Implementation of Energy Efficient Burnishing Process for Surface Integrity Improvement of Hole Finishing Tool

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Abstract.

Burnishing is a well-known cold working technique for improving the surface integrity. It is a very cost-effective and efficient approach for improving surface finish and hardness. Use of burnishing to replace current heat treatment and grinding processes on reamer shank is offered as a unique strategy for reamer shank processing. This change in processing reduces cycle time and resources while also conserves energy required for processing during heat treatment and grinding. In this work Taguchi optimization technique is used to determine the optimum parameter values of burnishing process to attain required surface finish and hardness to fulfil all functional requirements of shank. Test outcomes are convincing which shows that suggested process has capability to replace current heat treatment and grinding process, thus conserves energy.

Keywords. Energy conservation, Burnishing, reamer, shank, taguchi optimization.

1. INTRODUCTION

Energy is critical to the world's evolution, development, and existence. Rising energy consumption has a negative impact on the environment as well as increased government pressure. For a developing country like India, the energy criteria determine the country's growth. As the third biggest power generator, the country is ruled by energy shortage and need. Our country's energy consumption is expanding at an alarming rate. Energy conservation may be the greatest response to rising energy needs. Energy conservation is the practise of minimising energy consumption by utilising less of an energy service. Energy auditing is one of the most essential techniques to increase energy saving. It is a difficult effort to conserve energy without reducing consumption. The paper highlights the importance of conserving energy by substituting the processing technique used for reamer shank manufacturing, taking into account the energy consumed by the current manufacturing process, and suggesting a new efficient yet simple optimization based method, namely taguchi, to improve energy efficiency and compare results.

The cutting side of two-piece reamers is generally composed of H.S.S., while the shank side is constructed of a low-priced carbon alloy steel like EN31 to lower tool's cost.

EN31 steel attains more hardness after heat treatment, as well as strong abrasion resistance. As a result, this method is used to make reamers, drill bits, taps, ejector pins, bearings, and wear-resistant machine and press tool components, among other things.

Rotary friction welding is commonly used to attach the cutting and shank sides of reamers, since it is the most appropriate technique for combining divergent materials. Friction welding, on the other hand, causes thermal strains in TMAZ and HAZ. Air quenching hardens the HSS material (cutting side) in these zones. To enhance machinability, friction welded components are normalised and annealed, respectively. After rough turning, different heat treatment cycles are utilised for both sides because of differing material properties of the cutting and shank sides, as shown in Table 1. Heat treatment, on the other hand, is consumes lot of energy/electricity [1], necessitating careful adherence to energy conservation and environmental laws. This method is also not economically possible in today's competitive market [2]. As a result, the major focus of this research is on eliminating the heat treatment procedure by including the burnishing process into the reamer manufacturing process plan. Surface integrities, such as surface finish, hardness are enhanced during the burnishing process [3–5].

Cutting side hardness is in between 760 to 900 HV, while the hardness of the shank side is in between 180 to 450 HV, according to Indian Standard IS 5443 1994 Reff2021 of technical supply requirements for reamer [6]. Burnishing can increase the initial hardness by up to 45% [7]. Cutting side hardness is 247 HV, while the shank side is 178.3 HV before heat treatment. If heat treatment is substituted with burnishing, cutting sides' hardness can be increased to 356 HV and shank sides' hardness can be increased to 260 HV, respectively. As a result, it's clear that the burnishing technique can be used only for shank processing. As previously indicated, the burnishing technique may increase surface finish which can eliminate finish-grinding procedure in the traditional shank production process. Because of the removal of costly heat treatment and grinding processes, suggested technique will lower the cost of reamer production. In addition, the recommended strategy guarantees a secure working environment. As a result, in this study, an examination is carried out to evaluate the viability of the suggested shank process plan, as well as to compare its performance with traditional one.

Heat treatment for the shank section is therefore replaced with burnishing, a surface improvement method in current study to obtain the necessary characteristics. As a plastic deformation method, burnishing utilises the pressure of a hard roller or ball to deform the asperities on a workpiece's surface [7-9], producing a high-quality surface finish with increased hardness. To further understand how burning affects performance, several studies have been conducted [10-12].

Burnishing has been extensively studied for its influence on surface quality of steel materials including AISI 1045 [9,13,14], AISI 4140 [12] and AISI D3 [15], as well as O1 [16] and PDS5 [17]. Additionally, Shankar et al. [18] found that roller burnishing improved surface finish and hardness of Al(B4C)p MMC. Burnishing was used by Travieso-Rodrguez et al. [19] to enhance the surface quality of aluminium A92017 and steel G10380.

Burnishing can be used on the shank section of the reamer to increase surface hardness while lowering processing time and cost, according to the literature study. However, in order to effectively apply burnishing technique to reamer shank manufacturing, it is necessary to first identify most important burnishing process parameters; then, to form their relationship with process' outcomes(hardness and time required for burnishing), a taguchi optimization technique can be used..

2. MATERIALS AND METHODS

Like previously stated, the burnishing technique has the ability to eliminate the need of heat treatment for processing reamer shank. In addition to the present process plan (Fig. 1(a)), a novel process plan incorporating burnishing is offered (Fig. 1(b)). Heating and shank straightening operations are removed in the suggested process design, as indicated in Fig. 1, moreover burnishing substitute finish-grinding process also.

Dominant burnishing factors, like burnishing speed (v), burnishing feed (f), burnishing force (F), and no. of passes (N), are taken into account for successful integration of burnishing in current application, and one's impact on surface hardness (Hv) is studied with the help of taguchi optimization technique.

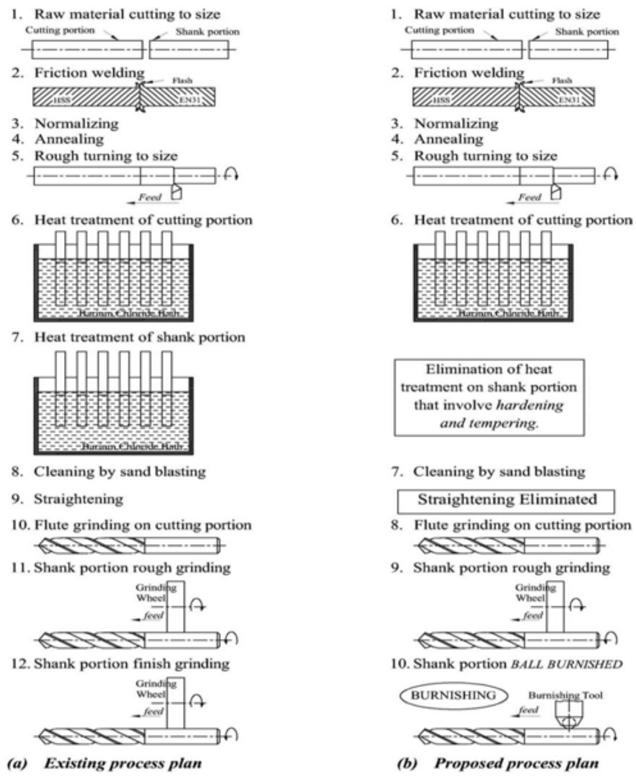

Figure 1. Process plan (a) Current (b) Suggested.

Hole-forming devices require a high degree of surface hardness. Burnishing time consideration is also essential to obtain the requisite rate of production. It's well-known that when burnishing speed increases, surface hardness decreases, while burnishing time decreases. Burnishing feed enhances surface hardness while decreasing burnishing duration. Increasing burnishing force results in surface flecks, which increase surface hardness. As burnishing duration rises, surface hardness improves. As a result, all process factors impact performance metrics in a contradictory manner. This is why the taguchi optimization approach is utilised to optimise the burnishing process for all answers.

Now, straight-shank reamer with size of Ø12 mm is taken into consideration in order to validate the suggested approach. EN31 bar used for shank side having diameter 14 mm and length 55 mm and HSS bar used for cutting side having diameter 14 mm and length 75 mm are connected by friction welding. Specimens are manufactured up to rough turning as per suggested plan as shown in Fig. 1. These components' shank section is then burnished in accordance with the experimental design.

Fig. 1(b) shows a suggested process design that eliminates heat treatment and straightening operations from the current process plan and replaces grinding with a burnishing process. As a result, main aim of current research is to determine most suitable burnishing process variables for this application and confirm that they are in line with reamer specifications.

Table 1. Process variables and their levels.

Process variables	Code	Unit	Levels				
			1	2	3	4	5
Burnishing Speed (v)	A	m/min	13	18	30	48	75
Burnishing Feed (f)	B	mm/rev	0.045	0.071	0.112	0.18	0.28
Burnishing Force (F)	C	Kg	10	25	40	55	70
No. of passes (N)	D	-	1	2	3	4	5

When determining the best burnishing parameters for a particular shank, the taguchi method is employed to see how closely process parameters correlate with the shank's performance. A total of 25 trials are performed, each with four parameters at five different levels, as indicated in Table 1. A burnishing tool is being used to burnish the shank section (which has an initial hardness of 180.4 HV on average).

The burnishing tool used during study features a 10 mm diameter tungsten carbide ball that is supported by a ball bearing that is attached to the fork arm. Using a spring-loaded subassembly, the required burnishing force may be applied to the workpiece. Fig. 3 shows how the burning tool shank fits on the tool holder of a lathe with ease.

Figure 3. Burnishing tool attached to lathe tool post.

3. RESULTS AND DISCUSSION

3.1 Analysis of means and Analysis of variance

The objective of this study is to see how burnishing factors affect hardness (Hv), as well as to optimise hardness during the burnishing process. Hardness has been assigned to the "larger the better" category. Eq. (1) is used to calculate the corresponding S/N ratios of objective functions for every test of OA. Table 2 shows the respective S/N ratios for every test of the L25 orthogonal array.

$$nij = -10log_{10}\left(\frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^{2}}\right) \quad (1)$$

Where yij represents the ith experiment at jth test, n represents total no. of readings for given (jth) answer, and s represents the standard deviation.

Table 2. OA, parameters level and respective S/N ratios of measured responses.

Exp.	Process Parameters Results				Results	
	Speed (m/min)	Feed (mm/rev)	Force (Kg)	No. of Passes (N)	Hardness, H (Hv)	S/N ratio for Hardness
1	13	0.045	10	1	227.00	47.1205
2	13	0.071	25	2	233.50	47.3657
3	13	0.112	40	3	246.50	47.8363
4	13	0.18	55	4	250.00	47.9588
5	13	0.28	70	5	252.00	48.0280
6	18	0.045	25	3	219.50	46.8287
7	18	0.071	40	4	252.00	48.0280
8	18	0.112	55	5	260.50	48.3162
9	18	0.18	70	1	244.50	47.7656
10	18	0.28	10	2	222.00	46.9271
11	30	0.045	40	5	250.00	47.9588
12	30	0.071	55	1	247.00	47.8539
13	30	0.112	70	2	251.50	48.0108
14	30	0.18	10	3	209.50	46.4237
15	30	0.28	25	4	234.50	47.4029
16	48	0.045	55	2	238.00	47.5315
17	48	0.071	70	3	244.50	47.7656
18	48	0.112	10	4	228.50	47.1777

Exp.	Process Parameters Results				Results	
	Speed (m/min)	Feed (mm/rev)	Force (Kg)	No. of Passes (N)	Hardness, H (Hv)	S/N ratio for Hardness
19	48	0.18	25	5	235.50	47.4398
20	48	0.28	40	1	210.00	46.4444
21	75	0.045	70	4	251.50	48.0108
22	75	0.071	10	5	229.50	47.2157
23	75	0.112	25	1	222.00	46.9271
24	75	0.18	40	2	216.50	46.7092
25	75	0.28	55	3	248.50	47.9065

Tables 3 show the contribution of various process parameters on surface hardness i.e. ANOVA.

Table.3 ANOVA for hardness

Parameter Code	Degree of Freedom	Sum of Square	Mean Square	F value	P value	% contribution
A	4	0.2602	0.0651	0.48	0.748	3.90
B	4	0.8780	0.2195	1.63	0.258	13.17
C	4	2.0582	0.5146	3.82	0.051	30.86
D	4	2.3945	0.5986	4.44	0.035	35.91
Error	8	1.0775	0.1347	1.00	-	16.16
Total	24	6.6684	-	-	-	100

Burnishing force (30.86 %) and no. of passes (35.91 %) are vital for optimising hardness, but burnishing speed (3.90 %) and burnishing feed (13.17 %) have no apparent influence on hardness, as shown in the ANOVA table.

3.2 Conformability with reamer standard

Ball burnishing increased hardness, according to the results of the investigation. IS 5443 reamer standard must be met for the improved quality attributes to be effective on a dependable hole finishing tool shank. The reamer standard IS 5443 is used to assess and certify quality attributes. The suggested approach saves time and energy while manufacturing the reamer shank part.

3.3 Hardness of shank side:

The optimal set of settings for burnishing the shank section is solution No. 8. The hardness of surface improves from 180.4 to 260.50 HV when this parameter is used. This is because at a modest feed rate, plastic deformation is more effective (since the contact time between the ball and the surface is appropriate), leading to larger hardness improvement. Increased burnishing force increases work hardening, resulted in enhanced hardness.

3.4 Time and cost:

The traditional technique of shank processing includes procedures like as hardening and tempering, which consume a significant amount of time during tool manufacture. It takes 219 minutes to heat treat 30 tools in a fixture. In other words, it takes 7.3 minutes to heat treat a shank part of a tool. To harden and temper the item, a lot of power is needed, which increases the expense and danger of the heat treatment process as a whole. Straightening requires 2 minutes and finishing grinding requires a 1.2 minutes after heat treatment. This set of three operations took a total of 10.5 minutes to complete. As per present method's requirement due to different heat treatment procedure for cutting section and shank section at dissimilar temperatures (as mentioned earlier), different tensions are generated, resulting in part bending. As a result, the component also requires a straightening procedure. However, in the proposed technique, the absence of the heating of the shank part decreases this issue and removes the operation of straightening. Heating, straightening, and finishing grinding on the shank part may be substituted by a burnishing process that requires just 23.5 s to process shank which saves 606.5 seconds per piece.

For a certain reamer size, the cost of heat treatment is Rs. 3.50 and final grinding is Rs. 6.00 per piece, but the cost of burnishing process is just Rs. 1.50 per piece when taking these prices into account. By using the burnishing technique, you may save around Rs. 8.00 each item.

4. CONCLUSIONS

Taguchi optimization is used to produce the appropriate hardness on the surface of the shanks in order to satisfy all functional needs. Taguchi's solutions may be utilised as a ready-to-use guide for choosing burnishing settings to attain the necessary quality attributes required by the process planner.

- Burnishing produced a surface hardness of 260.5 HV, which is within the specified limit in IS 5443.
- Heating, straightening and finish grinding take around 630 seconds using the traditional method. Burnishing (processing time 23.5 s) eliminates these steps, resulting in a processing time reduction of roughly 606.5 s.
- The burnishing method not only avoids the dangers of heat treatment, but it is also cost-effective, saving up to Rs. 8.00 each piece.
- Burnishing process will conserves energy by replacing heat treatment with burnishing.

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