This process produces strong splat-substrate and splat-splat bonding within the coating. The porosity of the coating can be controlled through the process parameters. Optimized porosity enhances the ring's ability to control cylinder-wall lubrication. Because plasma-sprayed molybdenum does not contain as much dissolved oxygen as flame-sprayed molybdenum, it is softer than flame-sprayed molybdenum. It conforms, therefore, to cylinder walls more readily and improves sealing efficiency. The low oxygen content, combined with the high-bond strength of plasma-sprayed coatings, eliminates the need for a grooved ring to support the coating, as illustrated on the right of the schematic of piston ring cross-sections on the previous page. Plasma-sprayed molybdenum-coated rings can provide 150,000-km vehicle life under normal use, a significant improvement over chromium-plated rings. Because the plasma-sprayed coatings are less susceptible to failure caused by oxides, they can be used successfully in more demanding applications, such as the higher efficiency, higher power engines typical of current automotive technology.

Molybdenum-based materials for piston ring and other coating applications

Material composition	Coating process	Applications	Desired properties
Pure Mo	Flame spray HVOF*	Piston rings, synchronizing rings, diesel engine fuel injectors, continuous casting and ingot molds	Lubricity
Mo-3%Mo_2C	Plasma spray	Piston rings, synchronizing rings, pump impeller shafts	Lubricity, wear resistance
Mo-17.7, Ni-4.3, Cr-1.0, Si-1.0, Fe-0.8, B	Plasma spray	Piston rings, synchronizing rings	Lubricity, wear resistance

* High-velocity oxy-fuel, a flame-spray coating process capable of higher temperatures and gas velocities than traditional flame spraying.

Molybdenum alloys for piston ring coatings

Three examples of molybdenum piston ring coating materials are shown in the table above. Pure molybdenum coatings are used where lubricity is required. When greater wear resistance is needed than can be provided by pure molybdenum coatings, alloys with molybdenum carbide and other elements are used.

Summary

Molybdenum metal coatings, while used only in small quantities, provide significant benefits in terms of fuel efficiency, emission control, power output and engine service life. The large benefits derived from these tiny quantities of metal, mean that molybdenum does indeed punch above its weight. (JS)

Molybdenum on point in fencing

A flèche or a lunge are just two of the many attacking moves in fencing that test the cold steel of foils, epees and sabers, subjecting them to brutal bending stresses. These weapons require flexibility and high toughness to ensure the safety of the fencers. The international standard for competition blades is a molybdenum-containing high-strength stainless steel that meets the challenge.

After more than one hundred years of know-how in hot forging of agricultural tools and steel fly-fishing rods, Blaise Frères, a small company from the Loire region of France, has earned highest standing in the fencing world. At the 2012 Summer Olympic Games in London, 95% of the fencers competed with their blades. Molybdenum made a decisive, if not official, contribution to this dominance.

An alloy approved by the International Fencing Federation

In the 1980s, competition injuries arising from failure of carbon steel blades led the International Fencing Federation (FIE) to seek an improved blade material. The primary objective was to guarantee faultless safety. However, it was also important to preserve the characteristic click-clack sound of crossing blades during attacks. This was a criterion of historic importance in this noble sport that harks back to the courts of the Renaissance, and it eliminated composite blades from consideration.

Fencing uses three different blade designs – foil, epee, and sabre. Foils and epees attack solely with the tip, which subjects the blades to substantial bending stresses during thrusts and impact loads during parries. Sabers strike primarily on the edge, the flat or the back of the blade, imposing sudden and repeated shocks.

A maraging steel, Z02 NKDT 18 09 05, was chosen and officially approved by the FIE. Maraging steels develop great strength and flexibility through the metallurgical reactions of martensite formation and age hardening. The steel is a low-carbon iron alloyed with 18% nickel, 9% cobalt and about 5% molybdenum. The steel's unique properties optimally balance flexibility and strength so that blades do not twist when bent, which maintains the accuracy of 'hits'. Molybdenum plays a crucial role in blade performance, providing the metallurgical properties required to withstand short and intensive, lightning-like attacks.

A flèche (attack) at the final of the épée world cup tournament in Paris in 2012. Fencing weapons have to be extremely flexible without breaking. © Marie-Lan Nguyen

A completely traditional manufacturing process

Blades begin their life with automatic hot forging of a conical 'mock-up' from a 200–260 mm long bar. The next step is 'free' forging, hot manual shaping of the blade's final profile using a tilt hammer. By the time the blades are forged to their maximum length (870 mm at most), they will have their typical profiles – square or rectangular for foils, V-profile for epees, and Y or V-profile for sabers.

Only the extremities of the blade are machined after forging. The base is threaded to secure the guard to the handle, and the 'tang' (the tip of the blade) is machined to house a micro-switch that registers hits. The switch's signal is transmitted through a 0.6 mm wire running in a groove along the blade. Grinding, polishing, heat treatment and marking give the blades their final appearance and mechanical properties.

During final inspection, tests to verify flexibility and resilience and, sometimes, fatigue and other destructive tests are carried out on equipment calibrated and approved by the FIE. The forging shop ships 70,000 blades around the world each year. High-level fencers, who use some 10 to 15 blades per year, particularly favor its competition models.

Hot forging (left) and cold hammering (right) are performed with the naked eye by experienced craftsmen. © Blaise Frères

A seal of excellence for the manufacturer… and molybdenum

This leader of the high-end blade market depends on the workmanship of its operators, who are capable of checking up to 90% of a blade's precision of shape with the naked eye. The professional skills of its journeymen, the result of a long apprenticeship and experience, earned the company the highly-coveted EPV (Entreprise du Patrimoine Vivant – Living Heritage Enterprise). This seal distinguishes French companies with excellent craftsmanship skills and industrial expertise. Now, molybdenum has become part of this tradition. (TP)