Single Response Optimization of Tool Wear and Surface Roughness by Taguchi Method in Band Sawing

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Abstract— Band sawing is a process of cutting metal pieces with the help of continuous band saw. In this research work, the optimization of process parameters for band saw cutting was done using Taguchi method. The objective of the research is to optimize the tool wear of bimetal blade and surface roughness of work piece. The methodology based on Taguchi's analysis of variance (ANOVA) and signals to noise ratio (S/N Ratio) to optimize the band saw process parameter. The designs of experiments for machining process control parameter are type of blade (A), speed (B) and feed (C). L9 (3*3) standard orthogonal array design of experiment consisting three levels and three parameter A, B and C respectively for each combination have been used for experimentation on EN1A material. Optimum results are obtained for band sawing through the signal to noise ratio (S/N ratio).

Key words: Band Saw, Taguchi Method, ANOVA, Tool Wear, SR, S/N Ratio, EN1A material

I. INTRODUCTION

Band saw machines are saws that consist of a continuous metal band known as band saw blade that rides on two wheels rotating in the same plane. A band saw machine contains a round and serrated blade, and can be used to process wood, metal and various other materials. Depending upon the lateral flexibility and the width of the band, a band saw machine can be used for straight, irregular or curved shape cuts. However, band saws are mostly used to cut irregular shapes. Band saws produce uniform cutting action as a result of an evenly distributed tooth load. These machines can be powered by many sources like wind, steam or electric power. [1]

The band saw machines use bi-metal blades to cut material or work piece. Blades are formed by welding or joining two dis-similar metals. Backing blade is made up of spring steel and cutting teeth are made up of H.S.S. (high speed steel). The variations in the process parameters, such as the blade, feed rate and speed greatly affect the measures of the machining performance, for example, the surface roughness and the tool wear. Therefore, proper selection of the machining parameters can result in better machining performance in the band sawing process. In this study, a double column band saw with fully automatic (DBM-250) model was used as the experimental machine. High speed steel of tooth thickness 0.9mm was used as tool to cut a work piece of EN1A of steel plate of hexagon shape and across face of hexagon is 27mm. The schematic diagram of the experimental setup is shown in fig. 1.

The tool wear and surface roughness as output parameter and optimization of machining settings for minimum tool wear and minimum surface roughness should be investigated experimentally and the obtained results should be interpreted and modelled statistically to understand closely the behavior of machining rate and accuracy in band sawing. In this study, the effect of the machining parameters and their level of significance on the tool wear and surface roughness are statistically evaluated by using analysis of variance (ANOVA). The settings of machining parameters were determined by using Taguchi experimental design method.

Fig. 1: Band saw machine

II. PROBLEMS IN BAND SAW BLADES

A. Failure Modes

In general, band saws fail due to one or a combination of parameters like out of square cutting, premature tooth failure, tooth wear or fatigue of backing metal as shown fig.2. Out of square cutting is the most important reason for bimetal band saw failure. Out of square cut is caused due to the lateral displacement of band on a side. This could be related to instability in the band due to higher applied thrust force or unsymmetrical wear in the teeth.

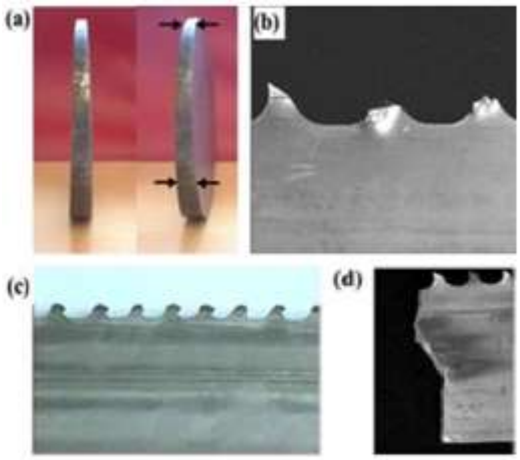

Fig. 1: Band saw failure modes: a) out of square cut b) tooth failure c) tooth wear and d) fatigue failure. [2]

An incorrect choice of cutting data can result premature tooth failure due to the application of large forces. When the total wear in the band saw teeth reaches a critical value, a change in tooth geometry takes place (i.e., blunt edge formation). This can gradually lead to a higher cutting force, ultimately stopping the band saw from cutting any further, if the band saw has not failed in another mode at that point. The development of alternating stresses in the band saw loop from bending and twisting can generate fatigue cracks while the loop is circulating around wheels and guides. These cracks grow until the band loop is broken by fatigue failure. [2]

B. *Wear Modes*

The wear modes in band saw tooth depend on the work-piece material chosen, type of band saw tool material and the selection of cutting conditions. In general, the principal wear modes in any band saw tooth can be identified as flank wear, corner wear, rake face wear and edge rounding as shown in fig. 3. Band saw teeth are worn in such a way that wear flat is produced at the tip of each tooth and the outer corners of the teeth are rounded. Rake face wear is generally not as severe as the flank wear. However, rake face wear can also contribute to a local change in cutting edge geometry. The change in edge geometry (edge rounding) will result inefficient chip formation due to an increase in the ratio of edge radius to depth of cut. [2]

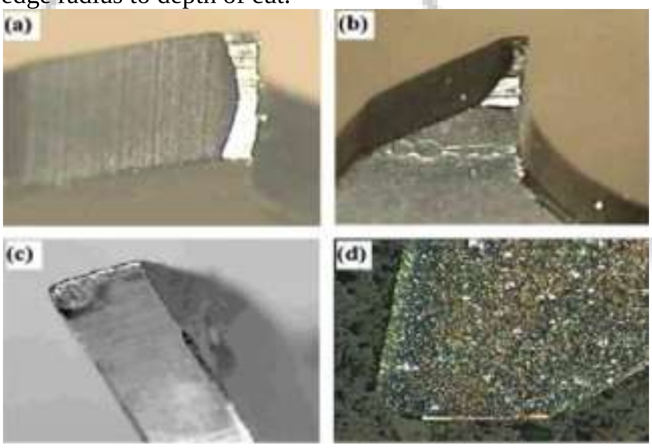

Fig. 2: Band saw wear modes: (a) flank wear (b) corner wear (c) rake face wear and (d) blunting or edge radius [2]

C. *Overcoming the Challenges of Sawing Structural Steel*

Guidelines for the overcoming challenges of sawing structural steel are discussed in this point. This is very essential to focus on effecting areas while sawing structural steel. Band saw can cut any simple and intricate shapes, so there is much challenge for fabricators to cutting any shape and size of structural steel. Hence different types of steel may require different blades and to make efficient cuts. Inefficient band sawing can lead to delays and cost overruns on projects. Difficulties in cutting structural steel can be made less severe by selecting the right blade. By following a few easy guidelines, metal fabricators can preserve their blades, make better cuts, and lower the cost per cut on construction projects.

1) *Getting the Right Tooth*

When cutting steel with a band saw blade, tooth selection is imperative. When cutting structural steel fabricators should consider wall thickness. Thin-walled structural steel requires saw blades with fine teeth, this means is very small and sharp edges required to cut thin material. Fineness of band saw teeth depends on number teeth fits within inch. Pitch of blade is decided on Tooth per inch (TPI). A fineness of 5-8TPI would work well for thin-walled structural steel. 5-8TPI is variable teeth per inch. Pitch changes alternatively, for 1 pitch it consist of 5 teeth and for adjacent pitch it consists of 8 teeth. Thicker-walled structural steel, such as I-beams, will likely require a coarser-pitched saw blade. Coarser pitch indicates larger pitch or tooth per inch.

2) *Proper Break-In*

Fabricators can cut costs and extend the life of their saw blade by properly breaking in new saw blades. Break in means cutting in of new blade on work piece for less speed and feed rate for good cutting initiation. Whenever selecting new blade and when it leads to cutting, it needs to dig into work piece very fine and smooth, so it is necessary to give low speed and feed rate to the blade. Band saw operators can properly break in new blades by selecting a slow band speed when using new blades. Reducing feed rates also helps to break in new blades. When cutting with new blades, operators should ensure that the teeth of the blade are forming a chip. Once the new blade has been properly broken in, speeds and feed rates can be increased.

3) *Choosing the Right Speed*

When using a band saw, operators need to select the right band saw speed. Softer materials should use higher speeds to ensure the blade gets in and out of the cut quickly. Harder materials require slower speeds. In general, if we are using mild steel or aluminum, we will need to use a much faster band speed than we would for molded steels or nickel alloy. Higher the hardness of work piece lesser the band speed need to use. Lower the hardness of work piece higher the band speed need to use.

4) *Proper Bundle Loading*

If we are bundle loading, we must ensure to the materials in the saw’s vise to ensure consistent cutting. Bundles also typically require coarser pitch saw blades. Bundle indicates proper stacking of material one above the other. If the stacking is wrong then blade will stuck up into work piece and taper cutting is formed on the work piece.

5) *Using Adequate Coolant*

If the band saw uses a flood application coolant system, be sure to have the proper mix ration for the fluid. The saw’s manufacturer will list the right ratios in the product information. Proper lubrication ensures the device works properly and increases blade longevity.

6) *Proper Maintenance*

We need to check regularly the condition and alignment of band saw’s guides, as well as the device’s blade tension and tracking. It is also important to clean the machine sump at least twice per year. It requires regular maintenance for each month. It means replacing oil used, cleaning dust and other contaminants with gas pressure, renewing coolants used and regular lubricating frictional parts in band saw by lubrication oil. [3]

III. METHODOLOGY

Fig. 4 Explains methodology for the present work as per order shown.

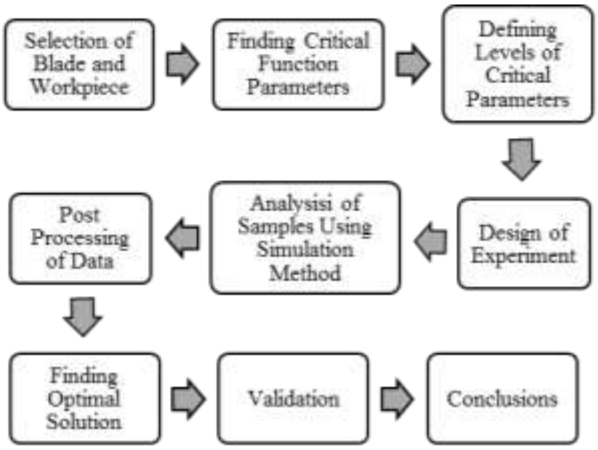

Fig. 3: Flow chart for methodology

A. Selection of Blade and Work Piece

Selection of band saw blade and work piece depend on each other. Proper blade is selected for respective hardness of material. For example: for soft material like mild steel, blade with less grade is used (M42, M51, and M71). As grade of blade increases its hardness value or carbon content in composition increases. For stainless steel which having higher carbon content and high hardness value, it needs to cut by blade of M51 or M71.

For this research work, bi metal band saw (Premier (M-42), Ambassador (M-51) and endure (M-51)) is used. These blade differ by the hardness and composition. (table V). And EN1A material is used which is soft and suitable for cutting by all three types of blades. For composition and properties of EN1A refer table IV.

B. Finding Critical Function Parameters

Function parameters are nothing but control parameters. Parameters which really affect the response of uncontrollable parameters such as tool wear, surface roughness, cutting force etc. are known to be critical function Parameter. In band sawing operation, there are many factors affecting for proper cutting and life of machine. Blade, Speed of cutting, Feed rate, Material used, Coolant condition, Tensioning of saw blade are few of effecting parameters.

For this research work, tool wear and surface roughness is used as response variable. The more effective variable for these responses is selected. Hence blade, speed, feed rate and material are the variables which are most effective for the response of tool wear and surface roughness.

C. Defining Levels of Critical Parameters

In this research work, three factors are selected. Levels indicate variation in the factors used for research work. Three levels of each parameter is selected for experimentation. These three levels are as follows.

Sr. No.	Factors	Levels
1.	Blade	Premier, Ambassador, Endura
2.	Speed	25,45,55 (m/min)
3.	Feed Rate	10,20,40 (cm^2/min)

Table 1: Levels of Critical Parameters

The levels are decided from manufactures catalogue and present machining (band sawing) procedures. [3]

D. Design of Experiment

Design of experiment is Technique used for experimentation. Various forms of DOE viz. Response surface method, Taguchi method, and Factorial design method are used for experimentation. For this research Taguchi technique is used. In experimentation, according to Taguchi design of L9 array, total 9 trials are experimented. Before experimenting, fresh blade dimension of tooth depth is checked for 5 tooth. It is then mounted to band wheel, and tightened by lever from tension end of band wheel to fix blade tightly. After mounting the blade, speed is given by stepped pulley attachments. Feed rate is given by knob attached to control panel of band saw. Now proper speed and feed rate are adjusted for respective blades according to the design of experiment. EN1A rod is fed for cutting. As the machine is automatic, cutting length is set according to the requirement. And after cut of each slice, it is slide forward automatically and ready for next cut. Before starting experimentation, single idle cut is taken to check if blade is guided properly or not. Further trials are taken according to design of experiment.

E. Analysis of Samples by Simulation Method

Now when design is created according to Taguchi technique and all experimental trials are carried according Taguchi experimentation plots, samples are segregated for testing. This includes measurement of tool wear using profile projector, Surface Roughness using surface roughness tester as per the tagging applied to the samples.

F. Finding Optimal Solution

After Experimentation carried, all the results obtained are plotted according to their trial number. Analysis of optimal solution is based on requirement. There are three conditions at which we get optimal solution.

- Larger is better: -10log 10 (sum $(1/Y^2)$/n)
- Nominal the Best: -10log 10 (Y^2)
- Smaller the better: -10log 10 (sum (Y^2/n))

For this research work, Smaller the better condition is used. Response variable tool wear and surface roughness needs to minimize to get good results. Hence smaller is better condition gives good results.

G. Validation

It is very necessary to validate obtained results. Results which we get experimentally are true or not is unknown part. Hence validation gives evidence behind every experimental result. Validation can be either way. One way is comparing both experimental and analytical result. Other way is to set target value and experimenting other value to ensure not to cross targeted value.

H. Conclusion

Conclusion is based on result obtained and validation part. Conclusion is what we have observed with results and graph obtained. It tells about effect and contribution of input parameter on response value.

IV. EXPERIMENTATION

A. Design of Experiments

The experimental layout for the machining parameters using the L9 orthogonal array was used in this study. This array consists of three control parameters and three level, as shown in table II. In the Taguchi method, most all of the observed values are calculated based on the 'higher the better' and the 'smaller the better'. Thus in this study, the observed values of tool wear, and surface roughness were set to minimum as desired values. Three blade selected for this experiment are Premier, Ambassador, Endura. Table II indicates the scheme of experiment and levels. Table III. Indicates Taguchi L9 orthogonal array.

Control Parameters	Levels			Observed Values
	1	2	3	
Blade (A)	Premier	Ambassador	Endura	Tool Wear in mm Surface Roughness (Ra) in µm
Speed (B)	25	45	55	
Feed (C)	10	20	40	

Table 2: Design Scheme Of Experiment Of Parameters And Level

Trial No.	A=Blade	B=Speed	C=Feed
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3: Taguchi L9 Orthogonal Array

B. *Response Variables Selected*

In the present study, the following two parameters have been use as response variables: tool wear and surface roughness (tool wear measured in mm and surface roughness measured in µm)

C. *Work piece Material*

EN1A is a very popular grade of low carbon-manganese free cutting steel, which is most suitable for the manufacture of repetition turned components, such as nuts, bolts, hydraulic fittings and studs, particularly where intricate drilling and machining operations are involved. It can be case-hardened, producing components with enhanced wear resistance. Hence is used as work piece for experimentation.

Fig. 5: Work piece of EN1A

C	Si	Mn	S	P	Ld
0.15	0.40	0.90-1.30	0.25-0.35	0.070	0.15-0.35

Table 4: Chemical Composition Of EN1A In %

Alloying Element	Premier (M42)	Ambassador (M42)	Endura (M51)
Carbon	0.70%	0.90%	1.25%
Manganese	0.50%	0.50%	0.50%
Vanadium	1%	1%	3%
Chromium	4%	4%	4%
molybdenum	10%	10%	3%
Cobalt	1%	1%	10%

Table 5: Chemical Composition Of Band Saw Blade For Premier, Ambassador, Endura

1) *Calculation for Number of Cuts and Time required for Total Cuts*

According to blade manufacturer the average blade life is 50000 cm^2. The work piece to be cut is of hexagonal section of each side 16 mm. hence the area of hexagonal section is 6.5 cm^2. If we are keeping two work piece at a time, area of two rods will be 13 cm^2.

Total no. of cuts taken on each blade = (average life of blade/ area of work piece) = (50000/13) = 3846 cuts.
Total no. of cuts taken on each blade for 10% life of blade = 5000/13 = 384 cuts.

Time required for total cuts = (total no. of cuts taken on each blade/time require for per cut)

Time is based on feed rate, if feed rate is more, time required cut slice of work piece is less. According to feed rate, time obtained for three levels (see 3.3) are as follows

Level	Time taken (hrs.)
1.	8.50
2.	4.25
3.	2.125

Table 6: Time Management for Each Level

D. *Tool Wear Measurement*

In this current study tool wear is measured using profile projector of 10X magnification lens. Three different blades have been used for cutting EN1A material. For each blade 1 inch distance is marked, consisting 5 teeth so that we can recognize them for the next cut. Tooth depths of all three blades are checked before cutting and after cutting. Then after taking 384 cuts on each blade, blade is again measured within same marked or punched distance. Teeth coming under marked length are measured to check error occurred as observed on profile projector.

Fig. 6: Profile Projector

Finally averaging difference of 5 teeth on blade, average tool wear on blade is obtained. Thus,

Tool Wear = Teeth depth before cutting – Teeth depth after cutting.

E. Surface Roughness Measurement

Surface roughness tester is used for measuring arithmetic roughness (R_a) value in µm. To measure average roughness (R_a) value, 3 samples or slices of each trial is taken. Now total cuts and total time require for each trial is decided. Total number of cuts taken on each blade are 384 cuts (from 4.4 calculation). Time taken by each trial to cut 384 pieces can be calculated. (table VII.) Now dividing time obtained from table VII. By 3, we get three intervals of cutting time. In each interval one slice of work piece is taken, like that we get 3 slices for each trial. These slices were kept in small packets and tagging them with trial no. and respective interval at which slices where taken. Then these slices were then checked under roughness tester. Mean value of R_a is calculated by averaging three roughness values.

Fig. 4: Samples for surface roughness measurement

F. Observed Response Values

According Taguchi design all the experiments should be carried. Brief procedure how response values are obtained are given in (D and E). Results obtained after experimentation and testing are as shown in table VII

V. RESULTS AND DISCUSSION

A. Determination of optimal process parameters for Tool Wear

In this section, we will discuss calculation procedure and results obtained by applying Taguchi method. L9 orthogonal array is used to determine the optimal process parameters. The results are reported in using S/N ratio and ANOVA analysis. In Taguchi method, there are three performance characteristics such as higher-is-better, nominal-is-better and lower-is-better. Here lower is-better characteristic is used to find the optimal process parameter for tool wear. The TW and S/N ratio for TW is listed in table VIII.

Trial	A	B	C	Tool Wear (mm)	Response of SR (µm)	S/N ratio for TW (dB)
1	1	1	1	0.0518	5.811	25.7134
2	1	2	2	0.0340	5.972	29.3704
3	1	3	3	0.0810	5.390	21.8303
4	2	1	2	0.1310	10.562	17.6546
5	2	2	3	0.0280	6.817	31.0568
6	2	3	1	0.0270	9.478	31.3727
7	3	1	3	0.0846	3.582	21.4526
8	3	2	1	0.2310	5.375	12.7278
9	3	3	2	0.0330	10.046	29.6297

Table 7: Observed Values Of Tw And Sr

1) Experimental Results For Tool Wear and S/N Ratio

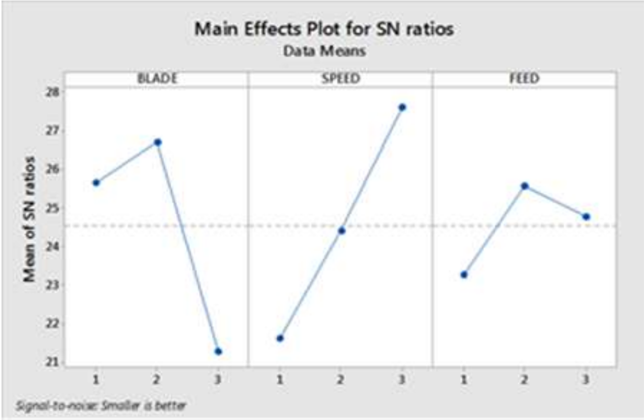

Fig. 5: Means of S/N ratio graph for tool wear

Above graph is obtained from table VII. Hence from above figure it is clear that, best combination obtained for tool wear is blade of level-2, speed of level-3, feed rate of level-2.

B. Analysis Means of S/N ratio for Tool Wear

As the experimental design is orthogonal, so it is possible to separate out the effect of each process parameter at different levels.

Level	Blade	Speed	Feed rate
1	25.64	21.61	23.27
2	26.69	24.39	25.55
3	21.27	27.61	24.78
Delta	5.42	6.00	2.28
Rank	2	1	3
Total Mean of S/N ratio 24.534 dB			

Table 8: Means Of S/N Ratio

From S/N ratio of tool wear in table VII, The mean of s/n ratio for tool wear, the optimal process parameters are obtained such as blade at level-2, cutting speed at level-3 and feed rate at level-2 (refer table VIII).

C. ANOVA for Tool Wear

The purpose of the ANOVA is to find the statistical significance of process parameters on the response shown in table IX. From table, it is found that values of P for all input parameters are greater than 0.05. Hence according to F value blade is most significant effect on tool wear.

Source	DF	Adj SS	AdjMS	F-Value	P-Value	% Contribution
Blade	2	0.0234	0.003325	0.3	0.768	65.16
Speed	2	0.0062	0.002208	0.2	0.833	17.34
Feed	2	0.0049	0.001446	0.13	0.884	13.68
Error	2	0.0014	0.011031			3.82
Total	8	0.0360				

Table 9: ANOVA Table For Tool Wear

D. Determination of Optimal Process Parameters for Surface Roughness (Ra)

In this process, S/N ratio for surface roughness is obtained based on response of surface roughness. 'Lower is better' criteria is choose for surface roughness. Results obtained are plotted in tabular form, which is given in table X.

Trial No.	A	B	C	Surface Roughness (μm)	S/N ratio for SR (dB)
1	1	1	1	5.811	-15.2850
2	1	2	2	5.972	-15.5224
3	1	3	3	5.39	-14.6314
4	2	1	2	10.562	-20.4749
5	2	2	3	6.817	-16.6719
6	2	3	1	9.478	-19.5343
7	3	1	3	3.582	-11.0825
8	3	2	1	5.375	-14.6076
9	3	3	2	10.046	-20.0399

Table 10: Experimental Results For Surface Roughness and S/N Ratio

E. Means of Response Table for Signal to Noise Ratios

Similarly, the S/N ratio for surface roughness is calculated. Here lower-is-better characteristic is used to find the optimal process parameter for surface roughness (Ra). From the means of response of S/N ratio for Ra from table XI, the optimal process parameters are obtained such as blade of level-1, speed of level-2 and feed rate of level-3.

Level	Blade	Speed	Feed rate
1	-15.15	-15.61	-16.48
2	-18.89	-15.60	-18.68
3	-15.24	-18.07	-14.13
Delta	3.75	2.47	4.55
Rank	2	3	1
Total Mean of S/N ratio 16.42778 dB			

Table 11: Means of S/N Ratio For Surface Roughness

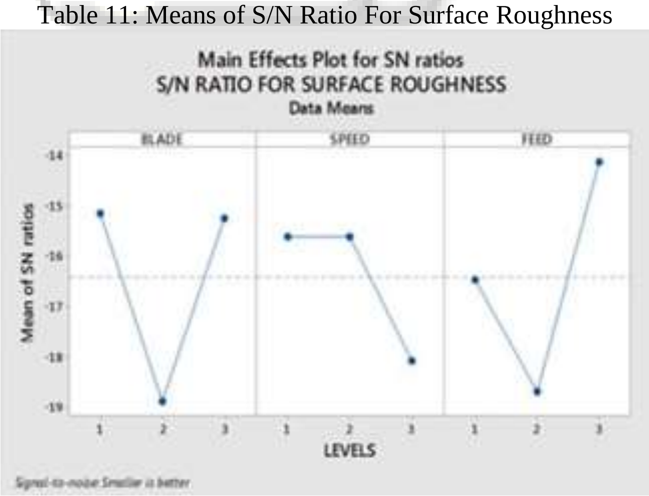

Fig. 6 Means of S/N ratio graph for surface roughness

From the above graph, it is clear that, Surface Roughness with lower value is better results for good combination. Hence from above figure we conclude that, blade of level-1, speed of level-2 and feed rate of level-3 are best combination result.

F. ANOVA for Surface Roughness (Ra)

ANOVA for surface roughness (Ra) is listed in the table XII. From the table it is clearly found that feed rate with highest contributing parameter for surface roughness of parameter. Therefore, feed rate is the most significant parameter for Ra followed by blade and speed.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%Contribution
BLADE	2	17.646	8.823	7.81	0.114	37.129
SPEED	2	8.151	4.076	3.61	0.217	17.150
FEED	2	19.468	9.734	8.61	0.104	40.962
Error	2	2.261	1.130			4.757
Total	8	47.526				

Table 12: ANOVA Table for Surface Roughness (R_a)

VI. CONCLUSION

This paper has presented an application of parameter design of the Taguchi method in the optimization of band sawing operations. The following conclusion can be drawn based on the experimental results of this study:

1) According to results obtained by parameter optimization of Tool wear is Blade with 2nd level, speed with 3rd level and feed rate with 2nd level. Blade is most significant effective parameter for tool wear compare to speed and feed rate.
2) According to responses of S/N ratio for Surface roughness Blade with 1st level, speed with 2nd level and feed rate with 3rd level is best combination of result. Feed rate is most significant effective parameter for surface roughness, followed by blade and speed.
3) According to ANOVA table for tool wear, blade is most significant effective parameter for tool wear.
4) According to ANOVA table for surface roughness, feed rate is most significant effective parameter for surface roughness.
5) One more conclusion we can draw from fig.8. If cutting speed of blade is increases tool wear is increases. Hence to optimum result speed should be minimum to enhance blade life.

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