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Experimental Data Based Model for Aluminum alloy (6351)Operation with Spherical Surface Burnishing Tool using Dimensional Analysis

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ABSTRACT

The paper deals with the effect of burnishing process on the Aluminum Alloy material 6351(HE 15) using Lathe. Surface roughness generated after the turning operation was used to ball burnishing. The surface roughness pattern which was further used to simulate ball burnishing process using ANN. Inherent irregularities and surface defects like tool marks and surface roughness are developed after conventional machining processes like turning and milling. These irregularities causes friction and surface damage which leads to low product life, poor metallurgical properties and overall poor product quality. Burnishing process is applied for better surface finish on the post machined components due to its chip-less and relatively simple operations.

Keywords: Burnishing, Surface Roughness, dimensional analysis, Buckingham's π theorem, Mini-max Principle, Sensitivity Analysis

I.INTRODUCTION

Inherent irregularities and surface defects like tool marks and surface roughness are developed on the work piece surface after conventional machining processes like turning and milling. These irregularities causes friction and surface damage which leads to low product life, poor metallurgical properties and overall poor product quality.These processes essentially depend on chip removal to attain the desired surface finish and also, skill and the experience of the operator in handling the process. To resolve these problems, burnishing process is applied for better surface finish on the post machined components due to its chip-less and relatively simple operations. A ball burnishing tool consists one or more over-sized balls that are pushed through a hole. Burnishing is a cold working surface finishing process which is carried out on material surfaces to induce compressive residual stresses and enhance surface qualities. The improvements in surface qualities include reduction in surface roughness, increase in surface hardness, improvement in grain size, wear-resistance, fatigue resistance and corrosion resistance. A burnishing tool typically consists of a hardened sphere which is pressed onto/across the part being processed which results in plastic deformation of asperities into valleys.

Mohammadpour et al. (2010) developed a two-dimensional finite element model for orthogonal cutting of AISI 1045 mild steel, and a numerical solution using the FEM. It investigated the effect of cutting speed and feed rate on residual stresses induced after orthogonal cutting. The stress distribution was found to be increasing with respect to cutting speed and feed rate when the experimental and simulation results were compared.

El-Tayeb et al. (2007) investigated the burnishing process on aluminum 6061 with interchangeable adapter for both roller and ball burnishing process. The effect of different burnishing parameters like burnishing speed, burnishing force and burnishing tool dimension on the surface qualities and properties were investigated. D. M. Mate, et al. (2011) studied the plastic deformation of structural RB40 steel when ball and roller burnishing were performed. It also investigated the roughness, hardness and wear resistance on RB40 steel. The above literature review shows the immense scope of development required in the surface characteristics developed by the ball burnishing process. The reason behind this is because of the non-linear characteristic generated on the surface of the workpiece after burnishing process. By carefully modeling the ball burnishing process the prediction of surface characteristic is possible which can be an answer for the time consuming and experimental dependent optimization techniques.

Hence, it was decided to design and fabricate the machine [2-9], which would upgrade the disadvantages offered by the present processing machines[2],[4][7]. The machine was fabricated and tested (shown in fig.1) for all successful test runs and found with good results

Fig 1: Fabricated Burnishing Tool using Lathe Machine

II. EXPERIMENTAL PROCEDURES

Ball Burnishing tools shown in fig.: 1 is utilized for burnishing. The process of formulation of mathematical model for aluminum alloy operation and its analysis is mentioned this paper. For experimentation purpose work piece samples of same sizes were collected. In processing, the objective of the experiment is used to gather information through experimentation for formulation of mathematical model for aluminum alloy material operation. During processing operations for the measurement force is measured using specially designed force tool dynamometer electronic kit. Energy and time is measured using energy meter and stopwatch respectively. Pilot experiments were performed to select test envelope and test points of process parameters for experimental design. These process parameters were used in experimental design for the investigation of process parameters like processing Energy, surface roughness and time during operation. In operation all twelve selected independent process parameters were manipulated on processing machine and observations were taken out at a speed of 340 rpm, 560 rpm and 800 rpm.

III. DESIGN OF EXPERIMENTS

In this study, 70 experiments were designed on the basis of sequential classical experimental design technique [7] that has been generally proposed for engineering applications. The basic classical plan [2] consists of holding all but one of the independent variables constant and changing this one variable over its range. The main objective of the experiments consists of studying the relationship between 9 independent process parameters with the Ra, E and t dependent responses for Internal knot removal. Simultaneous changing of all 9 independent parameters was cumbersome and confusing. A combination of the levels of parameters, which lead to maximum, minimum and optimum response, can also be located through this approach. Regression equation models of burnishing were optimized by mini-max principle.

3.1 Formulation of Approximate Generalized Experimental Data Base Model by Dimensional Analysis:

As per dimensional analysis [02], Processing Energy (E) was written in the function form as:-E=f (H_B, H_w, A_W, ω_B, f, F_B, D_B, N, μ, **g**)……… (Equ.1) By selecting Mass (M), Length (L) and Time (θ) as the basic dimensions, the basic dimensions of the forgoing quantities were mentioned in table 1: According to the Buckingham's - theorem, (n- m) number of dimensionless groups [21] are forms. In this case n is 9 and m=3, so π_1 to π_{11}dimensionless groups were formed. By choosing 'F_B', 'g' and 'ω_B' as a repeating variable, eleven π terms were developed as follows:

$$\left(\frac{E\,.\omega_B^2}{F_B.g}\right) = f\,x\left\{\left(\frac{H_W}{H_B}\right)\left(\frac{A_W\,.\omega_B^4}{g^2}\right)\left(\frac{f.\,\omega_B}{g}\right)\left(\frac{D_B.\,\omega_B^2}{g}\right)\left(\frac{\mu.\,g^2}{\omega_B^3.\,F_B}\right)\right\} \quad (1)$$

$$E_{01} = K.\left(\frac{F_B\,.g}{\omega_B}\right)\left\{\left(\frac{H_W}{H_B}\right)\left(\frac{A_W\,.\omega_B^4}{g^2}\right)\left(\frac{f.\,\omega_B}{g}\right)\left(\frac{D_B.\omega_B^2}{g}\right)\left(\frac{\mu.\,g^2}{\omega_B^3.F_B}\right)\right\} \quad (2)$$

3.2 Reduction of independent variables/dimensional analysis:

When n (no. of variables) is large, even by applying Buckingham's π theorem number of π terms will not be reduced significantly than number of all independent variables. Thus, much reduction in number of variables is not achieved. It is evident that, if we take the product of the π terms it will also be dimensionless number and hence a π term. Thus few π terms are formed by logically taking the product of few other π terms and final mathematical equations are given below:

Π_{0Ra1}= Mathematical Equation for Processing Surface Roughness (R_{a1}):

$$\pi_{0Ra1} = 1.84X10^{-4}.\left(\frac{g}{\omega_B^2}\right)\left\{\left(\frac{H_W}{H_B}\right)^{-3.22}\left(\frac{A_{W}.\omega_B^4}{g^2}\right)^{1.24}\left(\frac{f.\omega_B}{g}\right)^{-0.0031}\left(\frac{D_B.\omega_B^2}{g}\right)^{-1.18}\left(\frac{\mu.g^2}{\omega_B^3.F_B}\right)^{0.28}\right\} \quad (3)$$

The relationship between various parameters was unknown. The dependent parameter Π_{0Ra1}, i.e. relating to R_a were bear an intricate relationship with remaining terms (i.e. π_1 to π_5) evaluated on the basis of experimentation. The true relationship is difficult to obtain. The possible relation may be linear, log linear, polynomial with n degrees, linear with products of independent π_i terms. In this manner any complicated relationship can be evaluated and further investigated for error. This linear relationship now can be viewed as the hyper plane in seven dimensional spaces.

3.2 Model Formulation:

It is necessary to correlate quantitatively various independent and dependent terms involved in this very complex phenomenon. The mathematical model for internal knot removal operation is shown below:

Π_{0Ra1}= Mathematical Equation for Processing Surface Roughness

R_{amin}=1.85X10^{-}04 x (4.847734) [$(0.220183)^{-3.2251}$x $(25.2303)^{1.2472}$x $(4.27x10^{-5})^{-0.0031}$x $(10.38207)^{-1.1813}$x $(2.289x10^{-9})^{0.2813}$] = 0.001596613 mm. (4)

IV. RELIABILITY OF MODEL

(Rs) $= 1 - \prod_{i=1}^{n}(R_i)$ and for the parallel system the reliability of system is calculated by relation: System Reliability (Rp) $= 1 - \prod_{i=1}^{n}(1 - R_i)$ Therefore reliability of the system for this case is given by System Reliability (Rp)= $1 - \prod_{i=1}^{n}(1 - R_i)$ =1-[(1-RRa)*(1-RiE)*(1-Rit)] since, observations were taken simultaneously during experimentation. Reliability of model is established using relation Reliability =100-% mean error and Mean error = where, xi is % error and fi is frequency of occurrence. Therefore total reliability of model for material is equal to 1-[(1-0.882857)(1-0.14286)(1-0.825)=0.982429= 98.2429% .

V.PROCESS PARAMETERS SELECTION BY MINI-MAX PRINCIPLE (ESTIMATION OF LIMITING VALUES OF RESPONSE VARIABLES)

From above mathematical models the obvious aim was to minimize the values of Ra, E, and t. The ultimate objective

of this work is not merely developing the models but to find out best set of variables, which will result in maximization/minimization of the response variables. In this section attempt is made to find out the limiting values
of three response variables viz. processing Surface Roughness, energy and time.

VI.OPTIMIZATION

Optimization of internal knot removal operation is to search an optimal solution for a given objectives satisfying the required constraints. The objective was to minimize Processing Torque, Energy and time with the constraints involved were bound values of π terms. This adds to the complexities of the problem. Linear programming is a strong tool to optimize where the objective function and the constraints are linear. Based on the computed results, LPP model was formulated.

VII. SENSITIVITY ANALYSIS

The average values of the change in the dependent π term due to the introduced change of ± 10 % in each independent π term. This is defined as sensitivity.

VIII.CONCLUSIONS

1. The dimensionless π terms have provided the idea about combined effect of process parameters in that π terms. A simple change in one process parameter in the group helps the manufacturer to maintain the required E, R_a and t values so that the productivity is increased.
2. The mathematical models developed with dimensional analysis for material HE15 can be effectively utilized for aluminum alloy processing operations.

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