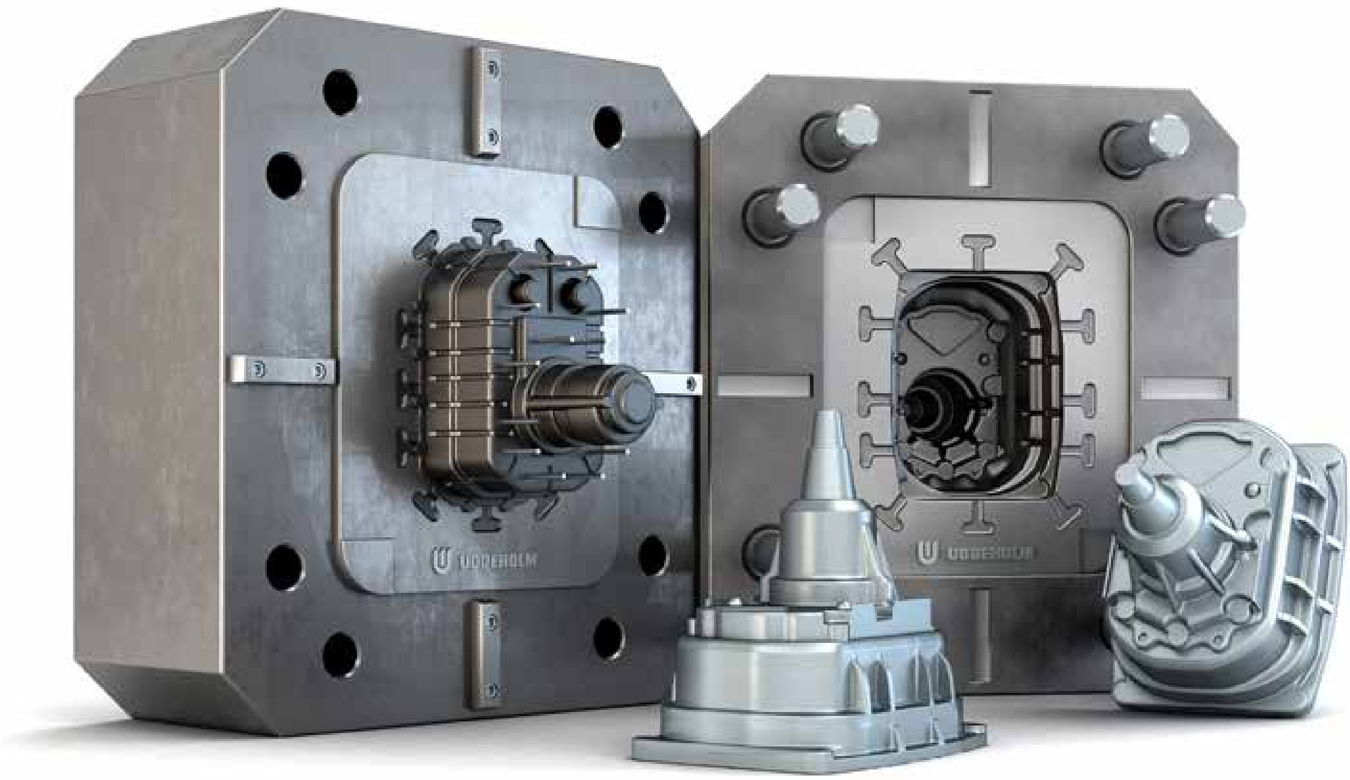
ASSAB TOOL STEEL FOR

DIE CASTING



ASSAB

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. Over the years , our steel mill in Sweden, Uddeholms AB, 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 ASSAB 8407 Supreme, Vidar 1 ESR, QRO 90 Supreme and Dievar.

Die casters are now experiencing real savings in production and tooling costs by using these premium die steel 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.

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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

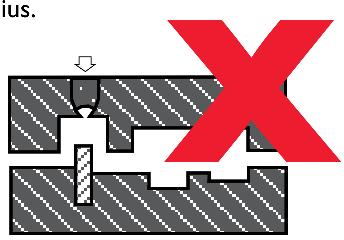
These factors favour the use of high pressure die casting over other casting methods like low pressure and gravity die casting.

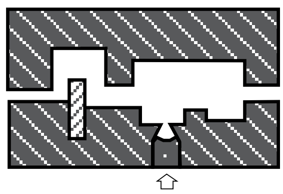
ASPECTS OF DIE DESIGN

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 steel 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.

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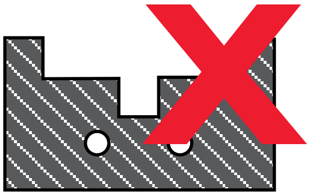
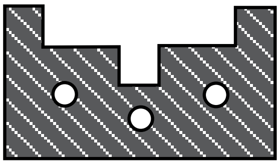
COOLING CHANNELS

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 but also for the resistance to corrosion.





RUNNERS, GATES AND OVERFLOWS

To get optimum casting conditions the cooling system must have a heat balance with "the hot parts" (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 (alternative vacuum assistant casting). 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.

Tool for high pressure aluminium die casting.

Aluminium pump housing fixed to the filling system, i.e. runners, gates and overflows.

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. Ratio of cavity depth to total thickness <1:3
3. Distance from cavity to cooling channel >25 mm
   Distance from cavity to cooling channel at corner >50 mm
4. Fillet radii
   Zinc >0.5 mm
   Aluminium >1 mm
   Brass >1.5 mm
5. Distance from gate to cavity wall >50 mm

DIE MAKING

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

- Machinability
- Electrical Discharge Machining (EDM)
- Heat treatment
- Dimensional stability
- Surface treatment
- Weldability

MACHINABILITY

The machinability of martensitic hot work tool steel is mainly influenced by the amount of non-metallic inclusions like manganese sulphides 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, ASSAB 8407 Supreme, ASSAB 8407 Superior, Vidar Superior 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 spheroidised carbides in a soft annealed ferritic structure with as low hardness as possible. The Microdising process gives Dievar, ASSAB 8407 Supreme, ASSAB 8407 Superior, Vidar Superior and QRO 90 Supreme a homogeneous structure with a hardness of approx. 160 HB for Dievar and 180 HB for ASSAB 8407 Supreme, ASSAB 8407 Superior, Vidar Superior and QRO 90 Supreme. The steel are characterised by a very uniform machinability.

General machining data for turning, milling and drilling of Dievar, ASSAB 8407 Supreme, ASSAB 8407 Superior, Vidar Superior 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 since many years.

Development of the process has produced significant refinements in operating technique, productivity and accuracy. As an alternative to EDM'ing high speed machining is growing.

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 re-solidified layer is formed on the surface and beneath that a re-hardened and tempered layer.

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

EDM OF ANNEALED MATERIAL

A Conventional machining.

B Initial EDM, avoiding "arcing" and excessive stock removal rates. Finish with "finesparking", i.e. low current, high frequency.

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.

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 lower than the highest previous tempering temperature.

HEAT TREATMENT

Hot work tool steel 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 he hardening temperature and soaking time, the cooling rate and the tempering temperature.

A high austenitising 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 ASSAB 8407 Supreme and QRO 90 Supreme these properties can be enhanced by austenitising at 1050°C instead of 1020°C. For Dievar 1030°C instead of 1000°C.

On the other hand, a high austenitising temperature gives an increased risk of grain growth, which can cause a reduction in toughness and ductility. Hence the higher austenitising temperature should only be used for small dies, cores and ore 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 ASSAB 8407 Supreme, the risk of failure is considerably reduced.

The quenching rate during hardening has a great significance for Dievar, ASSAB 847 Supreme and QRO 90 Supreme and for all other steel 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 will reduce the fracture toughness of the steel.

A high quenching rate gives the best possible structure and consequently the best die life.

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

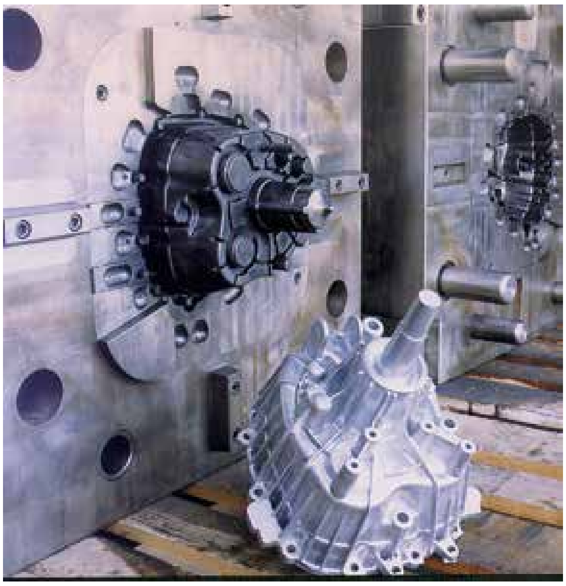
Decarburisation and heavy carburisation may cause premature heat checking and shall be avoided at all times.

The die should be tempered after cooling to 50–70°C.

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 generally recommended for die casting dies.

DIMENSIONAL STABILITY

DISTORTION DURING THE HARDENING AND TEMPERING OF DIE CASTING DIES



Aluminium part for the automotive industry.

When a die casting die is hardened and tempered, some warpage or distortion normally occurs. This distortion is usually greater when using higher austenitising 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 high speed machining, EDM'ing and grinding etc.

Cavity part for high pressure aluminium die casting.

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 or quenched. 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 significant distortion. Step quenching is recommended for larger, more complex dies.

TRANSFORMATION STRESSES

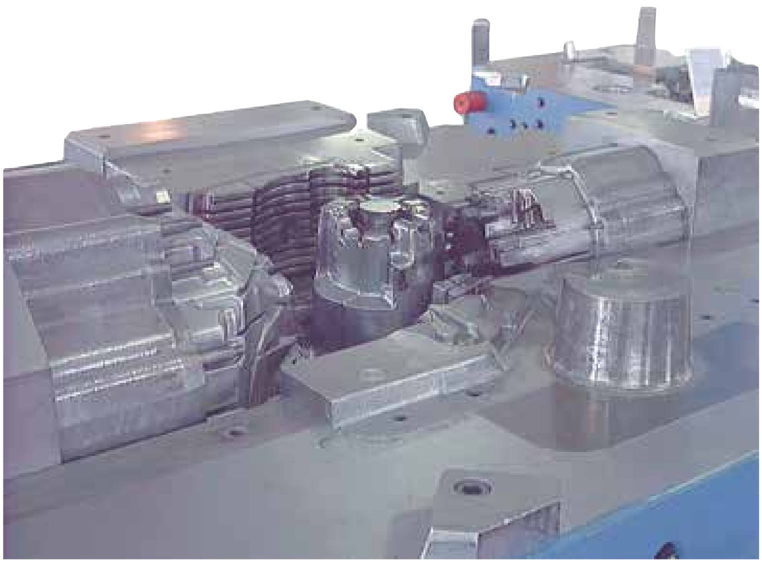
This type of stress arises when the microstructure of the steel is transformed. This is because the three microstructures in question—ferrite, austenite and martensite—have different densities, i.e. volumes.

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 a volume increase locally in a die giving rise to stresses in some sections. These stresses can lead to distortion and, in some cases, cracks.

SURFACE TREATMENT

Surface treatments like gas nitriding, salt bath or ion nitriding can have a beneficial effect like resistance to erosion and soldering on certain parts of a die casting die, such as shot sleeves, nozzles, runners, spreaders, gates, ejector pins and core pins. Different steel possess different nitriding properties, depending on chemical composition. Other surface treatments have also proved beneficial in die casting applications.



Aluminium die for
the automotive industry.

WELDABILITY

In many cases, it is important that a die casting die can be repaired by welding. The repair welding of 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 free from dirt and grease to ensure satisfactory penetration and fusion.

WELDING OF SOFT ANNEALED MATERIAL

1 Preheat to 325–375°C.

2 Start welding at this temperature. Never let the temperature of the tool go below 325°C Max. interpass temperature 475°C. 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 20–40°C/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 325–375°C.

2 Start welding at this temperature. Never let the temperature of the tool go below 325°C. Max. interpass temperature 475°C. 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 20–40°C/h for the first two hours and then freely in air.

4 Stress temper 25°C below the highest previous tempering temperature for two hours.

WELDING CONSUMABLES

QRO 90 Weld (SMAW), QRO 90 TIG-Weld or Dievar TIG-Weld.

DIE PERFORMANCE

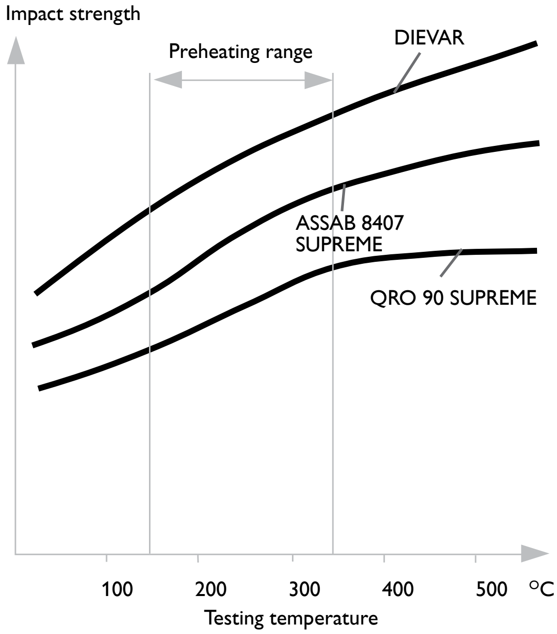
The life of a die casting die varies considerably depending on the size and design of the casting, the type of casting alloy, and the care and maintenance of the die.

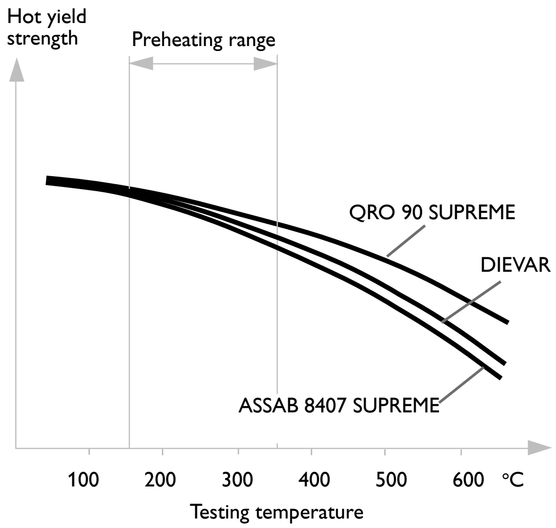
The life of a die can be prolonged by suitable treatment before and during casting by:

- 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.

The curves, in the graphs to the left, 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: It is important that heating is gradual

Preheating	Material Temperature
Tin, Lead alloys	100 - 150 °C
Zinc alloys	150 - 200 °C
Magnesium, Aluminium alloys	180 - 300 °C
Copper alloys	300 - 350 °C

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.

CORRECT COOLING

The temperature of the die is controlled via cooling channels by water or oil 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. Thermostatically controlled cooling systems are also common. Cooling water colder than 20°C is not recommended.

During breaks longer than a few minutes, the flow of coolant should be adjusted so that the die does not cool down too much.

SURFACE TREATMENT

Surface treatments like nitriding carried out either via gas, salt bath or plasma as well as nitrocarburising can improve the service performance of certain parts used for die-casting applications such as shot sleeves, nozzles, runners, spreaders, gates, ejector pins and core pins.

Oxidation of the die surface has also proven beneficial as the oxidised surface texture with good lubricant-retention characteristics increases the resistance to corrosion and soldering. The presence of the oxidised surface is particularly important for new die-casting dies before the die itself acquired a black protective oxide layer.

Duplex surface treatment by first applying nitriding or nitrocarburising, then combining it with oxidation is effective in protecting the die surface from the initial washout damages (e.g., corrosion, erosion and soldering) that are commonly encountered in new die-casting dies. Such duplex treatment will benefit toolmakers who often have to guarantee a minimum quantity of shots for each die they deliver to their end users. Duplex surface treatment of nitriding / nitrocarburising combined with oxidation is available from ASSAB.

STRESS TEMPERING

During die casting, the surface of the die 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 hereby 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 that ABP — ASSAB patented shot peening — be done in conjunction with each stress-tempering interval, that is, after the running in period and then after 1,000 - 2,000 and 5,000 - 10,000 shots. Such preventative maintenance procedure combining ABP and stress tempering 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 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 treatment of the die. Normally, two hours holding time at temperature should be sufficient.

Die for brass die casting.

DEMANDS ON DIE STEEL 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:

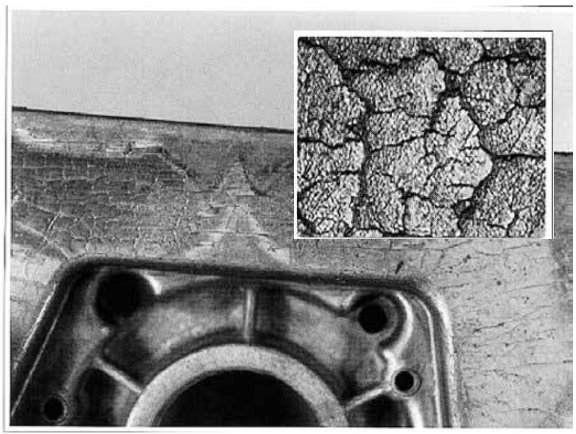
- Thermal fatigue (heat checking)
- Corrosion/erosion
- Cracking (total failure)
- Indentation

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 its heat treatment and the acceptance level of size and surface finish variations.

THERMAL FATIGUE

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

Die-casting dies are subjected to alternate heating and cooling when in use. 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 photo below.



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 ASSAB 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, ASSAB 8407 Supreme and QRO 90 Supreme.

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

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 is 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

DIE TEMPERATURE CYCLE

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 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 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 over-tempering 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 waterbased ones for environmental reasons.

BASIC DIE MATERIAL PROPERTIES

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 steel from ASSAB 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 centre of thick blocks.

STRESS RAISERS

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 oxidised, 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.

Uddeholms AB, our steel mill in Sweden, has investigated the corrosion tendency in different molten die casting metals.

FACTORS WHICH INFLUENCE CORROSION

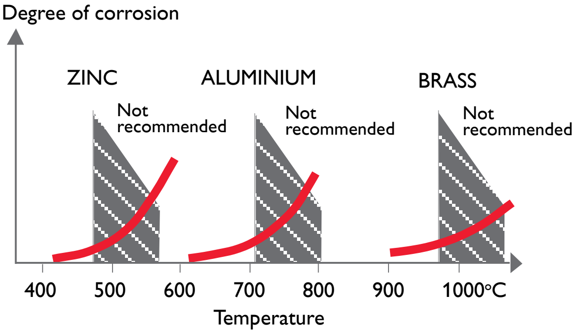
A number of factors influence die corrosion:

- 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 480°C and aluminium at about 720°C.

Copper alloys do not seem to have any really critical temperature, but corrosion increases slowly with temperature.



Soldering damage on a core pin

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.

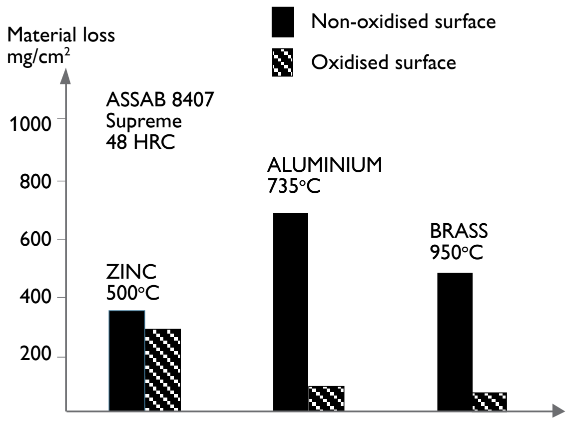
DESIGN OF THE DIE

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.

Erosion

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 nitrocarburised 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 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 hypereutetic aluminium melts containing more than 12.7% silicon, further increase the risk of erosion damage.

Most commonly a combination of corrosion and erosion damages occurs 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 high hot yield strength of the die material are important.

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, ASSAB 8407 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 AND ASSAB 8407 SUPREME

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

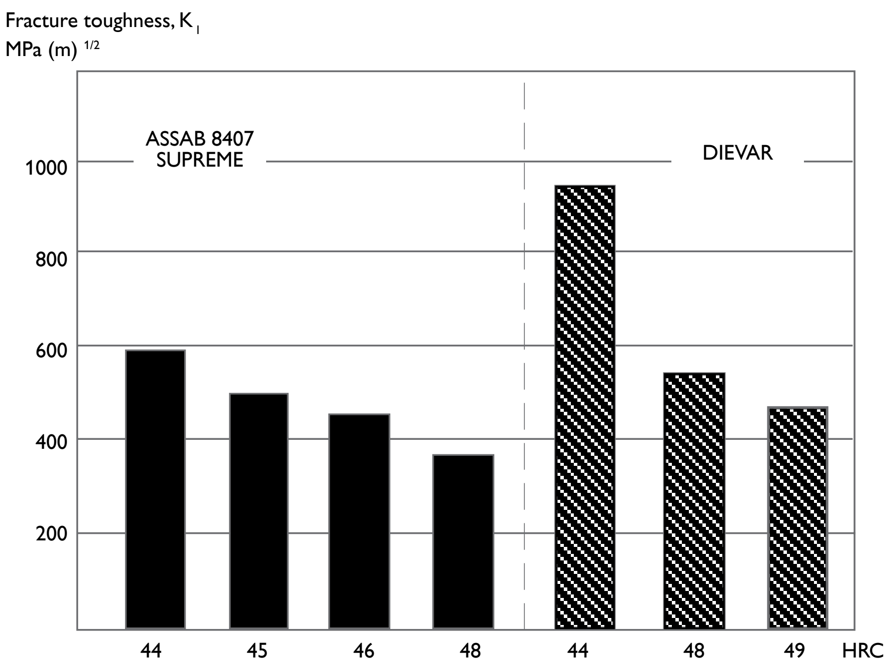
The fracture toughness of Dievar and ASSAB 8407 Supreme at different hardness are shown in the figure below.

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.



Facture toughness at room temperature (centre, short-transverse direction).

SURFACE TREATMENT

This section covers the various surface treatments commonly used as industrial solutions to improve die performance. The type of surface treatment should be chosen prudently according to the main failure mode encountered by the die steel. The resistance to failure modes such as heat checking, erosion, corrosion and soldering can be increased by applying the appropriate surface treatment.

Our heat treatment and technical staff will be glad to assist you in your choice of the appropriate surface treatment for each die-casting application.

NITRIDING AND NITROCARBURISING

Nitriding results in a hard surface layer, which is very resistant to wear, soldering, erosion and pitting. The superficial layer of $Fe_{2\text{-}3}N$ (ε-phase) and Fe_4N (γ'-phase) of the nitrided case, commonly referred to as the "white layer", is however porous and brittle leading to increased risk of cracking or spalling when exposed to mechanical or thermal shock — the risk increases with increasing layer thickness. A thin and dense white layer not exceeding 5 - 7.5 μm, is however, beneficial. It is such white layer over the diffusion zone that provides protection against soldering and corrosion, and increased wear resistance.

Nitriding to case depths of more than 0.3 mm is not recommended for hot-work applications. If inserts are to be nitrided, avoid too thick a nitrided layer.

Recommended case depths are as follows:

- Inserts max. 0.05 mm
- Cores max. 0.1 mm
- Shot sleeves max. 0.3 mm

Before nitriding, the tool should be hardened and tempered at a temperature at least 25 - 50°C above the nitriding temperature.

Nitriding in ammonia gas at 510°C, or plasma nitriding in a 75% hydrogen/25% nitrogen mixture at 480°C, both result in a surface hardness in the range of 1000 - 1180 $HV_{0.2}$ depending on the specific grade of ASSAB hot-work die steel and the type of nitriding process. In general, plasma nitriding is the preferred method because of better control over nitrogen potential; in particular, formation of the white layer, which is not recommended for hot-work service, can readily be avoided. However, careful gas nitriding can give perfectly acceptable results.

By adding carbon containing medium to the atmosphere or salt bath, it is possible to form a layer of carbonitrides. This type of surface treatment is known as nitrocarburising. It has good wear and corrosion resistance, especially when it is combined with a light oxidation. Nitrocarburising is suitable for die parts subjected to abrasion and friction, such as ejector pins and shot sleeves.

The surface hardness after nitrocarburising at 580°C is in the range of 850 - 1160 $HV_{0.2}$ depending on the specific grade of ASSAB hot-work die steel and whether it is nitrocarburised in gas or salt bath.

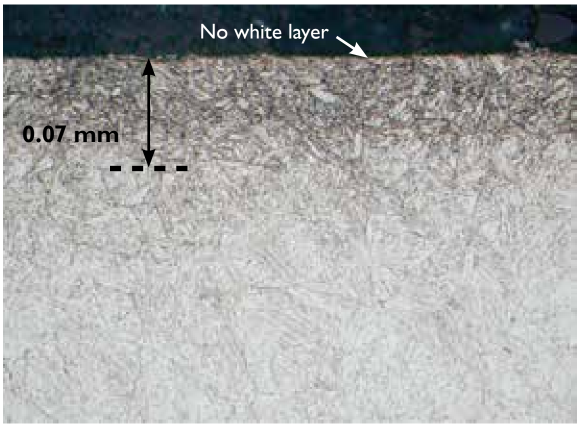
Process	ASSAB 8407 Supreme	Dievar	QRO 90 Supreme	Unimax
Gas nitriding 510°C				
10 h	1100 HV 0.12 mm	1100 HV 0.16 mm	1000 HV 0.16 mm	1180 HV 0.15 mm
30 h	1100 HV 0.20 mm	1100 HV 0.22 mm	1000 HV 0.27 mm	1180 HV 0.25 mm
Plasma nitriding 480°C				
10 h	1100 HV 0.12 mm	1100 HV 0.15 mm	1000 HV 0.18 mm	1180 HV 0.15 mm
30 h	1100 HV 0.15 mm	—	1000 HV 0.27 mm	1180 HV 0.25 mm
Nitrocarburising 580°C				
2.5 h in gas	950 HV 0.11 mm	1100 HV ≥ 0.13 mm	850 HV 0.20 mm	1130 HV 0.12 mm
1 h in salt bath	950 HV 0.06 mm	1100HV 0.08 mm	850 HV 0.13 mm	1160 HV 0.08 mm

Notes: Values in HV refer to the nitiriding hardness measurements were taken ~20 μm below the surface using icro Vickers hardness tester with indentation load of 200 gram-force.

Values in mm refer to the nitriding depth — the distance from the surface where hardness is 50 HV higher than the matrix hardness.

CONTROLLED GAS NITRIDING / NITROCARBURISING

Unlike conventional gas nitriding and nitrocarburising, where the white layer is often excessively porous, brittle and may crack or spall, NITREG® controlled gas nitriding and controlled nitrocarburising processes such as NITREG®-C and ASN are able to control the porosity and the quality of the white layer, which is beneficial for increased corrosion resistance and wear resistance. NITREG® is a registered trademark of NITREX, whilst ASN is propriety process developed by ASSAB and it stands for ASSAB Special Nitriding. The most important advantage is that the white layer formed by controlled gas nitriding / nitrocarburising is not brittle, while retaining the same hardness. In addition, process parameters such as nitriding potential can be adjusted to optimise the thickness of the white layer and/or diffusion layers for a given application. Such controlled process conducted at a processing temperature of 500 - 600°C can be used to obtain a white layer designed for optimum wear resistance, or to produce only diffusion layer (case depth) without the white layer for optimum fatigue strength. Conventional nitriding and nitrocarburising are largely applied to the components of the die-casting dies with great success. To a much lesser extent, these conventional treatments are used to treat the inserts with some success in reducing soldering, erosion and pitting. However, the treatment of die cavities and inserts by conventional processes remains an area of dispute due to instances of a definite decrease in die life caused by accelerated heat checking. The specific process and the parameters used by individual surface treaters obviously have a large bearing on the matter. The occurrence, or not, of the white layer and its associated phases (e.g., ε and γ'), the microstructure and depth of the nitrided layer plays a significant part in determining the eventual die life. Whilst conventional nitriding and nitrocarburising are largely restricted to the treatment of the components of the die-casting dies, their respective controlled versions such as NITREG®, NITREG®-C and ASN whereby the nitrided / nitrocarburised case comprises only the diffusion layer (no white layer) have been successfully applied to inserts and cavities of die-casting dies resulting in improved die performance due to its good fatigue strength.



Microstructure produced by ASN controlled gas nitrocarburising process.

OXIDATION

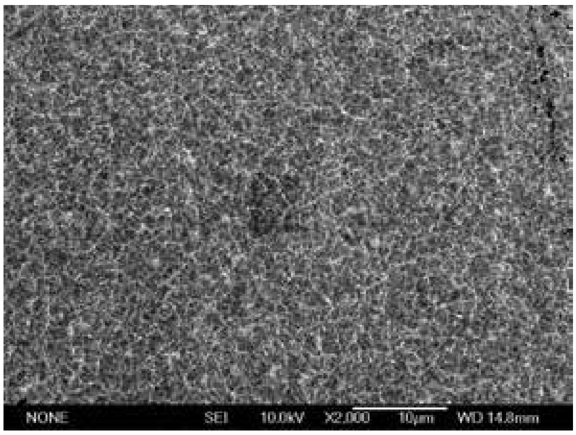
Oxidation is known by a host of proprietary or commercial names (e.g., blackening) but it essentially involves forming a protective oxide layer on the surface of the die steel at an elevated temperature.

It is normally carried out at 500 - 600°C for a duration, which varies from 30 minutes to several hours, to produce a controlled surface film of tight, tough and extremely adherent iron oxide, mainly Fe_3O_4, of varying thickness depending on the process variables. Oxidation can be conducted in atmospheres such as steam (typically 0.15 - 0.3 MPa), normal-pressure air (0.1 MPa) and low-pressure air (0.001 MPa).

The surface of the die can be oxidised by heating at approx. 500 - 550°C for 1 to 2 hours, followed by cooling in air. Heating in a steam atmosphere at 550 - 600°C for 1 to 4 hours also produces a protective oxide layer of suitable thickness, ranging from approximately 2 to 6 µm.

A proprietary steam-oxidation process developed by ASSAB known by its commercial name of ASO — ASSAB Steam Oxidising — has been successfully applied to die-casting dies to solve corrosion-related damage resulting from the dissolution of the steel and intermetallic compounds formed between the aluminium melt and die surface.

The surface texture produced by ASO tends to hold and retain the lubricant on the die surface, reduces the tendency of soldering, and enhances casting release.



SEM image showing the surface texture of ASO treated Dievar.

SHOT PEENING

Shot peening is a process of bombarding with small spherical media, called shot, to induce compressive stress and locally harden surface layers, resulting in increased fatigue strength — hence improving resistance to heat checking and stress corrosion, and consequently extending the die life.

ABP , which stands for ASSAB Benefits Process, is the registered trademark of ASSAB for its proprietary shot-peening process. ABP has proven very successful for several hot-work applications, including the treatment of die cavities and inserts for die-casting dies. In the ABP process, blast cleaning is followed by impingement of a stream of small spherical steel balls, directed at the metal surface at high speed under controlled conditions. Each steel ball striking the metal acts as a tiny peening hammer, imparting a small indentation or dimple on the surface. Overlapping dimples on the peened surface develop a uniform layer of residual compressive stress. These compressive stresses serve to improve fatigue resistance and inhibit stress-corrosion cracking.

The peened surface with overlapping dimples is beneficial for lubricant retention, reduces the tendency of soldering and facilitates better release of castings.

As nearly all heat checking and stress-corrosion cracking originate at or near the surface of a part, compressive stresses induced by ABP enhance die performance and extend the tool life.

Several properties are improved by the ABP process:

- Increased thermal-fatigue resistance
- Improved resistance to heat checking
- Increased wear resistance
- Increased resistance to stress cracking
- Increased surface strength
- Extended tool life

ABP is suitable for both new dies as well as used dies. It is recommended that ABP be incorporated as a preventative maintenance procedure for used dies in conjunction with each stress-tempering interval, typically 10,000–20,000 shots. During such maintenance, ABP improves the surface quality of the used dies — small surface scratches, scales and deposits are removed resulting in cleaner surface. In addition, ABP has the ability to help close minor heat checking that developed in used dies.

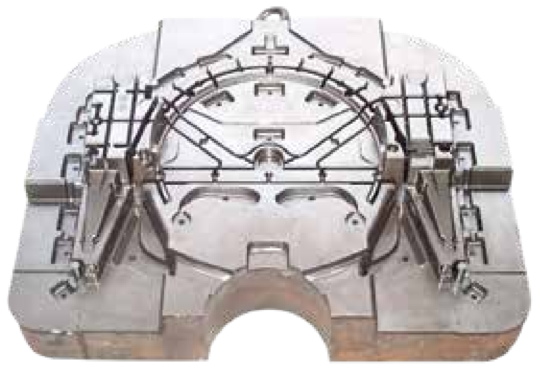
PVD

Physical vapour deposition, PVD, is a vacuum coating process of applying wear-resistant surface coating at temperatures between 200 - 550°C. In the PVD process, source material (e.g., titanium, chromium or titanium/aluminium) is vapourised to subsequently form a thin film of typically 1 - 4 μm thickness on top of the tool surface by condensation of the vapour phase. Thin films of ceramic compounds such as CrN (~1750 HV) and TiAlN (~3300 HV) are more commonly deposited on tool surface for die-casting application.

PVD coating is either applied as a single layer or as aduplex layer on top of a nitrided layer. Investigation of inserts used for aluminium die casting has shown that duplex layer obtained by plasma nitriding and PVD-TiAlN gives good protection against soldering.

The combination of two surface engineering techniques is commonly referred to duplex surface treatment, such as plasma nitriding and PVD TiAlN mentioned in the preceding section. Using a combination of surface treatments enhances surface characteristics by combining the advantages of each technique compared with those of the individual method itself.

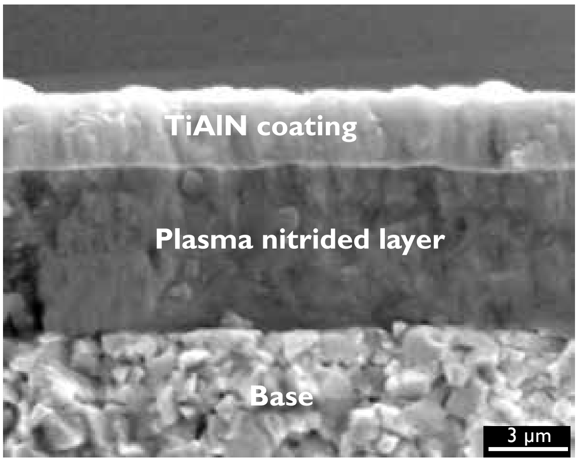
10,000 shots and before ABP



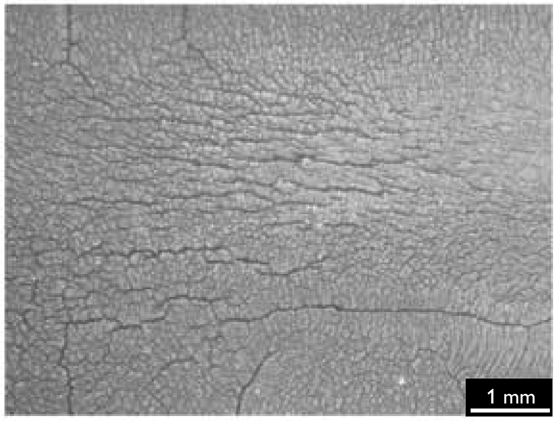
After ABP

Die of dimensions 780 x 620 x 170 mm weighting 430 kg used for die-casting of aluminium alloy.

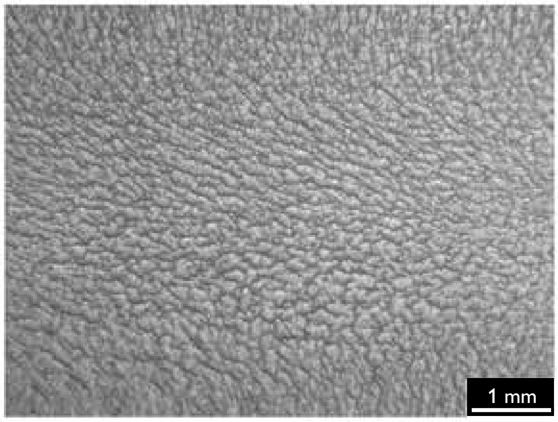
Duplex surface treatment combining nitriding or nitrocarburising with post-oxidation is generally recommended for new die-casting dies as it offers protection to the die surface from initial washout damages (e.g., corrosion, erosion and soldering).



Other duplex surface treatments include the combination of shot peening and nitriding or nitrocarburising. One such example, ABP shot peening with plasma nitriding, and its effect is illustrated by comparing the following two pictures.



Plasma nitrided die surface



Shot peened and plasma nitrided die surface

An investigation by Shanghai University on the effectiveness of ABP on the fatigue behaviour of diesteels. The two pictures above were taken after 1,200 shots.

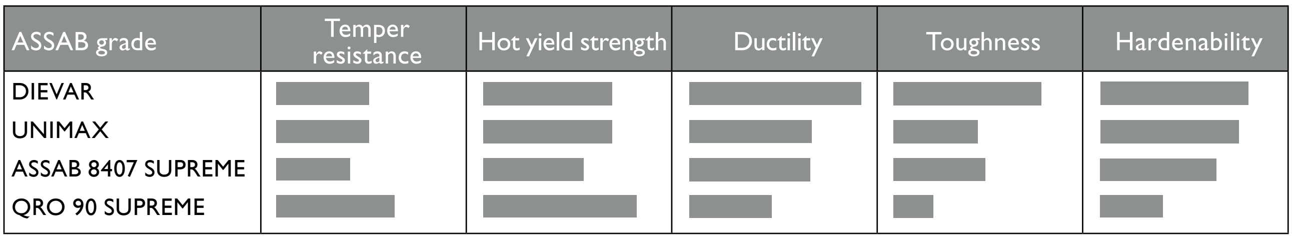
PRODUCT PROGRAMME FOR DIE-CASTING

ASSAB grade	Characteristic / Application
DIEVAR	Dievar possesses a combination of excellent toughness and very good hot strength, resulting in a superior hot-work die steel that have excellent resistance to heat checking and gross cracking. It is specifically developed to improve the potential heat-checking resistance above and beyond that of other commercially available die steels. Dievar is capable of achieving its very unique properties profile in even the largest of cross sections. Such unique properties profile makes it a suitable choice for high demand hot-work applications like die casting, forging and extrusion.
UNIMAX	Unimax is a universal tool steel with an excellent combination of high ductility and high hardness. Due to its exceptional properties, it can be used for cold-work, plastic moulding and hot-work applications. Unimax is suitable for small-to-medium die-casting dies where erosion is the dominant failure mechanism, especially in zinc die casting.
ASSAB 8407 SUPREME	ASSAB 8407 Supreme is an electroslag remelted steel, which attains high purity and a very fine structure. It is a premium H13 grade with significantly improved isotropic properties compared to conventionally produced H13 grades. This improvement, coupled with a high level of cleanliness and homogeneous structure, makes ASSAB 8407 Supreme particularly suitable for demanding applications (e.g., tooling subjected to high stresses). It meets the requirements of NADCA #207–2008.
QRO 90 SUPREME	QRO 90 Supreme has a good combination of hot yield strength, temper resistance and thermal conductivity. QRO 90 Supreme has given outstanding results for copper and brass die casting, particularly for smaller dies. It is also eminently suitable for small inserts and cores in aluminium die casting where heat checking or erosion is a problem.
ASSAB 618	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 and prototype dies.

CHEMICAL COMPOSITION

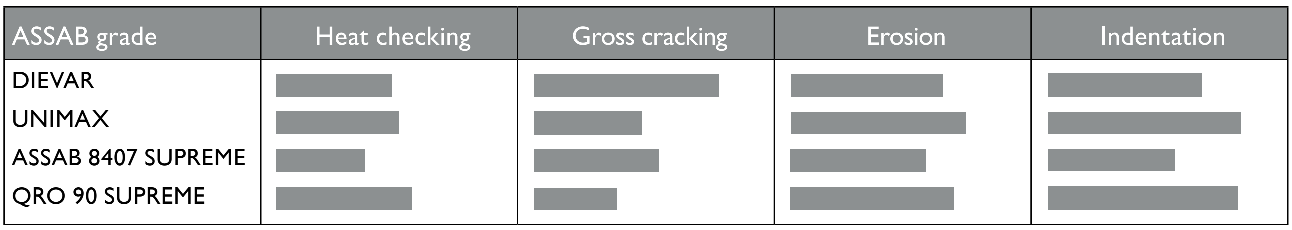
ASSAB grade	AISI (WNr.)	Analysis %							Supplied hardness Brinell
		C	Si	Mn	Cr	Mo	V	Others	
DIEVAR	-	0.35	0.2	0.5	5.0	2.3	0.6	-	~160
UNIMAX	-	0.50	0.2	0.5	5.0	2.3	0.5	-	~185
ASSAB 8407 SUPREME	H13 (1.2344)	0.39	1.0	0.4	5.2	1.4	0.9	-	~180
QRO 90 SUPREME	-	0.38	0.3	0.8	2.6	2.3	0.9	Microalloyed	~180
ASSAB 618	P20 modified (1.2738)	0.37	0.3	1.4	2.0	0.2	-	Ni 1.0	~310

RELATIVE COMPARISON OF CRITICAL DIE STEEL PROPERTIES



All steel tested at 44 - 46 HRC except for Unimax, which was tested at 54 - 56 HRC.

RELATIVE COMPARISON OF RESISTANCE TO DIFFERENT DIE FAILURES



Notes: All steels tested at 44 - 46 HRC except for Unimax, which was tested at 54 - 56 HRC. The longer the bar, the better.

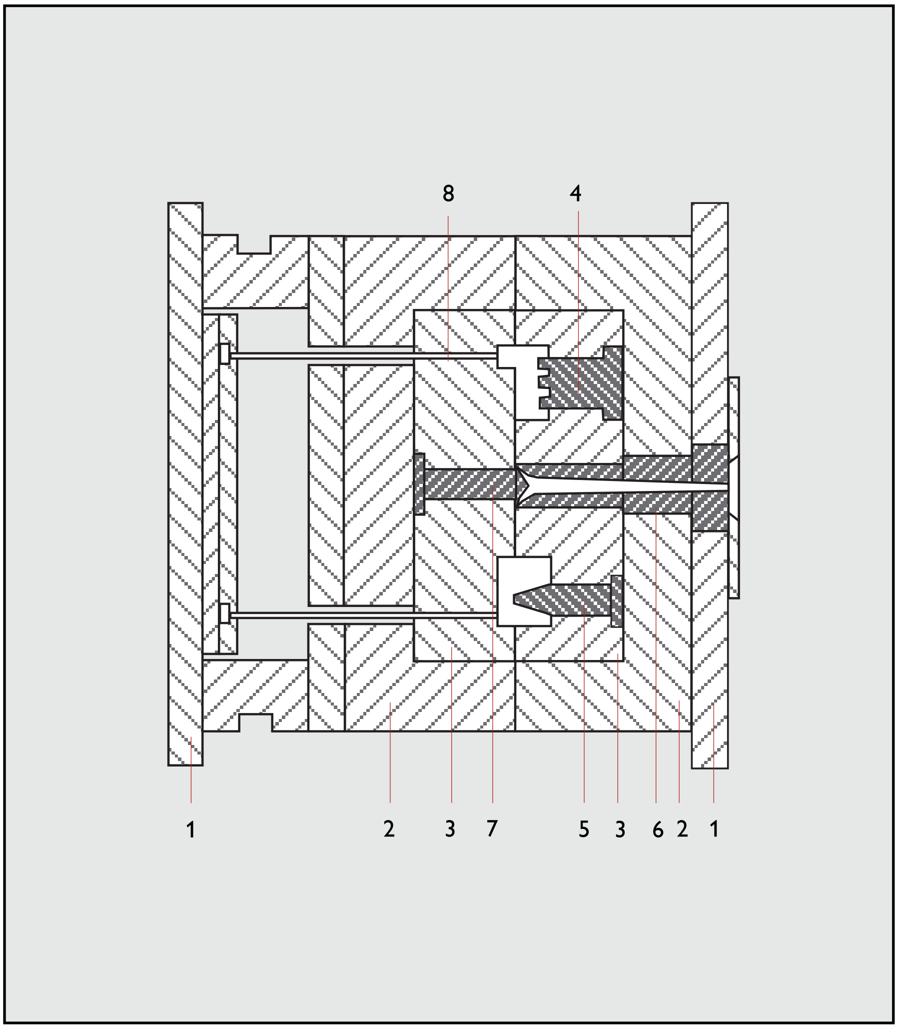
STEEL AND HARDNESS SELECTION

GENERAL RECOMMENDATION

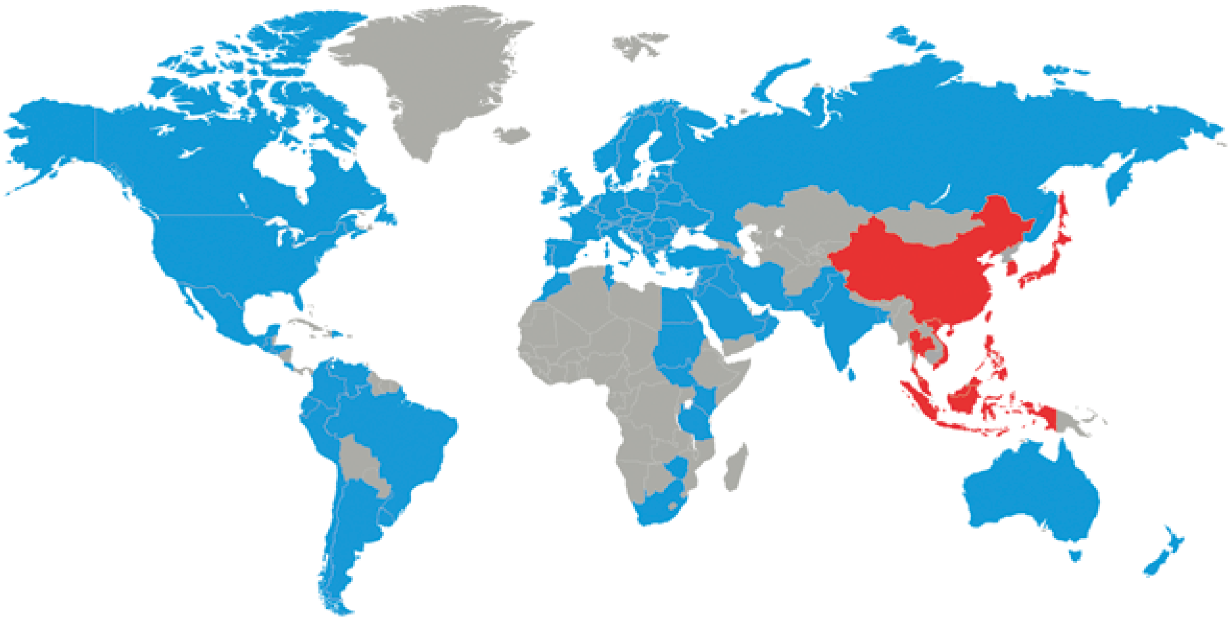
Die part	Tin / Lead / Zinc		Aluminium / Magnesium		Copper / Brass	
Clamping plates, Holder plates	ASSAB 618	~310 HB	ASSAB 618	~310 HB	ASSAB 618	~310 HB
Die inserts	ASSAB 618	~310 HB	DIEVAR	44 - 50 HRC	QRO 90 SUPREME	40 - 46 HRC
	ASSAB 8407 SUPREME	46 - 52 HRC	ASSAB 8407 SUPREME	42 - 48 HRC	ASSAB 8407 SUPREME	40 - 46 HRC
	UNIMAX	52 - 56 HRC	UNIMAX**			
Fixed inserts Core	ASSAB 8407 SUPREME	46 - 52 HRC	DIEVAR	46 - 50 HRC	QRO 90 SUPREME	40 - 46 HRC
			ASSAB 8407 SUPREME	44 - 48 HRC		
			QRO 90 SUPREME	44 - 48 HRC		
Core pins	ASSAB 8407 SUPREME*	46 - 52 HRC	QRO 90 SUPREME*	44 - 48 HRC	QRO 90 SUPREME*	42 - 46 HRC
Sprue parts	ASSAB 8407 SUPREME	48 - 52 HRC	ASSAB 8407 SUPREME	46 - 48 HRC	QRO 90 SUPREME	42 - 46 HRC
			QRO 90 SUPREME	44 - 46 HRC		
Nozzles	STAVAX ESR	40- 44 HRC	ASSAB 8407 SUPREME	42 - 48 HRC	QRO 90 SUPREME	40 - 44 HRC
	ASSAB 8407 SUPREME	35 - 44 HRC	QRO 90 SUPREME	42 - 46 HRC	ASSAB 8407 SUPREME	42 - 48 HRC
Ejector pins	QRO 90 SUPREME ASSAB 8407 SUPREME	46 - 50 HRC (nitrided)	QRO 90 SUPREME ASSAB 8407 SUPREME	46 - 50 HRC (nitrided)	QRO 90 SUPREME ASSAB 8407 SUPREME	46 - 50 HRC (nitrided)
Plunger Shot sleeves	ASSAB 8407 SUPREME	42 - 46 HRC (nitrided)	ASSAB 8407 SUPREME QRO 90 SUPREME	42 - 48 HRC (nitrided)	QRO 90 SUPREME ASSAB 8407 SUPREME	42 - 46 HRC (nitrided)

* Surface treatment is recommended

** For small Mg die inserts where a good erosion resistance is needed



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



Choosing the right steel is of vital importance. ASSAB engineers and metallurgists are always ready to assist you in your choice of the optimum steel grade and the best treatment for each application. ASSAB not only supplies steel products with superior quality, we offer state-of-the-art machining, heat treatment and surface treatment services to enhance steel properties to meet your requirement in the shortest lead time. Using a holistic approach as a one-stop solution provider, we are more than just another tool steel supplier.

ASSAB and Uddeholm are present on every continent. This ensures you that high quality tool steel and local support are available wherever you are. Together we secure our position as the world's leading supplier of tooling materials.

For more information, please visit
www.assab.com

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