Steel selection contributing to wear reduction of forging dies

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Every increase in tool life has positive effects towards reducing production costs of a forged part. This prolonged lifetime postpones a necessary tooling replacement, causing a beneficial decrease in downtime. As studies have shown, a major part for the breakdown of forging dies is due to wear. Consequently, the constant strive to increase the tool life directs the focus to minimize wear.

Wear must be regarded as a complex collective of stress factors, but the most common approach limiting wear is increasing the hardness. However, the common increase of the material matrix hardness is only possible to a certain extent. Above a steel specific hardness maximum the tool material lacks the necessary toughness and might suffer fracture. Therefore, the second approach against tool wear is the defined use of hard phases as carbides in the steel matrix. Those carbides reduce the tool wear due to their very high hardness, whereas the advantageous effect of carbides is limited to certain parameters like evenly dispersion, shape, size, quantity and the specific kind of the carbides.

The special hot-work tool steel CR7V-L respects these two approaches. The carefully balanced alloy concept was developed by Kind & Co. Compared to established hot-work tool steels it reveals a higher hardness and wear resistance. Due to its acquired properties, CR7V-L found widespread application in Europe, especially for very wear-intensive forging dies. This report describes the properties of the tool steel CR7V-L for demanding forging applications and will also point out some example applications.

1. Introduction

Widespread process optimisation towards cost reduction is pervasive in every part of today's industry. As the forging industry is competing with a wide variety of other production methods as i.e. die casting with more than 100 000 pieces per die, already good forging performances of 10 000 pieces per die are significantly lower but yet have to be increased. Improved tool life assists to cut down the part costs as well as the die setup effort and time and can be achieved by facing the main failure reasons of forging dies.

The approach to reduce tool wear by choosing proper wear resistant hot work tool steel represents also an efficient possibility to increase the tool life of forging dies. However, the life time of forging dies is a very complex system and has to be contextualized with a variety of parameters.

2. Performance of forging dies

The performance of a forging die is not only influenced by various mechanisms of wear, but it also depends on the complete handling and forging process. The numerous factors, illustrated in Figure 1, can be regarded as pieces of a puzzle. Only if these factors are well arranged they support each other and provide best prerequisites for an optimal tool performance.

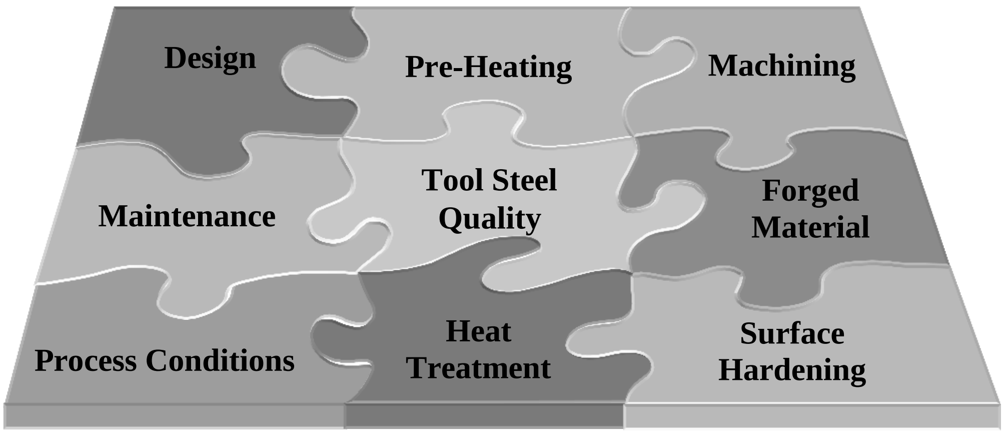

Figure 1: Factors influencing the lifetime of forging dies

Furthermore, the tool life time is also dependent on the particular forging machine, the lubricant and the desired part tolerances.

3. Loads leading to defects of forging dies

Forging dies are suffering from a complex collective of stress factors, such as thermal, mechanical, tribological and chemical nature [1] [2].

The thermal stress is a result of the thermal load composed of the continuous thermal load due to the die basic temperature (of 200 to 300 °C) and the alternating thermal load due to the contact with the hot work pieces (up to 1200 °C) and subsequent cooling (Figure 2). Furthermore, in die areas with high material flow further frictional heat is introduced into the die each forging cycle.

The continuous thermal load of the forging die is described by the basic die temperature, which can be understood as equilibrium between introduced forging heat and the dissipated heat due to convection and cooling and which stabilises after a few forging cycles. To avoid thermal damaging just due to the basic die temperature, appropriate actions to maintain the die temperature at any time below the tempering temperature are advised.

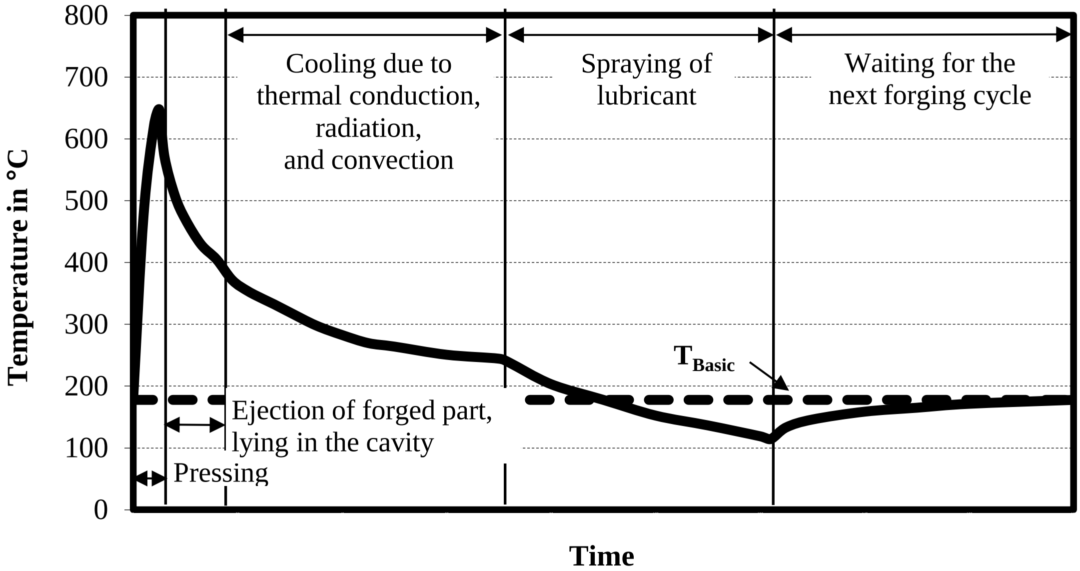

Figure 2: Schematic time-temperature profile in the surface of a forging die [3]

The mechanical stresses are induced due to forming process itself and the thermal stresses in the die. The forming process causes compressional, tensional and bending stresses which might lead especially in concave mouldings and radii to cracks. Besides, the thermally induced stresses result from the constantly changing temperature causing thermal cycling cracking.

Tribological loads occur due to the relative movement of the die and the deformed work piece. Furthermore, the intermediate layer between die and work piece consisting of scale, lubricant, abrasion particles from die and work piece is having a great impact on the occurring tribological system.
Chemically challenging for the die surface can be the interaction of the work piece, the intermediate layer and the surroundings, like surface oxidation or chemical reactions with the lubricant layer.

As the mentioned loads are just possible sources for wear, which is generally considered as the main reason for tool failure, it needs to be defined first. In the German industry standard DIN 50320 [4] wear is described as the continuous material loss from the surface of a solid body caused by mechanical reasons i.e. the contact and relative motion of a solid, fluid or gaseous counter body. The wear mechanisms are distinguished in adhesion, abrasion, tribological reactions and surface breakdown as illustrated in Figure 3. Usually, not only one of those wear mechanism but a combination of several mechanisms is involved in the degradation of a surface.

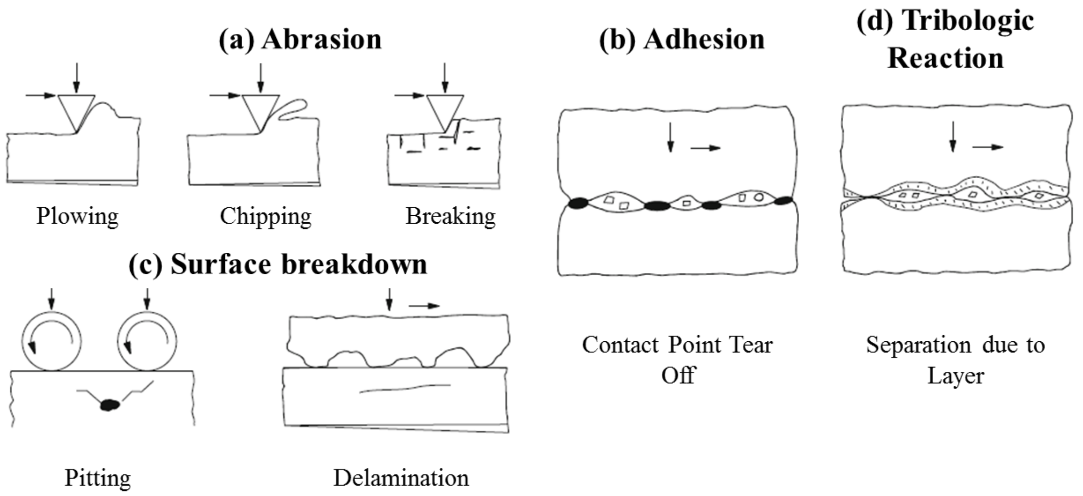

Figure 3: Wear mechanisms: Abrasion, adhesion, surface breakdown and tribologic reaction [5]

In several practical studies [6-12] concerning forging dies wear manifestations as cracks, material displacement due to plastic flow and surface cleavage are told to be omnipresent. Further forms of appearances and their individual intensities are depending on the die shape and process parameters as die and work piece temperatures, lubricant as well as the particular forming machine. According to the mentioned studies and further practical experiences wear emerges primarily at locations where larger amounts of working material is moving with high surface pressure and relative speed over the die surface accompanied by high thermal transfer. The occurring wear mechanisms at forging are in particular abrasion, surface breakdown and adhesion, whereby the tribological reaction is of minor significance.

Influence of the microstructure on wear

The microstructure and especially the hard phases called carbides can have a major influence on wear due to the effectiveness of the above mentioned wear mechanism. The impact of the microstructure is described hereinafter regarding abrasive wear. Fundamental, the hardness of the used tool steel has to be increased in order to minimize abrasive wear. There are two possibilities to increase the hardness:

The first possibility includes the increase of the martensite hardness by solid solution hardening. At the process of martensite hardening, the dislocation movement within the martensite lancets is effectively impeded by internal stresses. These occur due to the lattice distortion caused by the supersaturation with carbon. The solved portion of alloy elements chromium (Cr) and molybdenum (Mo) contributes with solid solution hardening to an increase of the hardness.

The second possibility, the precipitation hardening is based on incoherently precipitated iron carbides $(Fe,M)_3C$ and primary carbides (mainly M_6C, but also M_7C_3), as well as the coherently precipitated vanadium (V) carbides contributing together to the secondary hardness maximum.

As illustrated in Figure 4, the abrasive wear mechanism is further dependent on the size and distribution of carbides in the matrix as well as on the size of abrasive material shape. Finely dispersed small carbides do not withstand abrasion as well as bigger carbides which are inhomogenously dispersed. Only carbides of a certain size and homogenous distribution show a proper resistance against abrasion.

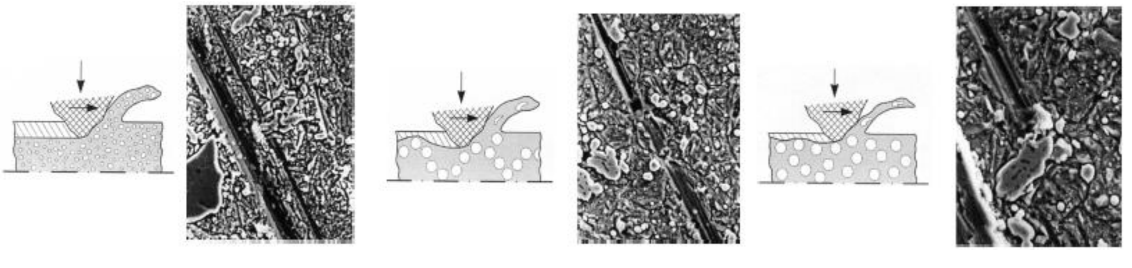

Figure 4: Influence of carbide size and distribution concerning wear resistance. Left: fine homogeneous distributed carbides; middle: bigger carbides in a network structure; right: homogenous dispersion of bigger carbides; after [13].

The size and distribution of the carbides can be considered as the result of chemical analysis and therefore the amount of carbide forming elements and the corresponding heat treatment.

Contrarily, the hardness can be reduced by the following effects: After the heat treatment the supersaturated carbon leaves the interstitial sites and segregates as Cr- or Mo-carbides resulting in an alloy element impoverished ferritic matrix, leading to a loss of martensite hardness and reduction of the solid solution hardening effect.

Furthermore, the vanadium (V) carbides are mainly responsible for the high secondary hardness and therefore, for the good high temperature strength. Due to high temperature input, these carbides grow larger and excess a critical radius (for the Orowan mechanism), resulting in a change of the dislocation movement, a loss of the partially coherence with the lattice and finally in loss of hardness, concluding in an undesired reduction of the precipitation hardening effect.

Therefore, a proper heat treatment leading to carbides of appropriate size and distribution is essentially to the wear resistance of a hot-work tool steel.

4. Tool Steel introduction

This report describes the influence of the die material on the performance of the forging tools. Figure 5 explains the general relation between hardness and lifetime of a die. First an increase in hardness extends the lifetime of the dies to an optimum but a further increase of the hardness results in a reduced tool performance.

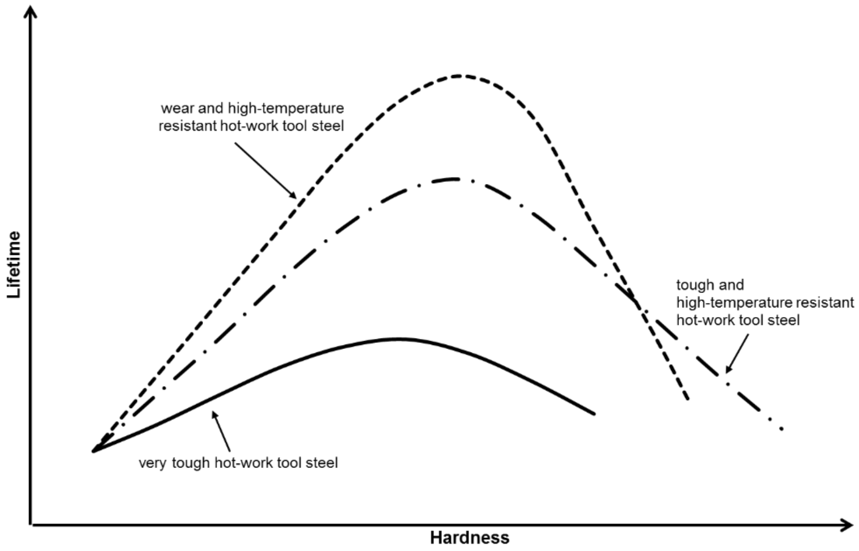

Figure 5: Schematic explanation of the correlation between hardness and lifetime of forging dies for three different types of hot-work tool steels.

Low hardness values favour the wear of the dies whereas a high hardness promotes the risk of tension cracks so that finally dies will fail due to gross cracking. Depending on the type of hot-work tool steel – very tough grade, tough and high-temperature resistant steel, wear and high-temperature resistant steel - the curve can be modified. This fact points out that it requires an intensive coordination between hot-work tool steel, forging process and parameters, and forged component, in order to provide the optimum tool performance. Only the direct contact to the forging industry gives the steel producer the chance to supply a suitable hot-work tool steel with the appropriate hardness for their individual forging applications. This also explains why a universally applicable hot-work tool steel offering best results for all forging processes cannot be available.

4.1 Properties

The impacts on the dies described above help to define the general requirements on the suitable hot-work tool steels:

- High-temperature strength
- High-temperature wear resistance
- High-temperature toughness
- High-tempering resistance.

The high temperatures during the contact with the forgings require a high tempering resistance and high-temperature strength in order to avoid a loss of hardness during operation which would promote wear and plastic deformation of the dies. For the purpose of withstand sudden thermal changes on the surface of the cavity of a die the suitable hot-work tool steel must offer a high resistance against thermal fatigue. This also requires a well-balanced combination of tempering resistance, high-temperature strength and toughness.

The resistance of a hot-work tool steel against abrasive wear is provided mainly by carbides – hard particles embedded in the hardened and tempered matrix of the steel. These carbides consist mainly of chromium (Cr), vanadium (V), molybdenum (Mo), and carbon (C) and therefore require certain concentrations of these elements in the chemical composition of the hot-work tool steels.

In order to sustain the high mechanical loads during operation a high strength is required at elevated temperatures. Simultaneously the steels must have a good toughness in order to compensate the high tensions during operation without any cracks i.e. shock like impacts at hammer dies.

Some of these properties are inverse: a high hardness lowers the toughness; a high carbide content in the steel improves its wear resistance but lowers its toughness and thermal fatigue resistance.

4.2 Common Hot-Work Tool Steel for Forging Application

In this chapter, steels for the press forging will be introduced. Table 1 shows the chemical components of different standard tool steel grades for die forging application and the tool steel CR7V-L.

Table 1: Chemical compositions and working hardness of recommended tool steels

Steel Designation				Mass Content in %						Recommended Hardness
Brand name	Mat.-No.	AISI		C	Si	Mn	Cr	Mo	V	HRC
USD	1.2344	H13	X40CrMoV5-1	0.40	1.00	0.40	5.20	1.30	1.00	48 – 52
RP	1.2365	H10	32CrMoV12-28	0.32	0.40	0.40	3.00	2.80	0.50	50 – 52
RPU	1.2367	---	X38CrMoV5-3	0.38	0.40	0.40	5.00	2.80	0.60	50 – 52
CR7V-L	---	---		0.42	0.50	0.40	6.50	1.30	1.00	52 – 54

CR7V-L special hot-work tool steel was developed based on the standard chromium-molybdenum-vanadium alloyed hot-work tool steels. Instead of 5 wt% chromium in steel grade 1.2367, CR7V-L contains 6.5 wt% chromium for an even higher wear resistance. And instead of 0.38 wt% carbon in grade 1.2344, CR7V-L contains 0.42 wt% carbon for higher hardness. The improved chemical compositions allows the tool steel CR7V-L to provide a more advanced hardness and wear resistance at the same time.

However, the general character of a hot-work tool is defined by its chemical composition, but the metallurgical melting technologies, the forging process and the heat treatment applied in the steel mill drastically influence the property profile of a steel. By optimising these parameters the best combination of properties for the designated application can be achieved. In Figure 6 the microstructure of CR7V-L obtained with corresponding process technology and appropriate heat treatment shows fine-grained martensite with dispersed carbides, meeting the profile of requirements for wear-intensive forging dies.

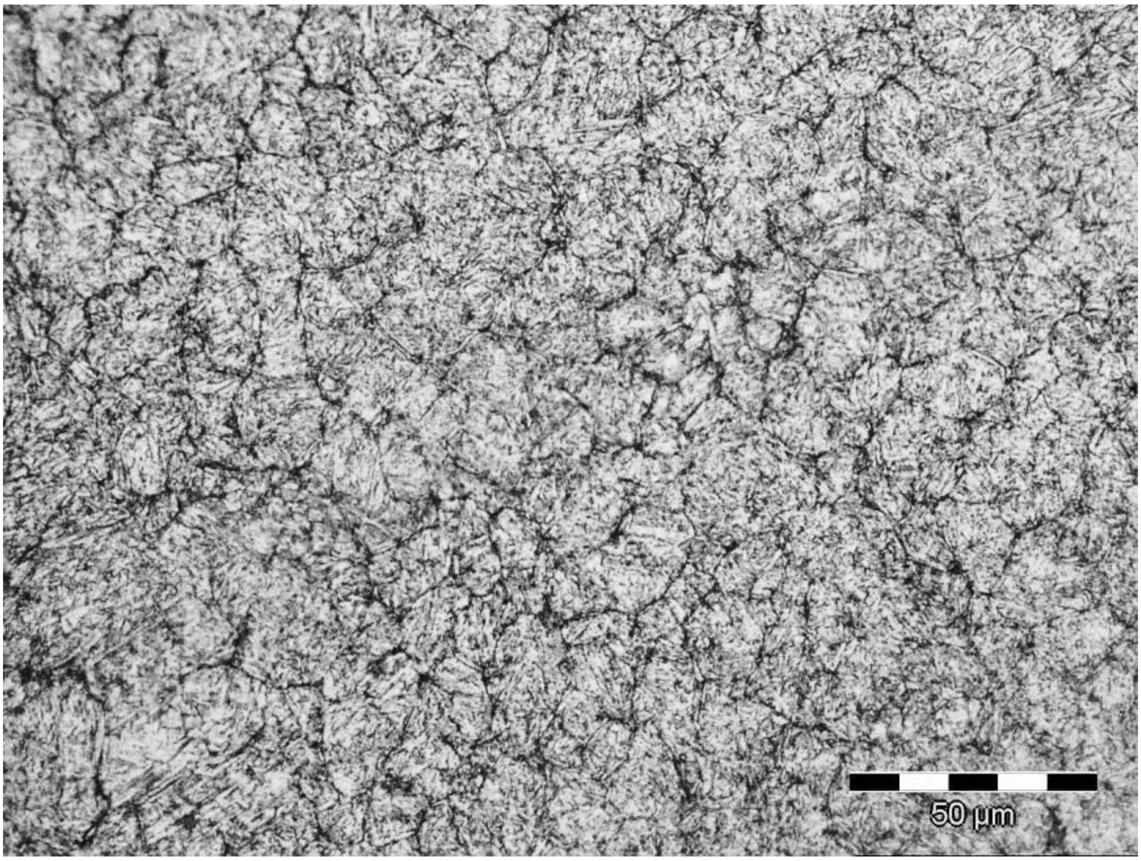

Figure 6: Fine-grained martensitic microstructure image of tool steel CR7V-L showing dispersed carbides.

In a qualitative comparison of the different standard grades (Table 2), it can be noted that the steel grade 1.2367 combines the high-temperature strength of the grade 1.2365 (H10) and the good wear resistance of grade 1.2344 (H13) which allows to substitute these two grades in many applications by the grade 1.2367.

As a result of the mentioned properties like a microstructural matrix with fine carbides, the CR7V-L shows comparable toughness as the 1.2365, the high-temperature strength equals the grades 1.2365 and 1.2367, but the wear resistance is by far better than the wear resistant regarded steel grades 1.2344 and 1.2367.

Table 2: Steel properties comparison towards toughness, high-temperature strength and wear resistance.

Steel designation			Main properties		
Kind & Co	Mat.-No.	AISI	Toughness	High-temperature strength	Wear resistance
USD	1.2344	H13			
RP	1.2365	H10			
RPU	1.2367	---			
CR7V-L	---	---			

Concerning the tempering properties, Figure 7 left shows the dependence of the hardness on the tempering temperature for CR7V-L and international standard tool steels 1.2344 and 1.2367. Here it is striking that the maximum secondary hardness of CR7V-L is 56.5 HRC, which is the highest of these three different steels. The CR7V-L also reaches generally higher hardness than the steels 1.2344 and 1.2367 under different tempering temperatures. Figure 7 right illustrates the high temperature strength of CR7V-L (special tool steel). CR7V-L shows a promising high temperature strength: i.e. at a temperature of 500 °C, the tensile strength R_m still reaches 970 MPa, compared to 930 MPa for the steels 1.2344 and 950 MPa for 1.2367 [14].

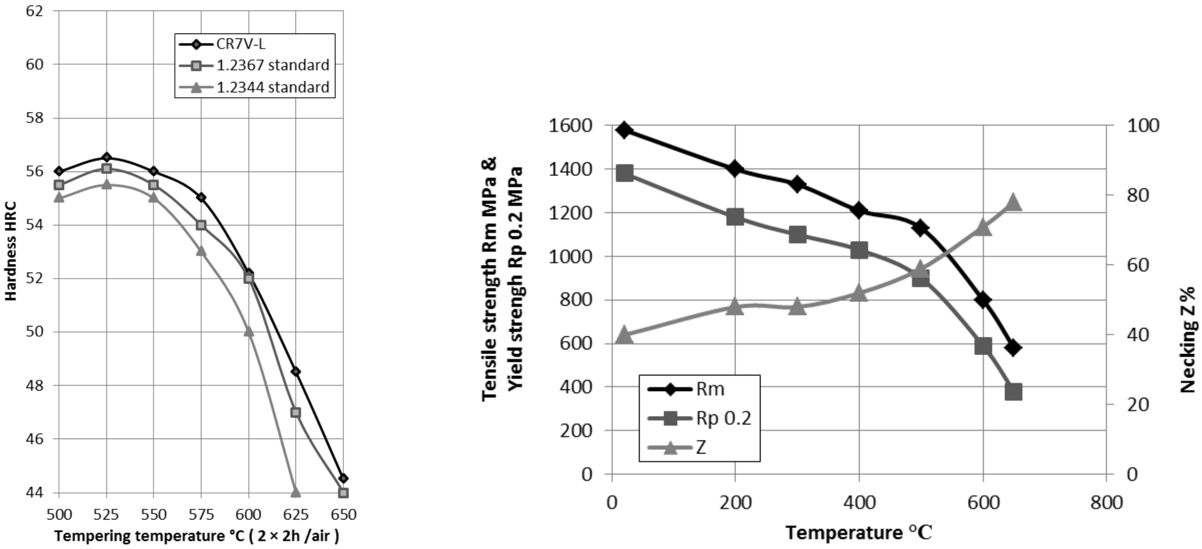

Figure 7 left: Tempering diagram of tool steels CR7V-L, 1.2367 and 1.2344; right: high temperature strength diagram of CR7V-L tool steel

5. Industrial applications and performance

The current developments of new hot-work tool steels for forging dies focus on larger production lots, shorter production cycles and increasing demands on the accurateness of the forged components.

It has to be noted, that a general hardness recommendation for forging dies cannot be given. The hardness of forging dies depends to a high degree on the size and shape of the forged components as well as on the forging machine. In some cases a surface treatment of the dies can be beneficial for the tool life.

In Figure 8 a typical forging die for crankshafts is shown. Having a hardness of 45 HRC these dies of CR7V-L raised the production numbers by approximately 60 % compared to the standard grades 1.2343 (H11) and 1.2344(H13).

Figure 8: Crankshaft forging die made of CR7V-L with a hardness of 45 HRC achieving a performance increase of 60 % compared to 1.2343 respectively 1.2344.

Besides, in a Spanish forge at a die the overall performance was increased by 81 % compared to the original die made of 1.2344 (H13). Other comparisons of a Czech forge with a die made of 1.2367 have revealed a 50 % better performance of CR7V-L, primarily due to less micro cracks and subsequently less production stops and manual grinding tasks, having a beneficial influence on the total part accuracy.

Furthermore, the special steel CR7V-L is found to be advantageous at the pre-forging stage. In this particular forging stage, the temperature of the piece is the highest. Therefore, good tempering resistance is needed. Besides, the pre-forging step is utilized to bring the material from a raw shape close to the final shape. Thereby, the flow of the material over the tool surface is the greatest, causing abrasive wear.

6. Conclusion

In the present report the several loads influencing the performance of forging dies are explained including the most frequent failure modes. Subsequently, the derived, compulsory properties of suitable hot-work tool steels are described and the dependence with the surrounding parameters like forging machine, forged material, pre-heating and cooling are considered.

The permanently increasing economic pressure, to which the forging industry is exposed, evidently promotes the development of new steels. Furthermore, technological developments as more near net shape forging or increasing accuracy influence the tool steel development. Thereby the main objective is the optimisation of the tool life, which can be realised by understanding and reducing tool wear.

The concept of the hot-work tool steel CR7V-L, developed by Kind & Co., is described with its analysis and corresponding beneficial effects towards wear and respectively tool life. The wear behaviour is significantly improved due to the increased contents of carbon, vanadium and chromium which lead to a higher carbide volume of the steel. Simultaneously, good high-temperature strength comparable to the steel grade 1.2367 is achieved by CR7V-L. CR7V-L also reaches best results in larger press dies or in extrusion dies where significant improvements of the tool life have been observed. Further results of example applications in the European forging industry point out the possibility of significant economic improvements for the forging industry by using optimized steels.

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Steel Selection
Contributing to Wear Reduction of Forging Dies

Christoph Mueller & Ingolf Schruff

Tool Steel - Competence and Partnership

KIND&CO
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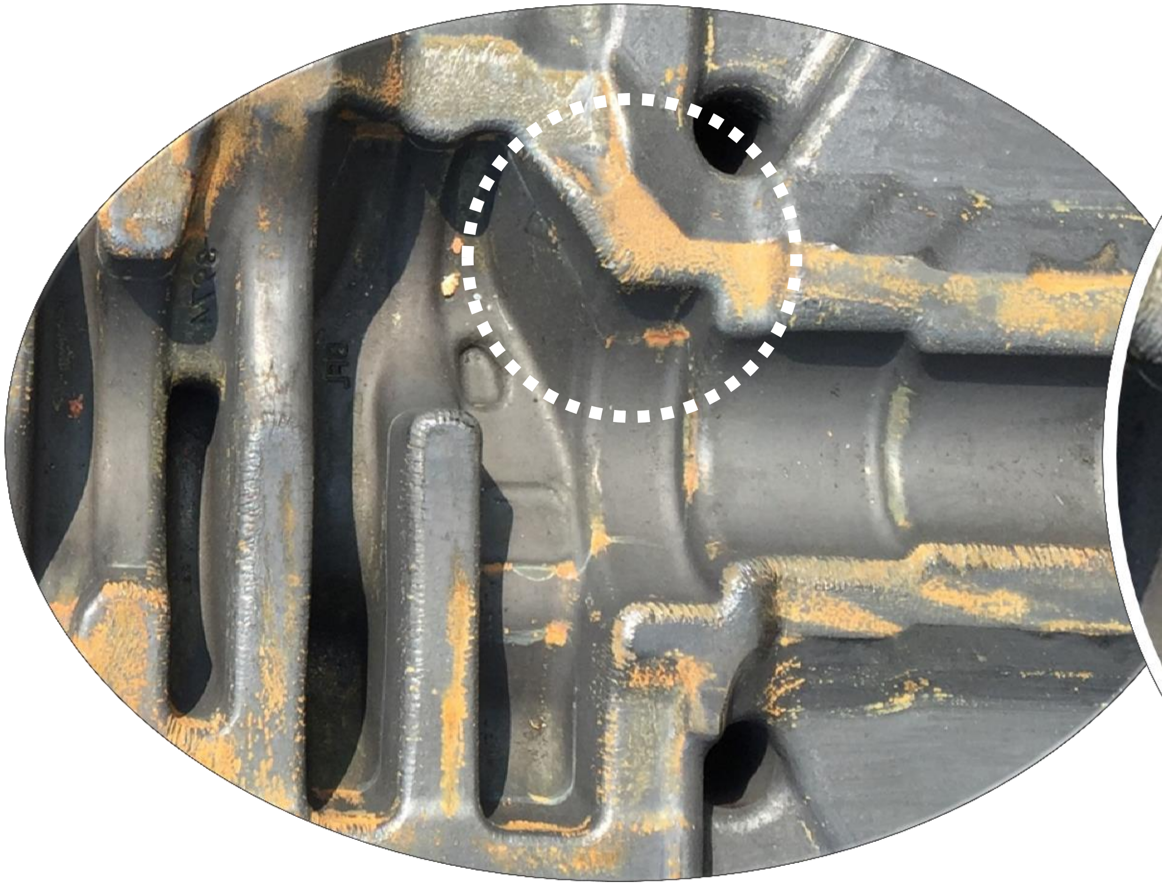
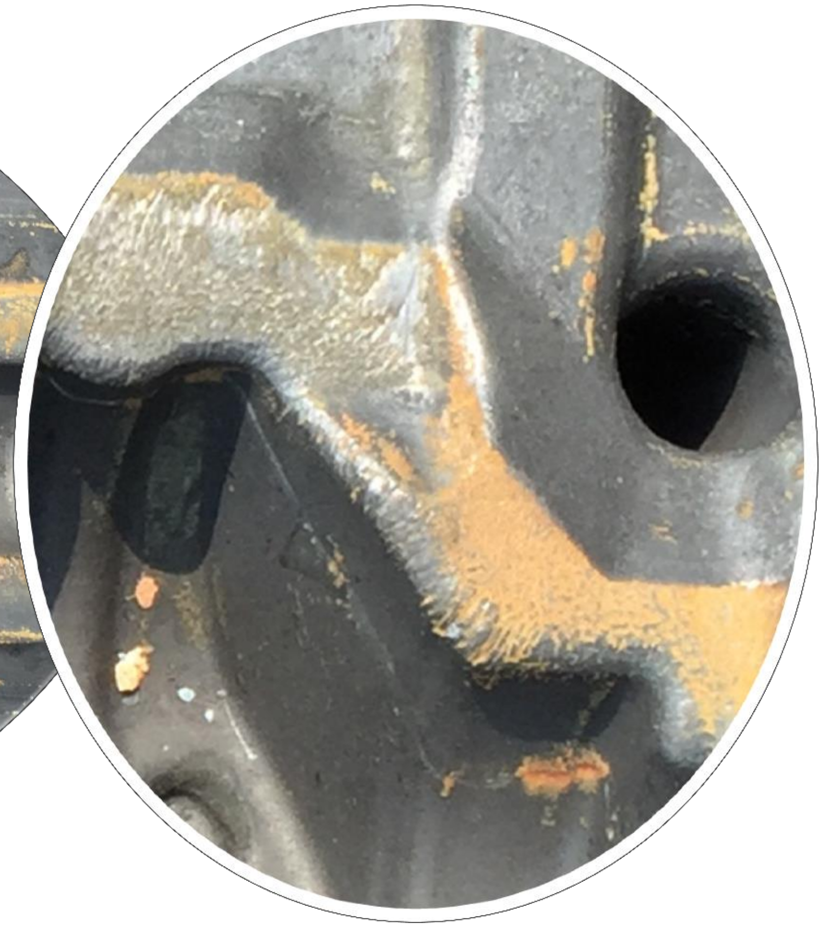
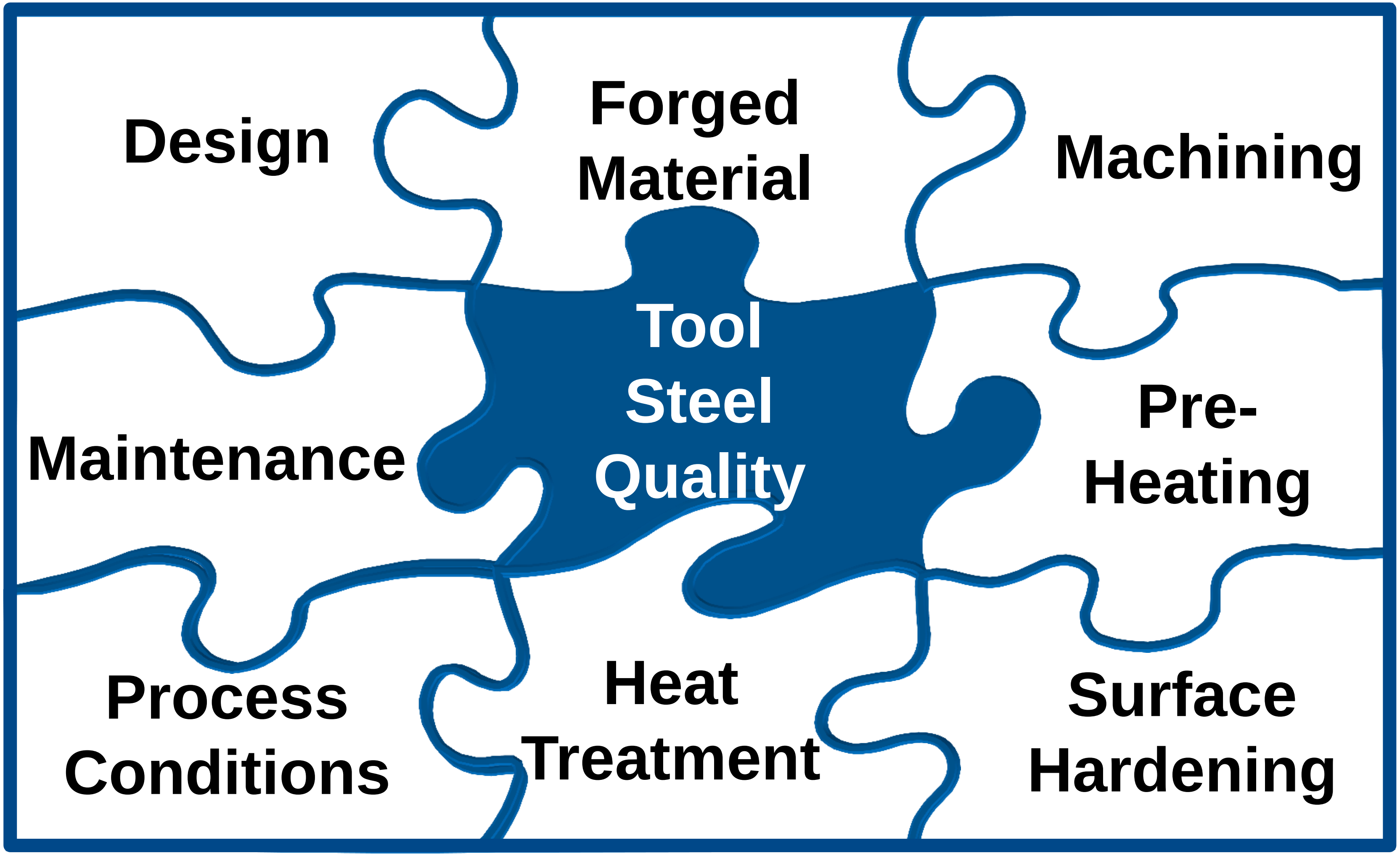
Motivation: Abrasive Wear Causes Poor Die Lifetime





Poor Lifetime ➡ High Costs

Influences on the Die Lifetime



Main Failure Modes of Forging Dies

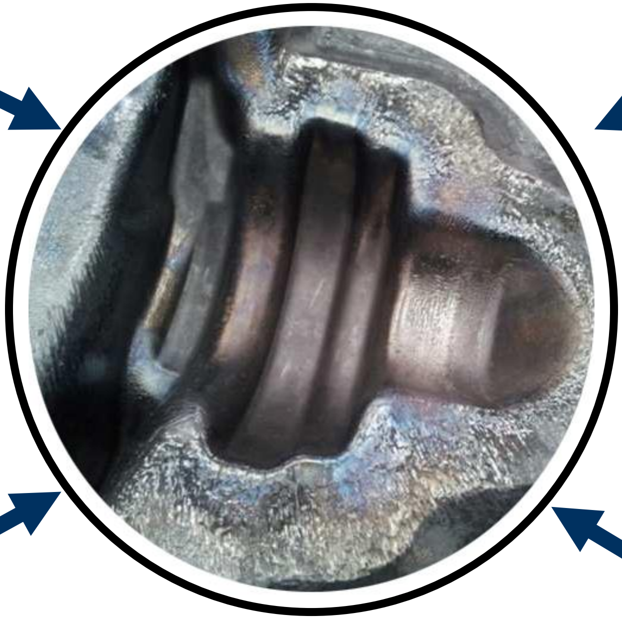
Abrasive Wear

Cracks

Main Effects on the Formation of Wear

Temperature

Micro Explosions



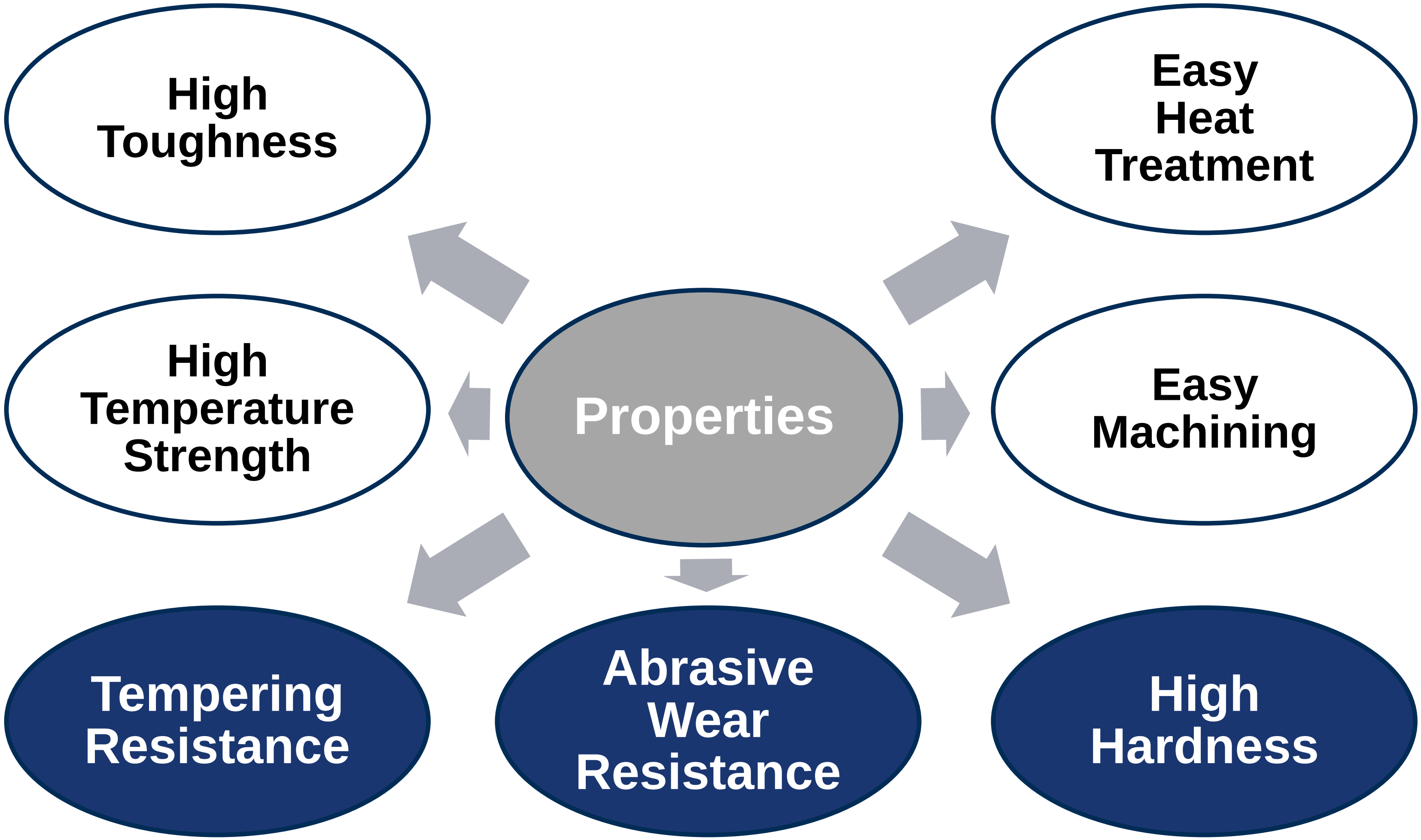
Oxidation

Pressure

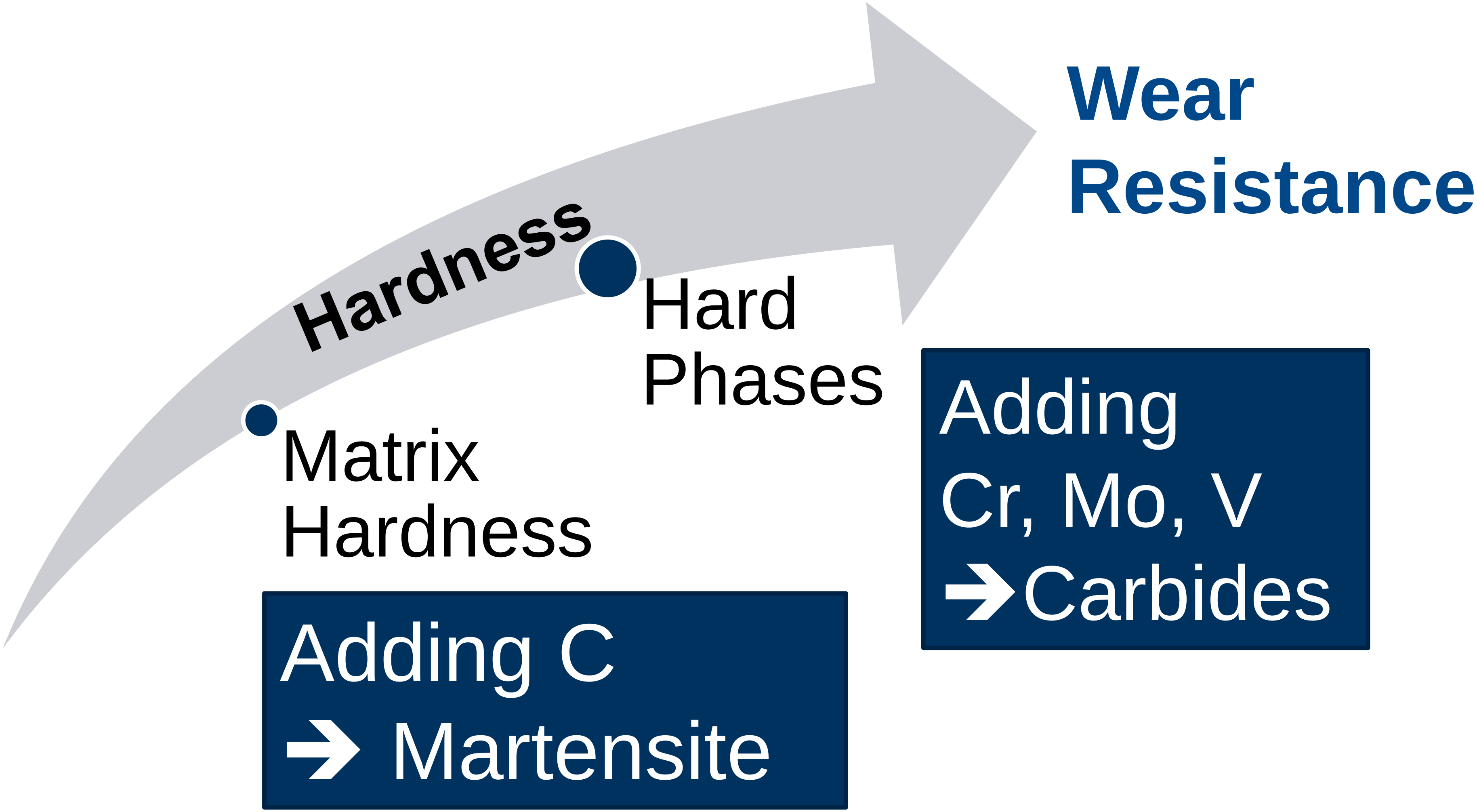
WEAR

Die-Part Motion

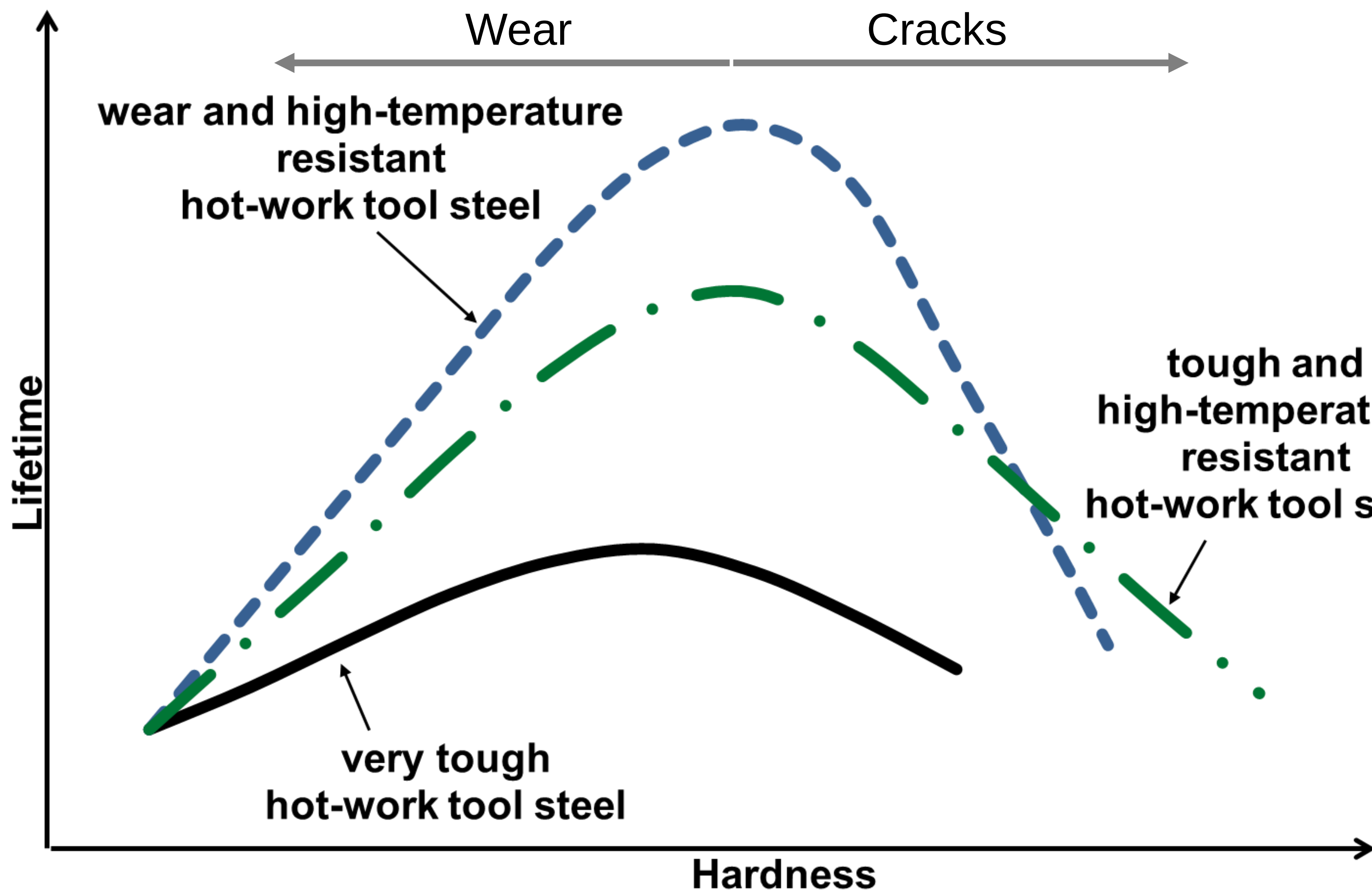
Important Properties for Hot Work Tool Steels



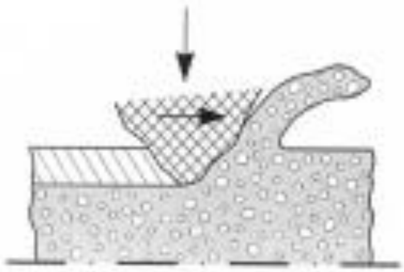
How to Reduce Wear or How to Increase Wear Resistance

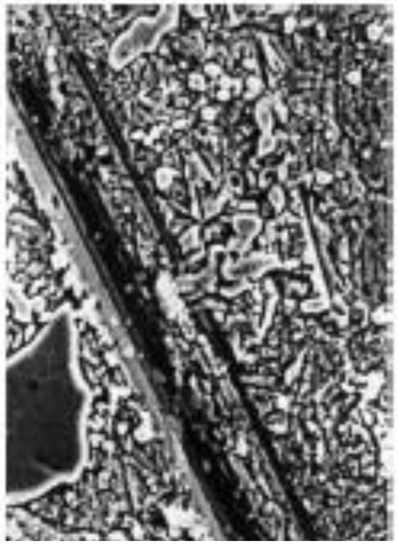


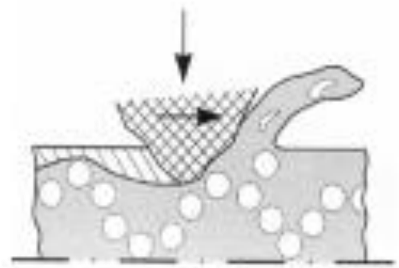
Correlation Between Hardness and Lifetime of Forging Dies

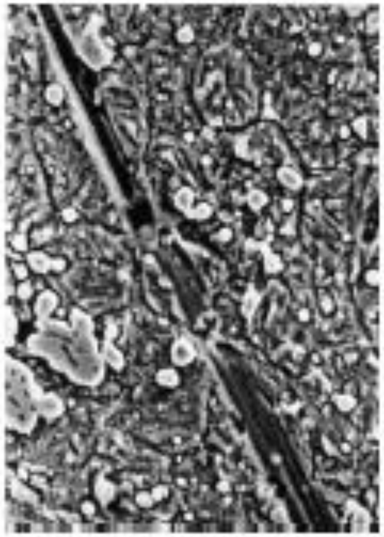


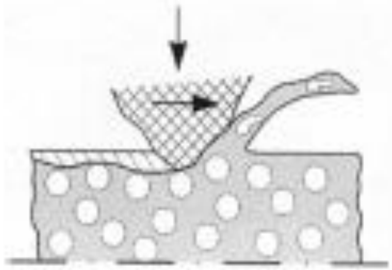
Influence of Carbide Size and Distribution

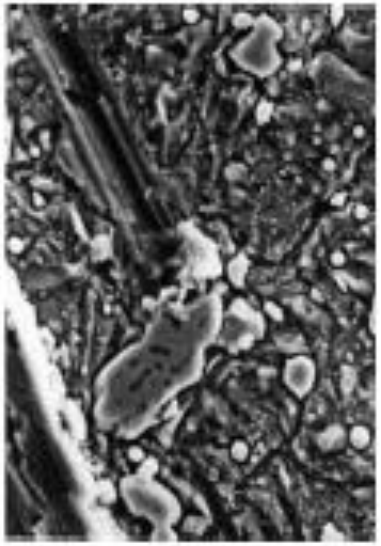












Acc. to
H. Berns
1985

Improved Productivity by Reducing Wear

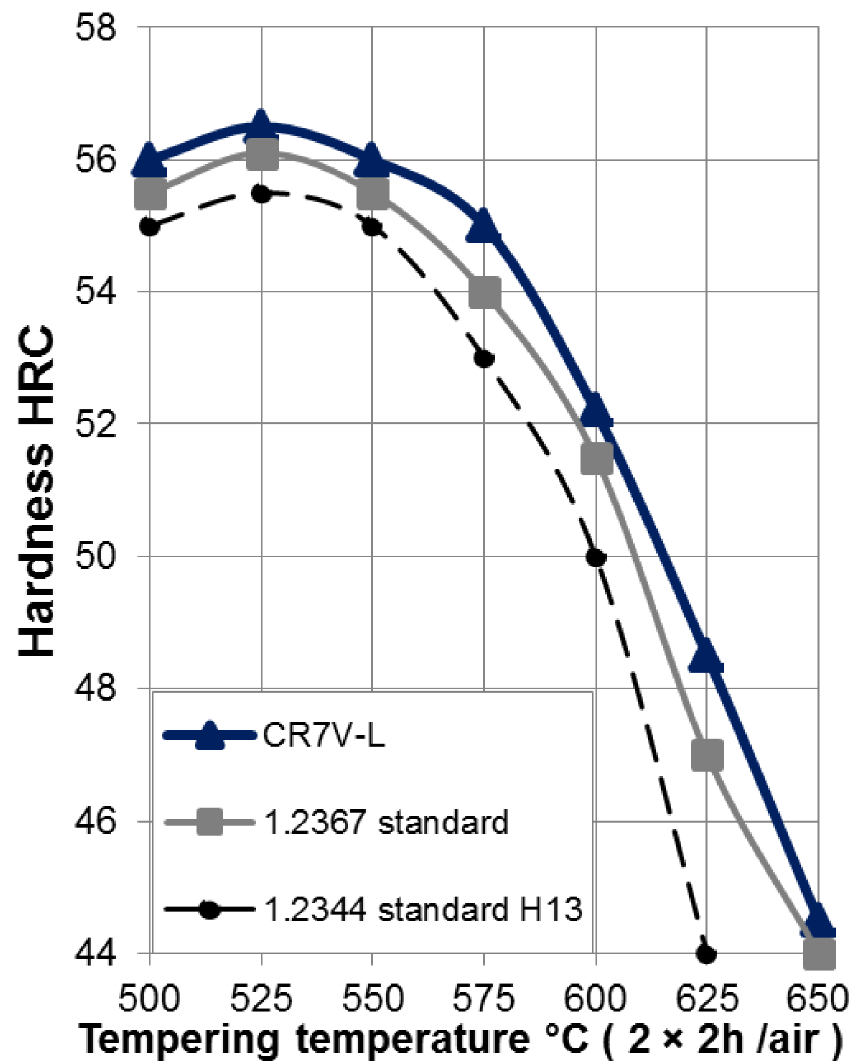
Kind & Co. CR7V-L

„The Wear Resistant One“

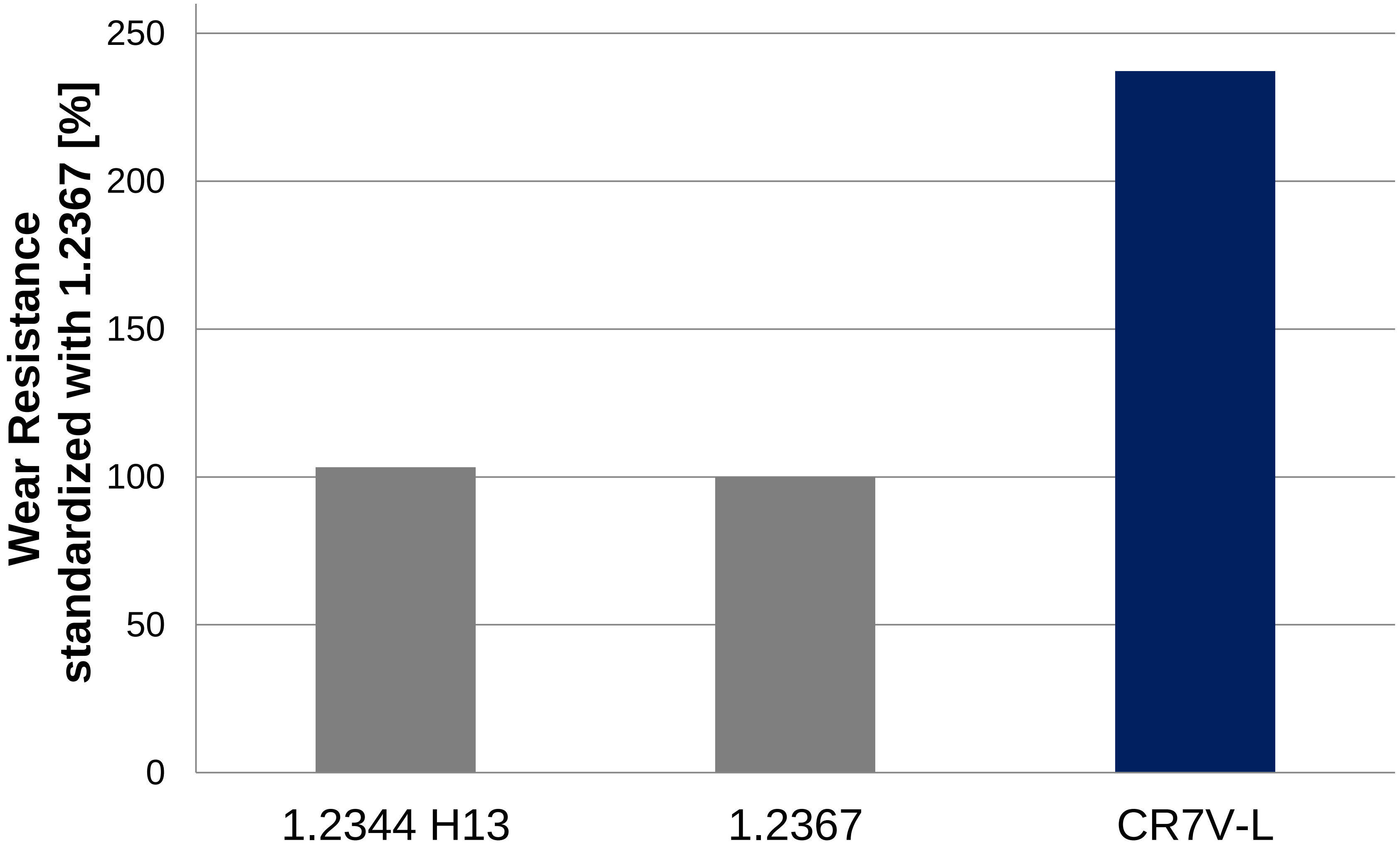
Steel Designation			Mass Content in %						Hardness Recommen-dation
Brand	Mat.-No.	AISI	C	Si	Mn	Cr	Mo	V	HRC
USD	1.2344	**H13**	0.40	1.00	0.40	**5.20**	**1.30**	**1.00**	46 – 50
RP	1.2365	**H10**	0.32	0.40	0.40	3.00	2.80	0.50	45 – 48
RPU	1.2367	---	0.38	0.40	0.40	**5.00**	2.80	0.60	46 – 50
CR7V-L	---	---	**0.42**	**0.50**	**0.40**	**6.50**	**1.30**	**1.00**	**48 – 52**

Improved Productivity by Reducing Wear

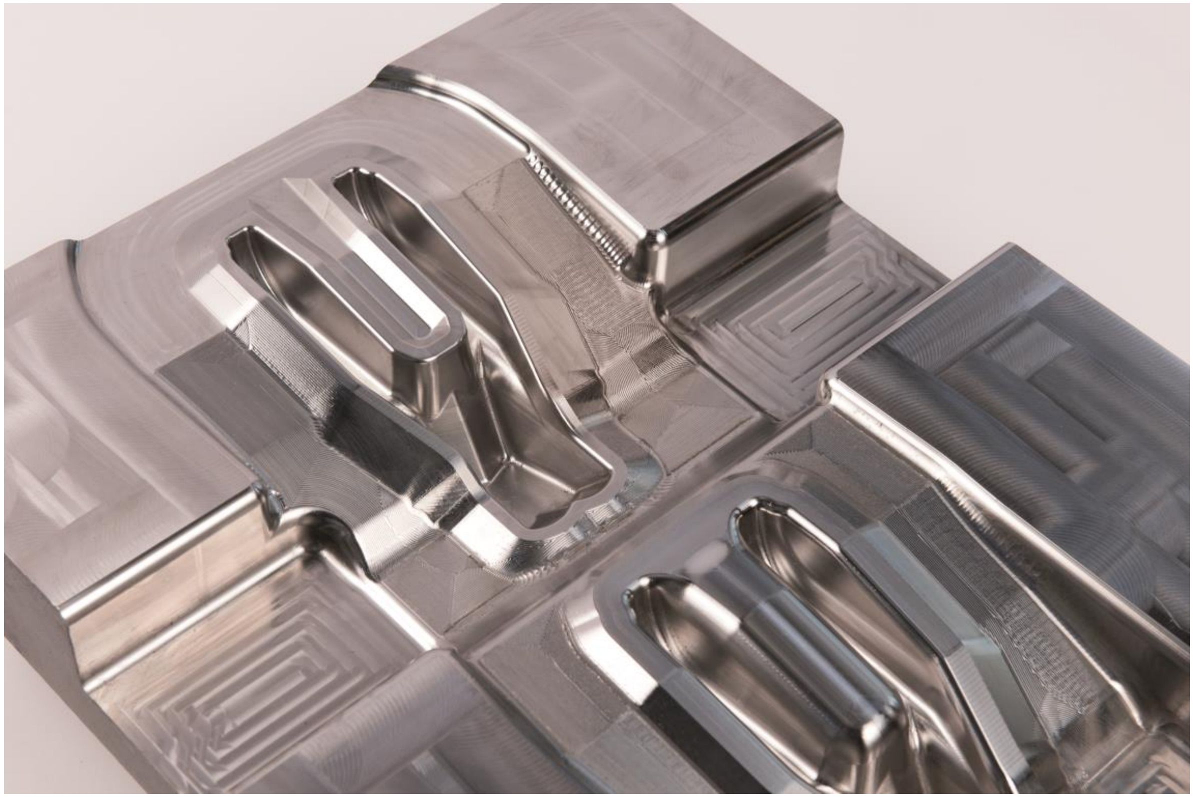
Steel Designation			Main Properties	
Brand	Mat.-No.	AISI	Toughness	High-Temp. Strength
USD	1.2344	H13		
RP	1.2365	H10		
RPU	1.2367	---		
CR7V-L	---	---		



CR7V-L Abrasive Resistance Result



Drop Forging Hot-work Tool Steel CR7V-L



Hydraulic 3200 Tons Forging Press: Finish Die
Die steel: CR7V-L 48 HRC
Improvement in performance: up to 65 % compared to standard hot-work tool steel H 13.

Drop Forging Hot-work Tool Steel CR7V-L

Hydraulic 2500 Tons Forging Press: Blocker Die

Die steel: CR7V-L 48 HRC

Improvement in performance: up to 70 % compared to standard hot-work tool steel H 13.

Drop Forging Hot-work Tool Steel CR7V-L

Hydraulic 6000 Tons Forging Press: Blocker Die for Crankshaft
Die steel: CR7V-L 46 HRC
Improvement in performance: up to 90 % compared to standard hot-work tool steel H 13.

Summary

→ **Wear causes poor die lifetime leading to high costs**

→ **Influences on the die and the lifetime are manifold**

→ **Compulsory properties and certain surrounding parameters have to be met**

→ **Increase in hardness may increase wear resistance**

→ **Main objective is the optimisation of the tool life:**

- → **Kind & Co developed the special hot work tool steel CR7V-L, showing potential for significant improvements of the tool life**

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