

Wear protection of processing tools by super hard diamond like carbon coatings

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Many tools used for forming, cutting, extruding or rolling suffer from wear damage. Either due to the surrounding conditions (dust) or by processed material itself containing abrasive particles, tool surfaces are microscopically damaged by abrasion, adhesion, surface fatigue or tribochemical wear.

To reduce tool wear, particularly hard tool materials are selected, surface treatments are carried out, or wear protection coatings (usually hard chromium) are used. This helps to reduce wear. However, for particularly demanding applications, such as those involving the processing of highly abrasive particles, the measures taken to date have reached their limits.

A concrete example of this problem is roller wear in the DRYtraec® process used for battery production. Here, the service life of the rollers is limited even when hard chromium coatings are used. Therefore, there is a need to generate even more wear-resistant surfaces by selecting suitable materials for the rollers.



Figure 1: DRYtraec®-process (left) using Cr-coated rolling tools and damaged surface of the Cr-coating on the tool surface caused by abrasive wear particles

Wear resistant materials

The wear resistance of a material correlates approximately with its hardness. Diamond is the hardest (10,000 HV) and also the most wear-resistant material. Ceramics such as aluminum oxide (2000 HV) or silicon carbide (2500 HV) are also known to be very wear-resistant, although their hardness is significantly lower than that of diamond. Even hard chromium (up to 1000 HV) is still harder and therefore more wear-resistant than steel.

Until now, it has been relatively unknown that there is another super-hard material besides diamond: the so-called tetrahedral amorphous carbon (ta-C), which can reach harnesses of up to 8000 HV.

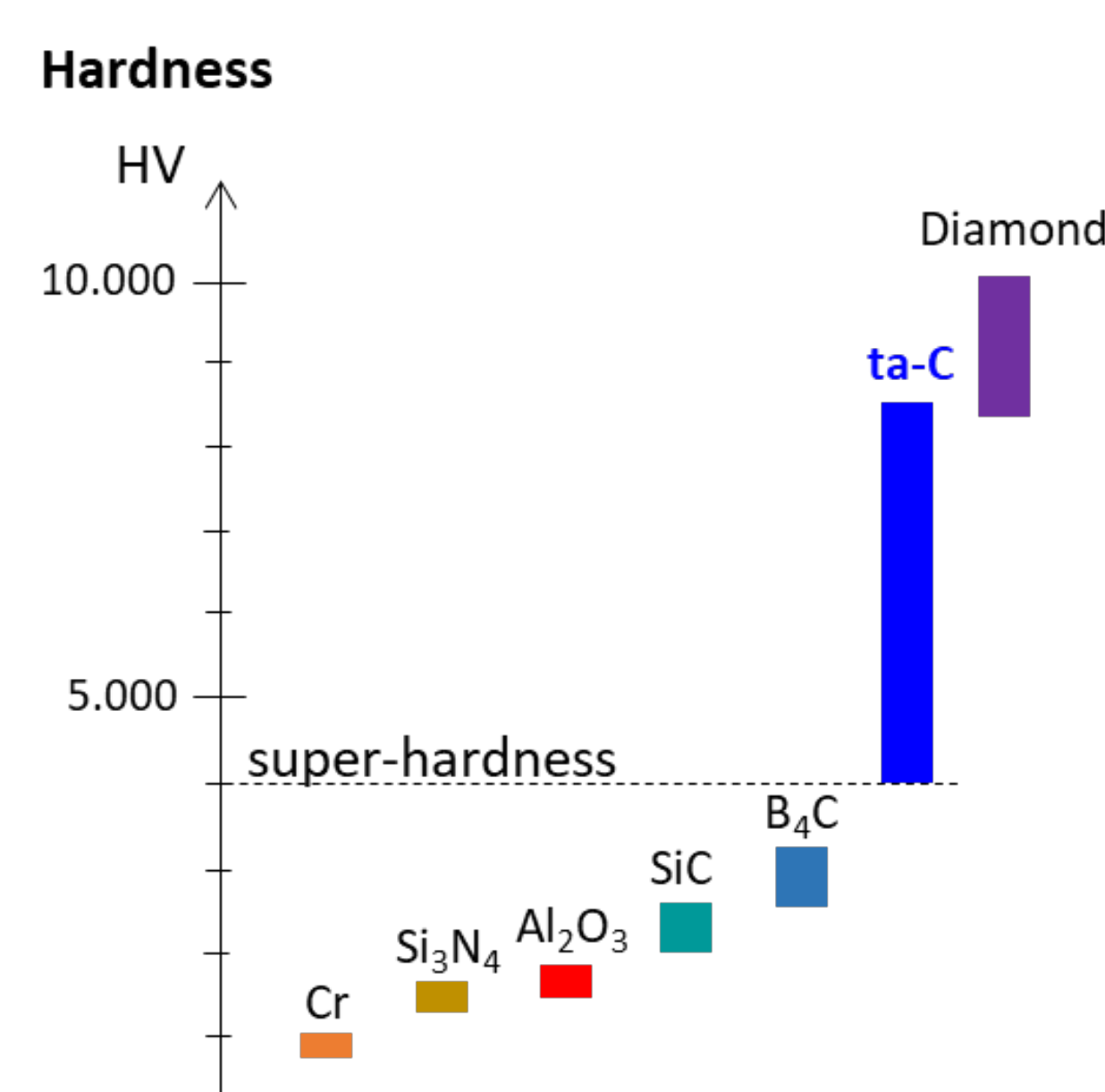


Figure 2: Ranking von different materials regarding their Vickers hardness (HV)

Super hard ta-C coatings

Tetrahedral amorphous carbon (ta-C) has a fully amorphous atomistic structure with a major portion of diamond (sp^3) bonds and a minor portion of graphite bonds (sp^2)

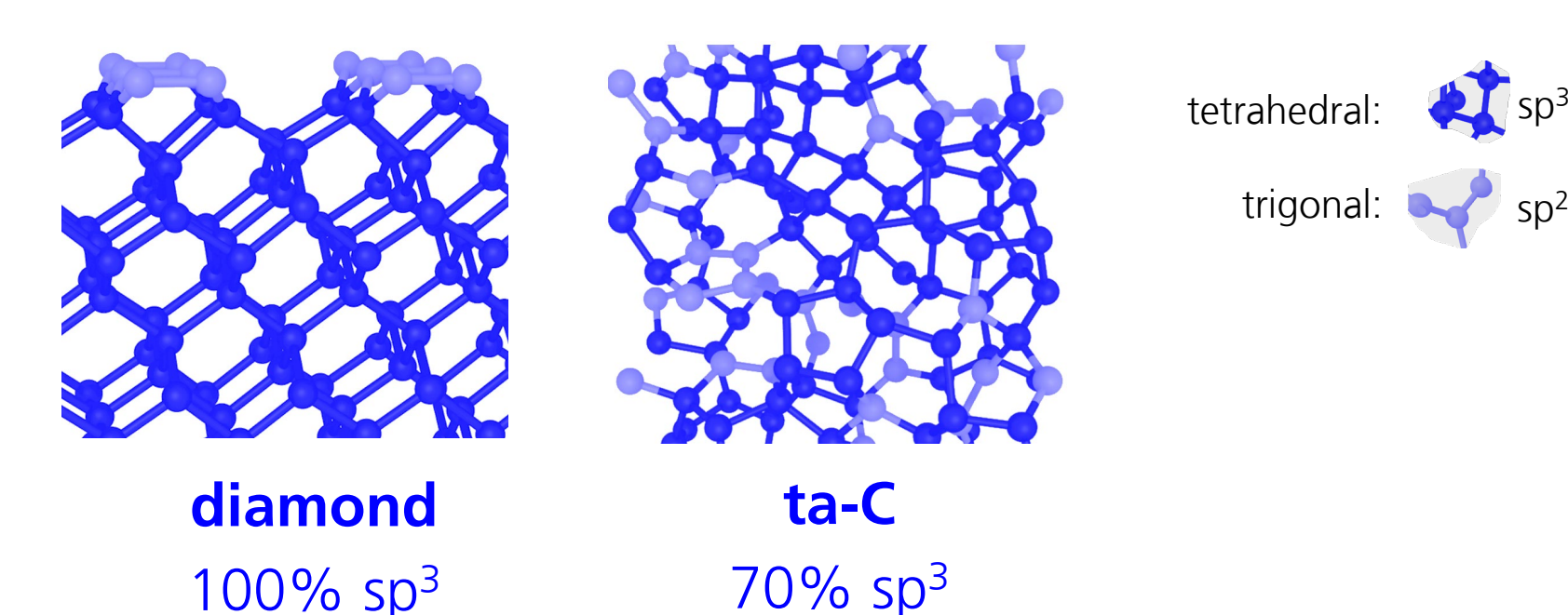


Figure 3: Atomistic structure of crystalline diamond (left) and tetrahedral amorphous carbon (right) distinguishing tetrahedral sp^3 - and trigonal sp^2 -bonds

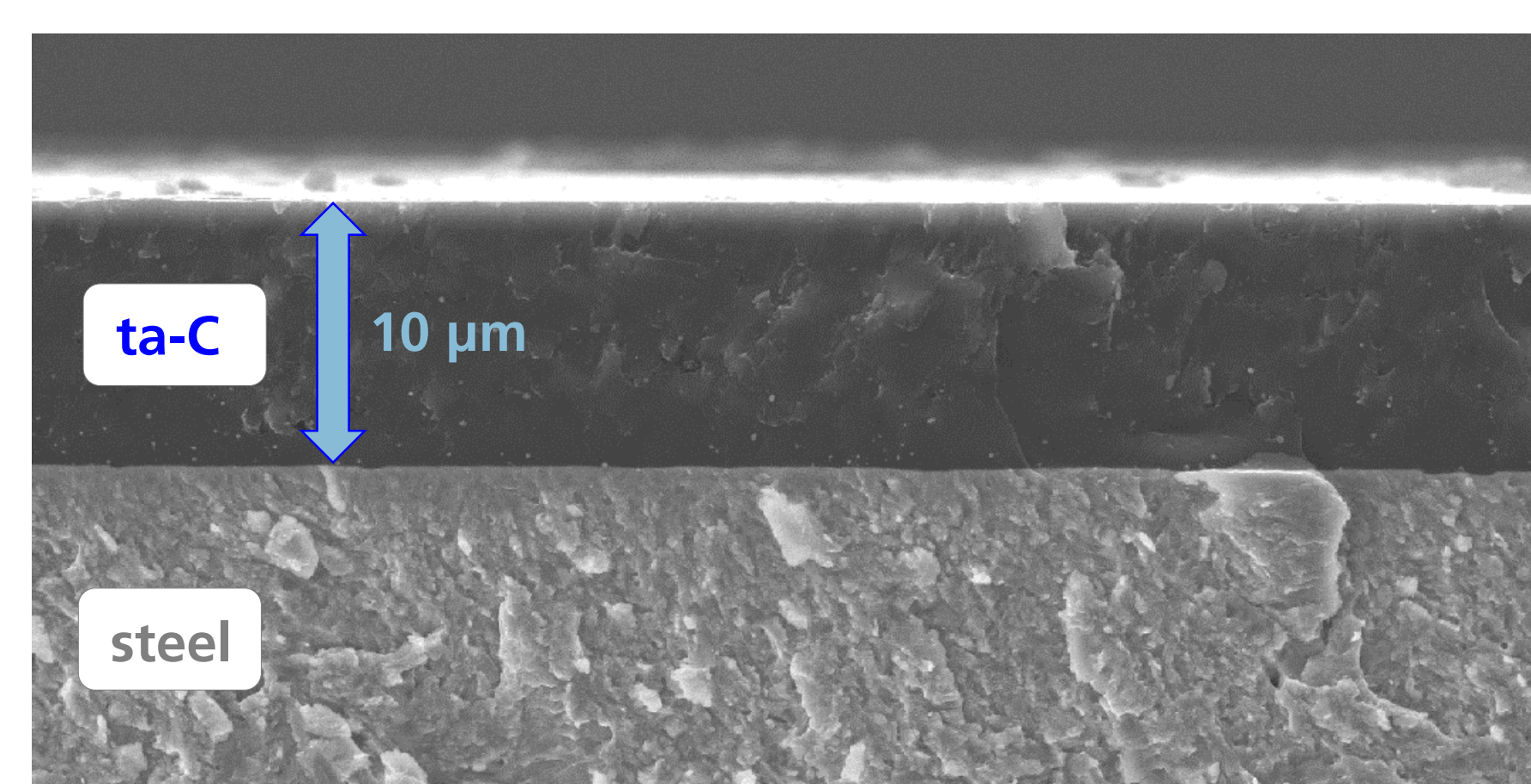


Figure 4: Morphology of a 10 µm thick ta-C coating deposited on a steel substrate after polishing the ta-C surface

ta-C coatings can be effectively deposited using vacuum-arc deposition techniques (kind of PVD technology). At Fraunhofer IWS a laser-controlled pulsed vacuum arc technique was developed, which is currently used in mass-production of ta-C-coatings on automotive engine parts and different kinds of tools.



Figure 5: ta-C coated parts: piston rings (left), piston pins (middle) and forming tools (right) used in industry

Laser-arc sources are used in combination with typical PVD-coating machines used for magnetron sputtering of dc-arc evaporation. Fraunhofer IWS has developed Laser-Arc modules for various kinds of applications.

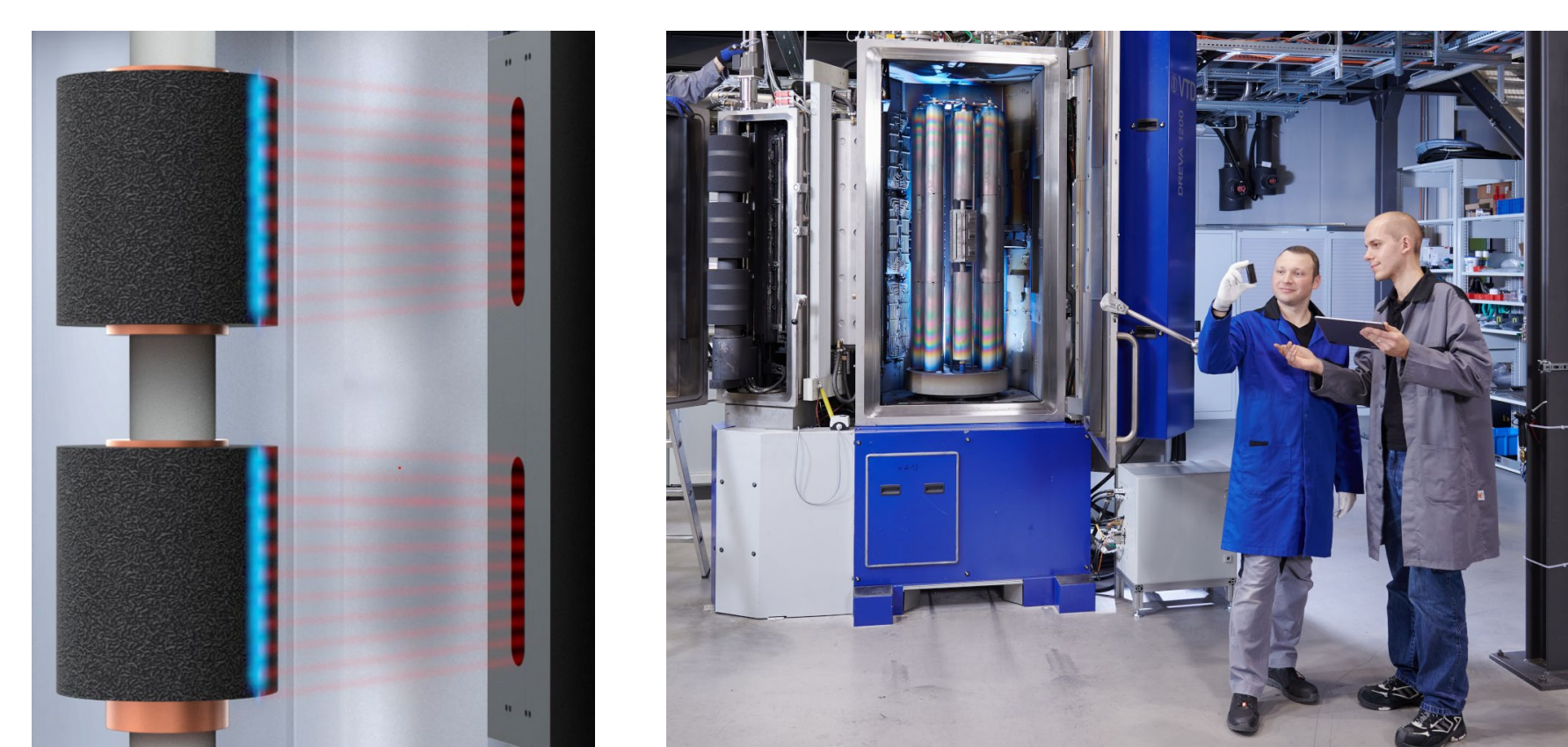


Figure 6: Schematic view on laser-controlled pulsed arc evaporation (left) to produce an ionized carbon plasma. Opened coating machine (right) showing Laser-arc module and parts to be coated by carbon plasma to produce ta-C coatings.

Friction and wear behavior of ta-C coatings

Friction coefficients and wear rates of a ta-C coated flat sample were measured against a steel ball counter body in an oscillating sliding wear test at different atmospheres, in water and in glycerol lubrication.

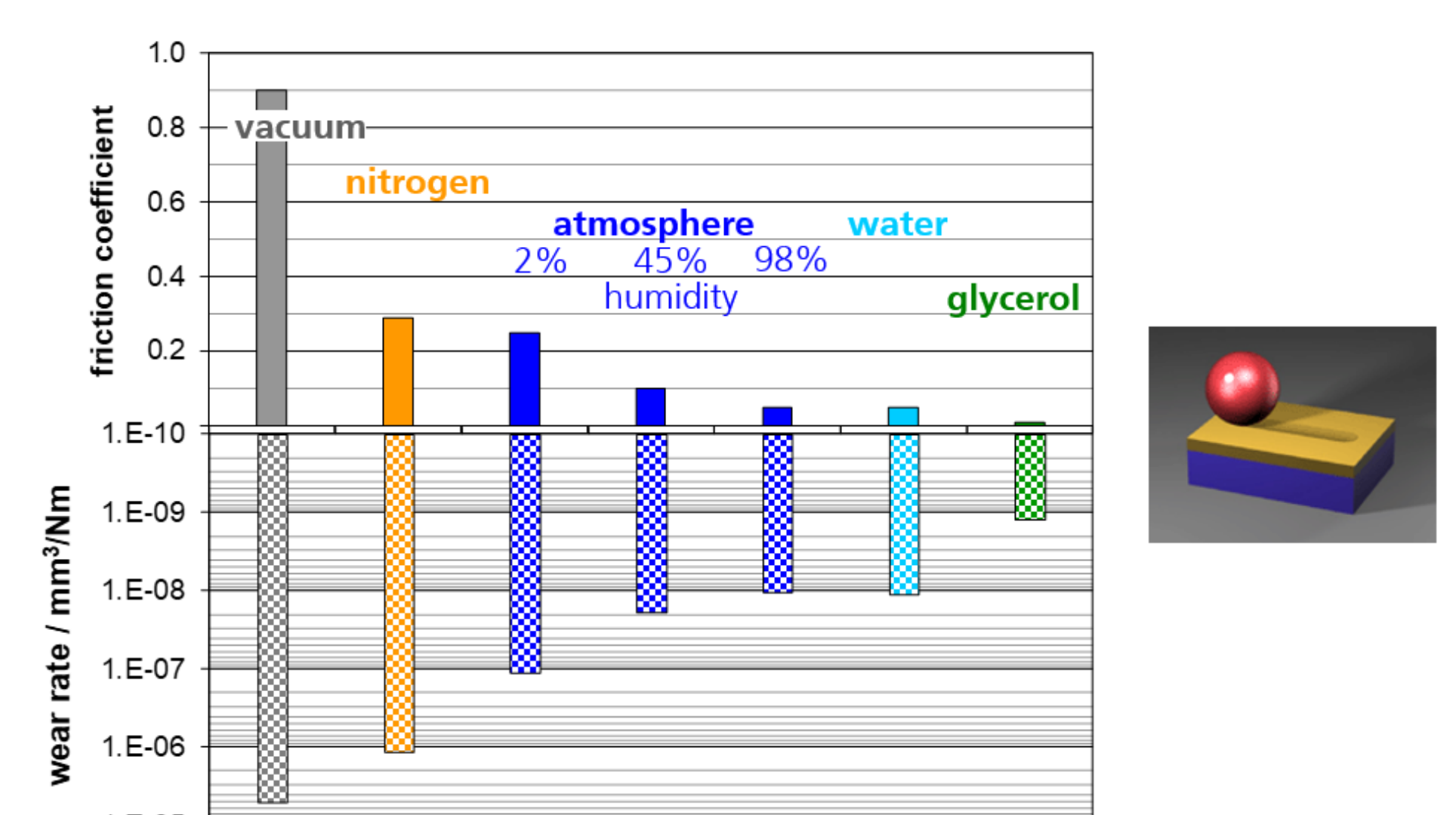


Figure 7: Friction coefficients and wear rates of ta-C coated flat sample vs. a steel ball by SRV test in different atmospheres, in water and in glycerol lubricant

The tribological results of ta-C coatings demonstrate a very promising wear and friction behavior in humid air and under lubrication with water and glycerol. Only under very dry conditions and in vacuum ta-C loses its advantage of a self-lubricating material and suffers from relatively high wear and high friction.

Summary

Various tools and components suffer from excessive wear when used in demanding environmental conditions or when processing abrasive materials. Processing of battery materials in the DRYtraec®-process is affected by wear of rolling tool surface even when using hard chromium protective coating.

The solution could be the use of super-hard diamond-like coatings of ta-C type, which could be applied to the rollers using PVD technology. ta-C fulfills the requirements and can be deposited with high thickness using the Laser-arc technology. The following benefits can be achieved by using the ta-C-coating:

- Hardness > 5000 HV, harder than any abrasive particle (except diamond)
- Very good adhesion to the tool surface
- Low deposition temperature (<120°C)
- ta-C coating thickness of 10 µm and more possible
- Low friction coefficients, but variable using surface treatments or laser micro structuring

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