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The New Premium Grade CS1 –

Solution for Die Casting Dies with Highest Surface Requirements

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ABSTRACT

The die casting industry is facing significant changes of its product portfolio. The development of alternative automotive power systems supplants traditional die cast components of the power train. More and more ambitious structural components, produced by die casting, contribute to weight reduction of passenger cars. Medical appliances or new telecommunication technologies require new challenging die cast components.

Due to technical and aesthetic demands the surface quality of the cast components high importance. Cracks on the surface of dies are directly transferred onto the castings, causing expensive post processing and limiting tool life. Innovations like minimum quantity spray cooling avoid thermal shocks on the die surfaces and contribute to improved surface quality of dies and castings. Simultaneously an increase of the die temperature has to be expected bringing traditional die steels like H11 and H13 closer to their end of applicability.

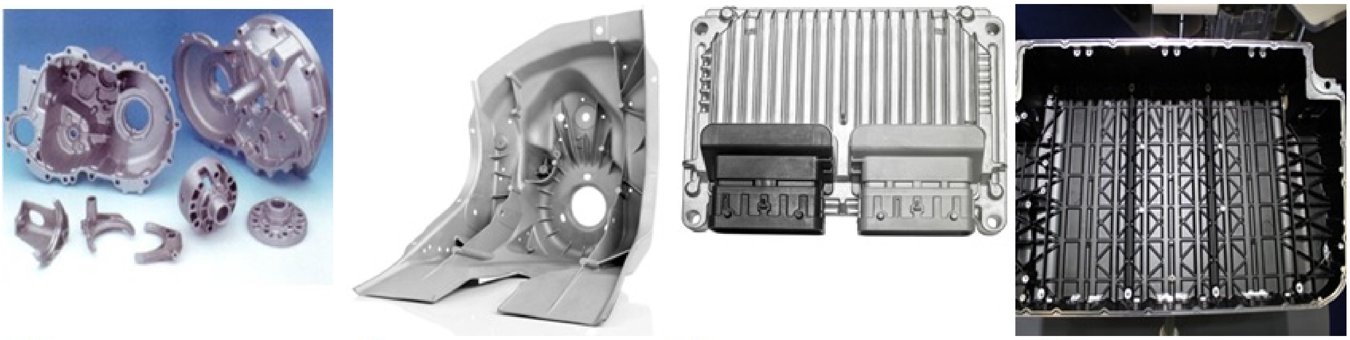
With premium grades like TQ1 and HP1 Kind&Co has been providing excellent tool materials contributing to improved die performance and die life. In order to match with further increased demands of surface quality Kind&Co has developed the new premium hot-work tool steel CS1. Due to the alloy concept and production process of CS1 dies can be hardened up to 56 HRC developing a very high high-temperature strength, excellent toughness, and thermal shock resistance.

This paper describes the properties of the new premium steel CS1 as well as results of industrial applications in which enormous improvements in lifetime of the dies were achieved and maintenance costs had been reduced drastically.

INTRODUCTION

The four different castings in figure 1 have been selected to demonstrate the various changes in the die casting industry.
The production of traditional castings of the power train (a) will go down as more and more alternative power systems will be developed. Modern die cast structural components like shock towers (b) are more and more state of the art in many passenger cars where they significantly contribute to control the car weight. Many electronic devices, whether for automotive assistance or safety systems or for telecommunication systems, require stable and leak-proof cases to protect the circuits installed inside (c). Batteries for electrically driven cars require stable and proof boxes (d) protecting the batteries against external impacts.

A proper sealing function of the cast boxes needs best surface quality of the corresponding sections of the die inserts.



a) b) c) d)

Figure 1- Examples of die cast products demonstrating the development towards parts with best surface quality.

THERMAL SHOCK CRACKS LIMIT DIE LIFE

During the casting process the surface of a die cavity is exposed to cyclic thermal shocks. Contact with the cast alloy heats up the surface in the cavity, spraying of the lubricant abruptly quenches it. Over the lifetime of a die these cyclic thermal shocks cause thermal fatigue of the die steel and generate thermal fatigue cracks (also called heat checking cracks) with their typical network appearance. The casting process transfers this pattern directly onto the surface of the solidifying casting (figure 2).

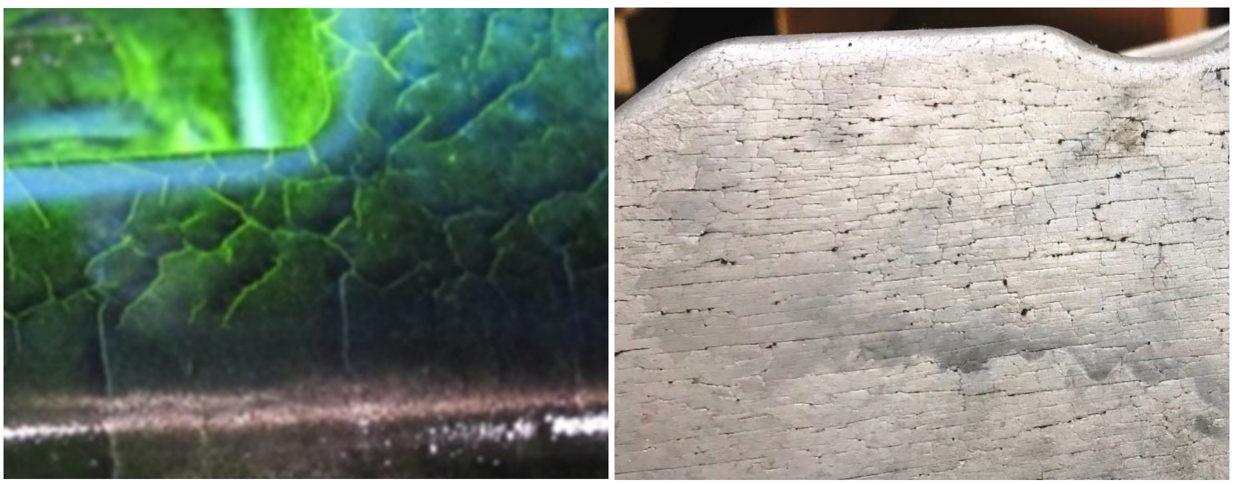


Figure 2- Thermal shock cracks on the surface reduce the quality of the cast product.
Typical crack appearance under UV-light during magnetic particle test (left);
Traces of severe thermal shock cracks on the surface of a cast product (right)

Thermal shock cracks are among the most frequent failure causes of die casting dies. Developments like the minimum quantity spray cooling technology are one contribution to the efforts reducing the surface defects on dies. On the other hand this technology needs newly designed internal cooling systems for a sufficient heat dissipation. More cooling channels and spot coolings are therefore installed in the die inserts, usually in a shorter distance to the working surface than before. Nevertheless, they often cannot avoid a significant temperature increase of the die surface. With respect to design aspects these numerous cooling channels have to be regarded as notches as they weaken the die steel.

The resistance against thermal shock cracks mainly depends on the high-temperature strength and toughness of the used hot-work tool steel. The relation between hardness and high-temperature strength of a hot-work tool leads to an increase of high-temperature strength with higher hardness – but automatically reduces toughness. This limits the range in which an increase of hardness can successfully improve the thermal shock resistance of a die.
The development of a hot-work tool steel which combines increased high-temperature strength and good toughness is a more promising approach to improved surface quality and increased lifetime of die casting dies.

CS1 – THE NEW PREMIUM HOT-WORK TOOL STEEL

The alloy concept of CS1 is based on the successful system Chromium – Molybdenum – Vanadium and aims at highly stressed tools. It uses the benefits of highest cleanliness (lowest concentrations of phosphorus, sulphur, and detrimental trace elements such as aluminum, copper or boron) in combination with experience in micro-alloying. Exclusively produced via Electro-Slag-Remelting (ESR) and sophisticated forging and heat treatment processes it provides a portfolio of unique property combinations.

Table 1 compares the composition of CS1 with the most frequently used grades H11 and H13.

Table 1- Chemical compositions of hot-work tool steels for die casting dies

Steel designation			Alloy content in mass-%						
Brand name	**AISI**	**Mat.-no.**	**C**	**Si**	**Mn**	**Cr**	**Mo**	**V**	**Nb**
USN ESR	H11	1.2343	0,37	1,00	0,40	5,20	1,20	0,40	-
USD ESR	H13	1.2344	0,40	1,00	0,40	5,20	1,30	1,00	-
CS1	-	-	0,50	0,30	0,40	5,00	1,90	0,55	+

Tempering behavior is one of the basic properties for hot-work tool steels for die casting dies. Tempering diagrams as the one in figure 3 do not only serve as a tool for the heat treater when tempering temperatures have to be defined. They also help to select suitable hot-work tool steels as these curves describe the resistance of a steel against undesired softening in the casting process.

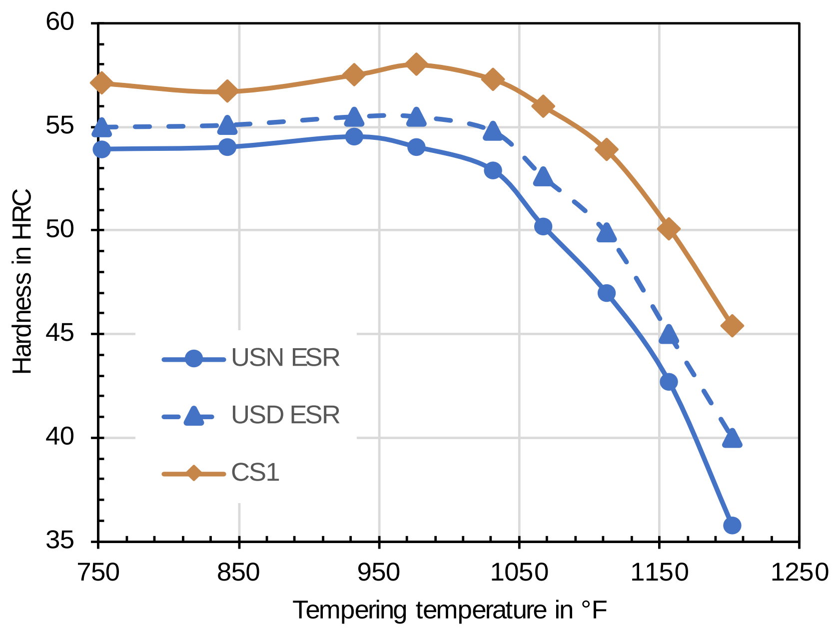


Figure 3- Tempering curves of the hot-work tool steels USN ESR, USD ESR, and CS1.

Figure 3 points out that CS1 achieves significantly higher hardness values than the two established grades USN ESR (H11) and USD ESR (H13). The decline of the tempering curve of CS1 is also shifted towards higher tempering curves indicating the higher tempering resistance of CS1. For die casting dies made of CS1 this characteristic tempering response of CS1 provides a higher resistance against softening during the casting process.

Impact toughness, usually measured on ISO-V-samples, can be described as a material's ability to compensate sudden mechanical stresses by plastic deformation. High toughness helps to prevent crack initiation and retards crack propagation in dies. Figure 4 compares the toughness potential of the three grades not only at the usual hardness of 45 HRC but also at increasing hardness levels and underlines the clearly improved toughness level of CS1.

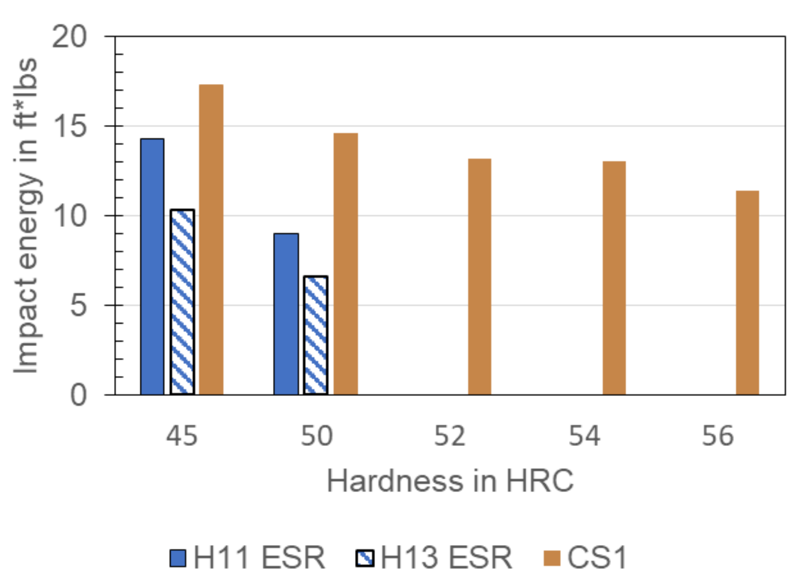


Figure 4- Comparison of impact toughness of USN ESR, USD ESR, and CS1. ISO-V-notch samples from the center of forged bars at increasing hardness (short transverse orientation)

Sufficient high-temperature strength is important to suppress the generation of thermal shock cracks on the surfaces of cavities. The values of the 0,2 % Yield strength, measured in tensile tests at increasing test temperatures, characterize the high-temperature strength of these three steels. All samples tested had been hardened and tempered to Rm = 1450 MPa (figure 5).

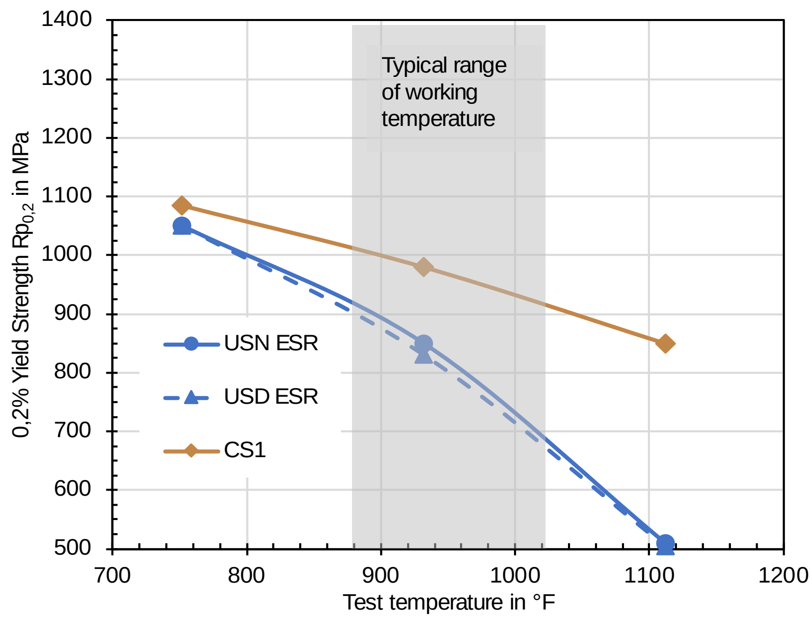


Figure 5- Values of the 0,2% Yield strength $Rp_{0,2}$ of USN ESR, USD ESR, and CS1 representing the high-temperature strength of these grades; All samples hardened + tempered to Rm = 1450 MPa (45 HRC)

Marked in grey is the temperature range to which the surface of the cavity is heated at least for a short moment with each shot. Within this critical temperature range CS1 clearly exceeds the values of the two other grades and with increasing test temperature the advantage of CS1 becomes even more evident.

Further benefit can be achieved by even higher hardness: Rising the hardness of CS1 up to 56 HRC leads to remarkable increase of the high-temperature strength (figure 6). In combination with the high toughness potential this effect gives way to die casting applications with enormous improvements of thermal shock resistance.

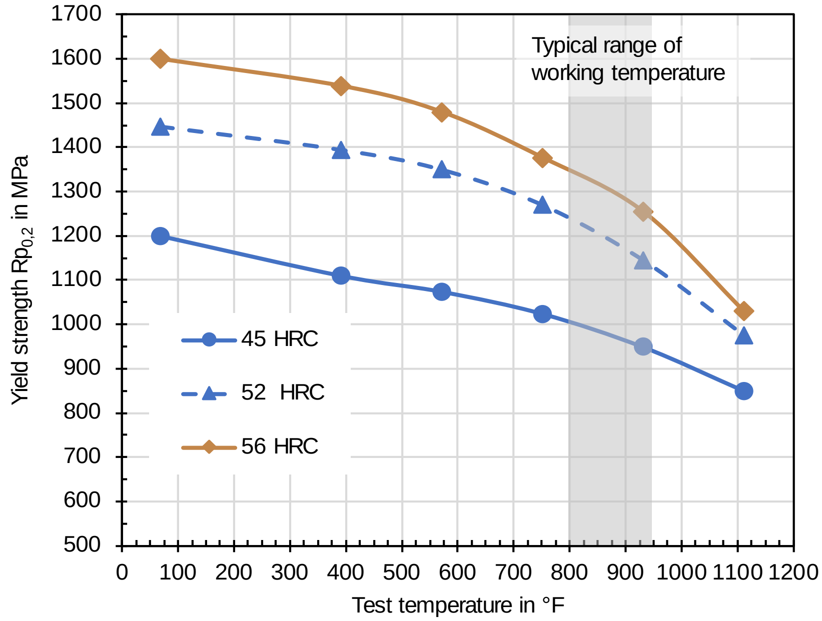


Figure 6- Influence of hardness on the high-temperature strength of CS1

HEAT TREATMENT RECOMMENDATIONS FOR DIES OF CS1

CS1 can develop its properties and advantages compared to other hot-work tool steels only if the tools are correctly hardened and tempered. Vacuum hardening of die casting dies is state of the art and CS1 is very well suitable for this technology. Kind&Co recommends a hardening temperature of 1886 °F with a soaking time on hardening temperature of 60 mins. Triple tempering of hardened dies is a must in order to develop not only high-temperature strength but also best possible toughness. Guidance for tempering is given in the tempering curve (figure 3).

Compared to steel grades like H11 and H13 the new premium grade CS1 reveals a great advantage in the transformation behavior. The comparison of the TTT-diagrams of USN ESR (H11) and CS1 demonstrates that the undesired, critical bainitic transformation is delayed in CS1 by approximately 50 minutes (figure 7). This means that even dies with large cross-sections can be hardened martensitically in the center with better process reliability than dies of H11 or H13.

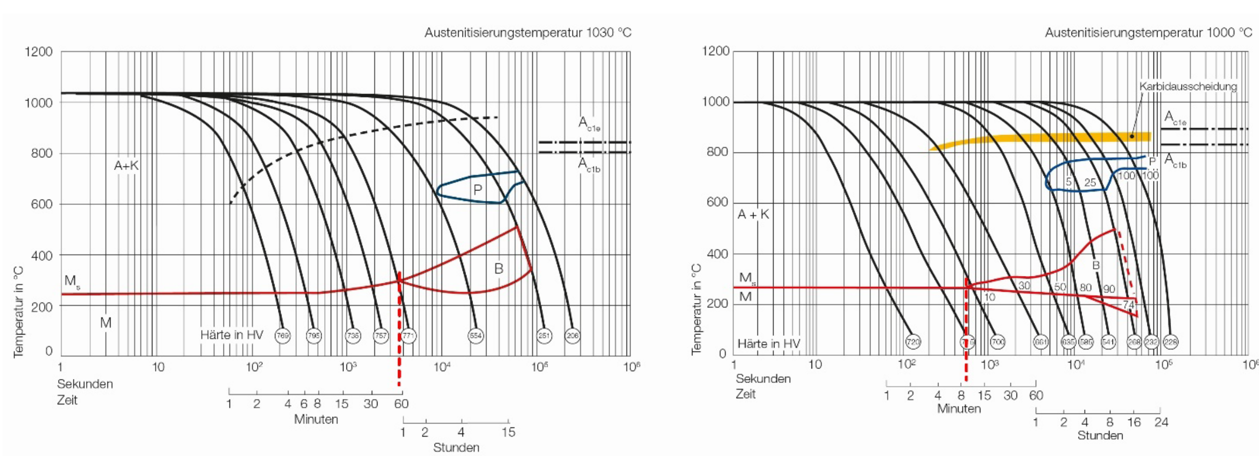


Figure 7- Continuous TTT-diagram of CS1 (left) in comparison with USN (H11; right)
The red dotted lines indicate the beginning of the critical bainitic transformation

APPLICATION RESULTS

Technical and aesthetic reasons are responsible for permanently increasing demands on surface quality of die cast products. This chapter therefore describes of different fields of applications which all require highest surface quality of the castings.

The first example is the die cast container for the brake fluid of a motorcycle (figure 8). The delivery condition for these products – chromium-plated or painted – is an extreme challenge as even smallest defects on the surface of the casting will be visible after painting or chromium plating. Furthermore the tank has to be leakage-proof so that the die surface condition in the sealing area has great importance.

Figure 8- Die cast and chromium-plated brake fluid tank of a motorcycle (example).

Due to the extreme surface requirements the caster had tried numerous standard and premium hot-work tool steels from various renowned producers but could not produce more than 3.500 shots with one die. Then surface defects appeared and the die inserts had to be discarded.
With inserts of CS1 the caster started with a hardness of 53 HRC and produced 13.000 shots. Meanwhile repeated tests, with hardness up to 57 HRC, have proved a constant and reproducible performance of 13.000 shots for this sensitive product.

Throttle bodies as the one shown in figure 9 require for technical reasons a very high surface condition. In the tested application the final customer did not tolerate any mark of thermal shock cracks in the sealing areas. With dies made of the traditional hot-work tool steel H11 ESR the caster had to do rework the inserts, especially in the sealing area of the dies, frequently in order to achieve a final performance of 90.000 shots. The caster tried dies of CS1 with a hardness of 52 HRC and during the lifetime of 90.000 shots only few very small defects showed up which could easily be laser-welded. Although at the end the caster did not achieve a higher number shots he documented a significantly reduced effort for maintenance. With dies made of H11 ESR the average maintenance effort per die was 780 hours whereas dies of CS1 required only 290 hours of maintenance. The caster stated a clear technical benefit because of improved surface quality as well as a significant economic advantage due to the reduced maintenance work.

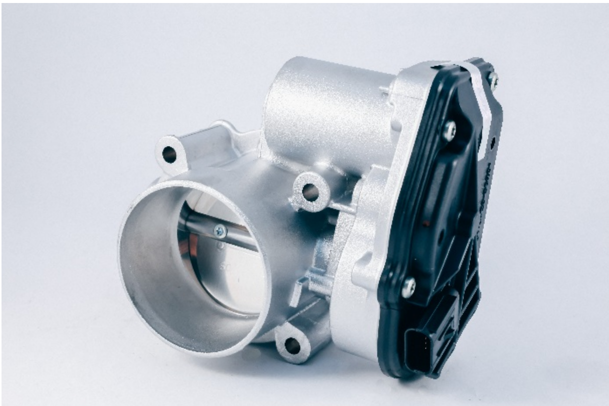


Figure 9- Die cast throttle body (example)

Die cast cases as the one shown in figure 10 are more and more installed in modern passenger cars. They often enclose very sensitive memory or assistance units and have to protect the installed electronic compounds against various impacts. Similar cases can also be found in modern data or telecommunication systems. All these light metal cases need to feature high mechanical and thermal, but also dimensional stability. Cooling fins which are often found on cases for electronic purposes are a further challenge as the corresponding groves in the die are potential starting points of cracks.

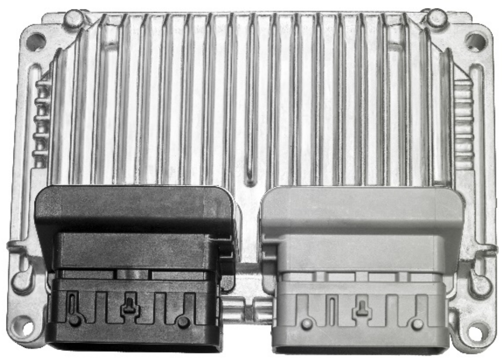


Figure 10- Die cast case of a memory unit (example)

In this application test CS1 replaced successfully dies made of the traditional grade H11 which after only 5.000 shots could not fulfill the high surface requirements in the sealing section. In the latest test with a die of CS1 and a hardness of 53 HRC the die did not reveal any critical indication within 7.100 shots so that test is being continued.

CONCLUSION

The large variety of die cast products is subject to permanent changes. Ongoing development of new cast products but also technical and aesthetic reasons are responsible for intensified surface requirements of the cast products and the dies accordingly. The development of the minimum spray cooling technology has contributed to reduced thermal shocks on the die surface but simultaneously higher surface temperatures were observed so that traditional hot-work tool steels have more and more come to the end of their applicability.
With hardness values up to 56 HRC the newly developed premium hot-work tool steel CS1 provides the chance to use hardness ranges which were impossible before. The high hardness gives rise to the high-temperature strength of the steel and as CS1 additionally provides excellent toughness this new grade reveals a significantly improved thermal shock resistance. Application tests show that using dies with hardness in the range of up to 54 HRC, even 57 HRC leads to remarkable improvements of the surface quality of the die and of the casting, to significantly higher production figures, and even to clearly reduced maintenance efforts.
Although this paper describes comparably small castings and dies CS1 has the potential to successful use in large dies. The delayed bainitic transformation during hardening indicates advantages in the heat treatment process.
Thus CS1 is a new premium hot-work tool steel with the potential for many improvements in the die casting process.