Minimal Spray Cooling and Tool Steel Selection

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Increasing demands on the surface quality of the castings as well as permanent efforts to increase die life have led to the development of minimum spray cooling – a technology with drastically reduced amounts of sprayed liquid and die lubrication. Minimal spray cooling no longer uses water as a carrier of the lubrication / release agent so that evaporation of water ceases to exist in the cooling of die casting dies. The heat from the cast alloy has to be dissipated completely by highly efficient cooling channels and spot cooling installations being much closer to the cavity than in traditionally cooled dies. This modified cooling leads to higher thermal and mechanical stresses in the remaining wall thickness between cooling and cavity surface. This paper introduces special hot-work tool steels with improved combinations of high-temperature strength and high-temperature toughness. Together with a high thermal conductivity these improved combinations of properties compensate the stresses in the surface area of die casting dies and support the minimal spray cooling technology. With drastically reduced wall thickness between cooling and cavity corrosion of the tool steels by the cooling water has to be controlled strictly in order to prevent water leakage from the interior cooling into the cavity. As none of the suitable hot-work tool steels is corrosion resistant special care has to be taken with respect to the quality of the cooling water. A strict cooling water management is urgently recommended.

KEYWORDS: PRESSURE DIE CASTING – SPRAY COOLING – MINIMAL SPRAY COOLING – HOT-WORK TOOL STEEL – TOOL STEEL SELECTION – HIGH TEMPERATURE PROPERTIES – CORROSION

INTRODUCTION

Die casting is a highly automated and efficient process to produce large series of metal components with high accuracy and repeatability. In the automotive industry die cast components replace more and more components which originally had been made of steel. This trend goes along with drastically increasing requirements concerning surface quality of these parts. Many components have aesthetical or functional surfaces on which traces of heat checking cracks of the dies have to be avoided.

For a fast and easy removal of the solidified casting from the die a release agent is sprayed onto the die surface. Most of the currently used release agents are water based media – oil-in-water-emulsions. Being sprayed onto the hot surfaces of the empty die the water evaporates and the embedded agent creates a thin film on the cavity. The evaporation of the water involved contributes to the cooling process of the die. Many die casters use this evaporation cooling in order to reduce the cycle time. Often spray cooling is intensified more than required for a proper application of the release agent. The permanently repeating thermal shocks on the surfaces lead to the formation of thermal fatigue cracks (heat checking markings) with their typical network appearance. The negative effect on the appearance of the castings as well as on the performance of the dies is well known.

With increasing requirements on surface quality of the castings and on the performance of the dies first water-free release agents and minimal spray cooling technologies were developed. Highly concentrated release agents have changed the spraying process drastically. The amount of liquid sprayed onto the cavities was suddenly reduced from some 10 litre to a few millilitres per shot.

MINIMAL SPRAYING AND THE THERMAL HOUSEHOLD OF THE DIE

Röse [1] has provided a detailed study on spraying and its influence on the thermal household of dies. He compared conventional and minimal spraying with respect to the formation of a sufficient film of the release agent on the die as well as on the thermal household of the die. According to his results minimal spraying requires only 0,25 – 1,0 seconds for a sufficient coating of the die cavity. Compared to conventional spraying the heat dissipation due to the spraying is enormously reduced which would lead to a significant temperature increase on the surface of the cavity. Depending on the nozzle diameter as well as on the distance between nozzle and die surface conventional cooling can discharge 2,3 – 6,0 times as much heat as minimal spraying. It can easily be understood that the temperature in the contact zone between melt and die are increased by minimal spraying. Röse recommends to keep the surface temperature of dies for minimal spraying above 250 °C. As a consequence of this the use of the minimal spraying technology should already be respected in the design of a die and especially in the design of the cooling system.

MINIMAL SPRAYING, DIE DESIGN AND RECOMMENDED TOOL STEELS

As the spraying no longer contributes to the cooling the surface temperature of the dies rises significantly. The complete cooling has to be done by the internal cooling. In most cases simple cooling channels and loops as in conventional inner cooling systems are not sufficient enough so that many highly efficient spot cooling systems have to be installed. In order to be sufficient these local cooling systems have to be close to the surface of the cavity. So between the tips of spot coolings and the surface of the cavity only a few millimetre of wall thickness remain. This as well as the high number of drilled holes weakens the die insert intensively (internal notches). Furthermore the thermal stresses are increased due to the reduced wall thickness. Suitable tool steels have to withstand these increased stresses so that more than ever before the tool steel selection should be based on high-temperature properties. Furthermore a high tempering resistance is needed in order to avoid softening of the dies in the contact zone to the melt during operation.
Special aspects during tool steel selection should be:

- Improved tempering resistance to avoid softening of the steels due to higher die temperatures,
- Sufficient high-temperature strength and toughness of the die steels,
- High thermal conductivity to support the heat transfer from the cavity into the internal cooling.

While many conventional die casting dies are still built of the well-known and internationally standardized [2] hot-work tool steel grades X37CrMoV5-1 (Mat.-No. 1.2343; AISI H 11) and X38CrMoV5-3 (Mat.-No. 1.2367). Kind & Co. recommends three special grades dies with minimal spray cooling: TQ 1, HP 1, and CS 1. The chemical compositions of these steels are listed in Table 1.

Tab. 1 – Chemical composition of hot-work tool steels

STEEL		ALLOY CONTENT IN MASS-%								
Mat.-No.	Brand	C	Si	Mn	P	S	Cr	Mo	V	Nb
1.2343	USN	0,38	1,00	0,40	≤ 0,020	≤ 0,005	5,20	1,20	0,40	---
1.2367	RPU	0,38	0,40	0,40	≤ 0,020	≤ 0,005	5,00	3,00	0,60	---
---	TQ 1	0,36	0,25	0,40	≤ 0,012	≤ 0,003	5,20	1,90	0,55	---
---	HP 1	0,35	0,20	0,30	≤ 0,012	≤ 0,003	5,20	1,40	0,55	+
---	CS 1	0,50	0,30	0,40	≤ 0,012	≤ 0,003	5,00	1,90	0,50	+

Figure 1 demonstrates that within the technically relevant tempering temperature range above 575 °C the steels TQ 1 and HP 1 exceed the traditional grade 1.2343 in tempering resistance and develop nearly the same high resistance as 1.2367. The higher alloyed newly developed grade CS 1 displays not only a clearly higher secondary hardness maximum, it is the by far the grade with the best tempering resistance among the discussed steels.

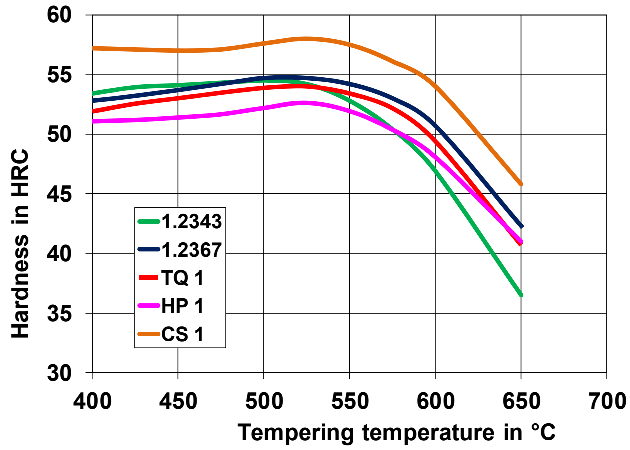

Fig.1 – Tempering behaviour of the discussed steels

High-temperature strength and high-temperature toughness values of these steels, measured in tensile tests, are displayed in Figure 2.

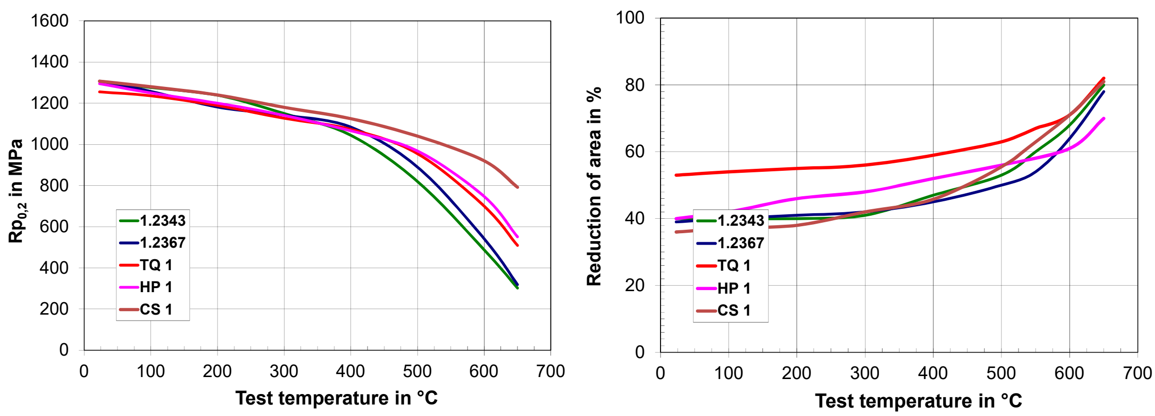

Fig.2 – High-temperature strength and toughness of hot-work tool steels

It becomes evident that above test temperature of 350 °C the grades HP 1 and TQ 1 exceed the traditional grades 1.2343 and 1.2367 in high-temperature strength. For CS 1 even higher values were measured.
TQ 1 and HP 1 also develop best toughness values. Despite its very high high-temperature strength CS 1 reaches toughness values, expressed by the reduction of area, nearly as high as TQ 1. This indicates that TQ 1, HP 1, and CS 1 offer a unique combination of high-temperature strength and toughness which makes these grades very suitable for the high thermal and mechanical loads which possibly come up due to minimal spraying. Thermal conductivity regulates the heat flow from the surface of the cavity to the inner cooling system. High thermal conductivity has a beneficial effect on the solidification of the casting but also on the reduction of thermal peaks. The values of thermal conductivity of the listed steels are in table 2.

Tab. 2 – Thermal conductivity hot-work tool steels (hardened + tempered to 45 HRC).

STEEL DESIGNATION		THERMAL CONDUCTIVITY λ IN W/(m *K)		
Mat.-No.	Brand	100 °C	400 °C	600 °C
1.2343	USN	26,8	27,3	29,3
1.2367	RPU	29,9	32,4	34,0
---	TQ 1	29,8	31,4	33,0
---	HP 1	29,5	30,5	31,5
---	CS 1	28,8	29,4	30,1

Temperatures above 350 °C have to be expected in the contact zone between melt and die at least temporarily. Based on the described requirements for minimal spray cooling it can be concluded that the special grades TQ 1, HP 1, and CS 1 offer a great potential for improved lifetime of dies for minimal spraying. The combination of high strength and simultaneously high toughness allows a much better compensation of the stresses in thin cross-sections than the standardized grades. Especially CS 1 offers outstanding high-temperature strength in combination with good toughness and thermal conductivity.

As mentioned before minimal spraying requires reduced wall thickness between cooling and cavity surface to maintain sufficient cooling and solidification. The mechanical properties described before are responsible to avoid cracking of the remaining walls due to mechanical and thermal loads.

Another aspect had been neglected in traditionally cooled die casting dies: corrosion within the cooling channels. None of the steels for die casting dies is corrosion resistant so that die casters using these special dies should carefully control the cooling water quality. Chlorine ions play an important role in aqueous corrosion. Concentrations of 250 ppm Cl^- - the maximum allowed concentration in drinking water in Germany – can already be critical to start corrosion. Increasing Cl^- -concentrations as well as increasing water temperature intensifies the corrosive attack [3]. A smooth surface of the drilled hole will be beneficial to retard corrosion. It is urgently recommended to use closed cooling water systems as "fresh" oxygen favours the corrosion. The addition of corrosion inhibitors should be considered, a regular cooling water management is mandatory. Under the influence of thermal and mechanical stresses corrosion pits within the cooling channels can be starting point for dynamically growing fatigue cracks and finally for risky water leakages from the cooling channels. The special grades TQ 1, HP 1, and CS 1 offer a high resistance against crack growth but corrosion should also be prohibited in these steels.

CONCLUSION

Increasing requirements concerning the surface quality of the cast products as well as striving for longer tool life are the motivation for minimal spraying in the die casting industry. Compared to traditionally cooled dies the cooling system of dies for minimal spraying needs to be newly designed. The missing water evaporation on the cavity surface increases the surface temperature of the dies and requires a high number of highly efficient spot coolings and cooling channels in the dies. These installations and the corresponding holes and channels weaken the die inserts especially the closer they come to the surface of the cavity.
In order to withstand these increased stresses sophisticated tool steels are required with higher high-temperature strength and high-temperature toughness than the standardized grades can provide. High thermal conductivity is beneficial to reduce local thermal peaks and to avoid additional thermal stresses.
The three special hot-work tool steels from Kind & Co., TQ 1, HP 1, and CS 1offer improved high-temperature properties which allow a longer tool life and better performance in case of minimal spraying.
As in case of minimal spraying all cooling installations have to be closer to the working surface of the cavity it is urgently requested to control corrosion of the cooling channels. Fine corrosion pits can result in fatigue cracks from the cooling system to the working surface and finally in water leakage. Casters are requested to operate a strict cooling water management in order to minimize the risk of corrosion.

REFERENCES

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