Steel Development for High-Pressure Die Casting Dies with Highest Surface Requirements

Due to technical but also aesthetic reasons the surface quality of cast products, and of the die casting dies accordingly, gains more and more importance. Surface quality is directly related to the appearance of thermal shock cracks which are transferred onto the castings during the casting process. This report describes the new premium hot-work tool steel CS1 which, due to its particular combination of properties like unusually high working hardness, tempering resistance, and simultaneously high toughness offers an exceptional resistance against formation and growth of thermal shock cracks.

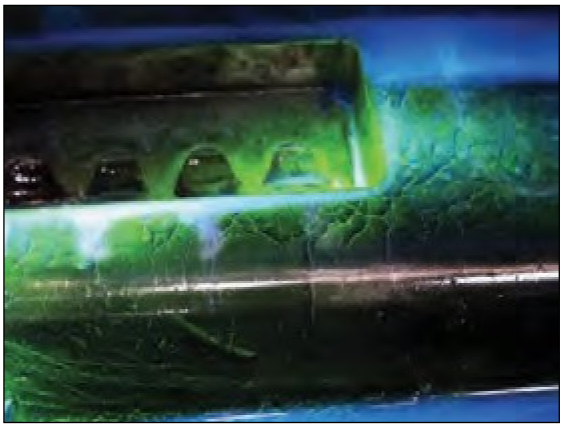


Figure 1: Thermal shock cracks on the surface of a die casting die, visualized in the magnetic particle test under UV-light

Thermal shock cracks as main failure cause of die casting dies

The cyclic change of heating due to contact with the melt and cooling due to the sprayed lubricant causes thermal fatigue of the die steel during the lifetime of a die and thermal shock cracks in their typical network appearance on the surface of the die (Figure 1).

By propagating into the steel but also by transferring the crack network onto the surface of the castings thermal shock cracks not only reduce the lifetime of the dies but also the surface quality of the castings. Thermal shock cracks are among the most frequent failure causes of die casting dies. Reducing spray cooling to the necessary minimum is one approach to delay the formation of such surface defects. The minimum quantity spray cooling technology is based on this idea but it requires a complete modification of the temperature control system, e.g. by installation of spot coolings directly below the working surface of the dies. These numerous drilled channels have to be considered as mechanical weakening of the die inserts. Furthermore they cannot completely avoid an increase of the general die temperature in the use of minimum spray cooling.

The resistance of a steel against thermal shock cracks mainly depends on its high-temperature strength and toughness. High-temperature strength is directly related to the steel's hardness. This way an increase of hardness results in an improved high-temperature strength but simultaneously in a reduced toughness. However, more success can be expected from the development of a steel which simultaneously offers a very high high-temperature strength in combination with a high toughness.

The new premium hot-work tool steel CS1

As a Chromium-Molybdenum-Vanadium alloyed hot-work tool steel CS1 was especially developed for mechanically and thermally highly stressed tool components. The combination of a tailored alloy concept with production processes which guarantee highest cleanliness as well as an optimized heat treatment grant high hardness and at the same time a high toughness level to CS1. According to the high requirements on hot-work tool steels for die casting dies CS1 is exclusively produced by Electro-Slag-Remelting (ESR). This also corresponds to the established grades USN ESR and USD ESR which, in respect to their chemical composition, correspond to the internationally standardized hot-work tool steels 1.2343 (AISI H11) and 1.2344 (AISI H13) [1].

The presentation of the tempering behaviour (Figure 2) indicates that CS1 offers not only a significantly higher secondary hardness maximum but also a clearly improved tempering resistance compared to grades USN ESR and USD ESR. This way it offers a considerably improved protection of dies against undesired softening during operation.

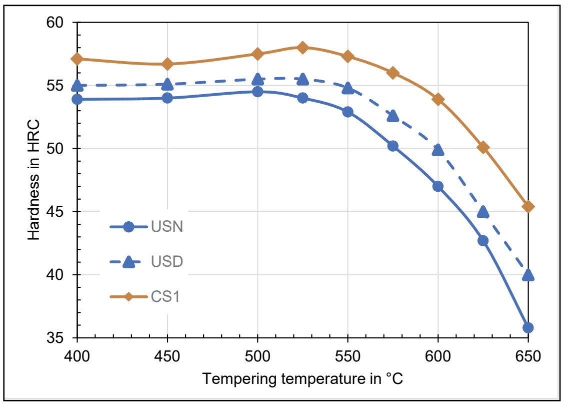


Figure 2: Tempering behaviour of the steel grades USN ESR, USD ESR, and CS1

Whereas the hardness of die casting dies made of steels like 1.2343 and 1.2344 usually ranges between 44 and 46 HRC the new grade CS1 allows working hardness up to 54 HRC, in some cases even up to 56 HRC. Also a clearly better long-time tempering resistance can be expected from CS1 which provides an improved protection against loss of hardness during the casting process. The chance to use CS1 with such a high hardness for die casting dies is derived from its high toughness potential. Figure 3 compares the toughness level of USN ESR and USD ESR with values of CS1 at the typical hardness level of die casting dies of 45 HRC. The improvement of the impact energy by 20 % is clearly visible.

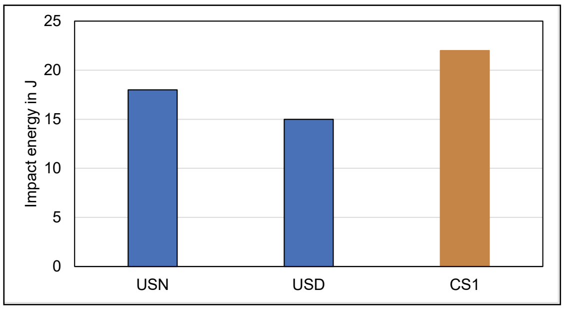
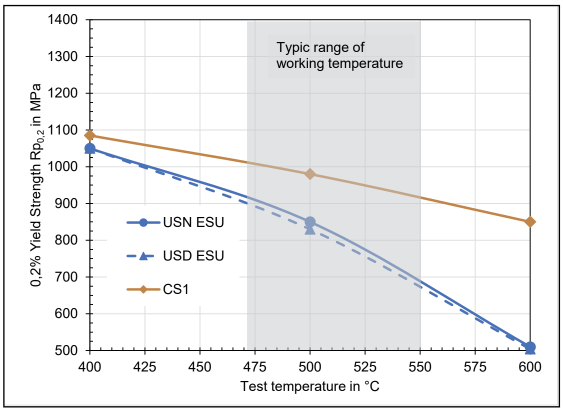


Figure 3: Comparison of toughness properties of the three grades USN ESR, USD ESR, and CS1, measured on ISO-V-notch samples taken in transverse orientation form the center of forged bars. Hardness: 45 HRC



High-temperature strength of the steel grades plays a great role in avoiding thermal shock cracks. Therefore Figure 4 compares the values of the 0,2%-Yield Strength Rp0,2 measured in tensile tests under increasing test temperature. All samples had been hardened and tempered to identical hardness of 45 HRC. While the yield strength of USN ESR and USD ESR drops in the same extent with increasing test temperature CS1 maintains a higher yield strength.

Thermal shock cracks are induced on those surfaces which are directly exposed to the melt. Marked in grey is the temperature range to which the surface of the die insert is exposed at least for a short time during each shot. Compared to the other two grades the clearly higher 0,2%-Yield Strength of CS1 contributes significantly to avoiding thermal shock cracks. With a further increase of hardness the high-temperature strength can rise even more (figure 5).

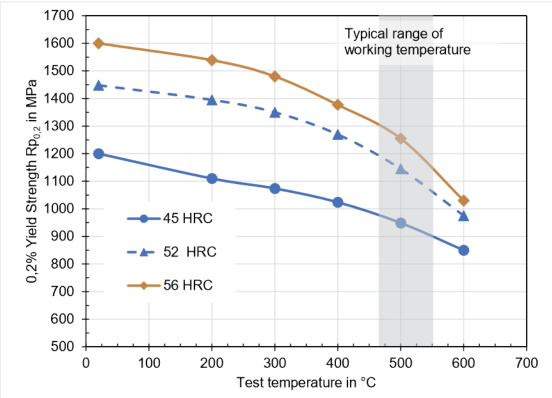


Figure 5: Influence of increasing hardness on the 0,2%-Yield Strength of CS1

Due to the high toughness potential (s. Figure 2) it is possible to harden and temper dies of CS1 to a hardness of up to 54 HRC. Of course also other geometric parameters of the die are responsible for the defined hardness. With the combination of these properties CS1 offers the precondition for die casting dies with highest resistance against thermal shock cracks as well as with highest geometric stability.

Hot-work tool steels receive their performance characteristics by hardening and tempering. Time-temperature-transformation (TTT) diagrams provide important information for appropriate hardening of tools. The comparison of corresponding diagrams of CS1 and USN highlight one great advantage of CS1 during hardening of larger dies (figure 6). Highest possible toughness of a die casting die requires a mainly martensitic transformation of the steel and consequently a fast quenching from hardening temperature. This is easy to adjust at the surface of a die. In the centre of the die the cooling rate is restricted by the thermal conductivity of the steel. Especially in the centre of large dies this leads to the risk of an at least partial bainitic transformation and a reduced toughness. In TTT-diagrams this is expressed by the position of the bainitic transformation with respect to the time axis. The direct comparison of the two diagrams demonstrates that the bainitic transformation of CS1 starts approximately 50 minutes later than of USN ESR. This allows an easy transformation of the core of a large die into martensite.

For an appropriate hardening of dies of CS1 a hardening temperature of 1030 °C and a soaking time of 60 minutes is recommended. Triple tempering is mandatory.

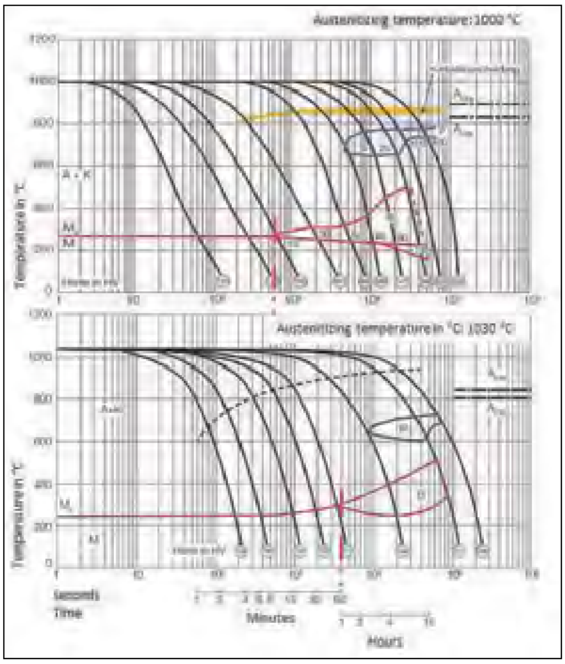


Figure 6: Comparison of TTT diagrams for hot-work tool steels USN ESR (top) and CS1 (bottom).

Note: the dotted red lines indicate the beginning of the bainitic transformation

Experience of industrial applications

The combination of the described properties is the basis of the operational performance of the steel grades in die casting operations. The following case studies describe the individual specific requirements and give an impression of the achieved casting performance.

Die cast tanks for brake fluid of motorcycles (Figure 7) are often a challenge for the dies in two aspects. On the one hand, such components are visible accessories whose aesthetic appearance is generally regarded as very important by drivers. Since even the smallest surface defects of the cast part become visible in painted or chrome-plated versions, the surface quality of the used dies must also meet the highest requirements. On the other hand, cracks in the dies in the sealing areas of such vessels very quickly endanger the functionality of the products. These high requirements were the reason why the caster had to reject the die inserts after a maximum of 3,500 shots. The use of a wide range of standard and special hot-work tool steels from various manufacturers was not able to achieve any significant increase in performance. By using CS1

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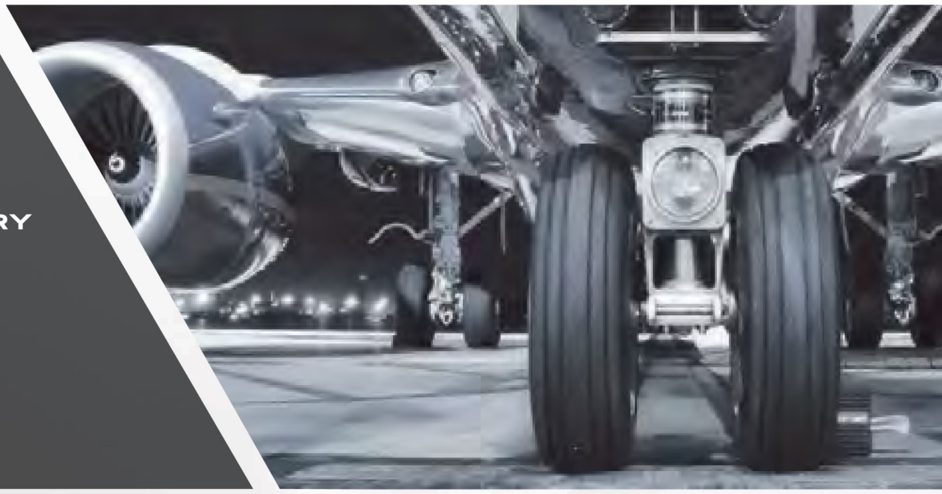

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with a hardness of 53 HRC, the caster was able to increase the output reproducibly to 13,000 shots.

Figure 7: Die cast tank for brake fluid of a motorcycle (example)

For functional reasons, very high demands are placed on the surfaces of die cast throttle bodies (figure 8). Through frequent reworking of the inserts, die inserts made of 1.2343 ESR achieved a maximum output of 90,000 shots. In the currently ongoing testing of die inserts made of CS1 with a hardness of 52 HRC, no reworking is required even after 80,000 shots.

Figure 8: Die cast throttle body (example)

To protect the electronic components installed in them, the assistance and safety systems installed in motor vehicles require housings of the highest surface quality. Corresponding demands are also made on sealing joints. Here, even the smallest surface cracks in the die endanger the functionality of the castings. The same applies to numerous telecommunications components. The housing of a storage unit shown as an example in Figure 9 must reliably meet the requirements described above. A further tightening of the quality requirements for the die steels results from cooling fins on the outside of the housing. Die inserts made of 1.2343 ESR for such a housing could not meet the strict specifications in the area of the sealing surfaces after only 5,000 shots. In the currently ongoing test with a die insert made of CS1 (hardness 53 HRC), no abnormalities were found after 7,100 shots.

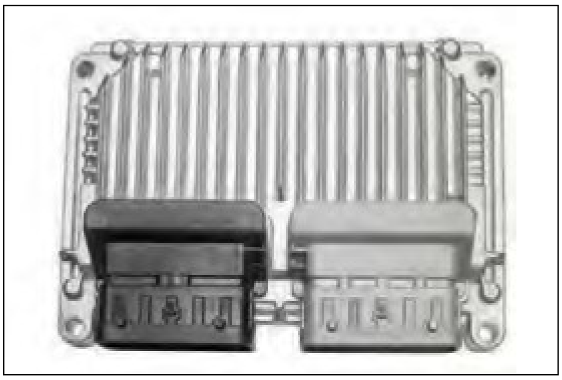

Figure 9: Die cast housing of a storage unit (example)

Conclusion

The die casting industry is currently undergoing a noticeable change in its product portfolio. For technical and aesthetic reasons, the demands on the surface quality of the castings and thus also on the die inserts are becoming considerably more stringent. Further developments in process technology such as minimum quantity spraying are helping to reduce damage to the die surfaces. Such measures, however, are accompanied by a significant increase in die temperature. The newly developed premium hot-work tool steel CS1 can be used with a significantly higher working hardness. As a result, it achieves a significantly higher high-temperature strength in the range of typical working temperatures and thus improved resistance to thermal shock cracks. Since the special transformation behaviour of CS1 has a positive effect especially on the hardening of large die inserts, the use of CS1 is now also being tested for significantly larger inserts.

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References:

[1] ISO 4957:2018 Tool Steels, 2018

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