Advances in Technology Innovation, vol. 1, no. 2, 2016, pp. 41 - 45

Experimental Investigation into Mechanical Properties of Nanomaterial-reinforced Table Tennis Rubber

Yu-Fen Chen[1,*], Jian-Hong Wu[2], Chen-Chih Huang [3]

[1]Office of Physical Education, National Formosa University, Yunlin, Taiwan.

[2] Taiwan Semiconductor Manufacturing Company Limited, Hsinchu, Taiwan.

[3]Department of Sport, Health & Leisure, Wufeng University, Chiayi County, Taiwan.

Received 02 February 2016; received in revised form 28 March 2016; accepted 02 April 2016

Abstract

A new table tennis rubber is prepared consisting of carbon nanotubes, zinc oxide and titanium oxide added to a mixture of natural and synthesized rubber. The Nano-reinforced rubber is attached to wooden table tennis blades and patterned with four different surface structures, namely flat, long pimples, short pimples and medium pimples. The results show that of the five rubbers, the Nano-reinforced rubber with a flat surface offers a significantly improved elastic and mechanical performance.

Keywords: table tennis rubber, surface modification, carbon nanotube, zinc oxide, titanium oxide

1. Introduction

Polymer compound materials have many advantages over traditional engineering metals and alloys, including a high strength, a low weight, good resilience, a low cost, and superior chemical resistance. Consequently, the synthesis and characterization of polymer composites has attracted significant attention in the literature [1-3]. Furthermore, with the advancement of nanotechnology, nanometer-scale materials are now used widely throughout the textiles, biomedical, agricultural, industrial, electronics and energy generation fields. Many studies have shown that nanoparticle addition provides an effective means of altering the mechanical properties of compound materials, thereby improving the performance of existing products or paving the way for the development of new ones [4-5].

Polymer compound materials have found extensive use in the sports equipment field. For example, the rackets used by table tennis players were originally made simply of wood, and hence games were played at slow speed with a lack of spin. In the 1920s, however, European manufacturers attached a rubber skin to the bat; thereby enabling players to strike the ball with a far greater velocity and to exert a higher degree of control over the ball trajectory [6-7]. In later years, Japanese manufacturers replaced the rubber skin with innovative polymer compound materials; leading to a further significant improvement in player performance [8-10].

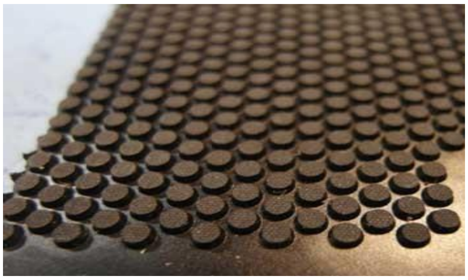
The literature contains many investigations into polymer compound materials and rubber modification. However, the modification of polymer composite materials for sporting applications has thus far attracted relatively little attention. Accordingly, the present study develops a new rubber material for table tennis rackets consisting of a mixture of carbon nanotubes (CNTs), zinc oxide (ZnO) and titanium oxide (TiO_2) added to natural and synthesized rubber. The Nano-reinforced rubber is attached to wooden table tennis paddles and patterned with four different surface structures, namely flat, long pimples, short pimples and medium pimples. The restitution coefficient and mechanical properties (yield stress, elastic modulus and shear modulus) of the four Nano-reinforced rubbers are then investigated and compared with those of a flat non-reinforced rubber skin.

* Corresponding author, Email: yvonne@nfu.edu.tw

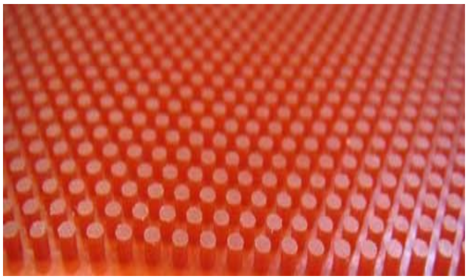
2. Experimental Process

0.035 g CNTs, 0.105 g TiO_2 and 0.175 g ZnO were added to a 35-g mixture of natural and synthesized rubber. The Nano-reinforced rubber was glued to wooden table tennis blades and patterned with four different surface structures, namely flat, short pimples, long pimples and medium pimples, as shown in Figs. 1(a)~(d), respectively.

(a) flat



(b) short pimples



(c) long pimples

(d) medium pimples

Fig. 1 The different surface structures of Nano-reinforced rubber

2.1. Restitution Coefficient

The restitution coefficients of the Nano-reinforced rubber skins were evaluated in a wind-less environment using the experimental setup shown in Fig. 2. In each test, a table tennis ball was placed at a height of 300 mm above the racket and was then dropped vertically onto the racket surface. The rebound height of the ball was recorded using a high-speed camera and the restitution coefficient of the rubber was then computed as $e = \sqrt{\frac{\text{rebound height}}{\text{drop height}}}$. For each rubber, the restitution coefficient was calculated in three separate tests and then averaged to obtain a final representative value.

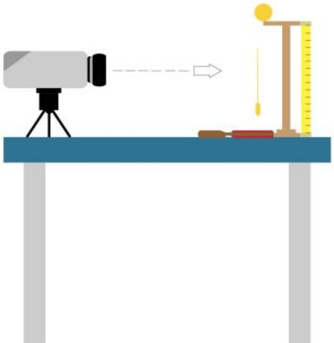


Fig. 2 Experimental setup used for restitution coefficient testing

2.2. Mechanical Properties

The mechanical properties of the Nano-reinforced rubber skins were evaluated using the Material Testing System (MTS 810) shown in Fig. 3. Test specimens with dimensions of 150 mm x 3 mm x 1 mm (length x width x thickness) were prepared. Each specimen was extended at a constant rate of 10^{-1} s^{-1} until the point of fracture. The load and displacement values were measured continuously during the test, and were then used to compute the elastic modulus and shear modulus of the rubber in accordance with basic engineering theory. The MTS system comprised three components, namely:

Power unit: a hydraulic power system used to actuate the system.

Load unit: a stand-alone testing unit consisting of a load frame, crosshead lifts and locks, actuators, servo-valves, transducers and grip controls.

Control unit: a control system used to coordinate and control the power unit and load unit.

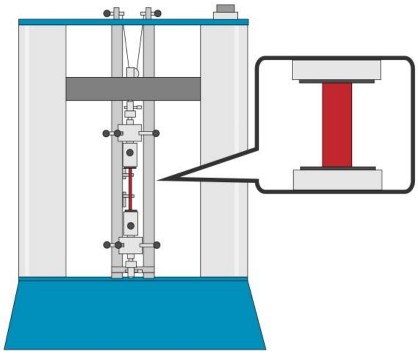


Fig. 3 MTS system used for mechanical property testing

3. Results and Discussion

3.1. Restitution Coefficient

Fig. 4 shows the restitution coefficients of the four Nano-reinforced rubbers. As expected, the restitution coefficient has a value of less than 1 for all five skins; indicating a non-fully-elastic collision between the ball and the racket. Notably, the Nano-reinforced rubbers all yield a slightly higher reinstitution coefficient than the non-reinforced skin. In other words, all four rubbers have a higher elasticity than the original skin. The performance improvement is particularly apparent for the three reinforced rubbers with pimples-out surface patterns.

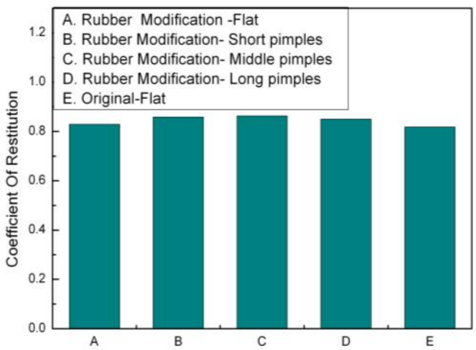


Fig. 4 Restitution coefficients of Nano-reinforced rubbers and non-reinforced rubber

3.2. Stress-bearing Capability

Fig. 5 shows the yield stress values of the Nano-reinforced and non-reinforced rubbers. (Note that the stress values indicate the maximum stress recorded in the tensile tests, i.e., the stress at which specimen failure occurred.) As shown, the flat Nano-reinforced rubber has a maximum stress of approximately 8.03 MPa. By contrast, the non-reinforced rubber has a maximum stress of around 7.04MPa. In other words, the reinforced rubber has an improved stress-bearing capability, and thus provides a better wear resistance. Notably, however, the pimples-out rubbers all have a lower stress-bearing capability than the non-reinforced rubber. The loss in strength is particularly apparent in the rubber with a long-pimple structure.

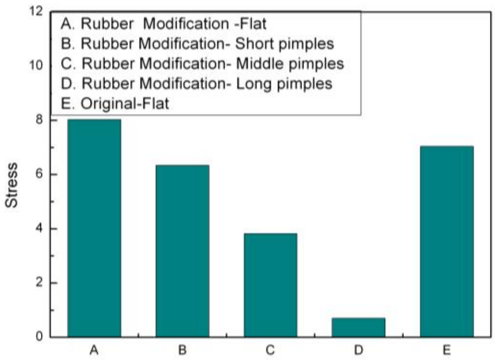


Fig. 5 Stress-bearing capabilities of Nano-reinforced rubbers and non-reinforced rubber

3.3. Elastic Modulus

For each rubber, the elastic modulus was computed as $E = \text{Slope} = \Delta\sigma/\Delta\epsilon = (\sigma_2 - \sigma_1)/(\epsilon_2/\epsilon_1)$. The corresponding results are shown in Fig. 6. It is seen that the flat Nano-reinforced rubber has an elastic modulus of approximately 1.8. For the non-reinforced flat rubber, the elastic modulus is equal to approximately 1.09. In other words, the addition of CNTs, ZnO and TiO_2 is beneficial in improving the stiffness of the rubber skin. However, the use of a pimples-out surface pattern greatly reduces the rubber stiffness. For example, the Nano-reinforced rubber with a long-pimple structure has an elastic modulus of just 0.13, i.e., around 8 times lower than that of the non-reinforced flat rubber skin.

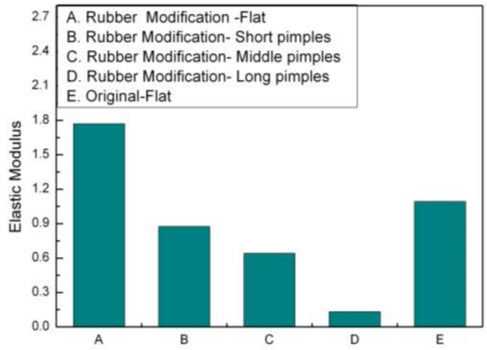


Fig. 6 Elastic modulus values of Nano-reinforced rubbers and non-reinforced rubber

3.4. Shear Modulus

For each rubber, the shear modulus was computed as $G=E/2(1+v)$, where v is the Poisson ratio (the values of the Poisson ratio for the present rubbers is 0.45). As shown in Fig. 7, the shear modulus of the flat Nano-reinforced rubber (0.6) is around 50% higher than that of the flat non-reinforced rubber (0.4). In other words, the reinforced rubber has a significantly improved shear resistance. However, for all the pimples-out rubbers, the shear modulus is lower than that of the non-reinforced rubber. Consequently, these skins are more prone to shear damage, and therefore fail at a lower maximum stress (see Fig. 4).

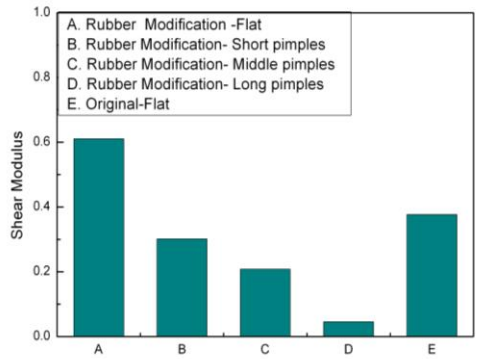


Fig. 7 Shear modulus values of Nano- reinforced rubbers and non-reinforced rubber

4. Conclusions

This study has synthesized a new table tennis rubber consisting of natural and synthesized rubber reinforced with a mixture of carbon nanotubes (CNTs), zinc oxide (ZnO) and titanium oxide (TiO_2). Reinforced rubber skins have been attached to wooden table tennis paddles and patterned with four different surface structures, namely flat, long-pimple, short-pimple and medium-pimple. The restitution performance and mechanical properties of the various rubbers have been evaluated and compared with those of a flat non-reinforced rubber skin. The experimental results have shown that the flat Nano-reinforced rubber outperforms the non-reinforced rubber in terms of a higher restitution coefficient, a superior stress-bearing capability, and an improved stiffness. As a result, it provides several important practical advantages over the non-reinforced rubber, including a superior elasticity and an improved wear resistance (i.e., a longer service life). The pimples-out reinforced rubbers provide a slightly higher elasticity than either of the two flat rubbers. However, the elasticity improvement is obtained at the expense of significantly lower mechanical properties. As a result, the pimple-based coatings are less practical for real-world table tennis applications.

Acknowledgement

The authors gratefully acknowledge the experimental assistance provided to this study by Professor S.C. Lin of the Department of Power Mechanical Engineering at National Formosa University, Taiwan. Furthermore, the preparation of the rubbers used in the present study by Training Co. Ltd, Taiwan, is also greatly appreciated.

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