Grinding of High Speed Steel

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Summary: "Grindability" is the term used to denote how easy a steel grade is to grind. Research into grinding of high-speed steel shows that the dominant factor affecting grindability is the percentage of hard vanadium carbides, which are harder than the aluminum-oxide grits in the grinding wheel. For a given alloy content, powder-metallurgy high-speed steel is much easier to grind because of the much smaller carbide size. The biggest issues affecting toolmakers in production grinding are thermal damage, also referred to as "grinding burn", and burr. A factor often neglected by toolmakers is the quality of the ground surface at the cutting edge. Negligent grinding results in large grinding scratches, which can cause fracture of the tool.

"Grindability": The term "grindability" is used to describe the ease at which a material can be ground. Grindability can encompass a given material's *sensitivity* to thermal damage, which takes the form of residual tensile stresses, overtempering, and martensite formation. Within the family of tool steels known as high-speed steel, however, grindability is best described in terms of how the steel affects the cutting properties of the abrasive grits in the wheel. A difficult-to-grind grade will dull the grits at a much faster rate than an easy-to-grind grade. This leads to poorer cutting properties of the abrasive, resulting in higher forces on the grits and increased wheel wear. Since nearly all the energy expended in grinding is converted to heat, it also increases the temperature of the workpiece and the likelihood of thermal damage.

The most common, easiest, and most robust method of measuring grindability is the G-ratio: the ratio of the volume of material removed to the volume of wheel lost. A series of tests measuring the relative G-ratio of various high-speed-steel grades is an excellent way to assess the grindabilitiy of these grades. Steel grades with higher G-ratios have a higher grindability. The accuracy and practicality of these tests can be corroborated by measuring the power required to drive the wheel. All high-speed-steel grades begin with approximately the same power consumption. As grinding proceeds, however, grades with lower grindability exhibit a much faster rate of power increase. This leads to an increased risk of thermal damage.

Factors Affecting Grindability: High-speed steel (HSS) consists of small, hard vanadium- and tungsten-molybdenum-carbides in a martensitic steel matrix. The carbides give the steel its wear resistance, the martensite its toughness. The vanadium carbides in the steel are harder than the grits in an Al203 wheel. Tests show that the dominant factor affecting grindability is the size of the vanadium carbides. The percentage of these carbides has a secondary affect (but more in terms of size, as in conventional steel the carbide size increases with carbide percentage.) The percentage of tungsten-molybdenum carbides, the matrix hardness and the presence of cobalt have a much lesser affect.

PM Steel: Power-metallurgy steel has much smaller carbides than conventional steel. This means that the hard vanadium carbides are much less likely to damage the grits. Consequently, for a given alloy content and vanadium-carbide percentage, a steel produced by powder metallurgy has a much higher grindability than the same steel produced by conventional means. This difference increases with increasing alloy content.

Carbide Size in Conventional Steel: Even within a given grade of conventional steel, efforts can be made to reduce the size of the carbides, in particular the size of the largest carbides. Even a small reduction in carbide size can lead to a significant improvement in grindability.

Production Grinding: Some of the main issues facing toolmakers in grinding are grinding burn and grinding burr. Grinding Burn is the general term used to describe thermal damage to the workpiece. There are four types of thermal damage.

Oxidation Burn is caused by a thin layer of oxidized metal and oxidized coolant and results in a discoloration of the workpiece. It is often strictly cosmetic and frequently occurs without metallurgical damage. Oxidation burn can be present on the ground surface and/or close to the region of grinding where temperatures are high due to conduction. Oxidation burn is a poor indicator of temperature and thermal damage as it can come and go unpredictably.

Thermal Softening occurs when the temperature exceeds the tempering temperature. It causes the surface to soften, resulting in a loss of hardness.

Residual Tensile Stresses are caused by constrained thermal expansion of the workpiece beyond the yield stress, resulting in material close to the surface that is under constant tension. It decreases the fatigue life of the material and, in extreme cases, can cause immediate cracking after grinding. Its depth and severity depends on the temperature and material properties of the workpiece.

Rehardening Burn is caused by a metallurgical phase change in the material when the temperature exceeds the austenitizing temperature, resulting in a thin layer of hard, brittle untempered martensite. The hard, brittle layer can lead to fracture of the tool during use.

Grinding burr is another issue faced by toolmakers. It is caused by plastic deformation of the workpiece. During grinding, material is continually pushed in front of the grits until a burr is formed at the end of the grinding zone. Burr can lead to poorer performance of the tool. It is particularly troublesome in coated tools. The burr causes incomplete coating of the tool, and when the burr breaks away during use, the coating is removed, leaving an uncoated cutting edge.

Surface Quality at the Cutting Edge: The quality of the grinding is particularly important at the cutting edge. Because the impact strength depends on the size of the largest defect, and this defect is often a large grinding scratch, fracture of the tool often occurs in tools that have large grinding scratches at the cutting edge. This is particularly true if the grinding scratches are in the "bad" direction, i.e. the forces acting on the tool during use cause the grinding scratches to "open up". Tests show that the impact strength is largely independent of surface roughness when the scratches are in the "good" direction and decreases rapidly with surface roughness when the scratches are in the "bad" direction. In addition, impact strength decreases drastically when the surface has suffered from thermal damage, even in the scratches are in the "good" direction. Toolmakers often spend considerable time producing a well-ground surface in parts of the tool where surface quality is less important, and produce a poor surface where it is most important, i.e. at the cutting edge. This phenomenon is also true in tool resharpening.

Conclusions: Grinding is one of the most important and most complicated aspects in tool production. Poor grinding results in poor tool performance. Toolmakers must pay attention to numerous factors during production, including thermal damage, burr and surface quality at the cutting edge. Material with poor grindability, grades with a high percentage of hard vanadium carbides, can be particularly troublesome. This can be alleviated by using powder-metallurgy steel, which is much easier to grind due to its smaller carbides.

Bibliography. Additional information on grinding of high-speed steel can be found in the January/March 2003 issue of *Grinding and Abrasives Magazine* or by contacting the author.

About the Author

Jeffrey A. Badger received his BS from The University of Texas at Austin, his MS from Pennsylvania State University, and his Ph.D. from Trinity College in Dublin Ireland. He has worked with numerous toolmakers throughout the U.S. and Europe. He worked two years at Erasteel's research laboratory in Söderfors, Sweden and two years at their facility in the U.S. He now works independently as a consultant in grinding, continuing part-time at Erasteel on their grinding programme. He is author of numerous technical publications in grinding and high-speed steel, including the regular question/answer column titled "Ask The Grinding Doc" in *Cutting Tool Engineering*.