CRACKING UNDER PRESSURE

Choosing the proper steel to minimize abrasive, adhesive tool wear

By Thomas Hillskog

The most disruptive type of failure in any tooling application is when the tool cracks. To prevent this type of failure in cold-work applications, it's important to select the correct steel.

Many tools crack because of abrasive or adhesive wear. If one type is mistaken for the other, the actions taken to extend the life of a tool can have the opposite effect.

Abrasive Wear

Abrasive wear is caused by hard particles, such as carbides and inclusions, on the surface or within the work material. These particles act as microcutting tools on a microscopic scale.

Because of the motion between the punch and work material, small microchips are cut out of the tool, which leads to a gradual loss of tooling material. On a macroscopic level, this type of tool wear causes a rounding of the punch edge, yet the punch still appears relatively smooth (see **Figure 1**). A closer inspection shows characteristic parallel scratch marks on the edge and along the sides of a punch where particles cut into the tool surface during the stamping.

The following actions might help to improve abrasive wear resistance:

- Increase steel matrix hardness. This can be achieved by increasing the hardening temperature or adjusting the steel's tempering temperature.
- Use steel that contains a high percentage of hard carbides. D2 and M2 are examples of traditional steels that contain carbides to improve wear resistance. Because of conventional production methods, the carbides in these steels are large and nonuniformly distributed.

This means that when cutting particles that are embedded in the work material move across the tool surface, they encounter fewer carbides, and a large portion of the softer steel matrix is exposed to their cutting action. The chemistry of traditional carbide steels was designed years ago, and the carbides are relatively soft with a Vicker's hardness of approximately 1,700.

- Change to powder metallurgical (P/M) produced steels that are designed to offer a higher degree of abrasive wear resistance. The P/M manufacturing process creates smaller, uniformly distributed carbides in the steel matrix and allows for the use of different alloying elements. This results in a harder carbide with a Vicker's hardness of approximately 2,800. Cutting particles encounter more and harder carbides as they move across the tool surface, and P/M steel can offer a better protection of the steel matrix.

Figure 1

High magnification of a punch edge shows a characteristic pattern caused by abrasive wear.

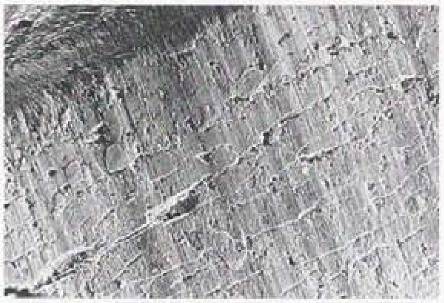

Figure 2

On a macroscopic scale, adhesive wear can cause microcracks, which will lead to an uneven appearance of the tool's edge.

For example, P/M M4 is a common grade for high-end cold-work applications if a high hardness for compressive strength and good abrasive wear resistance are needed. However, M4 is based on older chemistry, and new P/M grades have been developed specifically for cold-work applications. These newer materials are designed to have a better balance of cracking or chipping resistance and good wear properties.

P/M steels normally give the best protection for against abrasive wear of a tool surface. However, in some situations conventional steels with their large, blocky carbides are more cost-effective, such as if the cutting particles in the work material are much larger than the carbides in the P/M steel.

The microchips formed by the abrasive particles are so thick that they remove the smaller P/M carbides together with the matrix. The blocky carbides of conventionally produced steels like D2, D3, or D6 are larger than the abrasive particles' depth of cut and protect the softer steel matrix better than P/M steels in this case. For example, D3 or D6 often is used in brick pressing because the work material consists of refractory particles, which are very hard and larger than P/M steel carbides. Increasing the hardness and using highly alloyed P/M steels can improve performance in applications like brick pressing. However, the price-to-performance ratio normally is insufficient to use P/M steels for these applications.

- Tungsten carbide has a high volume of evenly distributed small and hard carbides to resist abrasive wear. The limitations of this tooling material are its lack of toughness, which can lead to cracking or chipping, combined with high initial toolmaking costs.

When the correct tooling material is found for the application, which creates stable working conditions without chipping or cracking, a surface coating can further improve the tool's abrasive wear resistance.

Adhesive Wear

Adhesive tool wear occurs when soft, adhesive work materials, such as aluminum, copper, stainless steels, and low-carbon steels, are used. Conditions that increase adhesive wear are high friction and heavy loading.

The origin of adhesive wear is the formation of microwelds between localized contact points on the tool and work material surface. During the movement of the tool and work material, these microwelds are broken up. If breakage takes place in the tool surface, small fragments will be torn out, which leads to a gradual loss of material.

Even if the microwelds do not break in the tool surface, repeated tearing will lead to the formation of microcracks. Over time these cracks will grow together, and when they reach a critical size, larger pieces of the edge will start to break out. On a macroscopic scale, adhesive wear leads to an uneven appearance of the tool's edge (see **Figure 2**) compared to abrasive wear, in which pieces are torn out of the tool surface.

To reduce adhesive wear, consider the following tool steel properties:

- **Low coefficient of friction.** This requires a good tool surface finish, preferably with the grinding and polishing performed parallel with the direction of tooling movement. Other solutions include lubricants or surface coatings.
- **High yield strength.** This creates a better resistance to breakage of tool surface microwelds and the forming of microcracks because of the repeated tearing action.
- **Hard carbides in the matrix.** Microwelds cannot form between the carbides and the work material; therefore, a high carbide volume in the tool steel will reduce adhesive wear. However, a small carbide size and even distribution are important because of their detrimental effect on tool steel ductility.
- **High ductility.** High ductility means that the tool steel can deform on a microscopic scale rather than forming cracks and therefore resist breakage or chipping. Cold work grades like D2, D3, and M2 have a low adhesive wear resistance because of their large, blocky, nonuniform carbide distribution. This microstructure results in tool steel with low ductility. Low ductility in these steel types can cause microweld breakage in the tool rather than in the work material, and it also leads to a rapid formation and growth of microcracks, which will result in chipping of tool edges.

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The smaller size and uniform distribution of the carbides in the matrix of P/M steels produce a higher ductility than in conventionally produced steels with similar carbide volume and hardness. P/M steels have a better resistance to microweld formation, breakage of the welds in the tool surface, and the formation of microcracks that lead to chipping.

Because ductility is an important property for good adhesive wear resistance, anything that compromises tool ductility should be minimized for optimum tool life. The limiting factor for ductility in P/M steel is internal defects, mainly the nonmetallic inclusion content.

During the last decade P/M steel producers have developed new grades with reduced content of internal defects. These second- and third-generation P/M tool steels are designed to have higher ductility than standard P/M grades with similar alloying content, which improves their adhesive wear resistance.

Distinguishing Wear Types

An increase in matrix hardness and volume of hard, uniformly distributed carbides in tooling material can improve its abrasive wear resistance. High ductility combined with well-distributed, small carbides increase adhesive wear resistance.

However, high matrix hardness and carbide volume, necessary for good abrasive wear resistance, also lead to lower ductility and decreased adhesive wear resistance. This contradiction is why it's important to establish which type of wear is dominating an application before taking actions to correct the problem.

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