The Dual Function of Sand on a Clay Tennis Court

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Sand is not normally regarded as a lubricant. Try replacing engine oil with sand. But don't replace the sand on a tennis court with engine oil. Sand allows a player to slide on a court without slipping, thereby reducing the possibility of injury. Along with other sports surfaces, tennis courts are classified as being fast, medium, or slow, depending on the magnitude of the coefficient of sliding friction. The grass courts at Wimbledon are described as fast, while the clay courts used for the French Open are generally described as slow. A ball that bounces off a grass court tends to leave the surface at a relatively high speed and at a low angle, whereas a ball bouncing off clay tends to kick up at a relatively high angle and at relatively low speed. Players respond by using different tactics appropriate to each surface.[2] For example, the first-serve speed for men at Wimbledon is about 185 km/h, whereas the corresponding figure at the French Open is about 160 km/h. At the French Open, speed is sacrificed for extra spin, which causes the ball to kick up at an awkward angle, forcing the opponent to return the ball near shoulder height.

These effects can be described in terms of the coefficient of restitution, and the coefficient of sliding friction (COF) between the ball and the surface.[3] For grass, the COF is about 0.5 and for clay, about 0.8. Clay has a relatively high COF resulting in a relatively large decrease in the horizontal component of the ball speed when a ball impacts the surface. In addition, the coefficient of restitution on clay is higher than on grass, which adds to the rebound angle. Clay courts are covered with a layer of fine sand that allows a player to slide into and out of a shot much more easily than on grass. In other words, the COF between the surface and the player's shoes on clay is relatively low. In this sense, clay courts can be either fast or slow depending on whether we are referring to the ball or the player.

There is an obvious question here, one that appears not to have previously been asked: Why is the COF high for a tennis ball and low for tennis shoes? I searched all the books on friction and tribology I could find, and could not find an answer. Consequently, I set up a simple experiment to simulate these effects.

First, I dragged a smooth, 0.3-kg wood block with a 3.4-kg lead brick on top at low speed across a flat rubber sheet. (I used rubber to simulate the softness of clay.) With the aid of a spring balance to measure the friction force, I found that the COF = 0.39. I then sprinkled fine, dry river sand (grain size about 0.3 mm, relatively smooth, no sharp points) on the sheet of rubber and repeated the experiment, obtaining a COF = 0.14. Clearly, the sand acted as a lubricant by rolling between the rubber and the wood block — perhaps not pure rolling, since the COF is typically less than 0.05 for rolling friction. With three 3.4-kg lead bricks on top of the wood block, and with sand between the rubber and the wood, the COF increased slightly, to 0.19.

I then glued tennis-ball cloth to the lower surface of the wood block. Without any sand, the COF = 0.35 between the cloth and the rubber. When sand was sprinkled on the rubber, the COF increased to 0.41. With three 3.4-kg bricks on top of the block, the COF increased to 0.52. The COF between cloth and rubber therefore increased when sand was used as a lubricant, and it increased with the applied load. An obvious clue to this behavior was provided by the tracks left in the sand. When a block of wood is dragged across sand, it smooths the sand into a thin layer, one grain high, even if the sand is initially spread unevenly and piled several grains high. A smooth single layer of sand is left behind after the wood passes over it. Such a result indicates that each grain rolls over the grain below it until it falls into a gap and it then rolls between the wood and the rubber surface. A wood block on cylindrical rollers (sand grains) moves twice as far as the rollers and the sand pops out the back as the block passes over the sand. However, when the tennis-ball cloth was pulled across the sand, it dragged the sand with it, leaving a bare strip of rubber behind.

An interesting and convincing demonstration that sand slides under the cloth was obtained by drawing a pattern or a transverse line in the sand before dragging the cloth-covered block along the rubber sheet. The block was placed over the pattern and then loaded with a lead brick before dragging the block. The pattern was dragged along with the sand and was still clearly visible when the block was lifted.

Thus we observed the duality: sand located between cloth and rubber slides along the rubber, but sand located between wood and rubber rolls along the rubber. The weighted cloth conforms closely to the shape of each grain and traps sand grains between the fibers, preventing them from rolling. Cloth-covered sand therefore acts like sandpaper with a high coefficient of sliding friction. We can assume that the same effect occurs between a tennis ball and clay. The sole of a shoe, however, like the wood block, does not conform to the shape of each grain as well as the cloth on a tennis ball. As evidence, note that a tennis ball impacting on clay leaves a clean mark on the surface where the sand is swept away by the ball. A player sliding on clay leaves a track in the sand, but most of the sand is left behind and is not swept up under the shoe. Sand gathers in the grooves in the sole, leaving a footprint on the surface, but if it is not subject to a normal force it will not contribute to a frictional force.

Given that most students own at least one pair of sneakers, it would be an interesting undergraduate experiment to figure out if the grooves in sneakers add to or reduce the grip on the ground, and why. Some relevant physics can be found in the journal *Ergonomics*, **38** (1995). Issue two is devoted to footwear, see pp. 197–241.

References

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