



## CHILLS



## CHILLS

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### 1. INTRODUCTION

It is clear that chills have an important influence on the quality (section quality) of a casting.

But it also can increase the casting yield (net casting weight compared to poured weight) as well as point for a particular microstructure.

Especially due to the tendency of decreasing the energy consumption in the casting process, which is emphasized by the government in several countries, the use of chills is back.

In past times, the use of chills was a matter of experience. Now it can be calculated and even most of the simulation programs do have the possibility to integrate the effect of chilling in their calculations.

The use of “fins” to cool the casting is already a long temps applied. It is not as effective as chills but has some particular advantages.



# CHILLS



## 2. DEFINITION

A chill is each item, which is used to decrease the temperature of the casting at its location. This is done by a high specific heat and high heat conductivity.

The chill can be made of all types of materials, which must have a higher specific heat and or conductivity as the moulding material.

This can be special sand as is chromite sand, zircon sand...

Or metal, as is grey or vermicular or ductile iron as in special cases copper.

Other materials as graphite are becoming more common.

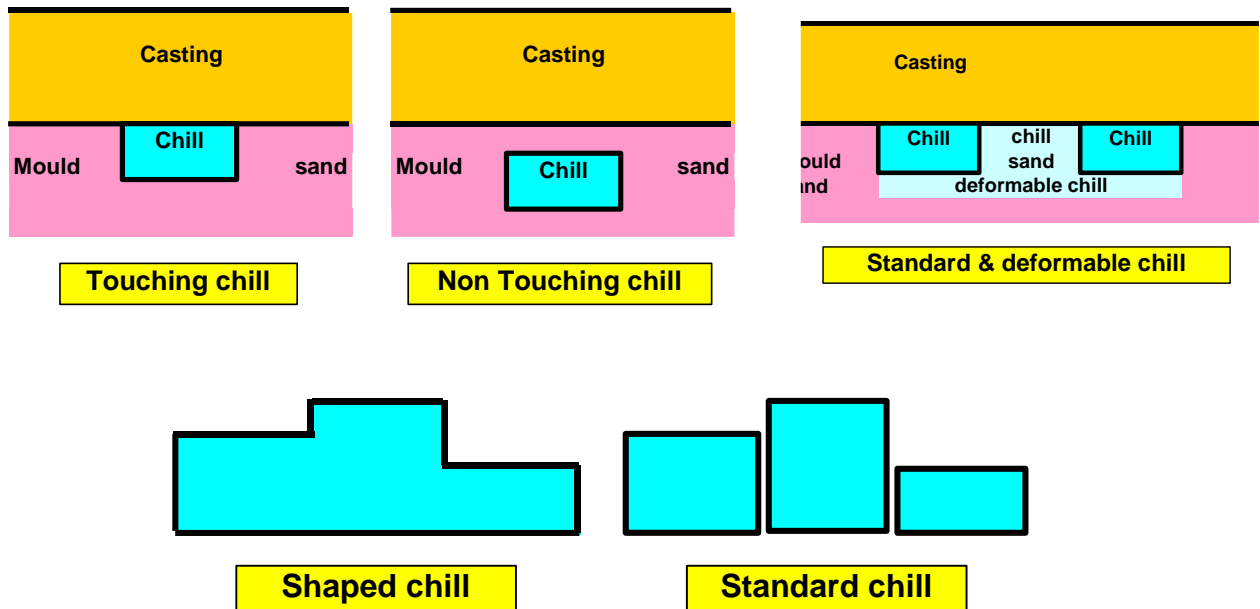
The other important requirement is that it will not melt, which means that the melting temperature must be sufficient high compared to the metal of the casting.

There are two types of chills, depending of their location compared to the casting:

### 1. external chills

The chill is located at the surface of the casting.

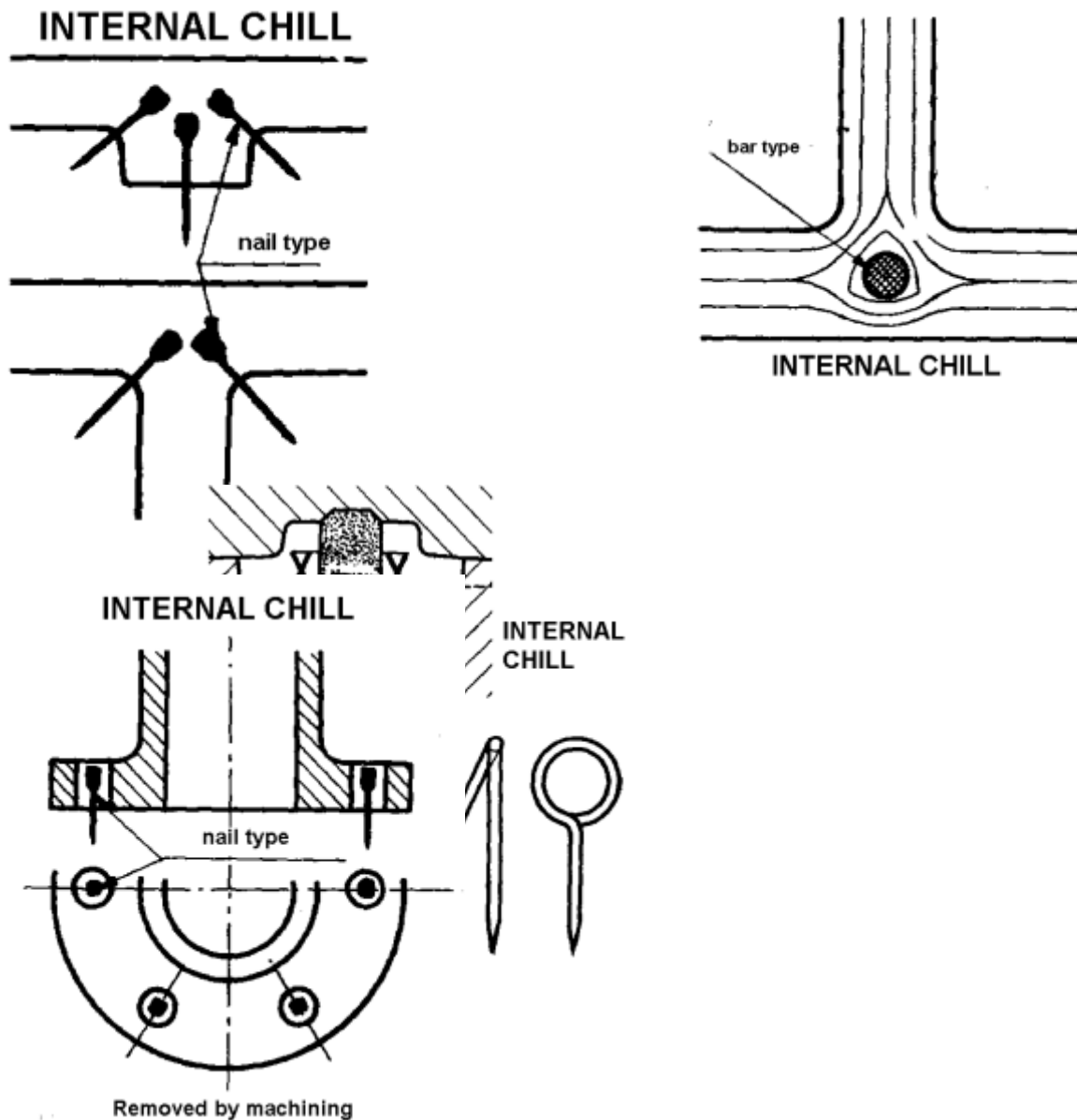
For the external chills, there are "touching" and "non-touching" chills. Another classifying is shaped chills, standard chills and deformable chills.



Pouring in metal moulds is a special type of use of chills.

## 2. internal chill

The chill is located inside of the casting and becomes part of the casting. This is very influencing the quality of the casting. Most of the quality standards do not allow non-melted chills (or inserts). It has to be of equal material as the casting in order to not influence the quality of the base iron. If it does not melt and is not allowed by the standard, it has to be removed by machining (drilling...).





### 3. PURPOSE

The chill is used to:

1. remove extra heat locally, which result in a lower modulus for the concerned sector (section crosses...)
2. increase feeding length of risers by promoting directional solidification
3. obtain locally a particular structure with (especially if metal has gas content):
  - finer grain
  - particular structure
  - higher strength and ductility
  - increasing hardness
  - increasing hardenability
  - less micro-porosity and other porosity
  - decrease segregation tendency
  - increasing pressure tightness.
4. avoid hot cracks (corners, around hot spots)...

**Chills never can compensate shrinkage, but will only relocate shrinkage!**

It will never decrease the liquid shrinkage of a material but it will concentrate the shrinkage into locations close by or in the influence zone (feeding zone) of the risers.

The requirements for a correct working chill are:

1. ability to remove of the extra heat:
  - heat due to overheating of metal (temperature > liquidus-temperature)
  - solidification heat
2. transfer of heat until the metal (of the casting) is solidified.

For that reason the “specific heat” as well as “heat conductivity” is important.



## 4. MATERIALS

These are of four different types:

1. iron
2. different types of sand
3. graphite
4. other material.

### 4.1 IRON

All types of iron are usable concerning the melting temperature and specific heat. But they do not have the same efficiency, due to the difference in heat conductivity.

The irons with the highest heat conductivity do have the highest efficiency. As can be seen in the table, grey (flake) iron with lamellar graphite is the best, followed by compacted iron with vermicular graphite and ductile iron with nodular graphite.

Malleable iron is not used and the “white irons” (martensitic with a lot of carbides) cannot be used due to the much lower heat conductivity (no free graphite) and the high tendency to cracking.

Sometimes steel chills are used. These are surely not the best, as is shown in the next table.

**Table with the specific heat and heat conductivity for iron**

<b>Material</b>		<b>Density</b>	<b>Specific heat</b>	<b>Heat conductivity</b>
		<b>Kg / dm<sup>3</sup></b>	<b>J / kg.K</b>	<b>W / m.°K</b>
Lamellar iron	Flake iron	7,20	720	39
Ductile iron		7,10	515	29
Vermicular iron	Compacted iron	7,10	620	35
Steel		7,80	520	25
Graphite		2,1	1510	60
Silico Carbide			963	

$$1 \text{ cal / g.°K equals } 4,1868 \cdot 10^3 \text{ J / kg.°K}$$



## CHILLS



Due to the “specific heat” the chill has the capability to remove a lot of heat very quickly. The higher the specific heat, the lower the mass (volume) of the chill can be for the equal cooling effect.

The “heat conductivity” is very important to continue the heat absorption until the concerned casting section is solidified.

### 4.2 DIFFERENT TYPES OF SAND

Silica sand is the basic material. The other sands are zircon, magnesite and chromite sand.

Material	Maximum packing density	Heat conductivity	Specific heat	Thermal expansion
	g / cm <sup>3</sup>	W / m.K	J / kg.°K	%
Silica sand	1,60	0,255 (0,71)	1130	1,50
Chromite sand	2,80	0,215 (0,58)	1214	0,26
Zircon sand	3,00	0,305	1424	0,01
Magnesite sand	2,80		1047	
Silico-carbide			963	
Cerabead	1,70	0,223 (0,56)	1842	- 0,03
Mullite	1,60		750	

It is clear that zircon sand is very good due to the heat conductivity and specific heat, but also due to the low thermal expansion. This low expansion will give a stable mould and the casting will benefit with a good surface quality.

The silico-carbide can be bought in pre-shaped and or bloc chills, as well as material to shape and harden with a (sand) binder system.

The effect of the sand-type chill material is low compared to the effect of iron. It is seldom used as particular chill, but as a smoothening material aside or in between iron chills. This is very easy because they can be formed with a binder system equal to the chemical binders of silica sand.

If they are used, less cracking will appear in steel type metals. For the irons, it will give a higher section quality to the casting.



## CHILLS





### 4.3 GRAPHITE

The cooling effect of graphite is relatively high and comes very close to this of iron.

The important advantage is that it does not have problems with gas in the casting surface and the maintenance cost is very low as well as the machinability. On the other hand, the cost price for the material is high.

It is very well suited in cores due to the high heat conductivity and the good surface condition.

### 4.4 OTHER MATERIAL

One of the other materials is silico-carbide, which is available in bloc shape as well as material to be bound with the equal chemical process as the mould sand. Neither there is nor problem for reclaiming it together with silica sand.

It is better as the sand-type chills but does also cost a lot more.

There are some other materials, based on aluminium-oxides and belonging to the family of mullite. They are mostly known by their trade name.

The advantage is that the thermal expansion is very low if there is not a very small expansion. The data for one of them is given in the table of chapter 4.2.

### 4.5 MATERIAL DATA ACCORDING TO J CAMPBELL

There are two important features:

1. **heat diffusivity** ( $\text{J.m}^{-2}.\text{K}^{-1}.\text{s}^{-1/2}$ ) HD

This is the capability of the mould to absorb heat and spread it over its volume.

$$\text{HD} = \text{TC.D.SH}$$

TC is thermal conductivity in  $\text{J.m}^{-1}.\text{K}^{-1}.\text{s}^{-1}$

D is density in  $\text{kg} / \text{m}^3$

SH is specific heat in  $\text{J.kg}^{-1}.\text{K}^{-1}$



## CHILLS



### 2. **heat capacity per unit volume** ( $J \cdot K^{-1} \cdot m^{-3}$ ) HC

This is the capacity of the material to absorb the heat. The higher the capacity, the more effective the chilling will be and the smaller the chill can be.

A summary of the data at 20 °C is given in the next table:

Material	Melting point	Solidification contraction	SH	D	TC	HD	HC
	°C	%	J/kg.°K	kg/m <sup>3</sup>	J.m/°K.s	J/m <sup>2</sup> .°K.s <sup>1/2</sup>	J/°K.m <sup>3</sup>
Silica sand			1130	1500	0,0061	3210	1700000
Mullite			750	1600	0,0038	2120	1200000
Iron	1536	3,16	456	7870	73	16200	3940000
Graphite			1515	2200	147	22100	3330000
Copper	1084	5,30	386	8960	397	37000	3600000

**This indicates also that graphite and iron is nearly equal concerning chilling possibility.**



## 5. CALCULATION

### 5.1 External chills

### 5.2 Internal chills

It is necessary to calculate the items, which do influence the efficiency.

These items are the “touching surface” and the volume of the chill. The touching surface must not touch physically the surface of the casting but must at least have an influence on the heat removal. In principle, the calculation is done on the base of heat removal from the casting to the chills, in such a way that the required cooling rate is reached.

The temperature of the chill (preheating) is very important:

1. preheating should only avoid presence of moisture
2. the temperature difference between the chill and the metal will influence the structure and free graphite appearance of the solidifying and later cooling iron.

### 5.1 External chills

#### Volume of chill

The minimum volume is calculated as:

$$V_{\text{chill}} = \zeta_{\text{metal}} \cdot V_{0c} \cdot (M_{0c} - M_{\text{req}}) [L_{\text{metal}} + C_{\text{metal}} \cdot (T_P - T_L)] / M_{0c} \cdot \zeta_{\text{chill}} \cdot T_{\text{chill}} \cdot C_{\text{chill}}$$

If the maximum allowed temperature of the chill material is set, the formula becomes:

$$V_{\text{chill}} = 1,66 \cdot V_{0c} \cdot (M_{0c} - M_{\text{req}}) / M_{0c} \quad \text{for chill temperature } 400 \text{ } ^\circ\text{C}$$

$$V_{\text{chill}} = 1,11 \cdot V_{0c} \cdot (M_{0c} - M_{\text{req}}) / M_{0c} \quad \text{for chill temperature } 600 \text{ } ^\circ\text{C}$$

$$V_{\text{chill}} = 0,83 \cdot V_{0c} \cdot (M_{0c} - M_{\text{req}}) / M_{0c} \quad \text{for chill temperature } 800 \text{ } ^\circ\text{C}$$

#### Surface of the chill

$$S_{\text{req}} = S_{0c} + 3 \cdot S_{T.\text{chill}} \quad \text{for chill in physical contact, no air gap during cooling}$$

$$S_{\text{req}} = S_{0c} + 2 \cdot S_{T.\text{chill}} \quad \text{for chill in physical contact, air gap during cooling}$$

#### Required modulus

$$M_{\text{req}} = V_0 / S_{\text{req}} \quad \text{with restriction that } M_{\text{req}} \geq M_0 / 2$$

Whatever the dimensions of the chill, the maximum efficiency is 50 % of the wall thickness



## CHILLS



of the casting!

Symbols:

$V_{chill}$	volume of chill in $cm^3$
$V_{oc}$	volume of casting, concerned in the chill area, in $cm^3$
$\zeta_{chill}$	density of chill metal in $g / cm^3$
$\zeta_{metal}$	density of casting metal in $g / cm^3$
$M_{oc}$	original module of the concerned casting location in cm
$M_{req}$	required modulus of the concerned casting location in cm
$S_{req}$	required surface of concerned casting area, to decrease modulus
$S_0$	original surface of concerned casting area
$S_{T.chill}$	contact surface of chill (contact with casting)
$T_P$	pouring temperature in $^{\circ}C$
$T_L$	liquidus temperature of casting metal in $^{\circ}C$
$T_S$	solidus temperature of casting metal in $^{\circ}C$
$T_{chill}$	maximum allowed temperature of chill
$C_{chill}$	average specific heat of chill metal (20 to $400^{\circ}C$ )
$C_{metal}$	average specific heat of liquid casting metal
$L_{metal}$	melting heat of casting metal

$L_{metal}$	grey (flake) iron		
	ductile iron	64 cal / g	
$C_{metal}$	grey (flake) iron	0,175 cal / g $^{\circ}C$	720 J / kg. $^{\circ}K$
	ductile iron	0,12	515
	compacted iron	0,15	620
	steel	0,125	520

The final temperature of the chill will be, depending on the ratio of chill volume ( $V_{ch}$ ) to casting section volume ( $V_{ca}$ ):

$V_{ch} / V_{ca}$	0,26	0,40	0,52	0,72	1,00
Final temperature	810 $^{\circ}C$	730	720	580	400
Cooling rate	11,4 $^{\circ}C/min$	16,6	21,1	28,5	38,9
Range $T_p - 730^{\circ}C$					

### 5.2 Internal chills



## CHILLS



The condition for this formula is that the internal chill has the equal chemical composition and will melt and mix with the casting metal.

It is very difficult to have a correct calculation, but the following formula has a fairly good result:

$$V_{\text{chill}} = V_{0c} * (M_{0c} - M_{\text{req}}) [ 0,33 * L_{\text{metal}} + C_{\text{metal}} * (T_P - T_S)] / M_{0c} * (C_{\text{metal}} * T_S + 0,5 * L_{\text{metal}})$$



## 6. RULES

1. MAXIMUM INFLUENCE
2. DATA FOR COOLING MEDIA
3. SOME GENERAL DATA FOR MODULUS MODIFICATION
4. LOCATION OF CHILLS FOR SECTION CONNECTIONS
5. COMBINATION OF CHILLS
6. ENLARGEMENT OF ENDZONE OF RISERS
7. MICROSTRUCTURE

### 1. MAXIMUM INFLUENCE

Maximum influence of an **iron chill** is the following, which ever is the lowest:

- Section thickness / 2
- Chill thickness / 2

The chill thickness mostly is doubled because of:

- the extra heat due to the “overheating” (temperature difference with the liquidus temperature) at the time of pouring
- the heating up of the chill during filling the mould, due to the flow over of the metal.

The optimum heat transfer is done if the thickness equals the thickness of the section. The following rules are valid:

- \* thickness chill equals thickness section                      good transfer
- \* thickness chill equals 1 to 2 times thickness section        equal good transfer
- \* thickness chill equals more than 2 times thickness section    decreasing transfer.

Concerning the influence at the side of the chill (T is thickness of section):

- \* 4 x T            high conductivity materials: aluminium, copper...
- \* 2 x T            steel.

#### Remark:

**The modulus of the chill can be as high as the modulus of the section concerned.**



## CHILLS



### 2. DATA FOR COOLING MEDIA (CHILLS)

The most important data, to use for a quick estimation of the required chills, are given in the next table.

Material	Air gap	Density	Specific heat	Heat Conductivity	Temperature chill	Y factor	M <sub>mod</sub>	Thick-ness chill	Influence zone
		g/cm <sup>3</sup>	J/kg.°K	W/mK	°C		x M <sub>0</sub>	x d <sub>0</sub>	x d <sub>0</sub>
Iron	no	7,2	670		500	3,0	0,50	0,50	1,5
	yes	7,2	670		500	2,0	0,65	0,50	2,0
Graphite	no	2,1	1510		500	2,60	0,55	0,36	1,67
	yes	2,1	1510		500	1,80	0,70	0,36	2,15
SiC-bloc	no	2,4	965		500	1,65	0,75	2,45	2,65
	yes	2,4	965		500	1,20	0,90	2,45	3,00
SiC sand		2,4	965		400	1,65	0,75	2,90	2,65
Chromite		2,8	1215	0,215	400	1,40	0,83	1,50	2,75
Magnesite		2,8	1045		400	1,32	0,86	1,60	2,80
Zircon		3,0	1420	0,305	400	1,35	0,85	1,60	2,80
Silica		1,6	1130	0,255	400	1,00	1,00		
Cerabead		1,7	1840	0,223	400				

1. Y-factor to use in the formula
2. M<sub>mod</sub> is the lowest possible value for the modulus after applying the chills. The value is given in comparison with the initial modulus.

$$M_{\text{mod}} = \text{factor} \cdot M_0$$

3. Minimum thickness of the chill, to be able to remove all necessary heat, is given in relation to the physical thickness of the casting section.

$$T_{\text{chill}} = \text{factor} \cdot d_0$$

4. Influence zone is the zone that is influenced, concerning solidification, by the chill (material). It is given in relation to the physical section thickness of the casting.

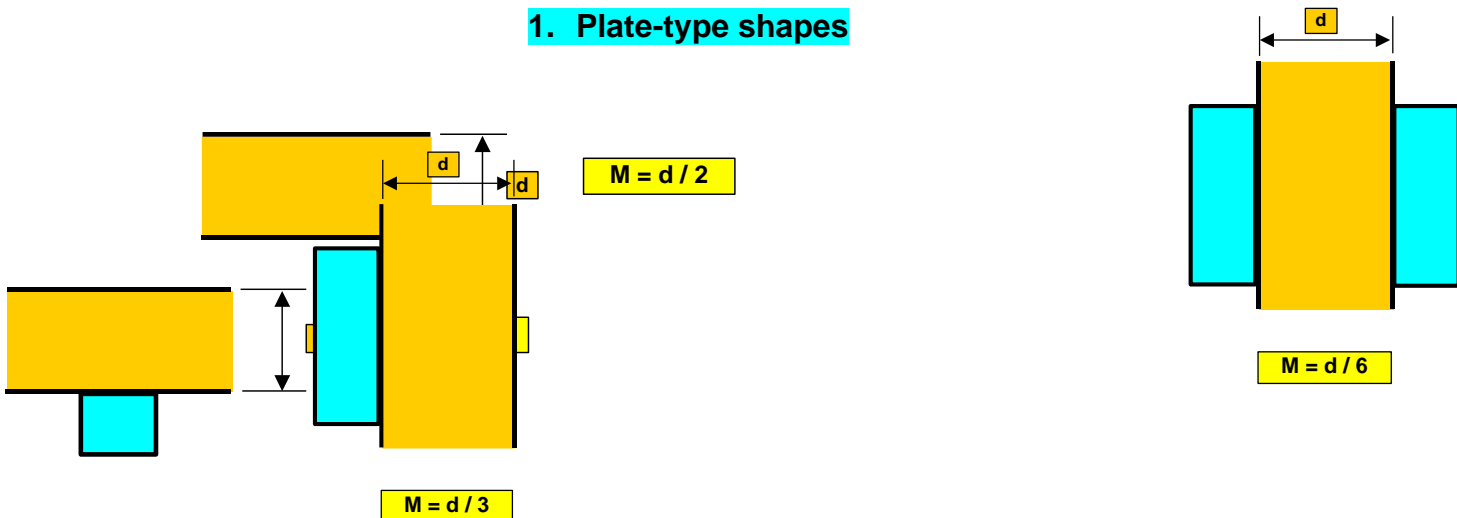
$$Z_{\text{chill}} = \text{factor} \cdot d_0$$

There are more types of chills:

1. iron chills:
  - most commonly used
  - should be pearlitic hematite iron (high carbon, low silicon)
  - no white solidified chill material!
  - Highest chill effect
2. graphite chills:
  - more expensive as material
  - much longer life time (up to 50 times)
  - less maintenance
  - no gas problems
3. SiC chills:
  - expensive
  - can be used as furane sand (any shape possible)
  - better chilling than chromite sand
  - not reclaimable!
4. Chromite chilling (and or zircon):
  - can be used as furane sand
  - lowest chilling effect
  - usable around iron and or graphite chills to smoothen the effect
  - nearly not reclaimable (special equipment)
  - if not properly prepared, risk for gas defects or bad surface condition.

### 3. SOME GENERAL DATA

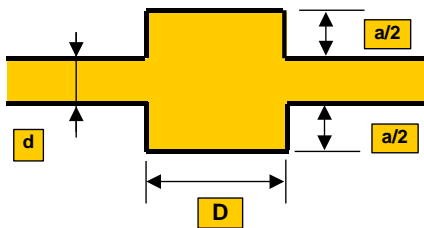
#### 1. Plate-type shapes



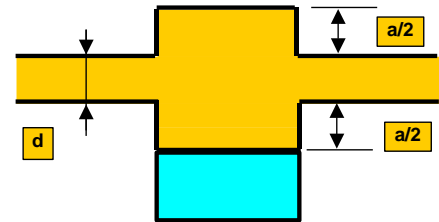
#### 2. Bosses



# CHILLS

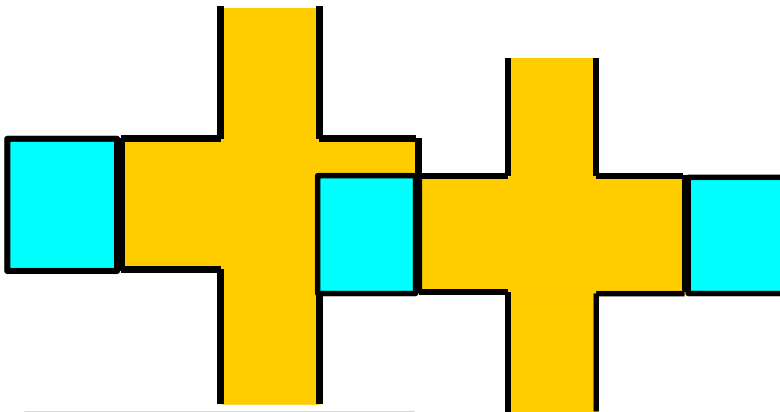


$$M = D (a + d) / 2 (D + 2a)$$



$$M = D (a + d) / 4 (D + a)$$

$$a < 0,95 D * d / (1,05 D - 2 d)$$



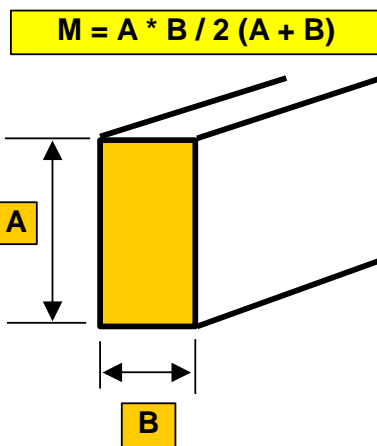
$$M = D (a + d) / (3 D + 4 a)$$

$$M = D (a + d) / 4 (D + a)$$

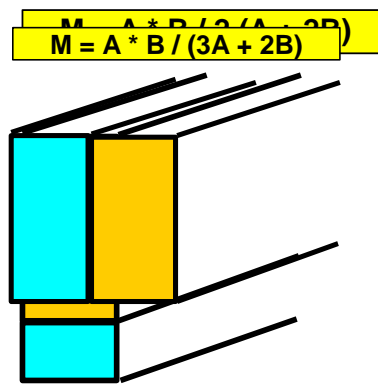
$$a < 0,95 D * d / (1,05 D - 2 d)$$

$$a < 0,95 D * d / (1,05 D - 2 d)$$

## 3. Bar-type



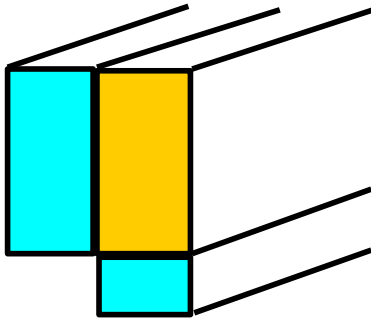
$$M = A * B / 2 (A + B)$$



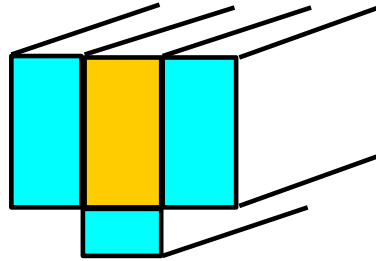
$$M = A * B / (3A + 2B)$$



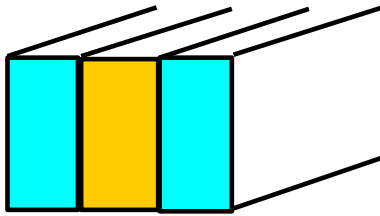
# CHILLS



$$M = A * B / (3A + 4B)$$



$$M = A * B / 4 (A + B)$$



## 4. LOCATION OF CHILLS IN CONNECTIONS

### 1. L-connection

$$M = A * B / 2 (2A + B)$$

A one-side chill, combined with the end effect of the corner, gives a fairly good effect. Anyhow there will be some small defect (porosity).

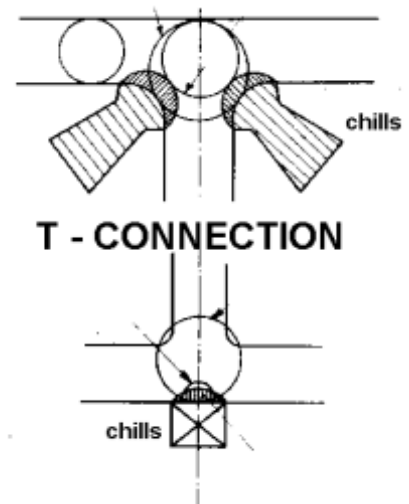
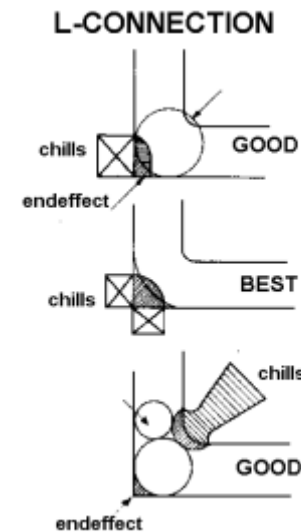
The equal result with a chill at the inner corner part.

The best result is obtained with a double-sided chill location at the outside of the corner.

### 2. T-connection

This connection can be fairly good compensated by a double chill at the inside side of the connection or a smaller chill at the flat side outside the connection.

There will always be some defect (porosity).





## CHILLS

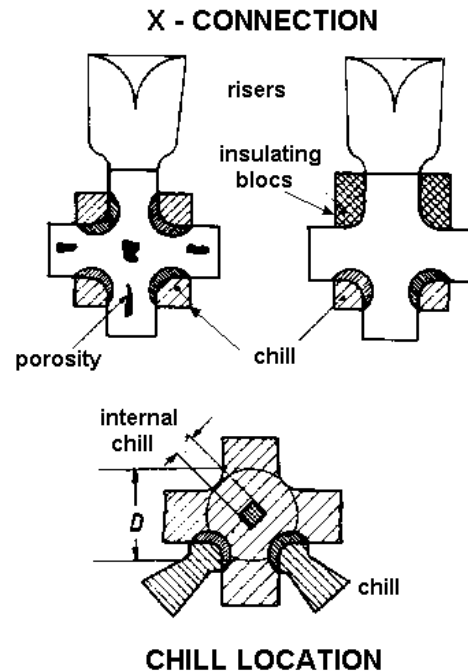


### 3. X-connection

This connection always needs a riser to avoid defects (porosity), whatever the concept of chills will be.

The best result is a riser, combined with insulating material to assure that the feeding of the riser will reach the connection of the section.

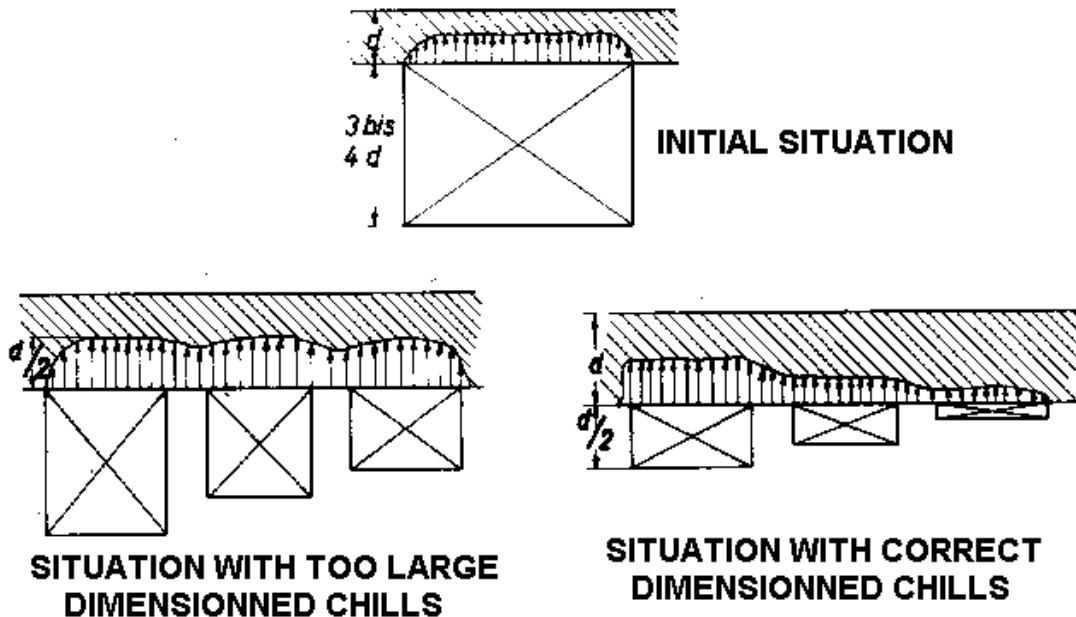
If this connection is vertically oriented, it is necessary to set a riser on the top. At the downside part, it is preferred (if this is allowed) to use an internal chill as indicated in the picture.



## 5. COMBINATION OF CHILLS

A chill is mostly over dimensioned concerning thickness; to assure that the heat from the “overheated” metal can be removed easily. The figure has a chill of 3 to 4 times the section thickness of the casting. This has no problem is one chill is used.

If there is a need for extending the influenced zone, it is necessary to decrease the thickness of the chills to assure a decreasing influence.



How to locate a group of chills?

There are several factors that come in. First there is the influenced depth of section and secondly there is the danger for cracking.

### 1. Influenced depth

If there is a zone with equal thickness chills, the effect of the chills must be equal. It is very important to check if the riser can feed the zone in between the chills. This is different for a vertically or horizontally oriented chill layer.

There is a difference between steel (dendritic solidification) and irons (more mushy solidification). It is accepted that the feeding continues through connection with a modulus equal or higher as 0,8 times the neighbouring modulus for ductile iron and even 0,4 times for grey iron (with a carbon equivalent  $> 4,2$ ).

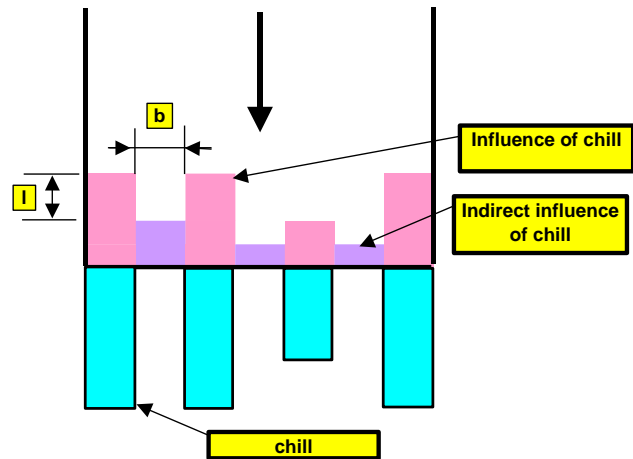
## 1. Vertically feeding

Because the feeding metal is coming from the top, the feeding will be sufficient, depending on the gap between the chills.

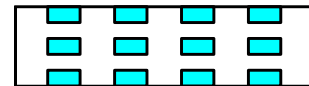
Depending on the material the dimensions of the non-influenced gap must meet the following requirements:

$l < 3 \cdot b$  for steel and high alloyed iron  
 $l < 6 \cdot b$  for irons

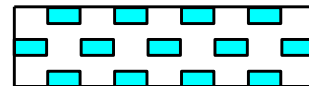
If the gap is equal to the dimension of the chill, the feeding is done and no cracks will appear.



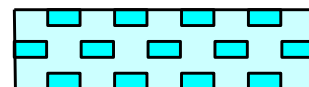
The location pattern as shown here is not the best one because at the crossing lines, there is a larger area of non-covered spots.



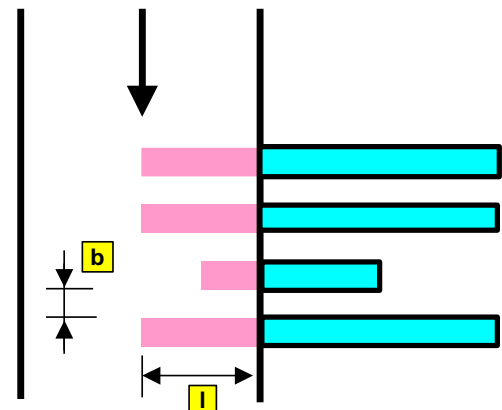
This layer type is better, having a more equal non-covered spot area.



If the previous type of layer is combined with cooling mould material (chromite sand...), the result will be very good.



If there is vertically feeding with sidewall chills, the rules of horizontally chilling and feeding are applicable. See next page.



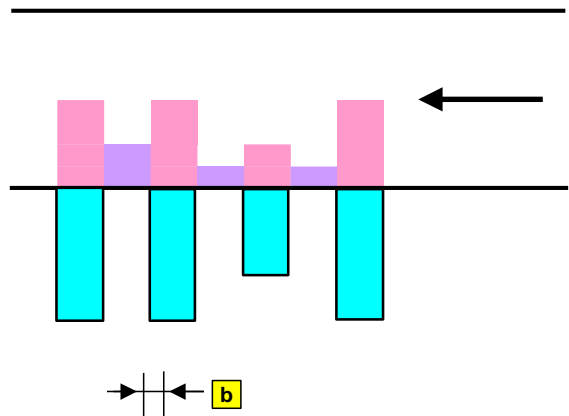


# CHILLS

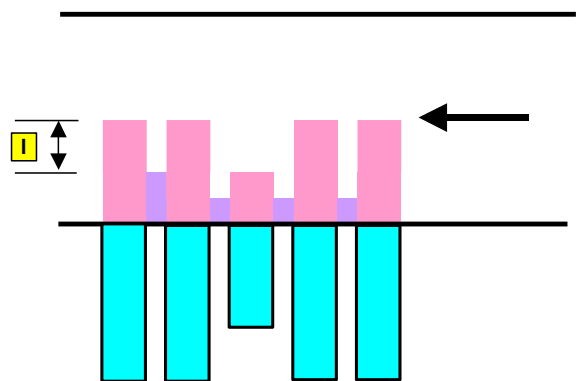


## 2. Horizontally feeding

The feeding of this situation will not be secured, especially due to the fact that the gap is equal to the dimension of the chill, but the difference in remaining section (non influenced thickness) is too large (difference between 0,8 and 1,0 can be fed in iron), especially for steel.

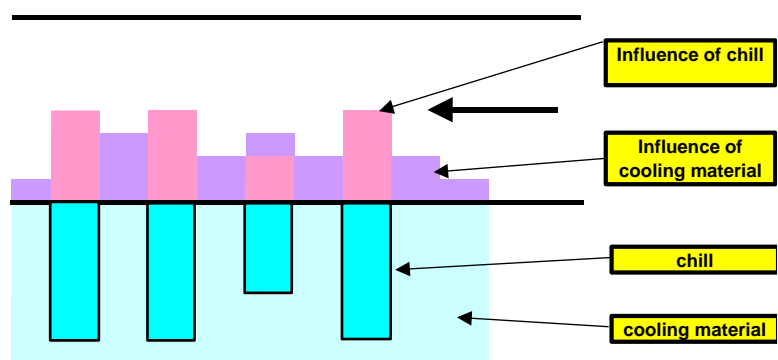


The feeding will also not be secured due to the same reason as above, with on top that the dimensions of the gaps do not comply with the rules as indicated for the vertically feeding:



$l < 3 \cdot b$  for steel and high alloyed iron  
 $l < 6 \cdot b$  for irons.

The best solution is given by filling the gaps (should be as small as possible) with cooling moulding material.





## CHILLS



### 2. Danger for cracking

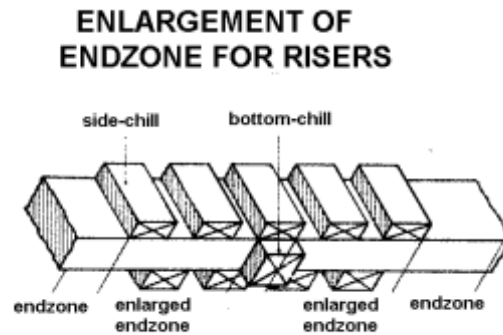
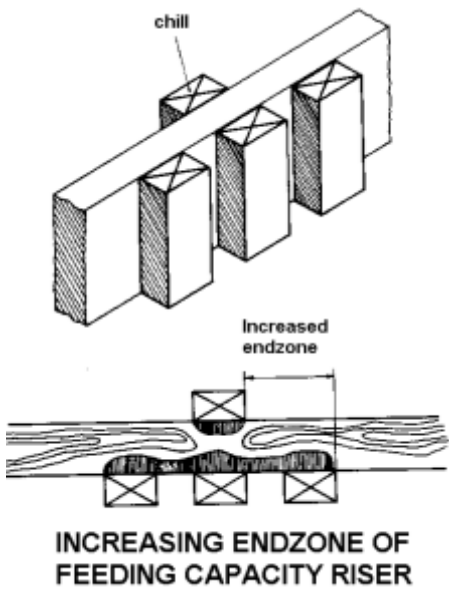
The materials that have a solidification with dendrites and a very small solidified surface layer, will suffer from the tension forces due to the shrinkage of the solidifying metal touching the chill surface.

This is the case with steel. This effect is shown in the chapter 7 Non Conformities. The solution is to decrease this effect by the use of neighbouring chill material, which smoothen the cooling effect.

Another solution is the decreasing of the influenced zone by decreasing the thickness of the chill. The distance between the chills must be around the “chill touching dimension”. But doing this, it can be that the cooling effect is not sufficient anymore.

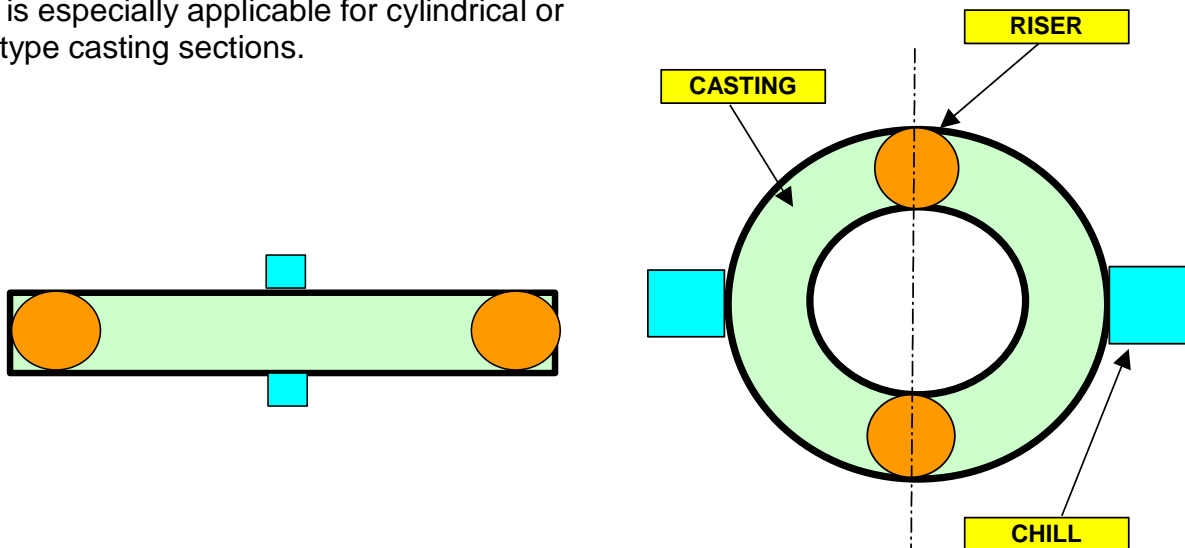
This problem is nearly non-existing for iron. The grey and ductile irons are forming immediately a surface layer and the solidification is progressing without dendrites. In this way the solidified metal can resist the tension forces. Anyhow the use of cooling mould material is preferred and will benefit the efficiency of the chills.

## 6. ENLARGEMENT OF ENDZONE FOR RISERS



The chills must be used to limit the feeding distance between two risers!  
 Whatever the pouring circumstances, the small differences in temperature in the area of one riser cannot modify the feeding distance from the other, due to the chill limitation.

This is especially applicable for cylindrical or ring type casting sections.





## CHILLS



### 7. MICROSTRUCTURE

Because a chill is removing a lot of heat in a very short time, the local material has a high cooling speed. Depending on the chemical position and the CCT-diagrams, the local microstructure can be different from the section.

For small sections, the material tends to form pearlite, bainite or martensite and even, with a special chemical composition, carbides. This area will have a high hardness and the machinability will be poor.

For medium sections, a similar trend is present. But due to the heat exposures from the section, the formed microstructures will be tempered. This tempering will reduce the hardness. But still the area of chilling will have a slightly higher strength and hardness.

For large sections, the influenced material will be heated up to temperatures very close to the  $A_{c3}$ -temperature and the formed pearlite (eventually also bainite, martensite is nearly impossible) will be decomposed in ferrite and graphite.

This leads to the situation that low-alloyed irons (alloying elements tend to segregate to the last solidifying metal, which is in the centre of the section) will have a softer material in contact with the chill, compared to the area, which were not in contact. The material will have a ferrite structure and mostly an increased amount of nodule count.

This contradictory effect happens frequently.

The quick solidification also leads to smaller grain sized material and a higher nodule count (for ductile iron). This material mostly has a higher strength and ductility, especially the shock resistance.

For this reason, material that is poured in metal or ceramic moulds will have smaller grains in the surface layer (may be up to 16 mm, depending on the wall thickness) and will have a higher strength and ductility after the proper heat treatment for restoring the required microstructure and carbide presence.

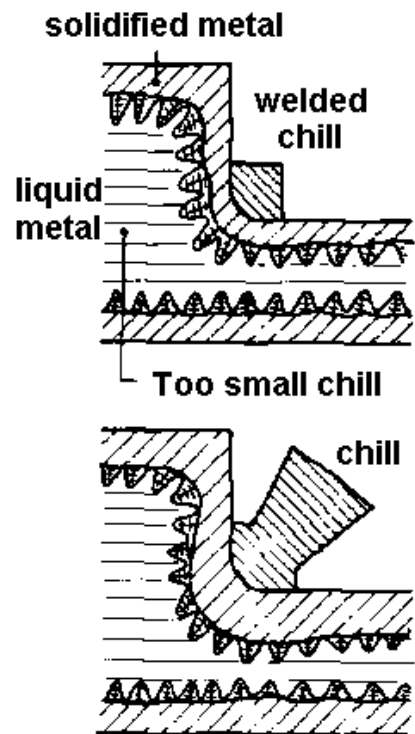
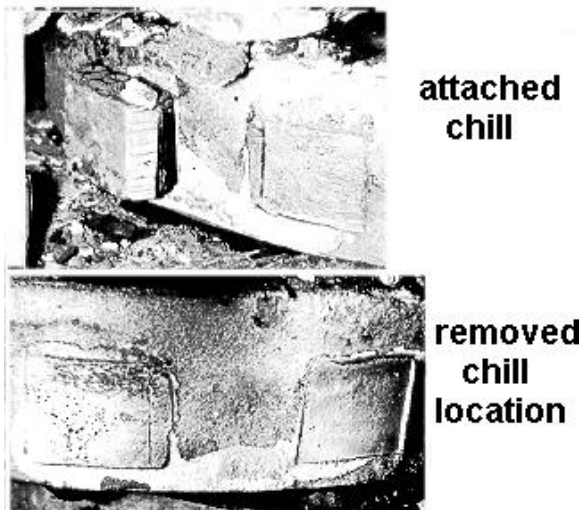
## 7. NON CONFORMITIES

The problems for internal and external chills are different. So it is fact to summarise them separately.

### 7.1 External chills

1. **Welding up to melting of chill into the casting.**

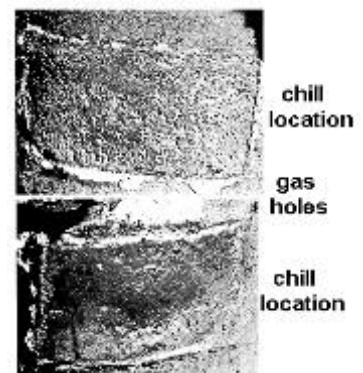
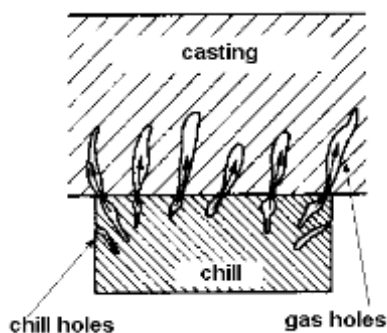
- too high melting temperature
- too small chill volume



## WELDED CHILLS

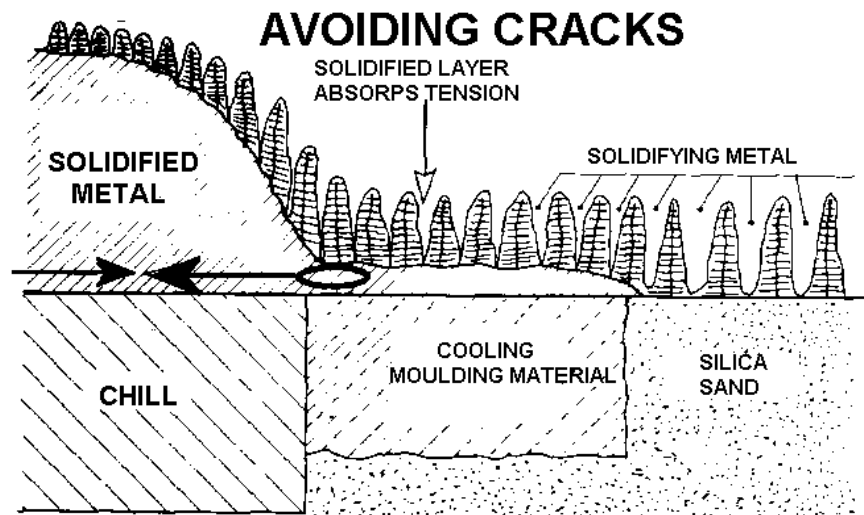
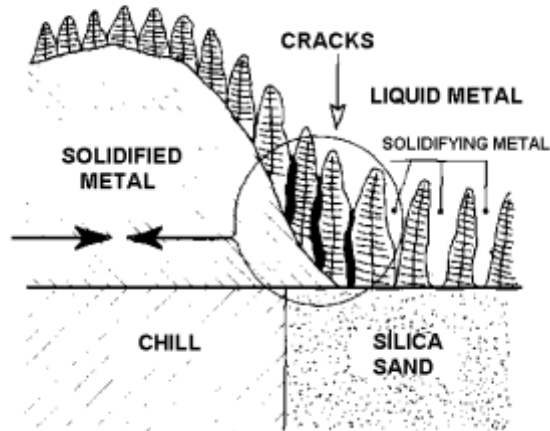
2. **Gas in "contact surface"**

- chills with holes, which contains air, moisture
- rusted chills ( $\text{FeO} + \text{C} \rightarrow \text{Fe} + \text{CO}$ )



3. Cracks below and or at the outside of the chill
  - too large temperature difference
  - too massive chill compared to casting wall thickness
  - restricted shrinking possibility of casting

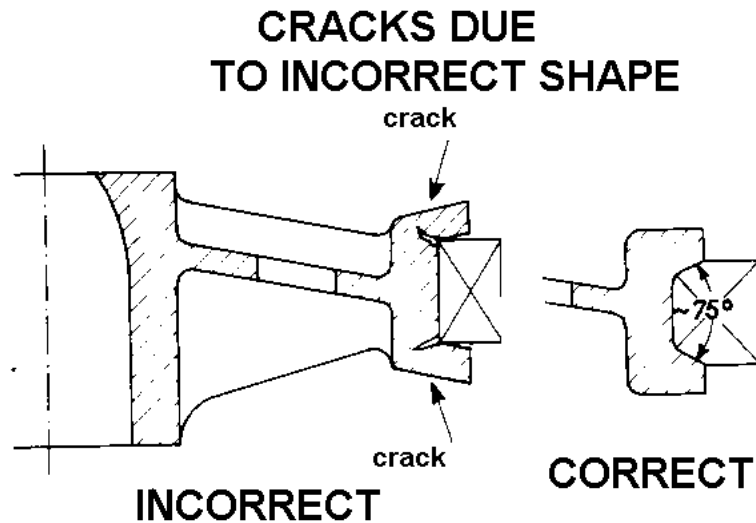
## CRACKS DUE TO CHILLS



USE OF CHILLS + COOLING MOULD MATERIAL

## 4. Stacking (blocking) of chill in corner

- sharp angle will hold the chill
- too high pouring temperature



## 5. Too low efficiency of chill

- chill located in area of ingates
- chill in area where most of the metal is running
- chill has too small volume
- chill metal is not correct (metal, sand or other material).

## 6. Too high hardness

- Ceq of metal is too low (especially for grey iron)
- Mg (+ RE) content is too high compared to the wall thickness
- Too much carbide promoting elements (Mn, Cr, Mg, Ti...)

## 7. 7.2 Internal chills

### 1. Gas around the chill

- Rusty, humid or oily chill
- incorrect shape
- horizontally located chill

### 2. Non conform material around chill (insert)

- zinc coated chills

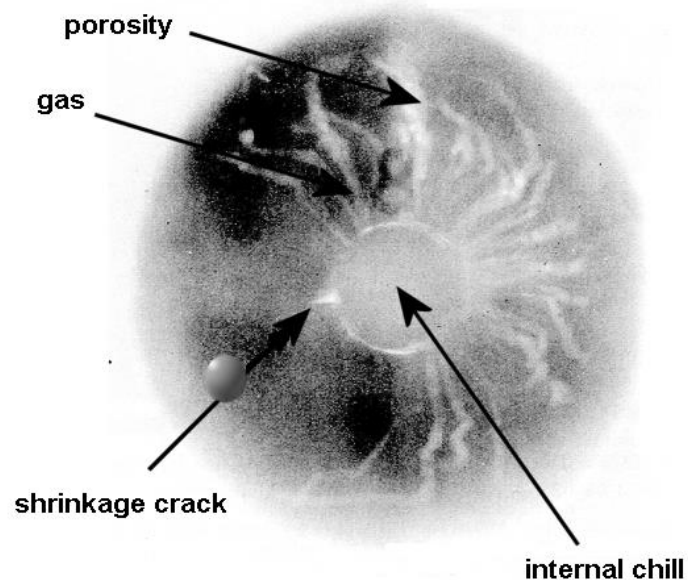
### 3. Cracks due to

- hindered shrinkage
- too small section

### 4. Non melted chill (insert)

- too low pouring temperature
- too high ratio: chill section / material section

## RT of INTERNAL CHILL SECTION





### 8. CONCLUSIONS

It is possible to use chills as a correct tool for controlling quality of material section (porosity), although there is a danger for cracking with some metals (steel).

The structure in the as-cast condition can be monitored by the use of chills. The result is different for small and large sections. Anyhow the material will be small grain sized and therefore have a higher strength and ductility.

The use of chills can reduce the amount of liquid metal; increase the yield (net casting weight to the poured casting weight). Doing this, it will reduce the energy consumption, which is a hot item in most of the countries.

The use of chills needs a “chill-management”, which means that all chills shall be checked before use. This is concerning surface condition, dimensions and location. The problems, faced with iron chills, can be avoided by using graphite and silico-carbide chills. They do not have a problem with humidity and gas inclusions.

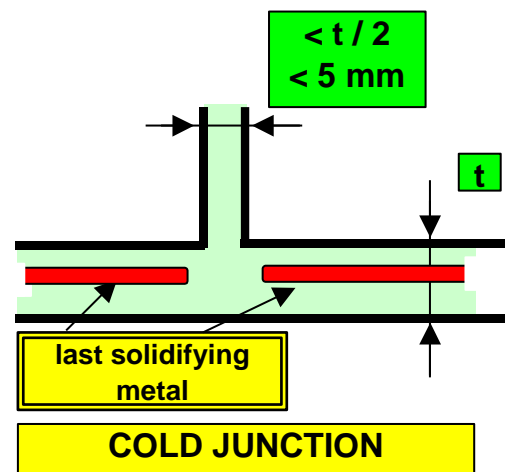
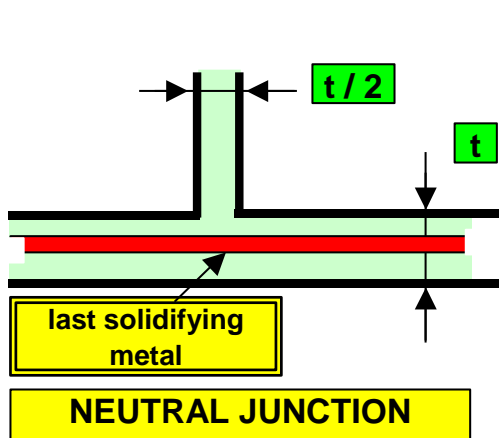
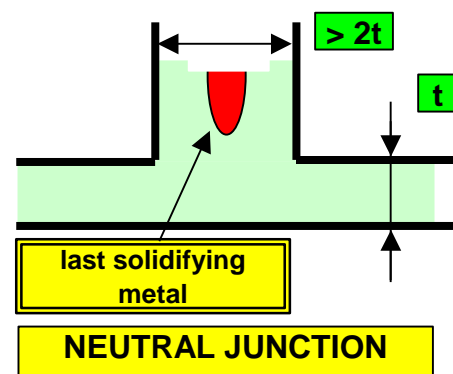
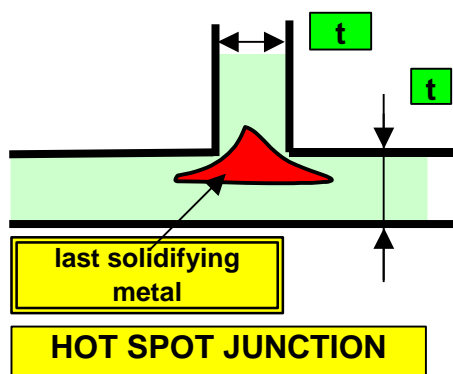
It is important to introduce the correct influence of each type of chill into pouring simulations!

## ADDITION: FINS

A fin is a part of metal, which is very thin compared to its length, that can remove heat from the casting. The principle is found after an examination of T-junctions.

If the body part has a thickness equal to:

"t"	hot spot porosity
"2 t"	no porosity in casting, porosity in body
"t / 2"	no influence in body
"< t / 2"	cooling effect from the body.

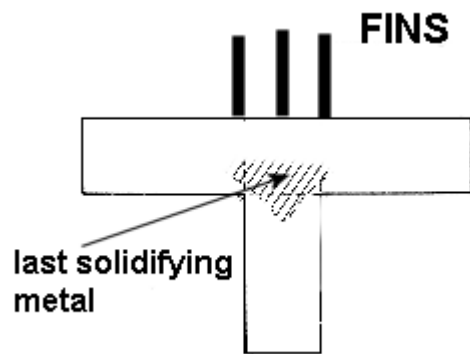


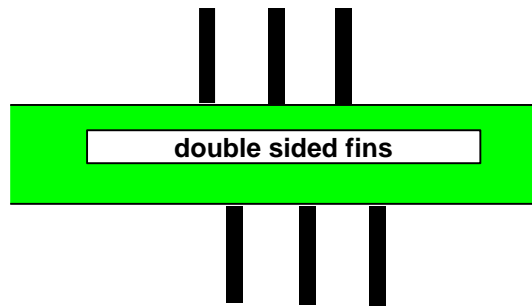
But it cannot be concluded that the thickness can approach zero. As a matter of fact, there is:

1. thickness to be able to remove heat (depends on thickness of casting)
2. length to be able to remove heat (must be a minimum material quantity).



# CHILLS



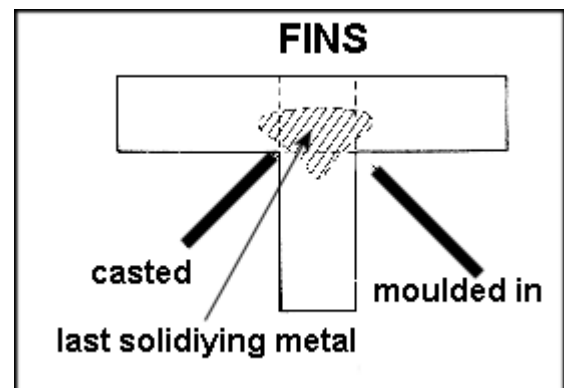


The optimum is a “double sided fin”!

- \* thickness equal 0,07 to 0,09 times thickness of casting section
- \* length equal 2 times the thickness of the casting section.

The lower the heat conductivity, the lower the efficiency of the “fin”. This means that the effect with iron and steel is lower as for copper and aluminium. A chill has a higher effect.

It is possible to use “loose” fins, which are moulded in the mould near to the area that must receive an extra cooling.



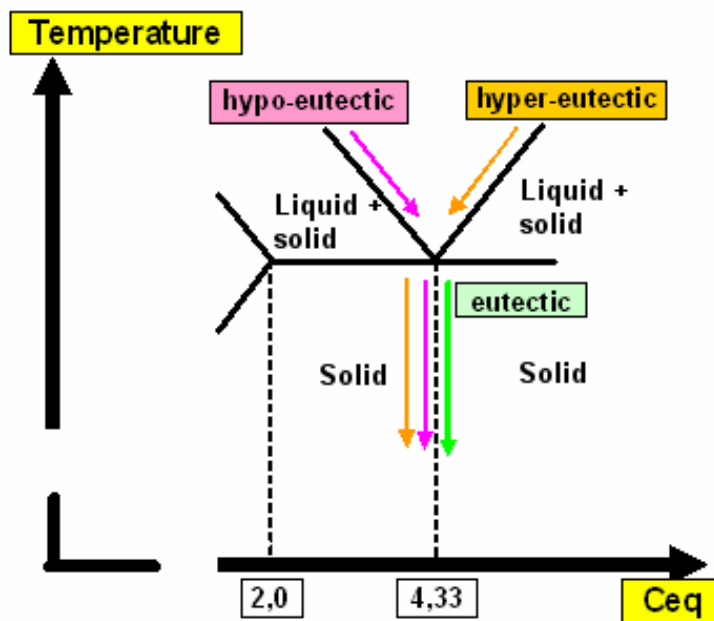
Comparison between chill and fin.

1. fin is better as chill for thin sections
2. fin has always contact with the casting (most of the chills form air gap)
3. no risk for falling out of the mould during handling
4. less risk for gas inclusions
5. less costly (fewer management, longer lifetime...)
6. part of the pattern: always correct located
7. a chill has a higher capacity to remove heat (higher contact surface and volume).

## ADDITION : DIFFERENCE IN EFFECT FOR GREY AND DUCTILE IRON

Both materials have a high efficiency for inoculation and nodulising for ductile iron, when chills are used.

The effect on the material structure and presence of carbides is totally different. The solidification of non-alloyed iron is shown in next figure.



The  $C_{eq}$  increase if the Mg-content increase. So the eutectic  $C_{eq}$  for Mg = 0,04 % is already 4,4 to 4,5 and for Mg = 0,06 %, it will be 4,6 at least. This means that the danger for a clear hypo-eutectic solidification (with more pearlite as is for grey iron) does increase.

Because ductile iron has a  $C_{eq}$  from (4,1 - 4,5 and more for thin castings), it mostly solidifies hyper-eutectic till very few hypo-eutectic. During this solidification, graphite first segregates and the chemical composition moves towards the eutectic one. The tendency to form carbides is very few till non existent if no carbide promoting elements are present.

Grey iron has a  $C_{eq}$  from (3,4 – 4,0), which renders the first solidifying metal hypo-eutectic with the tendency to form pearlite, cementite ( $Fe_3C$  and Fe) and carbides. Free graphite with ferrite (Fe and C) is segregated when the chemical composition of the liquid approaches the eutectic one.

This results in the following test figures:

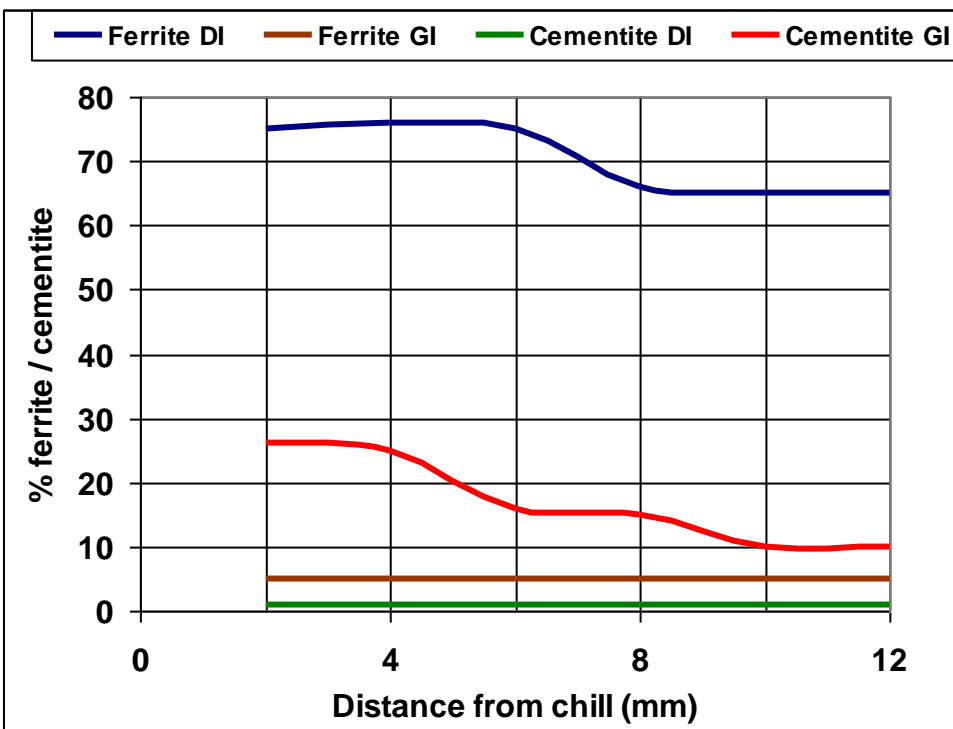
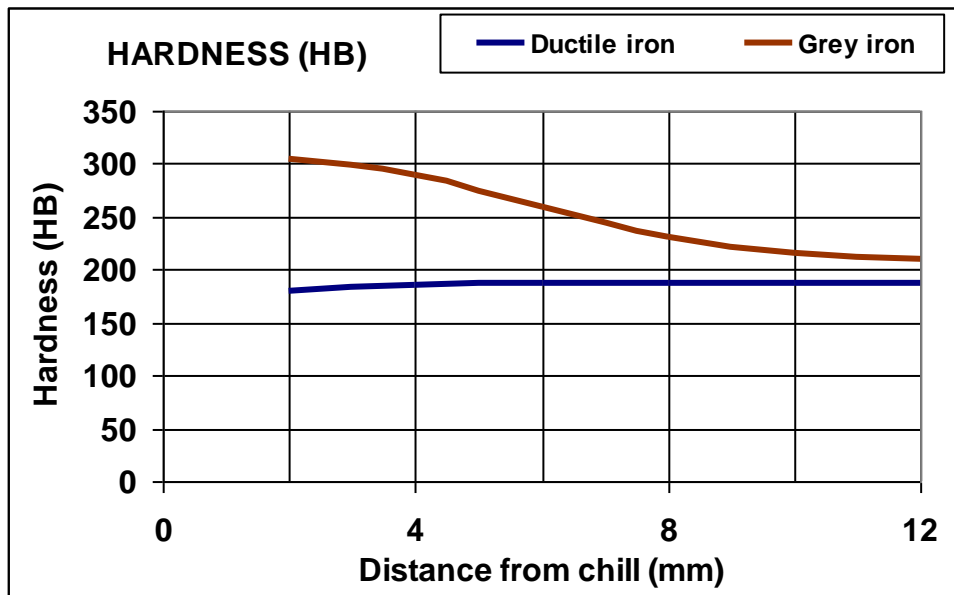


## CHILLS



Material	% C	% Si	% Mn	% P	% S	% Cr	% Mg	Ceq
Grey iron	3,15	1,43	0,61	0,097	0,079	0,15	0,00	3,66
Ductile iron	3,65	2,61	0,78	0,05	0,006	0,035	0,079	4,53

The hardness and % ferrite structure as well as the amount of cementite (iron carbide) is given in next figure, depending on the distance from the chill.





## CHILLS



This indicates at least 70 % ferrite in the surface layer for ductile iron and less than 2 % cementite, where as for grey iron the ferrite content is less than 5 % and cementite increase to more than 25 %.

How to check the iron before pouring? The wedge chill will give all necessary indications. For grey iron, an decreasing  $C_{eq}$  for non-inoculated grey iron metal will show an increasing white solidification in the wedge test. For metal with the chemical composition of ductile iron, before nodulising and inoculation, will show no (or very tiny) white solidification. After nodulising but before inoculation, the wedge test shows mostly a white solidified area.

Also important is to look at the nodule count for ductile iron, dependant on the volume of the chill compared to the volume of the casting (part involved) in function of the distance to the chill.

Important result is that an increasing chill volume compared to casting volume, will increase the nodule count. The effect disappears at a depth of about 15 mm.

