Electrification of Glass by Fracture

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Abstract In 1883, Faraday found that some crystals can be electrified by deformation and cleavage and many researchers reported that the brittle materials such as rock can also be electrified. Nowadays, a new technology was developed to forecast earthquake and collapse of mine well by detecting the electrification of rock. In the paper, we set up an instrument to measure the electrification of the broken glass. We observed the electrification of glass by fracture and the charges carried by the broken glass were measured. It was found that the amount of charges was directly proportional to the broken area of glass and the maximum surface charge density can be reached up to 0.5 $\mu C/m^2$. By SEM observation of broken surface, we can infer the charges distribute near initial nick.

Keywords Electrification of fracture; Glass slab; Surface charge density

1. Introduction

The study on electrification of fracture is not only to develop a new technology to ensure the security of mine wells [1-2], but also to be inferred an electrification mechanism of sand particles in wind-blown sand flux [3].

The fist study on the charge fracture date back to 1883, and Faraday found that some crystals can be electrified due to cleavage and deformation [4]. From then on, many researchers found that the rock can be electrified during the deformation and break. Kornfeld measured the charges and the electric field of the lithium fluoride crystal cleft by a sapphire chisel. He found that in the vast majority of cases, the field of one part of a specimen was positive over the entire extension of the cleavage, whereas the field of the other part of the specimen was negative. He thought the electrification of cleft lithium fluoride resulted from the presence of an intrinsic charge. Many researchers measured the electrification of broken rock, and inferred the charging mechanism, such as triboelectrification, electrification of electron escaping of broken surface [5-12].

Triboelectrification has been known for millennia[13] which means two materials surfaces are contacted (especially rubbed) and separated and the electrical charges can be transferred [13]. Nowadays, researchers like use the term contact electrification to name the charge transfer phenomena after two materials surfaces contact, because subsequent studies found that the contacted surfaces can be electrified if they are contacted and then separated, not necessarily rubbed. The current researches of contact electrification focus on electrification mechanism, that is what kind of charge is transferred, how to transfer charge and what is the drive force to transfer charge [14], which involve physics, chemistry and so on and interests many researchers on the electrification mechanism of chemically identical material.

However, the electrification of fracture may be different from the contact electrification, because the electrification of fracture results from the break of material, which means that the part of the broken material can be electrified, whereas the contact electrification means the two materials surfaces can be electrified after they contacted with each other. Therefore we infer that the electrification mechanisms are different. Recent studies on the contact electrification indicate that the charges transferred are electron, iron and material sites [15-18]. Though some researchers think that the electrification of fracture results from the electrons escaping during the break of the material, the fracture of material is always accompanied with the chemical bonds breaking in microscope [19]. Therefore the asymmetrical break of the chemical bonds may be one of main reasons leading to the electrification of fracture.

In this paper we set up a instrument to measure the charges carried by a part of glass slab broken by a glass sphere. The calculated surface charge density indicates that the amount of charges carried by the broken part of the glass slab is proportion to the broken area, and we infer the mechanism of electrification of fracture by scanning the broken surface.

2 Experiment setup and measurement

We set up an instrument to measure the charges carried by the broken part of the glass slab shown as Fig.1. Main part of the instrument was put into a closed glass container with a wire netting fixed on its inside wall to shield the electric field. We also can observe the experimental procedure through the glass wall. One end of a glass slab was fixed on a moveable slideway which can be controlled outside the glass container. When the glass slab moves above the Faraday’s cup, it will stop. A metal sphere falls and impacts with the glass slab which will be broken into two parts, and one part will fall into Faraday’s cup. Faraday’ cup induces the charge carried by the part of glass slab, which was named charge of fracture or broken charge, and the electric signal is displayed by electrometer (Type: Keighley 6517A; Precision: 100pC; Rang: 0~20nC).

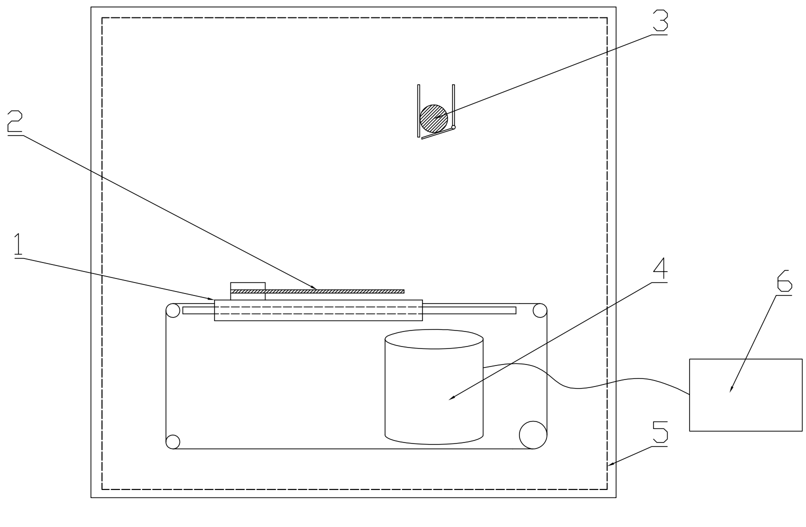

Fig.1 A sketch of instrument of electrification of fraction, in which 1 is slideway, 2 is specimen, 3 is metal sphere, 4 is Faraday cup, 5 is wire netting and 6 is electrometer

Before the experiment, we firstly mad a linear nick on the glass slab to ensure that the glass slab can be easily broken and also just broken into only two parts, by which we can easily calculate the broken area. If the linear nick is made in the middle of the glass slab, the glass slab can be symmetrically broken but otherwise asymmetrically broken, and in this paper the linear nick was made in one third of glass slabs. Then all glass slabs and glass spheres were cleaned by water and alcohol to eliminate the impurity of glass's surface and the net surface charges. The glass slabs used in our experiment were 3mm and 4mm in thickness, and 15mm and 20mm in breadth, and 150mm and 200mm in length. Given a size of the glass slab, we measured 30 results at least, that means we measured charges of 30 specimens.

3 Results and discussions

For all data we collected, we firstly eliminate the abnormal data by using Grubbs method and then classified the data by positive and negative signs. Fig. 2(a) and Fig. 2(b) show the amount of charge carried by parts of broken glass slabs, 4mm×20mm×200mm in size. The charges carried by the symmetrically broken parts shown in Fig. 2(a) and the ones carried by the asymmetrically broken parts shown in Fig. 2(b). It can be found that two parts of the glass slab broken by a metal sphere can be electrified, and the one part carried positive charge, whereas the other carried identically negative charge. The probability of presence of positive charge of negative charge is equal. For the asymmetrical case, mean amount of positive charges carried by the part is $+0.032059nC$ and mean amount of negative charges carried by the other part is $-0.03062nC$. By comparison Fig. 2(a) with Fig. 2(b), both the polarity and amount of charges carried by the broken glass slab are not related to the broken position, which is accordant with the results observed by Kornfeld [1]. We also measured the charges carried by broken parts of glass slabs with different length, and the results showed that the charge of fracture is not related to length of specimen. Therefore we only introduce the measurement results of symmetrical broken glass slabs with 200mm in length.

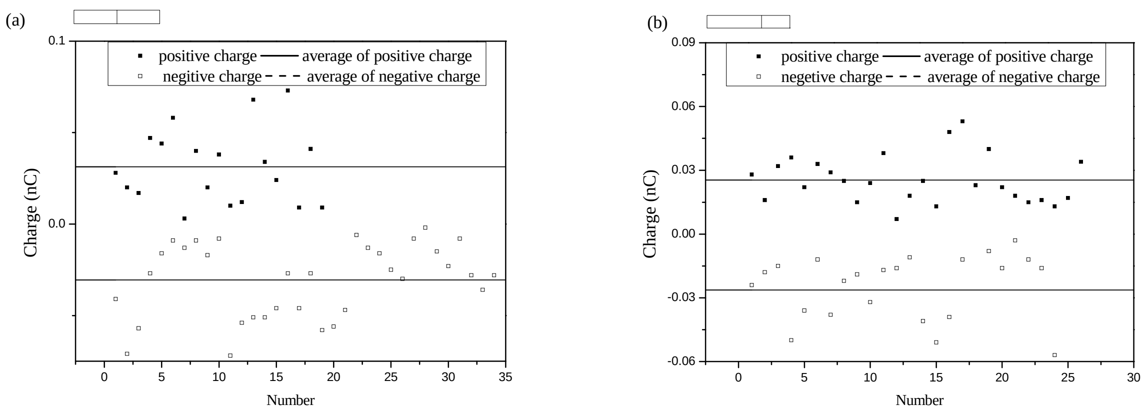

Fig.2 Charges carried by the broken part of glass slab, 4×20×200mm in size, (a) symmetric break and (b) asymmetric break

We also measured the charge of fracture of specimens in other thickness and breadth to know the effect of sizes of slabs on the amount of broken charge. Fig. 3(a) showed charges carried by broken slabs, 3mm×20mm×200mm in size. By comparing Fig. 2(a) and Fig.3(a), we found that they have a same charging law but the amount of charges shown in Fig. 2(a) is significantly lower than the one shown in Fig. 3(a), which shows that the thickness of glass slabs have an effect on the amount of broken charges. With increase of the thickness of the glass slab, the amount of charges also increases. Fig. 3(b) and Fig. 3(c) showed the charges carried by the broken parts of the glass slabs, 4mm×15mm×200mm and 3mm×15mm×200mm in sizes, respectively. We found that the breadth also has an effect on the charge of fracture, which increases with the increase of the breadth of glass slab. As mentioned above, the charge of fracture increases with the both the breadth and thickness. As well as we known, with the increase of both the breadth and thickness broken area increases, that means the increase of the broken area will lead to the increase of the charge of fracture. Therefore we calculated the mean values and standard variances of the surface charge density shown in Fig.4. From Fig.4, it can be found that the breadth has a significant effect on the charge of fracture. Especially, for the amounts of charges carried by the broken part of glass slabs, 4mm×15mm×200 and 3mm×20mm×200mm in sizes, the areas of these two cases are equal, but the surface charge densities are different and the amount of charges carried by the former is higher than the latter. The surface charge density can reach up to 0.5μC/m^2.

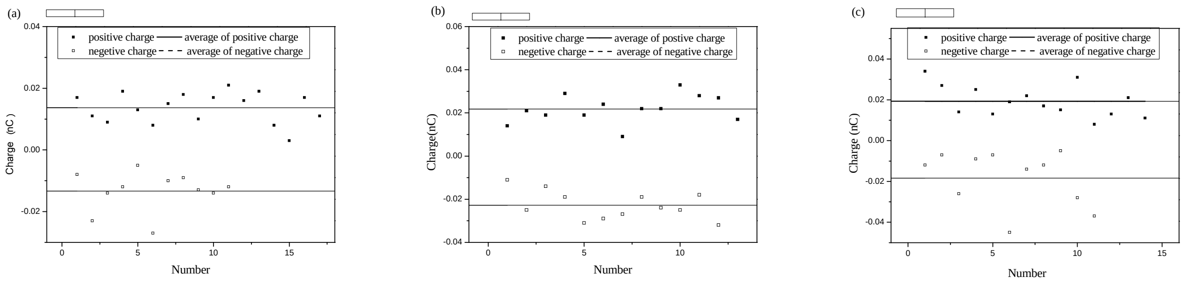

Fig. 3 Charges carried by the broken glass slab, (a) 3mm×20mm×200mm, (b) 4mm ×15mm ×200mm and (c) 3mm×15 mm×200mm in sizes

Although the charge of fracture increases with the thickness increasing when the broken areas of the specimen are given, it is still difficult to infer that the charge of fracture increases with the thickness. Because we make the linear nick on the specimen, it also has the effect on the real broken thickness. For given the deepness of nick, it has a significant effect on the broken thickness of glass slab with thinner thickness. But it is difficult to carry out the experiments to measure the charge of fracture with thickness more than 4mm, so if the surface charge density is related to the thickness is still open.

It is interesting that how to explain the electrification of fracture, which may be related to the glass network structure. We scanned the broken surface of glass by using SEM (Type: JSM-5600LV. Precision for SEM: 3.5nm. Precision for DES: 131.7eV) shown in Fig. 5(a). From the Fig. 5(a), it can be found that the broken surface is smooth but a few black spots (I), and white spots (II), which indicates it is a brittle fracture. Because the grayscale of the image is related to the atomic number to some extent, we analyzed the energy dispersive spectrum of black spots, I of Fig. 5a and white spots, II of Fig. 5(a), shown as in Figs. 5(b)-5(c), respectively. The chemical formula of glass used in our experiment is $Na_2O{\cdot}CaO{\cdot}6SiO_2$, in which Na_2O and CaO are about 15% and 16%. Our DES is not sensitive to the elements with smaller atomic number such as H, C, O and Na, so the energy spectrums of these elements cannot be displayed in Figs. 5(b)-5(c). Comparing the Fig.5(b) with Fig.5(c), the content of element of Si is highest than the ones of others, which has not large difference in quantity of different position. It is difficult to correlate it to electrification of facture.

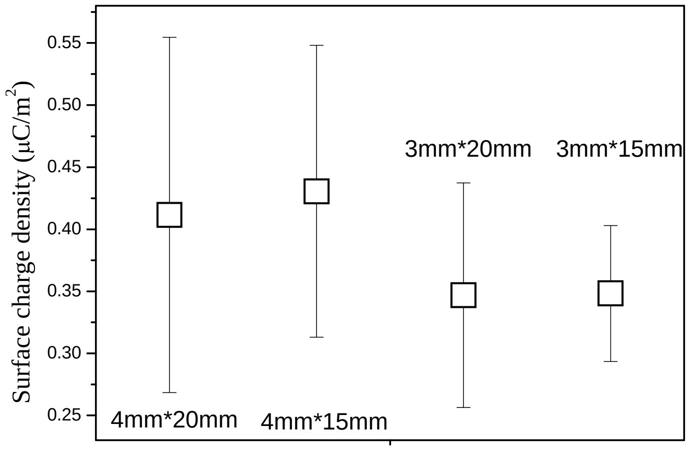

Fig. 4 Surface charge density of broken surface for different cross section

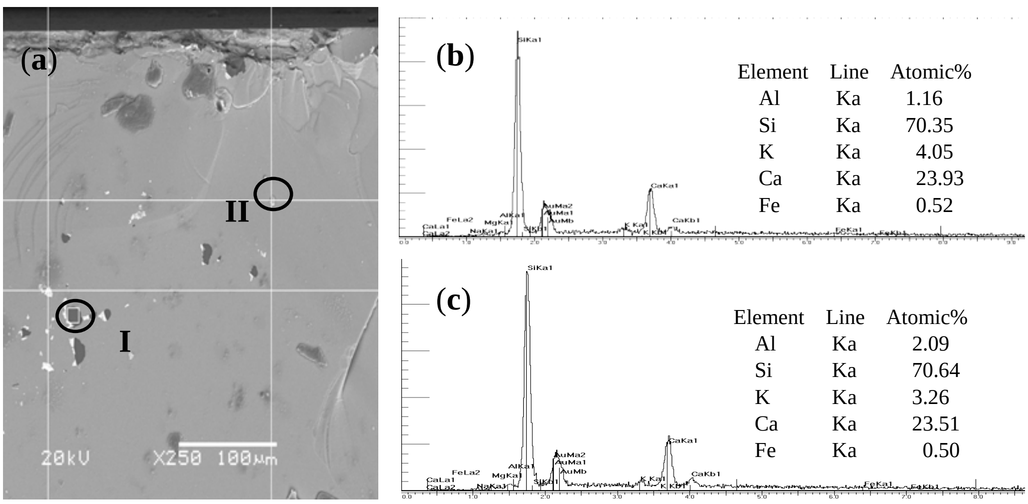

Fig. 5 SEM observation result for fractography of broken glass slab (a), in which I is a black spot and II is a white spot. (b) DES of I in (a), and (d) DES of II in (a).

It is worthy to point that, when we scanned the broken surface by SEM, we found an interesting phenomenon that is there are many white spots distributed in the broken surface and the number of white spots decrease with the distance away from the nick increasing shown as in Fig.6(a). A white spot is about 10μm in size (see Fig. 6(b)). And when we continually bombard the white spot by electrons, the white spot will disappear after several seconds. That means that the white spot is comprised by the elements with smaller atomic number. The scanned specimen has been neutralized when we scanned it, so we infer that when the specimen was broken, the positions occupied by the white spots are the charged ones, which absorbed the charged ions such as H^+ when the broken surface put in the air. It means that the positions occupied by white spots are the charged positions when the specimen is broken. As mentioned above, the main charged positions are distributed near the prefabricated nick, therefore we can easily explain why the surface charge density is related to the thickness of glass slab but it is not linearly relationship.

However, so far we cannot know the electrification mechanism of fracture. We cannot know what results in the broken part of glass charged and why the charges distribute near the nick when the glass slab is broken. Although some reports indicate that the existing Na^+ ions make some of the [SiO_4] three dimension network structures broken [20] and number of non-bridged oxygen significantly increases. Na^+ ions occurred near the center of the non-bridged oxygen hole neutralize the net charges. When the glass is broken, the Na^+ ions are free, therefore it may result in the broken glass charged. But the non-bridged oxygen should uniformly distribute in the glass, so if the inference mentioned is true, the charges also uniformly distribute in the broken surface and not near nick shown in Fig. 6(b). Unfortunately, we cannot know how to correlate the electrification mechanism with them and expect further studies.

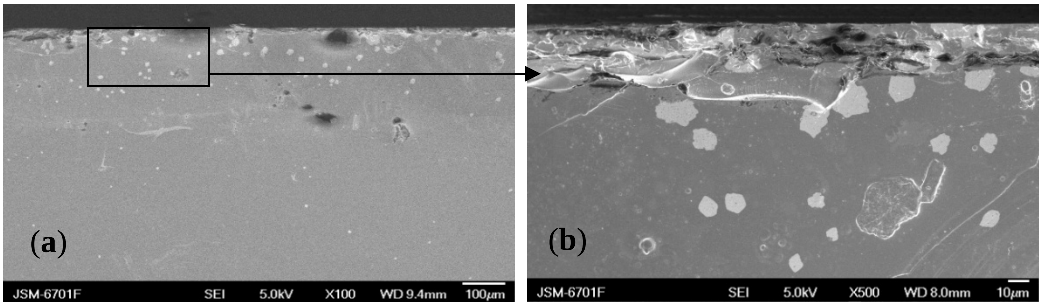

Fig. 6 SEM observation results of fratographies of broken surface of glass slab, in which many white spots distribute, (a) result magnified by 100 times and (b) result magnified by 500 times

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