to find cutting parameters which satisfied good surface properties of smooth spur gears tooth surface and good tooth hardness, in addition to machine efficiency. The GA parameters along with relevant objective functions and set of machining performance constraints are imposed on GA optimization methodology to provide optimum cutting conditions (Milon D. S. *et al*, 2012).

3. Experimental Work

Milling machine is used to manufacture spur gears with different cutting speed and feed rate using AISI 1045 carbon steel. Gear dimensions were listed in table (1) and the manufactured spur gear shown in Figure (1). With high speed steel cutting tool HSS (Gear cutter type NO.2), fifteen specimens of spur gears were manufactured with variable cutting parameters of cutting speed and feed rate. In the experiment conducted in this work, five cutting speeds and three feed rates were used. The cutting speeds and feed rates were decided using the suitable range recommended; which were 45, 63, 90, 125 and 180 rpm for cutting speed, and 28, 35 and 45 (mm/min) for feed rate.

For measuring of tooth surface roughness, *Ra* was selected to express the surface roughness in the present study. The surface roughness factor (*Ra*) is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. The *Ra* is specified by the following equation (Haider M. M., and Murtadha A. J., 2013):

$$Ra = \frac{1}{L}\int_0^L |Y(X)|\ dx \tag{1}$$

Where *Ra* is the surface roughness factor or it is a deviation from the mean line (μm), *L* is the sampling length, and *Y* is the ordinate of the profile curve, it is the arithmetic mean of the departure of the roughness profile from the mean line.

In measuring of tooth hardness, Rockwell test type B was used to measure the hardness values. The hardness of the base material used (AISI 1045) was (90.1 HRB).

Also, the efficiency of a motor was calculated. Machine efficiency determines how motor converts the input electrical energy into mechanical motion. It is the ratio of power output divided by power input, which can be represented by horsepower at spindle (HPs) as an output value and horsepower at motor (HPm) as input value as show below

$$E\% = \frac{horsepower\ at\ spindle\ (HPs)}{horsepower\ at\ motor\ (HPm)} * 100 \tag{2}$$

Table 1 Spur gear dimensions

Module	3
Pressure Angle	20°
Outside diameter	48 mm
Circular pitch	9.245 mm
Diametral pitch	8.466
Pitch circle diameter	42
Addendum	3
Dedendum	3.5
Number of teeth	14
Whole depth	6.471 mm

Figure 1 Spur gears manufactured

4. Results and Discussion

The discovered empirical equations were feasible to make the prediction of tooth surface roughness and hardness. The constants and coefficients of these equations were calculated by multiple regression method using data-fit software.

Data – fit for surface roughness

The multiple regression analysis method has been used in developing empirical models for prediction the spur gears tooth surface roughness that manufactured using milling machine.

By analysis of experimental results using data-fit software, an empirical equation for surface roughness was found. *Ra* model is given by equation(3) which describe the behaviour and predict the values of tooth surface roughness under the effect of cutting speed (rpm) and feed rate (mm/min):

$$Ra = \frac{A+f}{B+C*V^2} + D*Ln(f) \tag{3}$$

The values of constants are

A	B	C	D
-49.99	-2.804	-0.005268	0.3188

The experimental results of surface roughness were compared with the predicted values of eq. (3) as shown in Figure (2). The results obtained of surface roughness by empirical equation were shown to be agreed well against experimental values, the correlation coefficient (R) reaches to 0.9588.

Figure (3) shows the effect of cutting speed on surface roughness factor (Ra) of the spur gears tooth at different feed rates. It can see that as the values of cutting speed increase, roughness factor values were decreased and the surface become smoother (Anil A. S., *et al*, 2012).

Figure (4) shows the effect of feed rates on surface roughness factor of the spur gears tooth at different cutting speed. From this figure it was observed that roughness factor decrease with increase feed rate and cutting speed at 45 rpm, 63rpm, 90 rpm and 125 rpm (Haider M. M., and Murtadha A. J., 2013). At the speed of 180 rpm there is an increase in the cutting speed and slightly increase in the surface roughness factor , this attributed to reducing available time to carry out the heat from the cutting zone and the high amount of material removal rate and an accumulation of chips between the tool-work piece zones (Goutam D.R. *et al*, 2014).

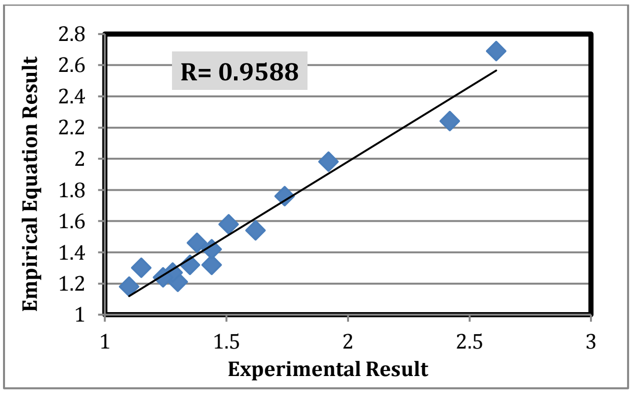

Figure 2 Comparison between empirical equation results and experimental results of spur gears tooth roughness Factor

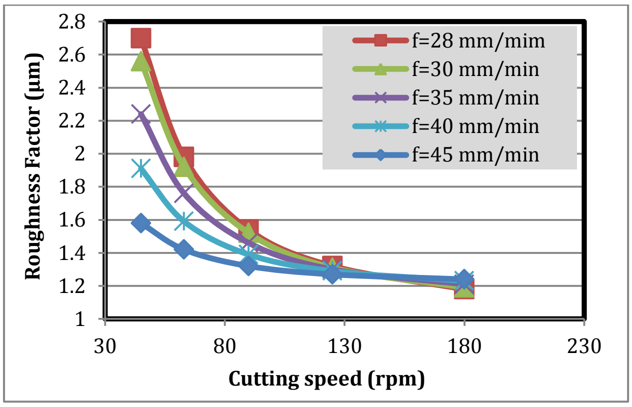

Figure 3 Effect of cutting speed on roughness factor at different feed rates

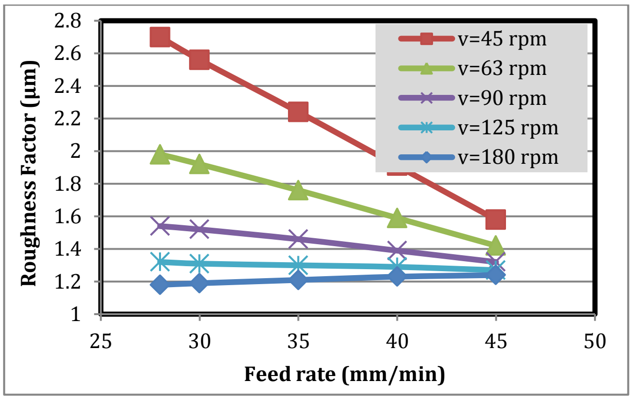

Figure 4 Effect of feed rate on roughness factor at different cutting speed

Data – fit for tooth hardness

Hardness was measured by Rockwell (HRB) to determine hardness variations of spur gears tooth which manufacturing with different cutting speeds and feed rates.

Different cutting speeds and feed rates have a notable influence on hardness values of spur gear tooth for AISI 1045. By using data-fit software, the multiple regression analysis method has been used in developing empirical models for prediction of the spur gears tooth hardness in the same manner of discovering empirical equation for surface roughness. From analysis of experimental results, hardness model is given by equation (4) which describes the behaviour and predicts the value of tooth hardness under the effect of cutting speed (rpm) and feed rate (mm/min).

$$HRB = \frac{A+V}{B+C*f^2} + D*Ln(V) \quad (4)$$

The values of constants are

A	B	C	D
120.2	-1.897	0.0000243	48.98

The experimental results of spur gears hardness were compared with the predicted values of eq. (4) as shown in Figure (5). The results obtained of hardness by empirical equation were shown to be agreed well against experimental values, the correlation coefficient (R) reaches to 0.9670.

Figure (6) shows the effect of cutting speed on hardness of the spur gears tooth at different feed rates. It can see that as the values of cutting speed increase until 90 rpm, hardness values were increase. the reason for increasing hardness with increase of cutting speed is due to increase in the cutting force that occurs for increased cutting speeds, and an increase in cutting speed produces an increased cutting temperature, which in turn increases the temperature on the machined surface, these changes generate a sticking friction condition between the tool-work interfaces; thus contributing to an increase in subsurface plastic flow, giving a higher hardness value (Goutam D.R. *et al*, 2014).

With an increase in cutting speed values more than 90 rpm to 180 rpm, it can see that hardness values decrease. This can be explained according to (G. H. Senussi, 2007), as cutting speed increased the cutting forces are decreased thus lowering the amount of heat generation and as a result the rate of strain hardening is decreased.

Figure (7) shows the effect of feed rates on hardness of the spur gears tooth at different cutting speed, it is clear that the hardness values do not vary much with the feed rate. It can be concluded the hardness value is almost independent of feed rate (Goutam D.R. *et al*, 2014).

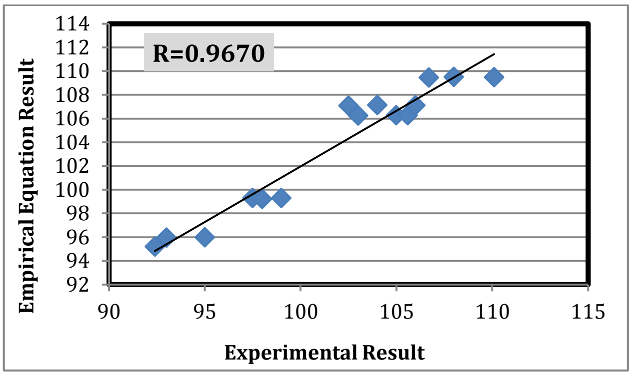

Figure 5 Comparison between empirical equation results and experimental results of spur gears tooth hardness

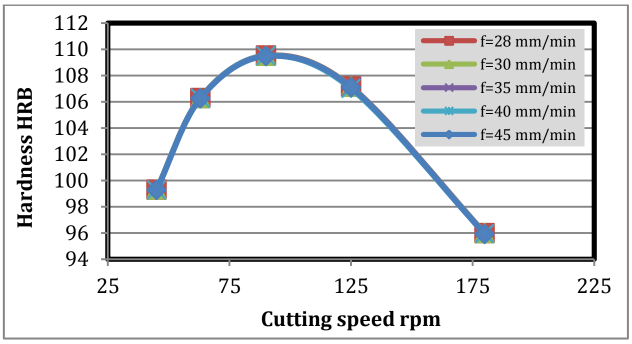

Figure 6 Effect of cutting speed on tooth hardness at different feed rates

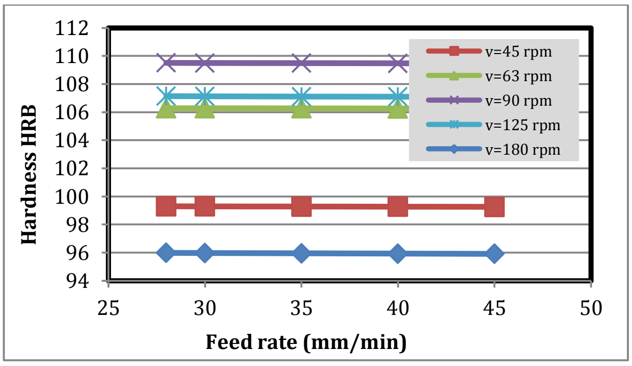

Figure 7 Effect of feed rate on tooth hardness at different cutting speed

Machine Efficiency

As spindle horsepower increase due to material removal rate increase, machine efficiency increase. Machine efficiency is also increase with feed rate increase as shown in Figure (8).

By calculation milling machine efficiency, it can be seen that maximum efficiency is 59.94 % at 45 (mm/min) feed rate which represent higher feed rate used in the present work. This percentage is considered acceptable in terms of the efficiency of the machine which gives good product output, which is spur gears surface characteristic and milling machine performance. This achieves the principle of sustainability of energy conversation with high productivity and quality.

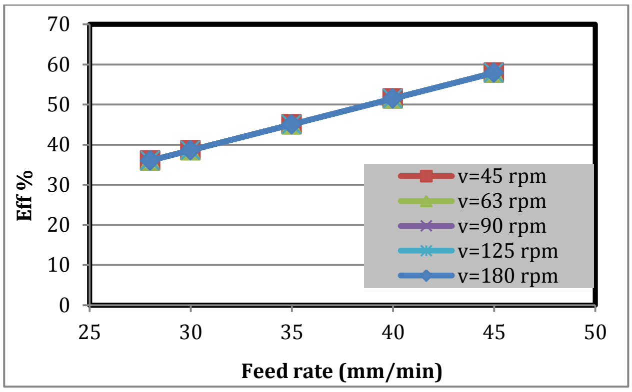

Figure 8 Machine efficiency change with feed rate at variable cutting speed

Optimization using Genetic Algorithm

By using genetic algorithm optimization, multi–objective optimization was applied. Optimum values of cutting speed and feed rate were found in order to find minimum surface roughness and maximum value of tooth hardness as shown in table (2). Figures (9),(10) and (11) showed the optimum values of cutting speed and feed rate that give smooth surface, high hardness, and high machine efficiency.

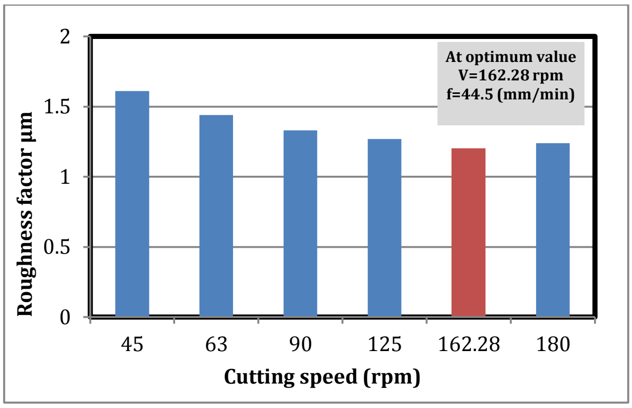

Figure 9 Optimum cutting speed which give lower tooth surface roughness

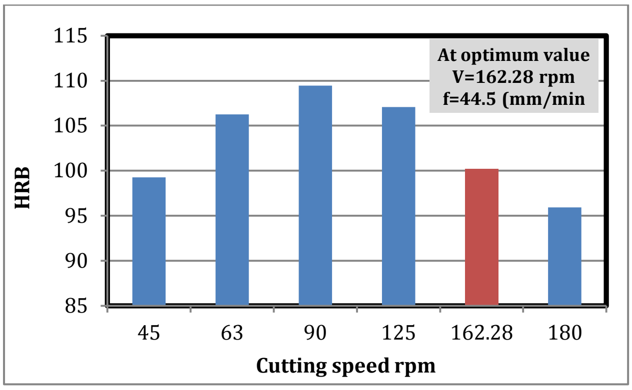

Figure 10 Optimum cutting speed which give good tooth hardness in addition to lower tooth surface roughness

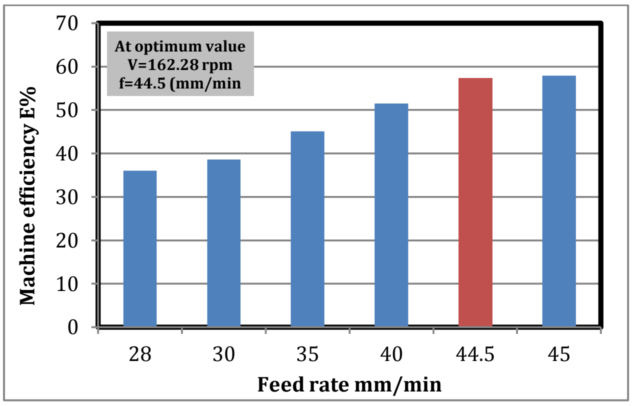

Figure 11 Optimum feed rate which give high machine efficiency in addition to good tooth hardness and lower tooth surface roughness

Table 2 Results of roughness factor and hardness at optimum value of cutting speed and feed rate

E%	HRB	Ra (µm)	Feed rate	Cutting speed (rpm)
57.34	162.28	1.24	44.53	100.19

Conclusions

The present work develops an empirical model to predict and find optimum values of cutting parameters (cutting speed and feed rate) using genetic algorithm which give good surface characteristics of spur gear tooth surface roughness that represented by roughness factor (*Ra*) and tooth hardness(HRB).From this work, the following conclusions could be reached:

- The optimum values of cutting speed and feed rate were achieved best surface characteristics of lower surface roughness and good hardness for spur gears tooth.
- Both cutting speed and feed rate have an obvious influence on the surface properties of gears tooth.
- At optimization conditions, sustainability achieved in machining performance and productivity.
- Surface roughness increase as cutting speed increase and feed rate decrease.
- It can be seen that cutting speed has the greatest influence on hardness of gears tooth, while it cannot seen significant of feed rate on the hardness.
- Genetic algorithm method is effective process to find optimum machining parameters which achieved multi-objective function of surface roughness and hardness of gears tooth.
- The discovered empirical equations were agreed well with experimental results.

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