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Modeling of contact surface morphology and dust particles by using finite element method

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Abstract: The effect of dust particles on electric contacts and a hazardous size range of hard dust particles using a rigid model were discussed before. As further research, elastic-plastic model of finite element analysis was established in this work, which is closer to real condition. In this work, the behavior of large size and small size particles, and the influence of particles hardness were investigated. The calculating result of small-size particles presents a general hazardous size coefficient for different contact surface morphology; for large-size particles, it presents a hazardous size coefficient for complicated composition of the dust. And the effect of the dust shape is also discussed.

Key words: Dust particles, Surface morphology, Finite element method (FEM), Hazardous size
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INTRODUCTION

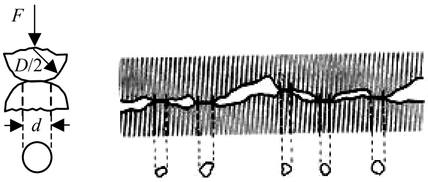
It is known that contact failure is one of the main factors influencing electric system's reliability. Dust particle is a contact failure causative factor that cannot be ignored. Some research results were published in earlier papers. In (Zhang and Yu, 1990), from the surface morphology point of view, pointed out that there is a range of hazardous sizes which would cause contact failure. Based on mechanics' model, Wan and Xu (2003) analyzed the size of particles which would be pushed away and analyzed failure condition when rigid particles embedded on contact surface.

As further research, in this paper, elastic-plastic model of finite element analysis are established. The behavior of both large-size and small-size particles, the influence of particles hardness and the effect of the dust shape were investigated.

SMALL-SIZE PARTICLES

In this paper, dust particles with radius of less than 2 μm are classified as small-size particles since these particles are comparable with the contact surface roughness. The experimental result (Zhang and Wen, 1986) showed that 90% of dust particles were smaller than 1 μm. So it is important to investigate the particles in this range. As Fig.1 shows, because of the morphology of contact surface, the real contact area is just some connecting spots. So particles in the space between these spots and particles are outside of the contact area (shown in Fig.2). Because the distinction of dimension between particles and probes is wide (Generally, the radius of probe for testing is about 3 mm, it is almost 1000 times larger than these small-size particles), so the model (shown in Fig.3) should be improved. The probe is supposed to be an infinite plane for these small-size particles here.

The elastic-plastic model of finite element analysis is established. As Fig.4 shows, considering that the roughness of probes is smaller than the coupons, the morphology of probes is neglected here. If we put this into consideration, it is more difficult to be moved, so the calculating result is relatively conservative.



(a) (b)

Fig.1 Real contact area
(a) Nominal contact area; (b) The area of mechanical contact

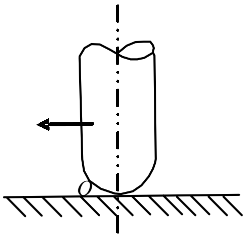


Fig.2 Particles outside of contact area

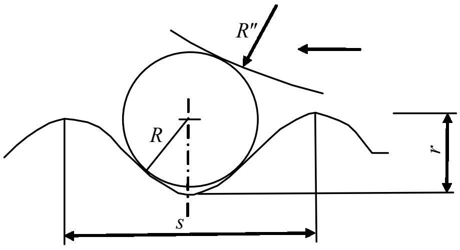


Fig.3 Former model of dust particles and morphology

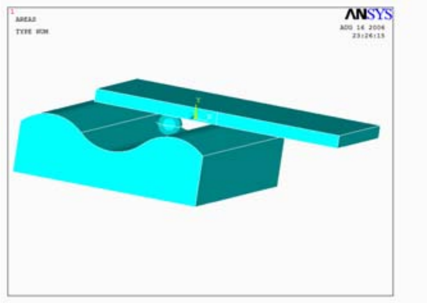


Fig.4 Finite element model of small-size particles

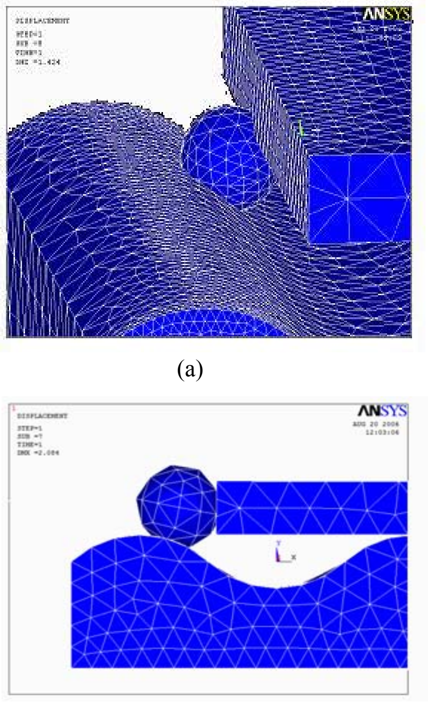
The finite element analysis used in this paper is ANSYS (Wan, 2004). Table 1 shows the material parameter of CuSn8. It is supposed that probe and coupon are of the same material (CuSn8). According to the experimental result, peak to peak height of copper coupons is 1 μm, average distance between two adjacent peaks is about 5 μm.

Table 1 Material parameter of CuSn8

Parameters	Value
Modulus of elasticity (MPa)	1.15×10^5
Shear modulus (MPa)	4.8×10^5
Poisson's ratios	0.34
Yield limit (MPa)	260

Considering that the embedding is due to the dimension of dust particles, 16 groups with different particle size were under consideration (from 0.5 μm to 2 μm). Fig.5a shows particles with radius of 0.6 μm, Fig.5b shows particles with radius of 0.8 μm.

Fig.5a shows that smaller particles are embedded into the coupon, and will stay in the contact area forever, which could be harmful for electric contact. If the radius of particles is larger than 0.8 μm, it can be moved away when the probe is sliding, it will be safer. It means that the hazardous size for small-size particles is 0.8 μm.



(a)

(b)

Fig.5 The simulation result of particle with radius of 0.6 μm (a) and 0.8 μm (b)

This conclusion is just for one special contact surface morphology. For general hazardous size, the models of different contact surface morphology have been established. According to experimental result (Zhang and Yu, 1990), the distance between two adjacent peaks for different contact surface is almost the same (5~7 μm), so we assume it is 5 μm in our finite element models.

Fig.6 shows that the hazardous sizes for the peak to peak height of coupons were 1 μm, 0.5 μm and 0.3 μm which is according to the morphology of coupon surfaces that have been polished by $400^{\#}$, $600^{\#}$ and $1000^{\#}$ emery paper. From Fig.6 it can be seen that we can control the hazardous size of particles by polishing the coupon surface. If the peak to peak height of coupons is 0.3 μm, the hazardous size of particles can be decreased to 0.3 μm. Otherwise, Fig.7 shows that there is a safety factor, which is that if the diameter of dust particle is over 2 times the coupon peak to peak height, it will be moved more easily and safer.

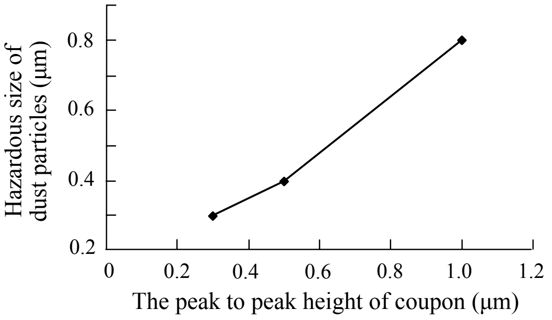


Fig.6 Hazardous sizes for different morphologies

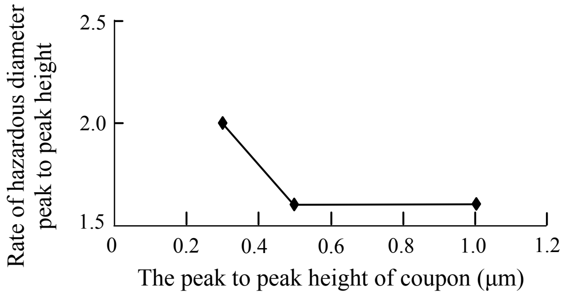


Fig.7 The safety factor of dust particle

This simulation result is consistent with the experimental results (Zhang and Yu, 1990). Coupon surfaces were polished by polishing powder $600^{\#}$ (the peak to peak height of coupons were 0.285 μm). And particles of two given sizes such as 1 μm and 0.3 μm (Al_2O_3 polishing powder) were densely spread on coupon surfaces. Diameter of the spherical testing probe was 3 mm. Contact resistance was checked during fretting cycles. Only resistances of over 100 mΩ were considered as failure. Cumulative numbers of failures were plotted with sliding cycles as shown in Fig.8a and Fig.8b respectively. In Fig.8 the size of particles was 1 μm, which was slightly larger than *Rz* (average maximum peak to peak height at a given distance). Failure was increased during sliding cycles. In Fig.8b, the particles size was 0.3 μm, cumulative number of failure was increased even higher. From the above experiment, the hazardous size range of particles is somewhere within 0.3 μm, which is consistent with the calculation results. It proves that the finite element model in this paper is reasonable, and that the calculation results are believable.

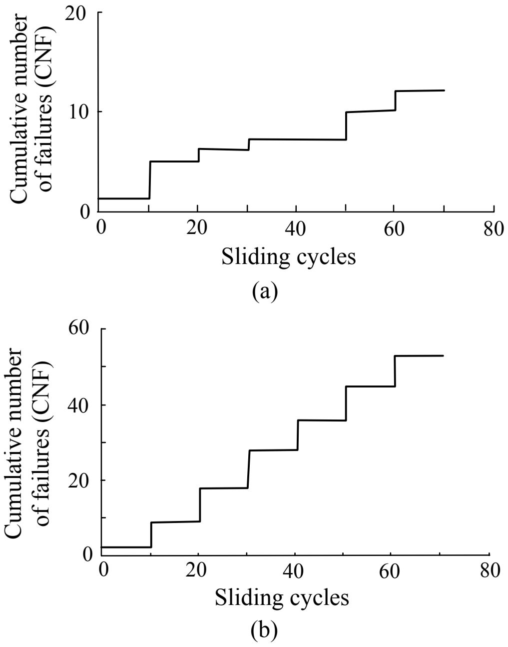


Fig.8 Number of cumulative failures for particles size of 1 μm (a) and 0. 3 μm (b)

LARGE-SIZE PARTICLES

In this paper, dust particles with radius of more than 5 μm are classified as large-size particles, because these particles are over 10 times the morphology of contact surface. So in calculation process the morphology of contact surface can be neglected. The elastic-plastic model of finite element analysis particles is established.

Fig.9 shows the finite element model, which intercepts 1/4 model of full probe due to the structural symmetry. The probe diameter is 3 mm. The material parameters of each part are the same as those in Table 1. It is supposed that different models have the same contact force (according to the experimental result of 100g) and the same distance of sliding (40 μm).

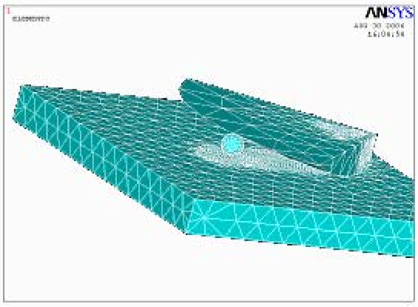


Fig.9 Finite element model of large-size particles

Fig.10 shows the calculation result of the dust particle with radius of 10 μm, it can be seen that the particle has been almost embedded into the coupon. Fig.11 shows embedding rate of different dimension of particles when the probe is sliding. Fig.11 shows that smaller particles will be embedded deeper into the coupon. If the radius is larger than 40 μm, the embedding rate is below 10%, it can be almost moved away. From the above calculation result, the hazardous size range of particles is somewhere within 40 μm, which is close to the analytic result (38 μm) in previous studies (Wan and Xu, 2003). It proves that the finite element model is reasonable and credible. The causative reason of the error is that the analytic model neglected the friction between the probe and particles, and the rigid model neglected the distortion. The calculation result is conservative. The result in this paper is closer to real condition.

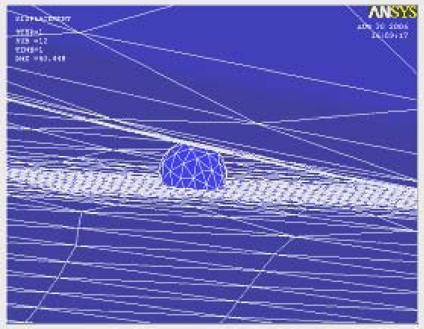


Fig.10 Calculation result of the dust particle with radius of 10 μm

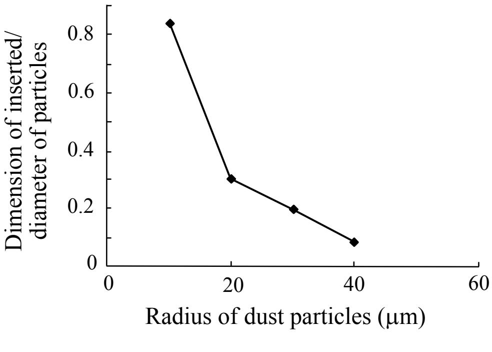


Fig.11 Embedding rate of different dimension of particles

HAZARDOUS SIZE FOR COMPLICATED COMPOSITION OF DUST

As we know, dust particles are very complicated (Feng and Zhou, 2005; Engel, 1991; Liang *et al.*, 1997; Wan *et al.*, 1999). It was found by XES that they included Si, Na, Mg, Ca and Al. The calculation result in Sections II and III is for dust particles harder than the contact surface (silicon dioxide, etc.).

The model of particles with hardness close to that of the contact surface (metal debris produced in the process of sliding) is established. The embedding rate of particles radius of 40 μm is 7.84% (Fig.12). It is very close to the result in Section II. So these particles can be classified with particles which are harder than the contact surface, so the hazardous size range of these particles is somewhere within 40 μm too.

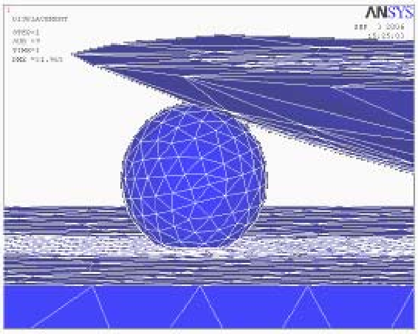


Fig.12 Calculation result of debris with radius of 40 μm

However, soft particles (gypsum, etc.) will not be embedded into contact surface when the probe is sliding, it does not mean that it is safer. They will be easily squeezed into tablets, so the contact area decreases greatly. Fig.13 shows the degree of squeezing for different dimension of dust particles. It can be seen that the degree of squeezing of particle with radius of 40 μm is 9.94%. Particles above this range cannot be squeezed seriously, and can be moved easily. So the hazardous size range of these particles is somewhere within 40 μm too.

So the unified hazardous size for complicated composition is 40 μm.

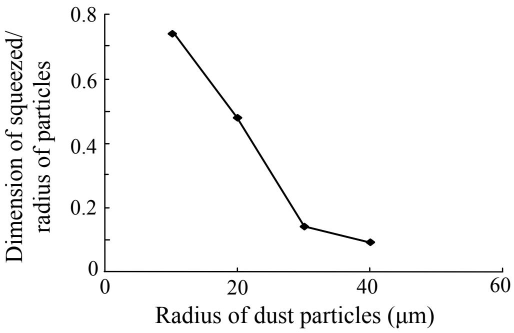


Fig.13 The degree of squeezing for different dimension of dust particles

EFFECT OF DUST SHAPE

The experimental result shows that the shape of dust particles is so complicated (Johnson, 1992; Zhang, 1986; Zhang *et al.*, 2003). In this paper, it is supposed to be spherical. It is harder to move away if the shape is not spherical. So the finite element calculation result here is conservative.

CONCLUSION

The effect of dust particles lies on these factors: composition and dimension of particles, contact morphology, contact force and electric current. In this paper, we described the first three factors.

Dust particles with radius of less than 2 μm are classified as small-size particles; these particles are comparable with the contact surface morphology. For general hazardous size, the models of different contact surface morphology have been established. There is a safety factor that if the diameter of dust particle is over 2 times the peak to peak height of coupon, it will be moved more easily and safely. From the calculation result we found that we can control the hazardous size of particles by polishing the coupon surface. If the peak to peak height of coupons is 0.3 μm, the hazardous size of particles can be decreased to 0.3 μm. This simulation result is consistent with the experimental results.

For large-size particles, the unified hazardous size for complicated composition dust is 40 μm. In this sense, according to the calculation result, a non-discriminatory protection range has been established.

As for future study, the other factors such as contact force and electric current and the problem of climbing will be taken under consideration.

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References

Engel, P.A., 1991. Vickers Microhardness Evaluation of Multilayer Platings for Electrical Contact. Proceedings of the 37th IEEE Holm Conference, p.66-72.

Feng, C.F., Zhou, Y.L., 2005. The character and formation of Dust contamination on the failure contact surface. *Electromechanical Components*, **9**:8-11 (in Chinese).

Johnson, K.L., 1992. Contact Mechanics. Higher Education Press, Beijing, p.51-87 (in Chinese).

Liang, Y.N., Zhang, J.G., Liu, J.J., 1997. Identification of Inorganic Compounds in Dust Collected in Beijing and Their Effects on Electric Contacts. 43rd IEEE Holm Conf. on E.C., Philadelphia, PA, USA, p.315-327.

Wan, Y.H., 2004. Study of Effect of Particles to the Reliability of Electric Contact. Master Thesis, Beijing University of Post & Telecommunications, Beijing, p.42 (in Chinese).

Wan, Y.H., Xu, L.J., 2003. Hazardous size for rigid particles in contact electric. *Electromechanical Components*, **12**: 13-17 (in Chinese).

Wan, J.W., Gao, J.C., Lin, X.Y., Zhang, J.G., 1999. Water Soluble Salts in Dust and Their Effects on Electric Contact Surfaces. Proceedings of the International Conference on Electrical Contacts, Electromechanical Components and Their Applications, Nagoya, Japan, **7**:19-24.

Zhang, J.G., 1986. Characteristic of Dust Deposition and the Effect of Dust on Electric Contact. Proc IC-CEMCA, Nagoya, Japan, p.878-881.

Zhang, J.G., Wen, X.M., 1986. The effect of dust contamination on electric contacts. *IEEE Trans. CHMT*, **9**(1):53-58.

Zhang, J.G., Yu, P., 1990. Electric Contact Performance: Effect of Contact Surface Morphology and the Size of Dust Particles. Proc. 36th IEEE Holm Conf., p.402-409.

Zhang, J.G., Gao, J.C., Lin, X.Y., 2003. Analysis of connector contact failure. *IEICE Transactions on Electronics*, **E86-C**(6):945-952.