of volatility and oxidative stability, both of which are key parameters in the consideration of specifications on oxidation stability. The TGA method was successfully used to evaluate two phosphate esters, trixylyl phosphate (TXP) and diphenyl t-butylphenyl phosphate (DPBP). Although both materials exhibited good oxidative stability, DPBP appeared to be somewhat more resistant to oxidation than TXP. At temperatures above 280 C, TXP showed an oxidation induced high molecular weight residue, while DPBP showed only normal (nonoxidative) evaporation. As new candidate intermediate and high-temperature lubricants are evaluated by this technique, in concert with other tribological tests, an extensive data base will be developed which will be invaluable to lubrication engineers for improving the tribological performance of mechanical components and systems that operate at elevated temperatures.

Lubrication at Elevated Temperatures

Advanced designs of low heat rejection engines present two significant tribological challenges, namely, lubrication at elevated temperatures and lubrication of ceramic materials. Anticipated peak temperatures for these engines are of the order of 600 C in the near future and 1200 C in the more distant future, which far exceed the performance limits (about 250 C) of all currently marketed lubricants. DOE has conducted research into a novel method of attaining effective lubrication at elevated temperatures by depositing lubricating films from the gas phase. Completed studies show that bearing lubrication may be continued to temperatures well above the stability of the liquid lubricant by delivery to the high-temperature bearings in a vapor state. Experimental data indicates that a wide variety of conventional liquid lubricants can be used in a homogeneous gas phase diluted with an inert carrier gas such as nitrogen or mixtures of nitrogen and oxygen to produce a friction-polymer-like film on metal-bearing surfaces at high temperatures. Studies have been successfully carried out at temperatures as low as 200 C and as high as 1600 C. It is believed that this technology will be useful in high-temperature lubrication of adiabatic or low heat rejection engines as well as in high-temperature metal forming operations. Further research on gas phase lubricant delivery to ceramic surfaces will also impact on the development of ceramic parts for new, more efficient advanced engine designs.

Coatings for High-Speed Cutting Tools

Improved tooling systems for automated machining operations have the potential to increase production rate, reduce tool replacement time, and improve energy utilization. These new tooling systems for high-speed machining can be developed based on improved understanding of tool wear mechanisms. A cooperative effort funded by DOE has developed processes for depositing hard coatings and a theoretical understanding of the wear behavior of hard coatings that explains the differences in performance of one coating over another in cutting operations. The two commercially viable processes are the high-rate reactive sputtering (HRRS) and the activated reactive evaporation (ARE) processes. Cutting performance tests have indicated that HRRS coatings outperform uncoated tool inserts by factors of between 3 and 10, depending on coating composition. ARE coatings were found to outperform uncoated inserts by a factor of 3. Two patent applications have been filed covering the HRRS processes, and two licensing negotiations are underway. The theoretical model that was developed includes, in addition to the effects of mechanical wear, the effects of chemical dissolution of the tool into the workpiece. The theory has been confirmed for high-speed steel (T-15) cutting tool inserts coated with carbides and nitrides of titanium (Ti) and zirconium (Zr). Cutting test results on titanium nitride (TiN) and zirconium nitride (ZrN) coatings on T-15 showed an increased wear resistance by about a factor of 3 for ZrN as compared to TiN, verifying predictions made using the theoretical model. This research has advanced tool wear understanding to