2Pa4-6

Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 119-120
8-10 November, 2011

Stress Analysis of Contact Surface in Ultrasonically Forced Insertion Process
超音波圧入加工における接触面の応力解析

Satoshi Ono[1†], Manabu Aoyagi[1], Hideki Tamura[2] and Takehiro Tamura[2]
([1]Muraon Institute of Technology, [2]Tohoku Institute of Technology)
小野　聡 [1†], 青柳　学 [1], 田村　英樹 [2], 高野　剛浩 [2]([1] 室蘭工大・院, [2] 東北工大・工)

1. Introduction

An ultrasonically forced insertion (USFI) process which is well known at manufacturing floors can reduce the amount of necessary insertion force. However there are only a few reports concerning this technique, because this technique has been designed and developed empirically according to functional specifications at each manufacturing floor. [1-2)]

The purpose of this study is to develop a USFI device with good performance and also to quantitatively estimate the effect of the ultrasonic vibration on the process.[3)] In this paper, a frictional stress and displacement on the contact surface of a metal rod and plate were simulated by a finite element method analysis (FEA). From analysis results, the effect of reduction of frictional stress was clarified.

2. Analysis Condition

An analysis model and boundary conditions are shown in Fig.1. Table 1 shows parameters of the model and constants used for the analysis. This model is the axial symmetry in the central axis (R=0). The metal rod is inserted into the hole of the metal plate by the horn attached at the end of a bolt-tightened Langevin-type longitudinal transducer (BLT). The diameter of the rod is a little larger than that of the hole. The clearance is -1µm. This insertion level is defined as “Driving” by Japanese Industrial Standards (JIS). The friction coefficient μ is defined by

$$\mu = \mu_\mathrm{d} + (\mu_\mathrm{s} - \mu_\mathrm{d})e^{-\beta v},\ ^{4)}$$

where μ_d is the coefficient of dynamic friction, μ_s is the coefficient of static friction, β is the damping coefficient, v denotes the relative velocity of the metal rod and plate.

Analyses were carried out under conditions that the horn had the static displacement, D_s =100µm, and the horn moved by the vibrational displacement,

$$D_\mathrm{t} = v_\mathrm{a} t + a \cdot \sin(2\pi f \cdot t) \quad [\mathrm{m}],$$

where v_a is thrust velocity, a, vibration amplitude, f, frequency and t, time.

3. Distribution of Frictional Stress on the Contact Surface

Frictional stresses on the contact surface were analyzed in the case that the horn moved statically and vibrated, respectively. Figure 2 shows the distribution of frictional stress at each position on the contact surface. The static frictional stress was calculated at the critical condition that the sliding starts to occur on the contact surface. The average of the vibrational frictional stress in 392µs was calculated.

The frictional stress concentrates near borders of the contact surface. The both borders are defined as point A (contact position = 0.0 mm) and point B (contact position = 3.0 mm), respectively. When the horn moved by the static displacement, the frictional stress at point A and point B reached to 116.0 MPa and 25.0MPa, respectively. Total frictional stress was 627.3 MPa. When the horn vibrated, frictional stress at point A and point B were 14.0 MPa and 9.38 MPa, respectively. Total frictional stress was 212.3 MPa. Therefore, the frictional stress at the point A was reduced by 87.9 %, and that at the point B was reduced by 62.5 %. Total reduction of frictional stress was 68.1 %. Hence, it was confirmed that an ultrasonic vibration was effective to reduce frictional stress near the shallowest area of the contact surface.

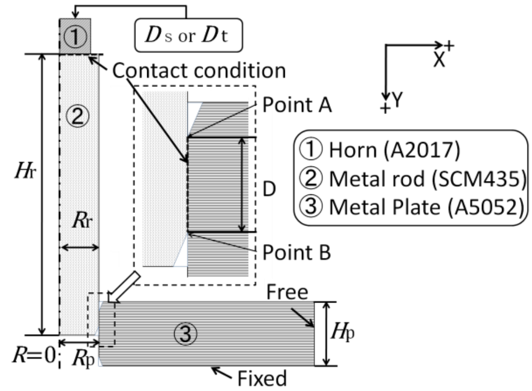

Fig.1 The definition of analysis model.

Table 1 Parameters of the model and constants for FEA.

$2R_\mathrm{r}$	Diameter of metal rod	12.001 [mm]
H_r	Height of metal rod	80 [mm]
$2R_\mathrm{p}$	Diameter of metal plate	12.000 [mm]
H_p	Height of metal plate	10 [mm]
L_p	Length of metal plate	40 [mm]
D	Insertion depth	3.0 [mm]
μ_d	Coefficient of dynamic friction	0.1
μ_s	Coefficient of static friction	0.4
β	Damping coefficient	0.3
v_a	Thrust velocity	2.0 [mm/s]
a	Amplitude of vibration	1.0 [µm]
f	Frequency	28 [kHz]
t	Time of vibration	392 [µs]

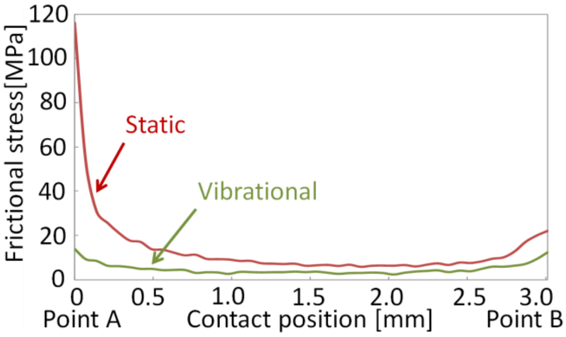

Fig.2 Comparison of static frictional stress with vibrational frictional stress.

4. Displacement on Contact Surface

4.1 Axial Displacement

Axial displacement on the contact surface was calculated to grasp motions of the metal rod and plate. Figure 3 shows calculated results at the contact position of 1.5 mm.

The frictional stress increased when the metal rod in the hole of the metal plate was thrust by the horn toward the insert direction. On the other hand, the frictional stress decreased when the metal rod was forced back by the elastic deformation of the metal plate and itself. The difference in axial displacements of the rod and plate was almost constant except sliding time. When the sliding occurred on the contact surface, the frictional stress decreased. Hence, the metal rod can be inserted more deeply, because the apparent frictional stress was decreased by ultrasonic vibration.

4.2 Radial Displacement of Rod

Figure 4 shows the calculated radial displacement distribution of the metal rod. Here, the radial displacement means the difference in deformation from the initial deformation of the rod in the radial direction under the condition that the rod was statically inserted into the hole. The distribution is the average of the displacement in 392μs. It is the DC component of the radial displacement.

At the point A, the displacement was decreased and the frictional stress increased sharply. It means that the area near the point A prevents the deformation of metal rod. Hence, it is necessary to consider the effective design of the rod and plate in which the frictional stress hardly concentrates near the point A.

5. Conclusion

In this paper, we described the reduction of the frictional stress on the contact surface simulated by a FEA. We compared the distribution of the static frictional stress and vibrational one on the contact surface. In a USFI process, the axial displacement and radial one on the contact surface were calculated to grasp the motion of the metal rod and plate. The obtained results are as follows:

- By adding the ultrasonic vibration, the frictional stress was reduced by 87.9 % near the shallowest area of the contact surface, and the frictional stress near the deepest area of the contact surface was reduced by 62.5 %. The reduction of total frictional stress was 68.1 %.
- The frictional stress increased and decreased when the metal rod was thrust toward the insertion direction and when forced back by the elastic deformation of the metal rod and plate, respectively. The sliding occurred on the contact surface in both directions of displacement, and the frictional stress decreased.
- Near the shallowest area of the contact surface, the displacement magnitude of the metal rod decreased and the frictional stress increased sharply. This area prevents the deformation of the metal rod.

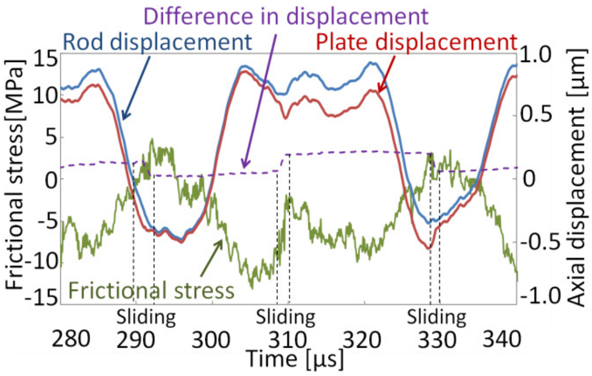

Fig.3 Time changes of axial displacements of metal rod and plate and frictional stress.

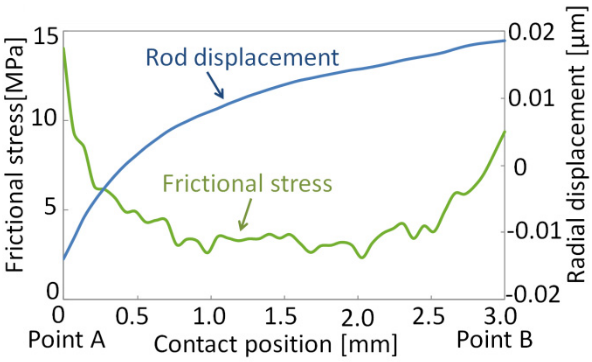

Fig.4 Distribution of radial displacement of metal rod and frictional stress.

Reference

1) M. Hayashi, M. Jin, S. Thipprakmas, M. Murakawa, J.-C. Hung, Y.-C. Tsai, and C.-H. Hung: J. Mater. Process. Technol. 140 (2003)

2) J. Tsujino, T. Ueoka, and E. Sugimoto: IEICE 108 (2009) 35.

3) S. Ono, M. Aoyagi, T. Takano, and H. Tamura: Jpn. J. Appl. Phys. 50 (2011) 07HE22.

4) J.Benson David, O. Hallquist John: Computer Methods in Applied Mechanics and Engineering, Vol. 78, No. 2. 1990.