Taiho Kogyo Tribology Research Foundation

Main report

Name: Dr. Yang Xu, Mr. Yan Chen, Prof. Robert L Jackson, and Prof. Bart Prorok

Theme: Measurement of the Real Area of Contact using Coating Technique and SEM

1. Progress and result of the research

All surfaces are rough down to the atomic scale. Therefore, the real contact area between rough interfaces consists of clusters of irregularly shaped contact patches. Many tribological problems in industry are strongly related to the real area of contact, e.g., electrical/thermal contact resistance, leakage, adhesive wear, and static friction. An accurate measurement of the real contact area is crucial to the successful research and development of many tribological components.

1.1. Experiment

In the current research, an experimental approach was developed to measure real area of contact using scanning electron microscope (SEM). A ceramic sphere (bearing ball, 99.5% Alumina oxide, Ø10mm, Ortech, USA) is under purely normal contact with the top flat surface of an aluminum cylinder (6061-T6, Ø32 x 20mm, Ted Pella, USA), see Fig. 1(a, b). Before the indentation test, a thin film of gold is sputtered on the upper hemisphere of the ceramic sphere. The fundamental assumption adopted in this work is that the adhesive transfer of the Au film occurs everywhere inside the contact area between the ceramic and the Al surface. The adhesive transfer of Au film is enhanced by a PMMA film, see Fig. 1. Due to the difference between the atomic weights of Au and Al, the SEM images in the BS mode may create a strong contrast between the contact and non-contact areas on both surfaces. For the Al surface, the contact and non-contact areas are represented by Al and Au, respectively. For the ceramic surface, the contact and non-contact areas are represented by Au and ceramic, respectively.

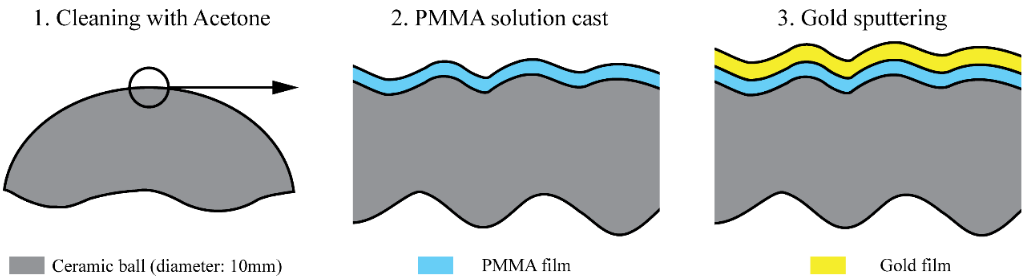

Figure 1. Steps of preparation of the ceramic surface

1.2. Proof of Fundamental Assumption

Theoretically, the adhesive transfer of Au film should only occur everywhere inside the contact area. The scanning electron (SE) images of the indents on the ceramic sphere and Al surface from the same contact pair are illustrated in Figs. 3(a, b) at a magnification of ×220. Multiple pits are found on the ceramic surface, see Fig. 3(b). Those pits act as natural fiducials which leave similar marks on the Al surface. Back-scattered (BS) images taken at the vicinity of one pit (marked by a blue square) are shown in Fig. 4 with higher magnifications. Since the Al surface does not come into physical contact with the ceramic sphere inside the pits, theoretically, the adhesive transfer of Au cannot be achieved. Fig. 4(a) shows a clear sign that the Au film does not transfer inside the non-contact area. The distribution of the Au films on the Al surface shown in Fig. 4(a) have a good agreement with that of the ceramic on the sphere shown in Fig. 4(c). This agreement is further validated using images at a higher magnification of ×30,000, see Fig. 4(b, d).

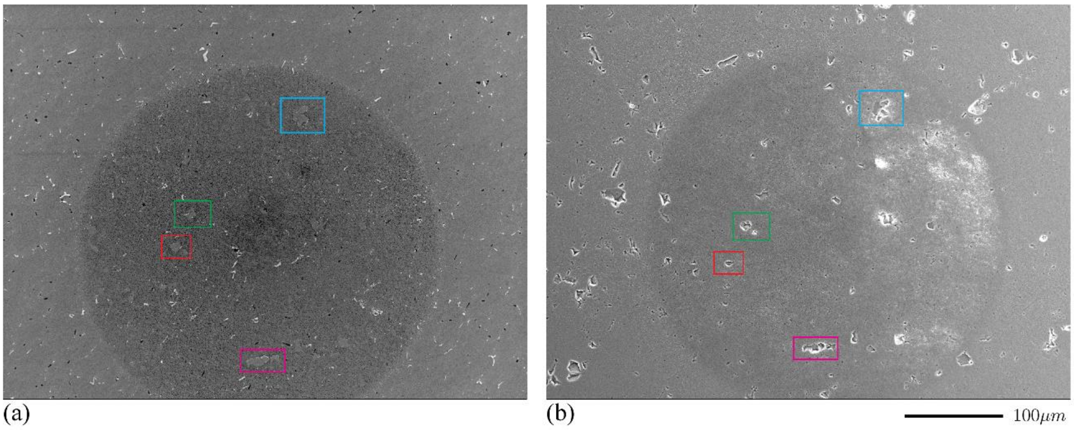

Figure 3. The entire indented region on (a) the Al surface and (b) the ceramic sphere captured in the SE images. Note that the SE image of the ceramic sphere (b) is flipped horizontally. (a-b) Magnification: ×220; Resolution: 0.42 μm; FOV: 534.69 × 404.08 μm.

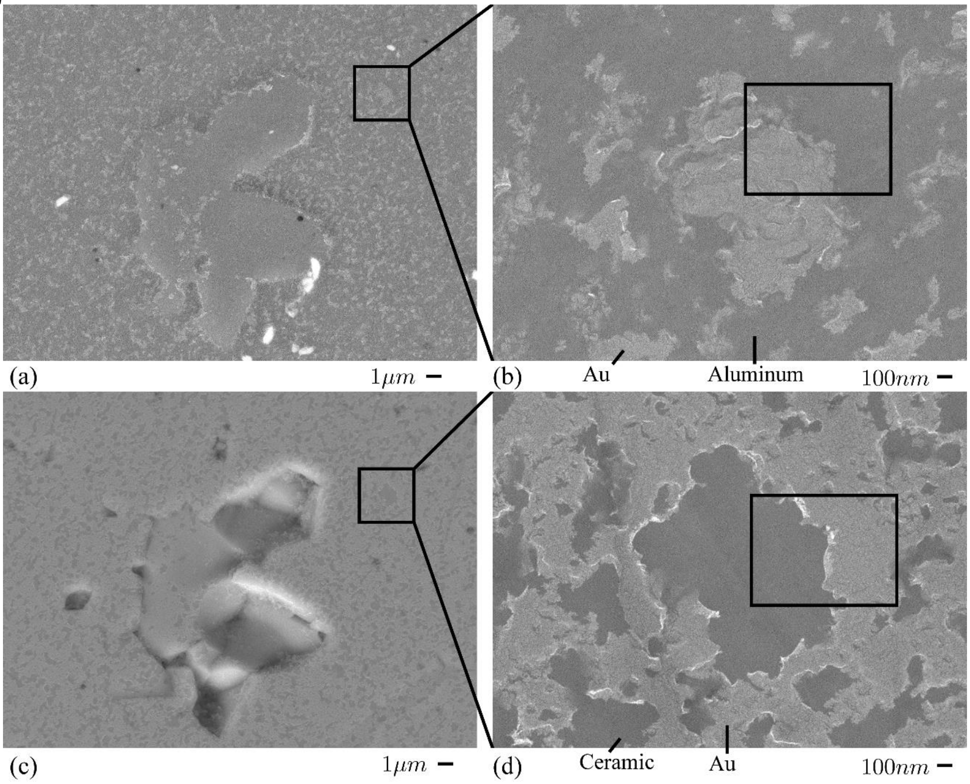

Figure 4. The BS images of the neighborhood of (a, b) a pit on the ceramic sphere and (c, d) the corresponding imprint on the Al surface (SEM images are flipped horizontally). Zoom-in images enclosed by the black squares in (b) and (d) are shown in Fig. 3. (a, c) Magnification: ×3,000; Resolution: 26 nm; FOV: 33.25 × 23.50 μm; (b, d) Magnification: ×30,000; Resolution: 2.60 nm; FOV: 3.33 × 2.35 μm.

1.3. Results

Four locations were picked along the radial direction of the indent on the ceramic sphere and the Al surface. The layout of the explored locations on the ceramic sphere is shown in Fig.4. Fig. 5 shows the BS images of four locations on the ceramic captured at a magnification of ×5,000. A general trend shown in Fig. 14 observed from locations #1 to #4 on the ceramic sphere is that the real area of contact (ceramic, dark color) decreases from the center (location #1) to the contact edge (location #4). The contrast between the non-contact (Au) and contact area (ceramic) is sufficient for the usage of digital imaging processing to create a binary contact map. Fig. 7 shows a clear measurement of the contact area at the vicinity of a pit with a magnification of ×10,000.

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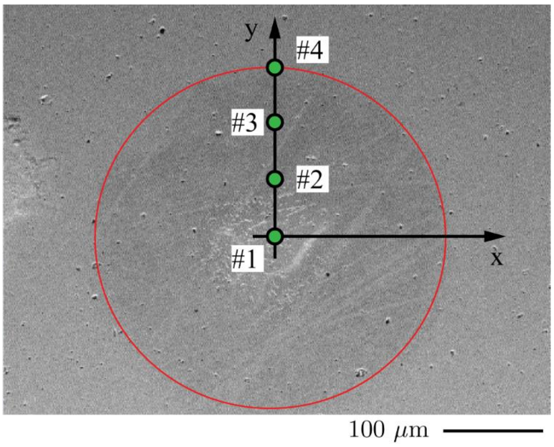

Figure 5. The layout of the explored locations (#1-#4) on the ceramic sphere in the BS image. Magnification: ×220; Resolution: 0.42 µm; FOV: 534.69 × 404.08 µm.

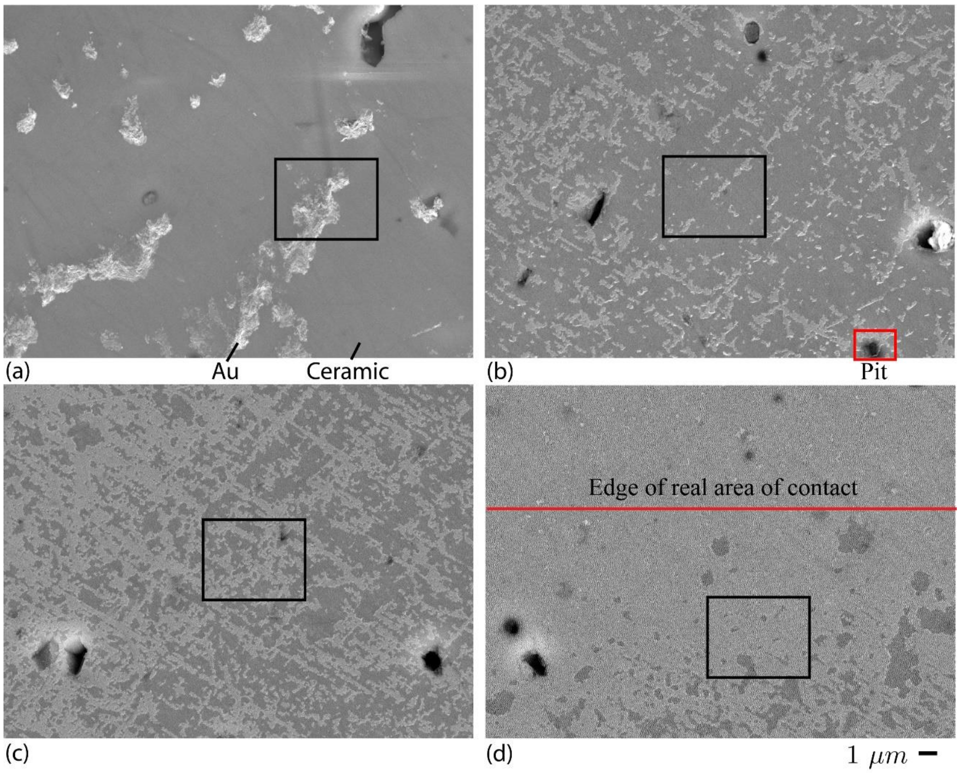

Figure 6. The BS images of locations (a) #1, (b) #2, (c) #3 and (d) #4 on the ceramic sphere. Dark color: ceramic; light color: Au. Magnification: ×5,000; Resolution: 19.55 nm; FOV: 25 × 18.8 µm. Black squares indicate the locations where zoom-in images are captured and shown in Fig. 5.

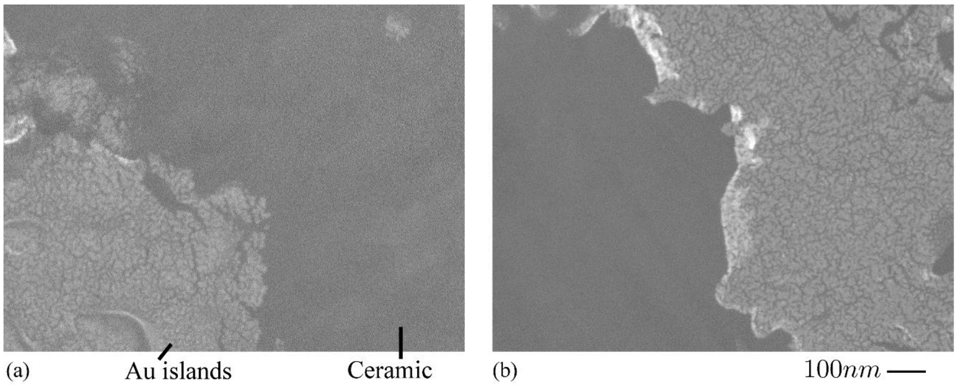

Figure 7. (a) Al and (b) ceramic surface. Magnification: ×100,000; Resolution: 0.89 nm; FOV: 1.14 × 0.85 µm.

2. Subjects remain to be solved in future/Subjects required further investigation

The subjects remain to be solved are tabulated below:

a) The contrast between contact and out-of-contact area in BS/SE images should be improved at low magnification;

b) The contact map of entire indent may be achieved through stitching multiple images capture with higher magnification;

c) The measurement of contact area distribution/real area of contact should be compared with that predicted by analytical/numerical models.

3. Plan and past presentation or publication of your research results

Journals:

Xu, Y., Chen, Y., Zhang, A., Jackson, R.L. and Prorok, B.C., 2018. A new method for the measurement of real area of contact by the adhesive transfer of thin Au film. *Tribology Letters*, **66**(1), p.32.

Presentations:

Oral presentation (by Prof. Robert Jackson), Measurement of the real area of contact using coating technique and SEM, 6th World Tribology Congress, Sep 2017, Beijing, China.