

# On the Surface Cracking and Crack Growth Due to the Oscilated Tangential Force without Macro Slip

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The occurrence of surface cracking in the contact field without any macro slip has been investigated. The effects of the static normal load and the range of alternating tangential force on the crack initiation and growth have been made clear. It was also shown that the stress field may be useful to estimate the total effects of the applied forces even on the surface cracking and growth.

## I. INTRODUCTION

It has become clear that the damage on the contact surface is much affected by the tangential force<sup>1)-4)</sup>. However, it seems that its influence over the wide range of contact conditions still remains indefinite quantitatively.

In this study, some experiments were performed under the various unlubricated contact conditions of a hard metal sphere against a hard metal flat subjected to the oscilated tangential force with several static normal loads. The occurrence of damage (especially cracking) on the surface in the contact field without any macro slip has been observed. The effects of the normal load and the range of oscilated tangential force on the occurrence of the surface cracking and its advance have been investigated. It was also found that these effects can be explained using stress field.

## II. EXPERIMENTAL

A rough sketch of testing machine is shown in Fig. 1. Specimens are set at A, where the upper one is in directly contact with the lower one. The lower specimen is a ball for bearing (SUJ2) and the upper is an end of cylindrical roller for bearing (SUJ2). Dimensions of the specimens are shown in Fig. 2. The specimens are subjected to static normal load  $P$  and reciprocated tangential force  $\pm T$ . The tangential force is generated by centrifugal force of unbalanced weight on the pair of rotating spur gear as shown in Fig. 1. The normal load  $P$  is determined using calibration curve of the relation between  $P$  and strain gauge output. The tangential force  $T$  is evaluated by the calculation of the centrifugal force.

All tests were carried out under the unlubricated condition without macro slip. The contact conditions in the experiments are shown in Table 1. At a proper interval of cycles, the upper specimen was taken out and crack initiation and/or growth was checked by micro scope. Crack length was measured on the photograph. Some of the specimens were re-loaded for the further experiments.

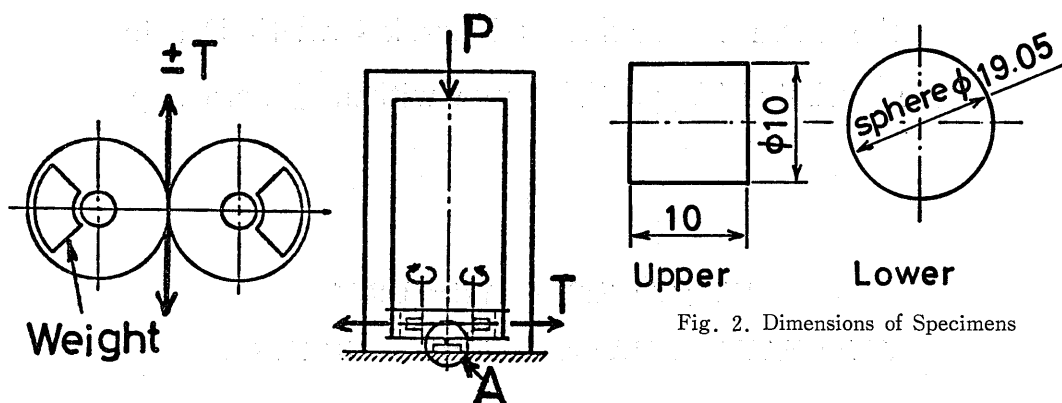


Fig. 1. Testing Machine

Table 1 Contact Conditions in the Experiments

Normal Load	Herz Pressure	Radius of Contact Circle
10 kN	6.48 GPa	0.858 mm
15	7.42	0.982
20	8.17	1.081
25	8.80	1.165
30	9.35	1.238

Range of Tangential Force
0.35 kN - 0.80 kN

### III. RESULTS AND DISCUSSIONS

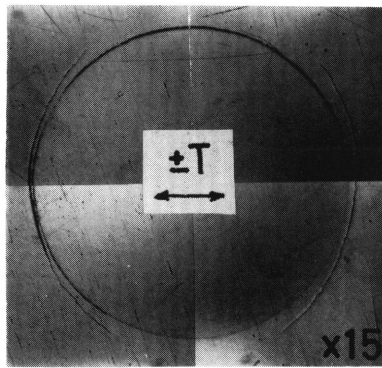
#### 1. Damage Appeared on the Contact Surface

The state of the contact surface after the tests are typically shown in Photo 1 (a)-(d). There exists an annular region extending to the edge of the contact area where fretting has arisen. A wide locked region in the central part of the circle also exists. This affords guarantee that no macro slip has been occurred. Crack has initiated at the intersection of the contact circle and a line through the center of the circle parallel to the tangential force on the surface. Crack begins to extend to the direction perpendicular to that of tangential force and grows drawing a locus of circular arc as shown in the Photos.

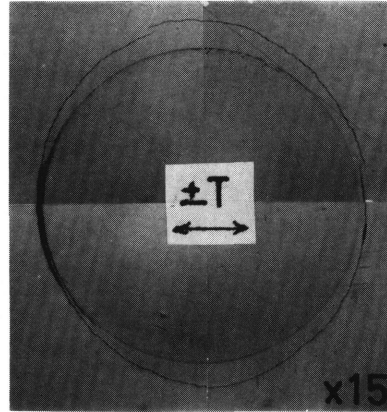
#### 2. On the Crack Initiation

Figure 3 (a), (b) shows the typical relation between the alternating tangential force range and loading cycles to crack initiation. It is recognized that the relation between the range of tangential force and cycles to the onset of crack is similar with the S-N curve in fatigue as already shown by Hirano and Goto<sup>1)</sup>. That is, the larger the tangential force range, the less is the cycles, and there is the endurance limit of the tangential force. However, if the normal load become increase, the line shifts to the left as the similar relation has been kept as shown in Fig. 4. In other words, the fatigue life to surface cracking is reduced by the increase of static normal load. It is indicated that stress distribution should be made clear in order to estimate the total effects of the normal load and the range of tangential force on the fatigue life.

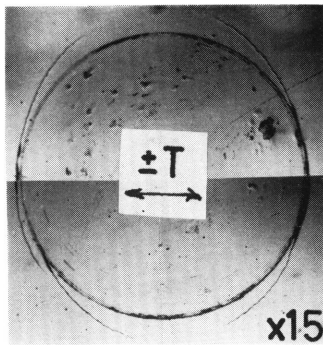
Hamilton and Goodman<sup>5)</sup> have already derived the stress field induced by the normal as well as by the



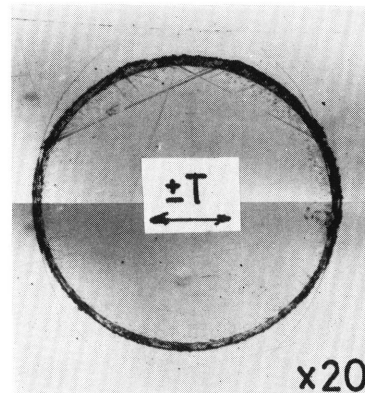
(a)  $P = 28.1 \text{ kN}$   
 $T = 0.62 \text{ kN}$   
 $2 \times 10^4 \text{ cycles}$



(b)  $P = 28.1 \text{ kN}$   
 $T = 0.62 \text{ kN}$   
 $10^5 \text{ cycles}$



(c)  $P = 17.6 \text{ kN}$   
 $T = 0.71 \text{ kN}$   
 $7 \times 10^4 \text{ cycles}$



(d)  $P = 8.36 \text{ kN}$   
 $T = 0.71 \text{ kN}$   
 $10^5 \text{ cycles}$

Photo 1 Surface Cracking and Propagation

tangential traction of Hertz-type. Since there exists the locked region in the actual contact, the distribution of tangential traction may be slightly different from Hertz-type which materialize in the case of sliding contact. Nevertheless, it seems that these solutions can be used as a first step to approximate the stress field of the present problem provided that the resultant of shear traction is the same.\*

Using stress field on the surface calculated from these solutions, the relations between the range of applied stress  $\Delta\sigma$  (maximum principal stress) and cycles to the onset of crack ( $N$ ) have been obtained as shown in Fig. 5. It should be emphasized that  $\Delta\sigma$ - $N$  relations are still dependent on the static normal load. This dependence, however, seems to be explained by mean stress. As a matter of fact, the applied stress is alternating as schematically described in Fig. 6 (a) under the present contact conditions, although tangential force is alternating as shown in Fig. 6 (b). This is because the normal load is rather large compared with the tangential force in order to prevent macro slip, consequently mean stress becomes high.

\*More suitable stress field to the present case (finite body) is being investigated by numerical method.

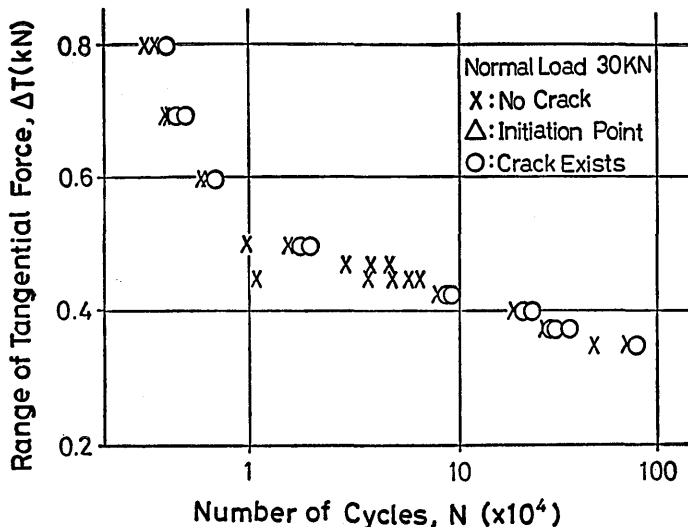


Fig. 3 (a)

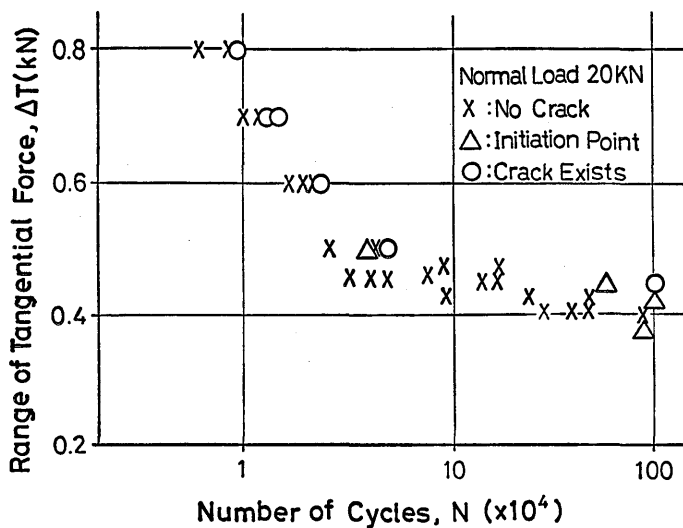


Fig. 3 (b)

Fig. 3 Number of Cycles to Crack Initiation

It can be suspected from these that the fatigue life has been much affected by the mean stress  $\sigma_m$  of alternating stress. The effects of the mean stress can be easily expressed by the endurance limit diagram. The limit diagram of the specific cycles was obtained as shown in Fig. 7 in the present cases. It is found that the diagram is similar with the one for non-contact fatigue.

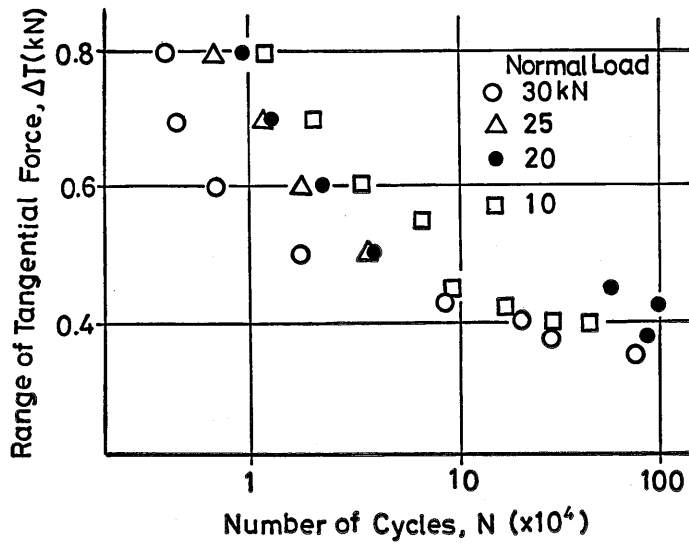


Fig. 4 Effect of the Normal Load on Cracking

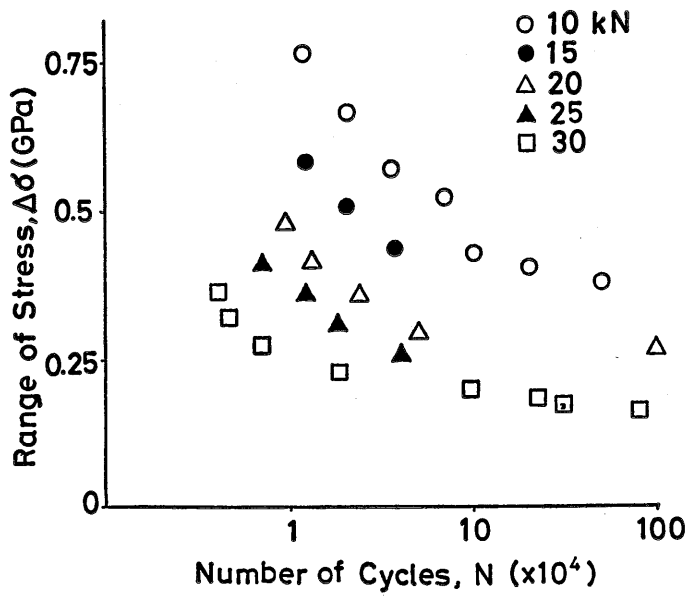


Fig. 5 Relations between the Range of Stress and Number of Cycles

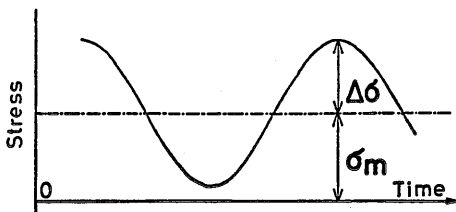


Fig. 6 (a) Cyclic Alternation of Applied Stress

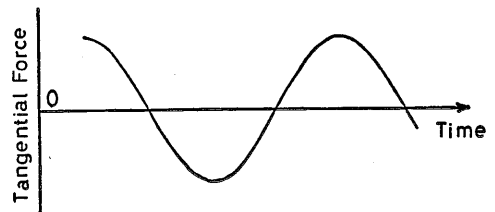


Fig. 6 (b) Cyclic Alternation of Applied Tangential Force

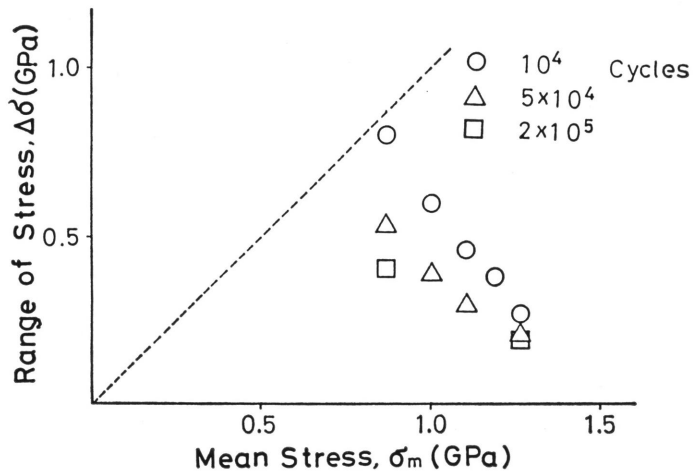


Fig. 7 Range of Stress–Mean Stress Relations for the Specific Cycles

### 3. On the Crack Propagation

As shown above, crack extends outer the contact circle. However, it was found that crack growth to the depth has almost not been recognized at  $10^5$  cycles despite that the growth on the surface has already saturated as shown in Photo 2. This indicates that crack propagates, in the beginning, along the shallow layer on and beneath the surface. Propagation of this shallow crack on the surface has also been investigated through an identical specimen. Figure 8 shows the typical relation between the amount of crack extension on the surface and number of cycles. In the early period after the crack started to grow, the crack length has increased so rapidly, but as the crack encircle the contact circle in the further several tens of thousands of cycles its increasing has saturated. Using the solutions of stress field mentioned above, it is found that the applied stress is higher near the initial cracking point than that of the side of contact circle. It is considered that the crack growth rate  $da/dN$  is also affected by the applied stress (range of the maximum principal stress).

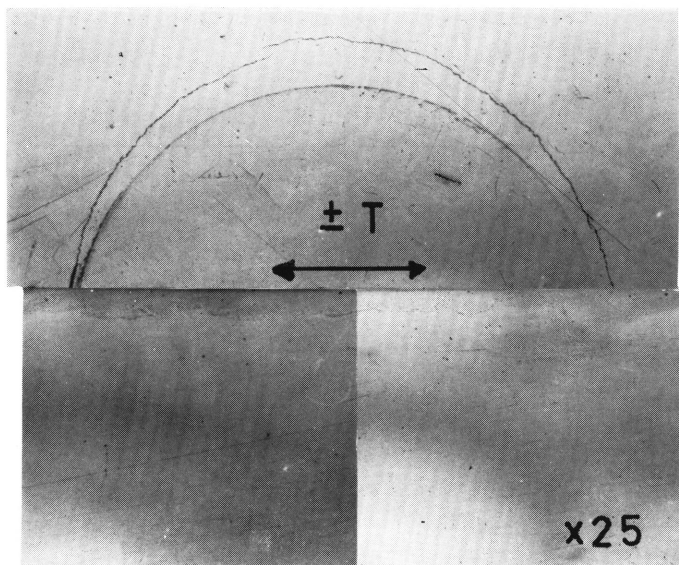


Photo 2 Crack Extension to the Depth  
( $P=28.1$  kN,  $T=0.62$  kN,  $10^5$  cycles)

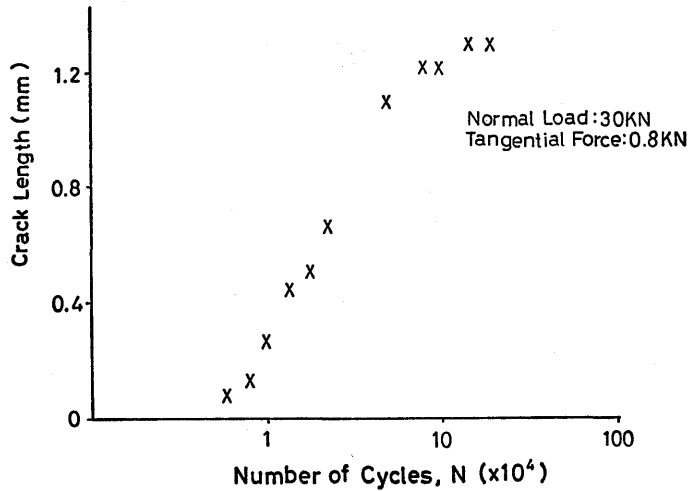


Fig. 8 Crack Extension on the Surface

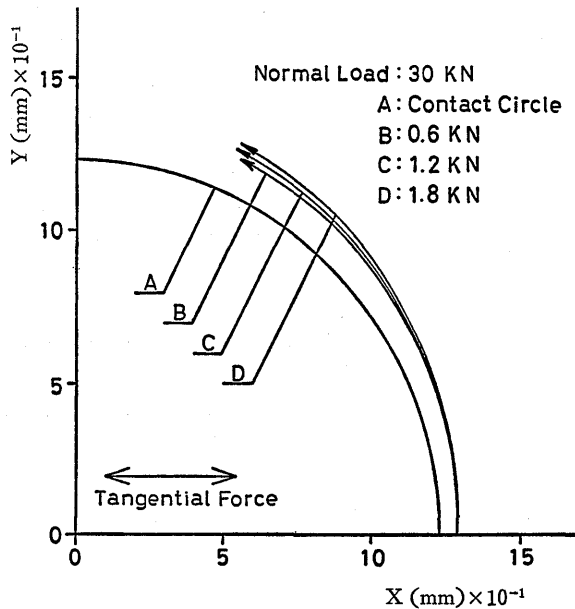


Fig. 9 Prediction of the Path of Crack Propagation on the Surface

Path of the propagating can be predicted using the present stress solutions as shown in Fig. 9. Provided it is assumed that the crack extends to the direction perpendicular to that of the maximum principal stress. As indicated by the experiments, the locus has not varied so much even if the range of tangential force increase by three-times.

#### IV. CONCLUSIONS

Conclusions can be summarized as follows;

From the experiments;

- (1). Crack initiation occurs at the ends of a diameter of contact circle parallel to the applied tangential force.
- (2). Relation between the range of tangential force and cycles to the surface cracking is similar with the

S-N curve in fatigue.

(3). Increase of statical normal load reduces the cycles to the cracking, although the similar relation with the S-N curve is kept.

(4). Crack begins to extend to the direction perpendicular to that of the tangential force and grows drawing a locus of circular arc.

(5). Rate of growth on the surface is rather high in the beginning, but it becomes slow by degrees and saturates finally.

(6). It is indicated that this propagating crack on the surface is a shallow crack and that the growth to the depth is not so much before the growth on the surface saturates.

From the analysis;

(7). Increase of the range of alternating tangential force cause that of the range of alternating applied stress, consequently the fatigue life is reduced.

(8). Increase of the statical normal load cause that of the mean stress of alternating stress, consequently the fatigue life is reduced under the present contact conditions.

(9). The crack growth rate is affected by the range of alternating stress.

(10). It seems that path of the propagation can be predicted on condition that crack extends perpendicular to the direction of the maximum principal stress. The path is not much affected by the tangential force nor by the normal load.

#### REFERENCES

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