Experimental Investigations and Comparative Analysis of Turning EN-8 & Cast Iron using L9 Orthogonal Array

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***Abstract*:- Modern industry mainly concentrates on the quality by choosing the material and method. The machining was carried out by turning operation in conventional lathe. The input process parameters chosen are spindle speed, feed rate and depth of cut and the output parameters measured are machining time, material removal rate and surface roughness. The analysis of the EN-8 and Cast Iron (C.I) material were done using the empirical equation. The effect of EN-8 and C.I materials were computed by comparing the obtained values of experimental and emperical method.**

Key words: Machining time, Surface Roughness , Metal Removal Rate and Design of Experiments.

INTRODUCTION

The fore coming & modern machining industries are mainly focused towards the achievement of high quality, considering work piece factors such as dimensional accuracy, surface finish, high production rate, economy of machining process in terms of cost saving and better performance of the product with reduction of impact on environment. Surface roughness plays an vital role in surface finish and is an important factor in the evaluation of machining accuracy. Tool selection parameter has an important role in determining the overall machining performance, including cutting forces, tool wear, surface finish and quality of the machined surface. The work piece chosen was EN-8 and C.I. The tool chosen to machine EN-8 is High Speed Steel and for Cast Iron is Carbide tool. The turning operation was carried out for the performance analysis. The input and output parameters were analyzed.

LITERATURE REVIEW

The cutting tool is used to remove the excess material from the work piece by shear force deformation. They are classified as single point, double point and multi point cutting tool. S.Sathiyaraj et al [1] discussed about the optimization of metal removal rate, tool wear rate and surface roughness by using tungsten carbide tipped tool and titanium nitride coated tool on EN 8 alloy steel using Taguchi method. Pranav R. Kshirsagar et al [2] reviewed the effect of machining parameters such as cutting speed , depth of cut Dcand feed rate on the surface roughness (Ra) in a turning of EN8 Steel and it is investigated using the both Taguchi method and ANOVA. Puneet N P et al [3] conversed about the the effect of cutting parameters has been studied on the flank wear during CNC turning of EN8 steel. Ankit Dogra et al [4] investigated the effect of cutting parameters and the work piece on the tool wear during a machining of EN8 material. V. Baskaran et al [5] discussed about modernistic approach to calculate the optimum machining parameters in CNC turning of EN 8 steel using coated carbide tool. FrankoPuh et al [6] discussed about the multiple objectives optimization of turning process for an optimal parametric combination to provide the minimum surface roughness (Ra) with the maximum material-removal rate (MRR) using the Grey–Based Taguchi method and also investigated the design and fabrication of an indigenously developed tooling setup for Electro Chemical Honing (ECH) of an external cylindrical components. Titanium alloys (TI 6AL 4V) and EN8 Steel are used as the work piece material for carrying out the experimentation to describe the material removal and surface roughness characters. Hemanandan Pugalenthi et al [7] discussed about the investigation carried out to determine the connection between cutting speed , feed rate ,depth of cut and the amplitude of vibrations with the surface roughness. Shanmugam Murugappan et al [8] discussed about turning of EN8 (AISI 1040) steel rod at different speeds and feeds with constant depth of cut of 1.5mm under two different environments they are cryogenic cooling environment using dry ice and dry turning environment. Hemant Jain et ak [9] discussed about a new method for the optimization and evaluation of machining parameters for turning operation on Inconel-625 on CNC machining with the help of Taguchi Method and obtained an optimal process parameters on turning setting for maximizing the material removal rate of the manufactured component. R.K.Bharilya et al [10] discussed about he optimization of machining parameters for turning operation of given work piece, the material being Carburized Mild Steel (hard material), Aluminium alloys and Brass (soft material) which were machined on CNC machine and analysed through the cutting force dynamometer. Paramjit Singh Bilga et al [11] focused mainly on the optimization of foremost energy consumption response parameters viz. energy efficiency, active energy consumed by machine (AECM) and power factor (PF). Mehmet Alper Sofuoglu Sezan Orak [12] suggested the soft computing methods to predict stable cutting depths in turning operations without chatter vibrations and estimated stable cutting depths with minimum error. Jingxiang Lv et al [13] investigated the predicted accuracy of the material removal power in turning processes, which could vary a lot due to different methods used for prediction. Shirish Kadam et al [14] discussed about the experimental studies of turning Super Duplex Stainless Steel (DSS) with uncoated and Physical Vapor Deposition PVD coated carbide inserts under dry cutting condition. D. Manivel et al [15] the cutting parameters are optimized in hard turning of austempered ductile iron (grade 3) (ADI) using carbide inserts based on Taguchi Method. Poorna Chandra et al [16] discussed about the effect of machining parameters on cutting force and surface roughness while machining alloy steels following ISO3685 standards. C.L. He et al [17] discussed about the influencing factors and theoretical modeling methods of surface roughness in turning process is presented in this work. Recep Yigit et al[18] discussed the results of an experimental investigation on the effect of cutting speed on turning nodular cast iron with coated as well as uncoated cutting tools. Varun Nayyar et al [19] discussed about the machinability of different grades of cast iron has been calculated in terms of cutting temperatures, cutting forces, tool life, deformed chip thickness and contact length in different continuous machining operations. The tests performed are external turning, boring and face turning. Jie Qin et al [20] studied tool wear, tool life, chemical composition on worn flank faces and failure mechanism of the cutting tools after turning tests. The results showed the improved cutting performance of the coated cutting tools can be attributed to the increasing wear resistance and toughness of the cutting tools with the covering of TiN/Al_2O_3 coatings, both in continuous and varied depth-of-cut turning. J.V.C. Souza et al [21] presented the results of an experimental investigation about the effect of cutting forces on gray cast iron turning using silicon nitride (Si_3N_4) based ceramic tool. E.E.T. ELSawyaet al [22] investigated a series of sixty-six cast iron samples with varied contents of chromium, manganese and silicon were prepared. The microstructure and the mechanical properties were studied. Md Abdul Maleque et al [23] investigated wear behaviour of Fe-C-Al and Fe-C-Si cast irons at different temperatures. The microstructure of Fe-C-Al cast iron contains thinly distributed graphite flakes in a ferrite-pearlite matrix while Fe-C-Si cast iron shows graphite flakes in pearlite matrix. The hardness value of aluminium modified cast iron is higher (240BHN) than the gray cast iron(B180BHN). K. Gajalakshmi et al [24] discussed about the classification of three grades of cast iron viz., gray, malleable and white, based on their texture is attempted, using Haralick features extracted from gray level co-occurrence matrix (GLCM) and histogram features extracted from local binary pattern (LBP). M. Wasim Akram et al [25] discussed about the wear mechanisms of this refrigerant using gray cast iron interfaces were investigated under a wide range of operating conditions.

Based on the literatures review, following are identified based on performance:

- Selection of tool and work piece material plays a crucial role in turning process.
- The combination of process parameters are identified based on the Design of Experiments (DOE) method.
- Also, the numbers of experiments to be conducted are chosen based on the level of process parameters with the help of DOE method.
- Machining parameters plays a vigorous role in deciding the cost and quality of the product.
- Experiments are conducted to analyze the MT, metal removal rate and surface roughness for different combinations.
- Experimental investigation of C.I is needed due to its high strength, ease of machinability, high strength to weight ratio and comparatively low cost.

EXPERIMENTATION

Turning plays the major role in analyzing the performance of EN-8 and C.I material. Turning is a material removal process which is used to create rotational parts by cutting unwanted material. Figure 1 shows the Conventional lathe machine used for turning operation. Experimental data for turning of EN-8 and C.I with the HSS tool is carried out in conventional lathe. Experiments were conducted based on L9 orthogonal array by the recommendation of DOE. The input parameters chosen are spindle speed (in rpm), feed rate (in mm/min) and depth of cut (mm). The output parameters measured are MT (in minutes), metal removal rate (in g/min) and surface roughness (in µm). The stop watch, weighing machine and surface roughness tester are used to measure the output parameters. Figure 3 shows the EN-8 and C.I work piece material before machining respectively. The material removal rate is the ratio of the difference between weight of the specimen before and after machining to MT which is measured by using weighing machine and stopwatch. Figure 4 shows the EN-8 and Figure 6 C.Iwork piece material after machining. Surface roughness measured by using surface roughness tester.

MT - Machining Time
MRR – Metal Removal Rate
SR - Surface Roughness
DOC – Depth of Cut


Fig 1: Conventional lathe


Fig 2: Surface Roughness Tester

Table 1: Level and ranges of input parameters

S. No.	Parameter	Units	Level and ranges of Input parameters		
			Level 1	Level 2	Level 3
1	Spindle speed	rpm	220	450	700
2	Feed Rate	mm/min	0.09	0.156	0.27
3	Depth of cut	mm	0.75	1.00	1.25

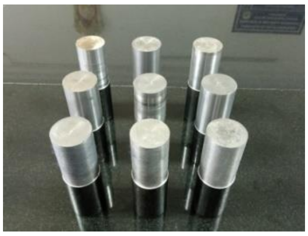
Fig 3: EN-8 after machining


Fig 4: C.I before machining


Fig 5: C.I after machining

Table 2: Measured values of EN-8

S. No.	Speed (rpm)	Feed (mm/min)	DOC (mm)	MT (min)	MRR (g/min)	SR (µm)
1	220	0.09	0.75	2.70	6.29	2.84
2	220	0.156	1	0.93	21.40	3.54
3	220	0.27	1.25	1.78	12.89	2.76
4	450	0.09	1	1.16	14.57	2.49
5	450	0.156	1.25	0.40	79.76	3.32
6	450	0.27	0.75	0.75	31.97	2.54
7	700	0.09	1.25	0.76	71.60	2.84
8	700	0.156	0.75	0.25	75.51	3.63
9	700	0.27	1	0.50	39.88	2.48

Table 3: Experimental results of C.I

S. No.	Speed (rpm)	Feed (mm/min)	DOC (mm)	MT (min)	MRR (g/min)	SR (µm)
1	220	0.09	0.75	1.62	3.98	6.95
2	220	0.156	1	1.38	18.56	7.25
3	220	0.27	1.25	1.02	35.66	8.03
4	450	0.09	1	1.09	34.13	4.32
5	450	0.156	1.25	0.86	48.71	4.62
6	450	0.27	0.75	0.63	32.43	6.53
7	700	0.09	1.25	0.52	65.93	1.49
8	700	0.156	0.75	0.43	47.13	2.91
9	700	0.27	1	0.06	64.23	3.70

FORMULATION OF REGRESSION EQUATION

The main objective of the work is to validate the experimental results and it is done by using empirical equations. Empirical Equation is statistical software and a primary tool used to form empirical formulae for the output parameters such as MT, MRR and surface roughness using spindle speed, depth of cut and feed rate as input parameters. The experimental results of EN-8 and C.I are given in table 4 and table 5 respectively. The empirical equations are formulated to maximize Metal Removal Rate, minimize MT and surface roughness and are given below.

Empirical equations are

Machining Time = 2.472 - 0.185 depth of cut - 2.80 feed rate - 0.002093 spindle speed

Metal Removal Rate = -52.3 + 44.5 depth of cut + 52.4 feed rate + 0.0827 spindle speed

Surface Roughness = 9.32 - 1.50 depth of cut + 10.19 feed rate - 0.00981 spindle speed

The table 4 shows the measured values of EN-8 and C.I using Empirical Equations.

Table 4: Results of EN-8 using Empirical Equations

Empirical equations for CI are

Machining = 3.13 - 0.00268 Spindle Speed -

Time 2.17 Feed Rate - 0.50 Depth Of Cut

MRR = -33.3 + 0.1014 Spindle Speed - 42 Feed Rate + 33.7 Depth Of Cut

Surface Roughness = 3.32 - 0.000124 Spindle Speed - 1.53 Feed Rate - 0.060 Depth Of Cut

The table 5 shows the measured values of C.I using Empirical Equation

Table 5: Results of CI using Empirical Equation

S. No.	Speed (rpm)	Feed (mm/min)	DOC (mm)	MT (minutes)	MRR (g/min)	SR (μm)
1	220	0.09	0.75	1.65	10.85	8.63
2	220	0.156	1	1.78	20.70	5.33
3	220	0.27	1.25	0.90	28.47	9.59
4	450	0.09	1	0.75	36.95	3.32
5	450	0.156	1.25	0.81	85.23	2.69
6	450	0.27	0.75	0.38	28.15	6.9
7	700	0.09	1.25	0.53	64	3.5
8	700	0.156	0.75	0.50	35.94	5.4
9	700	0.27	1	0.25	79.54	3.2

ESULTS AND DISCUSSION

The experimental results are validated by results from empirical equations and it is shown in figures 6,7,8,9,10 and 11 . The figures 6 and 9 show the comparative results of MT obtained by the experiments and empirical equation for EN-8 and C.I respectively. The table 6 gives the experimental and empirical values for EN-8 and C.I respectively. The maximum deviation of MT is of 73% and minimum deviation is of 2% for EN-8. The maximum deviation of MT is of 66.48 % and minimum deviation is of 25.46% for CI. The MT value varies for both the experimental and empirical method due to the speed, feed and depth of cut. The most influencing parameters are speed and depth of cut. Spindle speed is the most influencing parameter for MT. The MT is inversely proportional to the spindle speed. As the speed increases, the MT decreases. The figures 7 and 10 show the comparative result of MRR values obtained using the experimental method and empirical method for EN-8 and C.I respectively. The maximum deviation of MRR is of 63% and minimum deviation is of 7% for EN-8.The maximum deviation of MRR is of 39% and minimum variation is of 17% for CI. The figures 8 and 11 show the comparative result of surface roughne1ss values obtained using the experimental method and empirical method for EN-8 and C.I respectively. The maximum deviation of SR is of 57% and minimum deviation is of 6% for EN-8.The maximum deviation of surface roughness is of 18% and minimum deviation is of 11% for CI. The feed rate and depth of cut are the factors which influence the surface roughness. The surface roughness varies inversely to the depth of cut. The speed, feed and depth of cut are three prominent parameters which affect the MT, metal removal rate and surface roughness severely.

S. No.	Speed (rpm)	Feed (mm/min)	DOC (mm)	MT (min)	MRR (g/min)	SR (μm)
1	220	0.09	0.75	1.97	10.50	3.11
2	220	0.156	1	1.70	16.16	2.99
3	220	0.27	1.25	1.32	19.79	2.80
4	450	0.09	1	1.22	42.25	3.06
5	450	0.156	1.25	0.96	47.90	2.95
6	450	0.27	0.75	0.96	26.27	2.80
7	700	0.09	1.25	0.43	76.03	3.02
8	700	0.156	0.75	0.54	56.40	2.94
9	700	0.27	1	0.16	60.04	2.76

Table 6: Deviation of MT, MRR and SR values between experimental and empirical values of EN- 8

Sl No.	Spindle speed	Feed rate	Depth of cut	Experimental values			Empirical values		
				Machining time	Metal removal rate	Surface roughness	Machining time	Metal removal rate	Surface roughness
1	220	0.09	0.75	1.65	10.85	8.635	1.62	3.98	6.95
2	220	0.156	1	1.78	20.70	5.33	1.38	18.56	7.25
3	220	0.27	1.25	0.90	28.47	9.59	1.02	35.66	8.03
4	450	0.09	1	0.75	36.95	3.32	1.09	34.13	4.32
5	450	0.156	1.25	0.81	85.23	2.69	0.86	48.71	4.62
6	450	0.27	0.75	0.38	28.15	6.98	0.63	32.43	6.53
7	700	0.09	1.25	0.53	64.0	3.55	0.52	65.93	1.49
8	700	0.156	0.75	0.50	35.94	5.48	0.43	47.13	2.91
9	700	0.27	1	0.25	79.54	3.29	0.06	64.23	3.70

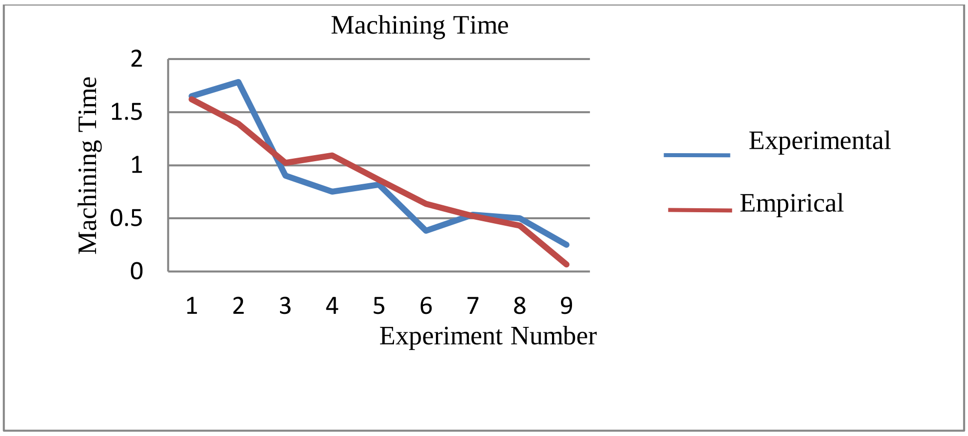

Figure 6: machining time

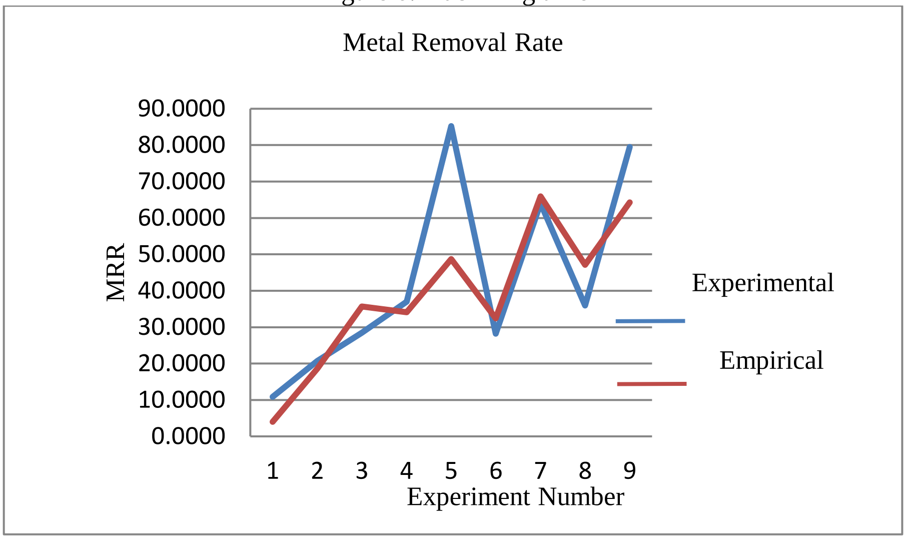

Figure 7: Metal Removal Rate

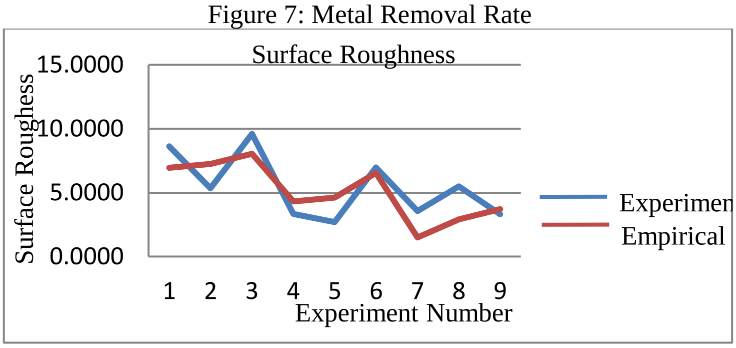

Figure 8: Surface Roughness

Table 7: Deviation of MT, MRR and SR values between experimental and empirical values of C.I

Sl No.	Spindle speed	Feed rate	Depth of cut	Experimental			Empirical values		
				Machining time	Metal removal rate	Surface roughness	Machining time	Metal removal rate	Surface roughness
1	220	0.09	0.75	2.70	6.29	2.84	1.97	10.50	3.11
2	220	0.156	1	0.93	21.40	3.54	1.70	16.16	2.99
3	220	0.27	1.25	1.78	12.89	2.76	1.32	19.79	2.80
4	450	0.09	1	1.16	14.57	2.49	1.22	42.25	3.06
5	450	0.156	1.25	0.40	79.76	3.32	0.96	47.90	2.95
6	450	0.27	0.75	0.75	31.97	2.54	0.96	26.27	2.80
7	700	0.09	1.25	0.76	71.60	2.84	0.43	76.03	3.02
8	700	0.156	0.75	0.25	75.51	3.63	0.54	56.40	2.94
9	700	0.27	1	0.50	39.88	2.48	0.16	60.04	2.76

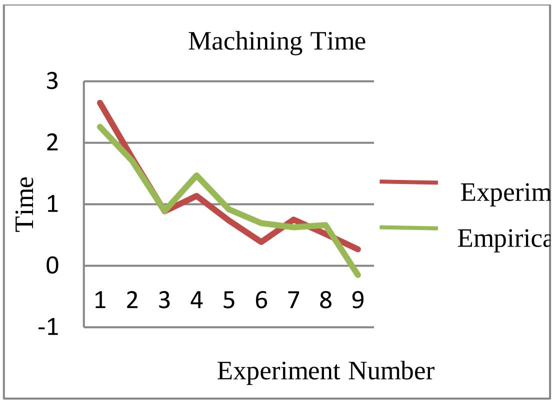

Figure 9: Machining Time

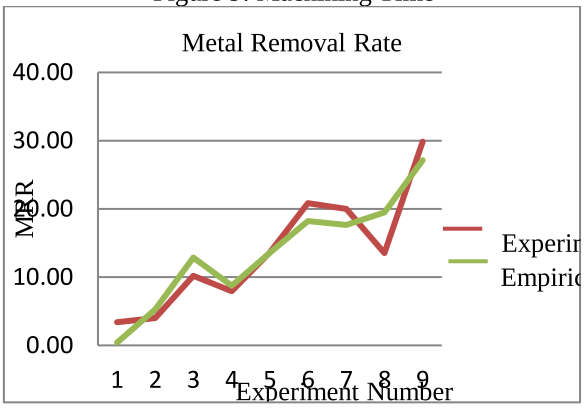

Figure 10: Metal Removal Rate

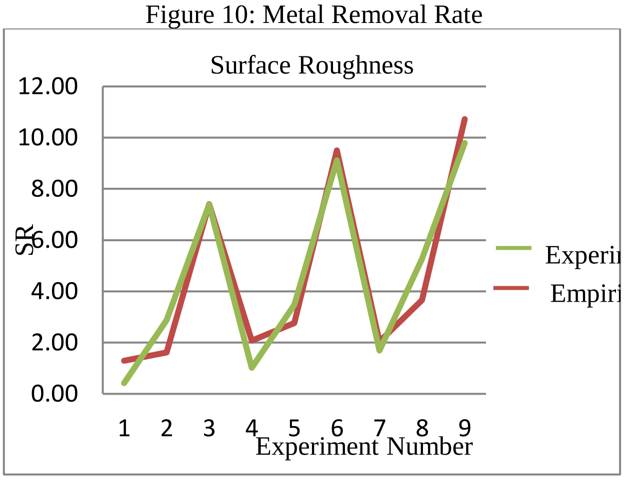

Figure 11: Surface Roughness

CONCLUSION

This work mainly focused on the performance of EN-8 and C.Iand the input and output parameters are analyzed experimentally. The experimental results are compared with formulated empirical equations. The performance was mainly computed based on the input and output parameters. The investigation on turning process of EN-8 and C.I

- Level and Ranges of speed, feed and depth of cut are chosen using the Design of Experiments (DOE) method.
- The turning operation of EN-8 and C.I is done in order to give satisfactory result for the output parameters
- The variations between the experimental and empirical methods are in the acceptable range.
- The comparison results of both the method made in order to analyse the machinability of the EN-8 and C.I.

REFERENCES

[1] S.Sathiyaraj, A.Elanthiraiyan, G.Haripriya, V.Srikanth Pari "Optimization of Machining Parameters for EN8 Steel through Taguchi Method", International Conference on Recent Advancement in Mechanical Engineering &Technology (Icramet' 15) Journal of Chemical and Pharmaceutical Sciences, Issn: 0974-2115, Page 157

[2] Pranav R. Kshirsagar, Somesh R. Pise, Sunil A. Pokalekar, Mahindra Goudadaba, Duradundi Sawant. Badkar "Optimization of Surface Roughness of EN8 Steel in CNC Turning Operation by Taguchi Concept", International Conference on Recent Innovations In Engineering and Management

[3] Puneet N P, Vasudeva Bhat P, Junaid Abdullam A "Flank Wear Analysis in Turning of EN8 Steel for Different Tool Inserts",

National Conference on Advances In Mechanical Engineering Science (Ncames-2016), Issn: 2231-5381, Page 119

[4] Ankit Dogra, Hartaj Singh, Dharampal, Vishal Singh, Sunil Kumar “Optimization of Turning Parameters of En-8 Steel Cylindrical Rods using Taguchi Methodology”, International Journal For Research in Applied Science & Engineering Technology (IJRASET), Issn: 2321-9653

[5] V. Baskaran, S. Prakash And J. Lilly Mercy “Experimental Investigation of Machining Parameters in CNC Turning EN8 Steel by Taguchi Design of Experiments”, Journal of Engineering and Applied Sciences, Vol. 12, No. 20, October 2017 Issn 1819-6608

[6] Franko Puh, Zoran Jurkovic, Mladen Perinic, Miran Brezocnik, Stipo Buljan “Optimization of Machining Parameters for Turning Operation with Multiple Quality Characteristics Using Grey Relational Analysis”, Issn 1330-3651 (Print), Issn 1848-6339 (Online)

[7] Hemanandan Pugalenthi, N.Kannan, S.Bhagavathi Shankar “Analysis of Vibration and Surface Finish in Turning of EN8”, International Journal of Engineering Research and Application, Issn : 2248-9622, Vol. 8, Issue 1, (Part -Iii) January 2018, Pp.94-97

[8] Shanmugam Murugappana, Sanjivi Arulb “Effect of Cryogenic Pre Cooling on Chip Reduction Co-Efficient During Turning of En8 Steel Rod”, Selection and Peer-Review under Responsibility of the Committee Members of International Conference on Advancements In Aeromechanical Materials For Manufacturing (Icaamm-2016) Icaamm-2016, Materials Today: Proceedings 4 (2017) 8848–8855

[9] Hemant Jain, Jaya Tripathi, Ravindra Bharilya, Sanjay Jain, Avinash Kumard “Optimisation and Evaluation of Machining Parameters for Turning Operation of Inconel-625”, 4th International Conference on Materials Processing And Characterization

[10] R.K.Bharilyaa Ritesh Malgayab, Lakhan Patidarc, R.K.Gurjard, Dr.A.K.Jhae “Study of Optimised Process Parameters in Turning Operation through Force Dynamometer on CNC Machine”, 4th International Conference on Materials Processing and Characterization, Materials Today: Proceedings 2 (2015) 2300 – 2305

[11] Paramjit Singh Bilga, Sehijpal Singh, Raman Kumar “Optimization of Energy Consumption Response Parameters for Turning Operation Using Taguchi Method”, Pii: S0959-6526(16)31125-8, Journal of Cleaner Production

[12] Mehmet Alper Sofuoglua, Sezan Orakb “Prediction of Stable Cutting Depths in Turning Operation Using Soft Computing Methods”, Applied Soft Computing, Pii: S1568-4946(15)00671-7, Reference: Asoc 3274

[13] Jingxiang Lv, Renzhong Tang, Wangchujun Tang, Shun Jia, Ying Liu, Yanlong Cao “An Investigation into Methods for Predicting Material Removal Energy Consumption in Turning”, Journal of Cleaner Production, Pii: S0959-6526(18)31362-3

[14] Shirish Kadam Rohit Khake Sadaiah Mudigonda “Experimental Investigations on Surface Roughness, Cutting Forces and Tool Wear In Turning of Super Duplex Stainless Steel with Coated Carbide Inserts” , Proceedings of the ASME 2017, 12th International Manufacturing Science And Engineering Conference, Msec2017, June 4-8, 2017, Msec2017-3008

[15] D. Manivel, R. Gandhinathan “Optimization of Surface Roughness and Tool Wear in Hard Turning of Austempered Ductile Iron (Grade 3) using Taguchi Method”, Measurement, Pii: S0263-2241(16)30347-5 Reference: Measur 4175

[16] Poorna Chandra , C.R. Prakash Rao , R. Kiran , V. Ravi kumar “Influence of Machining Parameter on Cutting Force and Surface Roughness while Turning Alloy Steel ”, Volume 5, Issue 5, Part 2, 2018, Pages 11794-11801

[17] C.L. He, W.J. Zong, J.J. Zhang “Influencing factors and theoretical modeling methods of surface roughness in turning process: State-of-the-art”, International Journal of Machine Tools and Manufacture, PII: S0890-6955(18)30041-5 Reference: MTM 3325

[18] ” Recep Yigit a,∗, Erdal Celikb, Fehim Findikc, Sakip Koksalc “Effect of cutting speed on the performance of coated and uncoated cutting tools in turning nodular cast iron

[19] Varun Nayyar*, Jacek Kaminski, Anders Kinnander and Lars Nyborg “An Experimental Investigation of Machinability of Graphitic Cast Iron Grades; Flake, Compacted and Spheroidal Graphite Iron in Continuous Machining Operations”, 5th CIRP Conference on High Performance Cutting 2012

[20] Jie Qin, Ying Longn, Junjie Zeng,Shanghua Wunn ”Continuous and varied depth-of-cut turning of gray cast iron by using uncoated and TiN/Al2O3 coated silicon nitride-based ceramic tools” Ceramics International

[21] J.V.C. Souza, M.C.A. Nono , M.V. Ribeiro , J.P.B. Machado, O.M.M. Silva “Cutting forces in turning of gray cast iron using silicon nitride based cutting tool”,Materials and Design

[22] ELSawy, E.E.T.a, EL-Hebeary, M.R. and El Mahallawi I.S.E. “Effect of manganese, silicon and chromium additions on microstructure and wear characteristics of grey cast iron for sugar industries applications”, Wear PII: S0043-1648(17)30231-4

[23] Md AbdulMaleque, SugribShah and NurulNabilahRazali “Wear Behaviour of Aluminium Modified Cast Iron in Comparison With Conventional Gray Cast Iron”, Module in Materials Science and Materials Engineering doi:10.1016/B978-0-12-803581-8.10460-6 1

[24] K. Gajalakshmi, S. Palanivel, N.J. Nalin, S.Saravanan “ Automatic classification of cast iron grades using support vector machine”, PII: S0030-4026(17)31603-0 International Journal for Light and Electron Optics (2010)

[25] M. Wasim Akram, Andreas A. Polycarpou “Wear Mechanisms of Gray Cast Iron in the Presence of Environmentally Friendly Hydro fluoroole fin-Based Refrigerant and the Effect of Tribofilm Formation” Journal of Tribology OCTOBER 2015, Vol. 137 / 041602-1