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MONTE CARLO SIMULATION TO PREDICT FATIGUE LIMIT OF BRASS SPECIMENS

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ABSTRACT: A theoretical model has been proposed to find the fatigue limit of brass specimen on the basis of the fracture mechanics and the physically meaningful concept of fatigue. The effect of residual stresses induced due to burnishing on the fatigue limit of brass was also simulated using a computer program. The Monte Carlo simulation is performed and the simulated data is compared with experimental data.

Keywords: Fatigue, Burnished & Unburnished Brass Specimen, Residual Stress

1. INTRODUCTION

The task of predicting the fatigue limit theoretically is difficult and troublesome, however the non-availability of the reliable fatigue limit data and the amount of expenses that are involved in providing experimental data make the fatigue limit model an imperative means of prediction of fatigue limit. In this research work owing to the complexity of fatigue limit of different materials the physically meaningful concept of fatigue under cyclic loading conditions has been adopted to simulate the fatigue limit of the brass s pecimen both in burnished and unburnished conditions. The theoretical model is proposed to simulate the fatigue limit of any material taking into consideration the physical parameters such as the initial & final crack length, fracture toughness, final crack length maximum tensile strength, minimum tensile strength, residual stresses, etc. The main feature of this work is that an attempt has been made to incorporate the effect of variability of various factors involved such as initial crack length, flow stresses. which contribute to the probabilistic nature of the fatigue limit of any material loaded under dynamic conditions.

Monte Carlo simulation, a simple procedure of generating random numbers Z (I) is adopted through a computer sub program. These random numbers are transferred to the required statistical distribution by making appropriate statistical fits to the reliability model. The simulated fatigue limit of brass is compared with the experimental data both for burnished and unburnished conditions of specimen.

2. THEORETICAL MODEL

The simulation of the fatigue limit for any material by using computer program involves the following steps:

- Developing the theoretical model by applying the fracture mecha nics approach to fatigue analysis.
- Collection of available information regarding mechanical properties used in the model.
- Collection of parametric constants of the fracture mechanics based model.
- Calculation of the fatigue limit of the brass materials using computer simulation under burnished and unburnished conditions.
- Finally the utilization of this predicting the fatigue limit of different materials.

The stress under consideration for fatigue analysis is assumed to be reversed stress type.

3. BURNISHING

Burning is a cold working process where in a highly polished roller is pressed against a metallic surface of flat of cylindrical component. To improve the surface finish and impart some residual strength to the material the ball or roller is fed in appropriate direction on the component surface. When the burnishing pressure exceeds the yield strength of the component material, localized plastic deformation at the surface takes place. This action leads to the spreading out of the surface peaks and filling of the valleys, leading to an improvement in surface roughness. Due to localized plastic deformation by burnishing a residual stress at the surface of the component is introduced which along with the improvement in surface roughness acts as most effective factor in improving the fatigue life of burnished components. The burnishing parameter considered is the burnishing force.

3. EXPERIMENTAL PROCEDURE

The chemical composition and mechanical properties of the brass specimen used in this investigation are as follows:

Chemical composition	Content	Al	Fe	Si	Zn	Sn	Pb	Ni	Cu
	%Wt	0.11	0.24	0.07	37.38	0.83	1.9	0.1	Remainder
Mechanical properties									
Ultimate tensile strength, MPa	425								
Vicker's hardness, Kgf/mm^2	158								
Shear strength, MPa	310								
Modulus of elasticity, MPa	103000								
Fracture toughness, MPa √M	120								

The chemical composition of the burnishing ball is as follows:

Si	Mn	Cr	Ni	C	S	Fe
0.23	0.29	0.25	1.44	0.95	0.006	Remainder

On account of burnishing a residual stress is subtracted from the maximum stress value at which the experiment has been performed. Therefore the net stress value is considered as $\delta_{net} = \delta_{max} - \delta_{res.}$ The compressive residual stress value is determined by "Hole drilling strain gauge technique" This semi destructive technique determines the stress at the surface of a sample through the incremental introduction of a small hole which relaxes the stress in that location. Initially a strain gauge rosette is attached to the surface of the sample and a precision stress free hole is drilled into the centre of the strain gauge rosette after each depth increment and the biaxial stress field is calculated using established equations.

4. RESULTS AND DISCUSSION

4.1 Effect of the Burnishing Forces

The intrusion of the burnishing ball into the metallic surface of the specimen would cause the peaks of the surface to spread over and subsequently would fill the valleys. This action would lead to an improvement in surface finish. The continuous increase in burnishing force might cause a continuous improvement in the surface finish and also the amount of plastic deformation until critical value was reached, beyond which plastic deformation would lead to micro-cracking on account of excessive work hardening of the metallic surface. The Estimation of fatigue limit of an Unburnished Brass specimen is as follows:

$$a_f = k_{ic} / \pi. \delta. \alpha \qquad \dots(1)$$
$$N_f = (a_i^{(-p/2 + 1)} – a_f^{(-p/2 + 1)}) / (-p/2 + 1). C. \alpha^P. \delta^p. \pi^{p/2} \qquad \dots(2)$$

Where N_f = fatigue limit.

4.2 Monte Carlo Simulation

In this computer simulation the fixed initial crack length was predetermined from a sample of normally distributed initial crack lengths, each length a_I was then compared with the critical crack a_f. Once the initial crack length was reached the critical crack length, the specimen was considered to have failed. This was repeated a number of times. The life of the brass specimen was estimated under the same nominal and process conditions.

Statistical distributions for random variables involved in the fatigue limit model were predetermined each time a simulation was performed. The tolerance limits of process variables are set busing a relation:

$$X (XI) = \mu (XI) + \delta (XI). Z(I) \qquad \dots(3)$$

Where μ & δ are mean and standard deviation of the variables, and Z(I) are the normally distributed random numbers which were generated using computer subroutines.

The fatigue limits of brass specimen under unburnished and burnished conditions are given in Table-1 and-2. The same kind of trend is observed in both unburnished and burnished materials. The theoretical and experimental results are comparable for unburnished brass material; whereas there is a remarkable difference in the experimental and theoretical results of burnished brass material. The data used for the simulation was taken from very few experiments. It is therefore necessary to add large data for the simulation and to remodel the relation for tolerance limits of the process variables.

Table 1: For Unburnished brass material.

S. No.	Stress (Mpa)	N_f (cycles) Experiment	N_f (cycles) theoretical
1	160	2.1 x 10^6	2.3 x 10^6
2	175	1.8 x 10^6	1.9 x 10^6
3	225	1.1 x 10^6	1.0 x 10^6
4	230	1.0 x 10^6	0.9 x 10^6
5	285	0.1 x 10^6	0.5 x 10^6

Table 2: For Burnished brass material.

S. No.	Stress (Mpa)	N_f (cycles) Experiment	N_f (cycles) theoretical
1	325	0.1 x 10^6	0.3 x 10^6
2	310	0.2 x 10^6	0.4 x 10^6
3	290	0.5 x 10^6	0.5 x 10^6
4	265	1.4 x 10^6	0.6 x 10^6
5	250	2.2 x 10^6	1.0 x 10^6
6	225	3.2 x 10^6	1.4 x 10^6

5. CONCLUSION

Theoretical model successfully estimated the fatigue limit of brass specimen under repeated loading. A comparison of fatigue limit of brass specimen under unburnished and burnished conditions has been made with experimental results. It is observed that the theoretical model simulated the fatigue limit both in burnished and unburnished conditions. The effect of residual stress induced during burnishing is also well introduced in the theoretical model.

Nomenclature:

$\delta_{res.}$	:	Residual stress due to burnishing
$\delta_{max.}$	:	Max. stress value
δ_{net}	:	Net Stress value
k_{ic}	:	Fracture toughness of the material
a_I	:	Initial crack length
a_f	:	Final crack length
α	:	Geometry factor
N_f	:	Fatigue limit of material
P	:	Hardening Strain exponent
C	:	Paris constant

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