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Non linearity of the ball/rubber impact in table tennis: experiments and modeling

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Abstract

Along with *comfort*, the *speed* is a key metric used to qualify the performance of a table tennis racket. The restitution coefficient which corresponds to the ratio between the velocities of the ball right before and after normally impacting the racket relates to the speed performance: the higher the restitution coefficient, the greater the *speed*. Thus, understanding the normal impact problem is key and suggests investigating the effects of the intrinsic properties and architectures of the constituents of the racket. In this work, both experimental and numerical studies were pursued. Experimentally, normal impact tests were performed for varying launching velocities on samples made of isolated or associated constituents of a table tennis racket and the restitution coefficients calculated. Numerically, 3D finite elements simulations were conducted to replicate the normal impact conditions while incorporating the time-dependent constitutive behavior of the polymeric elements contributing during the impact: the racket constituents (the foam and the compact) and the ball. The restitution coefficients are seen to decrease with increasing launching velocity, while being minimum when the two racket polymeric constituents are associated. A fair agreement is obtained with the FE simulations in which the sample/ball contact zone is identified as a ring with its mean radius increasing till the maximum crushing. Ultimately, additional FE calculations confirm that the friction plays a key role in the energy dissipation process, alongside with the rate-dependent behavior and architecture of the polymeric constituents.

Keywords: normal impact; restitution coefficients; polymers; architecture; energy dissipation

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1. Introduction

A table tennis racket is a complex layered hybrid materials comprising two polymeric sheets glued on to a wooden blade: an elastomeric dense foam and an architectured rubber (comprising a regular array of small cylinders) so-called compact. When impacted by a ball, both polymeric constituents can exhibit large reversible yet dissipative deformation, playing a key role in preserving the ball from breaking as well as contributing to the comfort and speed performances of the racket. Thus, manufacturers need to account for the polymeric constituents' properties and geometries in order to enhance the performances of new products.

Normal impact tests and the determination of the coefficient of restitution are used to evaluate the speed, which is the performance of interest in this study. Little is reported on the complex behavior of the racket constituents and their responses when normally impacted by a ball. However, the normal crushing of a thin-wall spherical launcher on a flat rigid surface has been widely studied. Quasi-static and/or dynamic behavior evidenced the buckling of the thin-wall sphere [1-5]. In studies where a table tennis ball is used, the celluloid constitutive materials is sometimes described as an elastic perfectly plastic material [1] even though glassy polymeric materials are complex viscoelasto-viscoplastic materials [6, 7]. Thus, the celluloid rate-sensitivity needs to be accounted

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for, specifically when the impact problem is considered and the properties measured under quasi-static conditions [4, 5]. Indeed, under dynamic conditions, the modulus and yield strength increase compared to low rate values. Recently, Zhang *et al.* used an inverse-fitting method to describe the visco-elastic properties of the celluloid material and to model the impact of a table tennis ball impacting a rigid surface [8].

Thus, the measurements of the visco-elastic properties of the ball is a real need and naturally, in the current problem where the rigid target can be replaced by polymeric ones, a precise description of the dissipative rate-dependent properties of the other polymeric counterparts are crucial. Thus, along with a precise account for the layers architecture, this work aims towards the identification of the key factors/effects altering the overall speed performance of a commercially available table tennis racket coating comprising a foam layer and a compact layer.

Nomenclature

${}^{R}C_R$, ${}^{F}C_R$, ${}^{FC}C_R$,	Coefficient of Restitution when the ball impacts a rigid, a foam or a foam+compact target respectively (-).
V_i , V_R	Incident and Reflected velocities respectively (m/s).
${}^{B}T_g$, ${}^{F}T_g$, ${}^{C}T_g$	Glass Transition Temperature of the ball, the foam and the compact respectively (°C).
ρ, $\underline{\rho}$	Absolute (kg/m^3) and relative (-) densities.
${}^{C}\nu$, ${}^{F}\nu$	Poisson ratio of the compact and the foam respectively (-)
DMA	Dynamic Mechanical Analysis.
DSC	Differential scanning Calorimetry.
FE	Finite Element

2. Normal impact experiments

2.1. Samples preparation

A commercial product from Cornilleau© is investigated. Xylene solvent was used to separate the foam layer from the compact layer. 100 mm x 100 mm squares of the foam and the foam+compact were cut, measured and weighted to determine their absolute densities (ρ) and glued onto rigid plates using double-sided adhesive tape. The balls were also measured and weighted to prevent abnormality.

2.2. Set-up and protocol

A home-made apparatus has been designed to launch table tennis balls yet controlling the ball's initial velocity and spin. The target is fixed normal to ball's trajectory onto the rigid frame, 260 mm away from the launcher's end. A camera coupled with stroboscopic lighting is set to acquire pictures which display the target as well as numerous traces of the ball before and after impact. Marks are drawn onto the target to locate its center and onto the ball to ascertain negligible spin and locate the joint equator. Two examples of recorded pictures are provided in Fig. 1a&b with clear identification of the drawn marks.

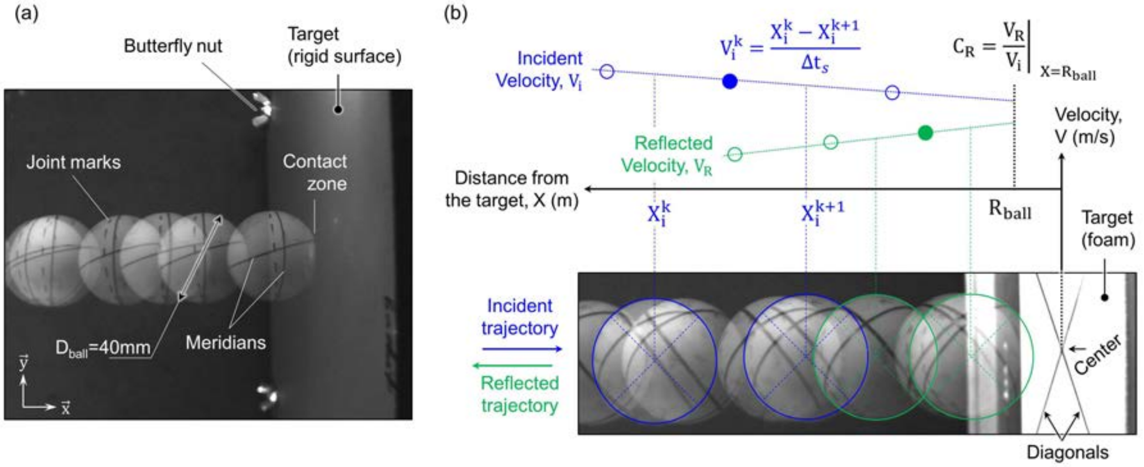

Fig. 1. Experimental determination of the restitution coefficient C_R: (a) raw image showing traces of the ball before, during and after contact with the rigid surface, (b) incident and reflected velocities are determined for different positions with respect to the impact location and extrapolated to determine the coefficient of restitution.