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Prediction and Estimation of the Power of Thermoplastic Composite Tennis Racket

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Abstract

It is heard that although a thermoplastic composite racket gives comfort feeling during tennis impact, it is inferior to the ordinary composite racket in power. This paper predicts and estimates the performance of thermoplastic composite and compares it with that of ordinary racket in terms of the restitution coefficient, the maneuverability, and the power. It is based on the experimental identification of the racket dynamics and the simple nonlinear impact analysis. The predicted results could explain the mechanism of difference in performance between the thermoplastic composite racket and the ordinary composite racket.

Key Words: Sports Engineering, Tennis Racket, Thermoplastic Composite

Introduction

At the current stage, very specific designs are targeted to match the physical and technical levels of each user. The optimum racket depends on the physical and technical levels of each user. Actually, however, the terms used in describing the performance of tennis rackets are based on the feeling of an experienced tester or a player. Accordingly, there are many unclear points regarding the relationship between the performance estimated by a player and the physical properties of a tennis racket. It is said that a thermoplastic composite racket gives comfort feeling during tennis impact, but it is inferior to the ordinary composite racket in power [1]. This paper predicts and estimates the performance of thermoplastic composite and compares it with that of ordinary racket in terms of the restitution coefficient, the maneuverability, and the power. It is based on the experimental identification of the racket dynamics and the simple nonlinear impact analysis [2-9].

Racket Physical Properties and Prediction of the Restitution of Coefficient between a Ball and a Racket

The main specifications and physical properties of the test rackets are shown in Table 1. The racket called FX-110TP is a thermoplastic (TP) composite racket (341 g including the weight of strings), while the racket called Ex-110 is a conventional composite racket (365 g including the weight of strings). The TP material is made of reinforced fiber and thin resin film. Standard modulus 12 K carbon fiber and a Nylon 6 based resin were selected for its suitable physical properties and cost balance [1].

In Table 1, the sign I_{GY} denotes the moment of inertia about the center of mass, the sign

Table 1 Specification and Physical Properties of Rackets.

Racket	FX−110TP	EX−110
Total length	685 mm	685 mm
Face area	705 cm^2	705 cm^2
Mass	341 g	366 g
Center of gravity from grip end	314 mm	325 mm
Moment of inertia I_{GY} about Y axis	36.3 gm^2	40.7 gm^2
Moment of inertia I_{GX} about X axis	1.40 gm^2	1.68 gm^2
1st frequency	127 Hz	132 Hz
Strings tension	55 lb	53 lb

I_{GX} the moment of inertia about the longitudinal axis of racket head.

Since the experimental modal analysis showed that the fundamental vibration mode of a hand-held racket is similar to the mode of a freely supported racket, it is assumed in terms of power that the racket is freely supported [2,7]. The impulse could be approximately derived using a model assuming that a ball with a concentrated mass and a nonlinear stiffness collides with the nonlinear spring of strings supported by a rigid frame, where the measured restitution coefficient e_{BG} inherent to the materials of ball/strings is employed as one of the sauce of energy loss. The contact time T_c could be derived, if it is determined by the natural period of a whole system composed of the mass m_B of a ball, equivalent compound stiffness K_{GB} of a ball and strings, and the reduced mass M_r of a racket.

On the basis of the approximation of the force-time curve of impact as a half-sine pulse and the application of its Fourier transform to the experimentally identified racket vibration model, the initial amplitude of racket vibration due to impact can be derived. The energy loss due to the racket frame vibration can be derived from the amplitude distribution of the velocity and the mass distribution along a racket frame.

The coefficient of restitution (COR) e_r between a ball and a racket can be estimated by considering the energy loss E_1 due to frame vibration as well as the energy loss E_2 due to large instantaneous deformation of the ball and strings. The coefficient of restitution e_r corresponds to the total energy loss E ($=E_1 + E_2$) could be obtained as

$$e_r = [\,1 - 2E\,(\,m_B + M_r\,)\,/\,(\,m_B M_r V_{BO}^{\,2}\,)\,]^{1/2} \tag{1}$$

Figure 1 shows a simple forehand ground stroke model used in this study. A player hits a coming ball V_{Bo} of the velocity with the racket head velocity V_{Ro} given by $L_X(\,\pi N_s\,/\,I_s\,)^{1/2}$, where the sign L_X denotes the distance between the player's shoulder joint and the impact location on the racket face, N_s the constant torque around the shoulder joint, and I_s the moment of inertia of arm/racket system around the shoulder joint.

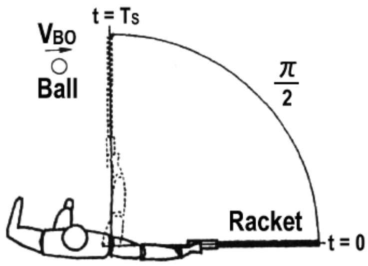

Fig.1 Simple forehand groundstroke swing model.

The predicted restitution coefficient e_r of a thermoplastic composite racket has been lower than that of a conventional composite racket, particularly at the off-center of the racket, where a player hits the ball ($V_{Bo} = 10$ m/s, $N_s = 56.9$ Nm).

Predicted Post-impact Ball Velocity and the Sweet Area in Terms of Power

Here we introduce the rebound power coefficient e defined by the ratio of rebound velocity V_B against the incident velocity V_{BO} of a ball when a ball strikes the freely supported racket at rest ($V_{Ro} = 0$) , written as Eq.(3) . The rebound power coefficient e can particularly estimate the rebound power of a racket for a volley.

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$$e = -V_B / V_{BO} = (e_r - m_B/M_r)/(1+m_B/M_r) \quad (3)$$

When a player hits the ball with pre-impact racket head velocity of V_{Ro}, the coefficient e can be expressed as

$$e = -(V_B - V_{Ro}) / (V_{BO} - V_{Ro}) \quad (4)$$

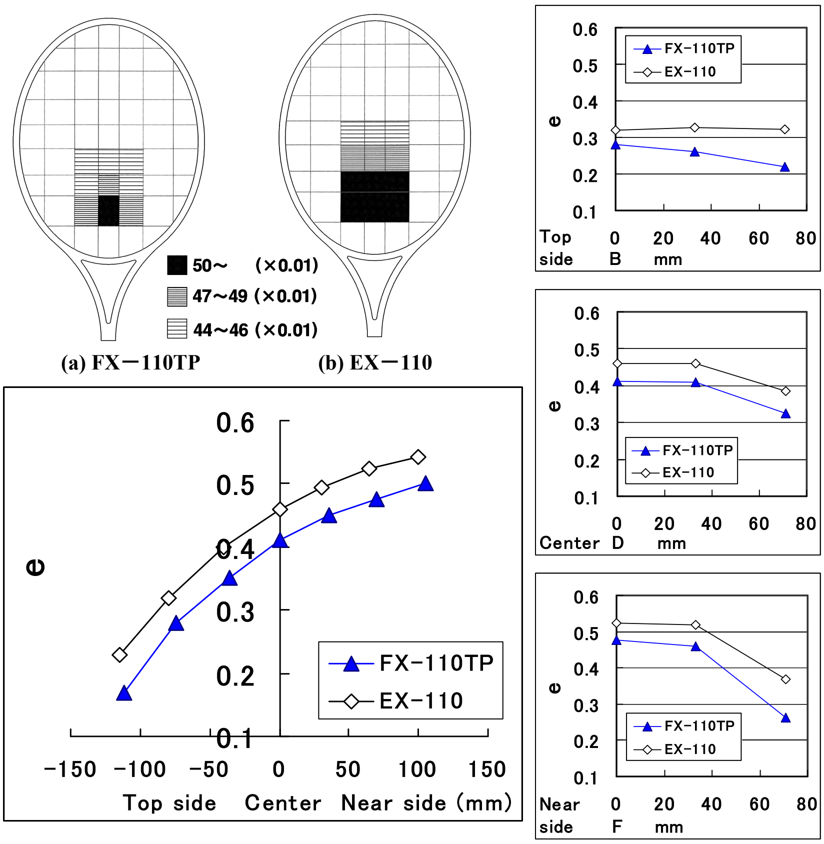
Figure 2 shows the predicted rebound power coefficient e when a player hits the ball at the longitudinal axis and off the longitudinal axis (V_{Bo} = 10 m/s, N_s = 56.9 Nm). It also shows the sweet area with respect to the rebound power coefficient e.
The post-impact ball velocity V_B could estimate the power of the racket when a player hits the ball. The V_B can be expressed as Eq.(5).

$$V_B = -V_{Bo}\, e + V_{Ro}(1 + e) \quad (5)$$

The predicted pre-impact racket head velocity V_{Ro} (N_s = 56.9 Nm) of a thermoplastic composite racket has been higher than that of a conventional composite racket.
Figure 3 shows the predicted post-impact ball velocity V_B when a player hits the ball at the longitudinal axis and off the longitudinal axis of the racket (V_{Bo} = 10 m/s, N_s = 56.9 Nm). It also shows the predicted sweet area with respect to the post-impact ball velocity V_B.
It is seen that the thermoplastic composite racket is lower than that of a conventional racket in terms of the post-impact ball velocity or power. However, there is no big difference.

Conclusions

It is said that a thermoplastic composite



(a) on the longitudinal (b) off the longitudinal

Fig.2 Predicted rebound power coefficient *e* (N_S=56.9Nm, V_{BO}=10m/s)

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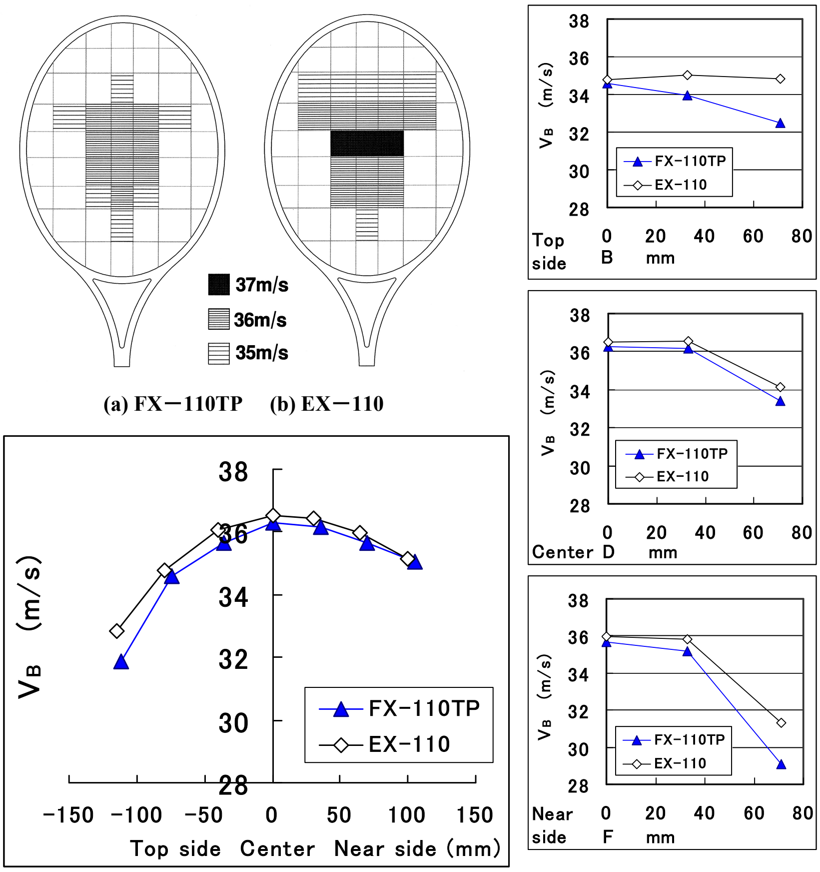

(a) on the longitudinal (b) off the longitudinal

Fig.3 Predicted post-impact ball velocity V_B

racket gives comfort feeling during tennis impact, but it is inferior to the ordinary composite racket in power. The predicted results could explain the mechanism of difference in power between the thermoplastic composite racket and the ordinary composite racket. Although the thermoplastic composite racket is lower than that of a conventional racket in terms of the post-impact ball velocity or power, there is no big difference between them.

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References

1. K. Muroi & Y. Shimizu, Proc. of 5th Japan International SAMPE Symp., 1317 (1997).
2. Y. Kawazoe, Dynamics and computer aided design of tennis racket. Proc. Int. Symp. on Advanced Computers for Dynamics and Design '89, 243(1989).
3. Y. Kawazoe, Theoretical and Applied Mechanics, Vol.41, 3(1992).
4. Y. Kawazoe, Theoretical and Applied Mechanics, Vol.42, 197(1993).
5. Y. Kawazoe, Theoretical and Applied Mechanics, Vol.43, 1994, pp.223-232.
6. Y. Kawazoe, *Science and Racket Sports*, E & FN SPON, 1994, pp.134-139.
7. Y. Kawazoe, Theoretical and Applied Mechanics, Vol.46, 1997, pp.165-176.
8. Y. Kawazoe, 5th Japan Int. SAMPE Symp., 1320 (1997).
9. Y. Kawazoe, Proc. of 6th Japan International SAMPE Symp, 783(1999).