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Review Article

Exploring Machining Characteristics of AISI A2 Tool Steel in Turning: A Taguchi Approach for Variability Analysis under Diverse Conditions

Prabhujot Kaur[1], Manpreet Singh[2]

Mechanical Engineering Department, Chandigarh University, Punjab, India.

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Corresponding Author:
Prabhujot Kaur,
E-mail Id:
kaurprabhujot517@gmail.com
Orcid Id:
https://orcid.org/0009-0003-1176-4823

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A B S T R A C T

To remain competitive in the market, modern businesses rely on their manufacturing engineers and production staff to quickly and efficiently set up manufacturing processes for new products. Taguchi Parameter Design is a powerful tool for tackling this issue since it is an effective and efficient way for enhancing the output and quality of industrial operations. This paper discusses the use of Taguchi Parameter Design to optimise the surface roughness produced by an HMT Lathe Machine during turning operations. In this study, a noise factor is introduced to a standard L18 orthogonal array to obtain the ideal tuning parameters. When compared to slightly worn jaws, which are a noise factor, spindle speed, feed rate, depth of cut are all controlled variables. The addition of the noise component strengthens the study's applicability and robustness. This study experimentally turned sample workpieces using the chosen orthogonal array and parameters, then gave a confirmed combination of controlled factors and a predictive equation for predicting surface roughness with a given set of parameters.

Keyboard: Exploring Machining Characteristics, Design of Experiments, Cutting Fluid, Spindle Speed,

Introduction

When designing such an operation, engineers and technicians should take other setup parameter effects, such as production schedules, processing times, noise considerations, into account. A more scientific, or experimental, approach to parameter selection should be used to make sure that the operation achieves the expected level of quality under the given noise conditions and without sacrificing production time. Instead of only setting a very low feed rate to guarantee a low surface roughness, an experimental technique may determine that a faster feed rate, in conjunction with other parameter settings, will produce the right surface roughness.

The Design of Experiments (DOE) methods are time-consuming and inconvenient when taking into account the numerous factors and noise that might effect such an activity, which is unfortunate given that time is typically restricted. To optimise such an operation with such constraints, a more effective experimental method is needed.

Taguchi Parameter Design is a fantastic solution to this issue. Taguchi Parameter Design is a kind of fractional factorial design that resembles traditional DOE methods in that it takes multiple input parameters into account for a certain outcome. The Taguchi Parameter Design method would be useful in this case since it would enable turning process optimisation with a rather modest number of experimental runs. According to one hypothesis, Taguchi parameter design takes advantage of a response parameter's non-linearity to lessen a quality feature's susceptibility to variation. Variability in a manufacturing process can be significant, frequently unpredictable, have a range of effects on quality indicators. Fortunately, Roy[4] asserts that the purpose of Taguchi parameter design is to enhance a naturally variable production process' performance by modifying the regulated elements. Additionally, because quality control may be performed throughout the design phase, Taguchi Parameter Design enables quality engineers to do away with the need for it later.

Review of Literature

F.W. Taylor was the first to introduce the science of metal cutting at the beginning of the 19th century. He achieved this by conducting tests for 26 years, producing about 400 tonnes of chips as a result of more than 30,000 carefully documented trials. Taylor's goal was to develop a surefire technique that could "be solved in less than half a minute by any decent mechanic" in order to get around the difficult problem of figuring out the best circumstances for cutting in order to assure both safe and efficient cutting. It is difficult to determine the ideal spindle speeds and federates for metal removal processes and the surface finish of a work item. Shop floor practise still relies on the "calibrated ear" of skilled machinists notwithstanding the availability of lookup tables. Finding the best cutting parameters for die and mould machining, which takes place in a setting where the geometry of the metal removal process is constantly changing, has the potential to result in significant financial benefits but is also a very challenging task. Surface roughness, tool life, power consumption, cutting force were the factor/level combinations for the recommended approximated parameters. For parametric optimisation of hard machining while milling hardened steel, Ghosh et al. (2009) investigated the use of the Taguchi technique. Surface finish and tool life were considered as response variables in the experiments, which were created using an L18 orthogonal array. The experimentation made use of machining parameters such cutting speed, feed, depth of cut, cut length. The two factors that contribute to wear the greatest are chipping and adhesion. The Taguchi technique produced results that were remarkably similar to those of the ANOVA, it was found that the cutting speed was the factor that had the greatest influence.

Kandananond et al. (2009) predicted the characterisation of the surface roughness of the fluid dynamics bearing sleeve based on the Taguchi methodology. The goal of this study was to identify the ideal cutting parameters for a ferritic stainless steel turning process that would produce the least amount of surface roughness (grade AISI 12L14). The surface quality of the sleeve depends on the imperfections in the material that result from the turning operations, so the impact of the machining parameters (depth of cut, spindle speed, feed rate) on the surface roughness was investigated.

The goal of this study is to quickly identify the turning operation's best parameters for achieving the smoothest surface attainable within that range of parameters, while also taking the noise component's influence into consideration. The following features will be included in this study in order to achieve this goal and differentiate it from the earlier research under consideration:

the use of a matrix that contains the fewest possible replicated experiments.

the connections between the control parameters and the response parameter.

The use of worn-out chuck jaws, which raises the noise level. The effect of the noise parameter on the response parameter

Experimental Design and Setup

In order to accomplish this goal in a way that is both successful and efficient, this research will apply the Taguchi Parameter Design approach. This involves choosing the parameters, using an orthogonal array, running experimental runs, analysing data, choosing the ideal combination, verifying the results. As noted in the introduction, this study uses regulated parameters for variables such spindle speed (v), feed rate (), depth of cut (d). It was decided that feed rate would need to have a greater number of levels of variation than the other factors in order to conduct an experiment that was both reliable and successful because prior research suggested that feed rate has a significantly greater influence on surface roughness than the other two parameters. The feed rate factor for this experiment therefore has three levels: 0.05, 0.1, 0.2 millimetres per revolution (mpr).

Following that, the spindle speed and the depth of cut were each adjusted to one of three distinct values (v = 192,325 and 420 rpm; d = 0.2, 0.6, 0.1 mm, respectively). The components should be finished well with these ranges of feed rates, the spindle speed and depth of cut were selected to meet the needs of the hardware setup specifications while still allowing for a reasonable amount of variation in the experiment. Additionally, it was hoped that this would allow for the selection of an orthogonal array with the fewest number of runs necessary while yet enabling the execution of an effective experiment.

The two-way interaction between the many various parameters is peculiarly tangled with the many different columns in the L18 array. As a result, this interaction has a smaller impact on how the principal effects of the numerous distinct parameters are assessed. Although it is hard to assess the likelihood of two-factor interactions in the L18 array, the major impact of the various process parameters can be assessed with a respectable level of accuracy. The table that has been given contains the typical L18 OA. The cutting tool has two levels for the sake of this investigation, although every other parameter has three levels; as a result, the cutting tool has one degree of freedom (DOF), whilst every other component has two DOF. As a result, this investigation has 11 degrees of freedom altogether. Using L18 OA as a foundation, the control log for the experimental has been constructed. The place in the first column was assigned to the cutting tool because it had two levels. The L18 orthogonal array's 18 rows correspond to the 18 various tests that will be conducted throughout the experimentation phase. The more practical and precise method is to express the level of each component throughout each trial on the experimenter's log sheet. The following five response variables-cutting tool, cutting fluid, spindle speed, feed, depth of cut-have been chosen as the primary focus of this investigation.

Table.1 Response Variables & factor level

Experiment Number	**Column**				
	1	2	3	4	5
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	3	3
11	2	1	2	1	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

Table 2

S. No.	**Response Name**	**Response Type**
1	Thrust Force	Continuous
2	Feed Force	Continuous
3	Radial Force	Continuous
4	MRR	Continuous
4	Surface Roughness	Continuous

Table 3

Factor Name	Level 1	Level 2	Level 3
Cutting Tool	A1	A2	------
Cutting Fluid	B1	B2	B3
Spindle Speed	C1	C2	C3
Feed	D1	D2	D3
Depth of Cut	E1	E2	E3

The Hindustan Machine Tool lathe machine used for experimentation consists of tool holder unit. The input power supply to the machine is 3 Phase A.C 415 V. The operating frequency is 50 Hz. The control voltage for the machine is 220 V and rated current is 23 amps The figure of the machine is shown figure 1.

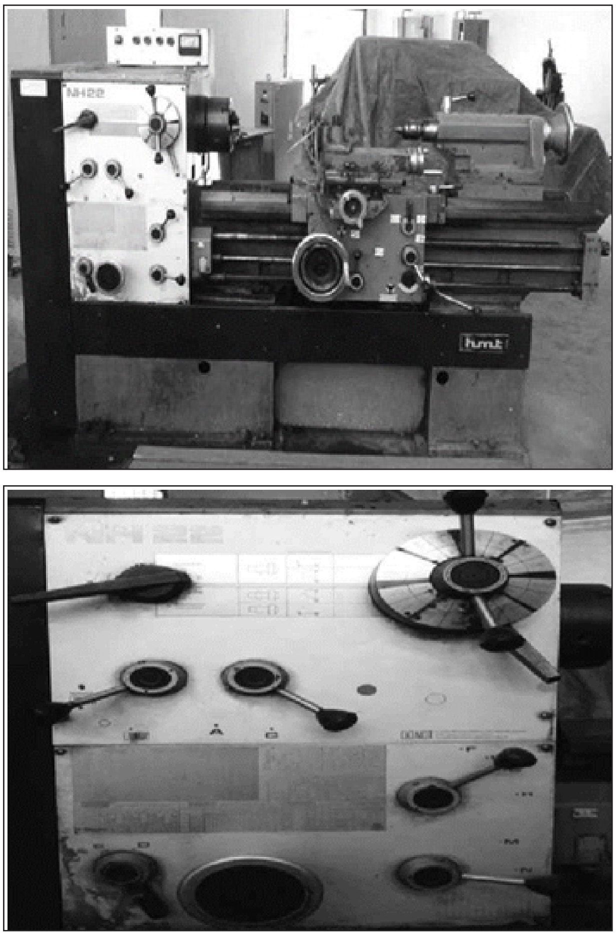

Figure 1.HMT Lathe Machine & control Unit

A total of 18 trial runs were used in the experimentation for the study, with a total of three replications for each trial. The major goal was to raise machining productivity while keeping the desired standard of surface smoothness. The experiment's execution sequence was completely arbitrary in every way. The table below compares the values of the thrust force, feed force, radial force, mean relative roughness (MRR), surface roughness of the machined surface to the input parameter settings for experiment number 1. For the extra trial runs, the values of these machining characteristics have also been tabulated, as was described earlier.

Observation table for Experiment No.1

Control factor setting

A1- Cutting tool = HSS

B1- Cutting oil = Servo Cut

C1- Spindle speed = 420 rpm D1- Feed 0.2 mm/rev

E1- Depth of cut = 1mm

Table 4

Trial No.	Thrust Force (Kg.)	Feed Force (Kg.)	Radial Force (Kg.)	MRR mm^3/sec	S.R. µm
1	157	178	42	90.00	3.55
2	138	155	36	93.10	3.73
3	137	162	39	93.80	3.76

The values of the output variables, which included cutting forces, MRR, surface roughness, were recorded and plotted in accordance with the design of experiments methodology created by Taguchi after the experiments with various configurations of the input factors, including the cutting tool, cutting fluid, spindle speed, feed, depth of cut, were finished. The procedure that Taguchi considers standard and advises was adhered to in order to carry out the analysis of the results that were obtained. The analysis's detailed description is given in the following format:.

The S/N ratio is calculated using the Taguchi technique. In this context, the terms "signal" and "noise" refer to the value that we want to reach (the Mean) and the value that we do not want to obtain (the Standard Deviation), respectively. As a result, the S/N ratio is a picture of how much variance exists in the performance characteristic. Maximising the response variables that may be controlled in this scenario includes the thrust forces, feed forces, radial forces, MRR, surface roughness. A type of signal-to-noise ratio known as “smaller is better” was used to transform the raw data for cutting forces into a more acceptable form with a lower value of cutting forces.

The primary effect can be investigated by analysing the level average response using mean data and the signal-to-noise ratio. The numbers are then plotted on a graph to finish the study. First, the Mean and/or S/N data at each level of each parameter are averaged. When studying the pattern of performance characteristics in connection to the variance of the component under inquiry, the level average response obtained from the Mean data is helpful. The S/N data-based level average response plots are a useful tool for optimising the objective function under consideration.

The main effects of Mean data and those of the S/N ratio for response variable

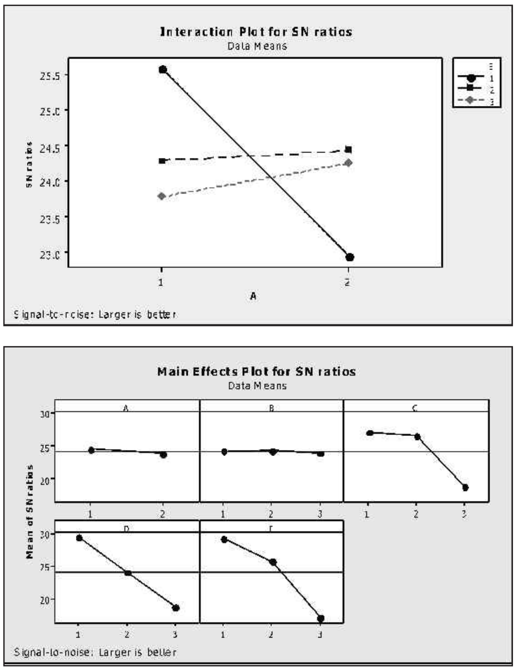

Figure. 2 Effect of Process Parameters on MRR -Mean data and S/N Ratio

Analysis of Variance (ANOVA) The percentage contribution of various process parameters on the selected performance characteristic can be estimated by performing analysis of variance test (ANOVA). Thus, information about how significant the effect of each controlled parameter is on the quality characteristic of interest can be obtained.

The analysis of variance, also known as the general linear model, was carried out on the Mean and S/N data in order to determine the significant factors and quantify the effect that these parameters have on the performance characteristics. By examining the response curves of the signal-to-noise ratio associated with the raw data, the ideal levels of process parameters have been determined. These levels correspond to the most desirable conditions. The ANOVA S/N results have been aggregated and are presented in the tables labelled “ANOVA Result for MRR (S/N Ratio)”.

Determining the Optimum Condition

The optimal condition, which is essentially the best combination of treatment levels for the given response and noise conditions, can be determined using both the response and the S/N ratio. The smallest response is the best level for a parameter since the quality characteristic, Ra, is a smaller-is-better characteristic. But since we always want the signal to be considerably greater than the noise, the S/N ratio will always be highest at the ideal situation. This necessitates a second analysis that takes into account all potential treatment combinations because not all treatment combinations have been tested in the experiment.

Cutting tool quality has been determined to be a significant impact in A2 Steel (Tool Steel) turning on a lathe. Cutting fluid, spindle speed, feed, depth of cut are unimportant additional considerations. Cutting tool was discovered to have the highest contribution for S/N response. “Input parameters setting of cutting tool as carbide, cutting fluid condition as dry, spindle speed at 192 rpm, feed at 0.02 mm/rev and depth of cut at 0.2mm have given the optimal

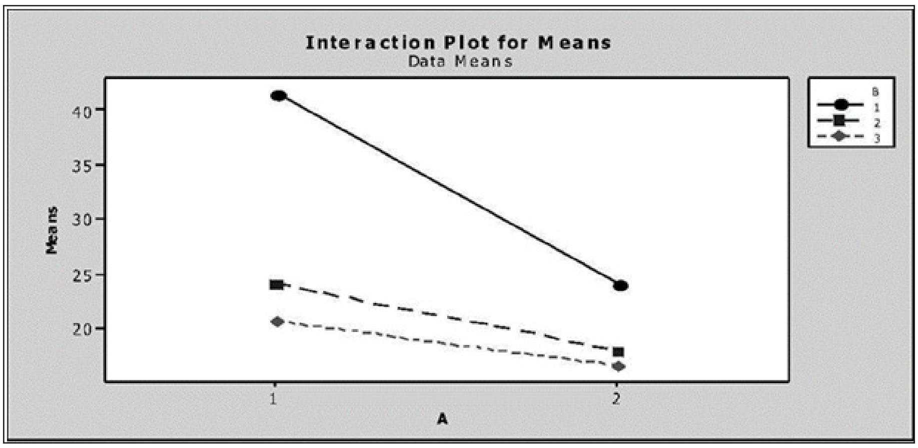

Figure 3.Effect of Interaction (A×B) on MRR-Mean data and S/N Ratio

results for surface roughness when A2 Steel (Tool Steel) was machined with a lathe machine," it has been determined.

This combination has actually been run in the experimental procedure and its value can be further analyzed and verified.

Predictive Equation and Verification

The average of the experimental results can only be used to get the point estimate of the mean. The term "estimate of the mean" refers to this mean estimate. This gives a 50% probability that the real average is higher than the fl value and a 50% chance that the real average is lower than the fl value, according to statistics. In order to indicate where the value is most likely to fall for a given degree of confidence, it is customary to report the value of a statistical parameter as a range. a range-shaped statistical parameter that shows where the result will most likely fall for a given level of confidence. This range of numbers is referred to as the "confidence interval". The range of numbers, from their maximum to their minimum, within which the true average should lie given the level of certainty that has been defined is known as the confidence interval.

For predicting the average performance qualities and figuring out the confidence intervals for the anticipated mean, the Taguchi approach has been chosen.

For cutting speed the overall population of the mean is: µ= 90.38 The predicted optimum value of cutting speed is calculated as

µ T.F= (µA2+ µB3+ µC3+ µD3+ µE3) – (4µ) = 24.15

Similarly, for Material removal rate:

µ MRR = (µA1+ µB1+ µC1+ µD1+ µE1) – (4µ) = 82.46

Similarly, for Surface roughness:

µ S.R = (µA2+ µB2+ µC3+ µD1+ µE3) – (4µ) = 3.5

For calculation of CIEC, the following equation has been used:

(fixed number of Fá (1, fe) = the F-ratio at a confidence level of (1-á) against the DOF 1 and error degree of freedom fe (for MRR fe = 44, so Fá = 4.02).

$$n_{eff} = \frac{N}{1 + Total\ DF\ involved\ in\ estimation\ of\ mean}$$

Ve= 920

N= Total number of experiments neff = 54/(1+9) = 5.4

R=samplesizeforconfirmatoryexperiments=3Henceputting all the values in equation

CICE(T.F) = ±43.63

The 95% confidence level for µCS is, CICE(T.F) = 00.55<µT.F<67.15

Similarly, for MRR: Ve =28.3 neff = 54/ (1+9) = 5.4

R = 3

Fá (1, 44) = 4.02

Putting the values in equation yields; CICE(MRR) = ±7.5 The 95% confidence interval for µMRR is,

CICE(MRR) =74.5< µMRR<89.70

For surface roughness,Ve =4.30 neff = 54/ (1+9) = 5.4

R = 3

Fá (1, 44) = 4.02

Putting the values in equation yields; CICE(S.R) = ± 2.97

The 95% confidence level for µS·R is, CICE(S.R) = 0.53< µT.F<6.47

The optimum value and the confidence interval have been tabulated in table. Three experiments were conducted at the optimum setting of the process parameters for all the response. The mean value of the response from these experiments has been found to be well contained in the confidence interval.

The Range of applicability In the present study the input parameter setting in the turning of A2 steel on the lathe such as cutting tool, cutting fluid, spindle speed, feed and depth of cut have been optimized for three machining characteristics

viz Thrust Force, Material Removal rate (MRR) and Surface Roughness.

Comparison of prediction and experimental results

There is a 90–95% confidence interval for the findings achieved under the optimisation process setting. According to the Taguchi resilient design technique, a process or product developed for one application in particular should be able to transfer its design to other applications and accommodate change as it occurs. The technique has been used in the current study to convert A2 Steel (Tool Steel). By making slight adjustments to the optimised conditions, taking into consideration the difference in response variable values when the original process is applied to the machining, this procedure can also be used for the other grades of steel. So much time and effort can be saved in creating a new method for machining the other grades of steel.

Conclusion

The Taguchi parameter design method was successfully used in this study to determine the best turning operation parameters for surface finish under a range of noise settings. The best turning operation parameters for surface finish were found using this method.

On the basis of the tests that were performed as part of this inquiry, the following hypotheses and conclusions have been formed:

The feed rate and depth of cut significantly affect the thrust force when turning A2 Steel, sometimes referred to as Tool Steel, on a lathe. The overall analysis of the responses revealed that the feed rate, followed by the depth of cut and the cutting fluid, was the most important variable. The element that is thought to have the least significant impact on the thrust force is the cutting fluid. It was shown that the depth of cut, followed by feed and cutting fluid, had the most impact on the S/N reaction. Based on the results, it has been concluded that "feed rate of 0.05 mm/rev, depth of cut of 0.2 mm, cutting fluid as servo cut have delivered the optimal results for thrust force when A2 Steel (Tool Steel) was machined with lathe." The conclusions drawn from the data are this. This is valid when contrasted to the conclusions drawn from the research carried out by the other researchers.

The depth of cut, the feed, the cutting fluid all have a significant impact on the feed force used to turn A2 Steel (Tool Steel) on a lathe machine. The depth of cut, followed by feed, has been found to be the single most significant component when analysing all of the replies. The element with the least importance is the cutting fluid. It was discovered that the depth of cut and cutting fluid both had major roles in the S/N reaction. From the conversation above, it can be inferred that "the input parameters setting of depth of cut at 0.2mm, feed at 0.05 mm/rev, cutting fluid as servo cut have delivered the optimal results for feed force when A2 Steel (Tool Steel) was machined using a lathe machine.

The feed rate, the depth of cut, the cutting tool all have a significant impact on the radial force used to turn A2 Steel (Tool Steel) on a lathe machine.One thing that is just very marginally significant is the cutting instrument. It was found that all of the other components contributed similarly to the variance in radial force, with the feed making the largest contribution, followed by the depth of cut.Feed was found to have the biggest contribution to the S/N response. In light of what has been said, it is possible to conclude that "the input parameters setting of feed at 0.05 mm/rev, depth of cut at 0.2 mm, cutting tool as carbide A2 Steel (Tool Steel) was created using lathe machine.

The depth of cut, feed rate, spindle speed used for turning A2 Steel (Tool Steel) on a lathe machine all have a significant impact on the material removal rate (MRR) that is attained. The depth of cut, followed by feed, has been found to be the single most significant component when analysing all of the replies. Spindle speed is arguably the MRR element that has the least impact. It was found that the feed rate contributed the most to the S/N response, followed by the spindle speed and then the depth of cut. Consequently, one can infer the following from the conversation above: "When A2 Steel (Tool Steel) was machined using a lathe, the input parameters setting of depth of cut at 1 mm, feed rate at 0.2mm/rev, spindle speed at 420 rpm had produced the ideal result for MRR.

When it comes to the surface quality of the A2 Steel (Tool Steel) being turned on the lathe machine, the cutting tool has been found to be the most crucial component. Other factors like cutting fluid, spindle speed, feed, cut depth don't really matter. The cutting tool has been found to contribute most significantly to the S/N reaction. When A2 Steel (Tool Steel) was machined on a lathe, it was found that "input parameters setting of cutting tool as carbide, cutting fluid condition as dry, spindle speed at 192 rpm, feed at 0.02 mm/rev, depth of cut at 0.2mm have given the optimal results for surface roughness. Conclusions have been reached regarding this matter.

There is still a need for more investigation into how this type of machining parameter optimisation may be used in practise, even though this work and others have demonstrated that it can be carried out with little downtime. The advancement of this field of study would benefit from the conduct of future research in an industrial setting, such as a manufacturing facility. Additionally, incorporating more typical scenarios and materials would make the study's findings stronger and more applicable. Variations in the types of coolant, cutting tools, steel bar stock could be among these circumstances and materials. It is crucial to overcome difficulties like the presence of several noise components that cannot be controlled and time constraints that must be met during experimentation and implementation in order to show the value of Taguchi Parameter Design.

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