

## **Premium tool steels solutions for efficient hot-stamping applications**

D. Wang

*Kind Special Alloys (Beijing) Trading Ltd.,  
Beijing, 100122/Chaoyang District, P.R. China  
E-mail: David.Wang@Kind-special-alloys.hk  
www.Kind-special-alloys.hk*

I. Schruff

*Kind & Co., Edelstahlwerk, GmbH & Co. KG  
Wiehl, 51674, Germany  
E-mail: Ingolf.Schruff@Kind-co.de*

Based on a study on the loads of tools the paper describes requirements for tool steels for hot-stamping tools and presents two premium tool steel solutions specially developed for hot-stamping tools. For Tailored Tempering, a process that allows for local adjustment of the properties of the component, electrically heated tool segments are required in addition to cooled segments. The paper describes a special hot-work tool steel which provides the specific properties for this type of tool segments. Finally the papers offers recommendations for proper adjustment of hardness and successful avoidance of corrosion induced tool failure.

*Keywords:* Hot-stamping; Tool steel; Tailored Tempering; Hardness; Corrosion;

### **1. Introduction**

Driven by the necessity to reduce the weight of vehicles hot-stamping has quickly developed to a leading technology for the production of light weight high-strength automotive components. Originally used to produce only few components for some passenger vehicles the variety of components as well as the total number of produced parts have been growing rapidly. Nowadays hot-stamped components are also used in the production of commercial vehicles as weight reduction is equally important for these vehicles. With the on-going development of e-mobility the importance of hot-stamping as a key production technology will be enforced, since weight reduction is supporting larger battery ranges and agility.

Hot-stamping is in a strong competition with technologies like pressure die casting of structural components – a technology which has also increasingly gained access to the car design. Efficient hot-stamping requires tools which allow a reliable production without premature tool failures or unexpected repair due to massive wear. In order to achieve short cycle times a quick transport of the heat out of the component and thus intense cooling is certainly desirable.

Some hot-stamped components require local variations of their mechanical properties. For crash safety reasons some sections of the B-pillar of passenger cars must have a drastically increased toughness in order to compensate crash energy by plastic deformation of the component. The tailored tempering technology using heated tool segments locally reduces the cooling rate of the sheet metal and this way avoids the martensitic hardening of the sheet metal, leaving this part of the component with more toughness.

The permanently on-going process development in the hot-stamping industry has led to various tool modifications. Shapes of components and tools have become more challenging, the distances between cooling channels and working surfaces have been reduced to a few millimetres to allow a faster heat transfer into the cooling channels and shorter production cycles. On the other hand, these developments have drastically increased thermal and mechanical stresses to which the tools are exposed during operation. E.g., due to intensive cooling corrosion induced cracks between cooling channels and working surface can increasingly be observed. Kind & Co. has investigated these phenomena and developed suitable recommendations and countermeasures to avoid these defects.

This paper describes the tool steel solutions recommended by Kind & Co. for the water-quenched as well as for the heated tool sections, advises on the appropriate hardness selection and offers help to avoid corrosion induced tool defects.

## **2. Stress situation in hot-stamping dies and required tool-steel properties**

A detailed analysis of the stresses to which a hot-stamping die is exposed during operation is the best prerequisite for tool steel selection and heat treatment.

### **2.1. *Stress analysis***

During operation hot-stamping tools are exposed to a complex system of thermal and mechanical stresses. With each stroke the contact zone of the tool is heated up momentarily. According to own estimations [1] the peak temperature of the tools might rise up to approximately 490 °C within a working shift. Cyclic cooling and heating will result in thermal fatigue during the lifetime of the tools.

The stamping operation itself induces intensive compression stress in the dies and the relative movement of the sheet metal over edges causes intensive abrasive wear.

### **2.2. *Required tool steel properties***

The required properties of suitable tool steels for hot-stamping tools can be derived from the loads on the tools.

High high-temperature strength is required to withstand the mechanical loads during operation. This goes along a high thermal fatigue resistance to avoid undesired softening of the tools.

High hardness and tempering resistance are required to provide sufficient wear resistance. But wear resistance does not only depend on the steel's hardness but also on the type, size, and distribution carbides in the steel.

A fast heat transfer from the sheet into the cooling system requires a high thermal conductivity of the tool steel. Nevertheless, more relevant are design and distance of cooling channels from the working surface. While thermal conductivity brings a linear advantage to cooling efficiency, the distance of the cooling channels to the surface is of much higher order dependency.

Good toughness helps to avoid cracks between cooling channels and working surface of the tools.

### 3. Recommended tool steels

The recommendation of suitable tool steels for hot-stamping tools always depends on the combination of properties. It should never depend on only one single property such as thermal conductivity. It should always be kept in mind that material properties often interact so that high values of one property might lead to low values of another property.

#### 3.1.1. Tool steels for water cooled hot-stamping tools

For water cooled tool segments Kind & Co. recommends the specially developed tool steel CR7V-L as it combines the required properties in an excellent way. It has successfully proven its suitability in numerous hot-stamping tools. For applications which require an even higher abrasive wear resistance Kind & Co. has recently developed the grade HS 1. Table 1 gives a survey of their chemical compositions. The standardized hot-work tool steel 1.2344 (AISI H 13) is listed here only for reference purpose.

Table 1. Chemical compositions of the special steel grades CR7V-L and HS 1.  
Alloy content in Mass-%.

Steel grade	C	Si	Mn	Cr	Mo	V	Recommended hardness in HRC
1.2344	0,40	1,00	0,40	5,20	1,30	1,00	---
CR7V-L	0,42	0,50	0,40	6,50	1,30	0,80	52 – 54
HS 1	0,50	0,90	0,80	8,00	1,50	1,70	54 – 58

As the tempering curves in Figure 1 clearly indicate, the special grades CR7V-L and HS 1 not only achieve higher hardness levels but also develop a better tempering resistance than the reference hot-work tool steel 1.2344. The high hardness contributes to the good abrasive wear resistance and the tempering resistance prohibits premature softening of the tool sets due to contact with the hot sheet metal.

Comparing the recommended hardness values for these steels (Table 1) with their tempering curves shows that Kind & Co. strongly recommends not using the steels at

their maximum hardness levels as the steels develop their lowest toughness at this hardness.

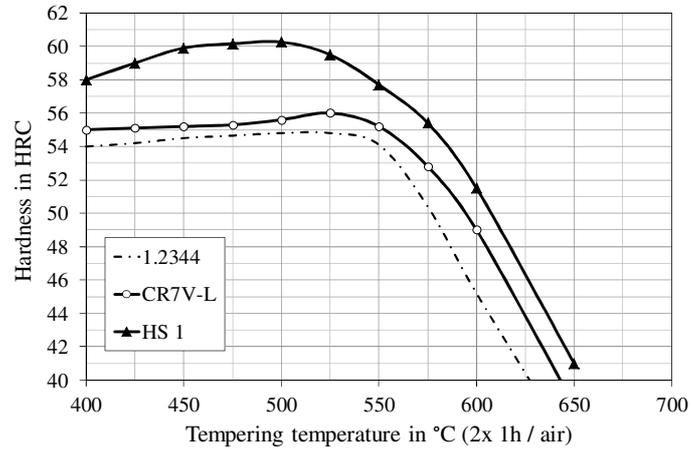


Fig. 1. Tempering curves of the steel grades 1.2344 (H 13), CR7V-L, and HS 1

Abrasive wear resistance is a property which depends on hardness and carbide content, carbide types and carbide distribution. A schematic comparison of the three steels with respect to abrasive wear resistance is shown in Figure 2.

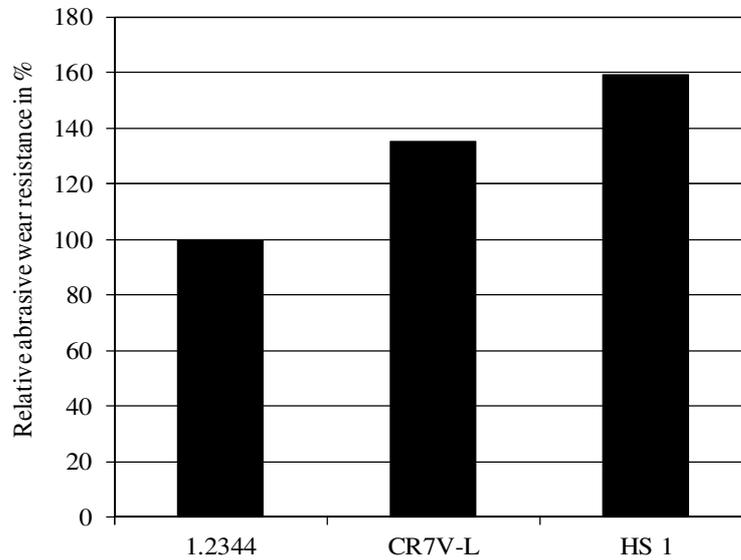


Fig. 2. Schematic comparison of the abrasive wear resistance of steel grades 1.2344, CR7V-L, and HS 1

Thermal conductivity is responsible for the heat transfer from the sheet metal into the cooling channels. Shortening the cooling period has the best chance to reduce the cycle

time of hot-stamping operations [2]. Nevertheless, in the process of steel selection for hot-stamping tools thermal conductivity should not be the only and decisive property as mechanical properties like tempering resistance, high-temperature strength, and wear resistance are opposing to thermal conductivity [1]. Table 2 underlines the good thermal conductivity of CRV-L and HS 1.

Table 2. Thermal conductivity  $\lambda$  in W / (m \* K) of the steel grades 1.2344, CR7V-L, and HS 1.

Steel Grade	Test temperature		
	20 °C	200 °C	400 °C
1.2344	25,5	27,1	21,7
CR7V-L	26,7	29,8	30,8
HS 1	25,2	27,3	29,3

The high mechanical and thermal loads on hot-stamping tools not only require hardness and wear resistance but also toughness. As water-cooled hot-stamping tools operate at a high hardness level each contribution to improved toughness will directly influence the tool life. Apart from a correct hardness and heat treatment of the tool segments the metallurgical production process of the steels has an important influence on the toughness and tool life. The Electro-Slag-Remelting (ESR) process improves purity and homogeneity of the steels and this way contributes to an improved lifetime potential of the tools. While the grade HS 1 is produced exclusively via ESR the grade CR7V-L is available as air-melted steel as well as an ESR grade. For highly stressed tool segments Kind & Co. recommends the use of the ESR version of CR7V-L.

### 3.1.2 Tool steels for tailored tempering

Electrically heated to temperatures of 550 – 650 °C tool segments for tailored tempering prohibit the martensitic transformation of the steel sheets generating locally restricted zones of reduced strength and simultaneously increased plasticity in the components. Besides hardness and wear resistance steels for these tool segments must provide a high long-time tempering resistance in order to withstand the high tool temperatures for long times. As steel grades like 1.2344, CR7V-L, and HS 1 cannot maintain this requirement long enough Kind & Co. recommends the steel grade HMoD for heated tool steel segments in tailored tempering applications.

As Table 3 shows up this grade is highly alloyed with elements like molybdenum and cobalt which contribute to the steel's excellent high-temperature strength and tempering resistance.

Table 3. Chemical composition of the special steel grade HMoD  
Alloy content in Mass-%.

Steel grade	C	Si	Mn	Cr	Mo	V	Co	Recommended hardness in HRC
HMoD	0,45	0,30	0,40	4,50	3,00	2,00	4,50	50 – 52

Due to the high alloy content Kind & Co produces the grade HMoD exclusively as ESR grade giving the steel improved purity, homogeneity, and toughness.

The tempering curve of HMoD (Figure 3) presents a much higher tempering resistance than CR7V-L and this way demonstrates the best suitability of HMoD for heated tool segments in tailored tempering applications.

The long-time tempering resistance of these two steel grades is expressed in Figure 4. Samples had been hardened and tempered originally to a hardness of 53 HRC and then exposed to a temperature of 550 °C for up to 100 hours. The curves show that over this long testing period the hardness HMoD declines only slightly. This demonstrates the enormous long-time tempering resistance of HMoD which makes this grade best suitable for heated tool inserts in tailored tempering applications.

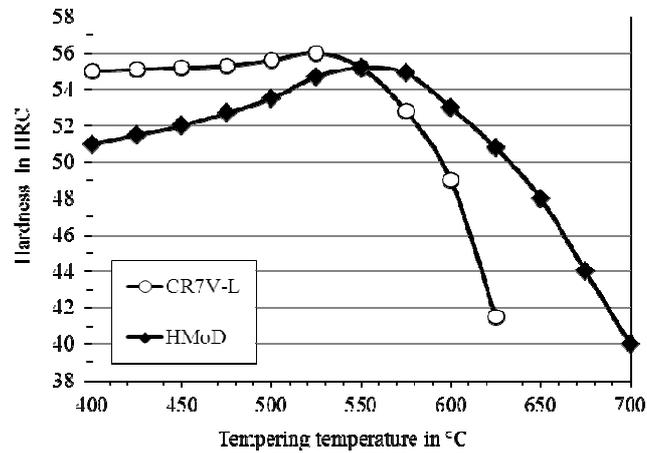


Fig. 3. Tempering behaviour of the steel grades CR7V-L and HMoD.

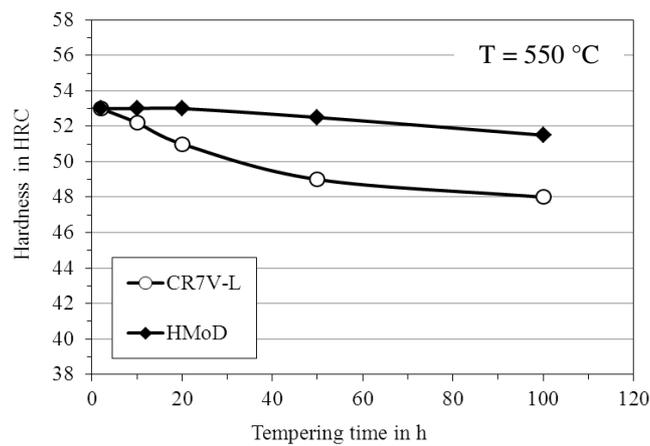


Fig. 4. Long-time tempering behaviour of the steel grades CR7V-L and HMoD at a temperature of 550 °C.

#### 4. Recommendations for improved tool life

Although being a fast growing technology hot-stamping is facing a technological and economic competition with technologies such as pressure-die casting of structural components. Economic hot-stamping production processes therefore require reliable tools which provide a long lifetime without interruptions or premature failure. Recent developments in the hot-stamping technology have led to many modifications of hot-stamping tools. Sizes and contours of the tools have changed significantly (Figure 5).

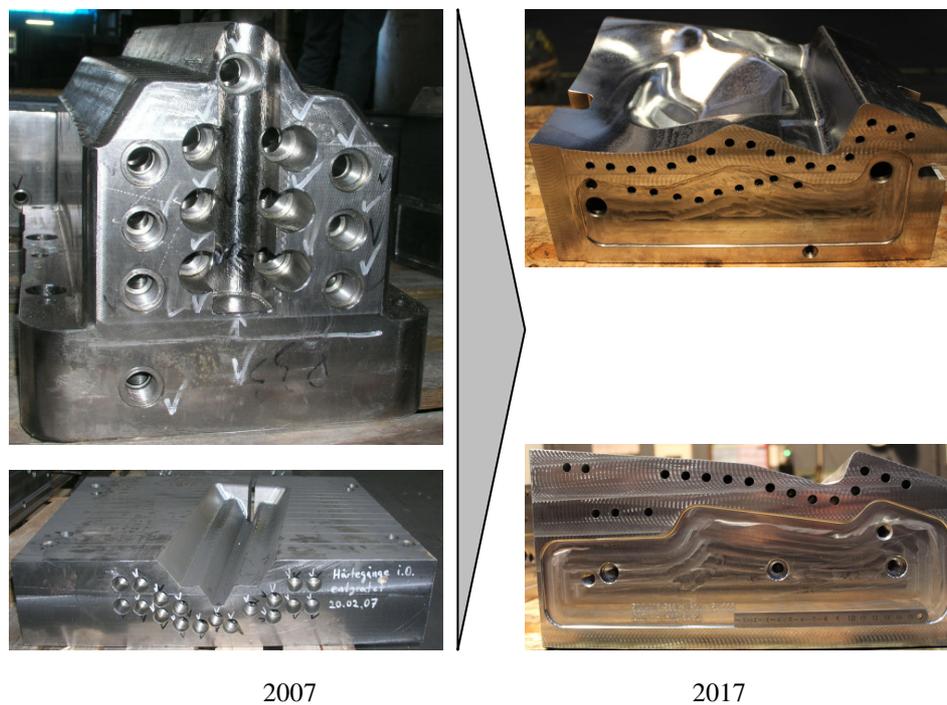


Fig. 5. Development of size, shape and cooling of hot-stamping tools between 2007 and 2017

Hardness values of the tools had been increased in order to optimize wear resistance and to extend lifetime of the dies. In order to optimize the quenching of the sheet components the distances between cooling channels and working surface of the tools had been reduced significantly to only few millimeters. As a consequence of all these modifications the stress situation of the tools had been drastically intensified and tool defects like water leakage (Figure 6) had been observed frequently.



Fig. 6. Water leaking from a cooling channel in a hot-stamping tool.

Kind & Co. investigated numerous of these tool failures and developed strategies to avoid them. The photos in Figure 7 represent an investigated tool which failed prematurely due to corrosion induced cracks.



Fig. 7. Section through a defect hot-stamping tool  
 Left: Cross-section; Middle: Detail with crack from cooling channel to the working surface;  
 Right: Corroded crack surfaces

As can be seen in Figure 7 the traces of corrosion in the cooling channels are clearly visible. A crack had developed from the cooling channel and had propagated through the wall thickness of approx. 6 mm towards the working surface. The corroded surfaces of the crack demonstrate the lateral extension of the crack. The starting point of the crack was a corrosion pit within the wall of a cooling channel (Figure 8).

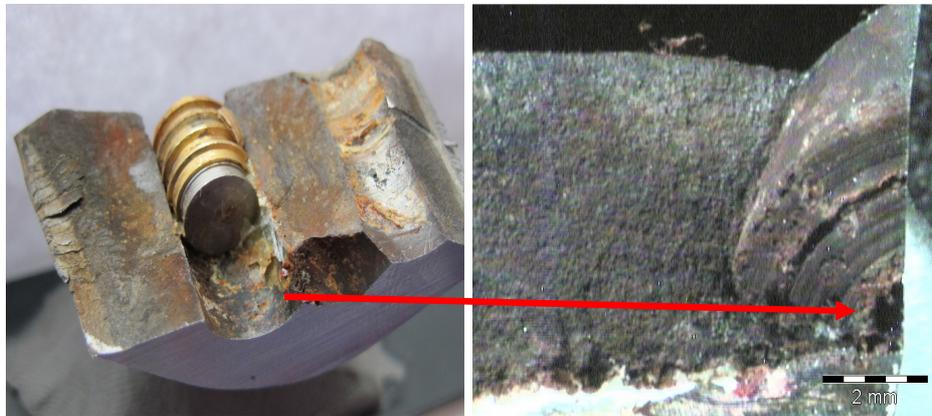


Fig. 8. Fragment from a hot-stamping die after corrosion induced crack (top; compare Figure 7 center); Corrosion pit as a starting point and rest lines of a dynamic crack (bottom).

These figures describe the dramatic effect of corrosion on tool life within only few months of tool operation.

Years ago, when the cooling channels were far apart (20 – 25 mm) from the contour of the tools corrosion induced tool failures were hardly observed. As only little information on corrosion of tool steels was available in the literature, Kind & Co. intensively investigated the corrosion behaviour of important tool steels. Apart from several steel grades the investigation included parameters such as metallurgical process route (ESR / Non-ESR), hardness of the samples, as well as water quality and test temperatures [3].

As expected none of the tool steels for hot-stamping tools is resistant against corrosion by cooling water. Three types of corrosion defects were observed:

- Rust,
- Pitting corrosion,
- Corrosion induced cracks.

Figure 9 illustrates the different types of corrosion induced defects.



Fig. 9. Photo micrographs of corrosion induced surface defects in hot-stamping tools. Left: Rust; Middle: Pitting corrosion; Right: Corrosion induced cracks

Rust appears as a comparably harmless type of corrosion as it covers mainly the steel surface.

Pitting corrosion proved to be the most critical type of corrosion in hot-stamping tools. Hardly visible from the surface these pores expand into the steel. Under the influence of mechanical and / or thermal stresses these pores can grow rapidly (see Figure 9, right) and finally result in cracks. Pitting corrosion is caused by halogenides like chlorine dissolved in the cooling water.

Many factors influence the intensity of corrosion attack on hot work tool steels. Increasing water temperature and chlorine concentrations intensify the corrosive reactions and surface defects. Kind & Co. therefore urgently recommends controlling the quality of the cooling water quality regularly with special focus on chlorine concentration and pH-value.

Special precautions should be taken into account in order to avoid corrosion of the tools. A closed water circuit should be mandatory as the input of fresh water accelerates corrosion processes. The addition of corrosion inhibitors to the cooling water should also be considered. During the process of tool making only best and sharp drills should be used to manufacture the cooling channels. A rough surface of the channels offers more potential starting points for corrosion than a smooth surface.

The use of tool steel produced by the Electro-Slag-Remelting (ESR) process provides several advantages for hot-stamping tools. Due to the ESR process the steel has a higher purity than conventionally produced material. As corrosion preferably starts at non-metallic inclusions, ESR materials offer less potential starting points for corrosion than conventional steels. A further advantage is the higher toughness potential of ESR material which in some cases allows a slight increase of the hardness and a further improvement of the wear resistance. The most important advantage of improved toughness is that it can counteract to the growth of cracks through the steel between cooling channel and working surface.

The special steel grade CR7V-L is available as an ESR grade upon request. HS 1 is exclusively produced by ESR.

In order to prevent premature cracks of hot-stamping tools the hardness of the tool segments should not be adjusted to the maximum hardness. This advice is given because of two reasons. In case of maximum hardness the tool steels have their lowest toughness level – and insufficient toughness can favour cracks between cooling channel and working surface. The hardness of the steels can develop a significant influence on the corrosion behaviour as hardness is directly related to precipitation of carbides during tempering. The steels discussed in this paper have a significant chromium concentration and develop a secondary hardness maximum (see also Fig. 1). During tempering carbides are precipitated in the matrix of the steels. These carbides, originally fine and

homogeneously dispersed in the matrix, can start to coagulate once the tools are tempered within the temperature range of the secondary hardness maximum. For this process of carbide growth the coagulated carbides consume the surrounding small chromium carbides. The consequence is the formation of a chromium depleted zone around the growing carbide. Within this zone the steel has a higher sensitivity against corrosion and local corrosive attack can easily start. This critical range of increased sensitivity extends to approx. 50 °C above the secondary hardness maximum. At higher tempering temperatures diffusion of alloying elements can compensate the chromium depletion and reduce the higher risk of corrosion [4].

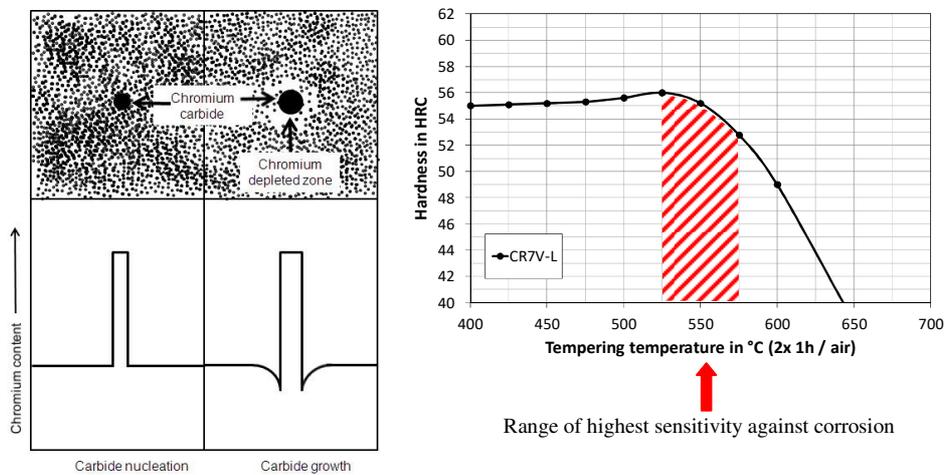


Fig. 10. Growth of chromium carbides and risk of corrosion during tempering at secondary hardness maximum.

Kind & Co. urgently recommends to follow this recommendation and to avoid maximum hardness of the tools, especially in case of tools with cooling channels only few mm below the working surface.

## 5. Conclusion

The fast growing market for hot-stamping applications requires highly developed tool steel solutions offering high hardness, high-temperature strength, wear resistance, enough toughness reserve for design optimization, and reasonable thermal conductivity. Fulfilling these requirements is an enormous challenge as these properties are opposing each other. With the two premium tool steel solutions CR7V-L and HS 1 Kind & Co. offers tailor-made steel grades for hot-stamping which successfully balance the required properties.

CR7V-L has proved its superior suitability in many industrial applications worldwide, not only for hot-stamping of steel sheet components but also for aluminium and nickel-base alloys.

For even higher abrasive wear resistance steel grade HS 1 can be recommended.

Recent developments which aimed at a reduced cycle time of hot-stamping operations have intensified the thermal and mechanical stresses in the tools and often resulted in tool defects like cooling water leakage. Own investigations demonstrated that corrosion and corrosion induced cracks are the most important failure reasons. Kind & Co. recommends balancing the properties in a way that provides sufficient toughness and avoids corrosion induced cracks. Lacks in thermal conductivity can be compensated by modern tool design.

Using the special steel grades CR7V-L as well as HS 1 and respecting the recommendations given in this paper will result in excellent tool life.

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