

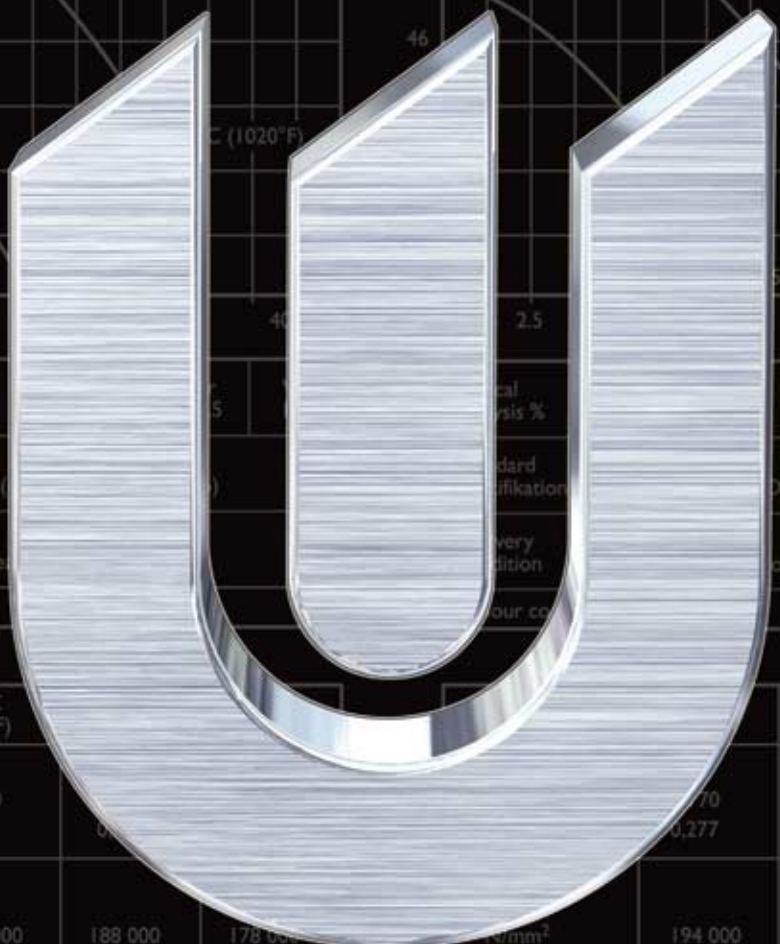
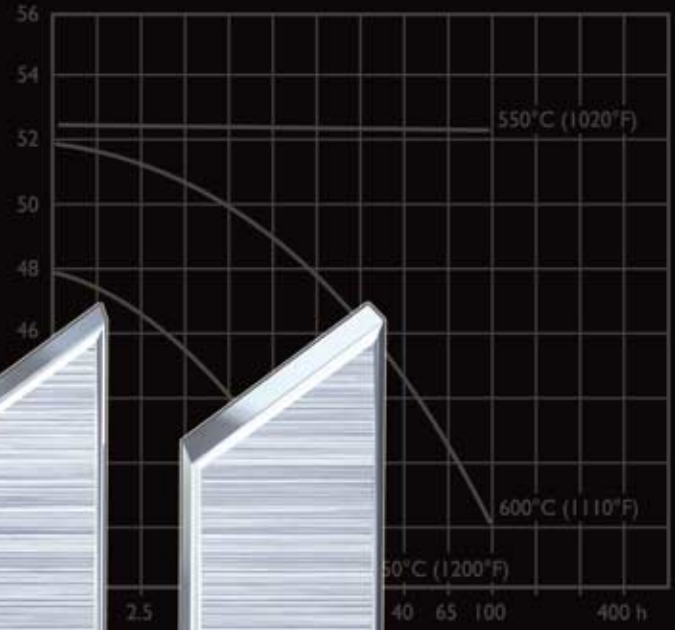
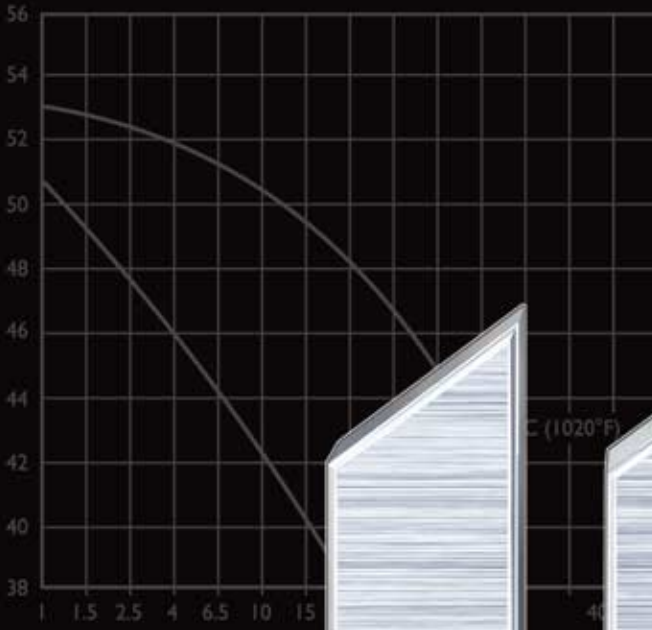
# Die steels and improved productivity in die casting

COLD WORK

PLASTIC MOULDING

HOT WORK

HIGH PERFORMANCE STEEL



Typical analysis %	C 2,05
Standard specification	AISI D6, ( )
Delivery condition	Soft anneal
Colour code	Red

Typical analysis %	Mn 0,8	Cr 4,5	W 0,2
Standard specification	D3) (W.Nr. 1.2796)		
Delivery condition	to approx. 200 HB		
Colour code	Your co		

Temperature	20°C (68°F)	200°C (390°F)	400°C (750°F)
Density kg/m <sup>3</sup> lbs/m <sup>3</sup>	7 770 0,281	7 670 0,277	7 650 0,275
Modulus of elasticity N/mm <sup>2</sup> psi	194 000 28,1 × 10 <sup>6</sup>	188 000 27,3 × 10 <sup>6</sup>	178 000 25,8 × 10 <sup>6</sup>
Coefficient of thermal expansion per °C from 20°C per °F from 68°F	to 100°C 11,7 × 10 <sup>-6</sup> to 212°F 6,5 × 10 <sup>-6</sup>	to 200°C 12 × 10 <sup>-6</sup> to 400°F 6,7 × 10 <sup>-6</sup>	to 400°C 13,0 × 10 <sup>-6</sup> to 750°F 7,3 × 10 <sup>-6</sup>
Thermal conductivity W/m °C Btu in (ft <sup>2</sup> h°F)	-	27 187	32 221
Specific heat K/kg °C Btu/lbs °F	455 0,109	525 0,126	608 0,145

Temperature	200°C (390°F)	400°C (750°F)
Density kg/m <sup>3</sup> lbs/m <sup>3</sup>	7 670 0,277	7 650 0,275
Modulus of elasticity N/mm <sup>2</sup> psi	194 000 28,1 × 10 <sup>6</sup>	189 000 27,4 × 10 <sup>6</sup>
Coefficient of thermal expansion per °C from 20°C per °F from 68°F	to 100°C 12,3 × 10 <sup>-6</sup> to 212°F 6,1 × 10 <sup>-6</sup>	to 200°C 14 × 10 <sup>-6</sup> to 400°F 6,7 × 10 <sup>-6</sup>
Thermal conductivity W/m °C Btu in (ft <sup>2</sup> h°F)	20,5 142	21,5 149
Specific heat K/kg °C Btu/lbs °F	460 0,110	- -

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# Contents

Introduction _____	3
Demands on the die cast product _____	3
Aspects of design _____	4
Die making _____	4
Dimensional stability _____	6
Die Performance _____	7
Demands on die steels for die casting _____	9
Die economy _____	13
Product programme _____	14
Steel and hardness recommendations _____	15

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This information is based on our present state of knowledge and is intended to provide general notes on our products and their uses. It should not therefore be construed as a warranty of specific properties of the products described or a warranty for fitness for a particular purpose.

## Introduction

Pressure die casting offers an economical way of producing large quantities of complex, high-tolerance parts in aluminium, magnesium, zinc and copper alloys.

The continued growth of the die casting process depends, to a large extent, on the greater use of die castings in the automotive industry, where weight reduction is increasingly important.

Long production runs have focused attention on the importance of obtaining improved die life. During the last years Uddeholm has occupied a leading role in developing die materials to meet this demand and that of higher die steel specifications. This has resulted in the grades *ORVAR SUPREME*, *VIDAR SUPREME*, *QRO 90 SUPREME* and now *DIEVAR*.

Die casters are now experiencing real savings in production and tooling costs by using these premium die steels with closely specified heat treatment procedures. Further improvements have been realized by paying close attention to good product and die design and improved die casting practices.

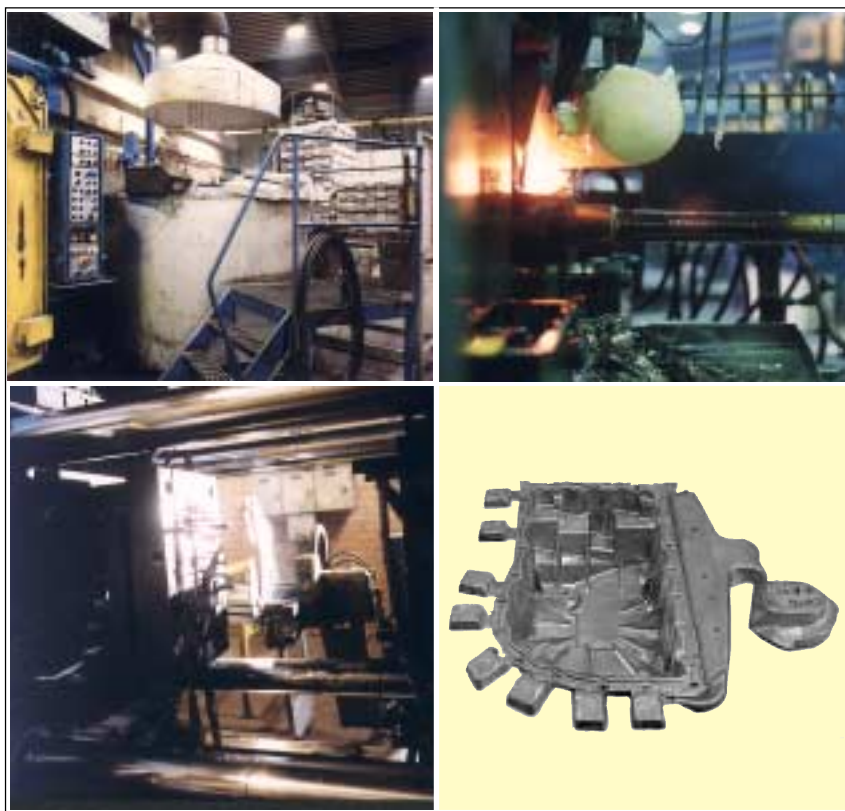
## Demands on the Die Cast Product

Increasing demands on die cast products will ensure continued development of die casting alloys with higher strength and ductility, improved machinability, weldability and corrosion resistance.

The trends in product design are going towards:

- **larger components**
- **thinner wall thicknesses**
- **more complicated shapes**
- **closer tolerances**

These factors favor the use of high pressure die casting over other casting methods like low pressure and gravity die casting.



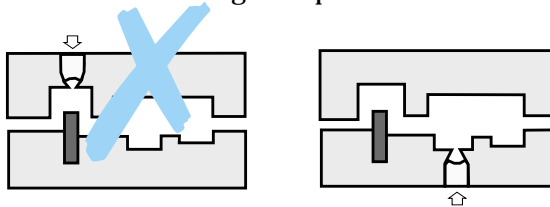
# Aspects of Die Design

The design of a die casting die is primarily determined by the shape of the finished component. But there are a number of aspects involved in the design and sizing of a die which can have an influence and important bearing on die life.

## CAVITY

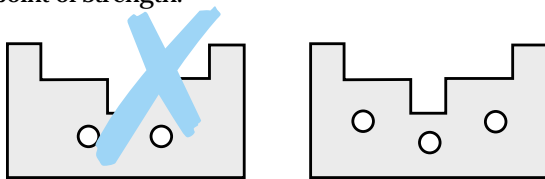
High-strength steels are extremely notch-sensitive. It is therefore important that the cavity is designed with smooth changes of sections and fillets of maximum possible radius.

In order to reduce the risk of erosion and heat checking on the die material near the gate, the cavity wall or any cores or inserts should be located as far from the gate as possible.



## COOLING CHANNELS

The location of the cooling channels should be such that the entire surface of the die cavity has as uniform a temperature as possible. Surface smoothness of the channels is important, both from the view point of cooling and from the view point of strength.



## RUNNERS, GATES AND OVERFLOWS

To get optimum casting conditions the cooling system must have a heat balance with “the hot part” (runners, gates, overflows and cavities). This means that the design of the runner, gate and overflow system is of great importance. In parts which are difficult to fill in the cavity, an overflow should be located to help casting metal to flow into this part. In multicavity dies with identical impressions it is important that all runners have the same path length and cross-sectional area and that the gates and overflows are identical.

The position of the gates and the thickness and width of the land is critical for the injection speed of metal. The gates should be designed so that the injected metal flows smoothly and freely

into all parts of the cavity. Casting metal that is sprayed instead of flowed into the cavity causes bad castings. Excessive turbulence of casting metal can cause erosion of the die.

## GUIDELINES FOR SIZING

The following are some guidelines for sizing a die for aluminium to meet strength requirements:

1. Distance from cavity to outer surface >50 mm (2 in)
2. Ratio of cavity depth to total thickness <1:3
3. Distance from cavity to cooling channel >25 mm (1 in)  
Distance from cavity to cooling channel at corner >50 mm (2 in)
4. Fillet radii
 

	Zinc	Aluminium	Brass
	>0,5 mm (0,02 in)	>1 mm (0,04 in)	>1,5 mm (0,06 in)
5. Distance from gate to cavity wall >50 mm (2 in).

# Die Making

When manufacturing a die casting die the following are of vital importance:

- **Machinability**
- **Electrical Discharge Machining**
- **Heat treatment**
- **Dimensional stability**
- **Surface treatment**
- **Weldability**

## MACHINABILITY

The machinability of martensitic hot work tool steels is mainly influenced by the amount of non-metallic inclusions like manganese sulfides and the hardness of the steel.

As the performance of a die casting die can be improved by lowering the impurities, i.e. sulphur and oxygen, *DIEVAR*, *ORVAR SUPREME*, *VIDAR SUPREME* and *QRO 90 SUPREME* are produced with an extremely low sulphur and oxygen level.

The optimum structure for machining is a uniform distribution of well spheroidized carbides in a soft annealed ferritic structure with as low a hardness as possible. The Microdizing process gives *DIEVAR*, *ORVAR SUPREME*, *VIDAR SUPREME* and *QRO 90 SUPREME* a homogeneous structure with a hardness of approx. 160 HB for *DIEVAR* and 180 HB for *ORVAR SUPREME*, *VIDAR SUPREME* and *QRO 90 SUPREME*. The steels are characterized by a very uniform machinability.

General machining data for turning, milling and drilling of *DIEVAR*, *ORVAR SUPREME*, *VIDAR SUPREME* and *QRO 90 SUPREME* can be found in the product information brochures.

### ELECTRICAL DISCHARGE MACHINING

The use of Electrical Discharge Machining (EDM) in the production of die casting dies has been firmly established in recent years.

Development of the process has produced significant refinements in operating technique, productivity and accuracy, while increasing the versatility of the process. EDM continues to grow, therefore, as a major production tool in most die making companies, machining with equal ease hardened or annealed steels.

The basic principles of EDM (spark erosion) are electrical discharges between a graphite or copper anode and the steel, the cathode, in a dielectric medium. During the process the surface of the steel is subjected to very high temperatures, causing the steel to melt or vaporize. A melted and brittle resolidified layer is caused at the surface and beneath that a rehardened and tempered layer.

The influence of the EDM operation on the surface properties of the die steel can in unfavorable circumstances destroy the working performance of the die. For this reason the following steps are recommended, as a precautionary measure:

#### EDM of hardened and tempered material

- A Conventional machining
- B Hardening and tempering
- C Initial EDM, avoiding "arcing" and excessive stock removal rates. Finish with "finesparking", i.e. low current, high frequency
- D
  - (i) Grind or polish EDM surface
  - (ii) Temper the tool at 15–25°C (30–50°F) lower than the highest previous tempering temperature.

#### EDM of annealed material

- A Conventional machining
- B Initial EDM, as C above
- C Grind or polish EDM surface. This reduces the risk of crack formation during heating and quenching. Slow preheating, in stages, to the hardening temperature is recommended.

More information about electrical discharge machining can be found in the brochure "EDM of Tool Steels".

### HEAT TREATMENT

Hot work tool steels are normally delivered in the soft annealed condition. After machining, the die must be heat treated in order to give optimum hot yield strength, temper resistance, toughness and ductility.

The properties of the steel are controlled by the hardening temperature and time, the cooling rate and the tempering temperature.

A high austenitizing temperature for a die has a positive influence on the hot yield strength and the resistance to softening, which reduce the heat checking tendency. In *ORVAR SUPREME* and *QRO 90 SUPREME* these properties can be enhanced by austenitizing at 1050°C (1920°F) instead of 1020°C (1870°F). For *DIEVAR 1030°C* (1885°F) instead of 1000°C (1830°F) and for *VIDAR SUPREME 1010°C* (1850°F) instead of 990°C (1815°F).

On the other hand, a high austenitizing temperature gives an increased risk of grain growth, which can cause a reduction in toughness and ductility. Hence the higher austenitizing temperature should only be used for small dies, cores and core pins.

Similarly, a higher hardness has a positive effect on heat checking, although a hardness exceeding 50 HRC is not recommended for aluminium die casting and similarly not exceeding 46 HRC for brass. The risk of cracking and total failure increases with higher hardness.

However, by developing the higher toughness in *DIEVAR* and *ORVAR SUPREME* and *VIDAR SUPREME* the risk of failure is considerably reduced.

The quenching rate during hardening has a great significance for *DIEVAR*, *ORVAR SUPREME*, *VIDAR SUPREME* and *QRO 90 SUPREME* and for all other steels of similar type.

A low quenching rate gives the best possible dimensional stability, but the risk for undesirable changes in the microstructure of the steel increases.

A too low cooling rate during hardening can reduce the fracture toughness of the steel.

A high quenching rate, for example, when using a vacuum furnace with 5 bar pressure or higher, gives the best possible structure and consequently the best die-life.

The right balance must be found between the lower rectification costs resulting from a low quenching rate and the better die-life achieved by using a high cooling rate. In most cases a high quenching rate is to be preferred where the total economy of the die is the major consideration.

Decarburization and heavy carburization may cause premature heat checking and shall be avoided at all times.

The die should be tempered after cooling to 50–70°C (120–160°F). A second tempering operation is essential to obtain a satisfactory structure. The tempering temperature should be selected to obtain the desired hardness of the die. A third temper is recommended for added safety.

# Dimensional Stability

## DISTORTION DURING THE HARDENING AND TEMPERING OF DIE CASTING DIES

When a die casting die is hardened and tempered, some warpage or distortion normally occurs. This distortion is usually greater when using higher austenitizing temperatures.

This is well known, and it is normal practice to leave some machining allowance on the die prior to hardening. This makes it possible to adjust the die to the correct dimensions after hardening and tempering by grinding, EDM'ing etc.

Distortion takes place because of stresses in the material. These stresses can be divided into:

- **machining stresses**
- **thermal stresses**
- **transformation stresses**

### Machining stresses

This type of stress is generated during machining operations such as turning, milling and grinding.

If stresses have built up in a part, they will be released during heating. Heating reduces strength, releasing stresses through local distortion. This can lead to overall distortion.

In order to reduce distortion while heating during the hardening process, a stress relieving operation can be carried out. It is recommended that the material be stress-relieved after rough machining. Any distortion can then be adjusted during fine machining, prior to the hardening operation.

### Thermal stresses

These stresses are created when the die is heated. They increase if heating takes place rapidly or unevenly. The volume of the die is increased by heating. Uneven heating can result in local variations in volume growth, leading to stresses and distortion.

Preheating in stages is always recommended in order to equalize the temperature in the component.

An attempt should always be made to heat slowly enough so that the temperature remains virtually equal throughout the die.

What has been said regarding heating also applies to quenching. Very powerful stresses arise during quenching. As a general rule, the cooling rates should be as fast as possible, relative to the acceptable distortion level.

It is important that the quenching medium is applied as uniformly as possible. This is especially valid when forced air or protective gas atmosphere (as in vacuum furnaces) is used. Otherwise temperature differences in the tool can lead to signifi-

cant distortion. Step quenching is recommended for larger, more complex dies.

### Transformation stresses

This type of stress arises when the microstructure of the steel is transformed. This is because the three microstructures in question—ferrite, austenite and martensite—have different densities, i.e. volumes.

The greatest effect is caused by transformation from austenite to martensite. This causes a *volume increase*.

Excessively rapid and uneven quenching can also cause local martensite formation, causing volume increases locally in a die giving rise to stresses in some sections. These stresses can lead to distortion and, in some cases, cracks.

More information about dimensional changes when hardening and tempering of *DIEVAR*, *ORVAR SUPREME*, *VIDAR SUPREME* and *QRO 90 SUPREME* can be found in the product information brochures.

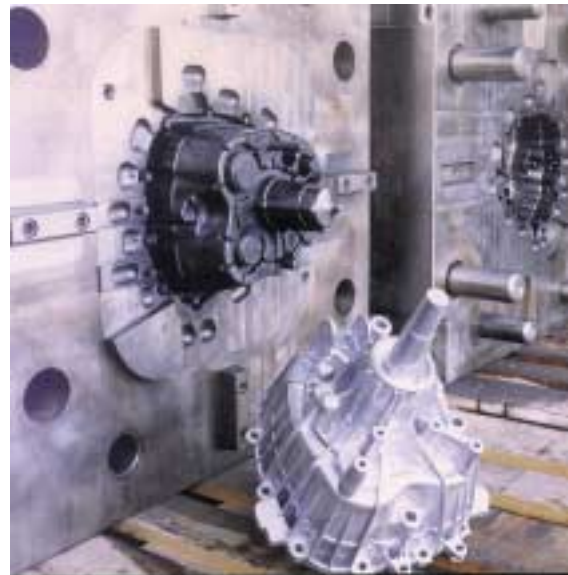
## SURFACE TREATMENT

Surface treatments like gas nitriding, salt bath or ion nitriding can have a beneficial effect on certain parts of a die casting die, such as shot sleeves, nozzles, runners, spreaders, gates, ejector pins and core pins. Different steels possess different nitriding properties, depending on chemical composition.

Other surface treatments, including the Solvinate, Metallife and Melonite processes have also proved beneficial in die casting applications.

## WELDABILITY

In many cases, it is important that a die casting die can be repaired by welding. The repair-welding of



Aluminium part for the automotive industry.

tool steel always entails a risk of cracking, but if care is taken and heating instructions are followed, good results can be obtained.

**Preparation before welding**

Parts to be welded must be adequately chamfered and free from dirt and grease to ensure satisfactory penetration and fusion.

**Welding of soft-annealed material**

- 1 Preheat to min. 325° C (620° F).
- 2 Start welding at this temperature. Never let the temperature of the tool go below 325° C (620° F). Max. interpass temperature 475° C (885° F). The best way to keep a constant temperature of the tool during welding, is to use an insulated box with thermostatically controlled electrical elements inside the walls.
- 3 After welding cool very slowly 10–20° C/h (20–40° F/h) for the first two hours and then freely in air.
- 4 Soft anneal immediately after welding.

**Welding of hardened and tempered material**

- 1 Preheat to min. 325° C (620° F).
- 2 Start welding at this temperature. Never let the temperature of the tool go below 325° C (620° F). Max. interpass temperature 475° C (885° F). The best way to keep a constant temperature of the tool during welding, is to use an insulated box with thermostatically controlled electrical elements inside the walls.
- 3 After welding cool very slowly 10–20° C/h (20–40° F/h) for the first two hours and then freely in air.
- 4 Stress temper 25° C (50° F) below the highest previous tempering temperature for two (2) hours.

**Consumables**

QRO 90 WELD (SMAW) or QRO 90 TIG-WELD. More information about welding and consumables can be found in the brochure “Welding of Tool Steel”.

**Die Performance**

The life of a die casting die varies considerably depending on the size and design of the casting, the type of casting alloy, and the care and maintenance of the die.

The life of a die can be prolonged by suitable treatment before and during casting by:

- **suitable preheating**
- **correct cooling**
- **surface treatment**
- **stress tempering**

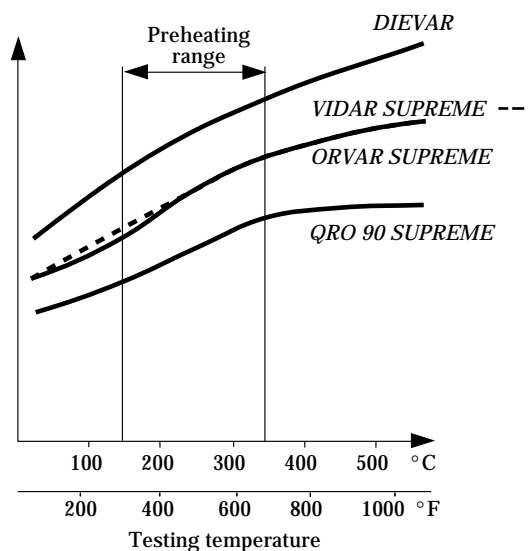
**SUITABLE PREHEATING**

The initial contact between a cold die casting die and the hot casting metal causes a severe shock to the die material. Heat checking can start at the very first shot and quickly lead to total failure. Further, it is important to note that the impact strength, i.e. the materials ability to withstand thermal and mechanical shock, is increased significantly during the first shots by proper preheating of the tool.

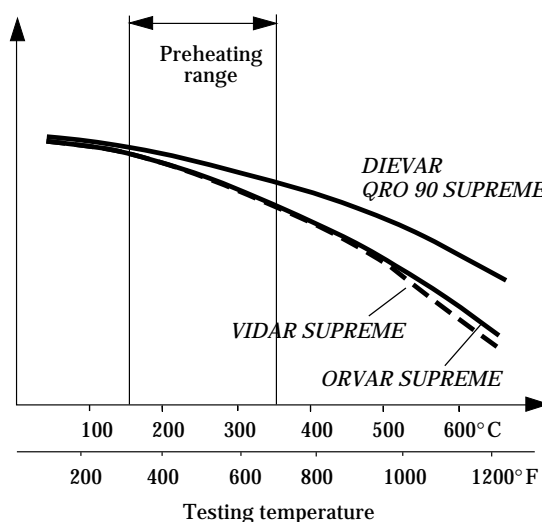
It is essential, therefore that the temperature difference between the die surface and the molten metal is not too great. For this reason, *preheating is always recommended.*

The most suitable preheating temperature is dependent on the type of casting alloy, but normally lies between 150 and 350° C (300 and 660° F).

Impact strength



Hot yield strength



The curves show the range within which the material can be preheated. It is important not to preheat to an excessively high temperature, since the die may become too hot during die casting, causing a tempering back of the die material. Observe that thin ribs get hot very quickly.

The following preheating temperatures are recommended:

Material	Preheating temperature
Tin, Lead alloys	100–150° C (210–300° F)
Zinc alloys	150–200° C (300–390° F)
Magnesium, Aluminium alloys	180–300° C (355–570° F)
Copper alloys	300–350° C (570–660° F)

It is important that heating is gradual and even. Thermostatically controlled heating systems are recommended.

When preheating, coolant should be gradually applied in order to obtain a state of equilibrium. Shock cooling should be avoided.

Dies containing inserts must be heated at a slow rate so the inserts and holders can gradually expand together.

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### CORRECT COOLING

The temperature of the die is controlled via cooling channels and by the lubricant on the die surface.

In order to reduce the risk of heat checking, the cooling water can be preheated to approximately 50° C (120° F). Thermostatically controlled cooling systems are also common. Cooling water colder than 20° C (70° F) is not recommended. During breaks longer than a few minutes, the flow of coolant should be adjusted so that the tool does not cool down too much.

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### SURFACE TREATMENT

To avoid metal-to-die contact it is important that the lubricant (parting compound) adheres well to the die surface. For example, a new or recently

repaired die should not have a glossy metal surface. It is therefore a good idea to coat the die surface with a thin oxide film to provide good adhesion for the lubricant in the running-in period.

The surface of the die can be oxidized by heating to approx. 500° C (930° F) for one hour followed by cooling in air. Heating in a steam atmosphere— 500° C (930° F)—for 30 minutes also produces a good oxide film, with suitable thickness.

To remove built-up deposits of die lubricants after a period of use, shot peening of the cavity surface is recommended. This treatment also closes some of the heat checking cracks.

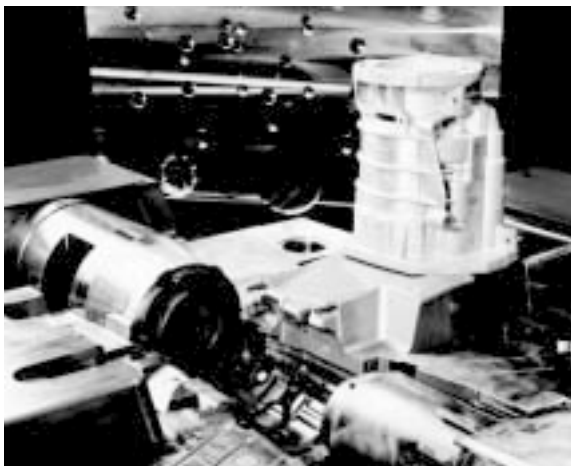
It induces compressive stresses in the surface layer, which compensate for some of the tensile stresses which cause heat checking. Parts which are subjected to abrasion and friction, such as ejector pins and shot sleeves, may be nitrided or nitrocarburized for longer life.

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### STRESS TEMPERING

During die casting, the surface of the tool is subjected to thermal strains derived from the variations in temperature; this repeated straining may result in residual stresses being generated in the surface regions of the die. In most cases, such residual stresses will be tensile in nature and thereby assist initiation of heat checking cracks. Stress tempering the die will reduce the level of residual tensile stress and thereby enhance die life. We recommend, therefore, that stress tempering be performed after the running-in period and then after 1000–2000 and 5000–10 000 shots. The procedure is then repeated for each additional 10 000–20 000 shots, so long as the die exhibits only minor amounts of heat checking. However, there is little point in stress tempering a heat checked die because the formation of surface cracks in itself reduces the level of residual stress.

Stress tempering is best carried out at a temperature about 25° C (50° F) below the highest tempering temperature which has previously been used during heat treatment of the die. Normally, two hours holding time at temperature should be sufficient.





# Demands on Die Steels for Die Casting

Die casting dies are exposed to severe thermal and mechanical cyclic loading, which puts high demands on the die material. There are thus a number of phenomena which restrict die life. The most important are:

- **thermal fatigue** (heat checking)
- **corrosion/erosion**
- **cracking** (total failure)
- **indentation**

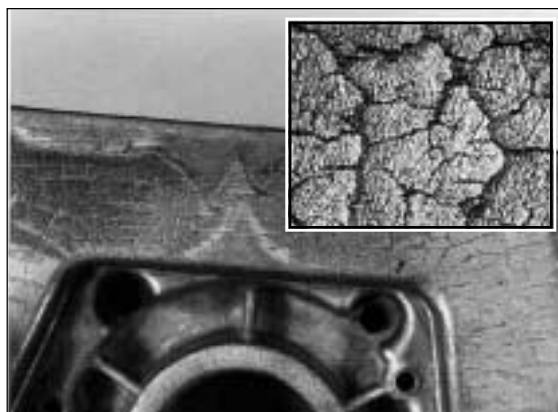
The number of shots achievable in a die casting die is strongly influenced by the working temperature, i.e. the casting alloy. The die life for a specific alloy can also vary considerably due to the design of the cast product, the surface finish, the production rate, the process control, the design of the die, the die material, and its heat treatment and the acceptance level of size and surface finish variations.

Casting alloy	Casting temperature		Factors which limit die life	Normal life, number of shots	
	°F	°C		Die	Core
Zinc	~800	~430	Erosion	0.5-2 million	0.5-2 million
Mag-nesium	~1200	~650	Heat checking Cracking Erosion Indentation	100,000 to 400,000	50,000 to 200,000
Alumi-num	~1300	~700	Heat checking Cracking Erosion Indentation	60,000 to 200,000	40,000 to 150,000
Copper/ Brass	~1780	~970	Heat checking Indentation Erosion Cracking	5,000 to 50,000	1,000 to 5,000

## THERMAL FATIGUE

Thermal fatigue is a gradual cracking due to thermal stresses from many temperature cycles and is a microscale phenomenon taking place only in a thin surface layer.

In use die casting dies are subjected to alternate heating and cooling. This gives rise to severe strains in the surface layer of the die, gradually leading to thermal fatigue cracks. Typical thermal fatigue damage is a pattern of surface cracks known as “heat checking”, well-illustrated in the following photograph.



During the last 15 years much attention has been paid to understanding the thermal fatigue process and to relate the resistance to heat checking to basic material properties. For this purpose Uddeholm has built a special device for simulation of the thermal fatigue damage. The aim of these efforts is to improve and develop the die material and has resulted in the premium steel grades *DIEVAR*, *ORVAR SUPREME*, *VIDAR SUPREME* and *QRO 90 SUPREME*.

### Factors which influence thermal fatigue

Thermal fatigue cracks are caused by a combination of thermal cyclic stress, tensile stress and plastic strain. If any one of these factors are not present, a thermal fatigue crack will neither initiate nor propagate. The plastic strain starts the crack and the tensile stress promotes the crack growth.

The following factors influence the thermal fatigue:

- **Die temperature cycle**
  - Preheating temperature
  - Surface temperature of the die
  - Holding time at peak temperature
  - Cooling rate
- **Basic die material properties**
  - Thermal expansion coefficient
  - Thermal conductivity
  - Hot yield strength
  - Temper resistance
  - Creep strength
  - Ductility
- **Stress raisers**
  - Fillets, holes and corners
  - Surface roughness

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### DIE TEMPERATURE CYCLE

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#### Preheating temperature

It is essential that the temperature difference between the die surface and the molten metal is not too great. For this reason preheating is always recommended.

The preheating temperature should be minimum 180°C (355°F) for Aluminium at which temperature the fracture toughness is almost twice as high as at room temperature.

#### Surface temperature of the die

The temperature of the surface layer of the die is very important for the occurrence of thermal fatigue. Up to 600°C (1110°F) the thermal expansion and the stresses are moderate for a normal hot work steel but at higher temperatures the risk of heat checking becomes significant. The surface temperature of the die is mainly determined by the preheating temperature, the casting temperature of the metal, the design of the cast product, the die shape and size and the thermal properties of the die material.

#### Holding time at peak temperature

Longer holding time implies an increased risk of overtempering and creep of the die material. This means a reduction of the mechanical strength and accordingly a lower resistance to mechanical and/or thermal loadings.

#### Cooling rate

The rate at which the surface layer cools is of considerable importance. More rapid cooling gives rise to greater stresses and leads to cracks at an earlier stage. The choice of coolant is normally a compromise between desired die life and production rate but most die casters have switched from oil-based lubricants to water-based ones for environmental reasons.

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### BASIC DIE MATERIAL PROPERTIES

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#### Thermal expansion coefficient

The thermal expansion coefficient ought to be low to get low thermal stresses.

#### Thermal conductivity

A high thermal conductivity reduces the thermal gradients and thereby the thermal stresses. It is, however, very difficult to predict or to investigate experimentally to what extent the thermal conductivity influences this matter.

#### Hot yield strength

A high hot yield strength lowers the plastic strain and is beneficial in resisting heat checking.

#### Temper resistance

If a die material with initially high hot yield strength becomes softer during use due to high temperature exposure it means that the heat checking damage accelerates. It is therefore important that the die material has a good resistance to softening at high temperature exposure.

#### Creep strength

The softening associated with temper resistance is clearly accelerated by mechanical load. The die material is exposed both to high temperature and mechanical load. It is thus obvious that a good die material will possess resistance to the joint action of high temperature and mechanical load as quantified by a high creep strength. In fact, it has been proven by experiment that heat checking cracks also can be produced by constant temperature and cyclic mechanical load.

#### Ductility

The ductility of the die material quantifies the ability to resist plastic strain without cracking. At the initiation stage of the thermal fatigue damage the ductility governs the number of cycles before visible cracks appear for a given hot yield strength and temperature cycle. At the crack growth stage the ductility has a declining influence.

The ductility of the material is greatly influenced by slag inclusions and segregations, i.e. the purity and the homogeneity of the steel. The steels from Uddeholm for die casting dies are therefore processed in a special way. The ductility of the steel has been considerably improved by means of a special melting and refining technique, a controlled forging process and a special microstructure treatment. This improvement is especially pronounced in the center of thick blocks.

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### STRESS RAISERS

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#### Fillets, holes and corners

Geometrical stress concentration and increased thermal gradients increase the stresses and strains at fillets, holes and corners. This means that heat checking cracks start earlier in these areas than on plane surfaces. The joint action of heat checking cracks and fillets increases the risk of total failure of the die.

#### Surface roughness

Surface defects such as grinding scratches affect the starting of cracks for the same reasons as fillets, holes and corners. Within the recommended

grinding range of 220–600 grit, surface roughness should not be a cause of heat checking. One advantage with a not too highly polished surface, for example sand blasted or oxidized, is that the parting lubricant adheres better and is distributed more evenly on the surface. Further, less soldering takes place and it gives better release of castings. This is especially important during the running-in of a new die.

**CORROSION/EROSION**

**Corrosion by molten casting metal**

During die casting, the molten metal is injected into the die. In cases where the cavity surface lacks a protective layer, the cast metal will diffuse into the die surface. At the same time, alloying elements within the die (especially iron), will diffuse from the die surface into the cast metal. These processes can create both dissolution of the steel and intermetallic compounds between the cast metal and the die surface. In cases where severe formation of intermetallic compounds occurs, the cast metal will solder to the die surface.

Uddeholm has investigated the corrosion tendency in different molten die casting metals.



Soldering damage on a core pin.

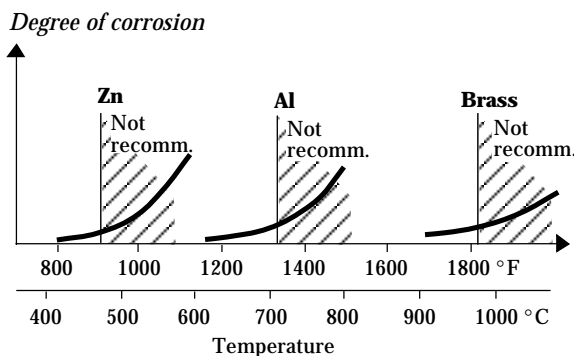
**Factors which influence corrosion**

A number of factors influence die corrosion:

- **Temperature of the casting metal**
- **Composition of the casting metal**
- **Design of the die**
- **Surface treatment**

**Temperature of the casting metal**

The die casting alloys have critical temperatures above which corrosion attacks increase. Zinc starts to react with steel at about 900° F (480° C) and aluminum at about 1330° F (720° C). Copper alloys do not seem to have any really critical temperature, but corrosion increases slowly with temperature.



**Composition of the casting metal**

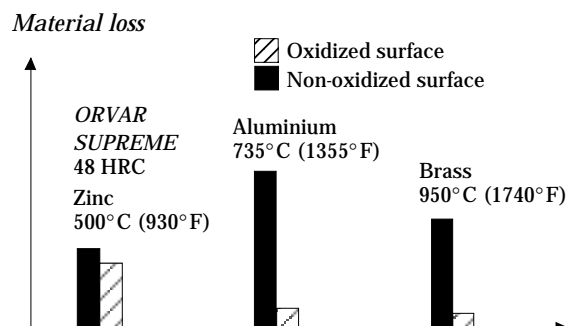
Pure metals attack tool material at a much greater rate than commercial alloys. This is valid both for zinc (Zn) and aluminium (Al). The corrosion of the die steel also increases when the aluminium melt contains a low iron content.

**Design of the die**

Die design is also of importance for corrosion. If molten metal is injected at too high a velocity, the lubricant on the surface of the cavity can be “washed” away. Too high a velocity is usually caused by incorrect gating design.

**Surface treatment**

The surface treatment of the die steel is of great importance. If metallic contact between the die steel and the molten metal can be avoided, the risk of corrosion is much less. An oxide film on the surface provides good protection. Nitrided or nitrocarburized surfaces as well as other coating methods also give a certain protection.



**Erosion by molten casting metal**

Erosion is a form of hot mechanical wear on the die surface, resulting mainly from the motion of the melt.

Erosion depends upon the velocity of the melt as it is injected into the die as well as its temperature and composition. Melt speeds in excess of 180 feet/s (55 m/s) substantially increase erosion damage.

A high temperature also affects the situation, as the surface of the die is more easily tempered back. Hard particles such as inclusions and/or precipitated hard silicon particles, in hypereutectic aluminium melts containing more than 12,7% silicon, further increase the risk of erosion damage.

Most commonly a combination of corrosion and erosion damages occur on the die surface. The type of damage that is predominant depends largely on the velocity of the molten metal into the die. At high velocities, it is normally the erosion damage which is predominant.

A good tempering back resistance and a high hot yield strength of the die material are important.



Erosion

**CRACKING (TOTAL FAILURE)**

The toughness of the die material is the ability to accumulate tensile stresses without cracking at sharp notches or other stress raisers. The toughness of a die is dependent on the die material and its heat treatment. Due to the fact that the mechanical and thermal stresses in a die are spread in all directions the toughness in the die has to be considered in all directions—longitudinal, transverse and short transverse.

*DIEVAR, ORVAR SUPREME, VIDAR SUPREME* and *QRO 90 SUPREME* are produced by a special processing technique which improves the isotropy of the mechanical properties.

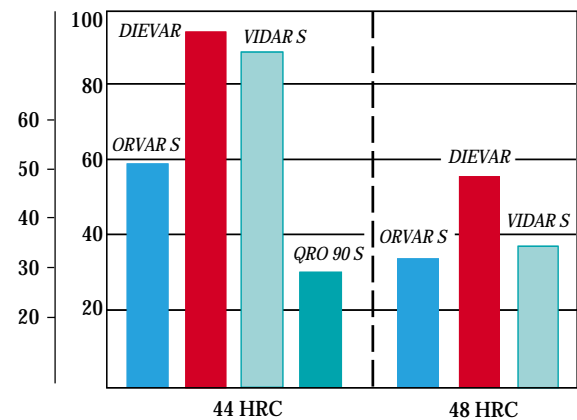
Thermal shock is total cracking due to occasional thermal overloading. It is a macroscale phenomenon and is one of the most frequent causes of total damage of the die.

**Fracture toughness of DIEVAR, ORVAR SUPREME, VIDAR SUPREME and QRO 90 SUPREME**

The ability of a material to resist stresses without unstable cracking at a sharp notch or crack is called *fracture toughness*.

The fracture toughness of *DIEVAR, ORVAR SUPREME, VIDAR SUPREME* and *QRO 90 SUPREME* at different hardnesses are shown in the following figure.

Fracture toughness,  $K_{IC}$   
ksi(in)<sup>1/2</sup>, MPa(m)<sup>1/2</sup>



Fracture toughness at room temperature (center, short-transverse direction).

**INDENTATION**

Indentation on the parting lines or sinking of the die is normally due to too low hot hardness.

At elevated temperatures, the strength of the steel and therefore its hardness will diminish. This means that the risk of indentation on a hot work die will increase with the operating temperature of the die. Both the locking pressure on the die halves and the metal injection pressure are so high that a certain high-temperature strength is required. This is especially important for die casting of aluminium (Al), magnesium (Mg) and copper (Cu) alloys.

## Die Economy

The drive for improved tooling economy has resulted in the development of “premium quality” die steels.

As the tooling cost is in the order of 10 per cent of the total cost of the finished aluminium die cast product, the validity of paying for premium die steel quality resulting in increased tool life is obvious.

The most decisive factors that govern tool life are the die material, its heat treatment and the die casting process control. The material in a die casting die accounts for 5–15 per cent of the die cost while the heat treatment cost is about 5–10 per cent. The picture below—The Cost Iceberg—shows the steel cost in relation to total tooling costs.

In order to assure a good steel quality a number of material specifications for die material have been developed during the last 20 years. Most of these contain requirements on chemical analysis, microcleanliness, microstructure, banding, grain size, hardness, mechanical properties and internal soundness (quality level).

One of the most advanced specifications for steel acceptance criteria and heat treatment at present is the Premium Quality H13 Steel Acceptance Criteria for Pressure Die Casting Dies # 207–97 released by the North American Die Casting Association (NADCA).

Further improvement of tooling economy must involve specifications on the heat treatment of the die. This should be optimized to avoid any excessive dimensional changes or distortion but to produce the optimal combination of hardness and toughness. The most critical factors are the hardening temperature and the cooling rate during quenching.

Precautions like proper preheating of the die as well as stress tempering will give a better die economy.

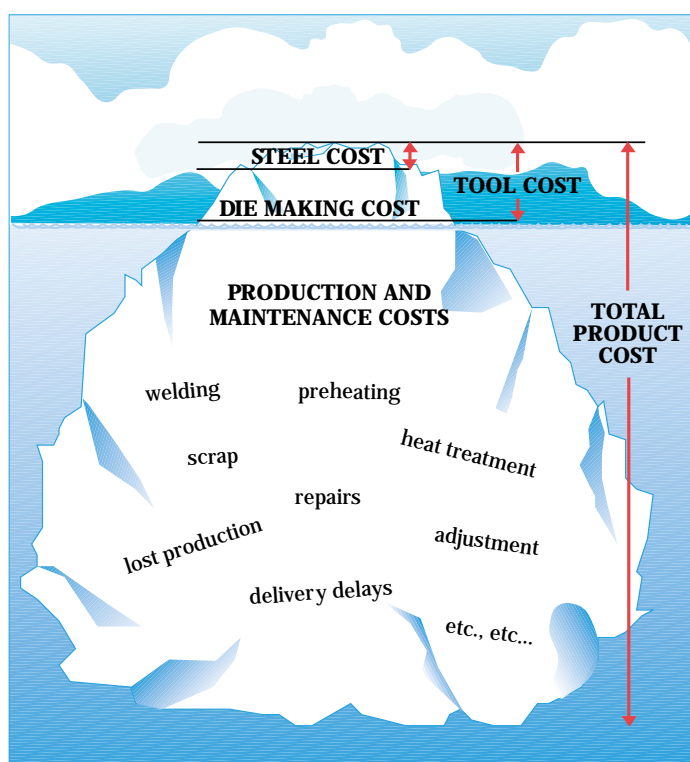
Surface treatments are methods to protect the die surface from corrosion/erosion and thermal fatigue.

New welding techniques have opened areas for maintenance and repair welding, both important ways to increase the die life.

Everyone involved in the chain—steel producer, die manufacturer, heat treater and die caster—knows that there can be large variations in quality level at every step of this process.

Optimum results can only be achieved by demanding and paying for premium quality all along the line.

“The Cost Iceberg”



# Product Programme

## General description

<i>DIEVAR</i>	A premium Cr-Mo-V-alloyed hot work die steel with good high temperature strength and excellent hardenability, toughness and ductility. Suitable for medium to big dies in aluminium die casting. It meets and exceeds the requirements of NADCA #207-97.
<i>ORVAR SUPREME</i>	A premium Cr-Mo-V-alloyed hot work die steel (H13) with good resistance to thermal fatigue. The steel is produced by a special melting and refining technique and meets and exceeds the requirements of NADCA # 207-97.
<i>VIDAR SUPREME</i>	A premium Cr-Mo-V alloyed hot work die steel (H11) with good resistance to cracking.
<i>QRO 90 SUPREME</i>	A premium hot work die steel with high hot yield strength and good temper resistance. Especially suited for die casting of copper, brass and for small inserts and cores in aluminium die casting.
<i>IMPAX SUPREME</i>	A prehardened Ni-Cr-Mo-steel supplied at 310 HB suitable for die casting of zinc, lead and tin. Also used as a holder material.
<i>HOLDAX</i>	A prehardened steel with very good machinability supplied at ~310 HB for clamping and holding plates.

## Analysis

Uddeholm grade	(W.-Nr.) AISI	Hardness HB	Analysis, %							Others
			C	Si	Mn	S	Cr	Mo	V	
<i>DIEVAR</i>	-	~160	Cr-Mo-V alloyed hot work tool steel							-
<i>ORVAR SUPREME</i>	(1.2344) Prem. H13	~180	0,39	1,0	0,4	max 0,0030	5,2	1,4	0,9	-
<i>VIDAR SUPREME</i>	(1.2343) Prem. H11	~180	0,38	1,0	0,4	max 0,0030	5,0	1,3	0,4	-
<i>QRO 90 SUPREME</i>	-	~180	0,38	0,3	0,8	max 0,0030	2,6	2,3	0,9	Microalloyed
<i>IMPAX SUPREME</i>	(1.2738) P20 mod.	~310	0,37	0,3	1,4	max 0,010	2,0	0,2	-	Ni 1,0
<i>HOLDAX</i>	(1.2312) 4140 mod.	~310	0,40	0,4	1,5	0,07	1,9	0,2	-	-

## Qualitative comparisons

Uddeholm grade	Temper resistance	Hot yield strength	Ductility	Toughness	Hardenability
<i>DIEVAR</i>					
<i>ORVAR SUPREME</i>					
<i>VIDAR SUPREME</i>					
<i>QRO 90 SUPREME</i>					

Qualitative comparison of critical die steel properties.

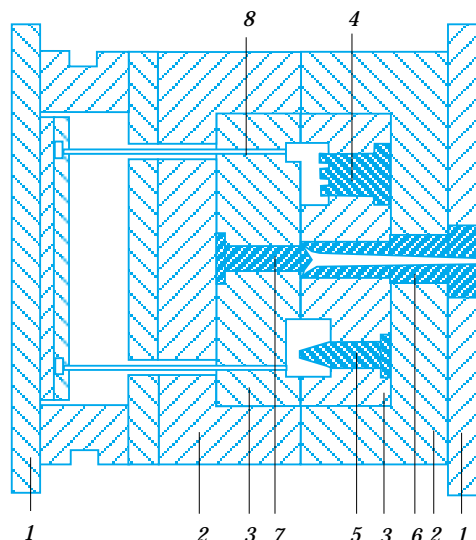
Uddeholm grade	Heat checking	Gross cracking	Erosion	Indentation
<i>DIEVAR</i>				
<i>ORVAR SUPREME</i>				
<i>VIDAR SUPREME</i>				
<i>QRO 90 SUPREME</i>				

Qualitative comparison of resistance to different die failures (the longer the bar, the better).

# Steel and Hardness Recommendations

Die Part	Tin/Lead/Zinc	Aluminium/Magnesium	Copper, Brass
<b>Clamping plates Holder plates</b>	<i>HOLDAX</i> (prehardened) ~310 HB <i>IMPAX SUPREME</i> (prehardened) ~310 HB	<i>HOLDAX</i> (prehardened) ~310 HB <i>IMPAX SUPREME</i> (prehardened) ~310 HB	<i>HOLDAX</i> (prehardened) ~310 HB <i>IMPAX SUPREME</i> (prehardened) ~310 HB
<b>Die inserts</b>	<i>IMPAX SUPREME</i> ~310 HB <i>ORVAR SUPREME</i> 46-52 HRC	<i>DIEVAR</i> 44-50 HRC <i>ORVAR SUPREME/</i> <i>VIDAR SUPREME</i> 42-48 HRC	<i>QRO 90 SUPREME</i> 40-46 HRC <i>ORVAR SUPREME</i> 40-46 HRC
<b>Fixed inserts Cores</b>	<i>ORVAR SUPREME</i> 46-52 HRC	<i>DIEVAR</i> 46-50 HRC <i>ORVAR SUPREME</i> 44-48 HRC <i>QRO 90 SUPREME</i> 42-48 HRC	<i>QRO 90 SUPREME</i> 40-46 HRC
<b>Core pins</b>	<i>ORVAR SUPREME</i> 46-52 HRC	<i>QRO 90 SUPREME*</i> 44-48 HRC <i>QRO 90 HT*</i>	<i>QRO 90 SUPREME</i> 42-46 HRC <i>QRO 90 HT</i>
<b>Sprue parts</b>	<i>ORVAR SUPREME</i> 48-52 HRC	<i>ORVAR SUPREME</i> 46-48 HRC <i>QRO 90 SUPREME</i> 44-46 HRC	<i>QRO 90 SUPREME</i> 42-46 HRC
<b>Nozzle</b>	<i>STAVAX ESR</i> 40-44 HRC <i>ORVAR SUPREME</i> 35-44 HRC	<i>ORVAR SUPREME</i> 42-48 HRC <i>QRO 90 SUPREME</i> 42-46 HRC	<i>QRO 90 SUPREME</i> 40-44 HRC <i>ORVAR SUPREME</i> 42-48 HRC
<b>Ejector pins</b>	<i>QRO 90 SUPREME/</i> <i>ORVAR SUPREME</i> 46-50 HRC (nitrided)	<i>QRO 90 SUPREME/</i> <i>ORVAR SUPREME</i> 46-50 HRC (nitrided)	<i>QRO 90 SUPREME/</i> <i>ORVAR SUPREME</i> 46-50 HRC (nitrided)
<b>Plunger Shot sleeve</b>	<i>ORVAR SUPREME</i> 42-46 HRC (nitrided)	<i>ORVAR SUPREME</i> 42-48 HRC (nitrided) <i>QRO 90 SUPREME</i> 42-48 HRC (nitrided)	<i>QRO 90 SUPREME</i> 42-46 HRC (nitrided) <i>ORVAR SUPREME</i> 42-46 HRC (nitrided)

\* Surface treatment is recommended.



- 1 Clamping plates
- 2 Holder plates
- 3 Die inserts
- 4 Fixed inserts
- 5 Cores
- 6 Sprue bushing (nozzles)
- 7 Sprue pin (Spreader)
- 8 Ejector pins