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Research Paper

MULTI RESPONSE OPTIMIZATION ON AISI 410 AND EN 19 STEEL IN TURNING OPERATION USING GREY RELATIONAL ANALYSIS

V Vignesh Kumar[1]*, K Raja[2], P Marimuthuc[3] and K Chandrasekaran[2]

*Corresponding Author: V Vignesh Kumar, ✉ vigneshkumar.sit@gmail.com

The machining industries are focused primarily on the attainment of high quality, excellent surface finish, high production rate, economy of machining. Surface Roughness (SR) of a product is very essential in determining the quality and Material Removal Rate (MRR) is an important to increase the making rate. In turning operation, there are many parameters such as cutting speed, depth of cut and feed rate that have great force on the response. Optimized cutting parameters are very important for controlling the required SR and MRR. The focal point of present experimental study is to optimize the cutting parameters for CNC turning on AISI410 and EN 19 steel during dry condition. The multi layered of 6 µm with titanium coated cutting inserts is used for turning all the trials. Multi response optimization of cutting parameters is obtained by using Grey Relational Analysis (GRA). Analysis of variance (ANOVA) is engaged to study the performance characteristics of machining parameters. Thus, it is possible to increase machine utilization and reduction of production cost in an automated manufacturing environment.

Keywords: AISI410, EN19 steel, Grey relational analysis, Material removal rate, Surface roughness, ANOVA

INTRODUCTION

Highly competitive market requires high quality products at minimum cost, products are manufactured by the transformation of raw materials. Industries in which the cost of raw material is a big percentage of the cost of finished goods, higher productivity can be achieved through proper selection and use of the materials (Mahapatra, 2006). Machining process is very important in manufacturing technology. These processes are applied for manufacturing the mechanical parts. Because of these processes have efficient and economical. There are many parameters to be

1 Department of Mechanical Engineering, Anna University, Regional Office, Madurai, Tamil Nadu, India.
2 Department of Mechanical Engineering, University College of Engineering, Anna University, Ramanathapuram, Tamil Nadu, India.
3 Department of Mechanical Engineering, Syed Ammal Engineering College, Ramanathapuram, Tamil Nadu, India.

considered for affecting the surface quality (Tosun, and Ozler, 2000; and Suhail *et al.*, 2010). Turning is the primary operation in most of the production process in the industry, surface finish of turned components has greater influence on the quality of the product Surface finish in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work hardness, unstable built up edge, speed, depth of cut, cutting time, use of cutting fluids, etc. (Trent, 1989; and Wardancy and Elestawi, 1997). There are three primary input control parameters in the basic turning operations. They are feed, spindle speed and depth of cut. Feed is the rate at which the tool advances along its cutting path. Speed always refers to the spindle and the work piece. Depth of cut is the thickness of the material that is removed by one pass of the cutting tool over the work piece (Selvaraj and Philip, 2010).

SR has a great impact and therefore industries are focusing on achieving high quality surface finished products by measuring surface finish of the material, machinability of the material can be determined. It greatly affects the performance of manufacturing cost and mechanical parts as well (Selvam, 1975). SR is one of the important responses for machined product quality. SR is affecting the functional behavior of the mechanical products. The mechanism of SR formation depends on various uncontrollable parameters that make its estimation difficult (Lasota and Rusek, 1983; and Diwakar Reddy and Krishnaiah, 2011). Surface finish also known as surface texture, are the characteristics of a surface and are a quantity to actuate the machinability of various materials. Surface roughness greatly affects the performance of production expenses as well as the mechanical parts. Optimization of machining factors increases the utility for machining economics and the product quality is also increased to a great extent as well (Anish Kumar *et al.*, 2012; Bhaskar Reddy *et al.*, 2012). Martensitic stainless steels (AISI410) are used many commercial and industrial applications. Such as reactor pressure vessel, heat exchanger, chemical container and nuclear processing plant, etc. AISI410 are generally regarded as being more difficult to machine material compare to carbon and other alloy steels due to their high strength, ductility and high work hardening tendency (Abdul Kareem *et al.*, 2011). Stainless steels are having different grades and different properties under variation of chemical compositions. Therefore, these variations in their properties have an influence on their machinablities (Liew *et al.*, 2003; and Senthikumar *et al.*, 2006).

En-19 is a high quality, high tensile alloy steel usually ready to machine, giving good ductility and shock resisting properties combined with resistance to wear (Vivek John *et al.*, 2013). In the Taguchi design of experiment method the parameters factors which can be controlled and noise factors which can't be controlled and which influence product qualities are considered. EN-19 was originally introduced for the use in the machine tool and motor industries for gears, pinions, shaft, and spindles, now widely used in areas like oil and gas industries. A considerable number of studies have investigated the general effects of various cutting parameters on the surface roughness (Bhaskar Reddy *et al.*, 2012; Rahul Davis and Mohamed Alazhari, 2012). Only a limited number of research articles are available on the turning of AISI410 and EN19 steel. Various compositions of cutting tools were used by past researchers for turning. However, comparisons of turning on AISI410 and EN19 with Titanium coated cutting tool during dry conditions were not carried out by them.

MATERIALS AND METHODS

The work material used in the present investigation is a round bar of AISI410 and EN 19 steel. The diameter of the material is 28 mm and machined length is 30 mm for all trials. The chemical composition of the work materials are given in Table 1.

Grey Relational Analysis

Grey relational analysis is a measurement technique which focuses on the quantitative explanation and comparison of variation. It quantifies all effect of various factors on response and their relation which is called the whitening of factor relation. In grey theory, the black box is used to point out a system lacking internal information. The black is indicating as lack of information but the white is full of information. Thus, the information which is either incomplete or undetermined is called Grey. A system having incomplete information is called grey system. The Grey number in Grey system represents a number with less complete information. The Grey element represents an element with incomplete information. The Grey relation is the relation with incomplete information. Grey relational analysis is a measurement technique in grey system theory that analysis the degree of relation in a discrete sequence (Jeyapaul *et al.*, 2006; and Al Rafie *et al.*, 2010).

Step 1: Calculate S/N Ratio for the corresponding responses using the Equations (1 and 2). This is applied for problem where maximization of the quality characteristic of interest is sought. This is referred as the larger-the-better type problem. This is termed as the smaller-the-better type problem where minimization of the characteristic is intended.

$$S/N\ ratio\ (\eta) = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{1}{y_{ij}^2} \qquad ...(1)$$

where n = number of replications, y_{ij} = Observed Response value.

$$S/N\ ratio\ (\eta) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}y_{ij}^2\right) \qquad ...(2)$$

Step 2: y_{ij} is normalized as Z_{ij} ($0 \le Z_{ij} \le 1$) by the following formula to avoid the effect of adopting different units and to reduce the variability. It is necessary to normalize the original data before analyzing them with the grey relation theory or any other methodologies. An appropriate value is deducted from the values in the same array to make the value of this array approximate to 1. Since the process of normalization affects the rank, we also analyzed the sensitivity of the normalization process on the sequencing

Table 1: Chemical Composition of Work Piece Materials

Material	C	Si	Mn	P	SI	Cr	Mo
AISI410	0.095	0.341	0.680	0.040	0.0063	12.170	–
EN19 Steel	0.40	0.20	0.60	0.035	0.050	1.10	0.30

results. Thus, we recommend that the S/N ratio value be adopted when normalizing data in grey relation analysis. Equation 3 shows the larger the better and Equation 4 shows the smaller the better characteristic.

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1, 2, \ldots, n)}{\max(y_{ij}, i = 1, 2, \ldots, n) - \min(y_{ij}, i = 1, 2, \ldots, n)} \quad \ldots(3)$$

$$Z_{ij} = \frac{\max(y_{ij}, i = 1, 2, \ldots, n) - y_{ij}}{\max(y_{ij}, i = 1, 2, \ldots, n) - \min(y_{ij}, i = 1, 2, \ldots, n)} \quad \ldots(4)$$

Step 3: Calculate Grey relational Co-efficient for the normalized S/N ratio values are Equation 5.

$$\gamma(y_0(k), y_i(k)) = \frac{\Delta\min + \xi\Delta\max}{\Delta_{oj}(k) + \xi\Delta\max} \quad \ldots(5)$$

where $\Delta_{\max} = \max\limits_{\forall j \in i} \max\limits_{\forall k} \| y_0(k) - y_j(k) \|$ is the largest value of $y_j(k)$, ξ is the distinguishing coefficient which is defined in the range $0 \leq \xi \leq 1$ (the value may adjusted based on the practical needs of the system).

Step 4: Generation of Grey relational grade by Equation 6.

$$\gamma_j = \frac{1}{k} \sum_{i=1}^{m} \gamma_{ij} \quad \ldots(6)$$

where γ_j is the grey relational grade for the j^{th} experiment and k is the number of performance characteristics.

EXPERIMENTAL DETAILS

The experiments were conducted on the Fanuc CNC lathe. Multilayered TNMG 120408 coated with Titanium of 6 μm is used as the insert for all machining operations. The range of cutting parameters was selected based on past experience, data book and available resources. Surface roughness is measured by the Mitutoyo surface roughness tester. The three cutting parameters selected for the present investigation is cutting speed, feed and depth of cut. Since the considered factors are multi-level variables and their outcome effects are not linearly related, it has been decided to use three-level tests for each factor. The machining parameters used and their levels chosen are given in Table 2. In addition, a statistical ANOVA is performed to see those process parameters that significantly affect the responses. Analyzed with ANOVA which is used for identifying the factors which significantly affecting the performance measures. This analysis is carried out for significance level of $\alpha = 0.05$, i.e., for a confidence level of 95%.

Table 2: Machining Parameters and Levels

Parameter	Designation	Level 1	Level 2	Level 3
Cutting Speed (m/min)	V	100	150	210
Feed (mm/rev)	F	0.1	0.2	0.3
Depth of Cut (mm)	D	0.55	0.65	0.75

RESULTS AND DISCUSSION

Performance of Titanium Coated Cutting Tool on AISI410

The signal to noise ratio for SR and MRR is computed by using Equations 1 and 2. Normalize the S/N ratio values for SR and MRR is computed by using Equations 3 and 4. Calculate Grey Relational Co-efficient for the normalized S/N ratio values by using Equation 5. The grey relational grade can be computed by Equation 6.

Table 3: Grey Relational Analyses for AISI410

Trial No.	Experimental		S/N Ratios		Normalized Values of S/N Ratios		Grey Relational Coefficient		Grey Grade
	SR (µm)	MRR (g/min)	SR	MRR	SR	MRR	SR	MRR	
1	0.55	0.015	5.193	–36.452	0.229	36.452	0.686	0.014	0.350
2	0.77	0.015	2.270	–36.452	0.437	36.452	0.533	0.014	0.273
3	0.38	0.015	8.404	–36.452	0.000	36.452	1.000	0.014	0.507
4	1.25	0.040	–1.938	–27.985	0.737	36.063	0.404	0.014	0.209
5	1.08	0.035	–0.668	–29.145	0.647	36.117	0.436	0.014	0.225
6	1.17	0.050	–1.364	–26.047	0.696	35.974	0.418	0.014	0.216
7	0.81	0.018	1.830	–34.845	0.469	36.378	0.516	0.014	0.265
8	1.44	0.018	–3.167	–34.845	0.825	36.378	0.377	0.014	0.195
9	1.46	0.014	–3.287	–37.343	0.834	36.492	0.375	0.014	0.194
10	0.64	0.033	3.876	–29.523	0.323	36.134	0.608	0.014	0.311
11	0.46	0.033	6.745	–29.523	0.118	36.134	0.809	0.014	0.411
12	0.65	0.027	3.742	–31.461	0.332	36.223	0.601	0.014	0.307
13	0.94	0.027	0.537	–31.490	0.561	36.224	0.471	0.014	0.242
14	0.98	0.033	0.175	–29.552	0.587	36.135	0.460	0.014	0.237
15	1.13	0.033	–1.062	–29.552	0.675	36.135	0.426	0.014	0.220
16	0.77	0.027	2.270	–31.526	0.437	36.226	0.533	0.014	0.274
17	1.68	0.027	–4.506	–31.526	0.921	36.226	0.352	0.014	0.183
18	1.86	0.027	–5.390	–31.526	0.984	36.226	0.337	0.014	0.175
19	0.63	0.032	4.013	–29.792	0.313	36.146	0.615	0.014	0.314
20	0.6	0.032	4.437	–29.792	0.283	36.146	0.639	0.014	0.326
21	1.21	0.032	–1.656	–29.792	0.717	36.146	0.411	0.014	0.212
22	1.34	0.032	–2.542	–29.808	0.780	36.147	0.390	0.014	0.202
23	0.93	0.032	0.630	–29.808	0.554	36.147	0.474	0.014	0.244
24	0.87	0.040	1.210	–27.870	0.513	36.058	0.494	0.014	0.254
25	1.32	0.024	–2.411	–32.264	0.771	36.260	0.393	0.014	0.203
26	1.91	0.024	–5.621	–32.264	1.000	36.260	0.333	0.014	0.173
27	0.51	0.081	5.849	–21.806	0.182	35.780	0.733	0.014	0.373

Finally, the grades are considered for optimizing the multi response parameter design problem. The results are given in the Table 3. The higher grey relational grade implies the better product quality; therefore, on the basis of grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined. The main effects are tabulated in Table 4 and considering maximization of grade values in Table 4 is the optimal parameter conditions obtained are V_1, F_1, D_3. The cutting speed set as minimum level (100m/min), the feed rate set as minimum level (0.1 mm/rev)

Table 4: Main Effects on Grey Grade for AISI410

Level	1	2	3
V	0.270437	0.262163	0.25584
F	0.334611	0.22756	0.226268
D	0.263316	0.252012	0.273111

Table 5: Analysis of Variance for SR on AISI410

Source	DF	SS	MS	F	P
V	2	0.0093	0.0047	0.04	0.964
F	2	1.9697	0.9848	7.82	0.003
D	2	0.1449	0.0724	0.58	0.572
Error	20	2.5192	0.1260		
Total	**26**	**4.6431**			

Table 6: Analysis of Variance for MRR on AISI410

Source	DF	SS	MS	F	P
V	2	0.0007118	0.0003559	1.14	0.340
F	2	0.0004510	0.0002255	1.44	0.262
D	2	0.0003582	0.0001791	2.27	0.130
Error	20	0.0031427	0.0001571		
Total	**26**	**0.0046638**			

and depth of cut set as maximum level (0.75 mm). The ANOVA for SR on AISI410 is given in Table 5, it is clearly shows that the feed rate is most significantly affect the SR with p value of 0.003 followed by the depth of cut with p-value of 0.572. The ANOVA for MRR on AISI410 is given in Table 6, it is clearly shows that the depth of cut is most significantly affect the MRR with p value of 0.130 followed by feed rate with p value of 0.262.

Performance of Titanium Coated Cutting Tool on EN19 Steel

Similarly grey relational analysis performed by above equation and results are given in the Table 7. Finally, the main effects are tabulated in Table 8 and considering maximization of grade values in Table 8 is the optimal parameter conditions obtained are V_3, F_1, D_3. The cutting speed set as maximum level (210 m/min), the feed rate set as minimum level (0.1 mm/rev) and depth of cut set as maximum level (0.75 mm). The ANOVA for SR on EN 19 steel is given in Table 9, it is clearly shows that the cutting speed is most

Table 7: Grey Relational Analyses for EN 19 Steel

Trial No.	Experimental		S/N Ratios		Normalized Values of S/N Ratios		Grey Relational Coefficient		Grey Grade
	SR (µm)	MRR (g/min)	SR	MRR	SR	MRR	SR	MRR	
1	3.49	0.007	–10.857	–42.958	1.000	0.082	0.333	0.859	0.596
2	0.45	0.028	6.936	–30.917	0.098	0.607	0.836	0.452	0.644
3	0.36	0.018	8.874	–34.999	0.000	0.429	1.000	0.538	0.769
4	3.29	0.032	–10.344	–29.947	0.974	0.649	0.339	0.435	0.387
5	1.13	0.028	–1.062	–30.970	0.504	0.605	0.498	0.453	0.475
6	1.82	0.028	–5.201	–30.970	0.713	0.605	0.412	0.453	0.432
7	1.7	0.016	–4.609	–35.891	0.683	0.390	0.423	0.562	0.492
8	2.87	0.022	–9.158	–32.968	0.914	0.518	0.354	0.491	0.422
9	2.4	0.019	–7.604	–34.307	0.835	0.459	0.374	0.521	0.448
10	1.93	0.033	–5.711	–29.585	0.739	0.665	0.403	0.429	0.416

Table 7 (Cont.)

Trial No.	Experimental		S/N Ratios		Normalized Values of S/N Ratios		Grey Relational Coefficient		Grey Grade
	SR (μm)	MRR (g/min)	SR	MRR	SR	MRR	SR	MRR	
11	1.97	0.014	–5.889	–36.945	0.748	0.344	0.401	0.592	0.496
12	0.47	0.019	6.558	–34.446	0.117	0.453	0.810	0.525	0.667
13	1.25	0.009	–1.938	–40.495	0.548	0.189	0.477	0.725	0.601
14	1.1	0.024	–0.828	–32.537	0.492	0.536	0.504	0.482	0.493
15	1.44	0.019	–3.167	–34.475	0.610	0.452	0.450	0.525	0.488
16	2.49	0.028	–7.924	–30.988	0.851	0.604	0.370	0.453	0.411
17	1.86	0.024	–5.390	–32.572	0.723	0.535	0.409	0.483	0.446
18	2.58	0.024	–8.232	–32.572	0.867	0.535	0.366	0.483	0.424
19	0.52	0.040	5.680	–27.916	0.162	0.738	0.755	0.404	0.580
20	0.92	0.052	0.724	–25.733	0.413	0.833	0.548	0.375	0.461
21	0.73	0.023	2.734	–32.777	0.311	0.526	0.616	0.487	0.552
22	1.01	0.080	–0.086	–21.911	0.454	1.000	0.524	0.333	0.429
23	1.07	0.034	–0.588	–29.270	0.480	0.679	0.510	0.424	0.467
24	1.06	0.006	–0.506	–44.833	0.475	0.000	0.513	1.000	0.756
25	1.33	0.040	–2.477	–27.888	0.575	0.739	0.465	0.403	0.434
26	0.93	0.029	0.630	–30.811	0.418	0.612	0.545	0.450	0.497
27	1.1	0.023	–0.828	–32.749	0.492	0.527	0.504	0.487	0.495

Table 8: Main Effects on Grey Grade for EN 19 Steel

Level	1	2	3
V	0.518496	0.4938	0.519115
F	0.575769	0.503272	0.45237
D	0.483016	0.489241	0.559155

Table 9: Analysis of Variance for SR on EN19 Steel

Source	DF	SS	MS	F	P
V	2	4.6377	2.3189	4.32	0.028
F	2	2.3472	1.1736	2.18	0.139
D	2	1.7705	0.8852	1.65	0.218
Error	20	10.7462	0.5373		
Total	**26**	**19.5015**			

significantly affect the SR with p-value of 0.028 followed by the feed rate with p-value of 0.139.

Table 10: Analysis of Variance for MRR

Source	DF	SS	MS	F	P
V	2	0.0012707	0.0006353	3.45	0.052
F	2	0.0000753	0.0000376	0.20	0.817
D	2	0.0006888	0.0003444	1.87	0.180
Error	20	0.0036883	0.0001844		
Total	**26**	**0.0057231**			

The ANOVA for MRR on EN 19 steel is given in Table 10, it is clearly shows that the cutting speed is most significantly affect the MRR with p-value of 0.052 followed by depth of cut with p-value of 0.180.

Comparison of AISI410 and EN19 Steel

The performance of the AISI410 and EN 19 steel for surface finish is shows in Figure 1 and

Figure 1: Comparison Chart for SR at Feed Rate 0.1 and doc 0.75

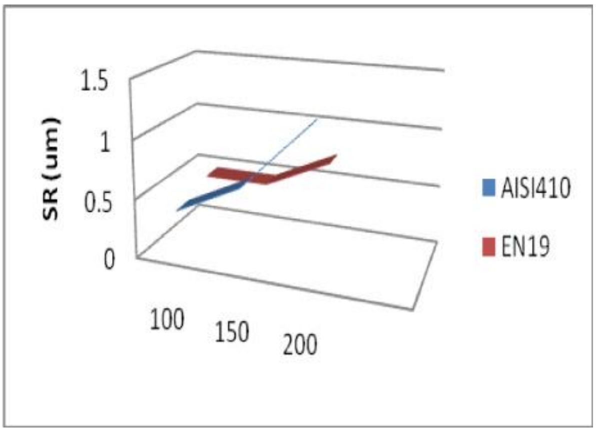

Figure 2: Comparison Chart for SR at Feed Rate 0.2 and doc 0.75

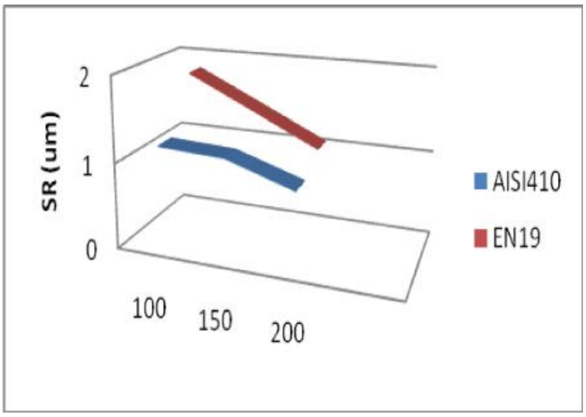

Figure 3: Comparison Chart for MRR at Feed Rate 0.1 and doc 0.75

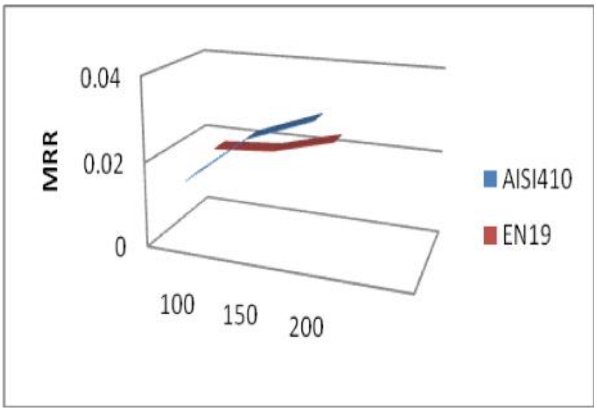

Figure 4: Comparison Chart for MRR at Feed Rate 0.2 and doc 0.75

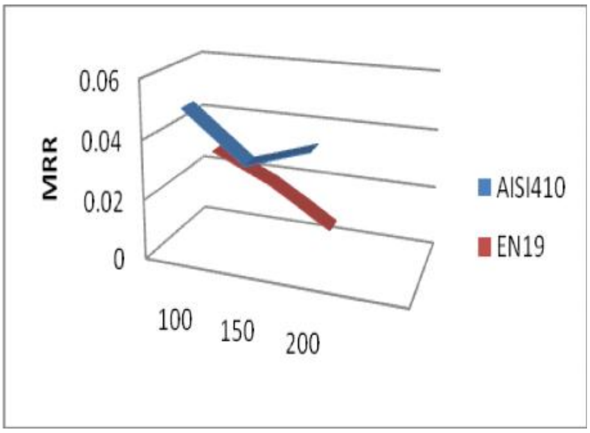

Figure 2 during feed rate 0.1 mm/rev and 0.2 mm/rev, depth of cut 0.75 mm with varying cutting speed. It shows the AISI410 produce the minimum surface finish than the EN19 steel. The performance of the AISI410 and EN 19 steel for MRR is shows in Figure 3 and Figure 4 during feed rate 0.1 mm/rev and 0.2 mm/rev, depth of cut 0.75 mm with varying cutting speed. It shows the AISI410 produce the maximum MRR than the EN19 steel.

CONCLUSION

The current investigation is focused on multi response optimization and analysis of CNC turning AISI410 and EN19 steel during change of cutting parameters. From the study of result in turning was using grey relational analysis and ANOVA. The following can be concluded from the present study.

- From grey relational analysis optimum setting for minimization of SR and maximization of MRR on AISI410 is the cutting speed set as minimum level (100 m/min), the feed rate set as minimum level (0.1 mm/rev) and depth of cut set as maximum level (0.75 mm) V_1, F_1, D_3.

- From grey relational analysis optimum setting for minimization of SR and maximization of MRR on EN19 steel is the cutting speed set as minimum level (100 m/min), The cutting speed set as maximum level (210 m/min), the feed rate set as minimum level (0.1 mm/rev) and depth of cut set as maximum level (0.75 mm) V_3, F_1, D_3.
- From ANOVA for AISI410, it is clearly shows that the feed rate is most significantly affect the SR with p-value of 0.003 and depth of cut is most significantly affect the MRR with p-value of 0.130.
- Form ANOVA for EN19 steel, the cutting speed is most significantly affect the SR with p-value of 0.028 and cutting speed is most significantly affect the MRR with p-value of 0.052.
- From comparison of figures the AISI410 perform better than EN19 steel during titanium coated cutting tool.

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