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Current Trends in the Die Casting Industry from a Tool Steel Producer's View

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ABSTRACT

The international die casting industry faces enormous technological challenges.
Die cast structural components for the automotive industry have reached a complexity of design and dimensions which were unforeseeable a few years ago. Dimensional changes or sharp bends in the product, variations of cross-sections within the product create stress accumulations within the dies. The larger the dies and the more intensive the differences in wall thickness of the inserts, the higher is the necessity to use hot-work tool steels with improved toughness properties and a transformation behavior safely avoiding the undesired bainitic transformation.

New assembly technologies and modern die cast products require best surface conditions of cast components and demand for die steels with outstanding thermal shock resistance. Surface quality is one of the key acceptance criteria for cases of electronic components or for castings with visible, aesthetic surfaces.

Hot-work tool steels like H11 and H13 have been used for most die casting applications but for products as described before they have reached the limits of applicability. Kind&Co has developed two premium hot-work tool steels combining good high-temperature strength and impact toughness: TQ1 and CS1. TQ1 clearly exceeds established grades in high-temperature strength and thermal shock resistance. Very high impact toughness and specific hardening behavior make TQ1 best suitable for large die inserts for structural components. CS1 not only allows to be used with hardness of up to 54 HRC, it also offers high impact toughness even at higher working hardness and grants extreme thermal shock resistance to die casting dies. CS1 the ideal hot-work tool steel for die casting dies with highest surface requirements.

INTRODUCTION

Motivated by economic and ecological necessities the world-wide automotive industry has been developing new body-in-white concepts in which die cast structural components contribute to the important weight reduction. Shock towers, door frames, or hatchback support frames have been produced by High Pressure Die Casting (HPDC) for many years[1, 2] but in the recent years the developments were quickly progressing. Integration of functions into the castings, new alloy concepts of aluminum, and new design trends of the components have caused additional growth in the production of die cast structural components. The expected growth in e-mobility will provoke this trend. Today large longitudinal members and cross members can be found in very many passenger cars from middle class to premium class. As a pioneer TESLA has opened new dimensions of the castings by casting very large and complex underbody structures. Meanwhile car producers from all over the world have started to develop and cast similar components.
This trend is accompanied by the necessity of larger die casting machines, larger and more complex die inserts, and new casting alloys. Die designers and die casters have to learn how to handle these new dimensions. Steel producers need to provide hot-work tool steels which offer properties well-adjusted to the new challenges.

Kind&Co has analyzed this trend and offers the premium hot-work tool steel TQ1 which offers a variety of properties well-adjusted to the new requirements.
The second challenge refers to castings with special surface requirements. Among them are for example die cast cases for numerous assistance systems of modern cars. To protect the sensible electronic equipment inside they require extremely smooth inner surfaces. Cooling fins on the outer surfaces need to be cast with highest surface quality. Battery boxes of electrically driven cars must offer highest accuracy in the sealing areas.
Thermal shock cracks on the surface of the dies are among the most frequent failures of die casting dies. As the crack patterns are transferred from the die surface onto the casting products with highest surface requirements require hot-work tool steels with highest thermal shock resistance. Kind&Co's new premium hot-work tool steel CS1 can be used with working hardness up to 54 HRC. As the steel also offers excellent impact toughness CS1 provides an outstanding thermal shock resistance which makes it best suitable for dies with highest surface requirements.

CHALLENGE 1: LARGE DIE CAST STRUCTURAL COMPONENTS

Political decisions[3] as well as economic and ecological considerations have been motivating the world-wide automotive industry for years to develop lightweight body-in-white concepts. Die cast shock towers, originally only found in premium class vehicles, are nowadays used in many middle class cars. Die cast longitudinal chassis beams and cross members indicate the tendency towards even larger die cast structural components. With the development of die cast underbody components TESLA has been a pioneer in the development of even larger and more complex die cast structural components. More and more automotive producers all over the world follow this trend and develop and cast similar structural components. The expected growth in electric vehicles supports the shift towards large die cast structural components also in the mass market.

The production of large structural components is only advantageous if subsequent heat treatment of the components can be dispensed with. This requires aluminum cast alloys which develop the required mechanical properties without heat treatment. Some of these alloy are listed in Table 1.

Table 1- Chemical compositions of some aluminum die casting alloys

Aluminum alloy	Alloy content in mass-%						Casting temp. in F	Purpose
	Si	Fe	Mn	Mg	Ti	others		
226	7.5–9.5	0.80	0.15–0.65	0.05–0.55	0.25	---	1112-1202	Multi-purpose
Castasil 21	8.0-9.0	0.50-0.70	0.01	0.03	0.01	---	1256-1328	Structural components
Castasil 37	8.5-10.5	0.15	0.35-0.60	0.06	---	0.1-0.3 Zr	1256-1328	
Silafont 36	9.5-11.5	0.15	0.5-0.8	0.1-0.5	0.04-0.15	0.01-0.20 Sr	1256-1310	
Silafont 37	8.5-10.5	0.15	0.35-0.60	0.06	0.04-0.15	0.006-0.025 Sr	1256-1310	
Magsimal 59	1.8-2.6	0.2	0.5-0.8	5.0-6.0	0.2	0.004 Be	1274-1346	

Significantly lower Fe-concentrations and higher casting temperatures are important differences of the alloys for structural components in comparison to the well-known multi-purpose alloy 226.
The solubility of Fe in Al is the reason why Al-alloys with low Fe-concentrations must be regarded as chemically more aggressive than alloys with high Fe-concentrations. This explains why many Al-alloys for structural components have a high tendency of soldering (sticking) on the die inserts.

Large die cast structural components are often characterized by dimensional changes or sharp bends. Numerous stiffening ribs contribute to the required mechanical properties of the castings (Figure 1).

Figure 1- Example of a die cast structural component (Source: Georg Fischer - https://www.georgfischer.com/)

These particular features are potential spots of stress concentrations during heat treatment and during the casting operation. In order to fill cavities with long flow ways completely casters often increase the casting temperature which results in higher thermal stresses. Special alloys for structural components which require higher casting temperatures than standard alloys further increase the thermal stress situation in the die inserts. High flow rates of the melt intensify mechanical stresses in the dies.

Structural components combine both functional and visible surfaces. Traces of thermal shock cracks on the casting prohibit proper assembling of the cast components and cause expensive machining operations on the castings. Traces of thermal shock cracks on visible surface reduce the visual quality of the components. Dies for structural components should therefore provide a high resistance against gross cracking as well as thermal shock cracks.

PREMIUM HOT-WORK TOOL STEEL TQ1

Kind&Co developed the premium grade TQ1 on the principle of highest cleanliness. This means that the contents of detrimental trace elements have been drastically reduced compared to standard hot-work tool steels like H11 and H13. Produced by Electro-Slag-Remelting (ESR) TQ1 is a chromium-molybdenum-vanadium alloyed hot-work tool steel with very high homogeneity and cleanliness. Table 2 introduces the chemical composition of TQ1 in comparison to standard hot-work tool steels like AISI H11 (Mat.-No. 1.2343) and AISI H13 (Mat.-No. 1.2344).

Table 2- Chemical composition of TQ1 in comparison to H11 and H13

Steel designation	Alloy content in mass-%					
	C	Si	Mn	Cr	Mo	V
TQ1	0.36	0.25	0.40	5.20	1.90	0.55
H11 ESR	0.37	1.00	0.40	5.20	1.20	0.40
H13 ESR	0.40	1.00	0.40	5.20	1.30	1.00

The well-balanced, adapted composition ensures best properties for large die inserts for die cast automotive structural components. The main properties such as tempering behavior, high-temperature strength, and impact toughness are illustrated in Figures 2 – 4.

TQ1 develops the same tempering resistance as H13 (Figure 2) and this way it provides the same resistance against undesired softening during casting operation as the well-established grade H13.

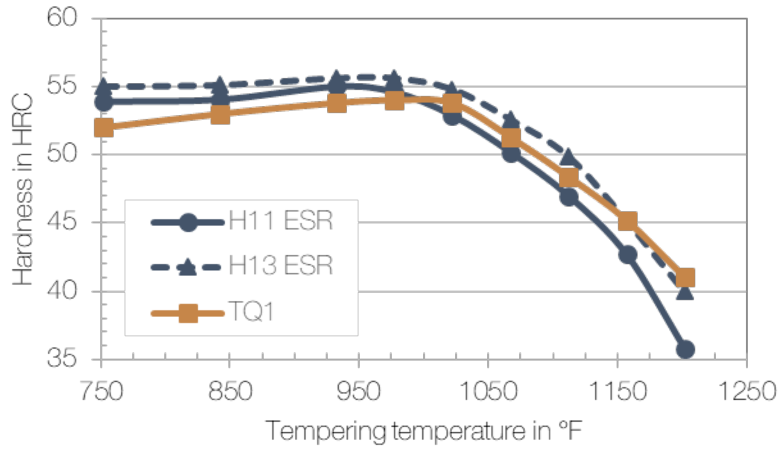

Figure 2- Tempering behavior of TQ1 in comparison to H11 and H13

High-temperature strength is an important property as it describes the resistance against crack initiation at elevated temperatures. In this report the Yield Strength $Rp_{0,2}$, measured in tensile tests at increasing test temperatures, is used to describe the high-temperature strength of the steels. All samples had been hardened and tempered to the same hardness of 45 HRC before being tested. The diagram in Figure 3 compares the three steel grades. Marked in gray is the temperature range to which the surface of a die is exposed for at least a short moment with each shot. The curves clearly demonstrate that at test temperatures above 600 °F TQ1 develops a significantly higher high-temperature strength than H11 and H13. This difference is the reason for the higher resistance to crack initiation in dies of TQ1 – an important advantage to be considered especially with respect to the higher casting temperatures of the alloys listed in Table 1.

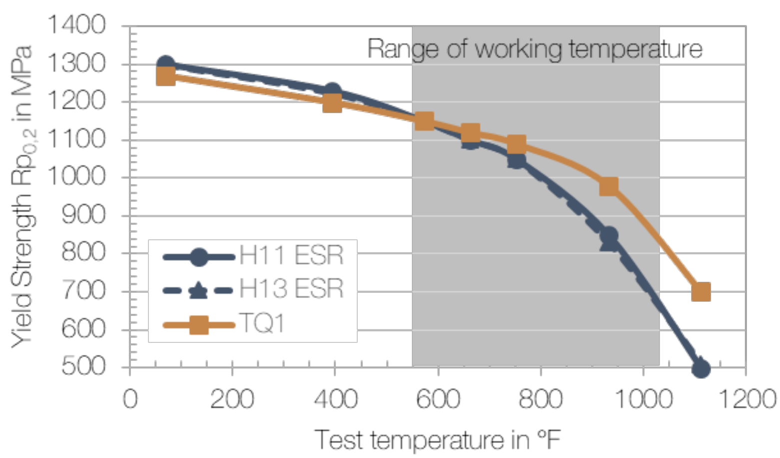

Figure 3- High-temperature strength of TQ1 in comparison to H11 and H13

Besides high-temperature strength hot-work tool steels for large structural properties need to have a high level of impact toughness in order to compensate the sudden mechanical stresses which come up with each shot. Typical places of stress accumulations in die inserts during the die casting process are small radii, sharp corners, and grooves for stiffening ribs. Figure 4 displays typical impact energy values measured in accordance with NADCA #207-2018 for H11, H13, and TQ1 with a hardness of 45 HRC. The advantage of TQ1 with respect to a higher toughness level is clearly visible.

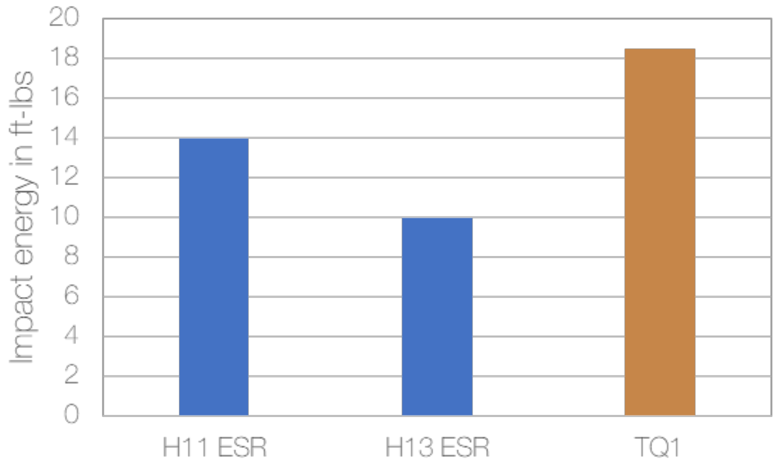

Figure 4 - High-temperature strength of TQ1 in comparison to H11 and H13

The combination of good high-temperature strength and high impact toughness finally results in excellent thermal shock resistance. As surface requirements had become more and more important for large structural components TQ1 offers the best precondition for great die performance.

Hardness as a key property of a die insert should always be considered individually and respect the design of the die inserts. Whereas standard die casting dies often have a hardness of 45 HRC the hardness of large inserts for structural components should be lower in order to provide best possible toughness. The improved high-temperature strength of TQ1 helps to provide best surface quality even at reduced hardness levels.

TQ1 is listed in the NADCA specification#207-2018. TQ1 has proved its suitability for die casting dies for large automotive components with very high toughness and surface requirements in numerous applications worldwide.

CHALLENGE 2: DIE CAST COMPONENTS WITH HIGHEST SURFACE REQUIREMENTS

Recent years have shown an enormous demand for castings with extremely high surface requirements. On the one hand this demand can be ascribed to the increasing use of castings with decorative, aesthetic surface in the automotive industry. On the other hand there are more and more technical reasons which require highest surface quality of the cast components. Here again the automotive industry plays an important role as more and more cars are equipped with assistance systems which all need cases with highest surface quality in order to protect the installed electronic components. Battery boxes of electrically driven vehicles must offer highest accuracy in the sealing areas and therefore need dies with excellent resistance against thermal shocks.

Progress in telecommunication technologies, e.g. the 5G-technology, has generated a huge demand of low-cost cast cases with high surface quality. Numerous cooling ribs as well as sealing sections are the challenges for die casters and require again a die steel with highest resistance against thermal shock cracks.

Examples of these products are shown in Figure 5.

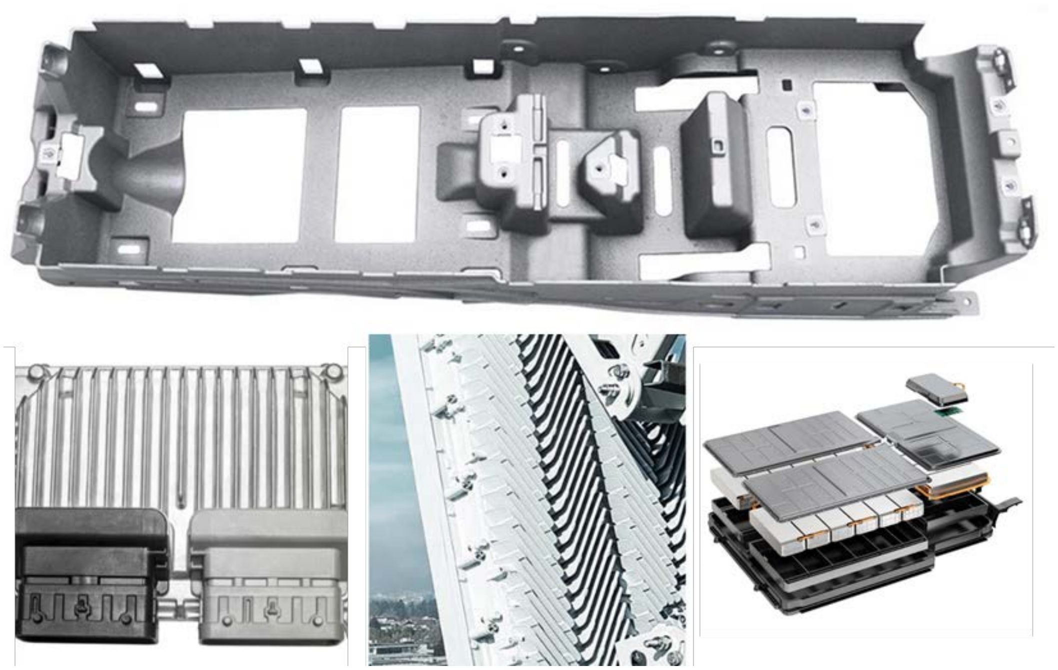

Figure 5 – Examples of castings with sophisticated surface requirements.
Top: Center console of a German sports car.
Bottom (from left): Cast assistance unit; case of a 5G telecommunication system; battery box for a hybrid car.

Very frequently thermal shock cracks on the die surfaces are responsible for expensive reworking operations of the die surface or even the end of the lifetime of dies. Thermal shock cracks with their typical netlike appearance are transferred onto the surface of the casting and drastically reduce the function (e.g. in case of sealing or mounting surfaces) or visual quality of the cast products.

In order to fulfill the extremely high requirements concerning surface quality dies need to provide a much higher resistance against thermal shock cracks than before in order to produce efficiently. Kind&Co has therefore developed the new premium grade CS1 which provides much higher resistance against thermal shock cracks than established hot-work tool steels like H11 or H13.

The general properties of CS1 had been presented in 2020[4] but for a better understanding the main data will be repeated here.

The chemical composition of CS1 is listed in Table 3. CS1 is a chromium-molybdenum-vanadium alloyed hot-work tool steel with increased carbon content. A minimal dose of niobium provides a fine-grained microstructure even at the comparably high hardening temperature of CS1.

Table 3 - Chemical compositions of CS1 and standard 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 ESR	1.2343 ESR	0,37	1,00	0,40	5,20	1,20	0,40	-
USD ESR	H13 ESR	1.2344 ESR	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	+

Due to the higher carbon content CS1 reveals a higher secondary hardness maximum and better tempering resistance than H11 or H13 (Figure 6).

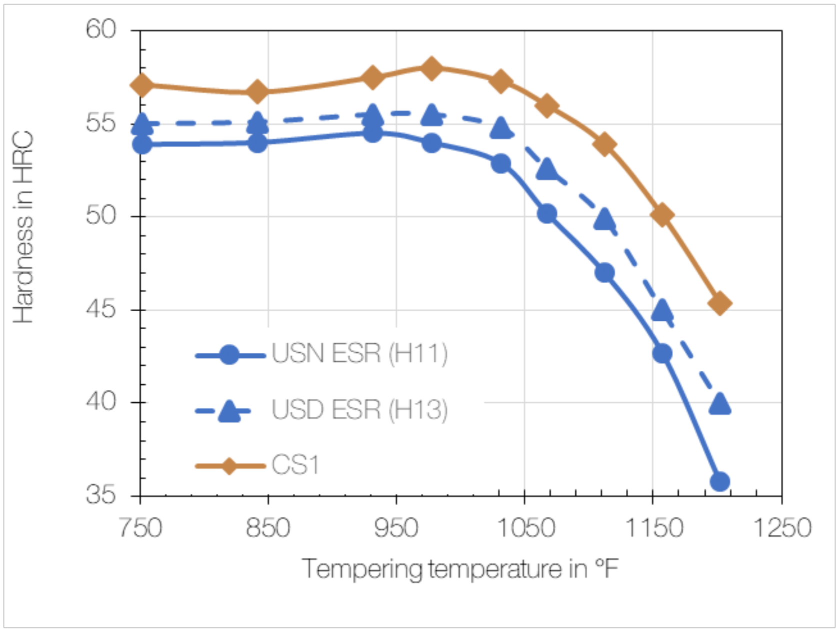

Figure 6 – Tempering behavior of CS1 in comparison to H11 and H13

The high-temperature strength of CS1 exceeds H11 and H13 clearly. Increasing hardness leads to an even higher high-temperature strength (Figure 7). Marked in gray is again the temperature range to which the surface of the cavity is exposed with each shot.

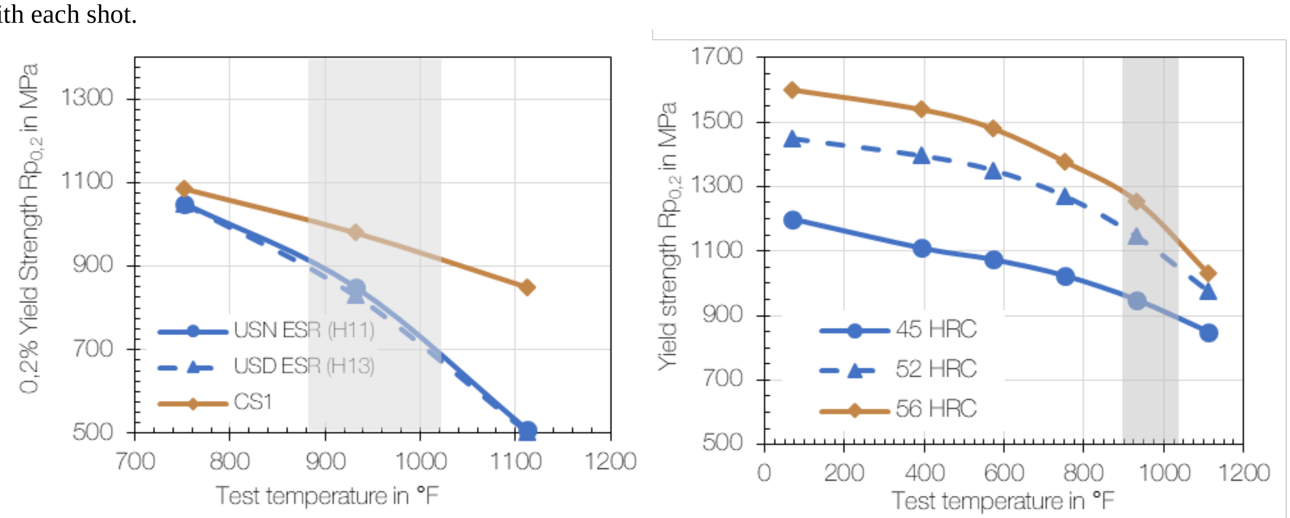

Figure 7 – High-temperature strength of CS1 in comparison to H11 and H13
Left: All samples hardened + tempered to 45 HRC
Right: Influence of the hardness on high-temperature strength of CS1

Despite the potential for unusually high working hardness CS1 provides an outstanding toughness so that even at a hardness of 56 HRC CS1 exceeds the NADCA requirement for H13 at 45 HRC (Figure 8).

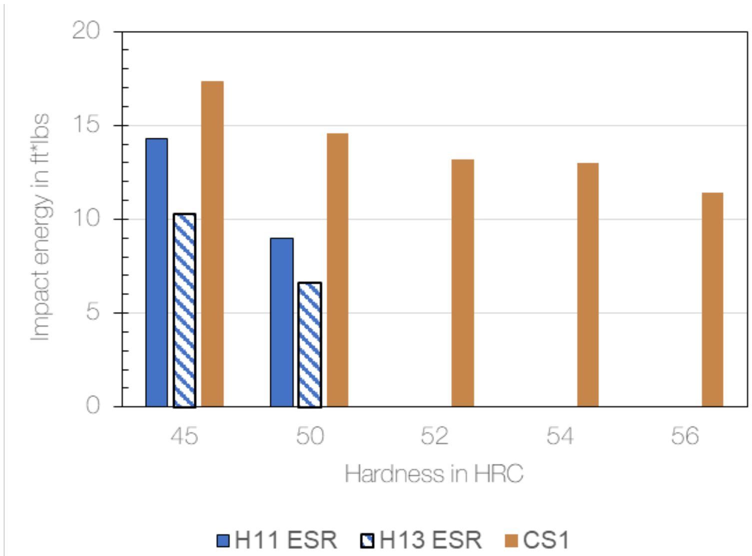

Figure 8 – Impact toughness of CS1 at different hardness levels
Values of H11 ESR and H13 ESR from NADCA #207-2018[5]

The combination of high hardness, high-temperature strength, and drastically increased toughness results in an excellent thermal shock resistance and great improvement of the die performance.

The results of the following case studies demonstrate the positive effects of the use of CS1 on the die performance as well as maintenance costs.

The first case study ever done with CS1 was made in a German die casting company producing motorcycle brake lever holders as shown exemplarily in Figure 9. The products are characterized by painted or chromium plated surfaces so that smallest surface defects on the die would appear on the product. The caster tried dies of H11 ESR as well as of many other premium grades but could not reach more than 3.500 shots per die. The success of the first trial with dies of CS1 and a hardness of 53 HRC - 13.500 shots – motivated the caster to increase the hardness up to 56 HRC. The result of 24.000 shots demonstrates an increase of die performance of approx. 600 %.

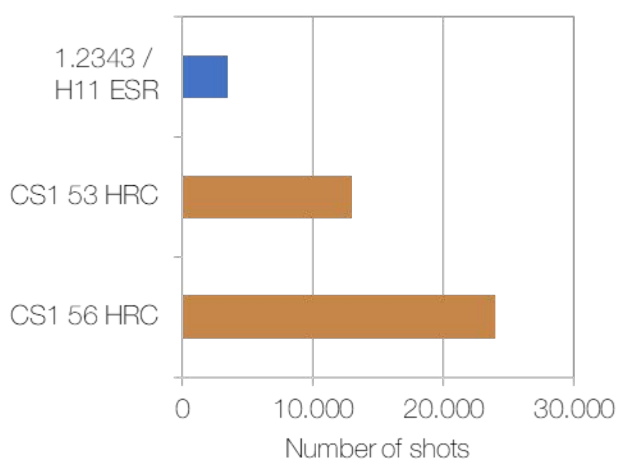

Figure 9 – Motorcycle brake lever holder and performance data of the dies

The second case study (Figure 10) represents a cast product with three challenging aspects. Cast covers of automotive electronic storage units need to have very smooth surfaces inside so that the installed electronic equipment is protected against abrasive influences. Sealing areas need to be cast with highest precision so that traces of thermal shock cracks must

be avoided in these sections. The third challenge are the cooling ribs on the outer surface of the cases. In all three aspects thermal shock cracks reduce the quality of the cast product and cause expensive reworking of die and product.
Due to high surface requirements die inserts made of H11 had to be taken out of service after only 5.000 shots. Dies of CS1 with a hardness of 53 HRC achieved a lifetime of nearly 10.000 shots.

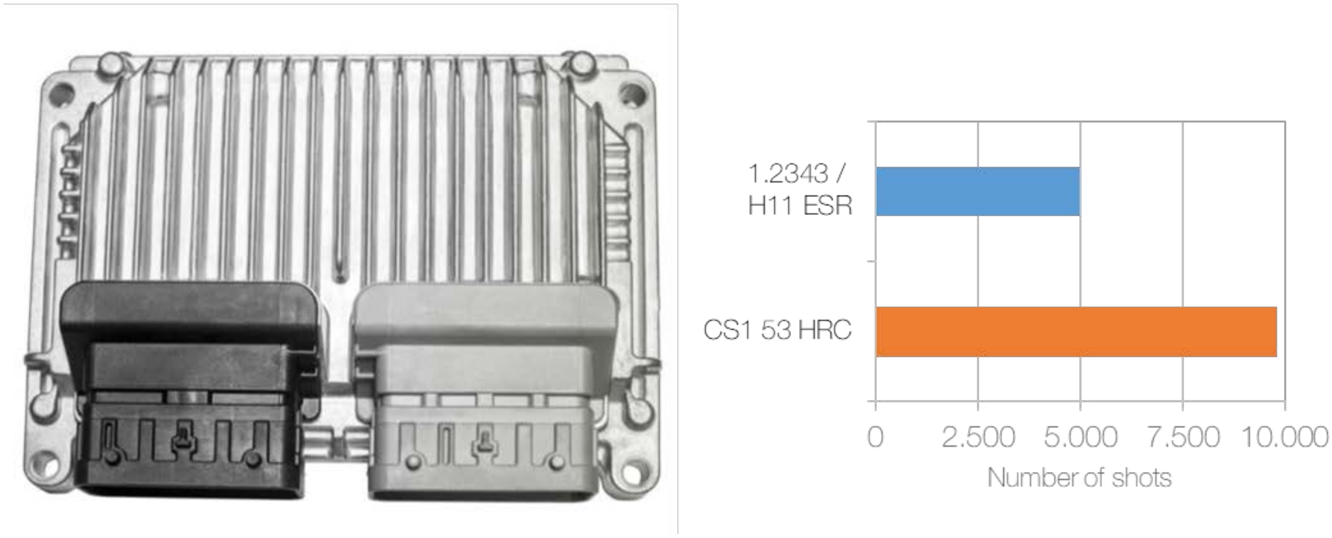

Figure 10 – Cast cover for an automotive electronic storage unit and performance data of the die

Cooling ribs or stiffener ribs on the cast product are a general challenge for dies. The corresponding deep grooves within the dies are locations of stress accumulations during die casting and thin, deep grooves are highly sensitive to thermal shock cracks. Thermal shock cracks on the ground of the grooves impede the demolding process. Aluminum infiltrates the serrated thermal shock cracks so that after solidification a higher force is required for demolding resulting in deformation of the casting. It has been reported that even ribs broke off during the demolding process causing expensive and time consuming repair work on the dies. A smooth die surface due to a die steel with excellent thermal shock resistance can reduce this risk.

The positive results gained in these application trials have led to considerations to use CS1 for dies of shock towers if the cavity is not too deep. Shock towers (Figure 11) unite several challenges. On the one hand the shape of their cavities requires a high toughness level of the steel. Stiffeners which stabilize the cast product require deep grooves and also a high toughness level of the steel. On the other hand shock towers have mounting and visible surface which require highest surface quality for technical and aesthetic reasons.

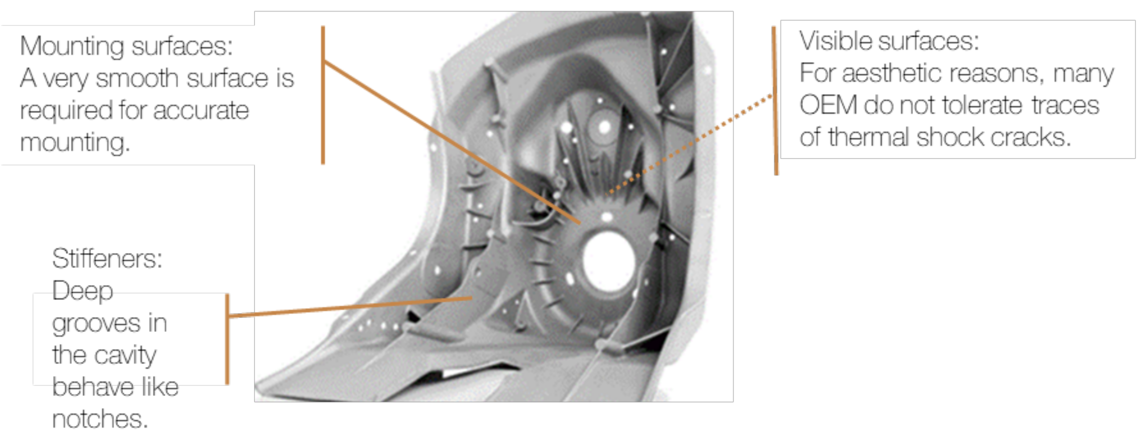

Figure 11 – Die cast shock tower and surface requirements

The results of further trials are listed in Table 4.

Table 4 – Results of application trials with dies of CS1

Application	Request	Dimension in in.	Hardness CS1 in HRC	Comparison steel	Hardness in HRC	Result
Al housing (electronics)	Very high surface quality, no traces of cracks	13.8 x 15.7 x 4.8	49 ± 1	H11 ESR mod.	47 ± 1	Wear reduced by 30 % after 90.000 shots
Center console German sports car	Very high surface quality, visible part	4.9 x 4.1 x 31.9	49 ± 1	H11 ESR	n.a.	130.000 shots, more than expected
Carrier for rear spoiler German sports car	Very high surface quality, painted component	5.5 x 19.3 x 40	49 ± 1	H11 ESR	n.a.	Customer satisfied after 60.000 shots, starts further applications
Engine block for German motor cycle	Very high surface quality, visible part	13.6 x 13.6 x 4.3	48 – 50	H11 ESR	n.a.	Trial successfully launched. Earlier dies to be scrapped after 20.000 shots
Gas pedal tractor	High surface requirements	15.2 x 14.0 x 4.3	52 - 54	H13 ESR mod.	n.a.	After 30.000 shots clear advantages visible for CS1
Engine cover tractor	Tight manufacturing tolerances	13.8 x 14.2 x 4.1	51 – 53	H13 ESR mod.	48 ± 1	Very good results. CS1 has replaced H13 ESR mod.

CONCLUSION

The international die casting industry currently faces great technological challenges to which die designers, die makers, die casters, and tool steel suppliers have to adjust if they want to ensure an efficient die casting production.

Driven by political decisions, economic and ecological necessities die cast structural components play an important role in automotive lightweight construction. The variety of die cast structural components has increased, their size and complexity have grown enormously in the last years. With the production of cast underbody structures TESLA has entered a new magnitude of die cast components. This trend towards larger and more complex dies requires hot-work tool steels with significantly higher toughness and thermal shock resistance than established grades like H11 or H13 can provide. For these purposes Kind&Co provides the premium grade TQ1 which offers excellent toughness and thermal shock resistance. TQ1 has proved its suitability for large die casting dies worldwide. TQ1 is listed in NADCA#207-2018.

Surface requirements of die cast components have been drastically intensified during the last years. Dies which can fulfill these requirements must be made of a hot-work tool steel with drastically improved thermal shock resistance. Kind&Co has developed the premium hot-work tool steel CS1 which, due to its composition, can be used with a work hardness of up to 56 HRC. Rising the hardness of a die goes along with a significant increase in high-temperature strength and thermal shock resistance. CS1 offers a toughness potential which at 56 HRC still exceeds the NADCA requirements for H13.

The use of dies of CS1 with adjusted hardness levels has repeatedly resulted in great improvements in surface quality and die performance. CS1 is expected to be listed in the next edition of the specification NADCA #207.

REFERENCES

1. Schruff, I., “Die Cast Structural Components – A Challenge for the Supplier of Hot-work Tool Steels,” *NADCA Transactions 2012, Paper 83*
2. Schruff, I., “Pressure die cast structural components for lightweight automotive construction”, Casting Plant & Technology, No. 2 (2015), pp 40-45
3. Anonym, “Decision No. 1753/2000/EC of the European Parliament and of the Council of 22 June 2000 establishing a scheme to monitor the average specific emissions of CO2 from new passenger cars”. www.europa.eu
4. Schruff, I., “The New Premium Grade CS1 – Solution for Die Casting Dies with Highest Surface Requirements”, *NADCA Transactions 2020, Paper 052*
5. North American Die Casting Association, “Special Quality Die Steel & Heat Treatment Acceptance Criteria for Die Casting Dies”, Publication No. 229, 2018