

METALLURGY

Premium hot work tool steels specialized to die forging application

by Dr. Petra Becker

The forging industry all over the world is subject to constantly increasing cost pressure [1]. In addition, both complexity and tolerances of parts are increased. Consequently, the die faces higher loads which in return causes higher maintenance costs and/ or an early die failure due to wear or cracks. For die forging applications, tool steels like 1.2714 (AISI L6), 1.2343 (AISI H11), 1.2344 (AISI H13) or 1.2367 are used as tool steels for the dies. In this context, the failure modes of forging dies are described, as well as the properties a die steel needs to prevent or delay them. Kind&Co. has developed several premium hot-work tool steels with properties explicitly tailored to these loads and therefore significantly extending die life. These steels are presented, including some case studies that demonstrate their improved performance. Founded in 1888, Kind&Co. has been part of GMH Gruppe since October 2024 with over 15 sister companies. As the only hot-work tool steel specialist worldwide, Kind&Co. supplies both standardized steels and premium steels specially developed for specific applications and can map the entire value chain from melting to final heat treatment in a vacuum. For the die forging industry, prefabricated dies can be supplied into which only the engraving needs to be applied. Kind&Co. application technology is available to discuss specific application issues.

Among all industrial branches, the forging industry is currently exposed to extreme economic pressure. To decrease costs for their products, an essential part is to decrease maintenance costs and

increase the lifetime of the dies. Die life is affected by many different factors, apart from the die material itself. This topic is covered later in chapter “What else is important”.

Loads on a die during forging and resulting failure modes

The loads on a die are manifold [2]. It is a complex system of mechanical loads during the forging process and thermal stresses due to the difference

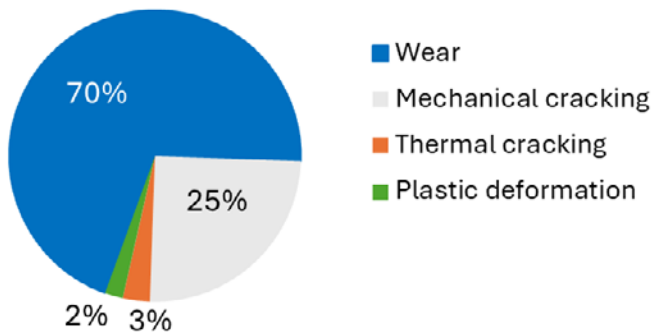


Figure 1: Wear and cracking are the main reasons for the failure of forging dies
Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG



Figure 2: Abrasive wear on a forging die
Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG

in temperature between the die (pre-heating temperature 200-300 °C), the processed material (1000-1200° C for steels) and the contact time of the two. Temporary temperature peaks of 500-700 °C can be reached in the die [3], followed by a cooling lubrication process. As it is a cyclic process, also fatigue weakens the die material. In addition to this, tribological and chemical loads can be identified [2]. Fig. 1 shows the resulting failure modes of the dies. Wear is the most frequent failure mode in forging dies, followed by mechanical cracking, thermal cracking, and plastic deformation.

Wear

Wear is defined as the continuous material loss from the surface of a solid body caused by mechanical reasons [4]. Abrasive wear is the most frequent failure mode in forging dies (Fig. 2). It occurs mainly where there is a major relative movement between the forging die and the forged material, accompanied by high heat transfer [5-6].

To optimize wear resistance, it is important to have an adequate hardness of the matrix accompanied by homogeneously dispersed, bigger carbides (Fig. 3, right picture) that fit the wear mechanism in size and distribution.

In case, the carbides are too small (Fig. 3, left picture), or they are arranged in a network structure (Fig. 3, center picture), they are less effective to reduce wear.

Looking at 1.2714, this material can be hardened and tempered to a hardness level of 47-48 HRC. But as there is little Chromium and Molybdenum in the composition, the carbide volume is low. For 1.2343 and 1.2344, the content of Cr, Mo, and V is higher and therefore also the carbide volume in the matrix.

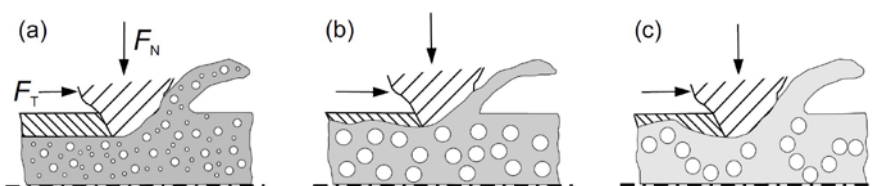


Figure 3: Influence of carbide size and distribution on wear resistance [6] Source: [6] Berns, H.; Theisen, W.: Eisenwerkstoffe Stahl und Gusseisen, 4. Auflage; Springer Verlag, Berlin, Germany, 2008, p. 252



Figure 4: Mechanically induced crack in a forging die
Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG

Mechanically induced cracking

The second most important failure mode of forging dies is mechanical cracking. It happens if the stress concentration in corners or edges exceeds the ultimate tensile strength. To prevent or delay this, hot-work tool steel is needed providing sufficient high-temperature strength combined with a good toughness level.

Thermally induced cracking

In Fig. 5, the typical network-like structure of thermally induced cracks can be observed. It is caused by thermal fatigue, due to constant temperature changes of the die material in contact with the hot forging material. The longer the contact time between die and forging material is the stronger the effect will be. To prevent or delay this effect, a die material with high-tem-



Figure 5: Thermally induced cracking
Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG

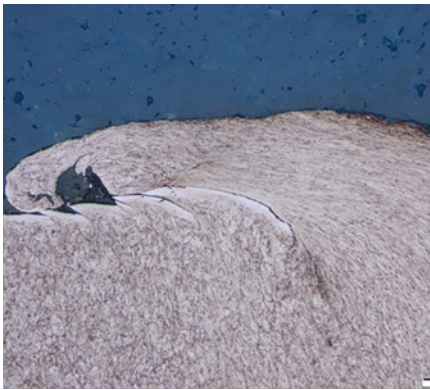


Figure 6: Plastically deformed die material
Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG

perature strength, high-tempering resistance and good toughness is to be recommended.

Plastic deformation

Plastic deformation occurs, in case stress concentration exceeds the hot yield strength of the die material (Fig. 6). This again is caused if the flow stress of the forging material or the temperature of the die is too high. It mainly happens at convex radii or on ridges because especially here, the temperature of the die tends to be hotter.

To prevent or delay this effect, a die material with elevated yield strength at high temperatures is favorable.

Premium tool steels

To stay competitive, the forging industry must improve the lifetime of its tools. With the main properties of tool steel presented in Fig. 7, a first indication is given which tool steel might perform best for a particular application.

The blue marked ones are internationally standardized steels, produced in a good quality and suitable for many forging applications. USN equals 1.2343/ AISI H11, USD is 1.2344/ AISI H13, whereas RPU is equivalent to 1.2367 (no AISI). 1.2714 (AISI L6) is not produced by Kind&Co. and is in these diagrams only as a reference.

The orange marked steels are premium steels developed by Kind&Co. providing optimized properties in terms of

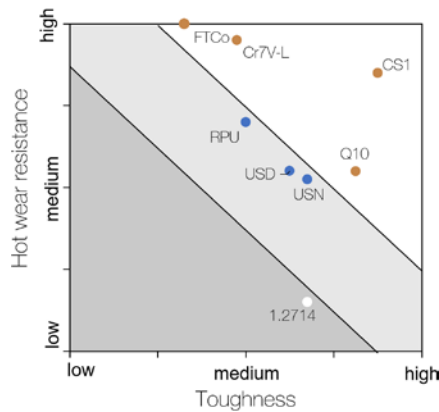


Figure 7: Comparison of Kind&Co.'s hot-work tool steels for forging dies and their main properties
Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG

wear resistance and high-temperature strength.

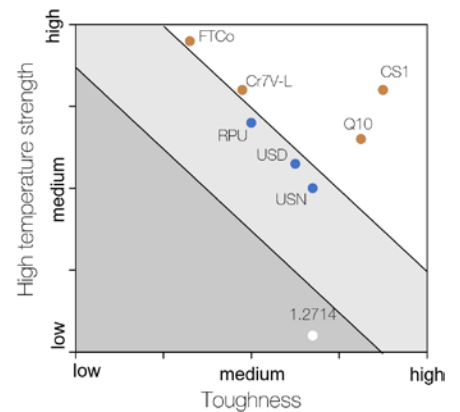
Case study: Q10

Q10 is a CrMoV-alloyed tool steel with an improved toughness compared to standard tool steels. Thanks to its higher molybdenum and reduced carbon content, carbide formation changes from type M23C6 to type M2C. This type precipitates finer and therefore leaves the material with better toughness. Additionally, for the production of this material only the highest quality scrap is used. This results in a lower content of undesired trace elements, which also increases toughness.

The first example is a wheel cup for a passenger car produced on a transfer press. Compared to 1.2343, Q10 has achieved a 200 % increase in performance. The hardness level of Q10 was 50 HRC in the blocker and the finisher die. The second product is a stainless common rail for a diesel engine produced on a 1600 t press. Here, Q10 was used in a pre-hardened condition (44-46 HRC) and compared to the 1.2714 at 40-42 HRC. The performance increase was more than 100 %.

Case study: Cr7V-L

Cr7V-L has a better wear resistance than standard steels (Fig. 8). This is mainly due to an increased chromium content compared to standard steels like 1.2344 or 1.2367. As shown before, to provide



good wear resistance it is essential to adjust a good hardness level of the matrix which is strengthened additionally by hard particles (carbides) of the right size and distribution. This is exactly how Cr7V-L is set.

The first product is a crankshaft for a passenger car produced on a 4000 t press. Cr7V-L was compared to 1.2344, both at the same hardness level of 43-46 HRC. The performance increase was 60 %. The second example is a connecting rod produced on a 2500 t press. Here, Cr7V-L was compared to 1.2344, both at a hardness level of 47-50 HRC. The performance increase was more than 50 %.

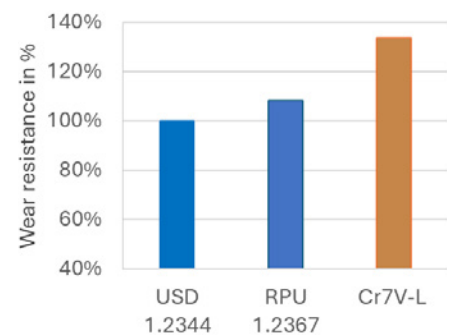


Figure 8: Comparison of wear resistance, Pin-on-disc test, test conditions: Hardness: 52 HRC, Ball on disc, Ball: Al2O3, Temperature: 20°C, Contact pressure: 5N, Rotation speed: 25 mm/s, Path: 2000 m
Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG

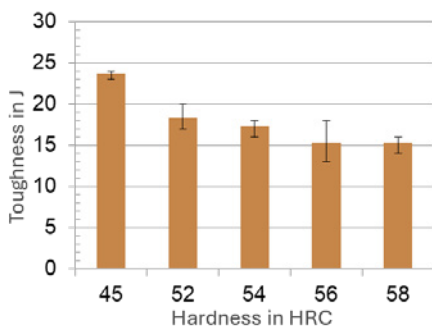


Figure 9: Toughness level of the CS1 with reference to its hardness

Source: Kind & Co., Edelstahlwerk, GmbH & Co. KG

Case study: CS1

CS1 is a CrMoV alloyed tool steel with an increased carbon content, but -thanks to its purity- still excellent toughness (Fig. 9), also providing high heat resistance. Therefore, it can be used for applications where high hardness and toughness are needed.

Here, the first product is a hot forged stainless-steel fitting, where CS1 at a hardness level of 52-56 HRC is compared to 1.2367 at a hardness level of 50 HRC. The performance increase was 60 %. The second product is a forged two-wheeler crankshaft. CS1 at a hardness level of 52-56 HRC was compared to 1.2344 at a hardness level of 43-46 HRC. In this case, the performance increase was 300 %.

Case study: FTCo

FTCo is a hot-work tool of steel with excellent high-temperature strength and hot wear resistance. As a matter of fact, its toughness is reduced and therefore it is not promoted in cases where toughness is important.

Using it as a punch for axe holes at a hardness level of 56-58 HRC solves all problems the producer had with the 1.2367 before. In the production of gears, the FTCo doubles its performance again compared to 1.2367.

What else is important

Apart from choosing the best tool steel solution for a particular part, it is important to take care of the die properly. Heat treatment after pre-machining is the first essential step concerning die care. Kind&Co. provides tailored heat treatment instructions for every premium hot-work tool steel and uses partner heat treatment shops all over the world, who are able to provide proper heat treatment. Prior to production, pre-heating of the die is essential. A pre-heating temperature of 150-180°C is important for every hot-work tool steel in order to utilize their material properties. Also important is pre-heating of the die to the core. The difference in temperature from surface to core should be as low as possible. The heating also helps increasing the toughness of a die. For H13 tool steel, the toughness is two times higher at working temperature of 200 °C, compared to room temperature. Pre-heating by flame is hard to control and not evenly pre-heating the die. If possible, pre-heating by placing the dies in a furnace is recommended. As soon as a forging press faces malfunction and forging has to be stopped, the dies should be kept at pre-heating temperature.

Summary

Four main failure modes influencing die life were presented, such as wear, mechanical cracking, thermal cracking, and plastic deformation. Also, the material properties of a die steel were presented to prevent or delay these. Kind&Co. offers a wide range of premium solutions for forging customers, four of which were presented in some detail here. Q10 provides high toughness potential, which makes it suitable for high series depth parts. The outstanding tool steel with superior

economics for press forging dies facing thermal fatigue. Cr7V-L comes with excellent wear resistance to prevent the early loss of precision of the dies and therefore of the parts produced. The premium tool steel to manage die wear. CS1 allows for a higher working hardness and is optimal for high surface/geometric requirements. The top performance tool steel to manage even highest impacts in forging. FTCo is a top performance tool steel providing excellent wear resistance and unparalleled high-temperature strength.

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