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The effect of maximum normal impact load, absorbed energy and contact impulse on the impact craters volume/depth of DLC coating under repetitive impacts

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1. Introduction

Recently, the requirements for measuring dynamic responses have become severe and varied in many industrial and research applications such as material testing, model analysis and crash testing[1]. Surface degradation often occurs due to this dynamic response. This phenomenon also appears in the DLC coatings material. In this present work, a self-developed horizontal impact tester can provides this type of response, which gives an effect to the impact craters volume/depth of DLC coating.

2. Experimental

Prior to the impact test, the absorbed energy response to the maximum impact force is evaluated using high speed camera. The influence of impactor mass is also considered, which each impactor have 115.4 g and 171.5 g, respectively. The impact test was performed using a self-developed impact tester as shown in Fig.1, where a DLC coated disc was repetitively impacted by chromium molybdenum steel (SCM420) pin under 400 impact cycles at room temperature. The diameter of disc and pin are 10 mm and 2 mm, respectively. The 90^o inclination of impact was run under lubricated conditions. Several different impact loads were applied to the disc specimen via a spring system and were observed by a load cell. The absorbed energy is determined from the plotted curve fitting of absorbed energy response to the maximum normal impact load. As for the contact impulse and maximum normal impact load on the DLC coating, it can be obtained from the graph generated by a load cell. The contact impulse is determined from the area below the graph of normal impact load with time. In addition, the impact craters volume/depth is calculated from the decomposition data of atomic force microscopy (AFM).

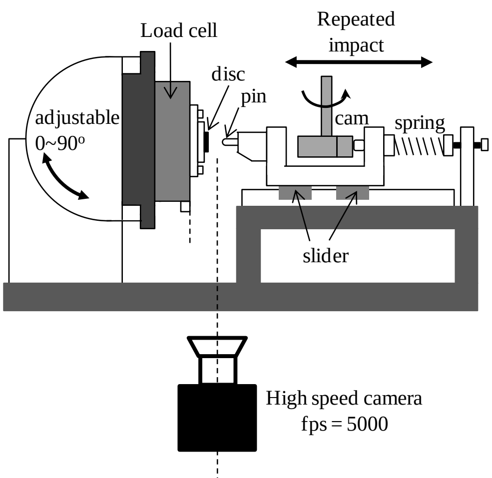


Fig. 1 Schematic illustration of a repeated impact tester

3. Results and discussion

Fig. 2 shows that the absorbed energy is dependent on the impactor mass. The absorbed energy is calculated using the following equation

$$E_a = \frac{1}{2} m (v_1 - v_2)(v_1 + v_2) \quad (1)$$

where m is the impactor mass, v_1 is the velocity before impact and v_2 is the velocity after impact. Besides, the lighter impactor has higher absorbed energy, while maintaining the maximum normal impact load. The method used to discuss about this result is described later in this paper. From a nonlinear regression analysis, the relationship between an absorbed energy and maximum normal impact load is given by

$$E_a = 2\times10^{-7} F^{1.5695} \quad \text{(for light impactor)} \quad (2)$$

$$E_a = 2\times10^{-8} F^{1.9216} \quad \text{(for heavy impactor)} \quad (3)$$

where F is the maximum normal impact load. Eqn. (2) and (3) are true if only all test conditions and parameters are the same as in this study.

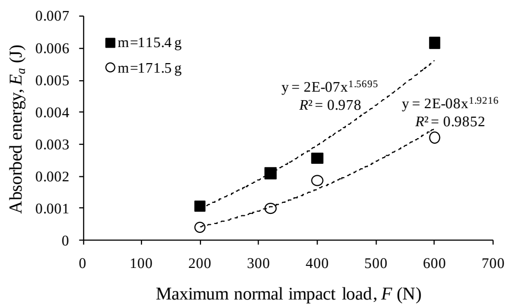


Fig. 2 The absorbed energy corresponding to the maximum normal impact load for different impactor masses

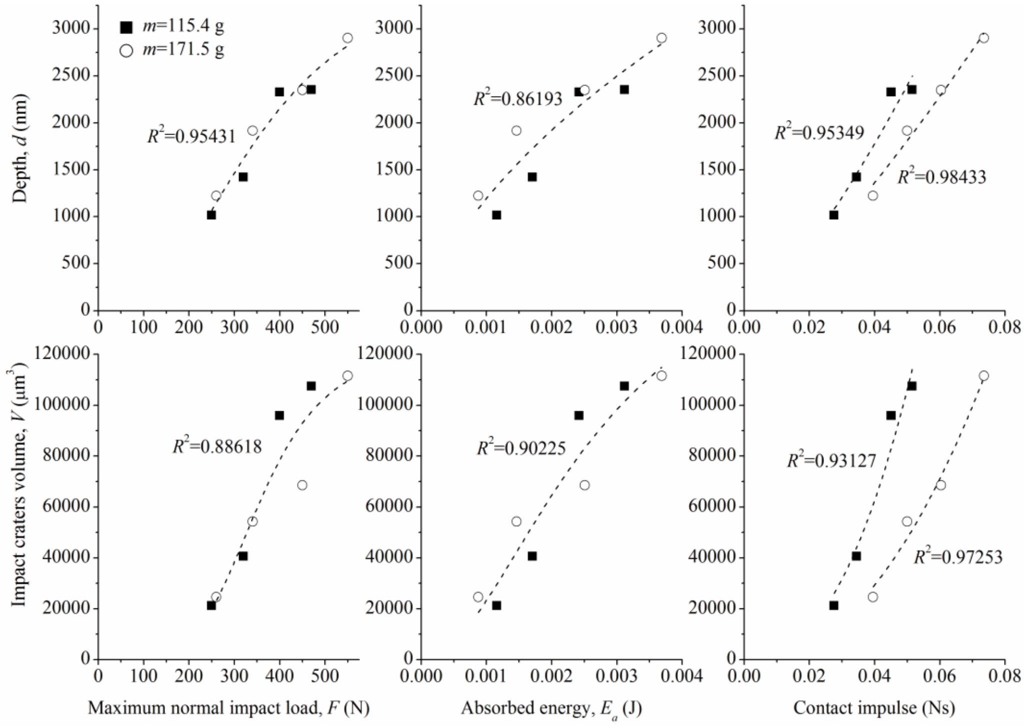
Fig. 3 shows that there is a fairly good agreement for the maximum normal impact load and absorbed energy. These dynamics characteristic affect the impact craters volume/depth of DLC coating. Although, the plotted graph of depth versus maximum normal impact load shows the best curve fitting, which indicates by the highest chi-squared value, R^2, a cluster of data points in its impact craters volume also can be seen at higher maximum normal impact load. This is due to the microslip effect as shown in Fig. 4. The pin, where attached to the light impactor, has a little bit tangentially shift during impact. This tangential movement is usually caused by an elastic deformation of the supporting structures[2]. Consequently, the microslip is occurred and the impact crater volume is larger than it should be. From this reason, pronouncedly indicates that the most important factor that affects the impact craters volume/depth of DLC coating is an absorbed energy.

It is assumes that there is another energy involved in order to evaluate the absorbed energy during impact. An expression of this energy can be derived as follows

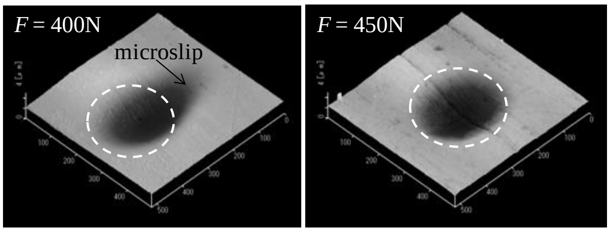
$$E_1 = E_2 + E_v + E_p \quad (4)$$

$$E_a = E_1 - E_2 = \frac{1}{2} m (v_1 - v_2)(v_1 + v_2) \quad (5)$$

$$E_a = E_v + E_p \quad (6)$$



where E_1 is the impactor energy just before impact, E_2 is the impactor energy just after impact, E_v is the vibrational energy caused by the impacted disc/load cell and E_p is the plastic deformation energy. If the relationship shows in Eqn. (6) is true, then the estimation of E_v and E_p is important in this study. Unfortunately, the equation for vibrational energy and energy due to the plastic deformation is still under investigation.



(a) (b)

Fig. 4 The AFM topography of a DLC coated disc after impacted with pin, by using (a) light impactor and (b) heavy impactor

The change in momentum of the pin and the impulse acting on the load cell, $\int F dt$, are equal according to the law of conservation of momentum if other forces can be ignored[1]. This is expressed as

$$\int F dt = m(v_1 - v_2) \quad (7)$$

Because of the velocity after impact, v_2 is in opposite direction with the velocity before impact, v_1, the Eqn. (7) becomes

$$\int F dt = m(v_1 + v_2) \quad (8)$$

Further, the implication of contact impulse to the impact craters volume/depth of DLC coating is shown in Fig. 3. The agreement is apparently not quite so good. Two different curves are clearly illustrated and might be dependent on impactor mass. As noted earlier, the plotted graph of absorbed energy versus maximum normal impact load also dependent on impactor mass. Thus, Eqn. (9) suggests that this discrepancy is due to the total different of impact velocity before and after the impact and directly independent of the impactor mass. By substituting Eqn. (8) into (1) yields

$$E_a = (v_1 - v_2)\int F dt = (v_1 - v_2)F\Delta t \quad (9)$$

where previously evident that the impact craters volume/depth of DLC coating should also be dependent on absorbed energy and maximum normal impact load.

4. Conclusions

The repetitive impacts test were performed to evaluate the significance of maximum normal impact load, absorbed energy and contact impulse on the impact craters volume/depth of DLC coating. The results show that the impact craters volume/depth of DLC coating is not in a good relationship with contact impulse and separated by two different curves fitting. It is demonstrated that these inconsistencies are caused by the total different of velocity before and after the impact. From the nonlinear regression analysis, it is shown that the impact craters volume/depth of DLC coating is dependent on maximum normal impact load and absorbed energy. However, a scattering data points at higher normal impact load is observed in the plotted graph of impact craters volume versus maximum normal impact load. This is believed due to the microslip effect by using light impactor during impact test. For this reason, it can be concluded that the most crucial factor that affects impact craters volume/depth of DLC coating is an absorbed energy.

5 References

1) Y. Fujii & H. Fujimoto: Design Note: Proposal for an impulse response evaluation method for force transducers, Meas. Sci. Technol, 10 (1999) 31.
2) G. W. Stachowiak & A.W. Batchelor, Engineering Tribology, Elsevier Butterworth-Heinemann, USA, 2005.