Laser Surface Modification in GOLF CLUBS

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Lasers are particularly well suited to processing golf clubs, given their flexibility, speed, and low cost relative to other surface engineering techniques. Many such processes are available, and the best choice depends on the type of club and the features sought. One benefit of the laser approach is that the surface can be processed to have high hardness to resist wear, while the core of the component is not hardened, thus retaining a high level of toughness.

Furthermore, titanium and its alloys react energetically with gaseous species that can be controlled to produce high modulus, high hardness compounds such as titanium nitride and titanium carbide on the surface. (Fig. 1). The high modulus of these compounds provides an opportunity to tailor the vibrational response of the golf clubs, discussed in more detail below. Many interesting surface morphologies have also been generated, with potential performance improvements that are the subject of ongoing research (Fig. 2).

The Laser Surface Modification (LSM) process is based on a high-power laser that functionally modifies the surface texture, microstructure, and/or chemistry of the hitting surface of a golf club. YAG lasers are particularly well suited to golf clubs because many golf club alloys, such as titanium and stainless steel, readily absorb laser energy at 1.06 microns, the wavelength of YAG lasers.

This article describes several surface engineering technologies in golf club design, including CVD, PVD, thermal spray, and CNC machining. It also details results of LSM as it relates to texturing that boosts golf club performance.

Thin-film coatings
Thin-film coatings (typically 1 to 5 microns) are primarily applied to golf clubs for aesthetic reasons. Many of the metal nitride and carbon-based coatings have particularly attractive colors ranging from a light silver to a deep black. They work well in the case of putters, which have low impact velocities and limited contact with abrasive materials in the soil. On the other hand, wear and spallation of the section of the club that comes into contact with the ground limits thin-film lifetime when applied to wedges, irons, and drivers.

Thin-film coatings are applied by chemical vapor deposition (CVD) and physical vapor deposition (PVD). Typical coating materials include metal nitrides such as TiN, CrN, and TiAlN, as well as carbon-based materials such as diamond-like carbon (DLC) and tungsten-carbide/carbon composites (WC/C).

Thick film coatings
The purpose of thick film coatings is to make the impact face hard and wear-resistant. Thick films can be deposited by a number of different processes, with thermal spray as one of the most common. In the general thermal spray process, a powdered material or wire is fed into a hot zone generated by a plasma arc (i.e., plasma spray) or a combustion flame. The melted material is directed to a substrate...
**Golf club materials**

Golf club design has changed dramatically over the last 40 years, centered primarily around two ideas: modifying weight distribution within a golf club head, and improving the materials. Better weight distribution was pioneered in the late 1950’s and early 1960’s in an effort to increase the moment of inertia. A higher moment of inertia minimizes the torque generated by striking the golf ball outside the ‘sweet spot’ of the club. Inertia was increased by moving as much mass as possible to the perimeter of the club face, giving rise to the term ‘perimeter weighting.’ This remains the basis for design of putters, irons, and drivers to this day.

Advanced materials have played a key role in the evolution of golf clubs from a monolithic persimmon wood head that dominated the market through the 1970s, to today’s oversized titanium drivers. Alternative materials for driver construction have been reported as far back as the early 1900’s with the Mills Bulger Driver (a steel alloy head), but it was not until the late 1970’s and early 1980’s that graphite-based composite shafts and metal heads re-emerged to quickly dominate the market. The last five years have shown titanium alloys to be the (almost) undisputed material of choice for the construction of driver heads. It beat out the competition because of its high specific strength and recent price reductions as more cost-effective manufacturing methods were developed in China and Taiwan.

The importance of the grooves in the performance of drivers have dominated the industry, as golfers discovered that they were able to dramatically increase drive distance. Titanium provides this satisfying result because of its high ‘coefficient of restitution,’ or COR, which relates to the energy transfer as the ball collides with the club. It is measured by shooting a ball at a club at a known speed, and comparing that with ball speed after it bounces off the club face. If the initial speed is 100 mph and the rebound speed is 80 mph, then the COR is 80%, or 0.80. As a result, the higher the COR, the longer the distance that the ball travels.

Coefficient of restitution

In the last couple of years, Ti-6Al-4V and beta-titanium-faced drivers have dominated the industry, as golfers discovered that they were able to dramatically increase drive distance. Titanium provides this satisfying result because of its high ‘coefficient of restitution,’ or COR, which relates to the energy transfer as the ball collides with the club. It is measured by shooting a ball at a club at a known speed, and comparing that with ball speed after it bounces off the club face. If the initial speed is 100 mph and the rebound speed is 80 mph, then the COR is 80%, or 0.80. As a result, the higher the COR, the longer the distance that the ball travels.

Golf ball spin

The spin rate of the golf ball is significantly affected by grooves, surface roughness, and texture. A golf ball is in contact with the club during impact for approximately 450 microseconds. During a full-swing shot, the ball is compressed into a ‘D’ shape, and returns to the spherical shape after rebounding from the club. During the de-compression stage, the ball moves up the face of the club by either rolling or sliding.

The ball that slides up the club has a lower degree of backspin than the ball that rolls up the club. The backspin is beneficial in many instances because it produces a higher flight and a limited amount of roll after the ball lands.

Most ‘iron’ style clubs (particularly wedges) utilize precisely shaped grooves in the hitting face of the club. The purpose of the grooves is to grab the ball during the de-compression stage to force it to roll up the club instead of sliding. The golf industry has expended a significant amount of effort to optimize the spacing and geometry of the grooves. The importance of the grooves in the performance of irons and wedges is evident from the close regulation by the U.S.G.A.

Another significant factor for golf ball spin is the surface roughness of the club face. Several manufacturers have successfully marketed wedge clubs with a higher surface roughness than a standard club in an effort to create high initial spin rates. As with the geometry of the grooves, the surface roughness is regulated by the U.S.G.A. with a current limit on the Ra to 180 micro-inches maximum.

While previous efforts to create high-spin faces focused on merely increasing the surface roughness, laser surface modification (LSM) provides an opportunity to orient the surface texture to increase the level of backspin without increasing the level of deleterious side spin imparted to the ball.

While a high spin rate is generally beneficial for irons and wedges, recent research shows that the performance of drivers is optimized with a relatively low spin rate (2800 to 3000 rpm) and a high launch angle (12 to 14 degrees). In fact, for a number of years an ultra-low spin rate was thought to provide the best flight for drivers.

However, one manufacturer recently showed that an ultra-smooth clubface, combined with a small amount of moisture, resulted in a very low backspin rate –yielding extremely bad results. Therefore, some spin is required to generate
aerodynamic lift. This example indicates the importance of properly engineering the surface texture, because a surface can be either too rough or too smooth.

The LSM process has the flexibility to produce textures that generate high spin rates for wedges and optimum spin rates for drivers, while still providing improvements to the feel of the club.

Club ‘feel’

During a golfer’s swing, energy is transferred from the golf club to the ball upon impact. The collision is inelastic, with energy dissipating as heat (primarily in the viscoelastic golf ball materials), vibration, and sound. Vibration is particularly important to golfers, since this defines the ‘feel’ of the club. When a club is hit on the ‘sweet’ spot, many golfers report a solid ‘feel,’ while off-center hits produce unpleasant vibrations that create a painful sensation in the hands.

Although this has been difficult to quantify in many cases, the general trend for the industry has focused on softer materials and alloys to provide a softer feel. Although this is the general perception of many golfers, hardness has little to do with feel, because the vibration transmission is a function of the elastic modulus.

Confusion has been exacerbated in recent years due to the success of polymer-insert putters that do provide a soft feel. However, the soft feel is actually a result of the low elastic modulus of the materials, not the low hardness.

Other approaches to optimizing the feel of golf clubs is to construct the shafts of graphite composites, make the grips of advanced polymers, and place viscoelastic materials on the back of the hitting face to damp the vibration.

Recent research has shown that surface texture can also enhance feel by transmitting the vibrations out of the impact zone on the club face, thereby preventing excitation of the high frequency vibrational bending modes that provide unpleasant feel. Figure 3 shows a laser profilometer scan of the surface of a driver golf club face that has been treated with laser radiation. The individual laser pulses and vibration channels are evident in this image.

Putting performance

Golf balls on a putting green rest in a small depression when they are stationary. In order to get the ball rolling, it must be lifted slightly up to the surface of the green. Most putter designs account for this by providing a small amount of loft (typically between two and five degrees) to get the ball up onto a rolling plane. However, the putter’s loft has a negative consequence. During impact, the ball slides up the putter face, producing a very small amount of backspin that allows the ball to skid along the grass. During this ‘skid zone,’ the ball can easily travel off the intended line due to the uneven texture of the green. The skid zone is typically between 15 and 30 inches for many of the common putters on the market.

More recently, it has been shown that a textured putter face grabs the ball, thus preventing it from sliding up the face on impact, thereby minimizing the skidding and producing a more solid roll (Fig. 4). Several companies have successfully introduced putters with CNC milled grooves to minimize skidding. LSM is a particularly attractive alternative to the CNC milled face from a cost standpoint, and initial research results indicate that the large number of laser-machined features provides some unique benefits (Fig. 5).

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