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Optimization and thermal analysis of Friction Drilling on Aluminium and Mild Steel by using Tungsten Carbide Tool

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Abstract -Friction drilling of the sheet materials and hollow tubes, now becomes a promising process particularly for mass production in the manufacturing and automotive industries. In this project work comparative analysis of friction drilled holes on Aluminium and Mild Steel by using tungsten carbide tool. Holes have been drilled on square tubes of AISI 1008 Aluminium and AISI 1015 Mild steel by the friction drilling process which utilizes frictional heat between a rotating conical tool and work piece to soften and penetrate the thin walled work piece to form a hole with bushing. The bushing increases depth for threading and the clamp load capacity which is best suitable for threading. Naturally formed bush during friction drilling have wide range of application in sheet metal operation and increases productivity. The t/d ratio of friction drilled holes and the spindle speed are the two main parameters affecting the process. Experiments have been carried out using Taguchi's L18 orthogonal array. Thermal analysis and Microstructural variation during the friction drilling process are measured and analysed using ANSYS APDL. Signal to noise ratio analysis also carried out for optimization of parameters.

Keywords-Friction Drilling, Taguchi Method, Material type, Speed, Feed, Temperature, Thermal Stress, Hardness, Bush length and Microstructural variation, S/N ratio, Optimization..

1.INTRODUCTION

Friction drilling [1] is a non-traditional hole-making method that utilizes the heat generated from friction between a rotating conical tool and the work piece to soften and penetrate the work-material and generate a hole in a thin walled work piece. The purpose of the bushing is to increase thickness for threading and available clamp load. The thread profile is produced by displacement of the material in a cascaded forming process. Basically all formable materials can be thread formed, usually materials with less than 1200N/mm^2 tensile strength and a breaking elongation of more than 8%.

1.1 Introduction to Taguchi approach for quality

The quality engineering methods of Dr. Taguchi is most important statistical tools for total quality management for designing high quality systems at reduced cost. Taguchi recommends a three stage process to achieve desirable product quality by system design, parameter design and tolerance design. While system design helps to identify working levels of the design parameters for best performance.The optimum condition is selected so that the influence of uncontrollable factors (noise factors) causes minimum variation to system performance.

2.MATERIALS AND METHOD

In this present work AISI 1008 Aluminium and AISI 1015 low carbon steel, materials are selected for experimentation purpose. The material is in the form of square tube having same thikness.

2.1 Methodology

Input process parameters: Spindle speed (rpm), Feed (mm/min) and Material type. Output (responses) measured during the experiments are: Bush length (mm), Temperature (^{0}C), Thermal stress and Hardness (Hv) input parameters and their levels are shown in Table.

Table-1:- Input Parameters

Level	Speed (rpm)	Feed (mm/min)	Material (Type)
1	2000	50	Aluminium
2	3500	80	Mild Steel (%0.18C)
3	5000	110	-

2.1 Selection of Taguchi L18 orthogonal array

Any nonlinear relationship among the process parameters, if it exists can only be revealed if more than two levels of parameters are considered. In friction drilling process many input process parameters affect on the vertical machining centre like tool type,tool material,material thickness, spindle speed, feed rate in present work the process parametrs i.e. material type, spindle speed, and feed rate depending upon the input parameter 3 levels were selected.

3.EXPERIMENTATION

The experiments are carried on Vertical Machining Centre PVM 40 machine, for experimentation the VMC program designed in such a way that initially drilling cycle will drill the hole through square tube work pieces. After completion of drilling cycle we change the level done the second friction drilling hole same process is applied for all the holes for both the materials. Fig 1 shows friction drilling on workpiece and Table2 shows Taguchi L18 Design Table.

Fig -1: Friction Drilling on Aluminium

Table-2:- Design Table(Taguchi Method)

Expt No.	Material (Type)	Speed (rpm)	Feed (mm/min)
1	1	2000	50
2	1	2000	80
3	1	2000	110
4	1	3500	50
5	1	3500	80
6	1	3500	110
7	1	5000	50
8	1	5000	80
9	1	5000	110
10	2	2000	50
11	2	2000	80
12	2	2000	110
13	2	3500	50
14	2	3500	80
15	2	3500	110
16	2	5000	50
17	2	5000	80
18	2	5000	110

4.RESULTS AND DISCUSSION

4.1 Output Responses: Temperature (^{0}C), Thermal stress (N/mm2) and Hardness (Hv)

Measurement of Temperature is done through infrared pyrometer on CMM and Hardness through Vickers Hardness Tester. Table 3 shows type of material with incremental values of speed and feed

Table-3:- Output Response Table.

Expt. No.	Tp (^{o}c)	Bl (mm)	Hardness (Hv)
1	378	11.5	58.67
2	468	10.2	55.33
3	427	10.3	61.33
4	377	10.3	68
5	555	10.3	61.67
6	437	10.2	68.67
7	540	10.3	67.33
8	506	10.4	57
9	507	10.4	62.67
10	396	11.4	139.33
11	353	10.3	162.33
12	280	10.1	161.33
13	373	10.2	147.33
14	227	10.3	126.67
15	219	10.2	147.33
16	394	11.3	150.67
17	278	11.4	175.33
18	257	11.4	151.67

4.2 Analysis by using software

A finite element model using the Ansys software was created for a more comprehensive approach. Experiments with similar process parameters were conducted for validation of temperature generated in the model. This study builds the foundation for friction drilling prediction and process optimization.. The Thermal stresses obtained for various experiments by FEA are tabulated.

4.3Multiple Regression Method

For establishing relationship between Temperature of Friction drilling and Three input parameters, Temperature(0C),thermal stress(℮) and Hardness(Hv) is expressed as an exponential function of Material type (Mt), Speed (S) and Feed(F) as,

$$Tp = K\, Mt^{m1} S^{m2} F^{m3}$$
$$\theta = K\, Mt^{m1} S^{m2} F^{m3}$$
$$Hv = K\, Mt^{m1} S^{m2} F^{m}$$

As per regression calculation, values of K, m1, m2, and m3 have been calculated. Regression Equations in Coded Form as

For Temperature (^{0}C)

$$Tp = 10^{2.6037} x Mt^{-0.0927} x S^{0.01008} x F^{-0.03981}$$

For Hardness (Hv)

$$Hv = 10^{1.9875} x Mt^{0.19304} x S^{0.01023} x F^{0.0049}$$

For thermal stress(N/mm^2)

$$\theta = 10^{0.9965} x Mt^{0.006} x S^{0.0046} x F^{-0.0078}$$

4.3 Optimization Using Linear-programming

Friction drilled hole. Out of these three parameters, optimize the best suitable parameter for all three responses

4.4 Micro-structural Variation

Following are the SEM Micrographs for Alumnium:-

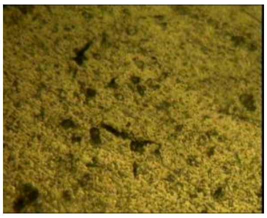

Fig-2: Speed- 2000 rpm, Feed - 50 mm/min, Temp – 378^{0}C

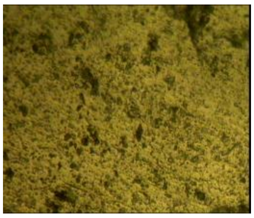

Fig-3: Speed- 3500 rpm Feed - 50 mm/min Temp – 390^{0}C

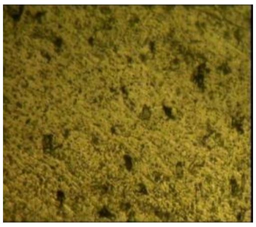

Fig-4: Speed- 5000 rpm, Feed - 50 mm/min, Temp– 437 ^{0}C

Following are the SEM Micrographs of Mild Steel:-

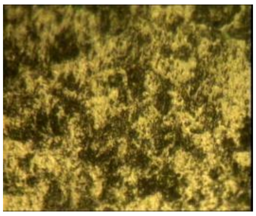

Fig-5: Speed- 2000 rpm, Feed - 50 mm/min, Temp – 378^{0}C

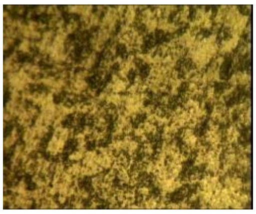

Fig-6: Speed- 3500 rpm Feed - 50 mm/min Temp – 390^{0}C

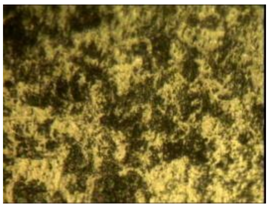

Fig-7: Speed- 5000 rpm, Feed - 50 mm/min, Temp– 396 ^{0}C

Table-4:- Experimental Outputs with FEA Results

Expt. No.	Actual output Responses					
	Material	Speed	Feed	Temperature	Thermal stress	Hv
	Type	rpm	mm/min	(0C)	(mm)	(Hv)
1	-1	-1	-1	378	5.00E+08	58.67
2	-1	-1	0	468	7.20E+08	55.33
3	-1	-1	1	427	6.50E+08	61.33
4	-1	0	-1	377	5.70E+08	68
5	-1	0	0	555	8.50E+08	61.67
6	-1	0	1	437	6.70E+08	68.67
7	-1	1	-1	540	8.40E+08	67.33
8	-1	1	0	506	7.80E+08	57
9	-1	1	1	507	7.80E+08	62.67
10	1	-1	-1	396	5.20E+08	139.33
11	1	-1	0	353	4.60E+08	162.33
12	1	-1	1	280	3.60E+08	161.33
13	1	0	-1	373	4.90E+08	147.33
14	1	0	0	227	4.30E+08	126.67
15	1	0	1	219	2.70E+08	147.33
16	1	1	-1	394	5.20E+08	150.67
17	1	1	0	278	3.60E+08	175.33
18	1	1	1	257	3.00E+08	151.67

4.4 Signal to Noise ratio Analysis

Taguchi recommends the use of the Signal to Noise (S/N) ratio to measure the quality characteristics. The main principle is that to minimize the variability in the products performance in response to Noise factors while maximize the variability in response to Signal factors.

Types of Signal to Noise (S/N) ratio are; 1.The-lower-the-better. 2.The-nominal-the-better. 3.The-larger-the-better. In our case the out put are Temperature, Bush length,Hardness and Microstructural variation. Hence in case of Temperature case Larger-the-better on the other side in case of Hardness the lower the better and in case of bush length Larger-the-better.

$\eta = -10 \log [(1/n) * \sum (1/y_i^2)]$

Where,

η = resultant S/n ratio

n = number of observations

y = respective characteristics.

Table-5:- S/N ratio (SNR)

Expt. no.	Temp SNR (db)	BL SNR (db)	HV SNR (db)
1	51.5498	21.19	-35.37
2	53.4049	20.17	-34.86
3	52.6085	20.25	-35.75
4	51.526	20.24	-36.65
5	54.8858	20.23	-35.8
6	52.8096	20.13	-36.73
7	54.6478	20.23	-36.56
8	54.083	20.33	-35.11
9	51.0289	20.33	-35.94
10	51.9539	21.11	-42.88
11	50.9554	20.25	-44.21
12	48.9431	20.09	-44.15
13	51.4341	20.15	-43.36
14	47.1205	20.22	-42.05
15	46.8088	20.15	-43.36
16	51.9099	21.03	-43.56
17	48.8808	21.12	-44.87
18	48.1986	21.12	-43.61

In Case of Temperature-Larger is better

Table-6:-Response Table for S/N Ratios for Temp

Level	Material (Type)	Speed (rpm)	Feed (mm/min)
1	**53.29**	51.57	**52.17**
2	49.58	50.76	51.56
3		**51.97**	50.58
Delta	3.71	1.27	1.59
Rank	1	3	2

Table-7: Response Table for Means for Temp

Level	Material (Type)	Speed (rpm)	Feed (mm/min)
1	**466.1**	383.7	**409.7**
2	308.6	364.7	397.8
3		**413.7**	354.5
Delta	157.6	49.1	55.2
Rank	1	2	3

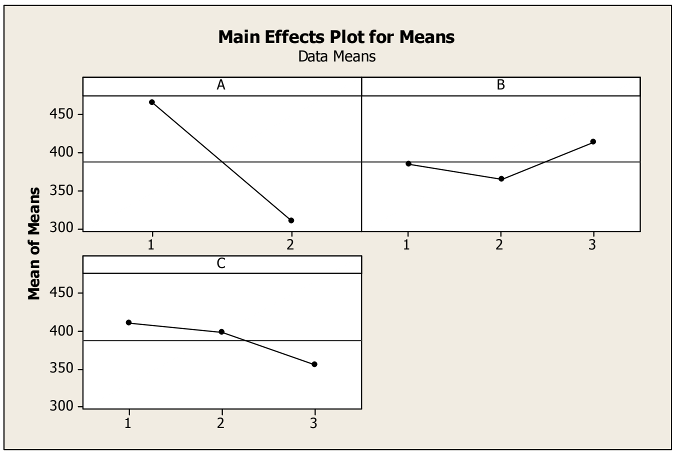

Chart-1: Main Effects Plot (data means) for Means

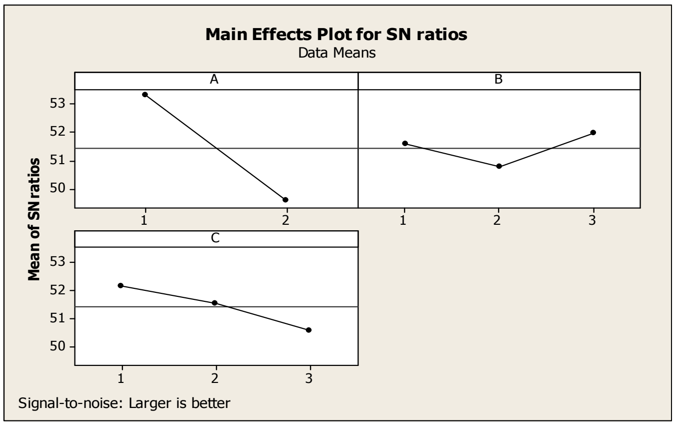

Chart-2 :- S/N graph for Temprature

From the S/N graph forTemprature , the greater S/N ratio corresponds to the smaller variance of the output characteristic which is desirable. S/N ratio is maximum for material at level 1 , in case of different speed it is at level 3 and For feed rate ,feed rate is higher at level 1. Thus it is clear that optimal process parameters for the Temprature are the for material at level 1, speed at level 3, and feed at level 1.

4.4.1 Taguchi Analysis: HV (Hardness) versus Material Type, Speed, Feed

In case of Hardness Smaller is better

Table-8:-Response Table for S/N Ratios of Hardness

Level	Material (Type)	Speed (rpm)	Feed (mm/min)
1	-35.87	-39.54	-39.73
2	-43.56	-39.66	-39.49
3		-39.95	-39.93
Delta	7.7	0.41	0.44
Rank	1	2	3

Table-9:-Response Table for Means for hv (Hardness)

Level	Material (Type)	Speed (rpm)	Feed (mm/min)
1	-35.87	-39.54	-39.73
2	-43.56	-39.66	-39.49
3		-39.95	-39.93
Delta	7.7	0.41	0.44
Rank	1	2	3

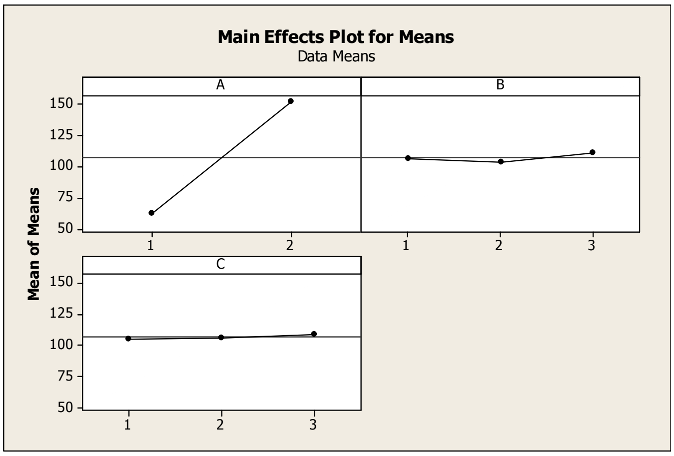

Chart-3:Main Effects Plot (data means) for Means

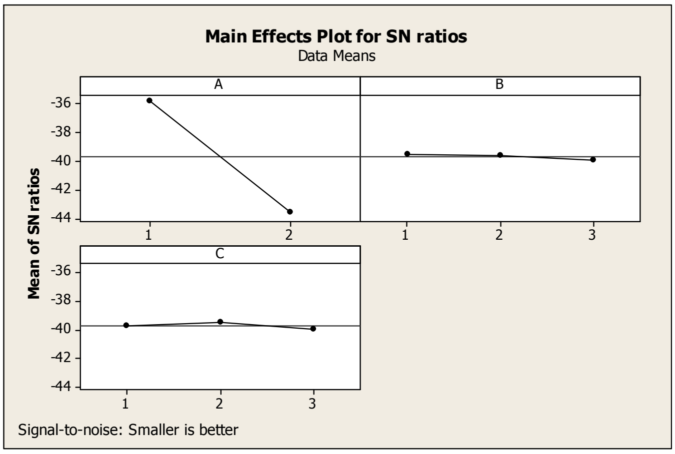

Chart-4:S/N graph for Hardness

From the S/N graph forHardness , the greater S/N ratio corresponds to the smaller variance of the output characteristic which is desirable. S/N ratio is maximum for materialat level 2 , in case of different speed it is at level 3 and For feed rate ,feed rate is higher at level 3. Thus it is clear that optimal process parameters for the Hardness are the for material at level 2, speed at level 3, and feed at level 3.

4.4.2 Taguchi Analysis: BL (Bush length) versus Material Type, Speed, Feed

In Case of Bush length Larger is better

Table-10: Response Table for S/N Ratios of Bush Length

Level	Material (Type)	Speed (rpm)	Feed (mm/min)
1	20.35	20.51	20.66
2	20.59	20.19	20.39
3		20.7	20.35
Delta	0.24	0.51	0.31
Rank	3	1	2

Table -11: Response Table for Means for Bush length

Level	Material (Type)	Speed (rpm)	Feed (mm/min)
1	10.41	10.62	10.81
2	10.71	10.22	10.47
3		10.85	10.42
Delta	0.3	0.62	0.39
Rank	3	1	2

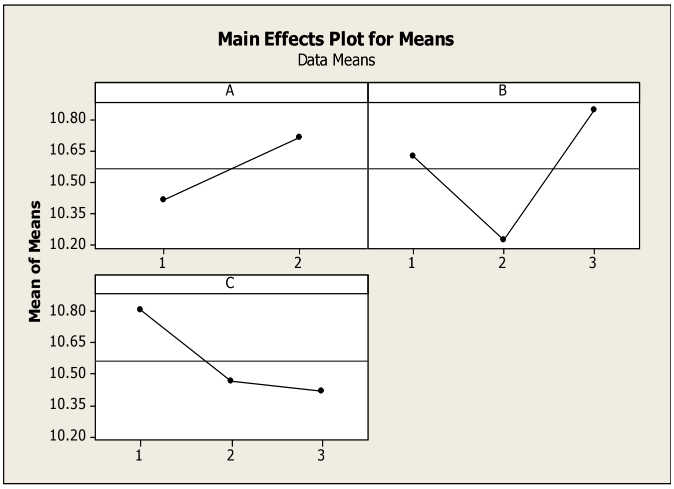

Chart-5: Main Effects Plot (data means) for Means

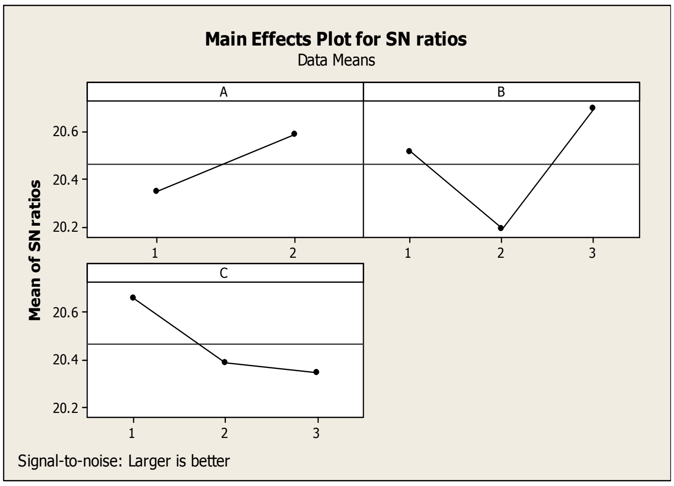

Chart-6: S/N graph for Bush length

From the S/N graph forBush lenght , the greater S/N ratio corresponds to the smaller variance of the output characteristic which is desirable. S/N ratio is maximum for material at level 2 , in case of different speed it is at level 3 and For feed rate ,feed rate is higher at level 1. Thus it is clear that optimal process parameters for the Bush lenght are the for material at level 2, speed at level 3, and feed at level 1.

From S/N graphs for Material(mm), Temperature (ºc), and Hardness(hv)

Table-12:- Summary of optimized conditions

	Material Type	Speed rpm	Feed mm/min	Optimum Parameters setting
Temperature (oc)	1	3	1	M1S3F1
Bush Length (mm)	2	3	1	M2S3F1
Hardness (hv)	1	2	1	M1S2F1

5. CONCLUSION

Taguchi analysis is carried out in order to determine the significant process parameters considering the responses as Temperature, Thermal stress ,Bush length, and Hardness in friction drilling operation. Taguchi analysis shows that the factors affecting the Temperature in the order of their significance (delta ranking) is Material type, Speed and feed the delta ranking for Bush length and Hardness are Material type, Speed, and Feed Respectively. The optimum parameter settings found according to the Taguchi analysis are M1S3F1, M2S3F1, and M1S2F1 for Temperature, Bush length and Hardness respectively. The maximum temp got for material A and B is 480 ºC and 320ºC the maximum Bush length for material A and B is 10.42mm and 11.02mm and minimum Hardness for material A and B is 55Hv and139.33 Hv. The regression equation in the form of coded values are derived for the Friction drilling operation based on the input parameters viz. speed, Feed, and Material type. The equation is quite useful to select the particular type of input parameter. Microstructural study shows aluminium as speed increases aluminium changes its phase that is pure aluminium with insoluble impurities FeAl and in case of mild steel fine pearlite grain in matrix of ferrite is formed as temperature increases formation of pearlite is more.

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