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CS1 - The new hot-work tool steel for die casting dies with the highest surface requirements

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The number of parts produced by die casting is increasing permanently. Furthermore, the diversity and the complexity of cast parts is growing higher. The products are not only larger, but also more complicated in their design. Economical die casting requires dies which allow continuous production without any unscheduled downtimes. This depends not only on a proper die design. The properties of the used hot-work tool steels are adjusted in order to fulfill the prevailing requirements and have a considerable impact, too. Consequently, the die casting industry has increasing demand of hot-work tool steels with specifically combined properties. Particularly the demand on the surface quality of end products is continuously increasing. In order to meet the new demands of the die casting market, Kind&Co has developed a new hot-work tool steel. This new steel is able to offer a working hardness of up to 56 HRC. At the same time, it has a very high toughness potential at such a high hardness. This high toughness potential of the new special hot-work tool steel leads to an outstanding resistance against thermal cracking. This premium grade – CS1 – has contributed to performance improvement of up to 600 %.

This paper presents the properies of CS1 and shows several examples of successful application.

KEYWORDS: PREMUIN STEEL CS1, HPDC, THERMAL SHOCK RESISTANCE, TOUGHNEES, INDUSTRIAL TRIALS

INTRODUCTION

Die cast components gain more and more importance in our daily life. The die casting process permits economical manufacturing of a diverse array of components including household articles, cases for electronic instruments or structural parts of cars. Surface quality in automotive is becoming increasingly important especially for components for e-mobility or structural parts. Due to the safety relevance of many structural parts, these parts must be free of surface defects. These defects like burrs or spots could initiate cracks. Furthermore, assembling and sealing surfaces require perfect condition in order to guarantee proper functions [1]. Beside the automotive industry, the communication industry with a growing market of the 5G devices is a futher driving force for the development in the die casting application. Projections from CCS Insight indicates that global 5G connections will exceed 1 billion in 2022, surging to 3,2 bllions in 2025 [2]. Triggered by the boom in 5G technology, cost effective die cast components with a high

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quality are required. For example cast heatsinks represent a major challenge for the foundries. These cast products are often used without additional finishing, although they include a lot of functionalities like cooling fins, mounting holes and fasteners. Therefore the highest demands are placed on the surface quality and geometrical accuracy, defects on the die surface as shown in Figure 1 have to be avoided.

It is therefore recommended to use hot-work tool steels with highest thermal shock resistance as die material in order to noticeably delay the formation of thermal shock crack networks. These crack networks also make the ejection the cast parts more difficult and can in the worse case deform the products. An increase in hardness can positively influence the thermal shock resistance as an augmentation of the hardness generates an increase of the tensile strength as well as of the fatigue strength [3]. At the same time, however, the toughness of the steel decreases and the risk of cracks rises. For this reason, for example, the hardness of a die made of hot-work tool steel type 1.2343 should not be set to over 47 HRC without consulting the tool steel manufacturer. The newly developed premium hot-work tool steel CS1 allows a hardness in use of up to 56 HRC, which leads to a further improvement in thermal shock resistance.

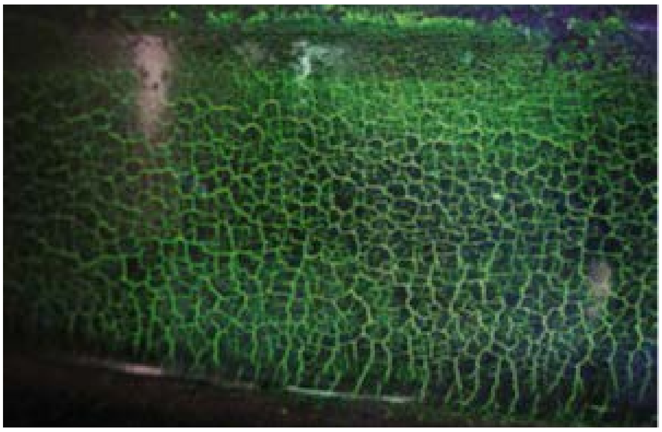

Fig.1 - Typical appearance of thermal shock cracks on the surface of a HPDC die during magnetic particle inspection.

CS1 - THE NEW PREMIUM HOT-WORK TOOL STEEL

The complex loads to which die castings dies are exposed in the process consist of chemical, mechanical, cyclic and thermal components. Because of these different loads, the hot-work tool steels used in die casting applications must combine various properties in an optimal way. Beside excellent thermal shock resistance a high strength and fatigue strength at elevated temperature, a good tempering resistance, a high toughness potential and a sufficient thermal conductivity are required. In order to cover the different requirements for die casting, Kind&Co developed the premium hot-work tool steel CS1.

The premium steel CS1 is a 5%-Cr alloyed hot-work tool steel based on the principle of highest puritiy. The concentrations of P and S as weel as the concentration of detrimental elements like B or Sn have been drastically reduced. The well balanced alloying concept with increased contents of C, Mo and Nb compared to 1.2343 combined with an accurante production allows to achieve an optimale properties profil. In order to respect the high demands concerning homogeneity and toughness, the premium steel CS1 is exclusively produced by eletcro-slag-remelting process.

The higher C-content confers the premium steel CS1 the highest secondary hardness maximum of 58 HRC (Figure 2, left). In comparison with the standard grades USN (1.2343) and USD (1.2344) the secondary hardness maximum of CS1 is 3 to 4 HRC higher.

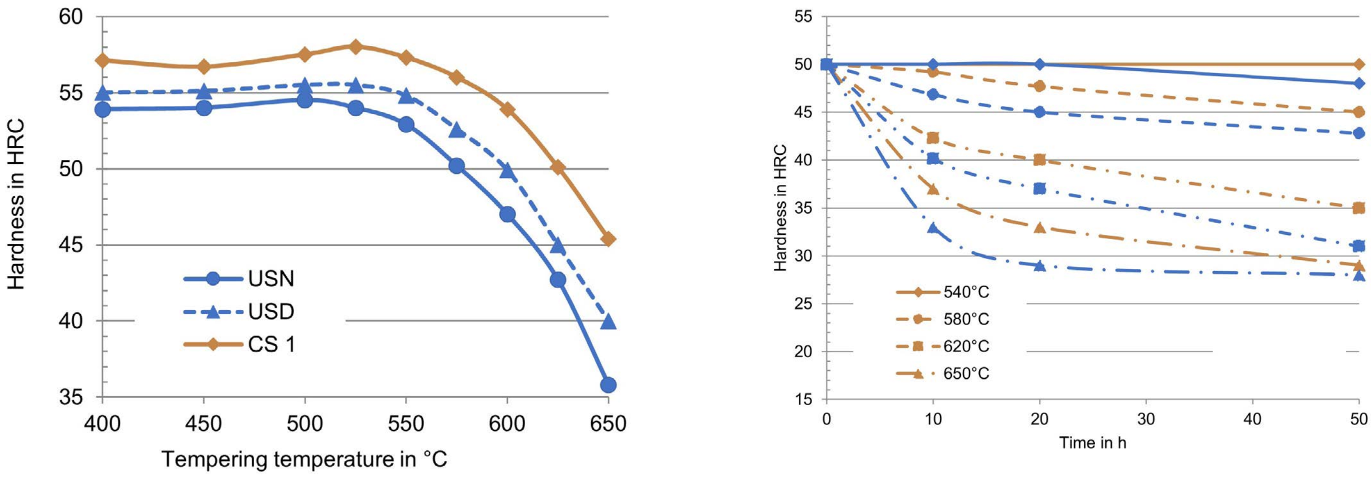

Fig.2 - Tempering curves of the discussed steels (left) / Long-time tempering of USN and CS1 (right).

Furthermore the grade CS1 shows an excellent resistance against tempering and thus against undesired softening during casting operation. This is confirmed by the results of long-time tempering tests (Figure 2, right). Samples, which were previously quenched and tempered to a hardness of 50 HRC, were kept at different temperatures between 10 h and 50 h. Hardness measurements demonstrate that long-time tempering at 540 °C does not affect the hardness. A temperature of 580°C leads to only moderate hardness loss. At temperatures above 600°C, the hardness is significally reduced. In comparison with the steel USN, the decrease of hardness is considerably slower. While the hardness of USN drops to 40 HRC after only 10 hours on 620°C the grade CS1 achieves this level after 20 hours on the same temperature. CS1 offers a clearly better long-time tempering resistance than USN and the risk of softening in use is reduced with CS1.

A futher important property is the high-temperature strength. A good high-temperature strength allows to withstand the thermal loads of the HPDC process. Depending on the process, the temperature at the die surface can achieve e.g. 500°C for a short while with each shot. As shown in Figure 3 (left), the tested steels have a similar yield strength up to 400°C. At higher temperature the benefit of CS1 is evident. Furthermore the premium grade develops a higher hardness and allows to apply a hardness up to 56 HRC depending on the process. The increase in hardness provides the steel CS1 an even better strength (Figure 3, right).

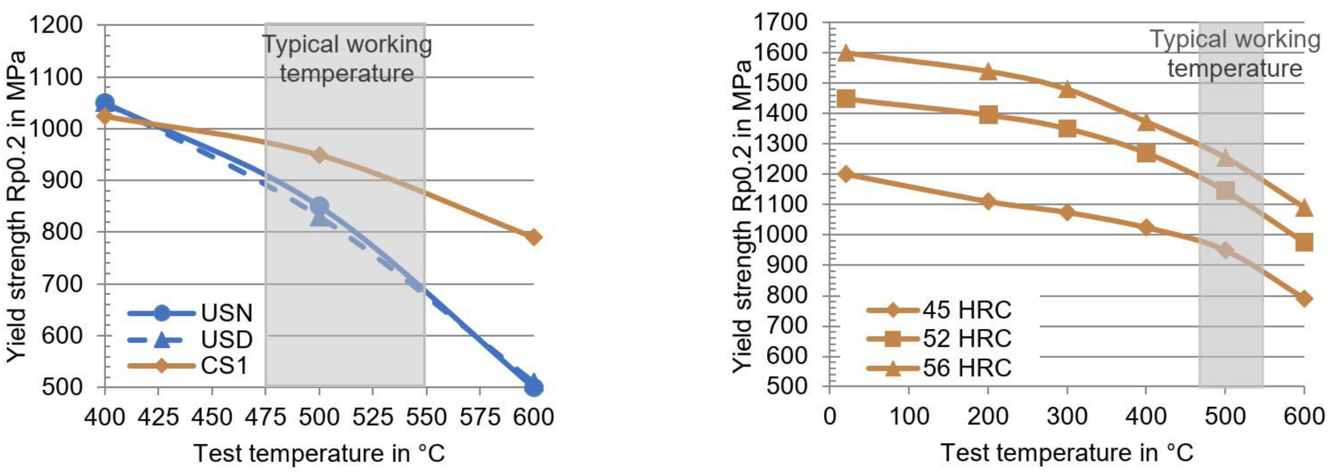

Fig.3 - Values of the 0,2% Yield strength Rp0,2 of the discussed steels as function of the test temperature All samples hardened + tempered to Rm = 1450 MPa (45 HRC) (left) / Influence of hardness on the high-temperature strength of CS1 (right).

In addition to high-temperature strength and hardness, the toughness of hot-work tool steels dedicated to die casting is important in order to withstand the sudden mechanical and thermal loads during the HPDC process without breaking. The toughness was tested after a heat treatment in the laboratory according to the NADCA-rules and at different hardness values (material was taken from a bar with a diameter of 230 mm). The impact energy values measured on ISO-V-notch samples are given in Figure 4. With 23 J, CS1 surpasses significantly the NADCA-requirements for the grade 1.2344 (at 45 HRC). Although higher hardness generally reduces toughness, CS1 is even able to achieve impact energy values of 15 J (NADCA level for 1.2344 at 45 HRC) up to a hardness of 58 HRC.

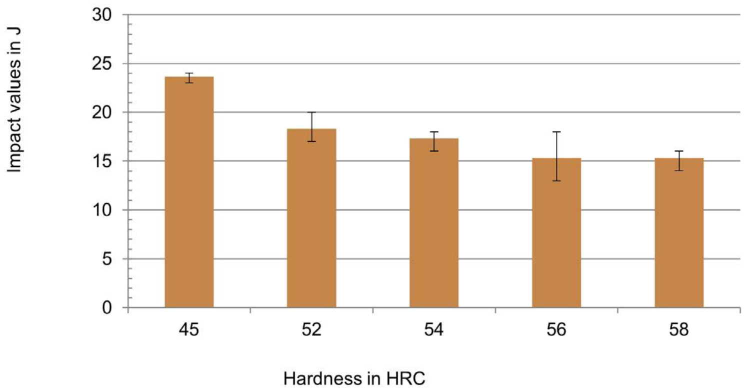

Fig.4 - Impact toughness of CS1 at different hardness (short transverse orientation).

HEAT TREATMENT RECOMMENDATION FOR DIES

In order to adjust the properties, each die casting die must be hardened and tempered. Figure 5 displays the CCT-diagramm of CS1 for a hardening temperature of 1030°C. The undesired bainite transformation takes place after 60 minutes, whereas the bainitic transformation starts already after 10 mintes. CS1 shows an outstanding through-hardenability. The comparably late beginning of the undesired bainitic transformation allows dies to be hardened martensitically with greater safety in the core. The pearlitic transformation is postponed to longer time in comparison to steels like 1.2343 and 1.2344 in the same way. In order to consistently achieve a martensitic microstructure a wider band of quenching rates compared to 1.2343 can be applied and thus lower risk of transformation-induced cracks.

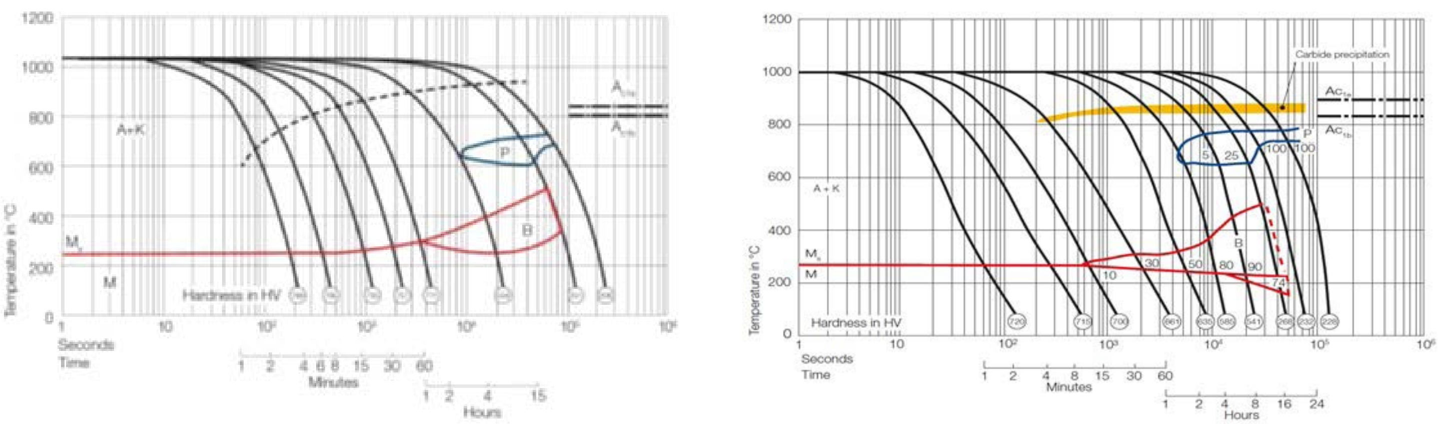

Fig.5 - Continuous time-temperature-transformation diagrams of CS1 (left) and USN (1.2343) (right).

APPLICATION RESULTS

As shown before, it is possible to apply a higher hardness with the steel CS1 in comparison to standard steels. Nevertheless the choice of the hardness depends on the dimension, the geometry and the complexity of die. In the following section some application examples of CS1 with a hardness above 50 HRC will be presented.

The first application example is a motorcycle brake lever holder (Figure 6 left). The surface demand of this visible part is very high, cracks in the die insert are not allowed. Even smallest surface defects of the die are transferred onto the cast component and are unavoidably visible after painting or chromium plating. Having tried numerous standardized and special hot-work tool steels the caster could not produce more than 3500 shots per die. Using CS1 with 53 HRC 13000 shots were achieved. Further tests were performed with a higher hardness of 56 HRC leading to a performance of 24000 shots. The increase of the hardness permitted to achieve 24000 shots. The lifetime of the dies was improved up to 600 % and a constant productivity could be achieved thanks to the use of CS1.

A second example is a throttle body (Figure 6 middle). For this piece, the high surface requirements demanded excessive remachining of die made of 1.2343, resulting in a maximum life of 90000 shots. In the tested application the final customer did not tolerate any mark of thermal shock cracks in the sealing areas.

A trial with CS1 as die material with a hardness of 52 HRC has recently been finished successfully. During the lifetime of 90000 shots only few very small defects showed up which could easily be laser-welded.

Although the caster did not increase the number of shots he could drastically reduce the maintenance efforts from 780 hours (1.2343) to 290 hours. The improvement of the surface quality as well as the reduced maintenance work are a clear technical benefit for the caster.

Fig.6 - Die cast and chromium-plated brake fluid tank of a motorcycle (left), Die cast throttle body (middle) / Die cast case of a memory unit (right) (examples).

The third example concerns memory unit housings, which are more and more installed in modern passenger cars (Figure 6 right). They often enclose very sensitive memory or assistance units and have to protect the installed electronic compounds against various impacts. In addition to the challenges concerning the high mechanical and thermal as well as dimensional stability, the cooling fins, which are often found on cases for electronic purposes, represent a further challenge for the die. In fact the corresponding grooves in the die are potential starting points of cracks. With the hot-work tool steel 1.2343, the very high demands on the sealing surfaces lead to tool failure after only 5000 shots. In a recent trial, the CS1 die with 53 HRC has so far achieved 7100 shots without any problems. The trial is still ongoing.

CONCLUSION

The variety of die-cast components is subject to constant changes. The demands on the surface quality and geometrical accuracy of the cast products are becoming much more stringent for technical and optical reasons. With the tool steel CS1, the die casting industry has a new premium hot-working steel at its disposal that enables hardness values of up to 56 HRC combined with very high toughness. In the range of typical working temperatures, CS1 achieves a significantly

higher high-temperature strength and thus greater resistance to thermal shock cracking. The special transformation behaviour of CS1 enables martensitic transformation with great certainty when hardening large dies.
Practical tests carried out by our customers show that dies made of CS1, thanks to its significantly higher hardness, show a noticeable improvement in performance, especially for castings with the highest surface requirements.

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