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MACHINABILITY OF MANGANESE STEEL DURING TURNING PROCESS

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ABSTRACT

In this research, workpiece studied minimum surface roughness Ra, minimum Amp for vibration and maximum material-removal rate MRR of Manganese steel Hadfield steel investigated. The turning processes were carried out on a center lathe machine. The machining conditions selected in this work are rotational speed, feed rate, depth of cut, and tool overhang. Taguchi's L16 (4^4) Orthogonal array applied for the design of experiments. The parameter processes significance quality estimated using analysis of variance ANOVA. Gray relation analysis utilised as a multi-response optimisation method. The results obtained by grey relation analysis (GRA) indicated that the Amplitude of vibration improved by 108%the material removal rate MRR was improved by 69.03%, while surface roughness Ra recorded a deviation of 7.30% from considering initial cutting conditions.

KEYWORDS: Manganese steel, Roughness, GRA, Taguchi, ANOVA.

1. INTRODUCTION

Manganese steel or Hadfield steel is alloy steel contains 11 to 14.5% manganese. This kind of manganese steel has good resistance to abrasion and high impact strength. Therefore, it's used in many applications such as grinding and crushing machinery, mineral and mining equipment, spline shaft, gears, cement plant, railway track work and stone crusher. The surface roughness Ra is a broadly utilized list of item quality and by and large a specialized necessity for mechanical items.

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Accomplishing the coveted surface quality is of incredible significance for the practical conduct of a section. In the meantime, the material removal rate is the primary parameter affecting the cost machining processes activity. Henceforth, different quality advancement technique investigated in many studies. The Gray relation analysis (GRA) and the Taguchi method utilized as an acceptable approach to deciding the ideal benefits of cutting parameters rotational speed n, feed rate f, depth of cut d and tool overhang L with a specific end goal to get the better surface roughness, minimum amp for vibration and maximum material removal rate in the complete the process of turning. Taguchi and ANOVA suitable approach is considered as acceptable techniques to optimize and analysis the performance of different machining processes. The effect of cutting parameter on surface roughness and MRR is applied by Taguchi and ANOVA methods [1-3]. Mechanical properties of aluminum metal matrix composite AMMCs evaluated by using grey relation analysis and Taguchi method to effect tensile strength, impact strength and hardness, density according to the base material, reinforcement, size of reinforcement particles, the percentage of reinforcement material [4]. The effect of the cutting parameter (cutting speed, feed rate and depth of cut) on surface roughness and MRR for CK45 carbon steel by using Gray relation analysis and Taguchi techniques [5]. The ANOVA test using cutting parameter cutting speed, feed rate, depth of cut to effect surface roughness and tool flank wear for turning operation [6, 7]. The turning process using parameter feed rate, nose radius, cutting time speed to effect surface roughness using ANOVA test and regression modelling analysis [8]. The studied the effect of different machining parameters an surface roughness in the milling operation. They used applied Taguchi ANOVA for designing their experiments. The input parameters ware cutting speed, feed rate and depth of cut. They found the most significant parameters on (Ra) and then cutting speed [9]. Tried to minimize the surface roughness when CNC turning aluminum 6061 approach and Taguchi method with L27 orthogonal array to find the optimal cutting condition of (Vc) cutting speed, (f) feed rate, and (d) depth of cut, which determine the minimum value of (Ra) by using analysis of variance ANOVA. They found that cutting speed was the most contribution parameter on (Ra) [10]. The optimized of metal removal rate for grey cast iron in turning operation using the Taguchi Method, they used HSS (High-Speed Steel) as a cutting tool. The metal removal rate (MRR) was the response parameter. They found that cutting velocity has the highest percentage contribution on the metal removal rate among all the three parameters [11]. Studied the machining parameter setting-for facing steel with-titanium carbide insert by using the Taguchi method. The selected machining parameters were feed rate, cutting speed, and depth of cut while the response was surface roughness. Their results showed that cutting speed and feed was the most influential factor in (Ra) [12]. investigated the relationship between the machining conditions and both cutting force and (Ra) during hard turning of steel, using hone edge uncoated CBN tool, the input processes parameters were the depth of cut, feed rate and cutting speed, while cutting force and (Ra) were the output responses. With the aid of design of Experiments (Taguchi and ANOVA), they found that most affecting parameter on surface roughness was cutting speed, but the most significant parameter on cutting force was the depth of cut [13]. showed a case study of grey relational analysis, Taguchi method and ANOVA in the optimization of process parameters in CNC turning of EN24 alloy steel. They found that the speed rate was the most affecting factor in responses [14]. Optimized CNC Turning Process by Taguchi method and ANOVA under various machining parameters using AISI 1045 steel under dry cutting condition, the input machining parameters were cutting depth, feed rate and cutting speed, while surface roughness (Ra) and metal removal rate (MRR) was the output parameters. They found that cutting speed has the highest contribution percentage on (Ra) and (MRR) [15]. applied two approaches to determine a multi-Response optimization for correlated responses, they used Taguchi L9 orthogonal array method and (GRA) in their experiments; they found that Taguchi’s SN ratio and quality loss, the relative significance of responses adequately represented and the response means and variation are assessed simultaneously. Multivariate statistical methods ANOVA and GRA are employed to uncorrelated and synthesis responses, ensuring that the weights of responses in synthetic performance measurements based on the total variance of the original data, which results in improved objectivity of the analysis. Analysis of the application of the proposed method on the here- observed experimental study and its comparison with other two methods for multi-response optimization showed that the proposed approach could yield to a better solution in terms of optimal parameters setting and synthetic multi-response performance measure [16]. The effect of a cutting parameter (cutting speed, feed rate, depth of cut) and spindle speed, feed rate, depth of cut, silicon carbide weight respectively for MMC steel Al6061 alloy, LM25 aluminum alloy on surface roughness by using Response surface methodology technic [17, 18]. The effect of tool wear and surface roughness for Al-Si cast alloy, EN 36 Nickel steel and SIC particle reinforced Al-MMC Material respectively Using parameter cutting speed, feed rate and depth of cut [19-21]. The influence of cutting conditions on built up edgy BUEs, cutting forces, tool flank wear and surface roughness for Al/sic MMC were investigated [22, 23]. The fuzzy logic technic using to affect the surface roughness for material AISI 4140 grade steel using parameter cutting speed, feed rate and depth of cut [24].

2. EXPERIMENTAL PROCEDURE

2.1 Workpiece Material

The workpiece material ware selected Manganese steel (Hadfield steel) standard DIN X120Mn12 of samples (Diameter=30mm, Length=70mm). Chemical composition and mechanical properties of DIN X120Mn12 steel given in Table 1 and 2, the casting and workpiece samples shown in Fig 1.

Table 1 Chemical composition of Manganese steel X120Mn12 % of the weight

Elements	C	Si	Mn	Cr	P	S
%	1.3	0.5	12.7	1.6	0.1	0.04

Table 2 Mechanical properties of Manganese steel X120Mn12

Material	Tensile strength (MPa)	Yield strength (MPa)	% of Elongation	Hardness (HB)
X120Mn12	835	952	34	355

Fig. 1. Casting and Machining Samples for Manganese Steel

2.2 Machining and Tools.

The lathe machine "Russian "Stankoimport" 1K62 Lathe and specification are shown in Table 3 used for this work. The holder PTENN 2525 M22 and the coated inserts type TNMM 22 04 -12 The tool with rake angle 10°, clearance angle 0°, and main cutting edge 60° with nose radius 1.2 mm. all tests were performed under cooling cutting conditions.

Table 3 Specification of lathe machine

Item	Specifications
Major Specifications	1K62
Max. Swing over bed	400mm
Max. Swing over cross slide	220mm
Max. Swing in gap	620mm
Distance between centers	710/1000/1400mm
Spindle Bore	47mm
The taper of spindle bore	No. 6 Morse
Range of spindle speed	12.5-2000 r.p.m.
Range of longitudinal feeds	0.07-4.16 mm/rev.
Range of cross feeds	0.035-2.08 Mm/rev.
Range of metric threads	0.1-14mm
Range of inch threads	2-112 TPI
Diametrical pitches range	4-112D.P.
Module pitches rage	0.1-7M.P.
The taper of tailstock bore	No. 5 Morse
Power of motor	7kw/10kw
Speed main drive	1500 rpm

2.3 Devices.

2.3.1 Surftest Mitutoyo SJ-310 Device to Measure Surface Roughness

The arithmetic surface roughness average (Ra) of the machined surface measured by Talysurf has shown in Fig. 2 (Mitutoyo SJ-310).

Fig. 2. Surftest Mitutoyo Sj-310 Devise While Measure Surface Roughness.

2.3.2 IRD Mechanalysis Model 880 to Measure Vibration

The Model 880 shown in Fig. 3 uses analogue Amplitude and Frequency meters to aid in interpreting vibration characteristics. Also, a digital LCD provides a high-accuracy readout of the frequency to which the filter is tuned, the vibration frequency, and the vibration amplitude. I am using to measuring vibration before and after the runs online in turning machine to all the experimental.

Fig. 3. IRD Mechanalysis Model 880 Devise While measuring Vibration

3 DESIGN OF EXPERIMENTS

Dr Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and sensitivity to noise. When appropriately used, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. In this work four dependent variables (rotational speed n, feed rate f, depth of cut d and tool overhang L) with four levels for each variable as shown in table 4.

The experimental planned by using Taguchi orthogonal array L_{16} (4^4) from Minitab

Table 4 Cutting variables and levels

Symbol	variables	Levels			
	orthogonal array	1	2	3	4
A	Rotational speed N (rpm)	250	300	315	400
B	Feed rate (mm/rev.)	0.1	0.15	0.2	0.26
C	Depth of cut d (mm)	0.25	0.5	0.75	1
D	Tool overhang L(mm)	40	50	60	70

program and by specifying the parameter, the level was entered into the program and choose the number of runs. The plan of this work can be summarized in the following the flow chart is shown in Fig. 4. The experimental results and the Taguchi L16 (4^4) orthogonal array from Minitab have appeared in Table 5.

4. RESULTS AND DISCUSSIONS

The MRR per minute obtained by using this Eq. (1).

$$MRR = \pi N f d D_{avg} \tag{1}$$

Where N (rpm), feed rate f (mm/rev), depth of cut d (mm), average diameter D (mm), material removal rate MRR shown in Table 5.

4.1 Grey Relational Analysis

In Grey relational analysis the standardised information handling for Ra and AMP relating to the smaller-the-better shown in Eq. (2).

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{2}$$

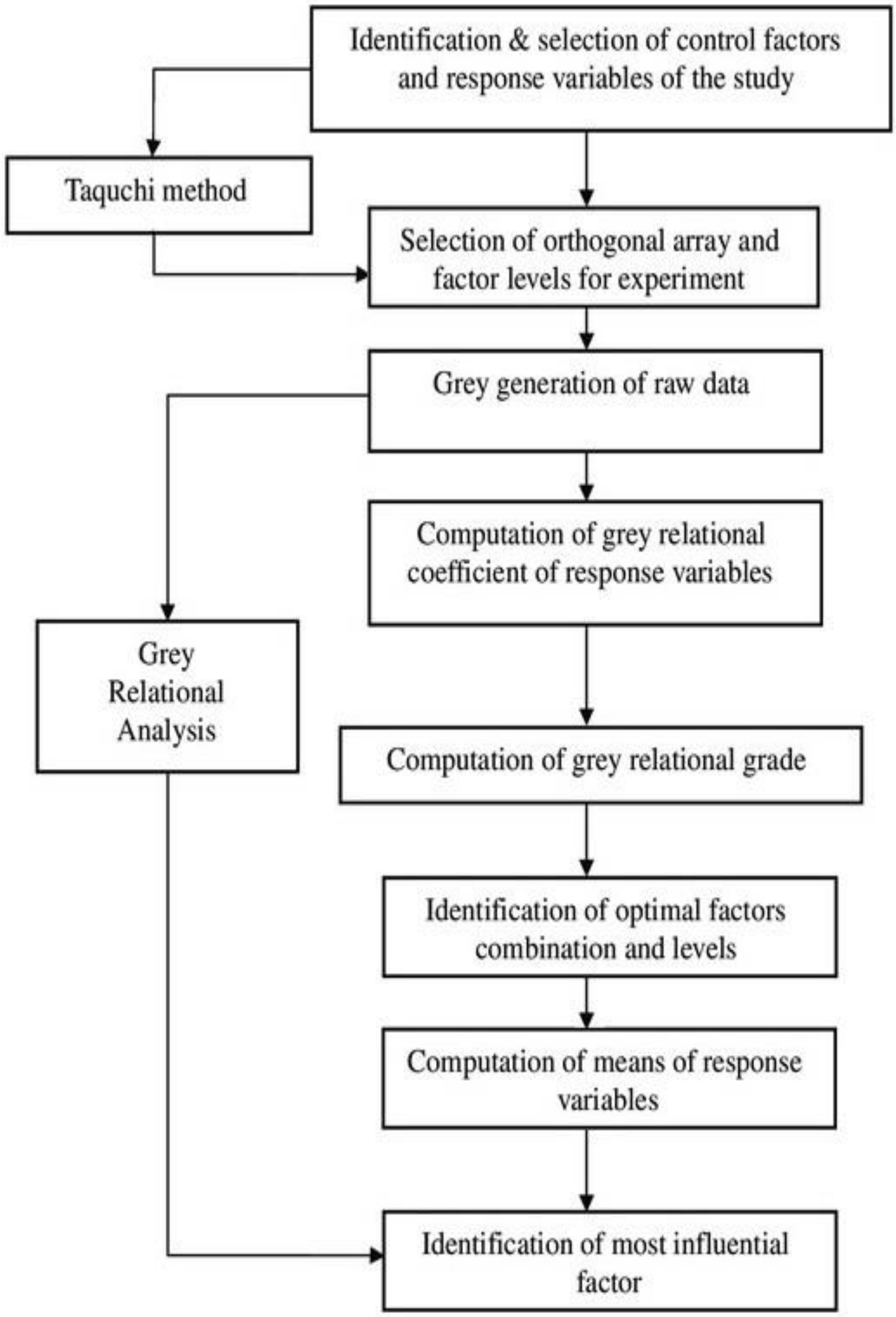

Fig. 4. The planned work summarized in the flow chart

Table 5 experimental runs and results

Exp. No.	A	B	C	D	Ra (µm)	AMP MAX (µm)	MRR (mm^3/min)
	N (rpm)	f (mm/min)	D (mm)	L (mm)			
1	1	1	1	1	1.888	1.55	474.925
2	1	2	2	2	1.276	1.85	1420.065
3	1	3	3	3	1.286	2.25	2854.260
4	1	4	4	4	3.652	5.25	4710.628
5	2	1	2	3	1.271	2.5	1190.256
6	2	2	1	4	1.115	5.3	889.013
7	2	3	4	1	1.126	2.3	4627.575
8	2	4	3	2	2.097	2.7	4527.193
9	3	1	3	4	0.685	1.95	2229.184
10	3	2	4	3	1.723	6.95	4465.787
11	3	3	1	2	1.588	3.15	1489.832
12	3	4	2	1	2.413	7.15	3831.773
13	4	1	4	2	0.735	0.95	3768.000
14	4	2	3	1	1.545	3.05	4196.610
15	4	3	2	4	1.506	1.35	3799.400
16	4	4	1	3	2.259	6.25	2445.118

The standardised information is handling for MRR corresponding to larger-the-better shown in Eq. (3).

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (3)$$

i = 1, 2, 3, 4, ..., m, m number of experimental runs L16. k = 1, 2, 3, ...,n, n number of responses. Min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response. Max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response. $x_i(k)$ the value after GRA. The standardized estimates of surface roughness and amplitude for vibration and material removal rate determined by Eq. (2, 3) shown in Table 6.

The following equations can estimate the Grey relation coefficient:

$$\xi_i(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{oi}(k) + \xi\Delta_{max}} \quad (4)$$

$$\Delta_{oi}(k) = \|x_0(k) - x_i(k)\| \quad (5)$$

Table 6 Normalized values and deviation sequences of responses

Experiment No.	Normalized values of responses			Deviation sequences $\Delta_{oi}(k)$		
	Ra (μm)	AMP MAX (μm)	MRR (mm^3/min)	Ra (μm)	AMP MAX (μm)	MRR (mm^3/min)
	Smaller the better	Smaller the better	Larger the better			
1	0.5947	0.9032	0.0000	0.4053	0.0968	1.0000
2	0.8008	0.8548	0.2231	0.1992	0.1452	0.7769
3	0.7973	0.7903	0.5617	0.2027	0.2097	0.4383
4	0.0000	0.3065	1.0000	1.0000	0.6935	0.0000
5	0.8025	0.7500	0.1689	0.1975	0.2500	0.8311
6	0.8550	0.2984	0.0978	0.1450	0.7016	0.9022
7	0.8513	0.7823	0.9804	0.1487	0.2177	0.0196
8	0.5243	0.7177	0.9567	0.4757	0.2823	0.0433
9	1.0000	0.8387	0.4142	0.0000	0.1613	0.5858
10	0.6501	0.0323	0.9422	0.3499	0.9677	0.0578
11	0.6956	0.6452	0.2396	0.3044	0.3548	0.7604
12	0.4178	0.0000	0.7925	0.5822	1.0000	0.2075
13	0.9830	1.0000	0.7775	0.0170	0.0000	0.2225
14	0.7103	0.6613	0.8786	0.2897	0.3387	0.1214
15	0.7232	0.9355	0.7849	0.2768	0.0645	0.2151
16	0.4697	0.1452	0.4651	0.5303	0.8548	0.5349

$\Delta_{oi}(k) = \|x_0(k) - x_i(k)\|$ is the difference between a value $x_0(k)$ and $x_i(k)$. Δ_{min} the minimum value of (Δ_{oi}) and Δ_{max} the maximum values of (Δ_{oi}). ξ is a distinguishing coefficient, $0 \leq \xi \leq 1$, to the moderate characteristic effects and good stability of results must be $\xi = 0.5$. The Grey relational grade γ_i can be estimated the following equations:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \tag{6}$$

i = 1, 2, 3 ... 16, (L_{16}) according to run selected, $\xi_i(k)$ the Grey relational coefficient, n is the number of responses. The Grey relational coefficients and Grey relational grade after estimated shown in table 7.

Table 7 Grey relational coefficient, Grey relational grade and S/N ratios

Experiment No.	Grey relational coefficient			Grey relational grade	Rank
	Ra (μm)	AMP MAX (μm)	MRR (mm^3/min)		
1	0.5523	0.8378	0.3333	0.5745	12
2	0.7151	0.7750	0.3916	0.6272	8
3	0.7116	0.7045	0.5329	0.6497	7
4	0.3333	0.4189	1.0000	0.5841	11
5	0.7169	0.6667	0.3756	0.5864	10
6	0.7752	0.4161	0.3566	0.5159	14
7	0.7707	0.6966	0.9623	0.8099	2
8	0.5124	0.6392	0.9203	0.6906	5
9	1.0000	0.7561	0.4605	0.7389	4
10	0.5883	0.3407	0.8964	0.6084	9
11	0.6216	0.5849	0.3967	0.5344	13
12	0.4620	0.3333	0.7067	0.5007	15
13	0.9672	1.0000	0.6920	0.8864	1
14	0.6331	0.5962	0.8047	0.6780	6
15	0.6437	0.8857	0.6992	0.7429	3
16	0.4853	0.3690	0.4832	0.4458	16

4.2 Effect of Different Variables of Grey Relation Grade.

Taguchi method recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. The signal-to-noise (S/N) ratio is a measure of the magnitude of a data set relative to the standard deviation. In the Taguchi method, signal-to-noise S/N ratio is used to represent a performance characteristic, and the largest value of S/N ratio means the optimal level of the turning parameters. There are three types of S/N ratio: the larger-the-better, the nominal-the better, and the smaller-the-better. The analysis of S/N ratio is used to study the different parameter of grey relation grade based on the larger-the-better criterion of grey relation grade using the following equation.

$$S/N = -10 \log \left[\frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{1}{{y_i}^2} \right] \quad (7)$$

n the number of runs, and y_i the tests characteristic value. Table 6 indicated the grey relation grade obtained from equ.7 and their ranks. The top value of Grey relational grade is the rank of 1, this the best mix of response for orthogonal array L16.

4.3 Main Effect Plot for Mean and S/N.

From main effect plot for main Fig.5 and main effect plot for S/N Fig.6, the optimum value rotational speed of N = 400 rpm, the feed rate of f = 0,1 mm/rev depth of cut d = 1 mm, and overhang L= 50 mm.

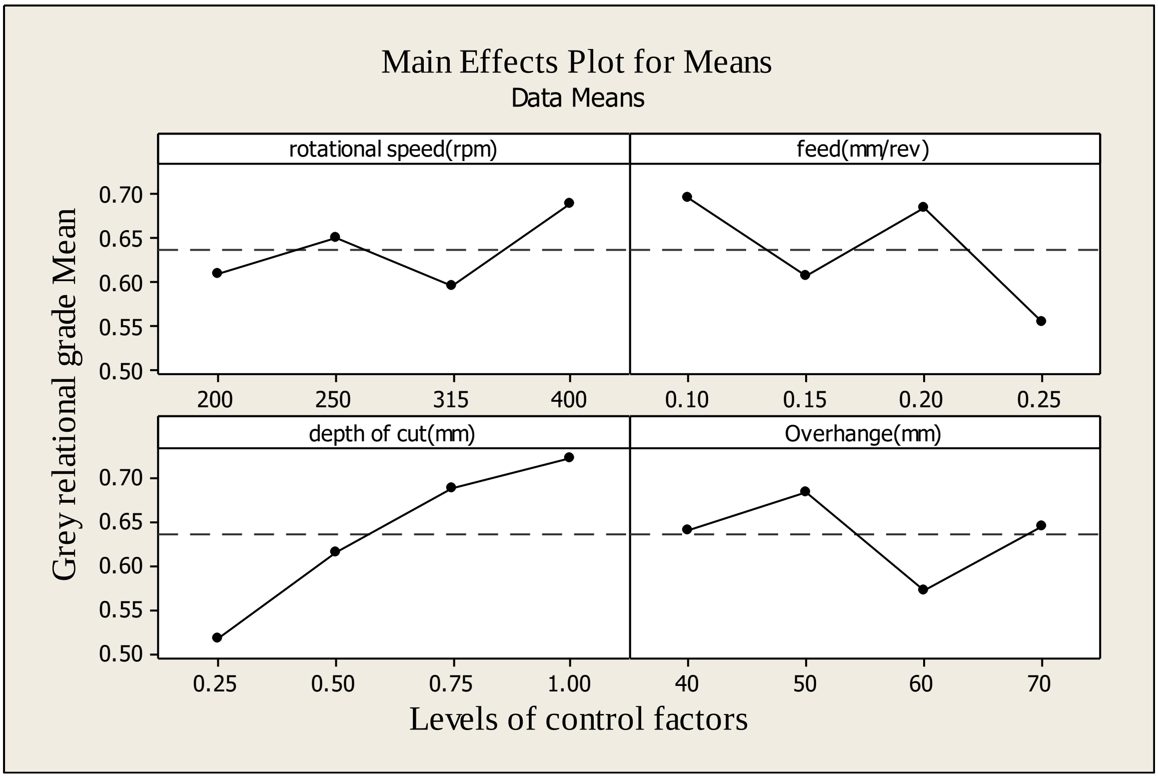

Fig. 5. Mean plot for the Grey relational grade

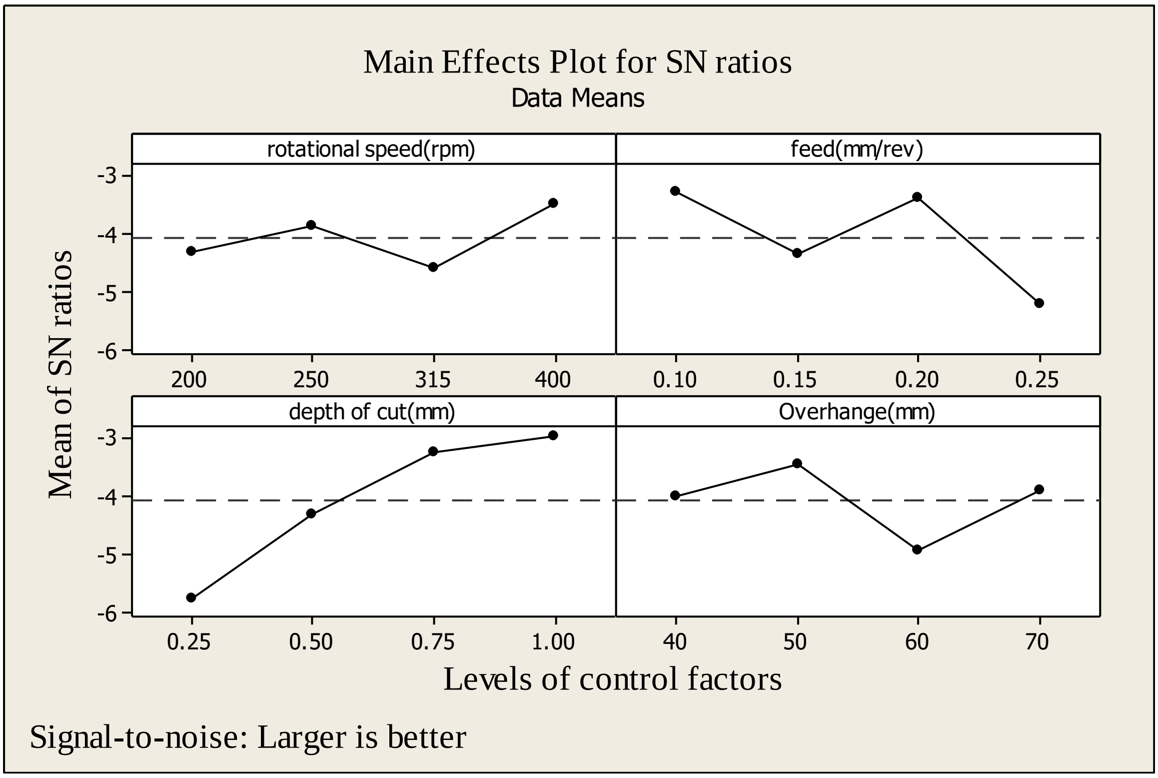

Fig. 6. S/N plot for the Grey relational grade

The best results for optimum level summarised as shown in table 8.

Table 8 The primary effect and ranks for grey relation grade

Parameters	Grey relational grade				Main effect (Delta)	Rank
	Level 1	Level 2	Level 3	Level 4		
A (N)	0.6089	0.6507	0.5956	0.6883	0.0927	4
B (f)	0.6965	0.6074	0.6842	0.5553	0.1412	2
C (d)	0.5177	0.6143	0.6893	0.7222	0.2045	1
D (l)	0.6408	0.6847	0.5726	0.6454	0.1121	3
The total mean value of the Grey relational grade = 0.6359						

From Fig.5,6 and table 8 the optimal parameter condition for turning of the DIN X120Mn12 Manganese steel for response (Ra, AMP, MRR): A-level 4 rotational speed of N = 400 rpm, B-level 1 feed rate of f = 0,1 mm/rev, C-level 4 depth of cut d = 1 mm, D-level 2 and overhang L= 50 mm.

4.4 Analysis of Variance (ANOVA)

Analysis of variance is a general method for studying sampled – data relationships. The method enables the difference between two or more sample means to be analyzed, achieved by subdividing the total sum of squares. One-way ANOVA is the simplest case. The purpose is to test for significant differences between class means, and this is done by analyzing the variances. The results of ANOVA for the values of grey grade shown in Table 9. The higher the percentage contribution was, the more important the factor was for affecting the performance characteristics. The results of the ANOVA indicated that the percentage contribution of rotational speed (N), feed rate (f), the depth of cut (d) and the overhang (l) influencing the multiple performance characteristics were 10,18 %, 25.50 %, 47,39 %, and 12,45 % respectively. From % of the contribution the ANOVA, the rotational speed and feed rate and overhang were three parameters fundamentally affect the Grey relational grade. Also, the depth of cut was the best factor on the effect.

Table 9 ANOVA results of turning process parameters

Main control factors	Symbol	Degree of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	F-ratio	Contribution, C (%)
rotational speed (rpm)	A	3	0.021267	0.007089	2.28	10.18271137
feed (mm/rev)	B	3	0.053264	0.017755	5.71	25.50346175
depth of cut (mm)	C	3	0.098979	0.032993	10.6	47.39147922
overhang (mm)	D	3	0.026007	0.008669	2.79	12.45223936
Error	-	3	0.009335	0.003112		4.470108305
Total	-	15	0.208851	0.069618		100

4.5 Confirmation Experiment

The Grey relational grade $\hat{\gamma}$ using to predict the improvement of the optimum combination of turning parameters. The Grey relational grade $\hat{\gamma}$ using the following equation:

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{0} (\overline{\gamma_i} - \gamma_m) \quad (8)$$

γ_m is the total mean Grey relational grade, $\overline{\gamma_i}$ the mean Grey relational grade at the optimal level. Table 10 represents the confirmation test, which shows the difference between the initial factor setting and optimal machining parameters predicted and experimental obtained by Grey relational grade. Namely, improved the Amplitude for vibration enhanced from 1.95 μm to 0.95 μm and the material removal rate MRR also improved from $2229.184\ mm^3/min$ to $3768\ mm^3/min$. While surface roughness Ra was from 0.685 μm to 0.735 μm and considering initial cutting conditions. In conclusion, it is shown that the multiple performance characteristics in turning X120Mn12 Manganese steel significantly improved by the increase in Grey relational grade of 0,0286.

5. CONCLUSIONS

The GRA and Taguchi applied in this work for multi-objective optimisation techniques of turning process.

Table 10 Results of the confirmation test

Condition description	Initial factor settings	optimal machining parameters	
	Machining parameters	Grey theory prediction design	Grey theory Experimental design
Factor levels	A3B1C3D4	A4B1C4D2	A4B1C4D2
Ra (μm)	0.685	-	0.735
AMP MAX (μm)	1.95	-	0.95
MRR (mm^3/min)	2229.184125	-	3768
Grey relational grade	0.7192	0.8840	0.8864

- The results obtained based on grey relation-based Taguchi, the optimal parameter combination for turning operation of the Manganese steel X120Mn12 regarding surface roughness and material removal rate various performance characteristics were levels: A-level 4, B-level 1, C-level 4, D-level 2. Namely, rotational speed of N = 400 rpm, feed rate f = 0,1 mm/rev and depth of cut d = 1 mm and overhang L= 50 mm.
- The results of the ANOVA shown the percentage contribution of the rotational speed (N) 10,18 %, feed rate (f) 25.50 %, the depth of cut (d)47,39 % and the overhang (L) 12,45 %. From the % contribution of the ANOVA, the depth of cut was the most effective factor on the performance.
- The confirmation test verified the effectiveness of this method. The Grey relational grade of the multiple objective characteristics was improved by 0,0268, the Amplitude for vibration improved from 1.95 μm to 0.95 μm (improvement 108%)

and the material removal rate MRR was also enhanced from $2229.184\ \text{mm}^3/\text{min}$ to $3768\ \text{mm}^3/\text{min}$ (improvement 69.03%) while surface roughness Ra was from 0.685 μm to 0.735 μm (deviation 7.30%) of considering initial cutting conditions.

Therefore, the process responses of the turning operations, such as the MRR and AMP and the Ra greatly improved by using a grey-based Taguchi method.

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تشغيل الصلب المنجنيزي من خلال عملية الخراطة

يدرس البحث تاثير عوامل القطع فى عملية الخراطة على كل من خشونة السطح ومعدل ازالة المعدن لسبيكة الصلب المنجنيزي حيث تم اختيار سرعة القطع وعمق القطع والتغذية وطول بروز الحد القاطع كعوامل تشغيل موثرة علي جودة السطح المشغل. واستخدم البحث لتحليل النتائج الطرق التجريبية (تحليل تاجوشي , تحليل التباين انوفا, ونظام تحليل العلاقة الرمادية) وعن طريق نتائج تاجوشي تم اختيار عدد التجارب ل ١٦ تجربة وتم استخدام نسبة الاشارات الموثرة علي العملية S/N وتحليل التباين ANOVA لبيان تاثير معاملات القطع علي نعومة السطع ومعدل ازالة المعدن. تم ايضا استخدام طريقة درجة الارتباط الرمادي GRA.ووفقا لتحليل النتائج تم استخارج المعاملات المثالية للقطع لتشغيل الصلب المنجنيزي وعن طريق نتائج تحليل التباين ANOVA تبين ان عمق القطع هو الاكثر تاثيرا علي خشونة السطح وعن طريق تحاليل العلاقة الرمادية تم تحسين الاهتزاز بنسبة ١٠٨% وتحسين معدل ازالة المعدن بنسبة ٦٩,٠٣%.