The Selection of Tool Steels for Hot-Stamping Tools with Respect to Increased Loads

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Abstract

The enormous increase of the hot-stamping production in the automotive industry goes along with an improvement of the complete process chain aiming for a more effective layout and exploitation of the resources. Requirements on the produced components have been modified so that nowadays different properties have to be combined within one part. This development leads to new design of hot-stamping tools.

The increased loads on the tools result from reduced wall-thickness between cooling channels and working surface and increased hardness of the tools. This makes the steels more sensitive to corrosive induced cracks.

Tools for Tailored Tempering are heated up to temperatures up to 550 °C in order to arrange the desired different mechanical properties within one component. This is a further increased load on the tools.

The report describes tool steels which are suitable to withstand these high loads. Furthermore it presents the results of corrosion tests with respect to different hardness levels of the steels.

1 Introduction

The enormous world-wide boom of the production of hot-stamped components goes along with large production lots, extended run times and increased loads of the tools. Due to the worldwide production of hot-stamped components tools are exposed to various operational conditions. Furthermore modified requirements on the produced components like areas of different strength are increasing. As a result the loads on the tools increase and consequently the requirements on the tool materials. The selection of tool steels requires a profound knowledge of various material properties of the tool steels.

2 Increased Loads on Hot-Stamping Tools

At the beginning of the industrial production of hot-stamped products the process optimization focused mainly the reduction of the cycle time. Tool steels with increased thermal conductivity had been developed in order to reduce the quenching period within the hot-stamping process [1–3]. Improved design and tooling technologies like segmented tools allowed to reduce the wall thickness between tool surface and cooling channels diminishing the importance of the thermal conductivity for the process optimization [4]. Nowadays distances of 6 – 10 mm between tool surface and cooling channels can be observed very frequently. This reduction of the wall thickness automatically leads to increased stresses and requires more toughness of the tool steel.

Due to the extremely growing production lots, abrasive wear resistance of the tools is getting more and more important. A higher wear resistance is often achieved by increased hardness of the tools which on the other hand has a strongly negative influence on the toughness of the steel.

Water which is used as a cooling medium causes corrosion of the cooling channels unless special precautions are taken. The concurrence of mechanical and thermal stresses modifies the corrosion from simple general or from pit corrosion to stress corrosion. During our investigations of defect tools corrosion induced cracks between cooling channel and working surface of the dies were observed frequently (***Figure 1***).

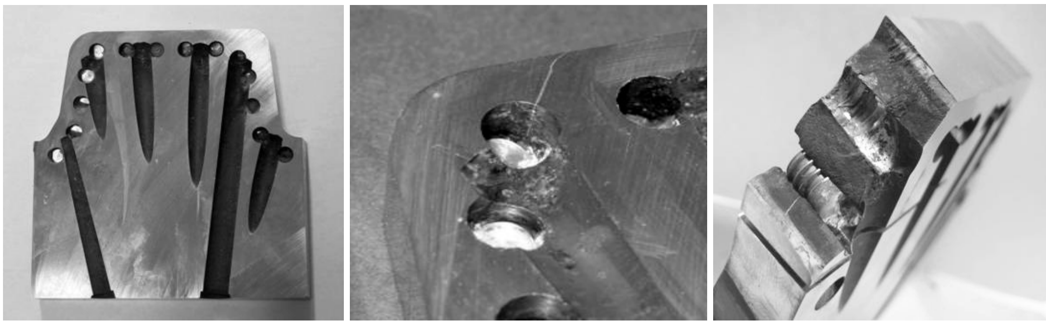


Figure 1: *Corrosion induced crack from a cooling channel to the working surface of a hot-stamping tool*
Left: section through tool; centre: detail with crack; right: corroded surface of the crack

Tailored-Tempering is a special method to locally reduce the hardness and strength of hot stamped components. Here tool segments are heated up to 550 °C so that the local quenching rate of the sheet metal is adjusted to the desired properties of the hot-stamped component [5]. In addition to hardness and wear resistance these tool segments require an outstanding long-time tempering resistance. This combination of properties is not available in most of the frequently used tool steels.

It can be concluded that in addition to “traditional” tool steel properties like tempering resistance, wear resistance, toughness, and thermal conductivity “new” properties like corrosion behaviour and long-time tempering resistance have to be taken in account.

3 Steels for Hot-Stamping Tools

Steels for hot-stamping tools recommended by Kind & Co. (***Table 1***) have been described with more details in the literature [6]. The chemical compositions of these steels are given in ***Table 1***.

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

Steel Designation		**Mass Content in %**								**Hard-ness**
Mat.-No.	**Brand name**	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Co**	**V**	**W**	**HRC**
1.2344	USD	0,40	1,00	0,40	5,20	1,30	---	1,00	---	50 – 52
1.2367	RPU	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	---	0,80	---	52 - 54
---	HTR	0,32	0,20	0,30	2,20	1,20	---	0,50	3,80	48 – 50
1.2889	HMoD	0,45	0,30	0,40	4,50	3,00	4,50	2,00	---	50 - 52

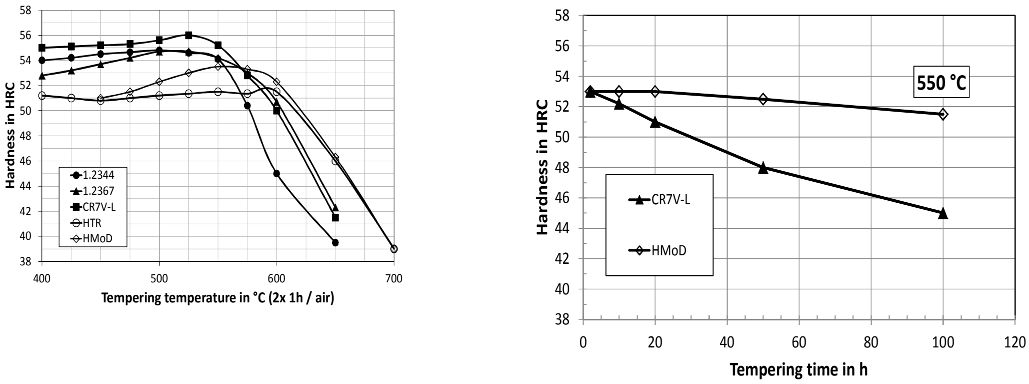
The internationally standardized [7] steels 1.2344 and 1.2367 are universally applicable hot-work tool steels. For higher hardness and wear resistance the carbon and chromium contents of CR7V-L had been increased. The special grade HTR has a high tungsten concentration in order to provide outstanding tempering resistance and high-temperature strength. Chromium had been reduced in order to increase the thermal conductivity.
Due to the addition of cobalt HMoD develops highest long-time tempering resistance and high-temperature strength. The high concentration of vanadium results in an excellent wear resistance due to the high carbide content. These special characteristics make HMoD highly recommendable for Tailored Tempering applications.

With respect to the balance of properties Kind & Co. recommends the hardness values listed above. The reduced toughness of these steels at the high hardness values can be compensated to a certain degree by using them in the electro-slag-remelted (ESR) condition.

3.1 Steel Grade for Tailored-Tempering Applications

As described above tool segments for Tailored Tempering applications are heated up to 550 °C and are kept constantly on this high temperature level for the complete production shifts. In order to avoid softening of the tool segments the suitable steels not only require a good short-time tempering resistance but also an excellent long-time tempering resistance.

The tempering curves of these five steels can be seen in ***Figure 2***. These grades develop different tempering characteristics. All steels develop a good tempering resistance up to tempering temperatures of approx. 550 °C (***Figure 2, left***). The curves in the left diagram describe the normal tempering behaviour of the steels. Tools for the application of the Tailored-Tempering technology require an enormous long-time tempering resistance as they are exposed to this temperature constantly for long a time. ***Figure 2, right***, shows a comparison of the long-time tempering response of the two tools steels CR7V-L and HMoD for this application, hardened and tempered to 53 HRC.



Tempering curves *Long-time tempering behaviour*

Figure 2: *Tempering behaviour of different tool steels for hot-stamping tools.*

The right diagram underlines the enormous long-time tempering resistance at 550 °C of the special grade HMoD.

Due to the addition of cobalt HMoD develops highest long-time tempering resistance and high-temperature strength. The high concentration of vanadium results in an excellent wear resistance due to the high carbide content. This composition makes HMoD highly suitable for Tailored-Tempering segments.

4 Corrosion Behaviour of Tool Steels for Hot-Stamping

Own investigations of failed hot-stamping tools demonstrated the trend that the distance between cooling channels and working surface is reduced in order to shorten cycle times. This automatically results in increased stresses in the remaining material between cooling channel and working surface. Water leakage from the cooling channels to the working surface, caused by cracks, has been observed frequently in these tools. Repeatedly it could be observed that these stress cracks had been induced by corrosion starting in the cooling channels (***Figure 1***).

As there are not very many publications on the corrosion behaviour of hot-work tool steels available Kind & Co. in co-operation with Institut für Werkstoffsystemtechnik Thurgau an der Hochschule Konstanz (WITg) conducted own corrosion tests. With respect to the stresses in hot-stamping tools ring-shaped samples (***Figure 3***) of the steels described above had been machined and hardened and tempered to different hardness levels. The surfaces of the samples were smoothly ground.

Pre-stressed to 800 – 1000 N/mm² these samples were immerged into water with chlorine ion concentrations of 250 ppm and 1250 ppm respectively. The chlorine ion concentration of 250 ppm reflects the maximum concentration for tap water in Germany, the higher concentration of 1250 ppm was selected in order to simulate more critical conditions.

Under ideal process conditions hot-stamping tools are fed with cooling water having a temperature between 10 and 20 °C. Higher temperatures appear to be possible under less ideal industrial conditions. In order to achieve results within reasonable times test temperatures were set to 30 °C and 50 °C, duration of the tests was three weeks for 30 °C and two weeks for 50 °C.

The test vessels were constantly aerated.

After the test periods the samples were cleaned and evaluated visually. Additionally metallographic investigations had been conducted.

Figure 3: *Sample for corrosion tests (photo courtesy of WITg)*

Three different types of corrosion were registered and evaluated:

- General corrosion,
- localized corrosion similar to pitting,
- Corrosion induced cracking.

The visual evaluation of the corrosion intensity was based on the following chart (***Figure 4***).

The symbols "0"; "+", and "++" indicate increasing intensities of the corrosive attack from "no corrosion" to "intensive corrosion".

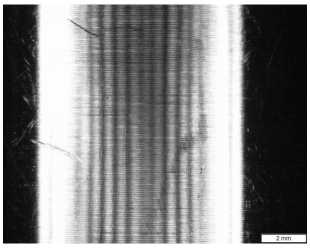
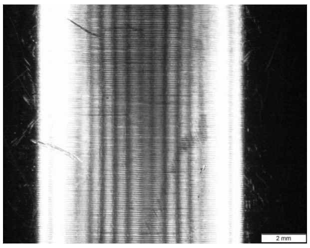
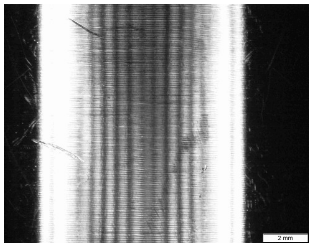
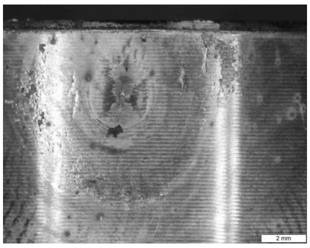
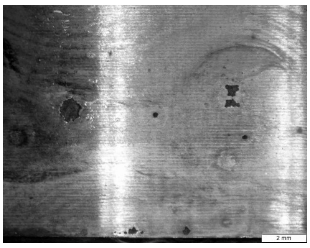
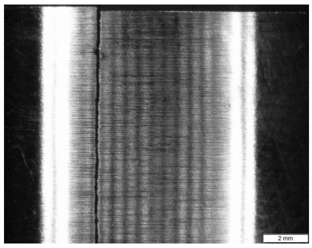
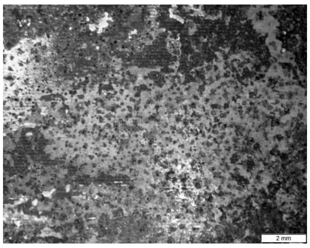
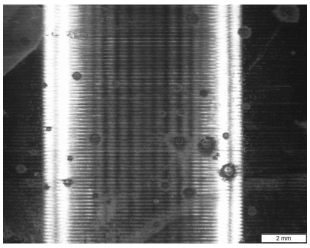
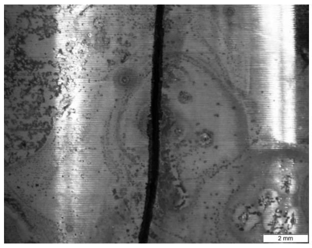
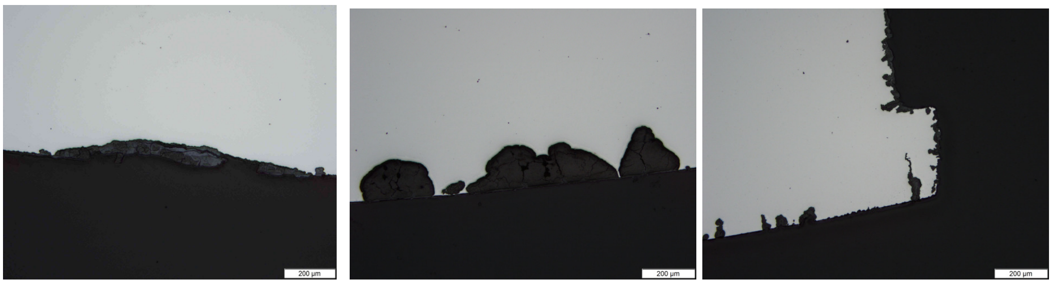
	General corrosion	Localized corrosion	Corrosion induced cracking
0			
+			
++			

Figure 4: *Microscopic appearance of different corrosion defects*

Microscopically these defects appear as shown in ***Figure 5***.



general corrosion *localized corrosion* *corrosion induced cracking*

Figure 5: *Microscopic appearance of different corrosion defects*

Steel 1.2344 appeared to be rather resistant against general corrosion and corrosion induced cracking. Independent from the hardness this grade develops sensitivity against localized corrosion. Increasing temperature and chlorine concentration lead to more corrosion pittings.

The steel 1.2367 did not develop any general corrosion but is sensitive to localized corrosion. While the chlorine concentration does not show a significant influence increasing temperature intensifies the formation of corrosion pits. During these tests steel 1.2367 did not develop severe corrosion induced cracks.

The samples of special grade CR7V-L were nearly free of general corrosion. Therefore this grade reacts critically with respect to corrosion pitting. Increasing hardness and temperature make this steel sensitive to corrosion induced cracking.

On the samples of steel grade HTR general corrosion could be observed easily. Due to the reduced chromium content the steel is also sensitive to localized corrosion but did not develop any corrosion induced cracks.

As the grade HMoD is not intended for use in water cooled tool inserts this steel was not part of the corrosion tests.

A comparison of all results can be seen in ***Table 2***. It can be concluded that increased temperature and chlorine concentration enhance localized corrosion. Also high hardness values favour the formation of cracks under corrosive conditions.

Table 2: *Results of corrosion tests*

			General corrosion			Localized corrosion			Corrosion induced cracks		
	Temperature		30 °C		50 °C	30 °C		50 °C	30 °C		50 °C
	Cl^- in ppm		250	1250	250	250	1250	250	250	1250	250
Steel		HRC									
1.2344	USD	42	0	0	0	+	++	++	0	0	0
		45	0	0	0	+	++	++	0	0	0
		51	0	0	0	+	++	+	0	0	0
1.2367	RPU	41	0	0	0	+	+	++	0	0	0
		45	0	0	0	+	+	++	0	0	0
		53	0	0	0	+	+	++	0	0	++
---	CR7V-L	40	0	0	+	+	++	++	0	0	+
		47	0	0	0	+	+	+	0	0	+
		53	0	0	0	++	++	++	++	+	++
---	HTR	38	++	++	++	+	+	+	0	0	0
		39	++	++	++	+	+	+	0	0	0
		44	++	++	++	+	+	+	0	0	0

0: no corrosion +: little corrosion ++: intensive corrosion

The fact that the investigated steels develop mainly localized corrosion pitting has to be considered critically. Each corrosion pit must be regarded as a notch in the material leading to stress concentrations in operating tools. Under critical conditions corrosion induced cracks might start from the pits and propagate through the remaining cross section (***Figure 6***).

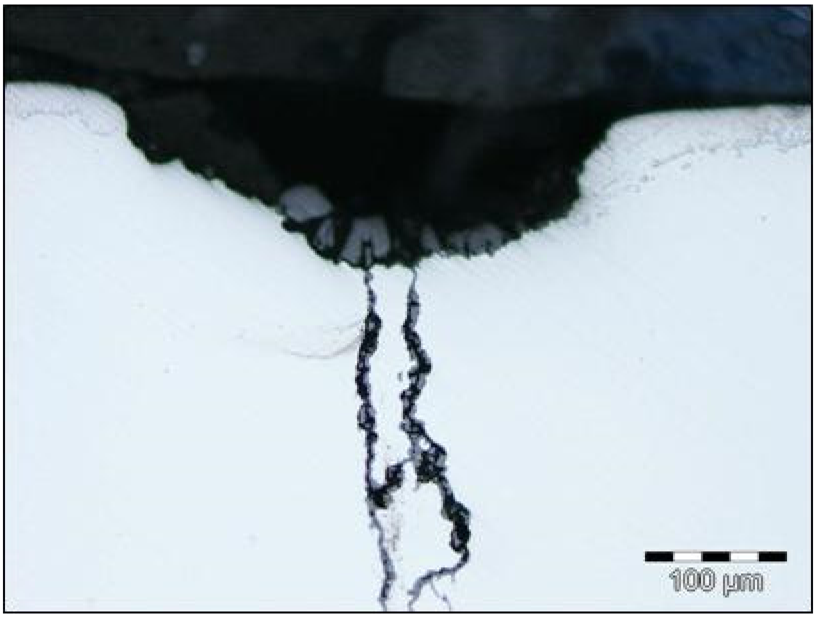


Figure 6: *Corrosion induced stress cracks propagating from corrosion pits in cooling channels to the tool surface (Detail of tool shown in figure 1)*

The defect shown in ***Figure 6*** had been detected in an industrial hot-stamping tool which failed due to severe leakage from cooling channels. The comparison of the defect in this tool with the results of the corrosion tests shows that the test results match very well with realistic situations.

High hardness of the segments within the range of the secondary hardness maximums of the steels is considered critical for two reasons:

- Within the temperature range of the secondary hardness maximum carbide nuclei start to coagulate. Once independent carbides start to grow they detract the required chromium from their surroundings and impoverish this area from chromium. The result is a higher local sensitivity to corrosion. As soon as all free carbon is involved in the precipitation of carbides the chromium distribution will re-adjust to the former level and the corrosion resistance will improve again. The highest sensitivity to corrosion is approximately 50 °C above the temperature of the secondary hardness maximum [8].

- High hardness always goes along with reduced toughness so that stress concentrations at corrosion pits (notches) cannot be compensated sufficiently.

It should be considered that these corrosion tests were done under static loads. It must be assumed that the influence of dynamic loads will increase and accelerate the deterioration of the tools.

5 Conclusion

Recent developments in the hot-stamping technology have influenced the loads on the tools enormously and have influenced the tool technology as well. Tailored Tempering of the products requires tool steels with an outstanding long-time tempering resistance. The grade HMoD provides this requested property.

As a consequence of the permanent efforts to reduce cycle times the distances between working surface and cooling channels have been reduced. Simultaneously expectations on the performance of hot-stamping tools, especially on the increased wear resistance of the tools, grow enormously. More and more tool steels are used with their hardness close to their secondary hardness maximum.

In this hardness range the risk of corrosion induced cracks increases due to an inhomogeneous chromium distribution in the steel. Furthermore the toughness of the steels is on a very low level. This means that today more and more circumstances have to be considered which had less importance in earlier years. Recently corrosion induced cracks have been observed more frequently than in earlier years. As none of the industrially used steels offers corrosion resistance the cooling water management – for example addition of corrosion inhibitors - is extremely important in this time. In case such a cooling water management is impossible it is urgently recommended not to exceed the hardness ranges mentioned in ***Table 2***.

With respect to the concurrence of the described loads more properties than just hardness and thermal conductivity have to be considered in order to provide long-lasting and reliable hot-stamping tools.

The highly developed press forging technology nowadays requires tool steels with elaborated cleanliness and toughness properties. Actually these requirements can only be met reliably with steels produced via Electro-Slag-Remelting Technology (ESR).

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