PYRAMID SEGMENTATION FOR LOAD MEASUREMENT BASED ON ELECTRIC CONTACT THEORY

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1. INTRODUCTION

Soil pressure is important for design and construction in many underground excavations. The prevalent pressure gauges based on the piezo-resistive effect are costly and relatively fragile. Therefore, the concept based on the electric contact theory is alternatively developed. Johnson (1985) proposed that the radius a of a contact area of two spheres can be expressed by Eq.(1) where P is the compressive load, R and E^* are the radius of the sphere and the equivalent strength which are the inherent properties of spheres:

$$a = \left(\frac{3PR}{4E^*}\right)^{1/3} \tag{1}$$

As the applied load affects the contact resistance between the particles, Holm (2013) proved that the contact resistance is inversely proportional to the radius of the contact area. Since the bulk resistance is small and hardly changes during the loading process, the contact resistance plays the main role of the variation. Theoretically, the larger the applied load, the lower the total resistance. The working principle of load sensor by measurement of the electrical resistance variation in numerous pressure-sensitive conductive balls using a simple circuit can be developed because the measured resistance of conductive spheres surrounded by many spheres relates to the compressive pressure. Although the size is bigger than the traditional pressure gauge, this study demonstrates that steel balls employed as the filler, which is cheap and highly conductive, can be economically used to develop the robust type of pressure gauge.

2. PRELIMINARY TEST

In order to test the change of resistance affected by the applied load, a simple compression test was conducted. The experiment setup is sketched in Fig.1. It consists of steel balls, containers, data logger, and a simple circuit. The 71.67 grams of high carbon chromium bearing steel balls (SUJ-2) with a diameter of 26 mm and roughness of 0.095 μm under JIS G60 standard was used in the test. The container made by a square pipe is inserted into the slotted thick plate to confine steel balls and to ensure that the path of force from the load applied by a uniaxial compression machine with a maximum capacity of 2 kN is aligned vertically. Falcon et al. (2005) proposed that the electric contact between the steel balls leads to micro-welding on the contact area because of Joule heat. To prevent contact loss, the load will not be completely unloaded and is applied considerably slow between 0.03 and 1.5 kN repeatedly. The experiment used a constant current set at 0.5A. The data logger records the load and voltage per second. The resistance can be calculated by the Ohm's law, and then the relationship between the load and the resistance can be obtained.

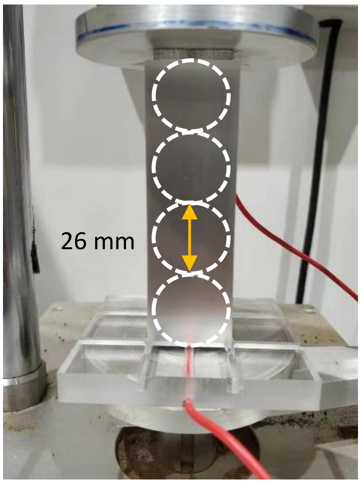

Fig.1 Experiment setup

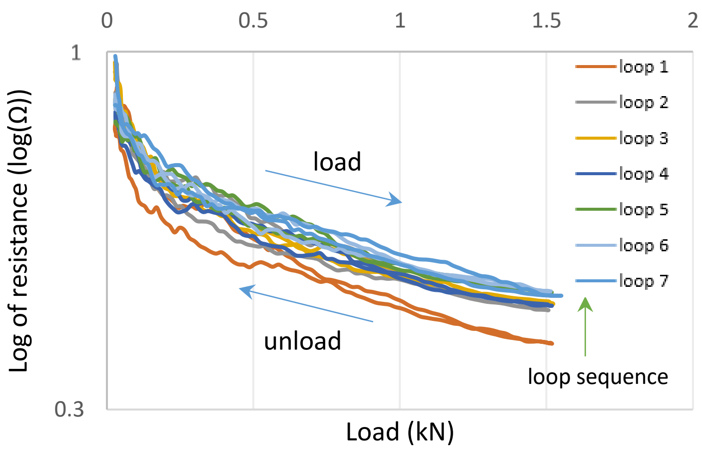

Fig.2 Compression test by 4 steel balls

In Fig.2, there are seven curves from repeating loading loops. The resistance of steel balls obtained in the first loop is relatively small and slightly increased in the subsequent loading. The slope of the curves is gradually declined as the load is increased. However, after many loops of loading/unloading, the curves are gradually overlapped or repeatable.

Keywords: Load measurement, Electric contact theory, Contact mechanics, Electrical resistance, Memristor
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The result indicating that the electrical resistance drops as the load increases is consistent with the theoretical hypothesis. The hysteresis observed in the experiment can represent a typical memristor contributed by the array of steel balls (García-Paniagua (2018)).

3. PYRAMOID SEGMENTATION

A housing of stainless balls (SUS304) using pyramid segmentation is fabricated by a 3D printer using PolyMax PLA material. One unit of pyramid segment is shown in Fig.3 to which an electric circuit for electrical measurement is connected for load calibration. The electrodes are made of copper sheets (1 mm thick, specific gravity 8.89) welded with electric wires and installed in the top and bottom of the pyramid. The pyramid is filled with stainless balls with a diameter of 3 mm and a roughness of 0.032 μm under the JIS G30 standard. The silicone resin (super-low viscosity rapid cure) is injected into the void inside pyramid to hold the arrangement and electric contacts of stainless balls. A preload 50 N was applied during the curing process of resin. The experiment was performed by a uniaxial compression machine with a loading loop 0.2-0.8 kN. The compression test result of the pyramid unit is shown in Fig.4. The relationship between the electrical resistance and the load is exhibited in the semi-logarithmic scale. Five loading loops almost show the same tendency. The electrical resistance in the loading steps is around 8.2% larger than that in the unloading steps under the same load level, indicating the electrical resistance is affected by the loading history. Despite the hysteretic loops found in loading and unloading steps, the curves are appeared almost a straight line on a semi-logarithmic scale and are closed at the minimum and maximum load levels. If four pyramids were connected to separate circuits for electrical resistance measurement and were assembled into a cubic housing unit, 3D stress sensor might be realizable.

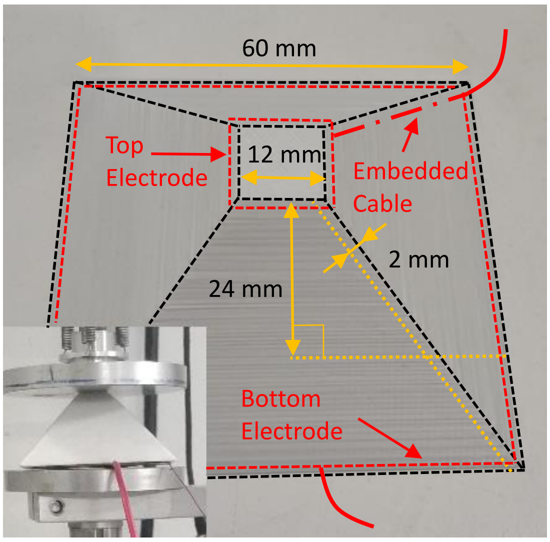

Fig.3 Pyramid unit and experiment setup

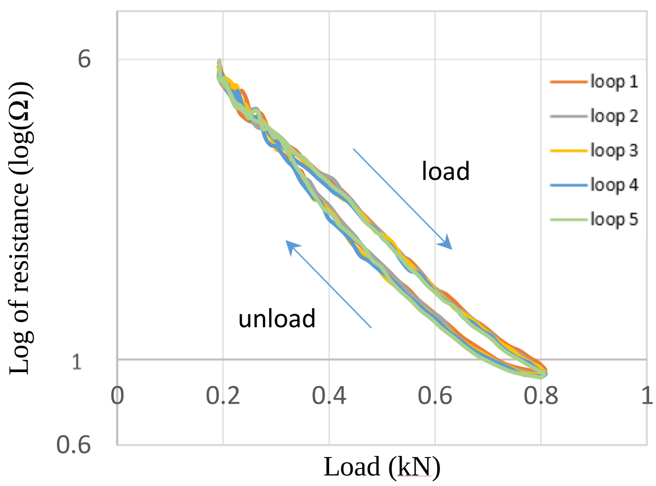

Fig.4 Compression test of a pyramid unit

4. CONCLUSIONS

Experiments indicated that the electrical resistance of stainless balls is varied with the applied load to some extent, and the load-resistance mapping is repeatable. Since the fabrication of this load sensor is quite simple, the housing can be customized to distinct shapes and dimensions for specific uses. Stainless balls can be set to any diameter to achieve different quantifiable accuracies and loading ranges, and can be replaced with other conductive or non-conductive fillers. However, there are still many unresolved issues with sensors. Not only does the load affect electrical resistance, but the loading history and electric current intensity also affect the electrical resistance. Due to the coherent effect, micro-contacts caused by local welding are very fragile. Therefore, once there is shocked or struck, they could be destroyed, and the electrical resistance would immediately increase. Therefore, more researches on the physical properties are needed, and the corresponding countermeasures will be adopted to conquer the instability of the sensor.

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