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Experimental Study on Parameters of P-20 Steel in CNC milling machine

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Abstract. Milling is the most common form of machining process used in the production of moulds/dies, due to the high tolerances and surface finishes by cutting away the unwanted material. The selection of Pre-hardened steel (P-20) is widely used in production of moulds/dies because of less wear resistance and are used for large components. Due to extensive use of highly automated machine tools in the industry, manufacturing requires reliable models and methods for the prediction of output performance of machining processes. The major objective of the present study is experimental analysis of machining parameters in end milling for surface roughness by considering the input parameters such as cutting speed, feed rate, depth of cut, cryogenic soaking duration.

1. Introduction

Several factors will influence the final surface roughness in a CNC milling operation. The final surface roughness might be considered as the sum of two independent effects. The ideal surface roughness is a result of the geometry of the tool & feed and the natural surface roughness is a result of the irregularities in the cutting operation [1].

Factors such as spindle speed, feed rate, axial depth of cut & radial depth of cut, Nose radius that control the cutting operation can be set up in advance. However factors such as tool geometry, tool wear, chip loads and chip formations or the material properties of both tool and work piece are uncontrolled. Even in the occurrence of chatter or vibrations of the machine tool, defects in the structure of the work material, wear of tool or irregularities of the chip formation contribute to the surface damage in practice during machining [2]. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place. As a starting point for determining cutting parameters, technologists could use the hands on data tables that are furnished in data hand books. Kumar et. al.[3] suggested that are trial and error approach could be followed in order to obtain the optimal machining conditions for a particular operation. To achieve the desired surface finish one should develop techniques to model, prediction and optimizing the surface finish of a product before milling in order to evaluate the fitness of machining parameters such as Nose radius, spindle speed, feed rate, axial depth of cut and radial depth of cut for keeping the desired surface finish and increasing product quality [4].

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2. Literature Survey

A milling machine is a machine tool that removes metal as the work is fed against a rotating multi-point cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. The machine can hold one or more number of cutters at a time. This is why a milling machine finds wide application in production work. This is superior to other machines as regards accuracy and better surface finish, and is designed for machining a variety of tool room work.

2.1. Machining Parameters

The machining process depends upon several parameters such as the work piece material, the cutting tool material, the rigidity of the machine, the rigidity of the work piece, cutting speed, feed, axial depth of cut, radial depth of cut, chatter, tool wear etc. Some of them that we have considered in this project work are described below:

2.1.1. Cutting Speed

The speed of milling cutter is its peripheral linear speed resulting from rotation. It is normally expressed in terms of surface speed in “m/min”. The cutting speed can be derived as shown in equation (1)

$$N= (1000*V) / (\pi *d) \tag{1}$$

2.1.2 *Feed Rate*

The feed rate in milling machine is defined as the rate with which the work piece advances under the cutter. The Units are expressed in “mm/min” or “mm/rev” or “mm/tooth”. The feed is expressed in a milling machine by the different methods.

Abbas Fadhel Ibraheem et.al.[5] investigated the effect of cutting speed, feed, axial and radial depth of cut on cutting force in machining of modified AISI P20 tool steel in end milling process. They concluded that, higher the feed rates, larger the cutting forces. They also developed the genetic network model to predict the cutting forces. Muammer Nalbant et.al.[6] used the multiple regression analysis and artificial neural network models for predicting the surface roughness in turning of AISI 1030 steel material. These techniques used full factorial design and analysis of variance (ANOVA). According to them, Surface roughness increases with increase of feed rate but decreases with increase of insert nose radius. R.A. Ekanayake and P. Mathew [7], investigated the effect of cutting speed, feed and depth of cut on cutting forces with different inserts while milling AISI1020 steel. According to them, the tool offsets and run-outs affect significantly on the cutting forces when it comes to high speed milling, where small cut sections are employed. This can cause uneven wear of the tool tips due to uneven chip loads. Lajis et al.[8] developed the response surface model to predict the tool life in end milling of hardened steel AISI D2. This technique used central composite design in the design of experiments and ANOVA. The objective was to obtain the contribution percentages o f the cutting parameters (cutting speed, feed and depth of cut) on the tool life. Richard Dewes et al.[9] carried out the study on rapid machining of hardened AISI H13 and D2 moulds, dies and press tools. The primary objective was to assess the drilling and tapping of AISI D2 and H13 with carbide cutting tools, in terms of tool life, work piece quality, productivity and costs. The secondary aim was to assess the performance of a number of water-based dielectric fluids, intended primarily for EDM operations, against a standard soluble oil cutting fluid, in order to assess the feasibility of a duplex machining arrangement involving HSM and EDM on one machine tool. Mohammad Reza Soleymani Yazdi and Saeed Zare Chavoshi [10], studied the effect of cutting parameters and cutting forces on rough and finish surface operation and material removal rate (MRR) of AL6061 in CNC face milling operation. The objective was to develop the multiple regression analysis and artificial neural network models for predicting the surface roughness and material removal rate. According to them, in rough operation, the feed rate and depth of cut are the most significant effect parameters on R_a and MRR and increases with the increase of the cutting forces.

Abou-El-Hossein et al.[11] predicted the cutting forces in an end milling operation of modified AISI P20 tool steel using the response surface methodology (RSM) and Minitab software. Khalid Hafiz et al.[12] developed the response surface model to predict the tool life in end milling of hardened steel AISI H13 hardened tool steel. This technique used central composite design in the design of experiments and ANOVA. The objective was to obtain the contribution percentages o f the cutting parameters (cutting speed, feed and depth of cut) on the tool life. Rahman et al.[13] compared the machinability of the P20 mould steel (357 HB) in dry and wet milling conditions. They considered a range of 75–125 m/min for the cutting speed and a feed ranging between 0.3 and 0.7 mm/tooth: they found the cutting forces in both processes to be similar, but with the flank wear acceleration higher in dry milling. Furthermore, they observed a better surface finish with wet milling. Nirmal S. Kalsi et al. [17] made a thorough examination of the systems followed in CTs and their impacts on properties of materials by differentiating CT from the cryogenic conditioning of the procedure. Long soaking periods from 24 h to 36 h, contingent upon the properties of the material, with most minimal conceivable soaking temperature in CT, are favored keeping in mind the end goal to accomplish greatest wear resistance. It was reported that Parameters like cooling temperature, soaking duration, austenitization temperature, quenching, warming-up cycle, and tempering cycle needs further investigations to optimize the process for various materials. Adem Cicek et al. [18] various examinations were performed on the hard turning of cryo-treated AISI H13 hot-work tool steel with two ceramic inserts under both wet and dry cutting conditions. Three classes of the hot-work tool steel were turned in the machinability studies: conventionally heat treated (CHT), cryogenically treated (CT) and cryogenically treated and tempered (CTT). Experimental results demonstrated that the most reduced wear and surface roughness (Ra) qualities were obtained in the turning of the CTT tests. Furthermore, regarding main cutting force (Fc), the surface roughness (Ra) and tool wear, Ti[C, N]-blended alumina inserts (CC650) demonstrated a preferable execution over SiC whisker reinforced alumina embeds (CC670) under both wet and dry cutting conditions.

The main findings from the literature survey are that efforts were mainly focussed on optimization of only single performance characteristics in CNC milling. Not much work has been done on optimization of parameters such as deep cryogenically treated soaking duration of end mill cutting tools, cryogenically treated different cutting tool materials, etc.,

So to bridge this gap, a series of machining experiments with different cryogenic soaking duration (time) on tungsten carbide end mill cutters were conducted. The aim of this paper is to identify the effect of deep cryogenic treatment soaking duration on tungsten carbide tipped end mill cutter and optimize the milling parameters to get the better surface finish, higher material removal rate and decrease tool wear rate.

3. Experimental Details

The tool material selected for the present investigation was carbide tipped end mill cutter with four flutes which are the most extensively utilized cutting tool material in today's metal cutting industry. The commercially available carbide tipped end mill cutter with 12mm diameter, 40mm long (ISO specification) with four flutes were procured for machining of P20 steel with dimensions 100x100x10mm with chemical composition of Carbon 0.28-0.4%, chromium 1.4-2%, Iron balance, manganese 0.6-1%, Molybdenum 0.3-0.55%, silicon 0.2-0.8%, sulphur 0.03 % (max). They have the hardness in the range of 28-37 HRC. Three different groups of end mill cutters were obtained as Untreated (UT), Cryo treated (CT) with soaking duration 24hrs, cryo treated (CT) with soaking duration 36 hrs respectively. Tools have been subjected to deep cryogenic treatment in which they were cryo treated in the indigenously developed cryo treatment system for 24 hours and 36 hours at 98K with 5 hours of cooling and 9 hours of warm up to room temperature. The entire cryo treatment process took nearly 38 hours consuming nearly 500 liters of LN2. The details of the cryo treatment system are discussed below. The machining parameters used and their levels chosen are given in Table 1. The design of experiments (DOE) technique has been utilized to perform the experiments. It is a powerful work tool which allows us to model and analyze the influence of determined process variables over the specified variables, which are generally known as response variables. These response variables are unknown functions of the previous design variables, also known as design factors. Within the DOE, there are different types that can be considered. One of the most widely known ones is the Response Surface Methodology (RSM). A box-behnken design of response surface methodology [17] is used to collect data for the study because it performs non-sequential experiments having fewer design points. It works in the safe operating zone for the process as such a design does not have axial points. Twenty-nine experimental runs need to be performed in Box–Behnken design.

The surface roughness (Ra) of machined surface of the work material is measured by a portable surface tester as shown in Figure 1. Surface roughness measurements on the work material, in the transverse direction, are repeated five times and an average of five readings of surface roughness values are noted down and tabulated. A similar type of calculation has been reported elsewhere [17].

Table 1 Machining Parameters and Their Levels

Control parameters	Symbol	Levels		
		Level 1	Level 2	Level 3
Cutting speed(m/min)	v	75	85	95
Feed rate(mm/tooth)	f	0.1	0.15	0.2
Axial depth of cut(mm)	d	0.5	1	1.5
Cryogenic Soaking duration(hours)	Hrs	0	24	36

Figure 1. Taylor Hobson Surtronic 3+ machine

4. Results and discussions

As mentioned earlier, cryo-treatment trials were conducted on the carbide tipped end mill cutters. The analysis was done on the experimental data collected based on box Behnken design to establish the connection of various parameters on the responses using Analysis of Variance (ANOVA) at a significant level of 0.05. The experimental results are presented in below Table 2.

The equations (3) - (5) in terms of coded factors obtained through Regression analysis is given below:

MRR = $619.31 + 124.48 \times A + 61.45 \times B + 122.50 \times C + 160.78 \times D - 11.66 \times AB + 116.15 \times AC + 129.13 \times AD + 22.26 \times BC + 62.18 \times BD + 58.50 \times CD - 24.46 \times A^2 - 30.07 \times B^2 - 54.15 \times C^2 + 26.47 \times D^2$ (3)

TWR = $65.40 + 5.15 \times A + 0.27 \times B + 4.40 \times C - 22.63 \times D + 1.53 \times AB + 5.22 \times AC - 3.90 \times AD + 2.63 \times BC + 0.18 \times BD - 0.16 \times CD - 2.98 \times A^2 - 2.03 \times B^2 - 1.14 \times C^2 - 0.48 \times D^2$ (4)

Surface Roughness = $1.28 - 0.17 \times A + 0.068 \times B + 0.10 \times C - 0.48 \times D + 0.010 \times AB + 0.082 \times AC - 0.026 \times AD - 0.10 \times BC - 0.071 \times BD - 0.053 \times CD - 0.060 \times A^2 + 0.046 \times B^2 - 0.039 \times C^2 - 0.31 \times D^2$ (5)

Table 2 Experimental results

S. No	Cutting Speed(m/min)	Feed (mm/tooth)	Depth of cut(mm)	Cryogenic soaking duration (Hours)	MRR (mm^3/min)	TWR (mm^3/min)	Surface Roughness(R_a) (microns)
1	85	0.20	1.50	24	848.07	65.32	1.15
2	85	0.15	1.00	24	636.05	54.32	1.01
3	85	0.15	1.50	36	763.26	45.32	0.44
4	85	0.10	0.50	24	424.03	48.86	0.85
5	85	0.15	0.50	0	424.03	85.65	1.32
6	85	0.10	1.00	0	381.63	82.51	1.35
7	85	0.20	1.00	0	466.44	80.35	1.58
8	75	0.15	1.00	36	466.44	35.23	0.52
9	85	0.15	1.00	24	835	75.32	1.01
10	95	0.15	0.50	24	508.84	42.32	0.41
11	95	0.20	1.00	24	720.86	60.52	0.96
12	85	0.20	1.00	36	1060.09	38.51	0.48
13	95	0.15	1.00	36	1187.30	40.81	0.36
14	75	0.15	0.50	24	424.03	50.62	1.15
15	95	0.15	1.50	24	1045.32	63.24	0.95
16	85	0.10	1.50	24	720.86	52.35	1.12
17	95	0.15	1.00	0	508.84	95.32	1.31
18	85	0.10	1.00	36	640.29	42.31	0.58
19	75	0.20	1.00	24	551.24	46.52	1.24
20	85	0.15	0.50	36	504.60	39.31	0.48
21	75	0.15	1.00	0	411.31	75.68	1.48
22	85	0.15	1.00	24	636.05	53.55	1.05
23	85	0.15	1.50	0	500.36	93.52	1.56
24	85	0.15	1.00	24	636.05	53.55	1.05
25	75	0.10	1.00	24	411.31	52.45	1.24
26	75	0.15	1.50	24	496.12	50.67	1.36
27	95	0.10	1.00	24	627.57	60.34	0.92
28	85	0.20	0.50	24	462.20	51.32	1.28
29	85	0.15	1.00	24	636.05	52.3	1.32

4.1 Formulation of Multi-objective optimization

The three objective studies considered in this study are:
1) Maximization of Material Removal Rate
2) Minimization of Tool wear rate
3) Minimization of surface roughness

The three objective functions are optimized based on the feasible set of input variables. The optimization problem is defined as follows:

Maximize MRR
Minimize TWR
Minimize Surface Roughness (Ra)

Subject to

$75 \leq A \leq 95$

$0.1 \leq B \leq 0.2$

$0.5 \leq C \leq 1.5$

$0 \leq D \leq 36$

Where A is Cutting Speed, B is feed, C is the depth of cut, and D is cryogenic soaking duration.
The optimal results obtained from the RSM is shown in the below Table 3. The optimized solutions from response surface methodology are shown in Table 3.

Table 3 The optimized solutions

S.No.	Cutting Speed(m/min)	Feed rate(mm)	Depth of cut (mm)	Cryogenic soaking duration(hrs)	MRR (mm^3/min)	TWR (mm^3/min)	Surface Roughness (microns)	Desirability	
1	95.000	0.200	1.113	36.000	1187.303	43.194	0.300	0.954	Selected

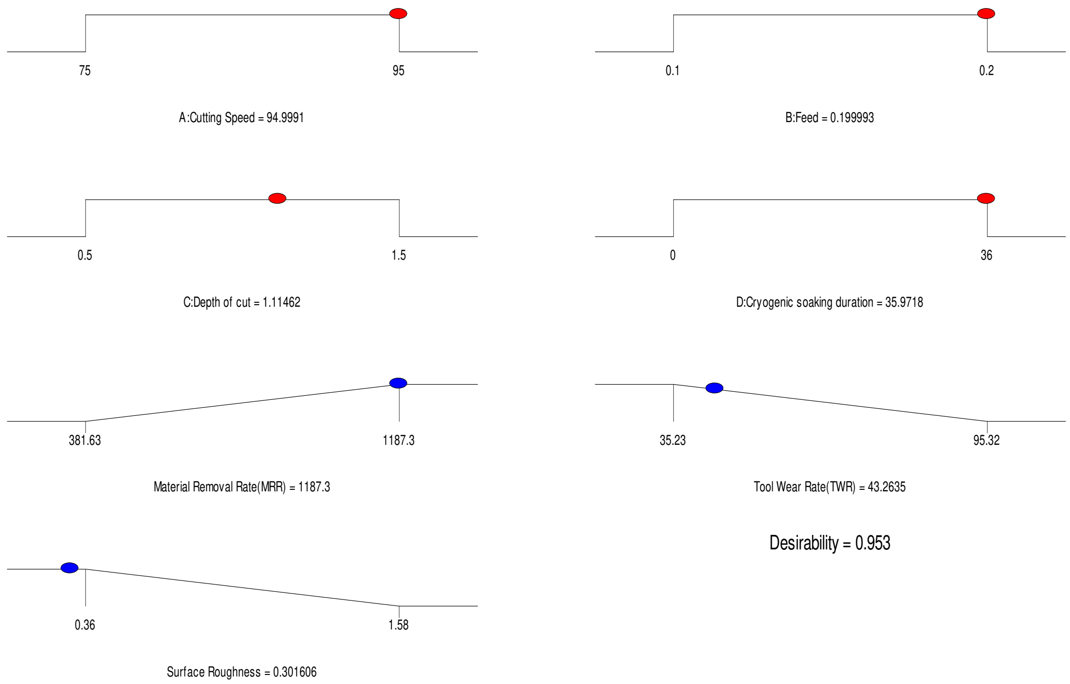

Figure. 2 Optimal conditions desirability chart

Table 4 Confirmation test results

Cutting speed	Feed Rate	Depth of cut	Cryogenic soaking duration	MRR			TWR			Ra		
				Predicted	Actual	%Error	Predicted	Actual	%Error	Predicted	Actual	% Error
95	0.2	1.11	36	1187.3	1150.5	3.2%	43.19	41.52	4%	0.30	0.285	5%

With RSM, it was determined that optimal conditions from Figure. 2 that should be used to achieve the objective are cutting speed is 94.99 mm/min, the feed is 0.199 mm/tooth, depth of cut is 1.114 mm, the cryogenic soaking duration is 35.91 hours.
In order to validate the results obtained from RSM, a confirmation test was performed and compared with the results and tabulated in Table 4. From the confirmation test, it can be seen that less % error which shows that the predicted results have good agreement with the experimental results.

5. Conclusions

Based on the experimentation and analysis of the results, the conclusion can be made as follows:

1. The deep cryogenic treatment can significantly improve the life of the end mill carbide cutting tools. However long cryogenic soaking duration is mostly influencing the tool wear compared to other soaking duration.
2. Tool life can be increased by long Deep cryogenic soaking duration cutting tools for higher machining speeds.

The surface roughness of the workpiece is improved mainly due to the reduction of tool wear rate by treating at deep cryogenic conditions. These reductions in tool wear rate and improved surface roughness causes increased tool life and enhancement of productivity

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