Engineering Journal of Qatar University, Vol. 3, 1990.

"INFLUENCE OF SURFACE FINISH ON FATIGUE LIFE OF STEEL SPECIMENS SUBJECTED TO PURE BENDING"

By

E.H. Roushdy and A.Y. Kandeil
Associate Professors
Faculty of Engineering, Qatar University
Doha, Qatar - Arabian Gulf

ABSTRACT

It has long been appreciated that surface conditions exert significant influence on fatigue behavior. The new capabilities of identifying and measuring surface parameters together with the significant development in data analysis by computers have facilitated the establishment of analytical models to quantify this influence. This paper displays the effect of surface Amplitude, Spacing and Hybrid parameters on the number of cycles to failure of standard steel specimens subjected to pure bending fatigue tests.

Specimens were polished to four different grades and surface texture was evaluated for each grade using a Rank Taylor Hobson-5 surface analyzer. High cycle fatigue (HCF) test were conducted at a constant stress level of (0.75) of the yield stress with (10) replications for each surface grade.

Results of the fatigue tests - together with all surface parameters and test conditions - were fed into an SPSS computer package. Fatigue life of the steel specimens was significantly affected by the change in surface parameters and the number of cycles to failure could be mathematically predicted - to a high level of confidence - from those parameters.

1. INTRODUCTION

It is well known that the surface texture characteristics of the material are important for the nucleation of fatigue cracks on the surface of cyclically loaded specimens. A very high proportion of all fatigue failures nucleate at the surface of the part, therefore the surface condition is an extremely important factor influencing fatigue strength. Irregular or rough surfaces generally exhibit inferior fatigue strength compared to smooth surfaces [1-3].

Extensive data on this topic has been published [2-4] however, very little attempt has been made to quantify the effects of surface parameters on fatigue life. The objective of this paper is to examine the effects of surface amplitude spacing and hybrid parameters on the number of cycles to failure of steel specimens subjected to pure bending fatigue tests.

2. EXPERIMENTAL PROCEDURE

a. Material: The material used in the present study was high carbon hot rolled steel. Tensile testing was performed on the steel material in order to determine it's tensile properties. A flat specimen 6 by 3 mm, with a gage length of 25 mm was used. The yield strength of the steel was 278 MPa and the ultimate tensile strength was 446 MPa.

b. Surface Preparation and Evaluation: Fatigue specimens were machined to standard dimensions for pure bending as shown in Figure (1). Steel sheets were milled close to the desired thickness and ground to final dimensions using a surface grinder. The surfaces of the specimens were polished using four different grit levels, namely # 2, 120, 600 and 3 μm. Polishing was perpendicular to the longitudinal direction of the specimens except for the fine polish (3 μm grit), where a rotating disc with alumina powder was used. Cooling water was used during polishing in order to avoid overheating of specimens.

   Amplitude, spacing and hybrid parameters of the polished specimens were measured and recorded using a Rank Taylor Hobson-5 Surface Analyzer [5]. Values of surface parameters for the prepared specimens are displayed in Table (1).

c. Fatigue Tests: Tests were carried out on an Avery Denison fatigue test machine model (1305). The machine is designed to apply reverse loads with or without initial static load. Reverse loads were applied by an oscillating

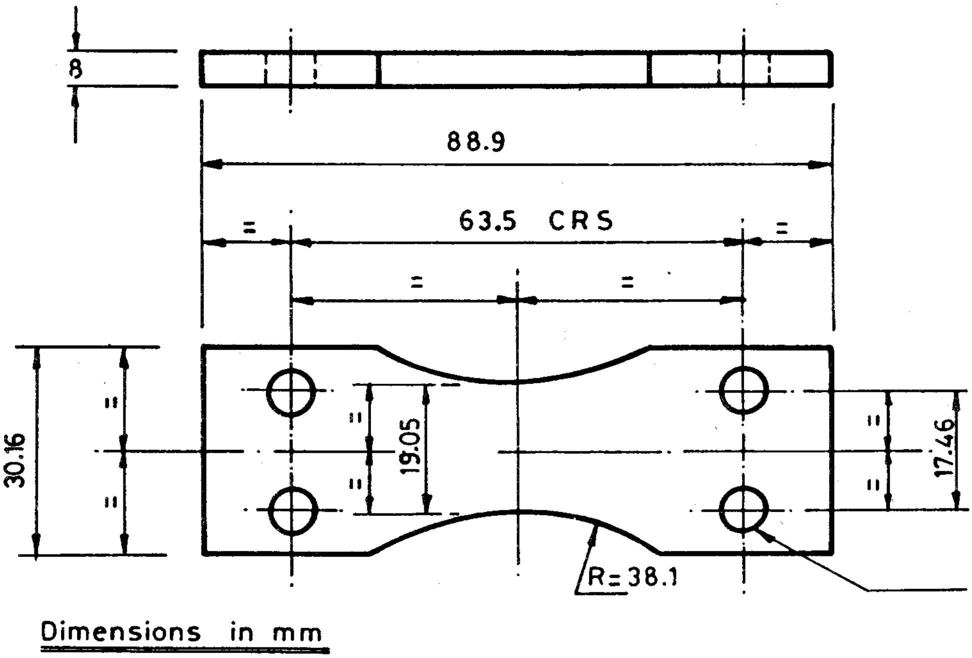

Figure 1: Schematic Fatigue Test Specimen for Pure Bending.

spindle driven by means of a connecting rod and double eccentric at a loading frequency of 1420 cycle/minute. The eccentric is adjustable to give the necessary range of bending angle. The load is measured at the opposite end of the specimen by means of torsion dynamometer. Initial static loads can be applied by rotating the dynamometer housing in its bearings by means of a pair of adjusting screws [6]. The specimens were subjected to pure bending causing skin stress of 208 MPa (0.75 σy). A revolution counter is fitted to the motor to record the number of stress cycles to failure. The number of cycles to failure of the four grades are shown in Table (2).

Table 1: Results of Surface Finish Parameters.

Surface Finish / Surface Parameters	3μm	600 Grit	120 Grit	#2 Grit
HSC	2	2	13	34
SM	500 μm	431 μm	87.54 μm	35.99 μm
LQ	34.93 μm	18.99 μm	35.4 μm	29.22 μm
DQ	0.007	0.023	0.062	0.171
RMAX	0.274 μm	0.353 μm	3.242 μm	9.214 μm
R3Tm	0.082 μm	0.227 μm	0.574 μm	1.572 μm
RTM	0.169 μm	0.313 μm	1.604 μm	4.422 μm
RP	0.137 μm	0.196 μm	0.860 μm	4.402 μm
RT	0.274 μm	0.391 μm	3.297 μm	9.213 μm
RSK	0.686	0.883	-2.714	-0.301
RQ	0.041 μm	0.068 μm	0.352 μm	0.793 μm
RA	0.029 μm	0.052 μm	0.208 μm	0.529 μm

3. ANALYSIS OF RESULTS

3.1. Metallographic Observations

Optical micrographs of the surface topography of test specimens with various surface finishes are shown in Figure (2). Variations in the surface roughness are evident. Typical fatigue cracks observed in tested specimens are shown in Figure (3). It can be observed that the cracks in the fine specimens are parallel to the lay with one crack origin, Figure (3)(a) and (b). In the rough specimens, however, the cracks initiated from two origins at the sides of the specimen then propagated towards the centerline where they overlapped and created a "ratchet mark" as shown in Figure (3)(c) and (d). An enlarged section of the rachet mark is shown in Figure (4). It is also noticeable that the cracks are almost at the center of the specimens where the cross-sectional area is minimum and the stress is maximum. In a few cases however, cracks were displaced from the center as a result of the presence of a material defect or a scratch or a small notch.

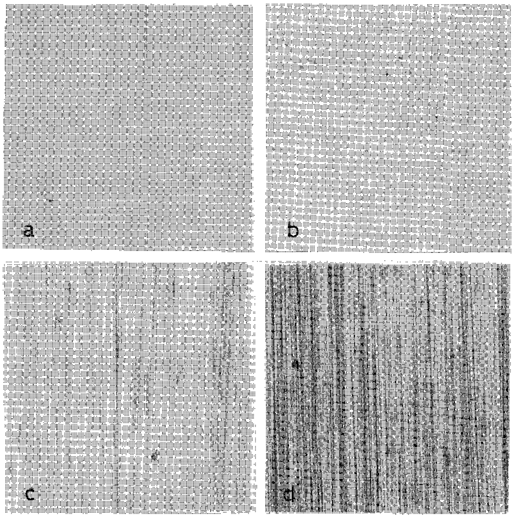

Figure 2: Optical Micrographs of Different Surface Finish of Test Specimens. (a) 3μm (b) 600 Grit (c) 120 Grit (d) #2 Grit

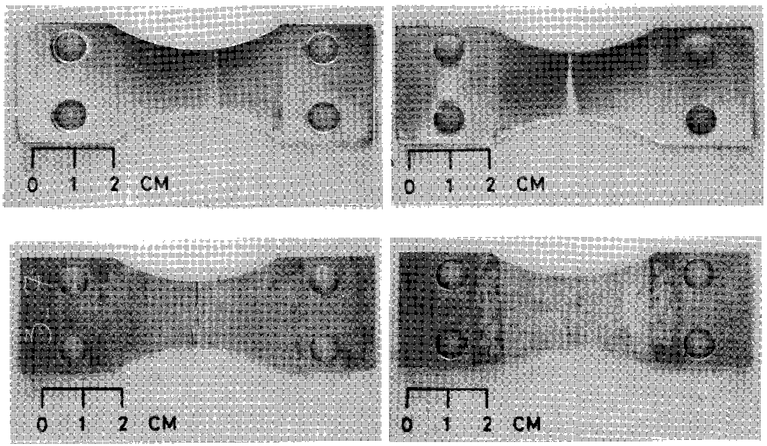

Figure 3: Typical Fatigue Cracks.

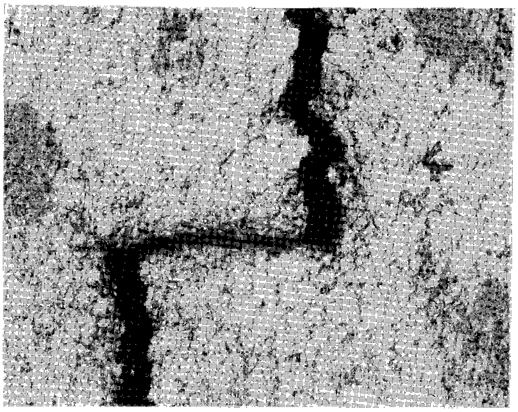

Figure 4: Enlarged Section of a Ratchet Mark.

Initially, fatigue cracks form due to a slip mechanism [7]. This portion of the fatigue crack (Stage 1) is crystallographically orientated along the slip plane and may take place at a microstructural imperfection such as second phase particles, shrinkage cavities, gas cavities or local scratches. The existing flaws act as stress concentrators and assist crack initiation. Eventually, the crack plane becomes macroscopically evident and crack propagates perpendicular to the direction of maximum stress as shown in Figure (5). These two stages of fatigue crack growth are shown schematically in Figure (6) and cracking is assumed transgrannular in both stages.

Figure 5: Crack Initiation at 45° to the Surface (Grit 600 and 500x).

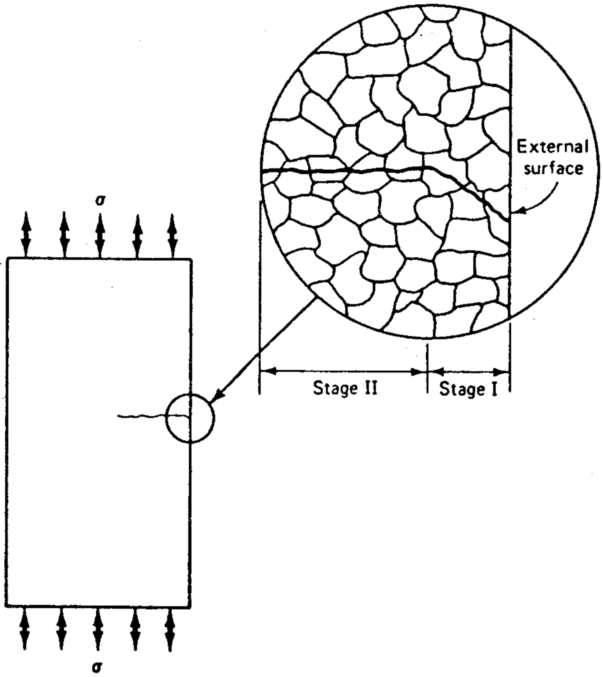

Figure 6: Schematical fatigue Crack Showing the Two Stages of Crack Initiation and Propagation.

3.2. Quantitative Analysis

Fatigue test results given in Table (2) indicate a noticeable increase in fatigue life with the improvement of surface quality as shown in Figure (7). To evaluate this relationship quantitatively, the value of "the number of cycles to failure" and the corresponding surface parameter values were fed into an SPSS statistical computer package. Multiple linear regression analysis were conducted on the data and the following equations were obtained:

Table 2: Fatigue Test Results

Specimen No. Surface Finish	1	2	3	4	5	6	7	8	9	10	X	R
3 μ	569	341	741	767	170	244	443	426	289	748	473	597
Grit 600	288	235	448	303	258	320	420	354	396	420	344	213
Grit 120	216	347	177	266	282	320	250	311	300	270	274	170
#2	218	230	162	164	222	175	182	169	158	238	192	80

Where: N x 1000, $\overline{X}$ = mean, R = range.

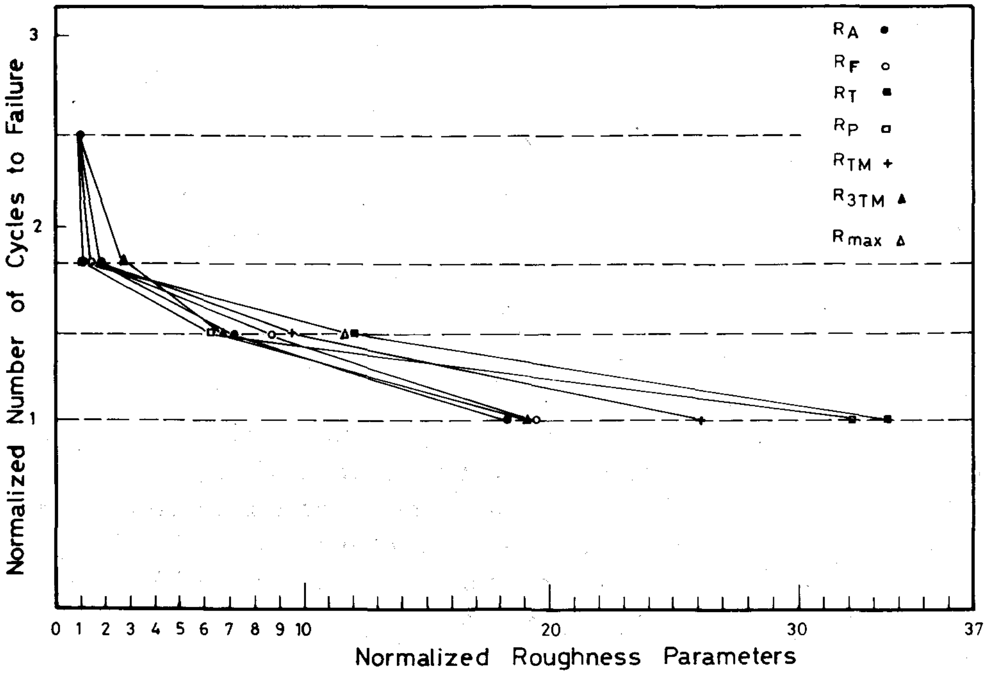

Figure 7: Normalized Fatigue Test Results Showing Effects of Surface Parameters on Fatigue Life.

1. When all parameters (Amplitude, Spacing and Hybrid) were fed, the following equation was obtained:

$$N = 5.211 * 10^{-4} * S_m + 6.288 * 10^{-3} * \lambda_q - 2.849 \quad (1)$$

2. When only Amplitude parameters were fed, the following equation was obtained:

$$N = -0.304 * R_q + 0.416 \quad (2)$$

3. When only Spacing parameters were fed, the following equation was obtained:

$$N = 4.664 * 10^{-4} * S_m + 0.198 \quad (3)$$

4. When only Hibrid parameters were fed, the following equation was obtained:

$$N = -1.429 * \Delta_q + 0.415 \quad (4)$$

4. CONCLUSIONS

1. The variability in fatigue life of steel members subjected to pure bending is significantly affected by the change of some Amplitude, Spacing and Hybrid parameters of the member's surface finish.

2. Fatigue life of flat steel specimens - measured in the number of cycles to failure - subjected to pure bending could be mathematically predicted to a high level of confidence from: Amplitude, Spacing or Hybrid parameters of the specimen's surface texture.

5. RECOMMENDATIONS

1. During the design and manufacturing stages, attention should be payed to the values of selected surface parameters to avoid fatigue failure.

2. Root Mean Square (RMS) value of the roughness (R_q) should be the decisive factor in classifying surface roughness in members subjected to fatigue loading. The arithmetic mean value of the roughness (R_A) is less sensitive to the values of very low valleys and high peaks of the surface which is believed to have a significant effect on crack initiation that leads to failure.

LIST OF SYMBOLS

HCF : High Cycle Fatigue
N : Number of Cycles to Failure
HSC : High Spot Count
R_a : Roughness Average
RMS : Root Mean Square
R_q : RMS Roughness
S_m : Mean Spacing of Profile Peak
$\triangle Q$: RMS Slope
λ Q : RMS Wave Length
n : Number of Specimen in each Grit = 10
σy : Yield Strength
SPPS : Statistical Computer Package
$\bar{x}$: Mean of 10 Readings
R : Range

REFERENCES

1. **Thomas, W.N.**, "Effect of Scratches and Various Workshop Finishes Upon the Fatigue Strength of Steel", Engineering, 116 (1923), 449 ff.

2. **Fluck, P.G.**, American Society for Testing Materials Proceedings, Vol. 51, pp. 584-592, (1951).

3. **Hooker, R.N.**, "Surface Finish vs. Fatigue Life for 72S-T6 Spar Cap Material", Tech Note Dev - 950, Douglas Aircraft Co., Long Beach, California, U.S.A.

4. **Siebel, E.** and **Gaier, M.**, VDIZ., Vol. 98, pp. 1715-1723, (1956). Abstracted in Engineers Digest, Vol. 18, pp. 109-112 (1957).

5. Manual for Surface Analyzer, Talysurf 5 System, Rank Taylor Hobson, Leicester, U.K.

6. Fatigue Testing Machine, Avery Type 7305, W and T. Avery Ltd., Birmingham, U.K.

7. **Thornton, P.A.** and **Colangelo, V.J.**, Fundamentals of Engineering Materials, Prentice-Hall Inc., New Jersey, U.S.A., (1985).