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"ANALYSIS OF PROCESS PARAMETERS OF FRICTION STIR WELDING OF AA 2024 AND AA 5056 DISSIMILAR METALS AND MECHANICAL PROPERTIES OF WELDED JOINT"

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ABSTRACT

The joining of dissimilar AA2024 and AA5056 aluminium plates of 5mm thickness was carried out by friction stir welding (FSW) technique. By using statical approach Optimum process parameters were obtained for joining two different material. To analyse the influence of rotation speed and traverse speed over the microstructural and tensile properties Five different tool designs have been used. By using FSW technique, the process of joining of the base material, well below it's melting temperature, has opened up new trends in producing efficient dissimilar joints. Analysis of welding speed on microstructures, hardness distribution and tensile properties of the welded joints were done. By changing the parameters of different process, defect free and high efficiency welded joints were produced.

Keyword: *FSW , Welding, Dissimilar Metals.*

I. INTRODUCTION

Friction welding is known for its welding procedure in which the heat required for welding is gotten by rubbing between the end to end sections to be joined. One of the parts to be joined is turned at a high speed around 3000 rpm and the other part is pivotally lined up with the second one and pressed tightly against it. Due to high friction between the two parts, the temperature at the interface increases. At that point the when the rotation of the part is stopped unexpectedly and it cause increase in pressure on the fixed part with the goal that the joining happens. This is additionally called as Friction Welding.

Friction welding can be considered as a forge welding since the welding is completed with the utilization of pressure. In this process the heat required for the welding is created produced because of the friction between two surfaces to be joined. When enough heat is produce and the temperature of the joint is achieved then surfaces may get welded together.

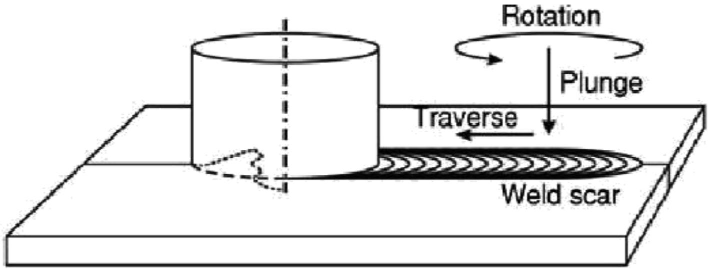

Figure 1.1 SFW

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TAGUCHI METHOD

Taguchi technique is statistical method developed by Genichi Taguchi to enhance the performance and quality of the products. Based on Taguchi, the main point just before analysis is establishment of the experiment. Only by this method, it's possible to enhance the quality of the process. This method could achieve the last output value and reduced the variability across the output value by minimum cost. He believed that the easiest way to enhance quality was to create and construct it into the product. The main purpose of this method is to create good quality product at inexpensive to the manufacturer. Taguchi developed a way for experiment design to examine how various parameters affect the mean and difference of a process performance characteristic. The fresh layout organized simply by Taguchi involves putting on orthogonal arrays to increase the guidelines impacting on the method plus the amount where they ought to be varies. Instead of experiencing to evaluate all possible mix just like the factorial layout, the actual Taguchi approach checks people of combinations. The following will allow for the quantity of the necessary facts to uncover which variables almost all have an effect on products top quality using lowest volume of experimenting, thus saving your time plus resources. The Taguchi arrays is often produced or even explored smaller arrays is often slow by hand; big arrays can be based for deterministic algorithms. Generally, arrays can be purchased online. The arrays are selected simply by the number of guidelines (variables) plus the number of ranges (levels).

II. DESIGN OF EXPERIMENT

The overall steps active in the Taguchi method are these:

- Determine the machining parameters which are to influence by the FSW variables such as spindle speed, feed rate and tool profile etc. The prospective of a procedure may also be a minimum or optimum, like; the prospective may be to increase the hardness value.
- Establish the strategy variables affecting the machining process. Variables are parameters within the strategy that influence the performance measures such as cutting speed, feed rate etc. that may be simply controlled. The number of levels that the variables should be varied at should be specified. Like, a feed rate could possibly be varied to a low and high value.
- Build orthogonal arrays for the variables design indicating how many and situations for every experiment. The decision of orthogonal arrays is on the basis of the amount of variables and the quantities of variation for every parameter, and will be discussed below.
- Perform the experiments indicated in the completed array to get data on the consequence on the performance measure.
- Total data analysis to discover the aftereffect of different variables on the performance measure.

Table 1: Array Selectors

		NUMBER OF PARAMETERS (P)													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15
NO OF LEVELS	2	L_{4}	L_{4}	L_{8}	L_{8}	L_{8}	L_{8}	L_{12}	L_{12}	L_{12}	L_{12}	L_{16}	L_{16}	L_{16}	L_{16}
	3	L_{9}	L_{9}	L_{9}	L_{18}	L_{18}	L_{18}	L_{18}	L_{27}	L_{27}	L_{27}	L_{27}	L_{27}	L_{36}	L_{36}
	4	L_{16}	L_{16}	L_{16}	L_{16}	L_{32}	L_{32}	L_{32}	L_{32}	L_{32}					
	5	L_{25}	L_{25}	L_{25}	L_{25}	L_{25}	L_{50}	L_{50}	L_{50}	L_{50}	L_{50}	L_{50}			

ISSN : 2455-9679
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ANALYZING EXPERIMENT DATA:-
TABLE 1.1 Experimental Plans

Experiment No.	P1	P2	P3	P4	T_1	T_2	….	T_N
1	1	1	1	1	T1, 1	T1, 2	….	T1, N
2	1	2	2	2	T2, 1	T2, 2	….	T2, N
3	1	3	3	3	T3, 1	T3, 2	….	T3, N
4	2	1	2	3	T4, 1	T4, 2	….	T4, N
5	2	2	3	1	T5, 1	T5, 2	….	T5, N
6	2	3	1	2	T6, 1	T6, 2	….	T6, N
7	3	1	3	2	T7,1	T7, 2	….	T7, N
8	3	2	1	3	T8, 1	T8, 2	….	T8, N
9	3	3	2	1	T9, 1	T9, 2	….	T9, N

Signal-to-Noise Ratio

Taguchi's concentrate on minimizing deviation from target directed him to accumulate measure of the technique final results that comes with each the location of the output as well as the variant. Those measures are called signal-to-Noise Ratios. The unique sign-to-noise ratio provides a measure of the influence of noise factors on performance. The greater the S/N, the greater robust the goods is against noise. Calculation of the S/N is dependent on the experimental purpose:

Bigger-the-Better
$S/(Bigger) = -10 \log (\sum(1/ y_i^2)/ n)$

Smaller-the-Better:
$S/ (smaller) = -10 \log(\sum(y_i^2)/ n)$

Nominal-is-best:
$S/ (Nominal) = 10 \log(y^2/ S2)$

After calculating the SN ratio for each experiment, the average SN value is calculated for each factor and level. This is done as shown below for parameter 3 (P3) in the array:

ISSN : 2455-9679
Impact Factor : 2.865

Table 1.2 SHOWS Experimental Plans with S/N Ratio

Experiment Number	P1	P2	P3	P4	S_N
1	1	1	1	1	SN 1
2	1	2	2	2	SN 2
3	1	3	3	3	SN 3
4	2	1	2	3	SN 4
5	2	2	3	1	SN 5
6	2	3	1	2	SN 6
7	3	1	3	2	SN 7
8	3	2	1	3	SN 8
9	3	3	2	1	SN 9

$SN_{p\,3,\,1} = (S_{N\,1} + S_{N\,6} + S_{N\,8}) / 3$

$SN_{p\,3,\,2} = (S_{N\,2} + S_{N\,4} + S_{N\,9}) / 3$

SN p 3, 3 = (SN 3 + SN 5 + SN 7) / 3

Once these SN ratio values are calculated for each factor and level, they are tabulated as shown below and the range R (R= high SN – low SN) of the SN for each parameter is calculated and the final values entered into the table. The larger the R value for a parameter, the larger the effect the variable has on the process. This is because the same change in signal causes a larger effect on the output variable being measured.

Table 1. 3 Effect variable table

LEVEL	P1	P2	P3	P4
1	SNP 1,1	SNP 2,1	SNP 3,1	SNP 4, 1
2	SNP 1, 2	SNP 2,2	SNP 3,2	SNP 4,2
3	SNP 1,3	SNP 2,3	SNP 3,3	SNP 4,3
	RP 1	RP 2	RP 3	R P 4
RANK	-----	-----	-----	-----

MINITAB SOFTWARE

Minitab is really a statistics package. It was developed at the Pennsylvania State University by analysts Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab offers a collection of software, support materials and services that enable you to control your quality and method development processes. This application is useful for Data and File Management- spreadsheet for better data analysis; Analysis of Difference; Regression Analysis; Power and Sample Size; Tables and Graphs; Multivariate Analysis - involves factor analysis; cluster analysis; correspondence analysis; etc., Nonparametric tests including sing test, runs test, Friedman test, etc., Time Series and Forecasting tools that help show trends in data as well as predicting future values. In this function, the Minitab 15 software is useful for obtaining ANOVA.

ISSN : 2455-9679
Impact Factor : 2.865

III. METHODOLOGY AND EXPERIMENTATION

The objectives of the present work have already been mentioned in the forgoing chapter.

Accordingly the present study has been done through the following plan of experiment.

- Checking and preparing the power hacksaw and Lathe ready for performing the machining operation.
- Cutting of aluminium, stainless steel-304 according to required length on power hack saw.
- Fix the cutting tool on tool post & fix the stainless steel-304 in rotating chuck on lathe for the preparation of different welding tool pin profile.
- Aluminium alloys AA2024 H32-AA5056 T6 has been cut into the required size are by power hacksaw cutting.
- Turning of tool to get the required diameter.
- Checking of required diameter with the help of vernier caliper
- Tool and Sample is ready for welding.
- Conduct tensile test and hardness test on Universal Testing Machine (UTM) and vicker's hardness testing machin

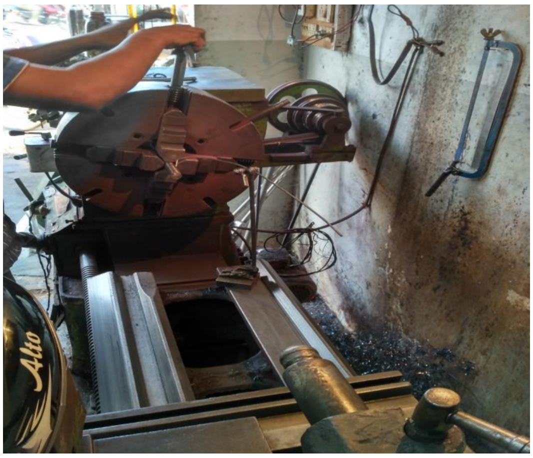


Fig 1.2 Making tool on lathe machine for FSW

WORKPIECE MATERIAL

The current experimental research is a try to discover the feasibility of using FSW method in joining dissimilar AA2024 H32-AA5056 T6 grade aluminium alloy sheets of 5 mm thickness. Two workpieces of size 300 mm x 30mm x 5mm are joined collectively to make butt joint. The composition and material properties of aluminium alloys are given in table 3.1 and table 3.2 respectively.

Table 2 Chemical Composition by wt%

Material	Mg	Mn	Si	Fe	Cu	Zn	Cr	Ti	Ni	Al
AA2024 H32	4.2	0.59	0.07	0.16	0.05	**0.15**	0.08	0.06	0.01	Balance
AA5056 T6	**5.3**	**0.48**	**0.58**	**0.65**	**0.09**	**0.10**	**0.25**	**0.03**	**0.01**	**Balance**

Table 2.1

Material	UTS (MPa)	Yield Strength (MPa)	% Elongation	Hardness (HV)
AA2024 H32	286	248	12	88
AA5056 T6	312	240	26	107

WELDING TOOL MATERIAL

The tool geometry plays an important role in FSW process. Localized heating and material flow are the two basic functions of FSW tool. Tool is used in this study is made of high-speed tool steel. This is the most commonly used material due to easy availability, thermal fatigue resistance, wear resistance, especially for aluminium and copper.

ISSN : 2455-9679
Impact Factor : 2.865

The selected tool geometries and the fabricated tool for FSW of 5 mm thick aluminium alloy is manufactured using lathe.

In the current study, the four types of tool profiles were designed and applied; namely,

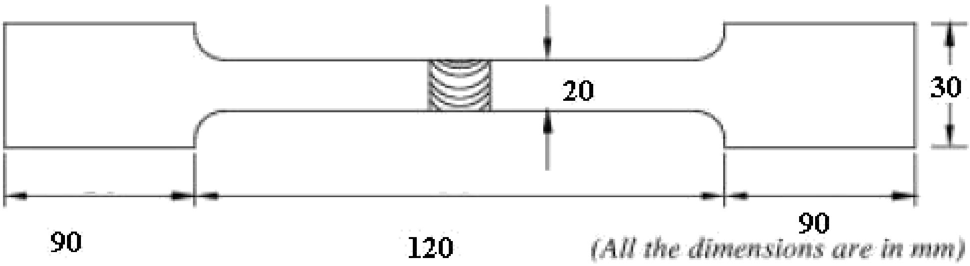
- Plain Circular or round tool profile
- Circular with Threaded tool profile
- Square tool profile

PROCESS VARIABLES AND THEIR LIMITS

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study spindle speed, feed rate and tool profile have been considered as process variables. The process variables with their units and notations are listed in Table 3.3.

Table 3: Process variables and their limits

Parameters/Factors		level		
		1	2	3
A	**Spindle speed (rpm)**	950	1150	1450
B	**Feed rate (mm/min)**	20	30	40
C	**Tool Profile**	Round	Round with threaded	Square



3 EXPERIMENTAL SET-UP

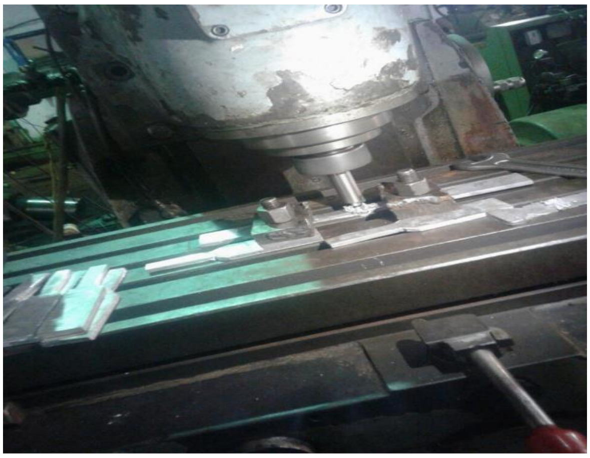
MACHINE USED

To set off the FSW experiment a vertical milling machine is used. The tool is fix inside the vertical arbour using the perfect collates. The plates to be connected are clamped to the horizontal bed with nil root gaps. The clamping of the check pieces are executed such that the strength of the plates is definitely constrained beneath each plunging and translational forces of the FSW tool.

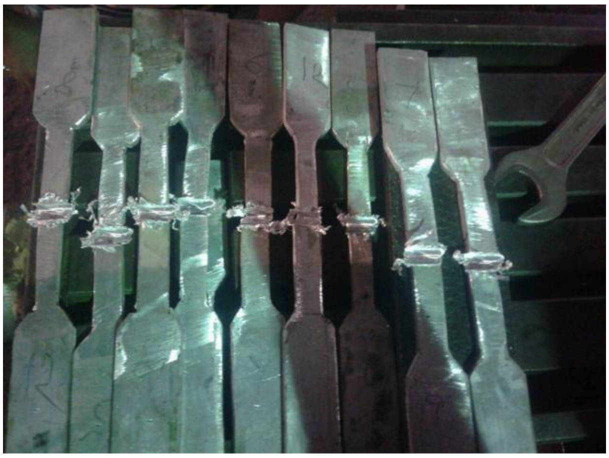
ISSN : 2455-9679
Impact Factor : 2.865

Table 3.1Specification of the milling machine

Manufacturer	(PACMILL) Simple milling machine
Spindle Position	Vertical position
Max. rpm	4700
Diameter of Tool Holder	17 mm
Motor	4 Horse Power(hp), 1420 rpm
Longitudinal Transverse speed Range	12-800 mm/min



Rotating tool is ready for friction welding



Friction stir weld samples

TENSILE TEST

After friction stir welding, tensile test is performed on universal testing machine. If A is the cross sectional area and F is the maximum force and tensile strength calculated by: Tensile strength=F/A

VICKERS HARDNESS TEST

The Vickers hardness test includes indenting the test material with a diamond indenter as shown in Fig. 3.12, within the shape of a right pyramid with a rectangular base and a perspective of 136 degree among opposite faces subjected to a load of 1 to 100 kgf. The whole load is usually applied for 10 to 15seconds. The 2 diagonals of the indentation left within the surface of the material after elimination of the load are measured the use of a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained with the aid of dividing the kgf load by means of the square mm area of indentation. The load applied was 5 kg

ISSN : 2455-9679
Impact Factor : 2.865

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool Profile	Tensile strength (MPa)
1	950	20	Round	25.31
2	950	30	Round with threaded	27.06
3	950	40	Square	28.16
4	1150	20	Round with threaded	26.11
5	1150	30	Square	27.21
6	1150	40	Round	28.18
7	1450	20	Square	27.69
8	1450	30	Round	26.28
9	1450	40	Round with threaded	25.13

Table 3.6 Vicker's Hardness results

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool Profile	HV
1	950	20	Round	52.4
2	950	30	Round with threaded	51.2
3	950	40	Square	56.1
4	1150	20	Round with threaded	53.2
5	1150	30	Square	54.8
6	1150	40	Round	57.1
7	1450	20	Square	53.7
8	1450	30	Round	54.3
9	1450	40	Round with threaded	56.8

CALCULATIONS OF S/N RATIOS FOR TENSILE TEST Calculation for Table 3.6

$$S / N(\text{BIGGER}) = -10 \text{ LOG} \left(\sum (1/Y_i^2) / n \right)$$

Bigger the better is selected for the calculation of S/N ratio

1. S/N Ratio (Experiment 1) = η1= -10log [1/n (∑ 1/Yi2)] =-10 log [1/ $(25.32)^2$] = 28.07
2. S/N Ratio (Experiment 2) = η2= -10 log [1/ $(27.05)^2$] = 28.64
3. S/N Ratio (Experiment 3) = η3= -10 log [1/ $(28.15)^2$] = 28.99
4. S/N Ratio (Experiment 4) = η4= -10 log [1/ $(26.12)^2$] = 28.34

ISSN : 2455-9679
Impact Factor : 2.865

5. S/N Ratio (Experiment 5) = η5 = -10 log [1/ $(27.2)^2$] = 28.69
6. S/N Ratio (Experiment 5) = η5 = -10 log [1/ $(28.25)^2$] = 29.02
7. S/N Ratio (Experiment 6) = η6= -10 log [1/ $(27.67)^2$] = 28.84
8. S/N Ratio (Experiment 7) = η7= -10 log [1/ $(26.25)^2$] = 28.38
9. S/N Ratio (Experiment 8) = η8= -10 log [1/ $(25.12)^2$] = 28.00

Table 3 S/N ratio for tensile test result

Experiment no.	Spindle Speed (rpm)	Feed rate (mm/min), f	Tool Profile	Ultimate Tensile Load, N	Tensile strength (MPa)	S/N ratio
1	950	20	Round	1862	25.31	28.07
2	950	30	Round with threaded	1990	27.06	28.64
3	950	40	Square	2070	28.16	28.99
4	1150	20	Round with threaded	1921	26.11	28.34
5	1150	30	Square	2001	27.21	28.69
6	1150	40	Round	2078	28.18	29.02
7	1450	20	Square	2035	27.69	28.84
8	1450	30	Round	1931	26.28	28.38
9	1450	40	Round with threaded	1848	25.13	28.00

MEASUREMENT OF F-VALUE OF FISHER'S F RATIO

The F values determine the importance of the parameters. Larger the F value, the greater the effect on the performance characteristic due to the change in that process parameter, F value is defined as:

$$F = S\ for\ the\ term / MS\ for\ the\ error\ term$$

ANOVA

ANOVA is a statistical tool which determines the contribution of individual factors to control the final response. It calculates the parameters like sum of squares (SS_S), degree of freedom, variance, f value P value for each factor. The ANOVA calculations were done using the help of the MINITAB 15 software.

ISSN : 2455-9679
Impact Factor : 2.865

IV. RESULTS AND DISCUSSIONS

4.1. ANALYSIS OF VARIANCE

The results obtained from the experiment were checked with the help of ANOVA, which predicts the significance of input parameter for any desired response function. It shows the most significant parameter which influences the results. A confidence interval of 95.25 % has been taken from analysis.

4.2. ANOVA FOR TENSILE STRENGTH

Results obtained for the tensile strength are shown in the Table 3.6. The results for tensile strength were obtained from the 9 experiments performed of Taguchi. The experimental results analysed with ANOVA are shown in the Table 4.1. The significance of f value is shown in in the second last column of of ANOVA software table which is calculated by MINI TAB 15 SOFTWARE. Significance is higher if the value of F is higher and significance is lower if the value of f is lower(Considering value to be 93 %).. The results show that only spindle speed is the most significant factor. In the Table 4.2 ranks have been given to the various factors. Higher is the rank higher is the significance so spindle speed is the most significant factor.

Table 4.1: Analysis of Variance for Means of tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Spindle speed (rpm), N	2	1.0771	1.0771	0.5385	0.23	0.815	10.08 %
Feed rate (mm/rev), f	2	0.9756	0.9756	0.4878	0.21	0.829	9.13 %
Tool profile	2	3.8838	3.8838	1.9419	0.82	0.82	81.85 %
Error	2	4.7450	4.7450	2.3725			
Total	8	10.681					
S = 1.54031		R-Sq = 55.58 %		R-Sq (adj) = 0.31 %			

Response table for means for tensile strength

Level	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool profile
1	26.84	26.37	26.61
2	27.19	26.83	26.1
3	26.35	27.17	27.67
Delta	0.84	0.8	1.58
Rank	2	3	1

 ISSN : 2455-9679
Impact Factor : 2.865

4.3. MAIN EFFECT PLOTS FOR TENSILE STRENGTH

Main effect plots for tensile strength are shown in the figure 4.1. Main effect plot shows the variation of tensile strength with respect to spindle speed, feed rate and tool profile. X axis represents change in level of the variable and y axis represents the change in the resultant response.

Fig 4.1: Main effects plot for means for tensile strength

4.4. ANALYSIS OF S/N RATIO FOR TENSILE STRENGTH

The signal to noise ratios tells us about the deviations present in the process. The values of all the results according to Taguchi array parameter design layout are presented in this section.

The S/N ratios have been calculated to identify the major contributing factors for variation of values. In this design situation, bigger-the-better is used.

Table 4.3 shows the ANOVA calculations for the S/N ratio. The analysis was carried out at a significance of α=0.05. The main effect is shown in the figure 4.2. Table 4.4 shows the response table for S/N for tensile strength. Ranks have been given to the various factors. Higher is the rank higher is the significance so spindle speed is the most significant factor. It was found that only spindle speed is a significant factor with F value of 11.01.

Table 4.3: Analysis of Variance for S/N ratio for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Spindle speed (rpm), N	2	0.11576	0.8560	0.4280	1.24	0.446	10.22 %
Feed rate (mm/rev), f	2	0.09769	0.8348	0.4174	1.21	0.452	8.62 %
Tool profile	2	0.41269	0.3665	0.1832	0.53	0.653	36.45 %
Error	2	0.50602	0.6886	0.3443			
Total	8	1.13216					

S = 0.5867 R-Sq = 74.92 % R-Sq (adj) = 0.25 %

ISSN : 2455-9679
Impact Factor : 2.865

Table 4.4: Response table for S/N ratio for tensile strength

Level	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool profile
1	28.57	28.42	28.49
2	28.68	28.57	28.33
3	28.41	28.67	28.84
Delta	0.28	0.25	0.51
Rank	2	3	1

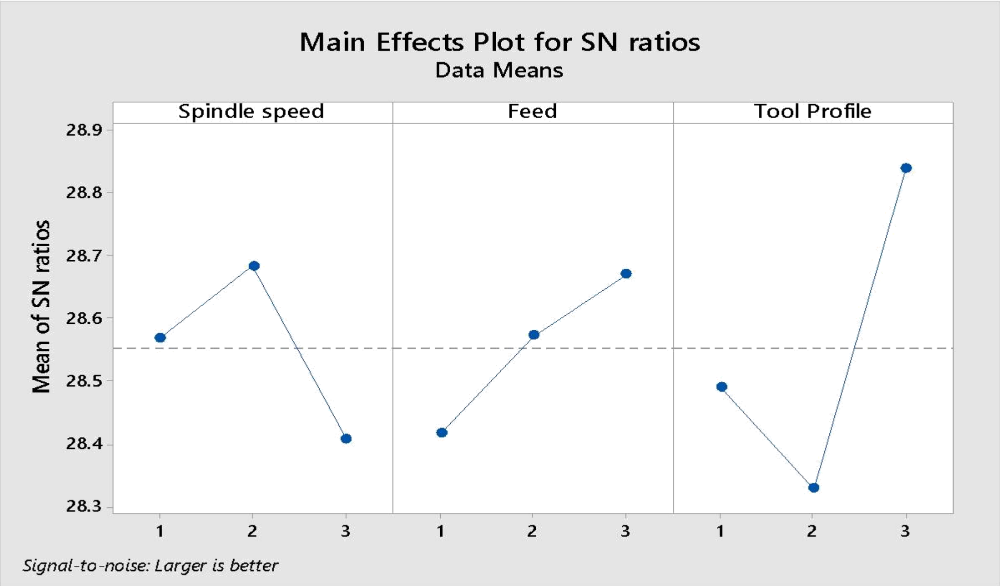


Fig 4.2: Main effects plot for means for tensile strength

ANOVA FOR VICKER'S HARDNESS

Results obtained for the vicker's hardness are shown in the table 3.7 have been analysed with ANOVA are shown in the table 4.5. The significance of f value is shown in in the second last column of of ANOVA software table which is calculated by MINI TAB 15 SOFTWARE. Significance is higher if the value of F is higher and significance is lower if the value of f is lower(Considering value to be 93).The results show that only spindle is the most significant factor. In the Table 4.6 ranks have been given to the various factors. Higher is the rank higher is the significance. Spindle speed is the most significant factor.

ISSN : 2455-9679
Impact Factor : 2.865

Table 4.5: Analysis of variance for means for vicker's hardness

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**Percentage Contribution**
Spindle speed (rpm), N	2	2.1956	2.1956	1.0978	4.96	0.168	18.47 %
Feed rate (mm/rev), f	2	2.2822	2.2822	1.1411	5.16	0.162	19.2 %
Tool profile	2	6.9622	6.9622	3.4811	15.74	0.06	58.59 %
Error	2	0.4422	0.4422	0.2211			
Total	8	11.882					

S = 0.4702 R-Sq = 96.28 % R-Sq (adj) = 24.64 %

Table 4.6: Response table for means for vicker's hardness

Level	**Spindle speed (rpm), N**	**Feed rate (mm/min), f**	**Tool profile**
1	56.3	55.43	56.87
2	55.37	56.07	54.83
3	56.5	56.67	56.47
Delta	1.13	1.23	2.03
Rank	3	2	1

4.7. MAIN EFFECT PLOTS FOR VICKER'S HARDNESS

Main effect plots for tensile strength are shown in the figure 4.4. Main effect plot shows the variation of tensile strength with respect to spindle speed, feed rate and tool profile. X axis represents change in level of the variable and y axis represents the change in the resultant response.

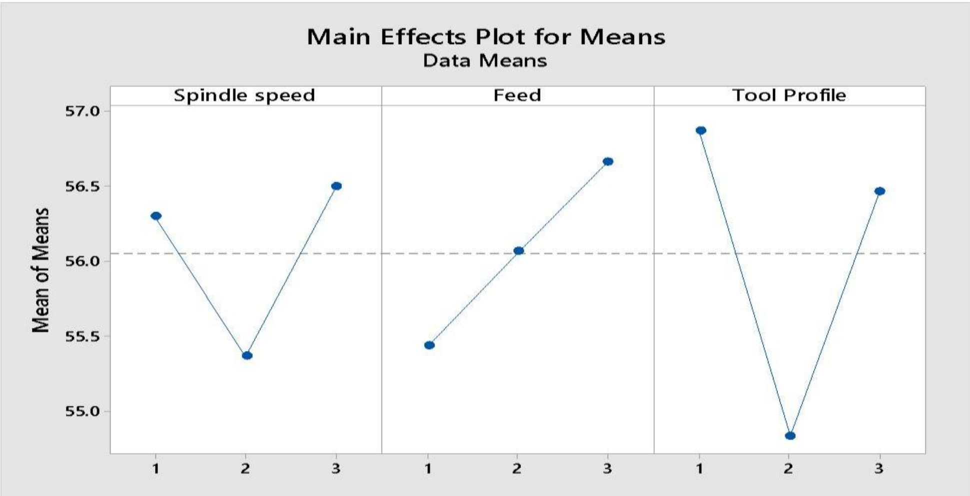


Fig 4.4: Main effects plot for means for vicker's hardness

ISSN : 2455-9679
Impact Factor : 2.865

4.8. ANALYSIS OF S/N RATIO FOR VICKER'S HARDNESS

The signal to noise ratios tells us about the deviations present in the process. The values of all the results conferring to Taguchi array parameter design layout are accessible in this section. The S/N ratios have been considered to identify the foremost contributing factors for variation of values. In this design situation, bigger-the-better is used.

Table 4.7 shows the ANOVA calculations for the S/N ratio. The analysis was carried out at a significance of α=0.05. The main effect is shown in the figure 4.5. Table 4.8 shows the response table for S/N for vicker's hardness. Ranks have been given to the various factors. Higher is the rank higher is the significance so spindle speed is the most significant factor. It was found that only spindle speed is a significant factor with F value of 54.31.

Table 4.7: Analysis of Variance for S/N ratio for vicker's hardness

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**Percentage Contribution**
Spindle speed (rpm), N	2	0.05722	0.05722	0.02861	5.29	0.159	19.46 %
Feed rate (mm/rev), f	2	0.05609	0.05609	0.02804	5.18	0.162	19.08 %
Tool profile	2	0.16976	0.16976	0.08487	15.69	0.06	57.76 %
Error	2	0.01082					
Total	8	0.29389					

S = 0.475 R-Sq = 98.58 % R-Sq (adj) = 94.32 %

Table 4.8: Response table for S/N ratio for vicker's hardness

Level	**Spindle speed (rpm), N**	**Feed rate (mm/min), f**	**Tool profile**
1	35.01	34.87	35.10
2	34.86	34.97	34.78
3	35.04	35.07	35.04
Delta	0.18	0.19	0.32
Rank	3	2	1

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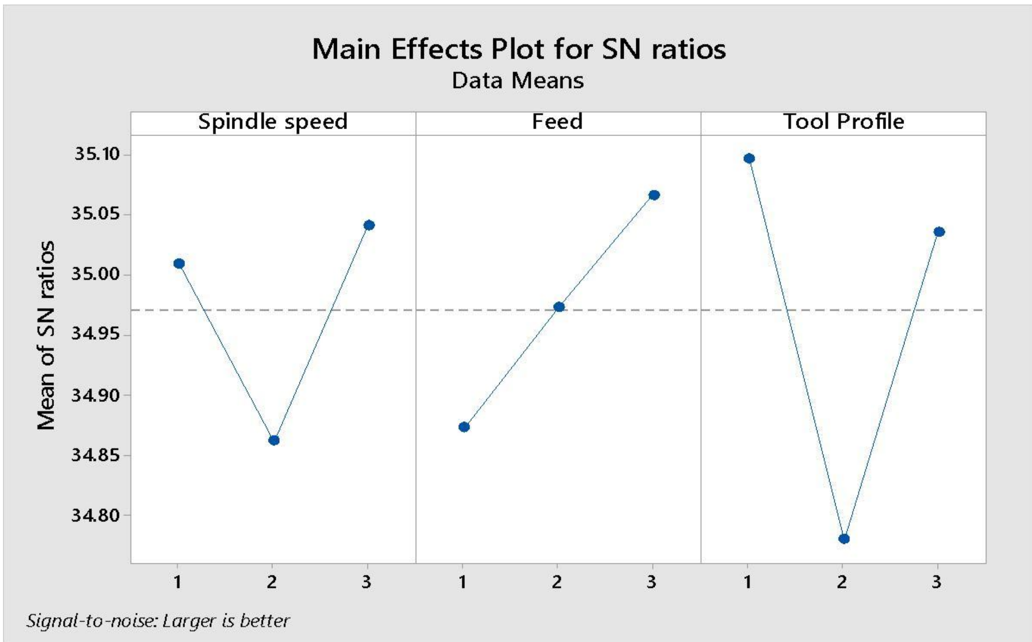

Fig 4.5: Main effects plot for S/N ratio for vicker's hardness

DETERMINATION OF OPTIMUM SOLUTION

Optimum parameter setting for higher tensile strength and higher hardness value with tool profile has been identified through Fig. 4.2 & 4.5. The best configurations are determined individually through Taguchi's approach. Table 4.9 & 4.10 indicates these individual maximum values and its related settings of the method parameters for the described performance characteristics.

Table 4.9: Parameters and their selected levels for maximum tensile strength

Parameter designation	Process parameters	Optimal levels
A	Spindle speed (rpm), N	2 (1200 rpm)
B	Feed rate (mm/min), f	3 (40 mm/min)
C	Tool profile	3 (Square)

Table 4.10: Parameters and their selected levels for maximum hardness value

Parameter designation	Process parameters	Optimal levels
A	Spindle speed (rpm), N	3 (1500 rpm)
B	Feed rate (mm/min), f	3 (40 mm/min)
C	Tool profile	1 (Square)

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4.11. CONFIRMATION TEST

Larger the better characteristic

$$S/(Bigger) = -10 \log\left(\sum (1/Yi^2)\, n\right)$$

Where yi are the responses and n is the number of tests in a trial. The level of a factor with the highest S/N ratio was the optimum level for responses measured. In order to test the predicted result, confirmation experiment has been conducted by running three trials at the optimal setting of the process parameters determine from the analysis i.e. A2, B3, C3 for tensile strength and A3, B3, C1 for hardness value.

Table 4.11: Confirmation test for maximum tensile strength

S.no	Trials			Avg. Tensile strength (MPa)
	1	2	3	
1	28.26	28.65	28.35	28.42

Table 4.12: Confirmation test for maximum hardness value

S.no	Trials			Avg. Hardness value
	1	2	3	
1	53.9	58	58	56.63

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