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A Taguchi Method-Based Experimental Design of Experiments in the Heat Machining Processes of High Manganese Steel using SNMG-Carbide Inserts

Sumit Ganguly, Om Kumar, Prakash Kumar, Gourav Kumar, Shubham Kumar Dutta,
Bikash Mandal & Pintu Thakur
Department of Mechanical Engineering
K.K. Polytechnic, Govindpur, Dhanbad, India

Abstract*: High shear strength and hardness materials are needed in the industrial world, but standard methods are expensive. Hot machining can increase surface polish, reduce tool wear, and use less power by raising the workpiece temperature. Tool-work interfaces have been heated using a variety of techniques; tests have revealed that plastic deformation and material shearing account for the majority of power consumption during turning operations. Shear strength and hardness values are lowered by temperature, indicating that a higher work piece temperature shortens tool life and power usage. The experiment uses an auto feed lathe and thermocouple for temperature control. When performing statistical analysis, the Taguchi method is employed with the goal of reducing response variation and preserving process accuracy. For more consistent output and performance, the approach incorporates statistical methodologies into the engineering process and makes use of orthogonal array designs, such as L4, L8, L16, L9, L16, and L18. In trials employing the Taguchi method and Hot Machining, control factors such cutting speed, depth of cut, temperature, and feed increase tool life by 14.8% and dramatically reduce power consumption.*

Keywords: Hot machining

I. INTRODUCTION

Technological and scientific developments have created a demand for materials with high shear strength and hardness. Traditional machining techniques are expensive and shorten the life of tools. Hot machining was created to improve machinability, power consumption, and tool life. This entails employing a variety of heating techniques to raise the workpiece's temperature in order to decrease shear strength. Because both shear strength and hardness values decrease with temperature, experiments demonstrate that raising the workpiece temperature saves power usage and extends the life of the tool.

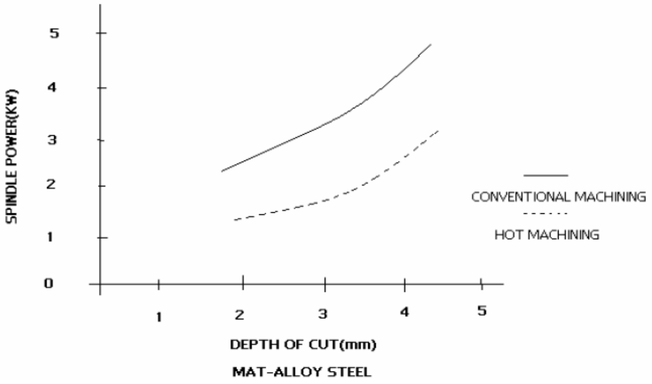

Figure 1.1: Spindle Power Vs Depth of cut

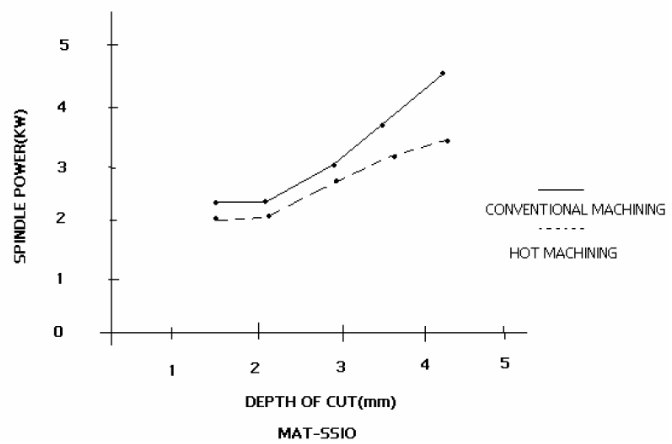

Figure 1.2: Hardness Vs Depth of Cut

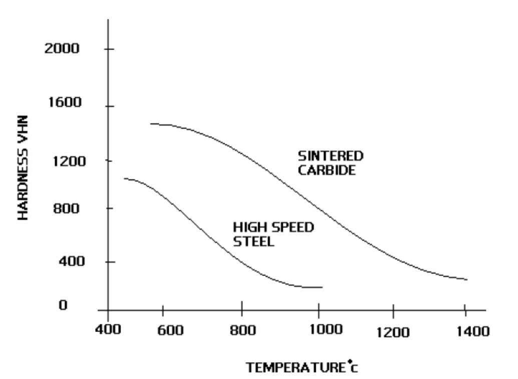

Figure 1.3: Hardness Vs Temperature

Essential specifications for the workpiece heating technique:

External heat application at the shear zone, limited to a small area, and integrated with a precision temperature control device are necessary for the hot machining process. Limitations caused by the size, form, circumstances, and machining process of the work piece should be minimized in the heat supply. The heat source should have a high specific heat input and the machined surfaces shouldn't be polluted or overheated. Heating apparatuses ought to require little upkeep and startup costs, and their operation shouldn't endanger the operator.

II. MATERIAL DATA SHEET:[3]

Table1.1:Nihard Material

Mechanical Properties	Specification
Hardness HBN(Typical)	600-640
Tensile Strength	59999 psi
PH Range	5-7

Chemical Composition (weight%)

C2.5-3.6%	P0.10max
Cr 7-11	S 0.15 max
Ni 4.5-7.0	Si 2.0 max
Mo 1.5 max	Mn 2.0 max
	Fe balance

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The author procured Nihard material from L&T Kansbhal but couldn't repair defects. They continued hot machining with high manganese steel with carbide inserts and conducted experimental investigations using Taguchi method.

III. EXPERIMENTAL SET UP AND PRINCIPLE OF WORKING

The material to be machined for the work piece is installed in the lathe between the head and tail stocks. The torch is attached as seen in figure 2.1 and is movable in tandem with the cutting instrument. An oxygen and LPG cylinder are attached to the torch. Previous researchers had already put this up [5]. Oxygen and LPG flow can be adjusted with accessible valves. The handle provided allows you to modify the torch nozzle's distance, as depicted in the illustration. The temperature of the work item can be determined using a temperature indicator. The temperature indicator allows for temperature setting, and the torch will automatically move away from the work item once the temperature is reached. This is accomplished by utilizing the offered control system, and the thermocouple-based temperature indicator. The system has a PID controller connected to it. Figure 2.1 illustrates how an SNMG carbide insert performs the machining.

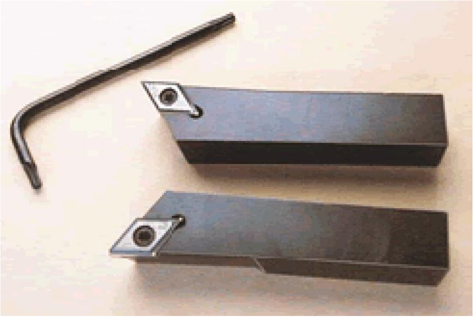

Figure 2.1

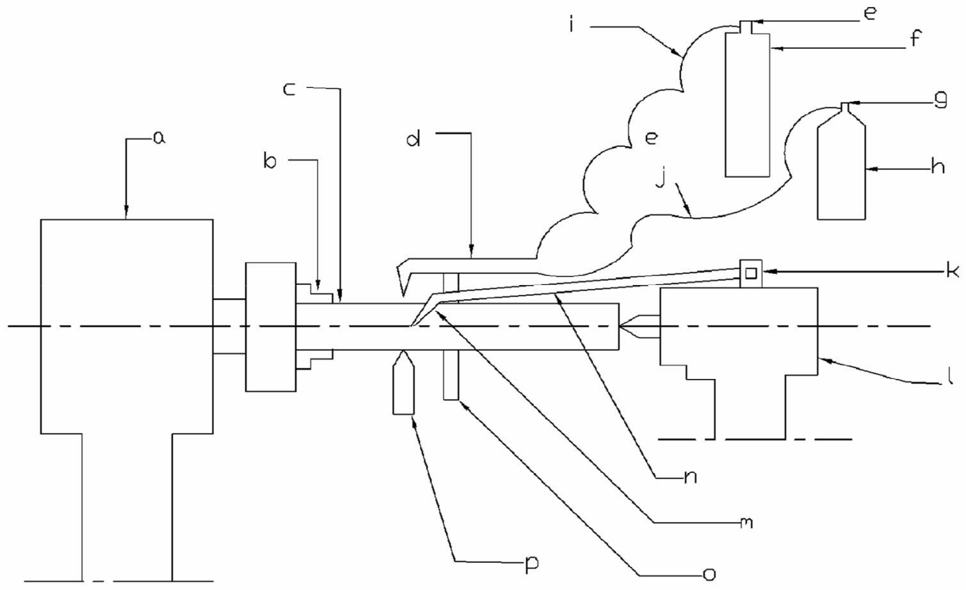

Figure2.2:Experimental setup

(a) Lathe head stock
(b) Chuck
(c)Workpiece
(d) Torch
(e) Oxygen
(f')Oxygen Cylinder flowvalve
(g) LPG flow valve
(h)LPG cylinder
(i) Oxygen pipe
(j)LPG pipe
(k)Temperature indicator
(l) Tail stock
(m)Thermocouple
(n)Wire
(o)Distance adjustment
(p) Cutting tool handle

IV. DESIGN OF THE STATISTICAL EXPERIMENT:-

TAGUCHI METHOD:

To develop products that function consistently and optimally under a range of conditions, Taguchi designs offer a potent and effective technique. The main objective is to identify factor settings that reduce response variation while modifying (or maintaining) the process on target. The result from a process created with this objective in mind will be more reliable. No matter what environment a product is utilized in, it will perform more consistently if it is designed with this in mind.

The Taguchi technique recommends allocating the components selected for the experiment using orthogonal array designs. The orthogonal array designs L4, L8, L16, L9 (i.e., four experimental trials), L16, and L18 are the most often utilized ones. The Taguchi method's strength lies in its ability to include statistical techniques into the engineering process.

Table 2.1: CONTROL FACTORS AND THEIR RANGE OF SETTING FOR THE EXPERIMENT

CONTROLFACTOR	LEVEL-1	LEVEL-2	LEVEL-3
Cutting speed	19.54m/min	32.57m/min	54.72m/min
Feed	0.050 mm/s	0.10mm/s	0.49mm/s
DepthOfCut	0.49mm	1.1mm	1.49mm
Temperature	600 C	400 C	200 C

The control factors for hot machining of high manganese steel are shown in the above table. We select the L4 taguchi design in accordance with the Taguchi approach as we have four control factors and three levels for each factor. Instead of using normal factorial design, we use orthogonal arrays in L4 taguchi design. With this design, there are just four planned experiments instead of the original 24.

SIGNAL-TO-NOISE RATIO:

By examining the degree of variation present in the response, one may rapidly determine the control element that might help to reduce variance. Taguchi has developed a transformation that converts the repetition data into a response measure of the variance that is there. Signal-to-noise ratio (S/N) is the transformation.There are three different S/N ratios based on the kind of characteristics.

1) LOWER IS BETTER:
$(S/N)LB = -10 \log (1/r \Sigma yi2)$
Where,
r = Number of tests in a single trial.

2) NOMINAL IS BETTER:
$(S/N)NB1 = -10 \log Ve$
$(S/N)NB2 = 10 \log ((Vm - Ve)/r\,Ve)$

3) HIGHER IS BETTER:

$(S/N)_{HB} = -10 \log (1/r \, \Sigma \, y_i^2)$

Where,

y_i = each observed value.

V. ANALYSIS STATISTICAL AND RESULTS INTERPRETATION:

Finding major main influences that affect the SNR is the next step after obtaining the average SNR values. A potent graphical tool known as half-normal probability plots (HNPP) is helpful in achieving this. Plotting the absolute values of the effects along the X-axis and the percent likelihood along the Y-axis yields a half-normal probability plot (HNPP). The following formula can be used to get the percent probability:

$(i - 0.5)/n * 100$ is P_i.

In this case,

n = the number of estimated impacts (15).

i = is the estimated effect's rank when placed in ascending order of Magnitude

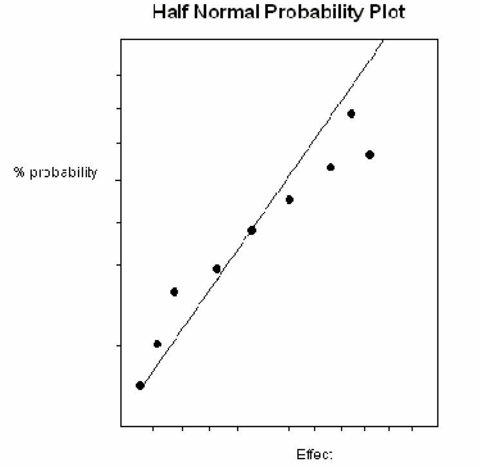

Figure 2.2: Half Normal probability plot

The HNPP graph is plotted to identify active and real effects, while inactive and insignificant effects are plotted along a straight line. A higher signal-to-noise ratio is needed for tool life, allowing for S/N table determination and control factor major effect plot.

$\text{Effect} = SNRf2 - SNRf1$

HOW TO DO A TAGUCHI EXPERIMENT:

Conducting a Taguchi experiment entails several discrete procedures. [6] They are

Step 1: Formulate the problem - a thorough grasp of the problem's nature is essential to any experiment's success.

Step 2: Determine which output performance traits are most pertinent to the issue at hand.

Step 3: Determine the factors that affect control, noise, and signal (if any). Factors under control are those that can be managed in a typical production setting. Noise factors are those that, in typical manufacturing circumstances, are either too expensive or too difficult to regulate. Signal factors are those that have an impact on the process's average performance.

Step 4: choosing the factor levels, potential interactions, degrees of freedom for each component, and the impacts of interactions.

Step 5: Creating a suitable orthogonal array (OA) is the fifth step.

Step 6: Get the experiment ready.

Step 7: is doing the experiment and gathering the necessary data.

Step 8: involves the interpretation of the experimental data and statistical analysis.

Step 9: Conducting an experiment's confirmatory run.

HARDENED HIGH MANGANESE STEEL HOT MACHINING:

The experiment focuses on cutting speed, feed, depth of cut, and temperature, with tool wear as the response. The L4 Taguchi design is used, with nine runs, measuring tool wear every two minutes, reducing the number of experiments from 24 to 4 [5].

Table 2.2: EXPERIMENT ROUND

RUNS	CONTROL FACTOR 1	CONTROL FACTOR 2	CONTROL FACTOR 3	CONTROL FACTOR 4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3

VI. EXPERIMENTAL SET UP AND PRINCIPLE OF WORKING

Table 3.1: TRIAL & CONTROL FACTOR DETAILS

TRAIL NUMBER(RUNS)	CONTROLFACTORS				RESPONSE
	CUTTING SPPED(1)	FEED(2)	DEPTH OF CUT(3)	TEMPERATURE(4)	
1	149	0.04	0.49	600	0.629
2	149	0.11	1.1	400	0.78
3	149	0.16	1.50	200	0.94
4	249	0.06	1.0	200	0.88

Table 3.2: AVERAGE SNR REPORT

FACTOR'S SNR	CUTTING SPEED	FEED	DEPTH OF CUT	TEMPERATURE
SNR1	2.2672	1.8591	2.0813	2.0158
SNR2	1.3104	1.4291	1.3640	1.124
SNR3	0.6327	0.9221	0.7650	0.8864
DELTA	1.6327	0.9371	1.3163	1.1294
RANK	1	4	2	3

HOT MACHINING OF "HIGH MANGANESE STEEL" BY TAGUCHI'S L4 DESIGN WITH TOOL LIFE AS RESPONSE:

The amount of time that a tool can effectively machine a specific work piece is known as its tool life. In this instance, the tool life is determined by how long it takes for the flank wear value to reach 0.4 mm.

DESIGN OF TOOL LIFE AT FIRST RUN OF TAGUCHI'S L4:

The tool is properly ground before the experiment begins, leaving 0% flank wear. The temperature, feed rate, depth of cut, and cutting speed are all adjusted to the proper, specified levels. Every two minutes, the tool is taken out and the flank wear is measured under a tool maker's microscope. This practice is continued till tool wear reaches 0.6 mm. A relationship is established between flank wear and time.

FIRST RUN:

Cutting Speed = 19.55 m/min
Feed = 0.04 mm/rev
Depth of Cut = 0.49 mm
Temperature = 600 degrees

S.NO	TIME (minutes)	FLANK WEAR(mm)	POWER (Watt)
1	0	0	0
2	2	0.078	30
3	4	0.098	20
4	6	0.12	30

SECOND RUN:
Cutting Speed = 19.55 m/min
Feed = 0.11 mm/rev
Depth of Cut = 1.11 mm
Temperature = 400 degrees

S.NO	TIME (minutes)	FLANK WEAR(mm)	POWER (Watt)
1	0	0	0
2	2	0.079	30
3	4	0.086	20
4	6	0.1	30

THIRD RUN:
Cutting Speed = 19.55 m/min
Feed = 0.16 mm/rev
Depth of Cut = 1.50 mm
Temperature = 200 degrees

S.NO	TIME (minutes)	FLANK WEAR(mm)	POWER (Watt)
1	0	0	0
2	2	0.12	30
3	4	0.129	30
4	6	0.156	30

FOURTH RUN:
Cutting Speed = 19.55 m/min
Feed = 0.06 mm/rev
Depth of Cut = 1.0 mm
Temperature = 200 degrees

S.NO	TIME (minutes)	FLANK WEAR(mm)	POWER (Watt)
1	0	0	0
2	2	0.07	30
3	4	0.09	20
4	6	0.12	30

Table 3.3: EXPERIMENT DETAILS

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Table 3.4 :EXPERIMENTAL OBSERVATION

TRAIL NUMBER(RUNS)	CONTROLFACTORS				RESPONSE
	CUTTING SPPED(1)	FEED(2)	DEPTH OF CUT(3)	TEMPERATURE(4)	
1	150	0.05	0.5	600	40
2	150	0.1	1.0	400	34
3	150	0.15	1.50	200	31
4	250	0.05	1.0	200	36

Table 3.5 :SNR REPORT

RUNS	SNRVALUE
1.	32.041
2.	30.62
3.	29.82
4.	31.12

VII. RESULT & CONCLUSION

The goal of the experiment was to use the Taguchi technique to optimize control parameters in hot machining turning processes. Reducing response variance and preserving process effectiveness were the objectives. Plastic deformation and material shearing were the main sources of power consumption during turning operations. It was discovered that 150 cutting speed, 0.05 feed, 0.5 depth of cut, and 600 temperature were the ideal parameters. Tool life was increased by 14.83% and power consumption was reduced by employing Taguchi design and hot machining.

The study reveals increased tool life and lower power using Taguchi statistical analysis and ATP grade tool for turning operation in hot machining. The ideal values for temperature, feed, depth of cut, and cutting speed are discovered.

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