Experimental Investigation of Grit Blasting Parameters on Alpha Case Removal of Forged Alloy Part Ti-6Al-4V used in Aviation Industry

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***Abstract*— Titanium and its alloys are attractive engineering materials used in aerospace industry because of their superior mechanical properties such as high specific strength and excellent corrosion resistance. Ti–6Al–4V alloy commonly used for manufacturing components in jet engines, such as fan blades, disks, wheels and sections of the compressor where the maximum temperature is in the range of 300–450 °C. Titanium forged parts are heated above 900°C during forging undergoes reduce roll, blocker, flattener, finisher, trimming etc. processes for producing final forging. During this process when surface of forged part gets contact with oxygen from environment and producing oxide layer. This oxide layer is commonly known as alpha case. The alpha–case layer has adverse effect on mechanical properties such as ductility, fracture toughness and especially the fatigue life when an engine component is subjected to dynamic loading. The effect of grit blasting parameters on the alpha case removal and surface roughness of Ti–6Al–4V alloy was examined using the Taguchi designs of experiments and Grey relational analysis.**

Keywords—Alpha–case, Taguchi design, Grey relational analysis, Surface Roughness, ANOVA, Grit Blasting Parameters

I. INTRODUCTION

During titanium forging when heated parts are in contact with atmospheric oxygen forms oxide layer on surface called as alpha case[1]. Failure of titanium forged parts may be causes due to crack propagation on alpha case layer present on the surface. Etching is the process which removes the alpha case layer and avoids formation of cracks on the surface. This process involves use of hazardous chemicals like concentrated hydrofluoric acid (HF) and nitric (HNO3) acid with required proportion, which makes this process dangerous and required proper attention and safety measures to carry out process. Chemical etching also have adverse effect on part surface by introducing pitting and/or intergranular corrosion and thus affects the fatigue strength[2]. Grit blasting can be used as alternate process for etching and can be used for removing alpha case layer by applying proper process parameters. Grit blasting process involves various process parameters like grit selection, exposure time, blasting pressure, blasting angle, distance of nozzle from the part surface. Hence it is required to develop scientific method to have both economic and damage free grit blasting surface in case of titanium forged parts.

Grit Blast cleaning with abrasive media removes old coatings, rust, and other unwanted material from a surface, and creates an anchor pattern to allow new coatings to adhere better. Manufacturers who turn to grit blast cleaning as an environmentally responsible alternative to chemical stripping processes often realize substantial cost savings as well.

II. EXPERIMENTAL PROCEDURE

A. Material

Titanium forged flaptrack Prolongations of material Ti6Al4V is used in experiment. The flaptrack is used in wings of Boeing 737 for aviation purpose. For experimental trails, the extracted prolongations are taken having dimensions height 48mm; width 77mm; length 120mm. The flaptrack material is given in table 1.

Table 1: Chemical composition of Ti6Al4V flaptrack

Element	Al	V	Fe	O	C	N	H	Y	Other	Ti
% weight	6.75	4.50	0.30	0.20	0.08	0.05 (500 ppm)	0.0125 (125 ppm)	0.005 (50 ppm)	0.50	remaining

B. *Prolongation and Bracket Preparation*

Bracket preparation is carried out for experimental work. Total 8 Prolongation are used to make 16 trials and for that it is required to mask half portion of prolongation. To mask that portion bracket preparation is done having dimensions 200mm×200mm×100mm as shown in figure 1 A). dia. 16mm and dia. 13mm rods are taken out from bracket which will further used for locating of prolongation while experimental trails.

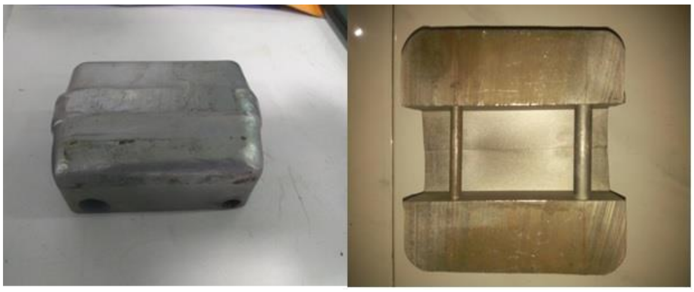

Figure 1: Shows A) Flaptrack Prolongation; B) Bracket

C. *Trail Setup*

Fig 2a-e shows the trial setup for the experimentation of grit blasting of the flaptrack prolongation and bracket component. This experiment consists of air receiver tank, air drier unit, hopper, and nozzle (L9 mm). For measuring alpha case hardness Clemex micro-hardness tester is used and Mitutoyo surface roughness tester is used for checking surface roughness of grit blasted surface.

Figure 2. a) Air receiver tank, b) Air Drier, c) Hoper Unit, d) Surface roughness testing and e) Clemex Microhardness tester.

D. *Experimental Parameters and levels*

Grit mix, grit flow rate, intensity, Grit blasting angle, grit velocity, distance between nozzle to work piece, coverage area, grit blasting pressure and exposure time are the input parameters. Since some parameters such as velocity, intensity, and coverage are difficult to control, controllable influential parameters such as grit mix selection, grit blasting angle, grit blasting angle and exposure time factors were considered in the present investigation. Pilot experiments are carried among GH050 and GH025 nominal size are in mm from which GH050 gives promising results to remove maximum material. Other controllable factors levels are determined from literature base. These shot peening parameters along with their levels are shown in Table 2.

Table 2 Grit blasting parameters and their levels

Process Parameter	Symbol	Level 1	Level 2	Level 3	Level 4
Nozzle Distance (mm)	**A**	300	350	400	450
Blasting Angle (Degree)	**B**	30	45	60	75
Blasting Time (Second)	**C**	60	90	120	150
Blasting Pressure (Bar)	**D**	4.5	5.0	5.5	6

III. DESIGN OF EXPERIMENT AND TAHUCHI METHOD

The Taguchi method is an optimization technique which is widely used in engineering analysis. This method reduces the no. of experimental runs and cost associates with it. The Taguchi method uses a loss function to calculate the deviation between the experimental values and the desired values. The design of experiment (DOE) was based on Taguchi design considering four factors each at four levels. In the present analysis total number of runs = L_{16} have been taken. The experimental results for alpha case depth (ACD) and surface roughness (Ra) are depicted in Table 3 for 16 runs. Both alpha case depth is measured on transverse section of mounting and surface roughness were measured at surface of grit blasted prolongation of flaptrack as shown in Fig. 1 B).

The effective use of Taguchi's Orthogonal Array Approach for predicting the effects of individual process parameters on thickness of deposited layer in powder coating process. An orthogonal array approach and the signal to noise ratio have been used to understand the factor effects in powder coating of EN8 Steel Shaft. Experimental results are also provided to confirm the effectiveness of this approach [4].

The body component traceability throughout the manufacturing process has the potential to change the way we approach the quality assurance and control issue. Thus, there is huge scope for data collection and analysis. This will assist to achieve the extremely ambitious goal of Zero Defect i. e. the title of World Class Manufacturer[5].

Table 3 Taguchi L16 factorial design and Experimental Observation

Sr.	Nozzle Distance mm	Blasting Angle Degree	Blasting Time Second	Blasting Pressure Bar	ACR (HV)	Ra (µm)
1	300	30	60	4.5	1	6.470
2	300	45	90	5.0	8	8.288
.3	300	60	120	5.5	6	5.816
4	300	75	150	6.0	11	6.659
5	350	30	90	5.5	18	5.505
6	350	45	60	6.0	4	7.586
7	350	60	150	4.5	19	5.877
8	350	75	120	5.0	26	7.654
9	400	30	120	6.0	24	4.629
10	400	45	150	5.5	16	6.794
11	400	60	60	5.0	9	4.536
12	400	75	90	4.5	19	6.285
13	450	30	150	5.0	17	3.674
14	450	45	120	4.5	3	7.245
15	450	60	90	6.0	18	6.333
16	450	75	60	5.5	31	7.461

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A. S/N RAITO ANALYSIS

The analysis of variance is done to investigate which of the following process parameters has more influence on response value. ANOVA table can be generated from Minitab software or manual calculations. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error [5]. The overall mean of S/N ratios can be calculated using the equations 1-3.

Lower the best type (LB) $\frac{S}{N} = -10log\frac{1}{n}\sum_1^n y_i^2$......(1)

Higher the better type (HB) $\frac{S}{N} = -10log\sum_1^n \frac{1}{y_i^2}$........(2)

Nominal the better type (NB) $\frac{S}{N} = -10log\sum_1^n \frac{\bar{y}^2}{y_i^2}$ ....(3)

In the Taguchi method the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the standard deviation. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. Loss function obtained from Taguchi analysis is further converted into a signal–noise (S/N) ratio[3]. Generally, there are three kinds of quality characteristics in the analysis of the S/N ratio, such as the higher the- better, lower-the-better and the nominal-the-best. [6].

The objective of this project is to reduce alpha case depth and surface roughness. Therefore, smaller the better characteristic is used shown in equation. Table 4 shows the experimental results for alpha case depth and the corresponding *S/N* Ratios using the equations mentioned above. The response table and *S/N* response graph for alpha case depth are shown below. Regardless of the lower-the-better or the higher-the-better quality characteristic, the greater the *S/N* ratio corresponds to the smaller variance of the output characteristic around the desired value[5].

The manufacturing, assembly process and powder coating process. There was a problem during assembly of parts of Manual Squeezer. By conducting experiments as per Taguchi's Orthogonal array, following results have been obtained after the Statistical analysis using descriptive method. The study showed influencing parameter in powder coating process is the spraying voltage. Because it shows large variation in response value if its level is changed from 1 to 2. One can say that as Voltage increases, the thickness of deposited layer increases. Also its has no effect on outcome even if its level is changed from 1 to 2. The bake time and Curing Medium showed less variation when their levels are changed from 1 to 2. The Amount of layer deposited on smooth part is less in comparison with that of Rough part if all other parameter settings remain unchanged [8].

The DOE trials conducted using Taguchi OA‟s L4 (2^3) experimental setup suggests optimum Laser engraving DMC parameters is 8x8 mm2 (DMC Size) and 3 Laser passes. The DMC code engraved by Laser has performed successful scanning within required time constraint in the various manufacturing environment. So, it implements for the mass production applications [9].

Table 4 Response Table for S/N Ratios

Level	A, [D(mm)]	B, [A(degree)]	C, [T(sec.)]	D, [P(bar)]
1	-13.61	-17.20	-13.66	-15.17
2	-21.25	-15.93	-23.46	-21.01
3	-21.96	-21.33	-16.62	-22.07
4	-20.69	-23.05	-23.77	-19.26
Delta	8.34	7.12	10.11	6.90
Rank	**2**	**3**	**1**	**4**

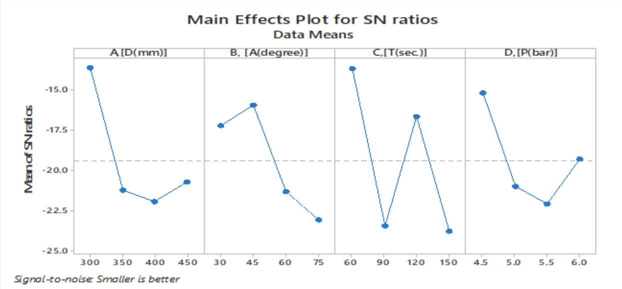
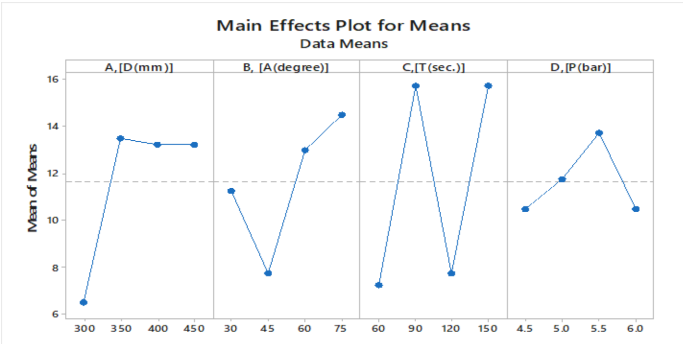


Fig. 3. Main effects ploy for S/N ratios

Table 5 Response Table For Means

Level	Nozzle distance	Blasting angle	Blasting time	Blasting pressure
1	6.500	11.250	7.250	10.500
2	13.500	7.750	15.750	11.750
3	13.250	13.000	7.750	13.750
4	13.250	14.500	15.750	10.500
Delta	7.000	6.750	8.500	3.250
Rank	**2**	**3**	**1**	**4**



Fog. 4. Main Effects plot for Means

B. ANALYSIS OF VARIANCE

ANOVA is a statistical method which is used to determine the interaction of individual for all the control factors in the test design. ANOVA is performed by using statistical software MINITAB 14 to determine the significant process parameter. It helps in predicting the best combination of process parameters for optimal performance characteristics.[4] In this study, ANOVA was used to analyze the effects of grit blasting distance, grit blasting time, grit blasting angle and grit blasting pressure on alpha case removal and surface roughness. This analysis was carried out a 5% significance level and a 95% confidence level. The

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significance of control factors in ANOVA is determined by comparing the F value of each control factor.

The last column of the Table 6 shows the percentage value of each parameter contribution which indicates the degree of influence on the process performance. According to Table 6, the percent contributions of the A, B, C and D factors on the surface roughness were found to be 25.23%, 18.22%, 49.08% and 5.08% respectively. Thus, the most important factor affecting the parameter on alpha case removal was blasting time (Factor C, 49.08%).

Table 6 Results of ANOVA for alpha case depth

Process param eter	Degree of free Dom DOF	Sum of squares (SS)	Mean square (MS)	F ratio	Contribution Rate (%)
ACD					
A	3	140.25	46.750	10.58	25.23
B	3	101.25	33.750	7.64	18.22
C	3	**272.75**	**90.917**	**20.58**	**49.08**
D	3	28.25	9.417	2.13	5.08
ERROR	3	13.25	4.417	-	2.39
TOTAL	15	555.75	-	-	100

IV. CONCLUSION

Grit Blast cleaning with abrasive media removes old coatings, rust, and other unwanted material from a surface, and creates an anchor pattern to allow new coatings to adhere better. Manufacturers who turn to grit blast cleaning as an environmentally responsible alternative to chemical stripping processes often realize substantial cost savings as well. Experimental work of removal of alpha case using grit blasting parameters based on Taguchi analysis has shown following important findings.

Taguchi's robust orthogonal array design method is suitable to analyze the alpha case depth problem. The parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameters. Further S/N ratio analysis for alpha case depth predicts the optimum parameter combination for grit blasting parameters as level 3 for nozzle distance, level 1 of blasting angle, blasting pressure at level 4 and for blasting pressure at level 2 give maximum value of S/N ratio. Thus, ANOVA for data means of grit blasting with L16 DOE shows that alpha case depth is most significantly affected by the blasting time is the most affecting factor on the alpha case depth with 49.08% followed by nozzle distance, blasting angle and blasting pressure with 25.23%, 18.22% and 5.08%contribution respectively.

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