Optimization of cryogenic treatment parameters to maximise the tool wear of HSS tools by Taguchi method

M. C. Kumar[1], Dr. P. VijayaKumar[2], Dr. B. Narayan[3]

1. Dept. of Mech. Engg., City Engineering College, Bangalore
2. Dept of Mech. Engg., UVCE, KR Circle, Bangalore
3. Dept of Mech. Engg, Dr. Ambedkar Institute of Technology, Bangalore

Abstract: *This work describes the optimization of cryogenic treatment (CT) parameters such as the cooling rate, the soaking temperature, the soaking time, the tempering temperature and the tempering time to maximise the tool wear of high speed steel tools in dry turning of AISI 316 grade austenitic stainless steels by Taguchi method. For this purpose, four iteration of Taguchi design (L16) have been used to arrive at the optimum CT parameters. The various levels of cryogenic treatement parameters have their own influence upon the flank wear resistance of the HSS tools. In this study, teh Taguchi method has been used to optimize teh process parameters for cryogenic treatment of commercial HSS tools. For optimization, four iterations of Taguchi design have been used to arrive at the optimum CT parmeters. The experimental results demonstrate that the soaking temperature was the major parameter influencing the flank wear rate for all samples, but, other parameters were found to have negligible effect on the flank wear rate.*

I. Introduction

High speed steel (HSS) is inexpensive, cutting tools can be shaped easily and it has excellent fracture toughness along with fatigue resistance. Due to its limited wear resistance it can be used at lower cutting velocities of 30-50 m/min [1]. Consequently, change in the chemical properties of HSS tool material to resist wear from the adverse machining environment. Cryogenic treatment (CT) shows promise as a tool material treatment for increasing tool life[2-5]. In this regards cutting tool industries have taken lot of interest on CT due to its effects on dimensional stability of the material, improv wear resistance and hardness of the materials. Many researchers [6-8] gave reasons for this improvement in properties because of complete transformation of retained austenite into marteniste and the precipitation of fine carbide into the martensitic matrix.

Although CT is governed by many operational factors like cooling rate, soaking temperature, soaking time, heating rate, tempering temperature, tempering time etc, Various researchers [9-10] have used different levels of the CT parameters in their studies and have claimed different percentages of improvements in the mechanical properties of steel components [11] (Barron, 1982; Mohan Lal et al., 2001). Each CT parameter influences the quality of the tools for example the soaking temperature depends upon the martensite finish temperature of the material considered and soaking period depends upon the time required for the carbides to precipitate[12]. But no study was done to optimise the CT parameters for maximising tool wear resistance yet, because visualization of impact of various factors in interacting environment is not possible. On the other hand, an inexpensive and easy-to-operate experimental starategy based on Taguchi design has been adopted in this study to investigate the effect of various parameters and their interactions, because, in actual practice the resultant erosion rate is the combined effect of more than one interacting variable. This procedure has been successfully applied for parametric appraisal in different process optimization problems [13-14]. Further, the analysis of variance (ANOVA) is done to identify the most significant control factors and their interactions. The present work was done to study the effect and optimise the CT parameters on tool wear behaviour of HSS tools in dry turning of AISI 316 grade austenitic stainless steels by Taguchi method.

II. Design of Experiment

The Design of experiments was assembled for the CT with the objective of achieving tool wear resistance considered as the response. Table 1 shows five factors and four levels used in the experiment. If four levels were assigned to each of these factors and a factorial experimental design was employed using each of these values, number of permutations would be 625. The fractional factorial design reduced the number of experiments to sixteen. The cooling rate (A), the soaking temperature (B), the soaking time (C), the tempering temperature (D) and the tempering time (E) were assigned to the 1st, 2nd, 3rd, 4th and 5th column of L16 array respectively. The orthogonal array of L16 type was used and is represented in Table 2. This design requires sixteen experiments with five parameters at four levels of each and the interactions were neglected. The S/N ratios were computed for wear rate in each of the 16th trial condition and their values are given in Table 2.

Table 1. Selected fermentation factors and their assigned levels

\Symbol	Factors	Unit	Levels			
			1	2	3	4
A	Cooling rate	°C/min	1	2	3	4
B	Soaking temperature	°C	-80	-115	-150	-185
C	Soaking time	h	06	12	18	24
D	Tempering temperature	°C	125	150	175	200
E	Tempering time	h	1	2	3	4

Table 1 shows five factors and four levels used in the experiment. If four levels were assigned to each of these factors and a factorial experimental design was employed using each of these values, number of permutations would be 625. The fractional factorial design reduced the number of experiments to sixteen. The cooling rate (A), soaking temperature (B), Soaking time (C), Tempering temperature (D) and Tempering time (E) were assigned to the 1st, 2nd, 3rd 4th and 5th column of L16 array respectively. The orthogonal array of L16 type was used and is represented in Table 2. This design requires sixteen experiments with five parameters at each of these four levels. The interactions between main factors were neglected. The S/N ratios were computed for wear rate in each of the 16 trial conditions and their values are as given in Table. 2.

Table 2. Experimental data and sample statistics

Ex. No.	Main factors					Observed response (Wear rate x10-5 mm^3/ m)			Average wear rate	Standard Deviation	S/N ratio (db)
	A	B	C	D	E	1	2	3			
1	1	1	1	1	1	4.4	4.553	3.451	4.135	0.597	-16.809
2	1	2	2	2	2	1.657	2.187	0.755	1.533	0.724	-6.516
3	1	3	3	3	3	3.45	3.876	3.132	3.486	0.373	-19.405
4	1	4	4	4	4	9.781	10.392	9.336	9.836	0.530	-25.368
5	2	1	2	3	4	3.37	3.81	2.955	3.378	0.428	-17.954
6	2	2	1	4	3	4.343	4.679	3.801	4.274	0.443	-19.689
7	2	3	4	1	2	4.173	4.34	3.382	3.965	0.512	-17.784
8	2	4	3	2	1	5.402	5.965	5.084	5.484	0.446	-21.792
9	3	1	3	4	2	4.379	4.535	4.257	4.390	0.139	-29.968
10	3	2	4	3	1	2.718	2.849	1.937	2.501	0.493	-14.105
11	3	3	1	2	4	4.466	5.097	3.634	4.399	0.734	-15.556
12	3	4	2	1	3	7.059	7.613	6.997	7.223	0.339	-26.566
13	4	1	4	2	3	5.102	5.928	4.77	5.267	0.596	-18.921
14	4	2	3	1	4	4.338	4.866	3.803	4.336	0.532	-18.231
15	4	3	2	4	1	5.435	5.784	4.534	5.251	0.645	-18.214
16	4	4	1	3	2	8.413	8.925	8.24	8.526	0.356	-27.581

III. Experimental studies

In this study, the HSS tools were cryogenically treated under dry conditions where the tools being treated were not exposed to the liquid nitrogen to eliminate the risk and damage of thermal shock. The procedure used for the treatment in this study is outlined in the following steps and is shown in Fig.1. Tools were placed in a container and the temperature was brought to -196°C in intervals by computerized controlled different rates. The temperature was held for different durations before the process was reversed. The tools were slowly brought to room temperature allowing the material to stabilize. Then, the tools were subjected to tempering cycles to relieve the stresses induced by cryogenic treatment. This was accomplished by increasing the temperature to various temperatures and then slowly reducing the temperature back to room temperature.

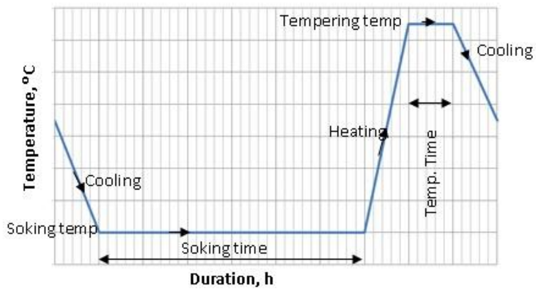

Fig. 1 Standard procedure for cyrogenic and tempering treatment for HSS tools

Since the cutting mechanics involved in turning operation is relatively simpler, a difficult-to-machine material like stainless steel was considered for the turning tests were carried out on a HMT Heavy Lathe. For the experiment, cutting velocity, feed rate and depth of cut are 100 m/min, 0.2 mm/rev and 1 mm respectively. The duration of machining for each trial was only 60 s. After 60 s machining, the condition of the cutting tools was studied using optical microscopy. Once flank wear reached 0.3 mm, the tool life was considered to be over.

IV. Results and discussion

Optical micrograph (OM was carried for both cryogenically treated and untreated HSS samples to study the microstructural changes. Results of the SEM analysis are shown in Fig. 2 (a) and (b) for untreated HSS tools and cryogenically treated tools respectively. The results showed the presence of the fine precipitated carbide particles in case of cryogenically treated samples which verify that the refinement of carbides takes place after the cryogenic treatment.

3.2 Taguchi's analysis of wear rate

Sixteen different set of experiments were performed using the design parameter combinations in the specified orthogonal array table. Three specimens were fabricated for each of the parameter combinations. The completed response table for these data appears in Table 2.

In order to estimate the effect of factor A (wt. % graphite) on the average value of response variable, three observed responses at level 1 of factor A, were summed together. Then the sum was divided by 4 to obtain the average response at level1 of factor A. The average responses at level 2, 3 and 4 were obtained in the similar manner. The estimated effects are presented graphically in Fig. 3.

The estimated individual factors effect on average flank wear of HSS tools is shown in Fig. 3. The range of average responses over the four levels of each experimental factor, is: for cooling rate (A), 2 °C / min, for soaking temperature (B), -175 °C, for soaking time (C), 12 h, tempering temperature (D), 150 °C and for tempering time (E), 1 h. In particular, factor A (2), factor B (3), factor C(2), factor D (2) and factor E(1) for minimum flank wear combinations were established,

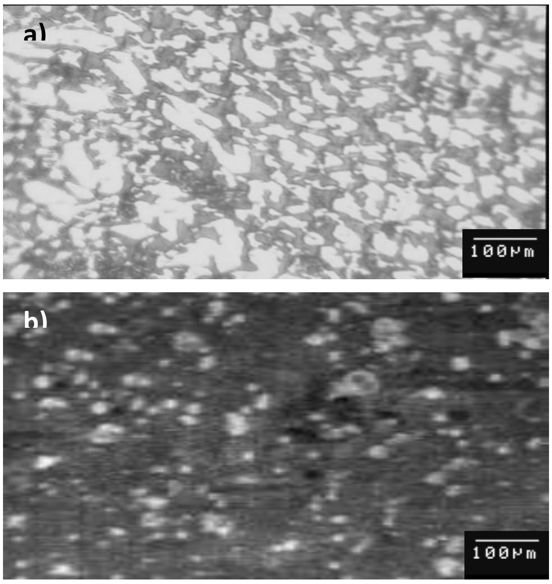

Fig. 2. Microstructure of a) untreated and b) cryogenically treated HSS tools

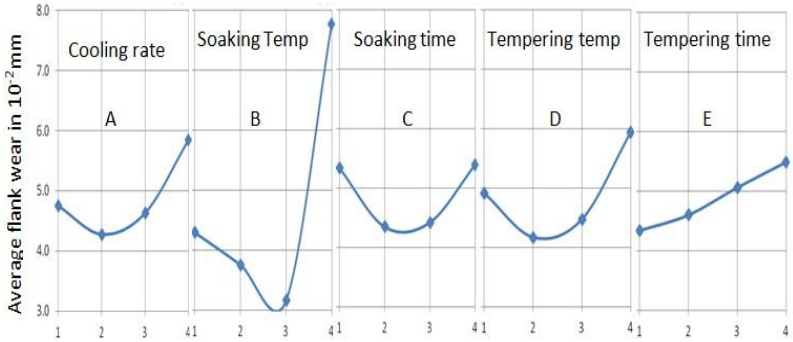

Fig. 3. Main effect and interaction effect plots for HSS samples

From Fig. 3, it can be seen that second level of factor (A) give the lowest average (i.e A2, which average of responses at cooling rate is 2 °C/min). The lowest average for factor B is at the third level (i.e B3, which is -175 °C), the lowest average soaking time (i.e C2 is 12 hour), the lowest average tempering temperature (i.e D2 is 150 °C) and the lowest average tempering time (i.e E1 is 1 hour). These predicted parameters are not used in the cryogenic treament which is indicated in Table 2. Hence experiments were conducted at the predicted parameters, i.e cooling rate 2 °C/min (A2), soaking temperature -175 °C (B3), soaking time 12 hours (C2), tempering temperature 150 °C (D2) and tempering time 1 hour (E1), tested the specimen by flank wear test. The resulting wear rate was 1.323 mm, which is lower than the average flank wear in Table 3.

Table 3 Summary ANOVA Table for wear rate of PA66/graphite composites

Factors	DOF	Sum of squares	Mean squares	Fcal	Ftab	Alpha	% of Confidence	% of contribution
A	3	5.51	1.84	0.3886	1.52	0.7629	7.77	23.71
B	3	51.30	17.10	3.6189		0.0381	72.38	96.19
C	3	3.84	1.28	0.2711		0.8452	5.42	15.48
D	3	7.16	2.39	0.5049		0.6847	10.10	31.53
E	3	3.07	1.02	0.2165		0.8834	4.33	11.66
SW	15	70.88	4.73					

Examination of the calculated Fisher's values (F) for all control factors also shows a very high influence of factor B and low influence of factor E on the flank wear of the HSS samples as shown in Table 3. The F value was calculated for each design parameters. The optimum test conditions were estimated from the significant factors. The computed value of Fcal (3.6189) was more than that from the statistical Ftab (1.52). The Ftab equals to 1.52 at 99.5% confidence level. Thus, based on the level of confidence (99.5%), factors of only B (96.19 %) were significant while the factors A (23.71%), C (15.48 %) , D (31.53%) and E (11.6 %) were less significant. The last column of the above table indicates the percentage of contribution (%P) of each factor, thus exhibiting the level of influence on the quality characteristic. The table shows that cooling rate (A), soaking temperature (B), for soaking time (C), tempering temperature (D) and tempering time (E), have percentage of contributions of 7.77 %, 72.38%, 5.42%, 10.10 % and 4.33 % on the flank wear respectively.

V. Conclusions

The Taguchi and ANOVA methods were applied to investigate the effects of cooling rate, soaking temperature, soaking time, tempering temperature and tempering time. The conclusions drawn from this work are;

- Cryogenic soaking temperature is the most significant factor and the maximum percentage contribution of soaking temperature on the flank wear of HSS tools was 72.38 %. The best soaking temperature in the possible range is -175 °C
- The second significant factor is tempering temperature and its contribution is 10.10 % for the improvement of flank wear resistance. The best level for this factor 150 °C.
- The other factors such as cooling rate (7.77 %), soaking time (5.42 %) and tempering duration (4.33%) contribution to wear resistance.
- The optimum test condition, at which the lowest rate is obtained, has been determined to be A2B3C2D2E1 levels

References

1. GogteCL,KumarMIyer,ParetkarRKandPeshweDR,DeepSubzeroProcessingofMetalsandAlloys:EvolutionofMicrostructureof AISI T42ToolSteel,*Materials&ManufacturingProcesses*,vol. 24(2009), pp. 718-722.
2. GogteCL,KumarMIyer,ParetkarRKandPeshweDR,DeepSubzeroProcessingofMetalsand Alloys: Evolution of Microstructure of AISI T42 Tool Steel, *Materials & Manufacturing Processes*, vol. 24, (2009) pp. 718-722.
3. Yong, A.Y.L., Seah, K.H.W., Rahman, M., Performance evaluation of cryogenically treated tungsten carbide tools in turning, Int. J. Mach. Tools Manuf., vol. 46(2004), pp. 2051–2056.
4. Yong, A.Y.L., Seah, K.H.W., Rahman, M., Performance of cryogenically treated tungsten carbide tools in milling operations, Int. J. Adv. Manuf. Technol., vol. 32, (2007) pp. 638–643.
5. Ramji.B.R ,Narasimha Murthy.H.N ,Krishna.M, Performance analysis of cryogenically treated carbide drills in drilling white cast iron International Journal Of Applied Engineering Research, vol. 1, (2010) pp. 553-560
6. *J.D. Darwina,, D. Mohan Lalb,1, G. Nagarajanb,1*Optimization of cryogenic treatment to maximize the wear resistance of 18% Cr martensitic stainless steel by Taguchi methodjournal of materials processing technology, vol.195(2008) pp. 241–247
7. Meng, F.,Tagashira, K.,Sohma, H.,Wear resistance and microstructure of cryogenic treated Fe–1.4Cr–1C bearing steel. Scripta Metall. Mater.., vol.31(2005), pp.865–868.
8. Mohan Lal, D., Renganarayanan, S., Kalanidhi, A., Cryogenic treatment to augment wear resistance of tool and die steels. Cryogenics vol.41(2001), pp.149–155.
9. Seah,K.H.W, Rahman, M., Yong, K.H.,Performance evaluation of cryogenically treated tungsten carbide cutting tool inserts, Proc. Inst. Mech. Eng. Part B: J. Eng. Manuf., vol. 217(2003), pp. 29-43.

10. Selvaraj D.P., Chandramohan P. (2010) , Influence of Cutting Speed, Feed Rate and Bulk Texture on the Surface Finish of Nitrogen Alloyed Duplex Stainless Steels during Dry Turning. Engineering, vol.2, (2010) pp. 453-460
11. Reddy, T.V.S., Sornakumar, T., Reddy, M.V., Venkataram, R., Senthilkumar, A. Turning studies of deep cryogenic treated p-40 tungsten carbide cutting tool inserts. Technical Communication .J. Mach Sci tech. vol. 13(2009), pp. 269-281
12. Paul S, Dhar NR, Chattopadhyay AB., 2001, Beneficial effects of cryogenic cooling over dry and wet machining on tool wear and surface finish in turning AISI 1060 stee1, J Mater Process Tech, vol.116 (2001), pp 44–48.
13. S. Thamizhmanii, S. Saparudin, S. Hasan, Analyses of surfaces roughness by turning process using Taguchi method, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 503-506.
14. D.H. Wu, M.S. Chang, Use of Taguchi methods to develop a robust design for the magnesium alloy die casting process, Materials Science and Engineering 379 (2004) 366-371.

M.C. Kumar, M.E is an Associate professor in the department of Mechanical engineering, City Engineering College, Bangalore, he has published 10 national and international papers.

Dr. P. Vijaya Kumar, M.E, Ph.d, is a Prof. and Dean of the faculty for Engineering studies at Department of Mechanical Engineering University Visvesvaraya College of Engineering, Bangalore University, Bangalore, he has 25 years of teaching both UG & PG, and He has published about 30 papers in national and international journals.

Dr. B. Narayan. M.E, Ph.d, is a Prof. in the Department of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bangalore he has 27yrs of teaching both UG & PG, he has published about 17 papers in national and international journals.