Investigations and Optimization of process parameters for Improving surface quality in the Internal Grinding of EN31 Steel

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ABSTRACT

In an industry Internal Grinding is one of the most important machining processes. In this process surface quality is most expected outcome to obtain the better result. Due to complexity and nonlinearity optimization of grinding process is a challenging task. From the literature, it was noted that many of the researchers were focused on only external surfaces of a component for improving its surface quality. It is identified that very few papers deliberated the characteristics of internal grinding process which indicates that, there is a considerable research potential in improving the product quality and process performance of internal grinding. This paper aims to optimize the internal grinding process parameters to increase the expected surface quality and process performance. Similar to external surface grinding process, internal surface grinding is also influenced by parameters such as cutting speed, feed and depth of cut. Considering the variance in optimized results, different samples of EN31 steel are taken into this experimental study. From the literature, it is identified that commonly used engineering materials in many engineering applications are EN 31 Steel. The various machining parameters such as feed, cutting speed, depth of cut were monitored to analyze the process responses such as surface quality. The effect of input and output parameters was described through the ‘‘signal to noise ratio” (SNR) and ‘‘analysis of variance (ANOVA)” using Minitab 18 software. The machining parameters were optimized through Taguchi method and Genetic Algorithm tools. By analyzing the final results, optimum working conditions are recommended to improved surface quality with respect to selected input process parameters.

1. INTRODUCTION

George et al., (2013) This seminar presents the experimental work/project done on studying the working of cylindrical grinding machine and effect of its process parameters Cylindrical grinding is one of the important metal cutting processes used extensively in the finishing operations. Surface finish is the important output responses in the production with respect to quantity and quality respectively[1].Daneshi et al., (2014) Performance of grinding operation is influenced by a variety of factors amongst which dressing process is the most important. Through the dressing process, the grinding wheel topography is produced. This affects, in turn, directly the grinding forces, work piece surface quality and grinding wheel wear. This research aims to develop appropriate dressing strategies for small abrasive wheels in internal cylindrical grinding [2]. Mei-Ling et al., (2016) Piston is one of the important parts for aircraft engine, and the quality of piston affects the efficiency and safety of the engine. This study applies Taguchi method, response surface methodology (RSM), and back propagation neural networks (BPNN) combining with genetic algorithm (GA) on the quality improvement of piston manufacturing processes to enhance the process yield. The Taguchi parameter design concerns three nominal-the-best specifications, including ring groove diameter specification, inner groove diameter specification, and inner diameter of pistons [3].Li Zheng et al., (2016) In order to develop the high-efficiency and precision machining technique of TiCp/Ti–6Al–4V particulate reinforced titanium matrix composites (PTMCs), high-speed grinding experiments were conducted using the single- layer electroplated cubic boron nitride (CBN) wheel and brazed CBN wheel, respectively. The comparative grinding performance was studied in terms of grinding force, grinding temperature, grinding-induced surface features and defects [4]. Puerto et al., (2013) Grinding is a machining process specially indicated for finishing operations in hard materials, in order to obtain low surface roughness (Ra 0.1 m to 2 m) and tight tolerances. The cutting tool is the grinding wheel which is formed by abrasive particles attached in a bond. The wear of these abrasive particles modifies significantly the roughness obtained in the work piece. In this work, the evolution of part roughness has been continuously monitored as the grinding process progresses and the wheel gets worn. The roughness evolution is then related to different process variables such as the dressing parameters, the grinding conditions, the grinding forces and the radial wear of the wheel [5]. Holtermann et al., (2016) Internal traverse grinding with electroplated CBN wheels using high-speed process conditions combines’ high material removal rates and a high surface quality of the work piece in one single grinding stroke. In order to capture the macroscopic and macroscopic thermo-mechanical loads onto the work piece during internal traverse grinding, numerical simulations are conducted at the two scales. This result in a hybrid approach coupling two finite element models with a geometric kinematic simulation.[6].Jayanti Das et al., (2016) Manual grinding operations are influenced by a number of variants such as a worker's posture and motion, in addition to the general parameters affecting automated grinding processes, for example, tool speed and feed rate. Moreover, dry cutting conditions and poor control of the machining process can negatively influence chip formation and part quality in terms of roughness, micro hardness, microstructure, etc. For this paper, we have limited our subject to one and thus have not studied the effect of worker's skills involved in manual grinding [7]. Mahajan et al., (2015) In grinding process, Surface quality and metal removal rate are the two important performance characteristics to be consider. In this paper, Taguchi L9 orthogonal array optimization method has been used to determine the optimum machining parameters in Surface grinding process operation on AISI D2 steel. The parameters considered in this paper are grinding wheel abrasive grain size, wheel speed, table speed and depth of cut. Empirical models are developed for surface roughness and metal removal rate by considering above parameters as control factors [8]. Dasthagiri et al., (2015) In the manufacturing sector, producing smooth surface finish plays an important role. To fulfill this smooth finish, surface grinding process is mostly used in which the parameters to be considered are surface quality and metal removal rate. Several factors which include depth of cut, wheel grade, wheel speed, material properties and table speed affects the machining process economics. This paper mainly focuses on developing the empirical models using response surface methodology for surface roughness and metal removal rate by considering control factors as wheel speed, table speed and depth of cut [9]. Rekha et al., (2014) The present work describes an application of hybrid approach using neural network (NN) and genetic algorithm (GA) for modeling and optimizing the process parameters in cylindrical grinding of AISI 316 stainless steel. In this study, each experiment was conducted under different machining conditions of cutting speed, feed rate and depth of cut, and machining performance such as surface roughness and metal removal rate were evaluated [10].Sandeep Kumar et al., (2015) As per the modern Industrial requirements, higher surface finish mechanical components and mating parts with close limits and tolerances, is one of the most important requirement. Abrasive machining processes are generally the last operations performed on manufactured products for higher surface finishing and for fine or small scale material removal. Higher surface finish and high rate of removal can be obtained if a large number of grains act together. This is accomplished by using bonded abrasives as in grinding wheel or by modern machining processes[11].

Vairamuthu et al., (2016) Material removal processes are one among several manufacturing processes that necessitates the enhancement of their precision capability to cater the demanding needs of higher technological innovations. The performance of a material removal process depends on several factors like the precision of the machine tool, process parameters, process consumables and to a certain extent on the skill of the operator. This paper presents an approach to develop a diagnostic system that can enhance the performance of cylindrical grinding process by monitoring vital process signals like grinding power and in feed of axis[12].Onwuka et al., (2016) Borosilicate (BK7) is widely applied in the automotive and optics industries for the production of a number of critical optical components. In normal manufacturing practice, the surfaces of BK7 components undergoes a series of manufacturing operations, such as grinding, polishing and lapping, in order to obtain Nano metric finish with high optical quality. In this study, we used an ultra-high precision grinding spindle mounted on ultra-high precision machine tool to machine flat surfaces from BK7. The process was observed by monitoring its acoustic signals which were acquired at a high sampling rate. Three grinding parameters, depth of cut, feed rate and wheel speed, were varied in this study [13].AbuBakkar et al., (2017) Cylindrical grinding machining is the most popular machining process of removing metal from a work piece surface in the form of tiny chips by the action of irregularly shaped abrasive particles. It has wide range of applications like automobile, aircraft, and marine industries. Precision and quality have been the critical issues for all these industries. To enhance the quality of machined parts, and to reduce the machining costs and to increase the production rate, it is very important to select the optimal machining parameters. The success of any grinding operation depends upon the proper selection of various operating conditions like work speed, feed rate, depth of cut etc.[14].Ravi Kumar et al., (2017) Cylindrical grinding is a metal removing process which is used extensively in the finishing operation. Surface finish is an important output parameter in the manufacturing processes with respect to quality. Cylindrical grinding is an essential process for final machining of components requiring smooth surfaces and precise tolerances [15].Yalcinkaya et al., (2017) Surface finish and dimensional accuracy play a vital role in manufacturing engineering applications. Grinding is one of the most important methods for producing a better surface quality**.** This paper describes a study of the influences of cutting parameters such as table speed, depth of cut and feed rate on surface finish of AISI 2080 steels, based on the Taguchi (L27) method. The experimental results showed that the table speed was the machining parameter, which had a greater effect on the surface finish, followed by depth of cut, whereas feed rate showed no significant effect. Analysis of variance indicated that a better surface finish was obtained at 190 m/min speed, 0.003 mm depth of cut and 0.08 mm/rev feed rate [16]. Kaifei et al., (2015) Precision cylindrical surfaces have attracted considerable attention and interest, due to the continual pursuit of perfect quality and high- performance products. Especially in bearing industry, high-performance bearing often requires specific cylindrical surface properties such as high hardness, wear resistance, high strength, and toughness, because it is normally used in poor working environment. Besides, it is usually finished to a mirror-like surface for higher chemical stability. Most of enterprises adopt bearing steel to manufacture bearing components [17] .ShaowuGao et al., (2017) Internal traverse grinding has shown its great potential in precision machining of valves in fuel supply systems. When grinding such valves, long grinding wheels with small diameter are necessary. However, the poor stiffness of grinding wheels causes large deflection of wheel quill during grinding, resulting in deviation between nominal radial feed and actual radial feed, finally reducing the grinding efficiency and consistency of ground parts [18]. Jiang et al., (2017) Bearing raceway grinding process has a large influence on the work quality and the rotate accuracy of the bearings. Surface roughness and heat affected layer, which have a strong relationship with grinding process quality, are important factors relevant to the bearing raceway surface quality [19].Pil-Ho Lee et al., (2015) The objective of this study was to investigate the thermal characteristics of a micro-scale grinding process using nanofluid minimum quantity lubrication (MQL) with experimental and numerical analyses. In the experimental analysis, a series of micro-scale grinding experiments were conducted with the miniaturized machine tool system, and the sub-surface grinding temperatures and tangential grinding forces were measured with an embedded thermocouple and a load cell, respectively [20].Shuyun Jiang et al., (2018)The grinding coolant supply subs system consists of innersole manufactured in the shaft and a non-contact high-speed rotary union equipped with air seal. The test study confirms that the predict value of the spindle’s vibration is consistent with experimental value, while grinding coolant supply subsystem enables to transfer the coolant to the grinding zone in the small-deep hole [21].Mekala et al., (2015) Recently Austenitic stainless steel AISI-316 finding many applications like Automotive, Aerospace, Nuclear, Chemical and Cryogenics. The cylindrical grinding parameters on Austenitic stainless steel are conducted using Taguchi design of experiments of L9 orthogonal array was selected with 3 levels with 3 factors and output parameters of Metal removal rate are measured. After conducting experiment optimized by S/N ratio and analyzed by ANOVA and predict Cutting speed is a dominating parameter of cylindrical grinding [22]. Vila et al., (2012) This work deals with the technological and economic considerations required to select face milling vs. surface grinding operations in the manufacture of hardened steel flat surfaces for dies and moulds. In terms of technological considerations, factors such as component geometry, material and surface quality (dimensional tolerance and surface finish) are taken into account. The economic considerations include the cost of machine depreciation, labour and consumables (cutting tools in face milling vs. grinding wheels and dressing tool in surface grinding) [23]. Uhlmann et al., (2016) Grinding tool topography is one of the several key aspects of the modelling of a grinding process. Simplifying it could mean less processing time needed, but it can lead to inaccurate simulation results. Considering that, this research aims to develop a reliable method for NC-grinding processes with abrasive mounted points, describing the grinding tool surface using a single profile of kinematic cutting edges instead of its whole topography. In order to achieve this, numerical and empirical experiments were conducted proving the feasibility of the model to implement it for future simulations [24].Sanchit Kumar et al., (2015) Surface quality of the machined component is one of the most important criteria for the assessment of grinding process. The importance of the surface finish of a product depends upon its functional requirements. Since surface finish is governed by many factors, its experimental determination is laborious and time consuming. So the establishment of a model for the reliable prediction of surface roughness is still a key issue for grinding [25]. Melwin et al., (2014) OHNS steel is a widely preferred material for manufacturing of Die blocks, fasteners, automotive components and cutting tools. Metal removal rate is an important performance factor to be considered in grinding process. Research activities that include experimental work and statistical analysis help in improving quality standards of manufacturing of components. Surface quality of OHNS steel after cylindrical grinding process is proposed to be studied in this experimental work using L9 orthogonal array selected for three levels and three input parameters [26]. Biermann et al., (2014) Internal traverse grinding with electro-plated CBN wheels combines the advantages of both internal hard turning and internal grinding, enabling a high material removal rate along with a high surface quality. The drawback, however, is a high thermal load on the work piece, resulting in shape and dimension errors of the finished part. This paper deals with the compensation of these manufacturing errors with a hybrid simulation system. It combines thermo-mechanically coupled finite element models on both meso- and macro-scale with a scale-bridging kinematic simulation system, enabling the prediction of the resulting temperatures and the development of corresponding simulation-based compensation strategies[27].

Rahul R. Chakule et al., (2017) Grinding is a precision machining process widely used for close tolerance and good surface finish. Due to aggregate of geometrically undefined cutting edges and material removal in the form of microchips, grinding requires more specific energy as friction is greater in the grinding interface. The optimum use and proper penetration of coolant is the prime requirement which is achieved by effective cooling and lubrication. In this research, a greater focus is on MQL technique, which is economical and eco-friendly. The paper presents important aspects of the grinding process considering the surface roughness and cutting force. The experiments were carried out on horizontal surface grinding machine using Response surface methodology (RSM). In addition, evaluation of grinding performance parameters like coefficient of friction, cutting forces, temperature and specific grinding energy for different machining environments has been discussed. The lowest surface roughness and coefficient of friction observed was 0.1236 μm and 0.3906, respectively for MQL grinding, whereas lowest specific grinding energy was found as 18.95 N/mm2 in wet grinding. The temperature recorded in MQL grinding was 29.07 °C, which is marginally higher than wet condition. The response obtained as cutting forces, temperature and surface roughness under MQL mode encourages its use for machining AISI D3 type material compared to other grinding environments. Mathematical modeling showing the relation between the factors and response variables was established using Response surface methodology. Regression analysis was performed to determine the accuracy of mathematical model, significant factors and interaction effects of parameters on responses. [28]

L.Langenhorstet al.,(2018)Mechanical impact in grinding processes can improve the properties of the work piece surface and subsurface layer and therefore have a positive effect on the functional performance of the finished component. Although changes in the surface integrity in grinding are mostly temperature-induced, the present work implies that for grinding with flattened coarse grains the mechanical strains can be dominant. By conducting experiments with differently dressed coarse grained grinding wheels, the influence of the grain size and the cutting speed on mechanically induced material modifications could be confirmed. Furthermore, to systematically adjust the material modifications in the work piece surface layer within the process, these findings were used to get a more detailed understanding of the mechanical modification mechanisms. With the internal material loads, calculated in the presented modelling concept, a correlation between the local strains and local residual stresses can be shown. According to the experiments, the simulations indicate a positive effect on the mechanical impact, e.g. for lower cutting speeds. [29]

Le XuanHungetet al., (2019) A study on optimum calculation of the exchanged diameter of grinding wheels in internal grinding of stainless steel. In this study, the effects of the grinding process parameters including the initial diameter, the total depth of dressing cut, the wheel life, the radial grinding wheel wear per dress and the ratio between the length and the diameter of the work pieces on the exchanged grinding wheel diameter were explored. The influences of cost factors including the machine tool hourly rate and the grinding wheel cost were also investigated. To evaluate the effects of these parameters on the optimum exchanged grinding wheel diameter, a simulation experiment was created and performed by and a computer program. A proposed model to determine the optimum exchanged grinding wheel diameter was given based on the results of the study [30].

Krzysztof Nadolny, et al.,(2020) A new method of hybrid cooling and lubrication of the machining zone conducted in dry conditions on the example of internal cylindrical grinding of bearing rings. The idea of the method consists in simultaneous application of a cooling agent in the form of compressed cooled air generated by the cold air gun (CAG) nozzle and a solid antiadhesive and lubricating agent fed to the grinding zone in the form of an impregnate in grinding wheel. Hexagonal boron nitride HBN was used as impregnate. The method of hybrid supply of cooling and lubricating agents configured in such a way allows for dry machining process (without the use of liquid coolants), simultaneously performing the cooling and lubricating functions of liquid coolants in a different, more environmentally friendly form [31].

R.Sanjeeviet al., (2020) To predict the optimal solution of surface roughness using Response Surface Methodology in surface grinding machining process. Response surface Methodology extracted for input parameters preparation to surface grinding process. EN 24 steel machining with various speed, depth of cut and feed rate timing. The surface roughness of the machined work piece measured by the conventional stylus probe. Then input and output parameters feed into the RSM and developed ANOVA and regression equation to produce the optimal solution [32].

NesredinChekoleDeresse,et al., (2020)Under the machining process, there are several factors which exert influence on material removal rate(MRR), including cutting condition, tool variables, machine status and work piece variables. In the cylin-drical grinding process (CGP), it is not easy to consider all process parameters that device MRR because it needs much experimentation which results in the consumption of money, time and human resources. Thus, this study investigated the impact of process parameters in external CGP for EN45 steel material using the Taguchi method. The originality of this study is based on the presence of fewer or probably no experimental investigation on the EN45 material as the work piece that has been performed previously inoptimising process parameters using the Taguchi method on external cylindrical grinding and MRR. Thus, the obtained results are important after having established the machining parameters for EN45 steel materials. [33]

2. MATERIALS AND METHODS

During the literature review, the common engineering materials were identified. Based on the applications of these engineering materials, EN 31 Steel was selected for conducting the experiments in internal grinding [20-24]. The machining outcome of any material is based on its chemical compositions and mechanical properties which are directly related with characteristics. The chemical compositions and mechanical properties of the EN31 Steel material used in this study are presented in Table 2.1.

Table 2.1: Chemical compositions and Mechanical properties

Chemical compositions		**Mechanical properties**	
Carbon	1.30%	Yield Stress	450 N/mm^2
Silicon	0.30%	Elongation	30mm
Manganese	0.50%	Hardness	207 kg/mm^2
Sulphur	0.025%	Impact strength	22 Nm
		Tensile strength	750 N/mm^2

2.1.Experimental section

The work piece is fixed in the rotating chuck of the grinding machine and the machining process was carried out in the internal surface EN31 Steel shown in figure 2.1. During the experimental investigation, the input parameters such as feed, cutting speed and depth of cut were predetermined and fixed based on the machine capability.

Fig.2.1: Specimen with Internal Grinding process Fig.2.2: Surface Roughness Tester

The experiments were carried out in the specified machine with samples of EN31. These materials are subjected to wide variety of engineering applications as the materials for shafts, spindles, studs and so on. For the grinding of internal surfaces of the work piece, abrasive grinding wheel were used. This setup was exclusively created for conducting the experiments, which enables the change of feed, cutting speed and depth of cut. Each of the machining process was observed carefully and the input parameters were modified in a sequential manner. The surface roughness was selected as the output responses of this experimental work. In the internal grinding operation, more amount of heat is generated and to reduce heat suitable coolant was used. The surface roughness for each specimen was directly measured through the surface roughness tester. The experimental conditions, the parameters and responses are presented in the Table 3.1. The input parameters feed is changed in three levels 0.01mm/rev, 0.02mm/rev,0.03mm/rev; cutting speed is varied in three levels 800rpm, 1100rpm and 1400rpm; and depth of cut is chosen in three levels such as 0.1mm,0.2mm and 0.3mm. The input parameters were selected based on the machine capability. The output responses for each of the experiments based on these input parameters were measured suitably.

2.2.Surface roughness

The surface roughness of the machined work piece was measured directly after each experiment by using a surface roughness measuring device shown in Figure 2.2. In order to measure the output response, three measurements were recorded for each of the samples of the work piece for calculating the average surface roughness. The high precise demand of modern engineering products requires surface quality along with dimensional accuracy to be a vital requirement. The surface quality greatly influences the functioning of the machined parts wherever installed and operated.

3. RESULTS AND OPTIMIZATION

3.1.Design of Experiments

The three significant machining parameters are feed, cutting speed and depth of cut. These parameters are each considered at three levels for this work. The parameters and their levels are given in Table 3.1. The experimental design ($3^3= 9$) is given in Table 3.2 was selected for conducting the nine experiments as a part of this study.

Table 3.1. Parameters and their levels

Parameter	**Notation**	**1**	**2**	**3**
Feed (mm/rev)	A	0.01	0.02	0.03
Cutting Speed (rpm)	B	800	1100	1400
Depth of cut (mm)	C	0.1	0.2	0.3

The surface roughness of the work piece after internal grinding was measured at three different and the average surface roughness (Ra) was computed from these measurements. These details are presented in Table 3.3. The corresponding surface roughness and S/N Ratio values are calculated by using “smaller the better” formula given below.

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Table 3.2 Experiment Design

Ex. No.	**A**	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3.3 Surface Roughness after the internal grinding

Ex. No.	**A**	**B**	**C**	**Surface roughness (µm)**			
				R1	**R2**	**R3**	**Ra**
1	1	1	1	0.610	0.623	0.605	0.612
2	1	2	2	0.662	0.687	0.670	0.673
3	1	3	3	0.625	0.640	0.633	0.632
4	2	1	2	0.648	0.659	0.649	0.652
5	2	2	3	0.667	0.672	0.665	0.668
6	2	3	1	0.630	0.651	0.629	0.636
7	3	1	3	0.657	0.666	0.645	0.656

8	3	2	1	0.675	0.692	0.665	0.677
9	3	3	2	0.689	0.694	0.688	0.690

Taguchi method is a proficient problem solving tool, which can enhance the performance of any process with a considerable reduction in experimental time and cost. It uses special set of arrays called orthogonal arrays for the conduct of experiments and the concept of signal-to-noise (S/N) ratio, which jointly considers how effectively the mean value (signal) of the parameter and the amount of variability (noise) have been experienced. The quality characteristics frequently used are nominal- the-best, smaller-the-better. The S/N ratio depends on the quality characteristics of the process to be optimized. The S/N Ratio and average responses values are shown in table 3.4 and 3.5. The variation in feed, cutting speed and depth of cut values for EN31steel with respect to surface roughness is graphically shown in figure 3.1.

Here, the S/N ratio curve indicates the operating conditions of machining in which feed rate is highly influencing the surface quality. The increasing feed rate increases the amount of material removed but not quality of machining. When the feed rate is more, the surface roughness is high. Depth of cut and cutting speed is the other factors which also affect the surface quality. Surface roughness decreases with decrease in depth of cut. The percentage contribution of surface roughness based on S/N ratio and ANOVA shown in figure 3.2 and 3.3.

Ex no	A	B	C	Surface roughness, **µm**	S/N ratio
1	1	1	1	0.612	4.26497
2	1	2	2	0.673	3.43970
3	1	3	3	0.632	3.98566
4	2	1	2	0.652	3.71505
5	2	2	3	0.668	3.50447
6	2	3	1	0.636	3.93086
7	3	1	3	0.656	3.66192
8	3	2	1	0.677	3.38823
9	3	3	2	0.690	3.22302

	A	**B**	**C**
Level 1	3.897	3.881	3.861
Level 2	3.717	3.444	3.459
Level 3	3.424	3.713	3.717
Max-Min	0.472	0.437	0.402

% Contribution	36.00	33.33	30.66

Table 3.4: S/N ratio &Surface Roughness Table 3.5: Average S/N Ratio response

Fig. 3.1: Response graph of EN31 surface Roughness Fig. 3.2: Percentage contributions of Surface roughness based on S/N ratio

Table 3.6 ANOVA of EN31Steel Surface Roughness

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**%**
A	2	0.001916	0.000958	141.36	0.007	38.69
B	2	0.001628	0.000814	120.07	0.008	32.88
C	2	0.001394	0.000697	102.80	0.010	28.15
Error	2	0.000016	0.000007			0.32
Total	8	0.004951				100.00

Fig.3.3: Percentage Contribution of Surface Roughness based on ANOVA

3.2 . Genetic Algorithm

Genetic algorithm (GA) is a well suited heuristic technique that can find global optimum solution by searching the space with a high probability. The genetic operators i.e. reproduction, crossover and mutation provide ways of defining new populations from existing populations.

The effect of internal grinding parameters on average surface roughness (Ravg) was evaluated by using non-linear regression analysis with the help of MINITAB software. Non-linear regression model developed is shown in Figure 3.4 and is given in the form Equation (3.1)

Ravg = 0.5278 + 0.0008 Feed - 0.0298 Cutting speed + 0.1387 Depth of cut + 0.0350 Feed x cutting speed - 0.0329 feed x depth of cut - 0.0251cutting speed x depth of cut.(3.1)

It was noticed that $r^2 = 0.966$ where ‘r’ is correlation coefficient. The value of r^2 specifies the closeness of the model signifying the process. Since r^2 is approaching unity, this equation can be considered as an objective function to use it for genetic algorithm which predicts the better parameter setting.

Fig.3.4: Non-linear Regression Model

Fig.3.5: GA generation

The Figure 3.5 depicts that there is a subsequent reduction in the fitness value through generations and the optimized surface roughness in the final generation is 0.511045μm. It is observed from the final generation that the optimal conditions for the parameters like feed, cutting speed and depth of cut were found as 0.01 mm/rev, 800 rpm and 0.1mm respectively.

3.3 Confirmation analysis

The confirmation experiments were carried out for the optimum parametric condition determined through Taguchi Method and genetic algorithm. The average surface roughness (predicted and tested) values are given in Table 3.7. It is evident that the experimental results on the surface roughness are found to be in good agreement with predictions from analytical models.

Optimization tool	**Optimum parametric condition**			**Average Surface Roughness, (µm)**		**% error**
	Parameters	**Coded**	**Un coded**	**Predicted**	**Tested**	
Taguchi method	Feed	1	0.01	0.614	0.612	0.32
	Cutting speed	1	800			
	Depth of cut	1	0.1			
Genetic algorithm	Feed	1	0.01	0.610	0.611	0.16
	Cutting speed	1	800			
	Depth of cut	1	0.1			

Table 3.7 Optimum parametric conditions

The optimum parametric setting for feed (0.01 mm/rev), cutting speed (800 rpm) and depth of cut (0.1mm) was noted to be same in the Taguchi method and Genetic algorithm. With respect to cutting speed, the optimum setting of genetic algorithm is lesser than the setting of Taguchi method. It is expected that the decrease in cutting speed could result in fine surface finish during internal grinding operation. From the confirmation experiments, it was verified that genetic algorithm would give better optimized value than Taguchi method with respect to surface quality.

4. CONCLUSION

The experimental investigations on the internal grinding process were intensively carried out with certain, selected parameters and outcomes. The outputs may vary with reference to the environmental conditions and advancement in machine tool technology. However, under the specified working conditions and material properties, the following results were obtained. From that we conclude that,

- Feed is highly influencing parameter directly involving in enhancement of surface quality and material removal rate to the next level.
- Depth of cut creates an intensive impact on surface quality and its improvement with lesser depth of cut leading to smaller surface roughness values and thereby improving the surface finish.
- These three parameters are alternatively influencing the output characteristics; which was optimized for the selected materials, by using optimization tools such as Taguchi method and Genetic Algorithm.
- By considering the selected materials, the outcome parameters were highly positive for EN31 Steel as it is evident from higher surface quality.
- From the confirmation experiments, it is evident that the error occurred was nominal range of less than 5% between predicted and tested value which ensures the optimized working condition.

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