Forging-Die Material Development: From Research to Implementation

Patricia Miller, senior technical manager, Bohler-Uddeholm Corporation

Determining the use of a new tooling material for forging applications requires careful analysis of the overall issues and a good understanding of the failure mechanisms that can cause the tooling life to be lower than desired. This article looks at several key developments in the area of physical and mechanical properties that have led to new tool-steel development.

Historical data on forging-die life is well established. A study of over 120 different cavity forms from 20 different forgers showed that more than 70% of all forging-die failures are associated with abrasive wear; more than 25% are due to mechanical fatigue and gross cracking; and thermal fatigue cracking and plastic deformation account for the rest. However, this information only provides a focus for material development and a starting point for material selection. It is the understanding of these phenomena and what to do about them that can lead to proper development and use of new die material grades.

In this article we look at new developments in tool steels for these key forging applications while also providing a blueprint for enhancing the characteristics of these grades in their applications.

Steps in the Development of a New Tool Steel

A methodical approach to improving tooling performance is essential to success. A brief summary of some of the more important steps in tooling analysis is as follows:

- Choose one or two areas of poor performance.
- Carefully determine tool failure mechanisms. A full failure analysis is needed.
- Review the past performance of the current tool material. Determine what the material is and how it was manufactured, thermally treated, coated, machined, etc. Run simulations.
- Review the production environment and factors that could affect tooling performance.
- Proceed with trials: decide number of tooling sample tests per trial; get detailed heat-treatment charts for each trial; get detailed coating parameters, provide samples for coating; and establish manufacturing parameters.
- Run and follow up on trials – track tool performance and photograph results regularly.
- Implement results on immediate tooling.
- Implement results on tool groups.

Two of the most important stages of these evaluations are the proper identification of tool failure mechanisms and the running and following up on the trials. If either of these two stages is not performed properly, then all efforts in between are futile. Once the tool failure mechanism is determined, a focus on proper steel selection for the tooling can begin.

Die Material Properties

The properties profile for forging-die tool steels has a number of general characteristics that will always be required in forging operations.

- The steel should have improved physical properties over conventional tool steels.
- The steel must show sufficient hardness and ability to retain this hardness at elevated temperatures.
- The steel must have an enhanced level of hot tensile strength.
- The steel must have good toughness and ductility at low and elevated temperatures.
- The steel must have sufficient hardenability and retain wear resistance and thermal properties as dies are resunk.
- The steel must have adequate fatigue resistance.

Development of tool steels for forging applications has been focused in two areas. The first is on richer alloy concentrations. These, due to their cost and capability, are directed towards small- and medium-size forgings and applications in which long contact times are a factor. The second is on steel manufacturing processes that allow for larger tooling of bigger block dimensions to have better uniformity in mechanical properties. A compilation of some common tooling materials and their chemistries is given in Table 1.

It is important to understand that chemistry alone does not tell the complete story of a steel's capabilities, which is why it is important to ask questions about how the steel is processed. If the steel is not remelted, it is important to stipulate the minimum forging reduction ratio and to know if a homogenizing heat treatment has been performed to get good properties from a conventionally produced grade.

If the steel has been remelted, find out how and in what type of unit. Not all remelted steels are produced using the same updated technology. For example, grades like Uddeholm's Premium H13 (Orvar Superior), Dievar and Bohler's Premium H13 are remelted through controlled solidification in a steel bath and under a protective atmosphere, giving better homogeneity of structure and steel cleanliness than in previous ESR furnaces. Bohler's VMR grades are melted in vacuum arc remelting furnaces, obtaining extremely high cleanliness levels. An example of the toughness enhancements by going to cleaner steelmaking practices is shown in Figure 1.

Table 1. Tool steel grades and typical chemistries

Steel	Grade	%C	%Mn	%Si	%Cr	%Mo	%V	%W
AISI H13	1.2344	0.39	1.1	0.40	5.2	1.4	1.0	
AISI H11	1.2343	0.38	1.1	0.40	5.0	1.3	0.4	
Bohler W400 VMR	~1.2343	0.37	0.2	0.3	5.0	1.3	0.5	
Uddeholm QRO90 Supreme	-	0.38	0.75	0.3	2.6	2.3	0.9	
Bohler W303 ISODISC	1.2367	0.38	0.40	0.40	5.0	2.8	0.55	-
Uddeholm Dievar	-	0.35	0.5	0.20	5.0	2.3	0.5	
Bohler W403 VMR	~1.2367	0.38	0.20	0.25	5.0	2.8	0.65	-
Bohler W360 ISOBLOC	-	0.50	0.20	0.20	4.5	3.0	0.55	-

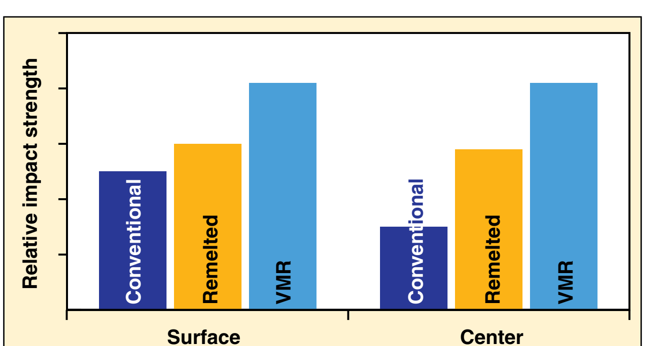

Figure 1. Comparison of ductility of tool steel as a function of steel production method. VMR indicates vacuum melted remelted steel. Note the uniformity between surface and center for the remelted and VMR processing methods.

Tool-Steel Property Enhancements

Physical Properties – Thermally induced stresses are proportional to the thermal expansion coefficient, the elastic modulus and the temperature differences during the forging process. Temperature

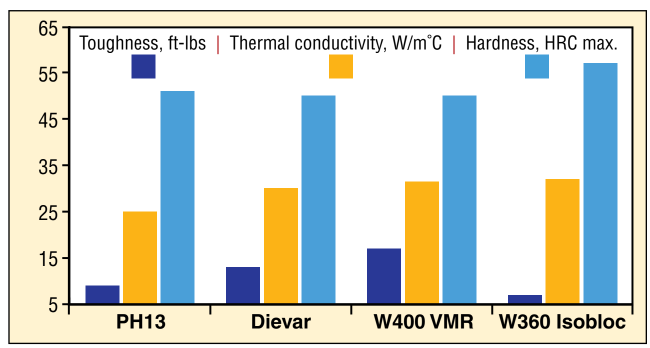

Figure 2. Thermal conductivity, toughness and hardness of several new tooling grades. Thermal conductivity is taken at room temperature.

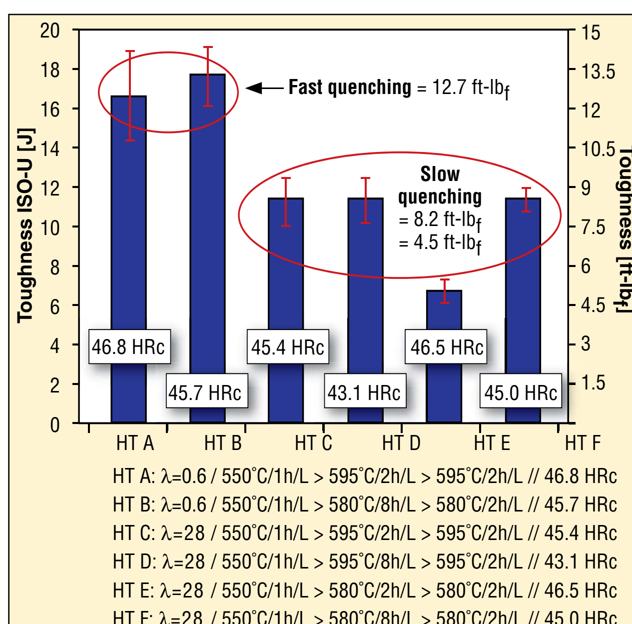

Figure 3. Toughness in Joules as a function of heat-treatment modifications.

difference and maximum temperature can be reduced by increasing the thermal conductivity, which can also reduce the temperature gradient and the resulting stresses on the tool. An advantage of the newly engineered tool steels is that their thermal conductivity is improved over that of an AISI H13 chemistry, as shown in Figure 2.

Microstructure – A good heat treatment is critical to the success of tools in forging applications. When cooling rates are slow due to marginal heat-treating capabilities, a desire to minimize dimensional change after heat treatment (thereby reducing machining time) or if the section size of forging blocks increases, the microstructure of the steel contains increasing percentages of bainite. Testing of cyclically heated samples of H11 tool steel indicates that localized deformation occurs in the bainite, which is associated with early onset of heat checking. Toughness can also be significantly reduced, as shown in Figure 3.

Although proper heat treatment can enhance the properties of all hot-work tool steels, new tool steels can optimize these characteristics by pushing the carbide and bainite formation times out significantly. This means larger blocks can be heat treated, giving better uniformity of structure even in thicker cross sections or slower cooling rates (Figure 4).

Hot Hardness – Tool steels will lose hardness if operating temperatures exceed the temperature at which the secondary hardness peak is achieved. New alloys have been developed with increased strength retention at elevated temperatures while taking more time to reduce hardness commonly seen by most current hot-work die materials. As shown in Figure 5, with the high-hardness grades containing molybdenum, the time at which the steel will fall to the same hardness as the starting hardness of 1.2367 alloy will be 10 times longer. Therefore, for long contact times and higher temperatures, these grades should be considered.

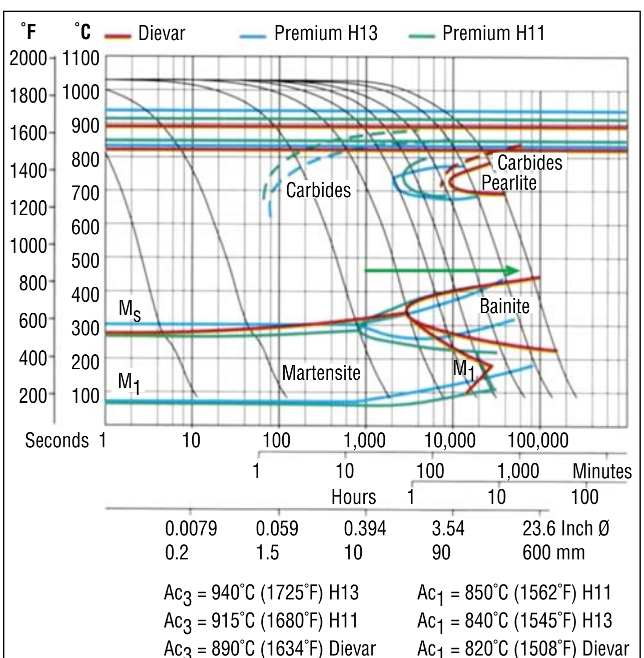

Figure 4. CCT curves for Dievar, Premium H13 and Premium H11. Carbide and bainite noses are pushed out in time for Dievar, for increased cooling time.

Application Results

Examples of positive results with new tooling materials have been significant. In one case, a screw press was used to manufacture a wheel rack of 1.2312 steel at a forging temperature of 1150-1180°C (2100-2156°F). The die was 280 mm x 150 mm x 65 mm, and the part weighed 640 grams. The previous die was made from H13 steel, hardened to 50-52 HRC and nitrided. Severe wear was obvious after 3,000 parts produced. A change to Bohler W360 Isobloc steel at a hardness of 56 HRC without nitriding was able to obtain an improvement of over 120% from previous results and four reworkings.

We conducted one study to improve not just the tooling material but the heat treatment as well. A die (Figure 7) was originally produced of standard H13 material. The die material was kept at H13, but the steel source was changed. That, along with an improvement in heat-treatment control, increased the die life average from 3,000 parts to 3,700 parts. When Dievar was introduced, that average increased to over 7,000 parts. Then, to further improve the situation, the outer die was replaced with Dievar and the inner die with W360 Isobloc. Die-life improvement went to 20,000 parts with Dievar and 10,000

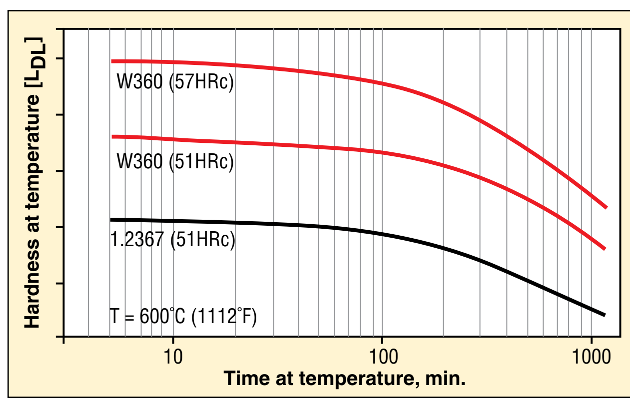

Figure 5. W360 Isobloc hardness as a function of time at 600°C (1112°F). Even at a lower hardness of 51 HRC, the material will not soften below the initial hardness until 800 minutes, versus that of 1.2367, which begins to soften below 51 HRC at 40 minutes.

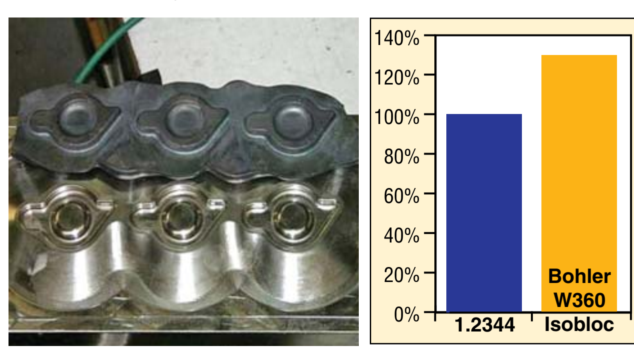

Figure 6. Example of forging die showing a substantial improvement in die life.

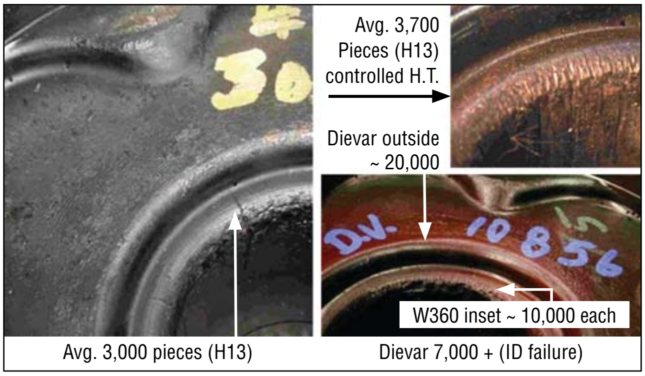

Figure 7. The original die obtained an average of 3,000 pieces. When heat treatment was enhanced, the average went up to 3,700 pieces. The use of Dievar for the entire die resulted in over 7,000 pieces before wear and cracking occurred. By using Dievar for the outer die and inserted with W360 Isobloc, the average went up to over 10,000 pieces.

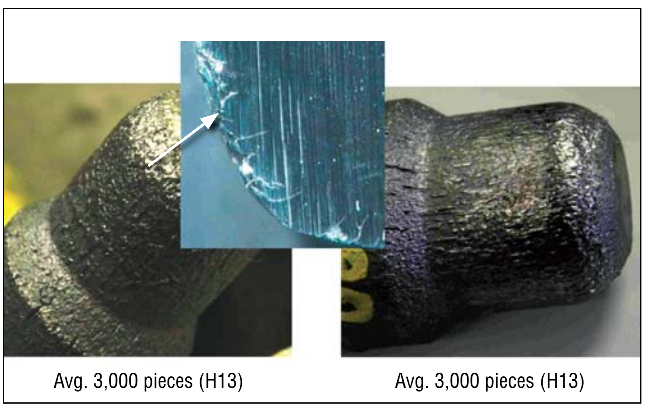

Figure 8. Improvement in punch life using a conventional 1.2367 alloy.

parts with the W360 Isobloc.

Our last example is a punch nose (Figure 8). It is interesting to look at the hot wear at the surface of the H13. In actuality, the tool damage is a function of heat checking as well as wear. A change of the material to a more heat-resistant tool steel, type 1.2367, more than doubled the punch life.

Conclusions

To obtain the best tooling economy in forging it is important to follow a methodology for evaluating new tooling materials and related processes. This article has examined several key material properties and shown how recent improvements in tool-steel development have created new grades that can address some of the key concerns in many forging applications.

This article was adapted from a paper presented at the International Forging Congress held in Chicago, September 2008, by author Patricia Miller, senior technical manager, Bohler-Uddeholm, Elgin, Ill. She may be reached at 800-652-2520 x8732; or at Patricia.Miller@bucorp.com

All photos and graphics courtesy Bohler-Uddeholm Corporation

Customer Service Card

FORGE A supplement to Industrial Heating

Reach FORGE directly by faxing this form to: (847) 763-9538

Name: ______ Title: ______

Company: ______

Address: ______

City: ______ State: ______ Zip: ______

Work Phone: (___) ______ Work Fax: (___) ______

E-Mail Address: ______

By providing your e-mail address and fax number, you're giving us permission to e-mail or fax future notices to you. If you do not wish to receive third-party e-mail offers regarding information relevant to your industry, please check here to opt-out. ❑

Does your company make forged parts?
❑ Yes
❑ No

Does your company make forged parts at this location?
❑ Yes
❑ No

Is this location a: (Check one only)
❑ Maker of Forgings
❑ User of Forged Parts
❑ Corporate Office
❑ Design Facility
❑ Research and Development Center
❑ Supplier to Forgers
❑ Other: ______

What is your principal job function? (Check one only)
❑ Corporate Management
❑ Plant/Operations Management
❑ Plant Engineering
❑ Research and Development
❑ Design Engineering
❑ Purchasing
❑ Sales
❑ Other: ______

What types of forging do you perform at this location? (Check all that apply)
❑ Closed Die
❑ Open Die
❑ Ring Rolling
❑ None
❑ Other: ______

What is the primary type of forging performed? (Choose one from above)
❑ Closed Die
❑ Open Die
❑ Ring Rolling
❑ None
❑ Other: ______

What metals do you forge at this location? (Check all that apply)
❑ Carbon Steel
❑ Alloy Steel
❑ Stainless Steel
❑ Aluminum
❑ Titanium
❑ Brass & Copper
❑ High-Temp Alloys
❑ None
❑ Other: ______

What is the primary metal forged? (Choose one from above)
❑ Carbon Steel
❑ Alloy Steel
❑ Stainless Steel
❑ Aluminum
❑ Titanium
❑ Brass & Copper
❑ High-Temp Alloys
❑ None
❑ Other: ______

What is the number of employees at this location?
❑ 0-9
❑ 10-19
❑ 20-49
❑ 50-99
❑ 100-249
❑ 250-499
❑ 500-999
❑ 1000-2499
❑ Over 2500

Is your Forge shop?
❑ A captive operation
❑ An independent operation
❑ A combination of both