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Performance Prediction of Tennis Rackets with Materials of the Wood and the Modern Composites

Yoshihiko KAWAZOE
Dept. of Mechanical Engineering, Saitama Institute of Technology
1690 Okabe-machi,Ohsatogun,Saitama, 369-02, Japan

ABSTRACT

This paper investigates the physical properties of an old wooden racket and a modern composite racket, predicting racket performamce in terms of the ball post-impact velocity and the shock vibrations of racket handle. It is based on the the experimental identification of the racket dynamics and the simple nonlinear impact analysis. The results show that the restitution coefficient and the post-impact ball velocity of the composite racket is higher and the amplitude of grip shock vibration smaller than those of the wooden racket. It also showed that the shock vibrations remain longer with the composite racket.

KEY WORDS: Impact, Tennis Racket, Coefficient of Restitution

1. INTRODUCTION

Material composites have increased the degree of freedom of design and manufacturing for sports products. At the current stage, very specific designs are targeted to match the physical and technical levels of each user. However, ball and racket impact in tennis is an instantaneous non-linear phenomenon creating large deformations in the ball/string and vibrations in the racket. The problem is further complicated by the involvement of humans in the actual strokes. Therefore, there are many unknown factors involved in the mechanisms explaining how the materials of the racket frame influence the racket capabilities.

This paper investigates the physical properties of an old wooden racket and a modern composite racket, predicting racket performamce in terms of the ball post-impact velocity and the shock vibrations of racket handle. It is based on the experimental identification of the racket dynamics and the simple nonlinear impact analysis. It also clarifies the mechanism of a difference in performance of these two different type of tennis rackets.

2. EXPERIMENTAL IDENTIFICATION AND IMPACT ANALYSIS

The racket vibration characteristics were investigated using the experimental modal analysis for a racket placed horizontally on a soft sponge (corresponding to mid-air hanging, freely supported racket) and a racket with the handle held firmly by a hand. Figure 1 shows the impact points of a test racket during experimental modal analysis using the impulse hammer method[1][2]. It also shows the impact locations when hitting a ball. The main

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specifications and physical properties of the test rackets are shown in Table 1. The frame of composite racket is made of carbon graphite. The racket geometry of wooden and composite rackets are shown in Fig.2. Figure 3 shows an example of the frequency response functions (compliances) and coherences when the racket was freely supported. Figure 3(a) shows the results obtained when the racket frame was impacted and Figure 3(b) shows the results obtained when the center of the string surface was impacted. Figure 4 shows the vibration

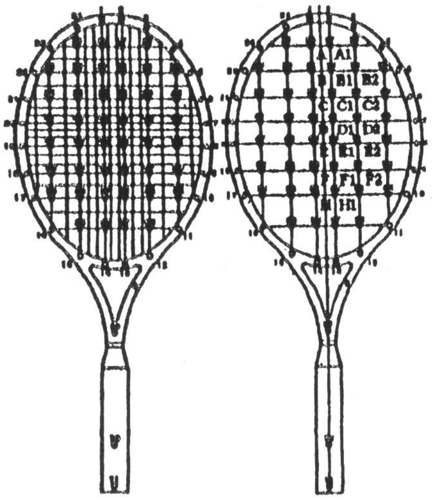

Fig.1 String mesh and impact location on the racket face.

Table 1 Physical properties

Racket	Wooden	Composite
Total length	685 mm	680 mm
Face area	516 cm ²	606 cm ²
Mass	375 g	370 g
Center of gravity from grip end	335 mm	317 mm
Moment of inertia I_{GY} about Y axis	41.2 gm ²	36.6 gm ²
Moment of inertia I_{GX} about X axis	0.937 gm ²	1.62 gm ²

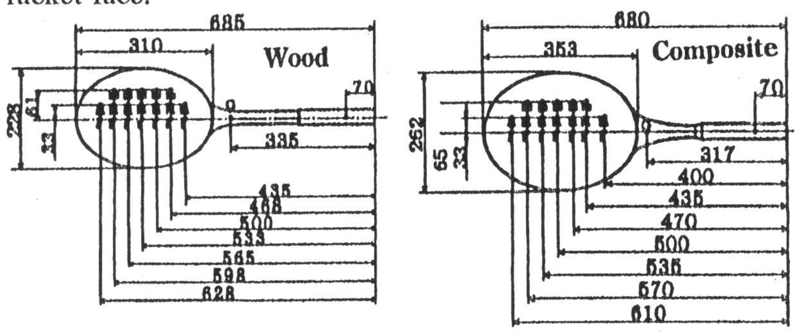

Fig.2 Racket geometry(Wooden racket and composite racket).

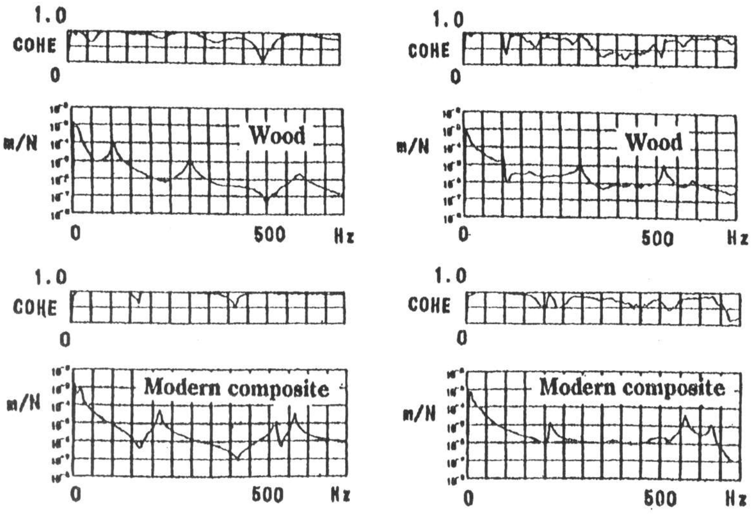

Fig.3 Measured frequency response function.

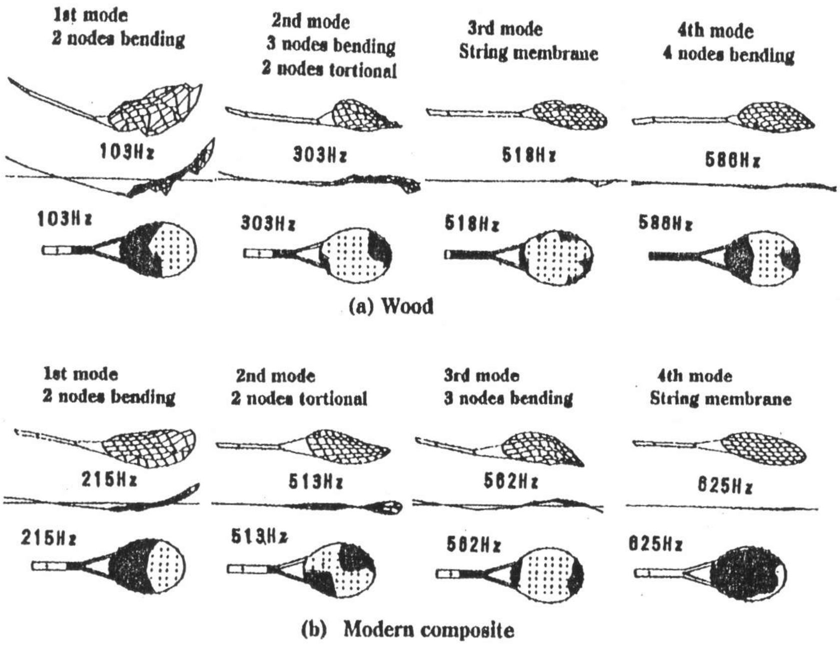

Fig. 4 Racket vibration modes derived by an experimental modal analysis.

modal analysis results for freely supported rackets. The points that cross the horizontal axis correspond to nodes of the frame vibration mode. The boundaries between the black and white regions represent the nodal lines on the string surface. Although the frame vibration damping for the hand-held racket was remarkably larger than that for the freely supported racket, there is no big difference in the modal shape.

The impulse could be approximately derived using a model assuming that a ball with a concentrated mass m_B and nonlinear stiffness collides with the nonlinear spring of strings supported by a rigid frame, where the measured restitution coefficient e_{BG} inherent to the

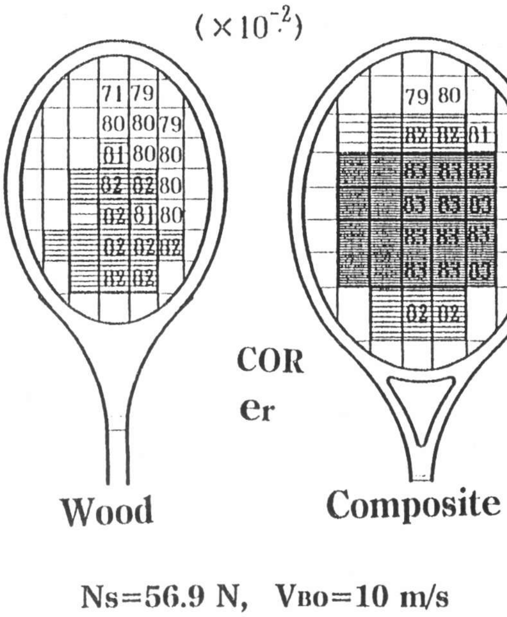

Fig.5 Predicted coefficient of restitution er on the racket face at impact.

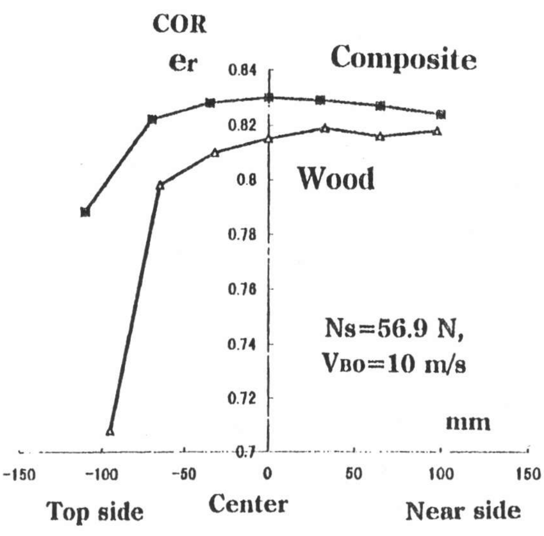

Fig.6 Predicted coefficient of restitution er on the racket face at impact.

materials of ball/strings is employed as one of the souce of energy loss[3]. The contact time T_C could be derived, if it is assumed that the contact time T_C, which is not much affected by the frame stiffness according to the experiment, is determined by the natural period of a whole system composed of the mass of a ball, equivalent compound stiffness K_{GB} of a ball and strings, and the reduced mass M_r of racket[4]-[7].

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 experimentaly identified racket vibration model, the initial amplitude of racket vibration due to impact can be derived. The amplitude seems to be somewhat larger for the hand-held racket compared to the freely supported

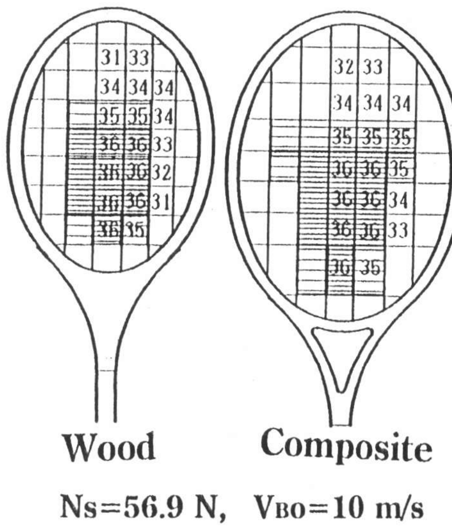

Fig.7 Predicted post-impact ball velocity V_B and impact location on the racket face.

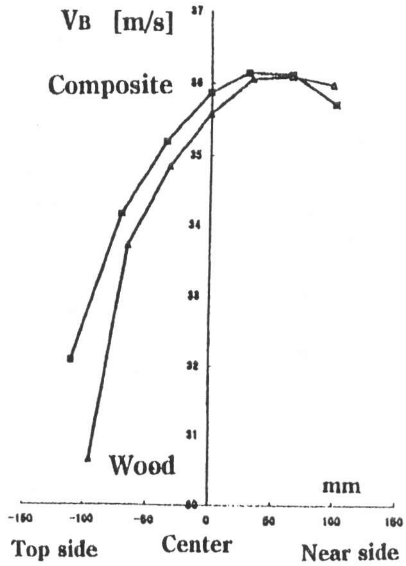

Fig.8 Predicted post-impact ball velocity V_B at the longitudinal axis.

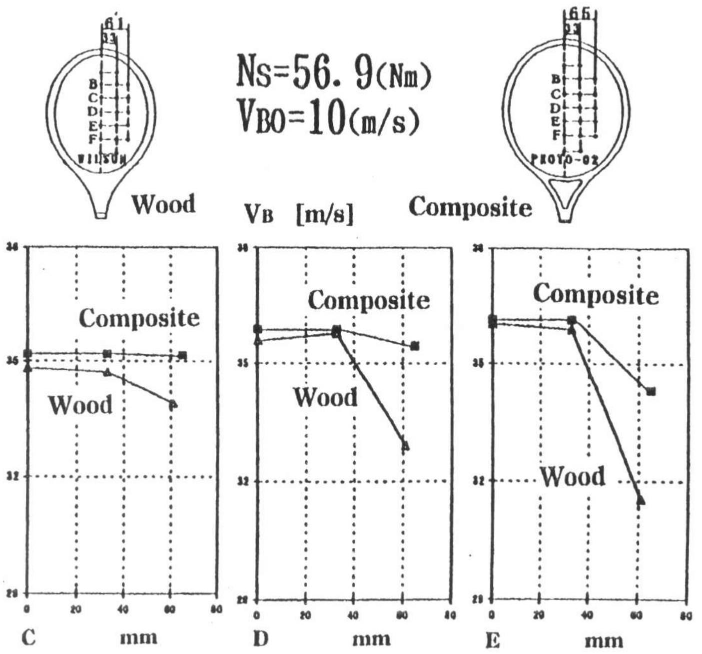

Fig.9 Predicted post-impact ball velocity V_B off the longitudinal axis.

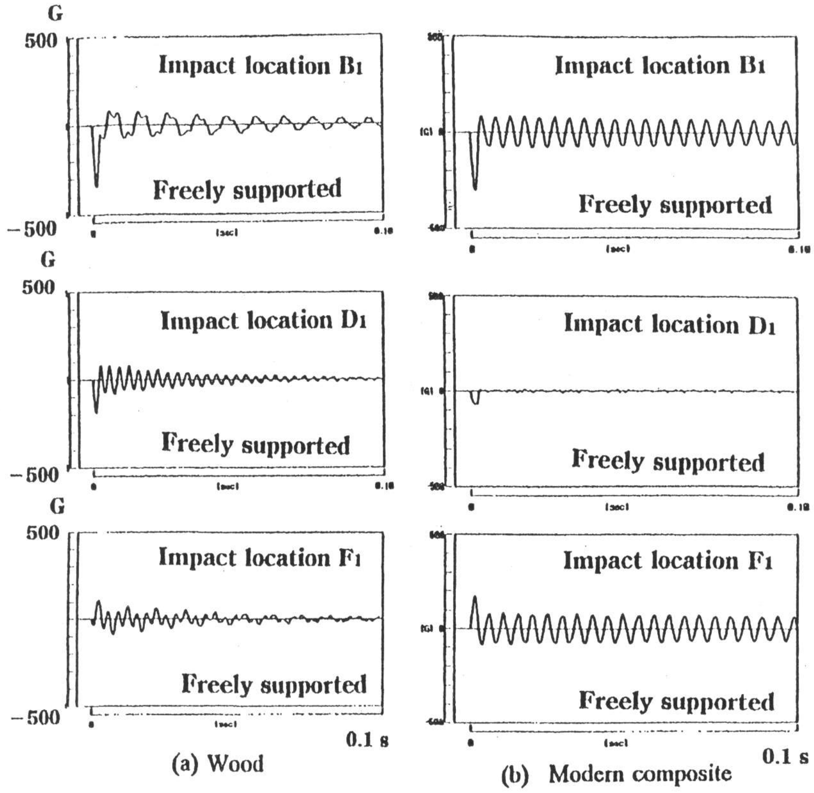

Fig.10 Predicted shock vibrations at the grip of a freely supported racket when a ball hits the racket at a velocity of 30 m/s.

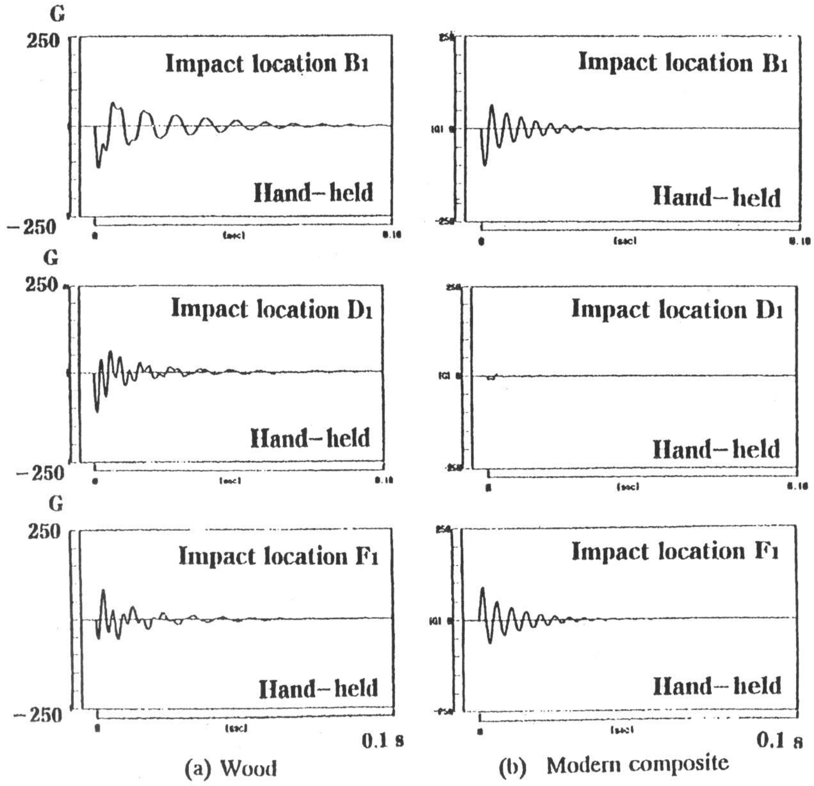

Fig.11 Predicted shock vibrations at the grip of a hand-held racket when a player hits flat forehand drive(Impact velocity between a ball and racket head is 30 m/s).

racket, there is no big difference in both cases. 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 e_r between a ball and a racket can be estimated by considering the energy loss due to large instantaneous deformation of the ball and strings and the energy loss due to frame vibration. The restitution coefficient e_r with a hand-held racket considering the reduced mass of a player's arm is almost the same as that with a freely supported racket[2].

Figure 5 and Fig.6 shows the predicted coefficient of restitution e_r on the racket face when a player hits a coming ball with a velocity of 10 m/s, where a simple forehand ground stroke swing model is used[6]. The restitution coefficient of a composite racket is higher than that of a wooden racket, particularly at the top of the string face.

Figure 7, Fig.8 and Fig.9 shows the predicted post-impact ball velocity V_B when a player hits a coming ball with a velocity of 10 m/s. Figure 8 shows V_B at the longitudinal axis, whereas Fig.9 shows V_B when a ball is hitted off the longitudinal axis. The post-impact ball velocity V_B of the composite racket is higher than that of a wooden racket at the top side of the string face.

It was shown that the predicted wave forms of the shock vibrations with the racket handle and the wrist joint agrees fairly well with the measured ones during actual forehand stroke by a player[7]. The Figure 10 shows the predicted shock vibrations of a grip 70 mm from the grip end when a ball strikes the freely supported racket at the top side, the center and the near side on the racket face. The shock vibrations are composed of the shock acceleration and the racket vibration components, and each copmponent has its own time history and magnitude depending on the impact velocity, impact location, grip location of racket handle and the physical properties of a racket. It is seen that the shock vibration of the wooden racket diminishes faster compared with composite racket. Figure 11 shows the predicted shock vibrations at the grip of a hand-held racket when a player hits flat forehand drive. The impact velocity between a ball and racket head is 30 m/s. The damping ratio of a hand-held racket during actual impact is estimated as about 2.5 times those of the one identified by the experimental modal analysis.

3. CONCLUSIONS

Although the restitution coefficient and the post-impact ball velocity of the composite racket is higher and the amplitude of grip shock vibration is smaller than that of a wooden racket, the shock vibrations remain longer with the composite racket.

References

1. Y.Kawazoe,Trans. JSME, 56-526,pp.1511-1517(1990).(in Japanese)
2. Y.Kawazoe,Theor.and Appl.Mech.,46,(1997).(in print)
3. Y.Kawazoe, Trans.JSME, 59-562,pp.1678-1685(1993).(in Japanese)
4. Y.Kawazoe, Trans.JSME, 58-552 ,pp.2467-2474(1992).(in Japanese)
5. Y.Kawazoe,Theor.and Appl.Mech.,41,pp.3-13(1992).
6. Y.Kawazoe and Y.Kanda, Trans.JSME,59-562,pp.3108-3115(1993).(in Japanese)
7. Y.Kawazoe,R.Tomosue and A.Miura,Proc.Int.Conf. on New Front. Bio. Eng.,285(1997).