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ELECTROMAGNETIC RADIATION EMITTED DURING FRICTION PROCESS

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Abstract. A series of studies of electromagnetic radiation (EMR) emitted during fracture of materials, enabled us to obtain a relationship between the width of a fracture and the wavelength of the emitted EMR. Applying this relation to friction we could check one of its suggested mechanisms, namely the Bowden-Tabor model, which states that during a friction process, asperities on the two contacting surfaces are "welded" together (at a microscopic level) and fractured. A uniaxial tension machine was used, whereby two half cylinders of chalk (CaCO3) bound together, were moved one against the other, generating friction. Calculations based on EMR observations showed that the average width of the fractured asperities was ~26.3 µm, while mechanical profilograph measurements of the average width of the total number of "long" asperities before and after the experiment, yielded values of 15.6 and 18.4 µm, respectively, implying that ~25% of "long" asperities were fractured during a single friction process.

Key words: Electromagnetic radiation (EMR), fracture, friction

1.Introduction

1.1. One of the most popular models of both static and dynamic types of friction is that of Bowden & Tabor (see Bowden and Tabor, 2001): adjoining two objects together generates pressure at the contact points (asperities) of the two "flat" surfaces which causes deformation and "welds" the contact points together. Lateral loading leads to force increase up to the moment when a relative motion starts (the dynamic phase) – when the static friction is maximal. The commencement of relative motion is characterized by two mechanisms: 1) Shearing across the asperities or the bulk itself and 2) Ploughing i.e. breaking of the protrusions on the two attached surfaces or notching the surface of one of the objects. Following the failure of larger asperities, smaller one begin to be effective and, due to the relative motion of the two surfaces, fracture as well, and so on, as long as the force, emulating scission, is exerted .

1.2. A novel model of EMR emission from material fracturing is described in Frid et al. (2003). This model enables us, among other things, to estimate fracture width. Thus, assume that a material wave (which is the origin of EMR) generated on the fracture surface is restricted by its width, 'b', Rabinovitch at el. (2000) showed that the values of 'b', the EMR wave length λ, the peak EMR frequency ω and the Rayleigh wave velocity v_R are related by:

$$b \approx \frac{\lambda}{2} = \frac{\pi \cdot v_R}{\omega} \qquad (1)$$

1.3 The main objective of this work was to examine the possibility of EMR registration during rock friction and to compare EMR results thus obtained to the ones observed during direct measurements of asperities' sizes on the rubbing surfaces.

2. Research arrangement and materials. We used cylinders of chalk *($CaCO_3$)* with the following properties: length 102.2 mm; diameter 53.01 mm; density $2.16 \pm 0.1 \cdot 10^3 kg \cdot m^{-3}$; Young modulus 9.30 GPa; Poisson ratio 0.14. The properties of this material and sample preparation procedure were described in detail in our previous papers (Rabinovitch et al., 2000, Bahat et al., ,2001). The sample was cut into two longitudinal half cylinders (HC) (Fig. 1a).The two surfaces of the HC were "mapped" across their central lateral axis, before and after the friction test, with a Rank Taylor Hobson Surtronic 3+ profilograph. One end of each HC was glued to an end-cup and, subsequently, the HC were bound tightly together to reach a maximum contact and obtain a normal force between their two "flat" surfaces (Fig.1a). This assemblage was attached to a tension machine (TerraTek System). The bottom end-cup was connected to the tension machine table and remained stationary during the test, while the top end-cup was joined to the moving piston (Fig. 1b).Two deformation detectors placed between the two end-cups together with the closed servo-loop of the tension machine supplied a constant rate of relative HC movement ($1x10^{-5}s^{-1}$).

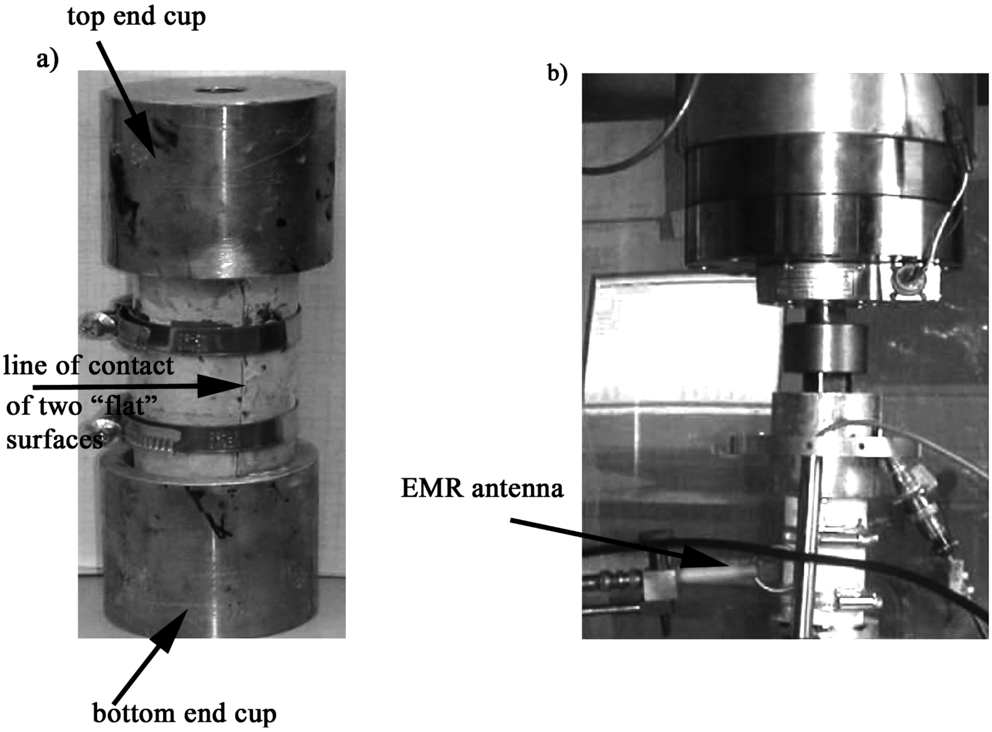

Figure 1. a. The two half cylinders (HC) bound together by two rings. Left HC is glued to the top end cup while right one – to the bottom end cup. An arrow shows the line of contact between the two surfaces of the HCs. b. Part of our experimental assemblage. The top end cup is connected to the piston of the tension machine. Arrow shows EMR antenna placed about 2 cm from the line of contact. The normal to the antenna is parallel to the plane of the surface of contact.

A one-loop magnetic antenna, 3 cm in diameter, was placed between the rings (Fig. 1) and about 2 cm away from the two surfaces of the HC, with the normal of the antenna plane parallel to the surfaces (Fig. 1b). The system was placed in a "Faraday Cage" to avoid external noise. Our electronic arrangement is described in detail in our previous works (see e.g. Bahat et al.,2004]).

3. Preliminary results and discussion. 10 profile maps along a lateral line at the center of the surface were obtained both before and after the friction process, out of which 200 and 237 (before and after the friction experiment, respectively) - the most outstanding - asperities were measured in detail. Fig. 2 shows an example of such mapping. Fig. 3 shows histograms of asperities' widths together with a Gaussian fit.

As is seen, the average width before the friction process was 15.6 μm (Fig. 3a), while after it, it increased to 18.4 μm (Fig. 3b).

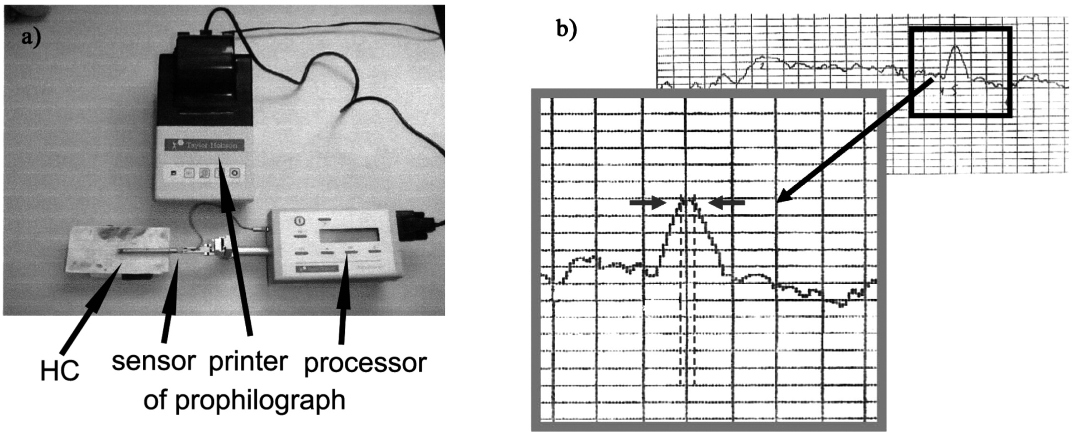

Figure 2. a. Propilograph assemblage including sensor, processor, printer and HC installed for mapping; b. A sample of asperity mapping by the prophilograph together with its enlargement.

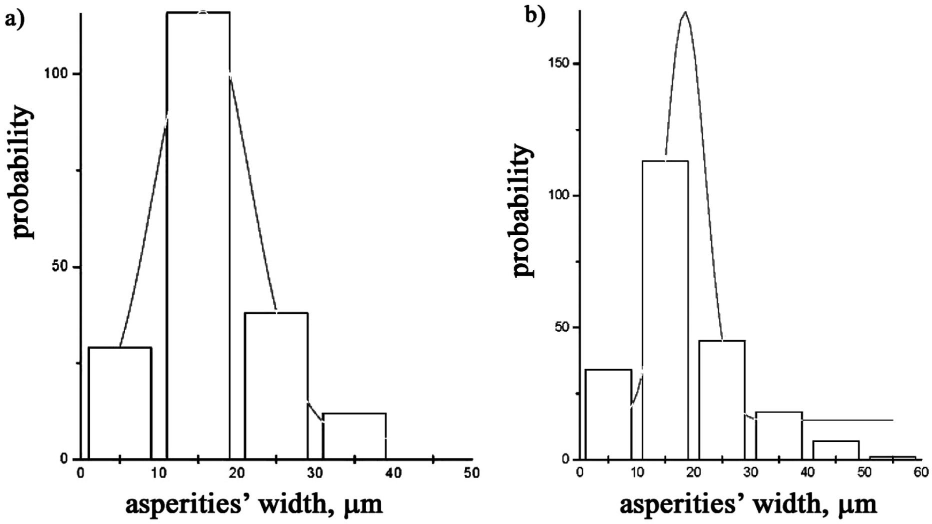

Figure 3. Histograms of asperities' widths together with its Gaussian fit before (a) and after (b) the friction test.

21 EMR pulses were observed during the friction experiment. The frequency of each pulse was obtained by extrapolation (Fig. 4a) and the fracture width was calculated by Eq. 1. Fig. 4b shows the calculated histogram of asperities' widths together with its Gaussian fit. As is seen, the average fracture width is 26.3 μm.

Denoting by 'n' the number of broken asperities and by 'N' the total number of "long" asperities we assume that the measured total average width after the experiment '*l*' is obtained by averaging the widths 'b' of the broken asperities (calculated by EMR) and that of the unbroken ones 'a'. Thus, $\frac{n \cdot b + (N-n) \cdot a}{N} = l$. A crude estimate of the ratio between the number of broken asperities (n) and the total number of lengthy asperities (N) is therefore: $\frac{n}{N} = 0.261$, which seems feasible.

4. Conclusions

Our experiment showed that EMR does emanate during the friction process. An analysis of the "flat" surfaces of the rubbing rocks before and after friction showed that the average asperity width prior to the friction process was less than the one after it, implying fracture of asperities during the friction experiment. A consistency of the results obtained by EMR during, and by profilometer before and after, the friction process was obtained. Further research is presently under way.

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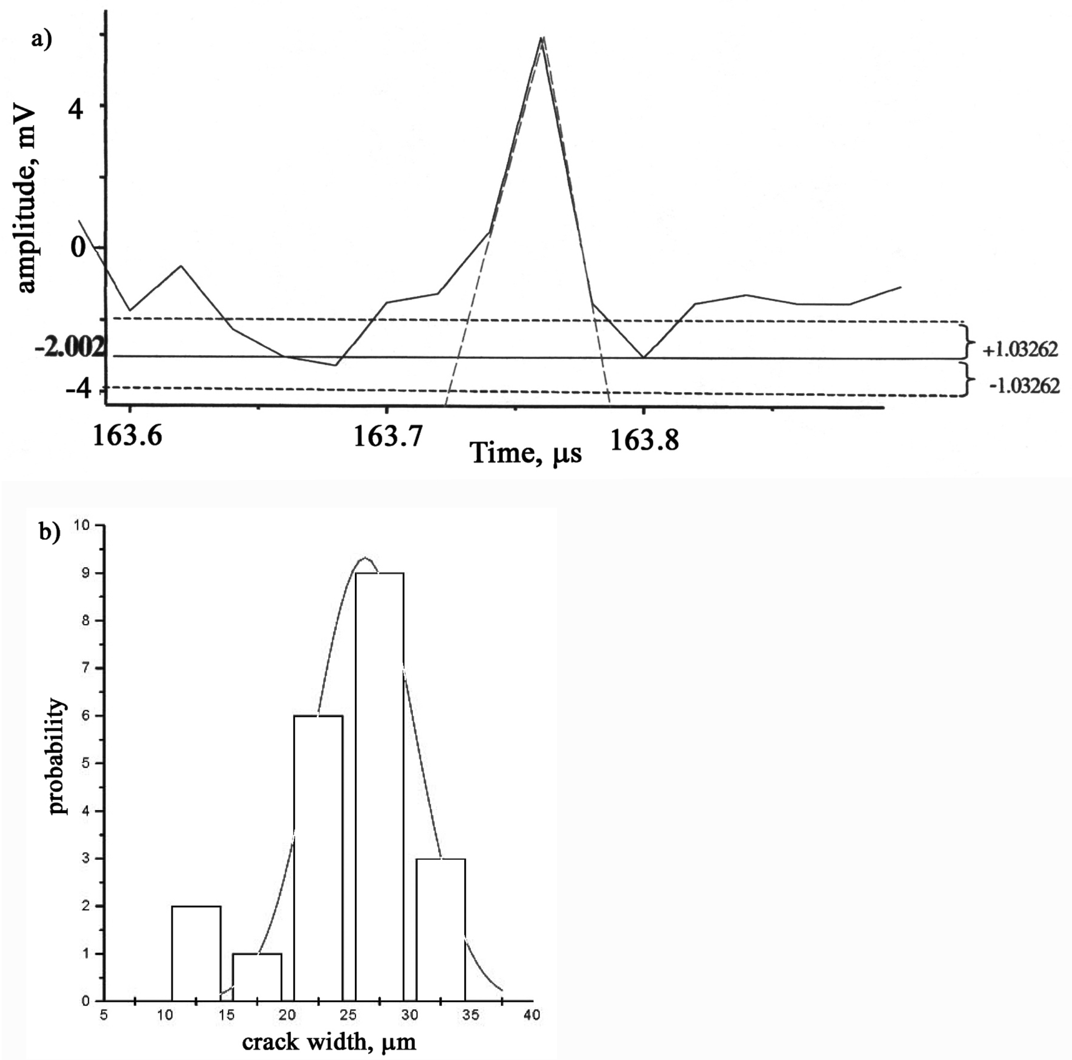

Figure 4. a. A sample of EMR signal, the frequency of which was obtained by extrapolation (dashed lines); b. Histogram of asperities' widths calculated by Eq. 1. according to the frequency of EMR signals together with its Gaussian fit.

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