

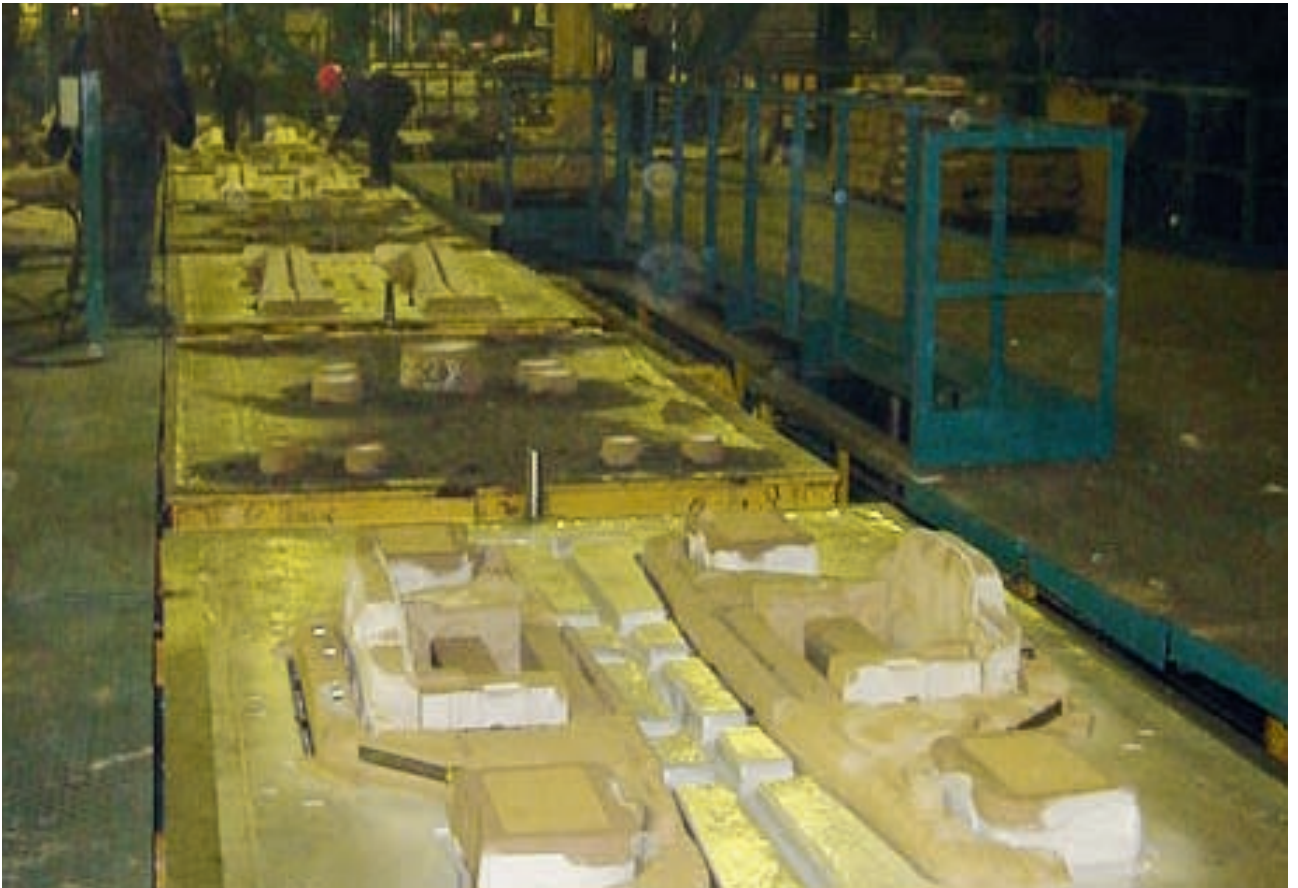
VACUUM MOULDING PLANTS

V-PROCESS

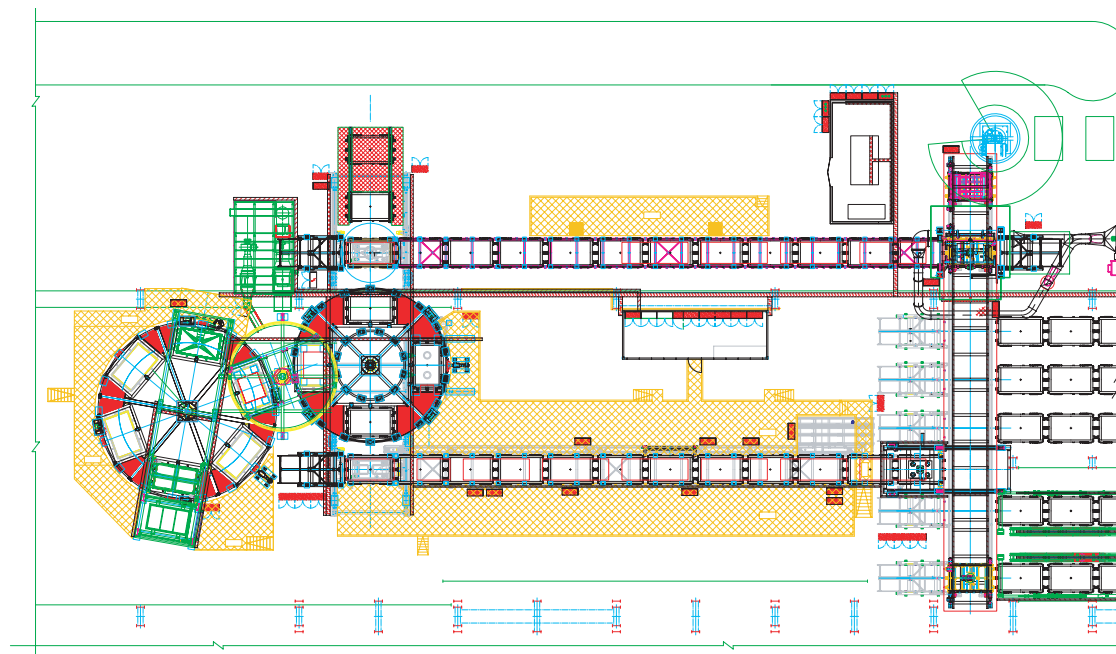
The moulding process for high-quality castings

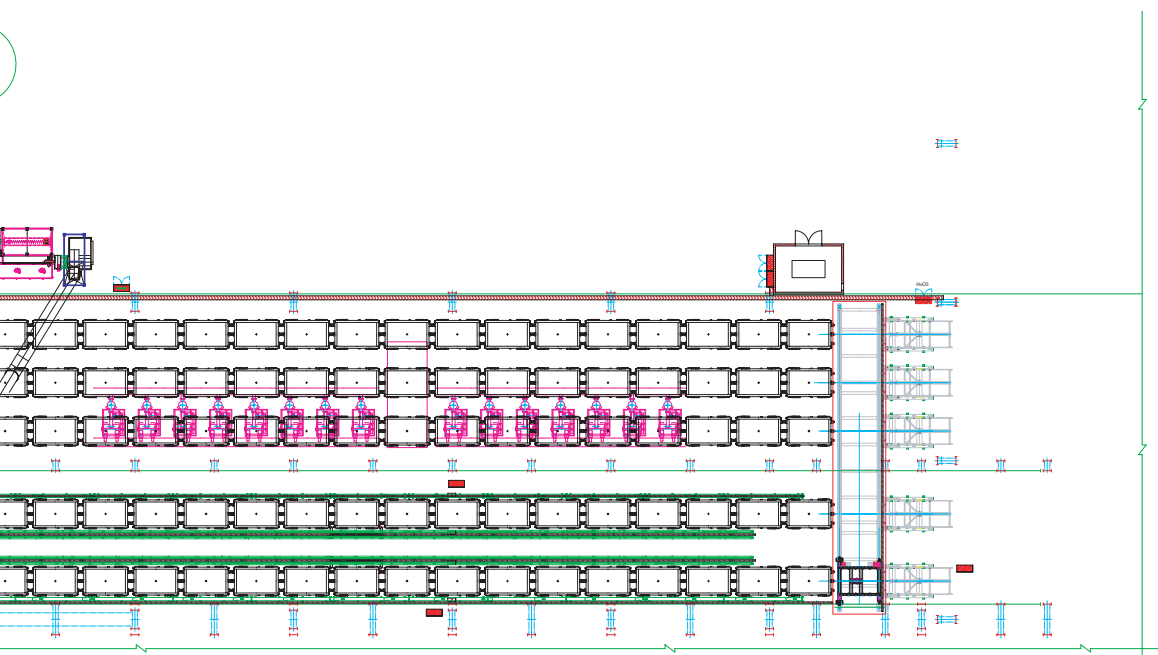
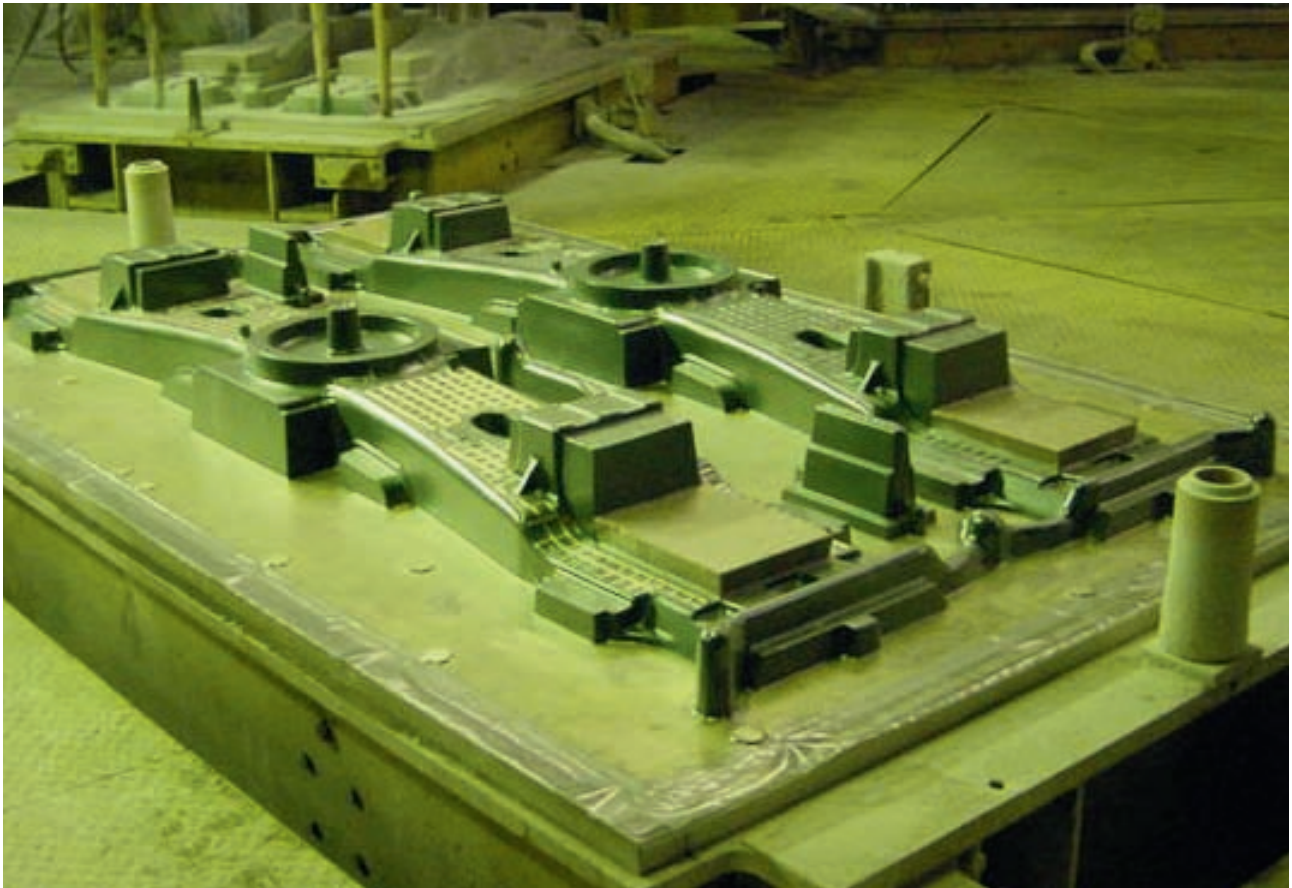


MODERN VACUUM MOULDING PLANTS



Sample of Vacuum Moulding Plant VDK 10

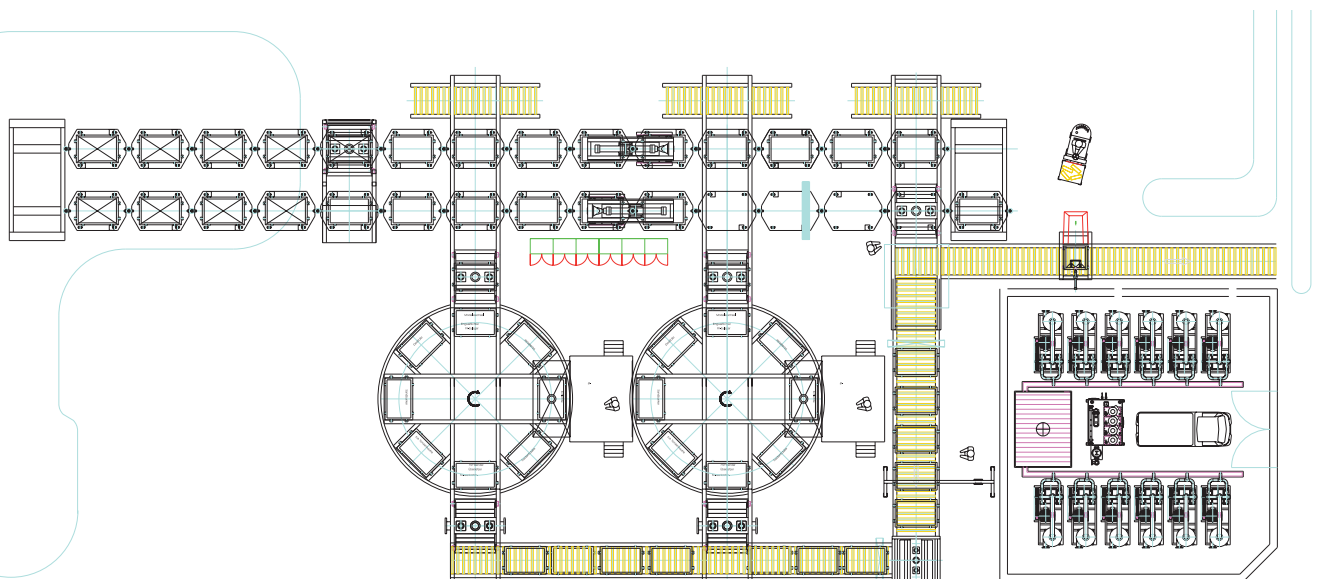




MODERN VACUUM MOULDING PLANTS

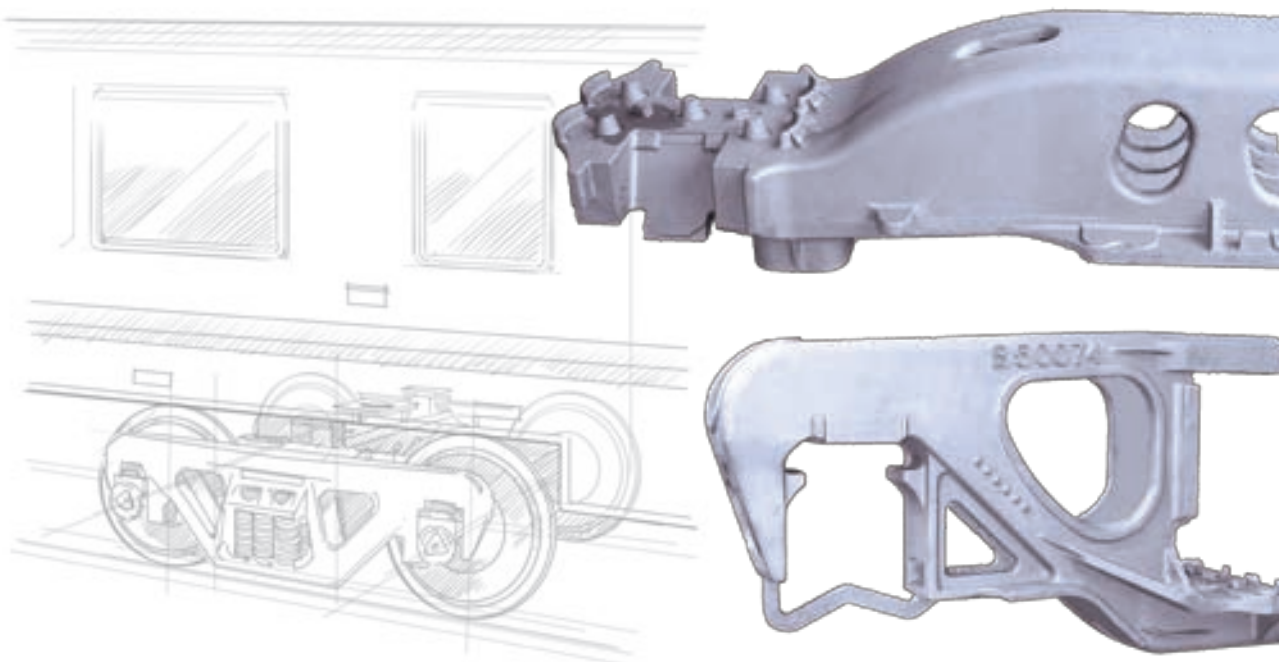


Sample of Vacuum Moulding Plant VFK 7





Sample of a Vacuum Moulding Plant VSA 10



VACUUM MOULDING PLANTS FOR HIGH-QUALITY CASTINGS

A characteristic feature of the process is the inclusion of dry, binder-free silica sand between two plastic films with a sub-pressure of 0.3 – 0.6 bar. This can be compared to coffee or peanuts in a vacuum packaging, for example. What sets vacuum-moulded casting - „Vacuum casting“ apart from others is, above all, the high quality of the surface and the excellent dimensional accuracy. On certain conditions it can be utilized without pattern draft which usually is necessary. That means reduction or even elimination of subsequent machining in individual cases.

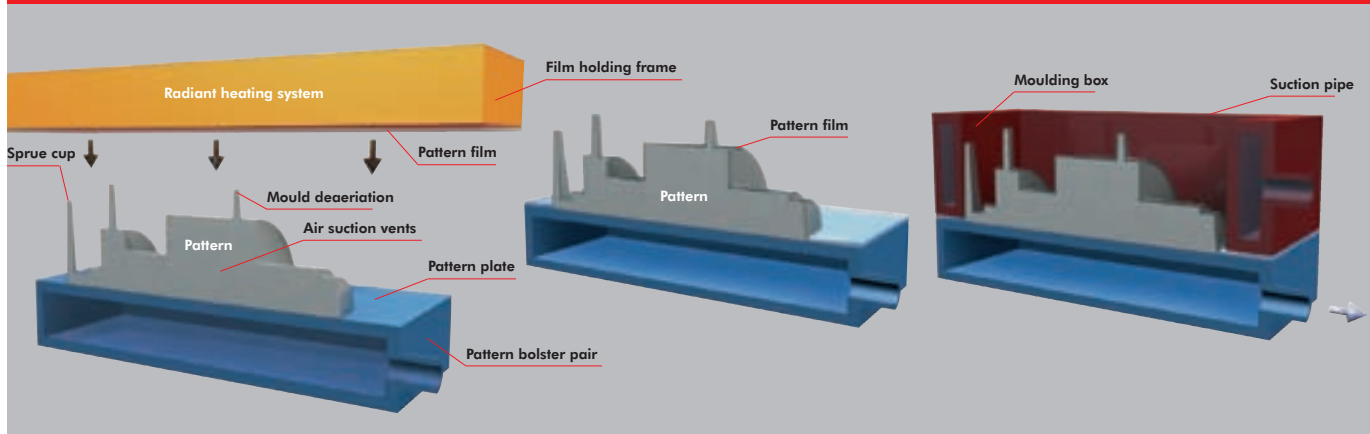
The pattern is mounted on a closed evacuating case - the vacuum box. Both are equipped with numerous vents. Above the thermoplastic plastic film – the pattern film - which is tensed in a frame, the appropriate radiant heating system is situated.

The warmed-up and so to a high degree workable plastic film is lowered onto the pattern. The vacuum box is admitted with a sub-pressure of 0.5 – 0.6 bar and so the film is sucked accurately to the shape of the pattern. After that a black wash is applied on the film.

Further advantages are:

- no pattern wear
- low wall thickness are pourable
- there are no or only small burrs in the mould joint
- the fettling costs are low
- the process is environmentally-friendly and ergonomical favourable

Diagram of the process at horizontal mould joint



■ Picture 3: Part of a vacuum moulding plant with horizontal mould joint (core setting line)



■ Picture 6: Finished mould part with vertical mould joint



■ Picture 9: Finished casting – a slide case DN 400/PN 10, made of nodular graphite iron GGG-40

The double-walled flask, equipped with suction tubes and windows on the inside, is lowered onto the pattern device.

The flask is filled with fine-grained, dry and binder-free sand and is precompacted by vibration. The mould part is covered by a plastic film. The sand between both films is pressed together through the atmospheric air pressure by switching on the vacuum.

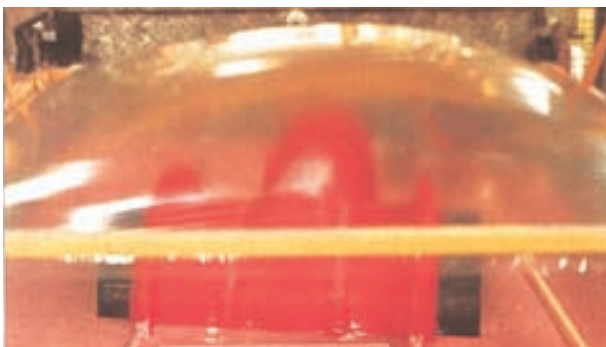
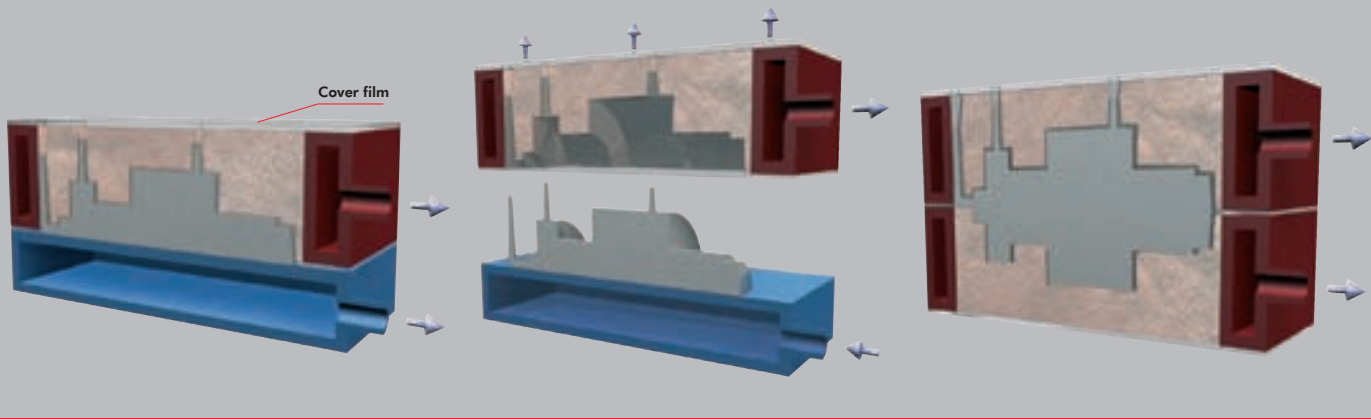
After switching off the vacuum in the pattern carrier, the mould part which is covered with plastic film on both sides and still is admitted with the vacuum is picked-up from the pattern device.

The drag mould is produced in the same way and rotated by 180° afterwards. Necessary cores are set and the two flasks

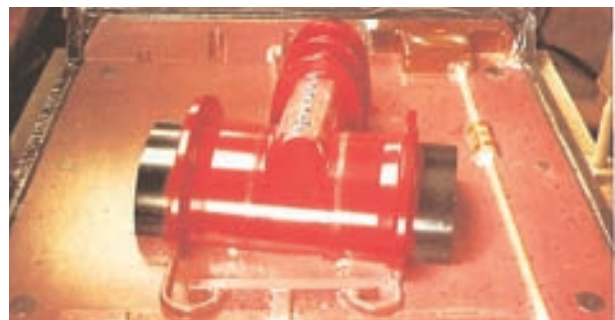
are put together to a ready-to-pour mould. The vacuum remains switched on during pouring and solidifying of the melt.

During the pouring process the film evaporates and/or burns when filling in the casting metal. Because of the vacuum the residues of the film penetrates into the mould and they form a thin shell with the sand particles which compacts the mould in its skin layer. This process is supported by the applied black wash.

For shaking out the flask the vacuum is switched off, the sand flows out and the casting is free for further handling.



■ **Picture 4: Lowering of the warmed-up pattern film**



■ **Picture 5: Pattern with film sucked accurately to the shape by vacuum**



■ **Picture 7: Casting with set core**



■ **Picture 8: Pouring of vacuum moulds with vertical mould joint**

DIMENSIONAL ACCURACY

Dependent on the special characteristics of the vacuum moulding process

- using very fine-grained, graded moulding sands,
- high and consistent sand compaction,
- no wear of the pattern equipment,
- less or no need of draft,
- possible elimination of vibration table for stripping the pattern off the mould,
- no movement of the mould wall due to high mould hardness,
- no deformation by volatilizing moulding sand additives,

the dimensional accuracy and weight constancy of the castings are excellent. The same applies to large casting dimensions, high casting weights and difficult geometric moulds. The reproducibility of the good values at the serial production is excellent, from batch to batch there are no differences ascertainable.

Approximately $\pm 0.3\%$ can be indicated as a reference value for the dimensional accuracy. Further information concerning the reachable tolerances are given in picture 15.

The accuracy to size and repeatability of the vacuum casting offer the worker excellent starting conditons; especially the requirements of modern machining techniques with NC- and CNC- machines are met, an adjustment is usually not necessary.

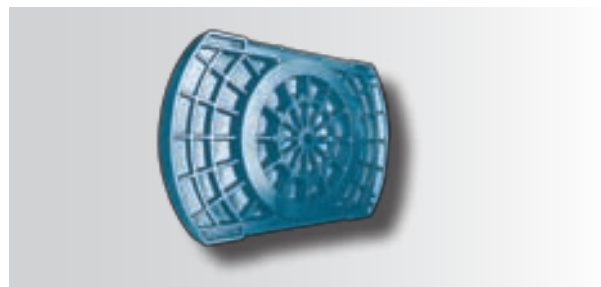
In general the following influences the dimensional accuracy: Is it a so called mould bonded or non-mould bonded size, that means is it formed by one single part of the mould or by several parts of the mould.

An example for this is given with picture 10 showing the table of a milling machine; its outside dimensions are 1250 x 803 x 143 mm (length x width x height). Table 1 shows the corresponding evaluation of the measuring results of 10 parts compared to the accuracy grade GTB 15

Table 1: Mass and dimensions of 10 vacuum moulded castings of the table for milling machines according to picture 10

Serial number	Mass [kg]	Length [mm]	Width [mm]	Height [mm]
1	561.5	1250.3	805.2	143.3
2	560.0	1249.7	804.7	144.3
3	557.5	1250.5	804.3	142.2
4	561.0	1250.1	804.4	142.3
5	558.0	1250.3	804.4	142.5
6	562.5	1249.9	804.4	142.0
7	557.0	1249.8	804.2	142.2
8	561.5	1250.0	804.5	142.8
9	562.0	1250.3	804.5	142.6
10	558.0	1249.8	803.6	142.3
Desired dimension		1250.0	803.0	143.0
maximum value x_{max}	562.5	1250.5	805.2	144.3
smallest value x_{min}	557.0	1249.7	803.6	142.0
average \bar{x}	559.9	1250.1	804.4	142.7
standard deviation s	2.08	0.27	0.40	0.69
range R	5.5	0.8	1.6	2.3
	$\pm 0.98\%$	$\pm 0.06\%$	$\pm 0.20\%$	$\pm 1.61\%$
permissible tolerance range according to DIN 1686 GTB 15		4.4	4.0	2.6

which is the exacting general tolerance for grey cast iron according to DIN 1686. At the mould bonded length dimension of 1250 mm the range is 0.8 mm, this corresponds to 0.06 %; comparatively GTB 15 permits for this basic dimension a tolerance zone of 4.4 mm as per DIN 1686.



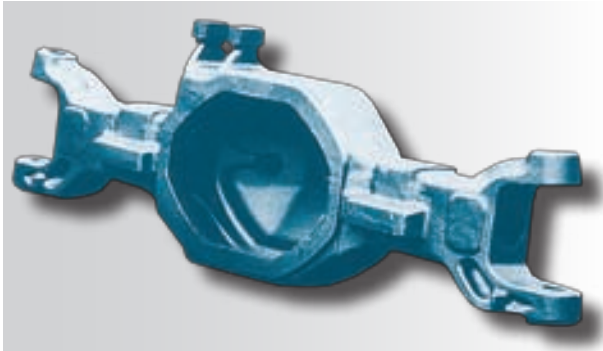
■ **Picture 10: Table for milling machine; material: GG-25, size: 1250 x 803 x 140 mm, Mass: 560 kg; dimensional evaluation of 10 castings, see table 1.**



■ **Picture 11: Rope drum; material: GGG-40 or GGG-40.3, dimensions: 790 x \varnothing 650 mm, Mass: 280 kg; dimensional evaluation of 15 castings see table 2**

Table 2: Dimensions of 15 vacuum moulded castings of the rope drum according to picture 11

Serial number	Distance of the groove peaks [mm]	Diameter of the groove peaks [mm]
1	789.7	650.5
2	789.7	651.5
3	790.5	650.4
4	789.8	652.0
5	790.6	651.4
6	791.0	650.0
7	790.4	650.2
8	790.1	650.4
9	790.7	651.2
10	790.2	651.5
11	790.3	651.5
12	790.2	651.0
13	790.0	651.2
14	790.1	651.3
15	789.7	652.0
Desired dimension	790.0	650.0
maximum value x_{max}	791.0	652.0
smallest value x_{min}	789.7	650.0
average \bar{x}	790.2	651.1
standard deviation s	0.39	0.63
range R	1.3	2.0
	$\pm 0.17\%$	$\pm 0.31\%$
permissible tolerance range according to DIN 1685 GTB 15	3.8	3.8



■ Picture 12a: Axle bridge for a steering type axle; material: GGG-40 or GGG-40.3

The width dimension of 803 mm is also mould bonded; its range is 1.6 mm (= 0.2 %, as per GTB 15 possible: 4.0 mm). At a non-mould bonded height of 143 mm – this is formed by drag and cope mould –with 2.3 mm (= 1.6 % is possible according to GTB 15: 2.6 mm) the range is higher.

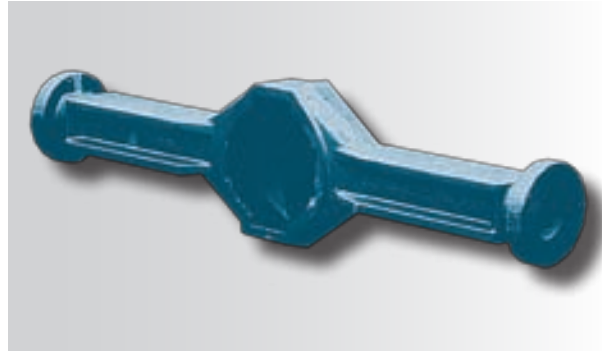
At the width dimension, see table no. 1, it is conspicuous that the desired dimension of 803 mm is outside the tolerance zone reached in the production. The reason is that not all influencing variables at the contraction allowance to be calculated could have been taken into consideration at the production of the pattern. But this does not influence the repeatability of the vacuum moulding process, as shown by the table.

Parallel walls are a typical characteristic of the rope drum, see picture 11. They are perpendicular to the grooves and are vacuum poured without conical form.

Now the wear of the rope is much less than in the past because of the high surface quality. Table 2 shows measured values for the diameter and the mutual distance of the walls. At the tolerance zone of 3.8 mm each according to GTB 15

Table 3: Mass and sizes of 15 vacuum moulded axle bridges of utility vehicles

Serial number	Mass [kg]	Length [mm]	Width [mm]	Height [mm]
1	149.5	1615.0	182.3	386.0
2	150.0	1614.0	182.3	385.3
3	150.0	1614.0	182.1	385.6
4	151.0	1613.5	182.7	385.3
5	150.0	1614.0	181.5	384.9
6	152.0	1613.5	181.6	385.4
7	150.0	1613.0	182.4	385.3
8	151.5	1614.0	181.6	385.2
9	150.0	1614.0	181.8	385.3
10	150.0	1614.0	181.7	384.7
11		1614.0	181.6	385.6
12		1614.0	182.4	385.6
13		1613.0	181.7	384.9
14		1614.0	181.9	384.3
15		1613.5	181.8	384.9
maximum value x_{max}	152.0	1615.0	182.7	386.0
smallest value x_{min}	149.5	1613.0	181.5	384.3
average \bar{x}	150.5	1613.8	182.0	385.2
standard deviation s	0.81	0.49	0.38	0.43
range R	2.5	2.0	1.2	1.7
	$\pm 1.66\%$	$\pm 0.12\%$	$\pm 0.66\%$	$\pm 0.44\%$
permissible tolerance range according to DIN 1685 GTB 15		5.0	2.8	3.2



■ Picture 12b: Axle bridge for a rigid axle; material: GGG-40 or GGG-40.3

this is only 13 mm (= 0.17 %) at a mould bonded distance dimension of 790 mm, however, at the non-mould bonded diameter of 650 mm it is 2 mm (= 0,31 %).

Axle bridges of utility vehicles from which a rigid axle and a steering type axle are shown in picture 12, may have considerably bigger dimensions than the components mentioned so far. According to the dimension they have piece weights of approximately 100 to more than 250 kg. The dimensions of 15 vacuum moulded axle bridges are shown in table 3.

At an average linear dimension of approximately 1614 mm, the difference between the largest and the smallest size is only 2 mm and that corresponds to a tolerance zone of 0.12 %; according to GTB 15.5 mm are permissible. The comparison of the mass with the axle bridge which has been produced conventionally with green sand casting before, is remarkable because the same pattern has been used. Because of its high mould stability and/or mould hardness resp. the vacuum moulding process lead to a (unmachined part) mass which was approx. 6 % lower.

The segment shown in picture 13 was produced for an underground tunnel ring with an inside width of 5800 mm. The arc length is approximately 2200 mm, the nominal value for the width „B“ is 1104.9 ± 1.5 mm. The evaluation of 445 segments shows that with vacuum casting the standard deviation „s“ with a probability of 68 % has been reduced to only 0.5 mm, that corresponds to 0.045 %. Concerning size, geometry and position, the accuracies reached eliminate the need to machine the arc-shaped flanges.

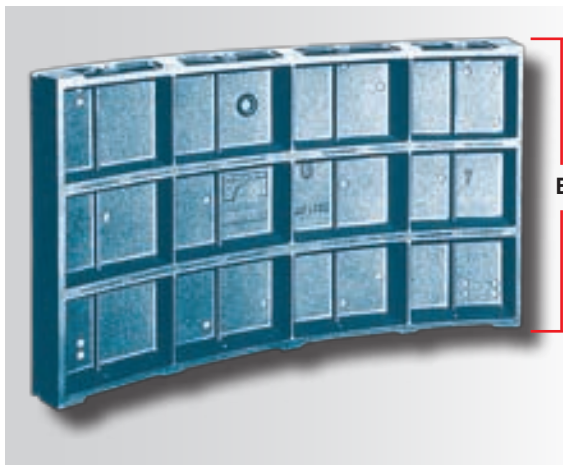
DIMENSIONAL ACCURACY

With a maximum size of only 440 mm the workpiece, shown in picture 14 – closing cylinder for an injection moulding machine - is proportionally small for a vacuum casting. As you can see from the evaluation of the measuring result in table 4, the range of the dimensional variations is within the „usual“ scope; this applies to the mould bonded linear and latitudinal size as well as to the non-mould bonded measure of altitude.

The averages mentioned in the tables 1 – 5 as well as in picture 13 to the size tolerances are compared in picture 15, dependent on the nominal size, to the accuracy grade GTB 15 which is the smallest tolerance series for cast iron with nodular graphite (ends at 800 mm nominal size) and is the

smallest tolerance series for grey cast iron according to DIN 1686. It demonstrates that the permissible tolerances according to GTB 15 are half by using the vacuum moulding process and even the accuracy grade GTB 12 according to DIN 1680 is reached. The non-mould bonded sizes are an exception because here the tolerances are a bit higher.

The experience and tables mentioned so far have been made available by different foundries. To find out possible differences in production dependent on the foundries, five foundries united to a co-operative test and they worked with the same pattern equipment. As workpiece they used the table of a milling machine (Picture 16) with a mass of 495 kg which could be poured horizontally as well as vertically and

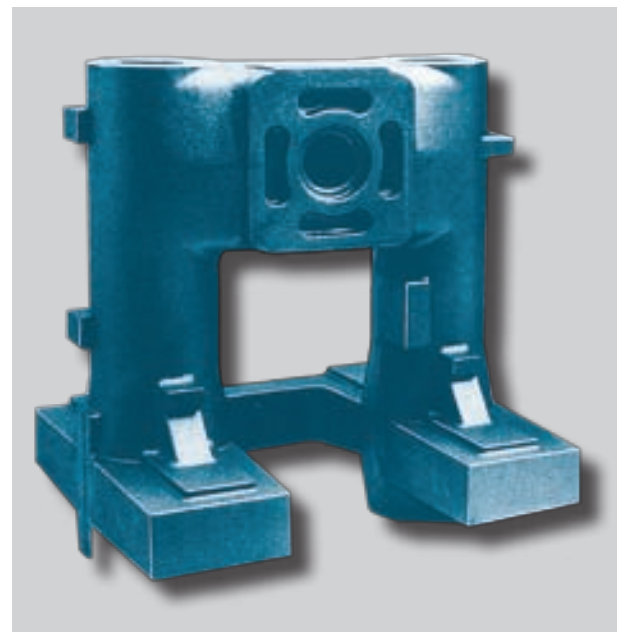


■ Picture 13: Segment for a tunnel ring with a clear opening of 5800 mm in a lightweight construction and evaluation of the latitudinal measure B of 445 castings; material: GGG-50, dimensions: 2200 x 1100 mm, thickness of back wall: 8 mm, Mass: 400 kg

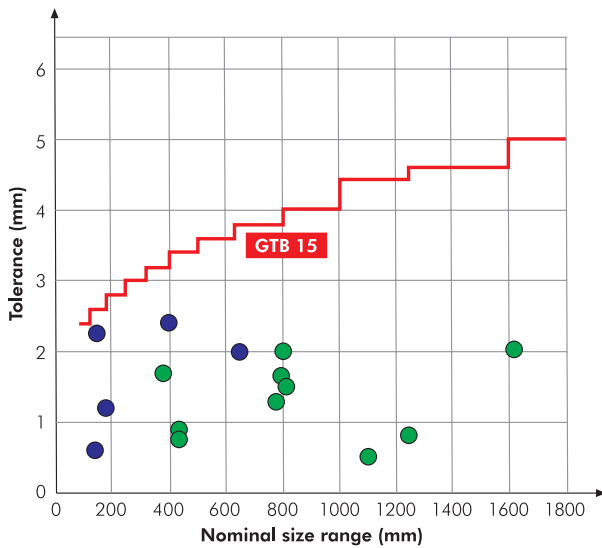
Projekt / Werkstück-Nr.: Segment-Mr. 1 Datum: 01.08.1986 Merkmal: B Sollwert: 1104,9 ± 1,5 Unterer Sollwert: 1103,4 Oberer Sollwert: 1106,4 Untere Sperrgrenze: 1100,9 Obere Sperrgrenze: 1108,9 Klassenzahl: 36 Klassenbreite: 0,5									
Gr.	Gr.	Werte JGr	Rel. z	Summ. z	k = 31 Rel.				
1100,9	1104,4	1,0	0,22	0,22					
1105,4	1103,9								
1101,9	1102,4								
1102,4	1102,9	2,0	0,45	0,67					
1102,9	1103,4	35,2	3,18	8,86					
1103,4	1103,9	242,8	54,26	65,12					
1103,9	1104,4	104,2	22,45	85,76					
1104,4	1104,9	40,5	0,24	74,84					
1104,9	1105,4	13,5	2,03	92,87					
1105,4	1105,9	4,5	2,31	98,08					
1105,9	1106,4	3,0	0,47	99,55					
1106,4	1106,9								
1106,9	1107,4								
1107,4	1107,9	1,0	0,22	99,78					
1107,9	1108,4								
1108,4	1108,9								
Werte über dem oberen Sollwert: 31 = 2,42 % Anzahl der Werte: n = 445 Mittelwert: x̄ = 1103,9 Werte unter dem unteren Sollwert: 1 = 0,22 % Standardabweichung: s = 0,5 ± 0,0452 Maximum: Max = 1107,0 Minimum: Min = 1102,9 Summe Max-Min: s = 4,1 Stat. Sicherheit 95%: 3-2s = 1102,9 Stat. Sicherheit 95%: 0-2s = 1104,9 Stat. Sicherheit 99,9%: 3-3s = 1102,2 Stat. Sicherheit 99,9%: 0-3s = 1105,4									

Table 4: Mass and sizes of 10 vacuum moulded closing cylinders for a plastic-injection moulding machine according to picture 14

Serial number	Mass [kg]	Length [mm]	Width [mm]	Height [mm]
1	147.6	439.0	440.1	399.6
2	147.6	439.1	440.2	401.5
3	148.0	439.4	439.5	401.8
4	147.9	439.3	439.7	401.4
5	148.0	439.9	440.0	401.7
6	147.5	439.7	439.8	401.7
7	147.9	439.7	440.0	401.5
8	148.3	439.9	439.9	401.5
9	148.0	440.3	439.7	401.2
10	148.5	440.0	439.7	402.0
Desired dimension		440.0	440.0	400.0
maximum value x_{max}	148.5	439.9	440.2	402.0
smallest value x_{min}	147.5	439.0	439.5	399.6
average \bar{x}	147.9	439.6	439.9	401.4
standard deviation s	0.32	0.9	0.7	2.4
range R	1.0	0.9	0.7	2.4
	$\hat{=} 0.67\%$	$\hat{=} 0.20\%$	$\hat{=} 0.16\%$	$\hat{=} 0.60\%$
permissible tolerance range according to DIN 1686 GTB 15		3.4	3.4	3.4



■ Picture 14: Closing cylinder for a plastic-injection moulding machine; material: GGG-40, dimensions: 440 x 440 x 400 mm, mass: 148 kg; dimensional evaluation see table 4.



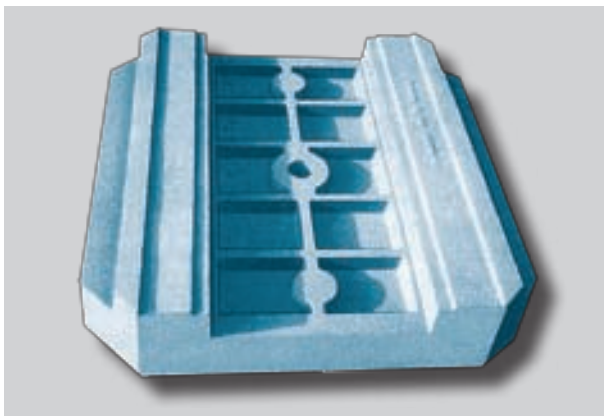
■ **Picture 15: Dimensional tolerances of vacuum casting in mm (left) and % (right) in dependence on nominal size compared to the accuracy grade GTB 15 according to DIN 1680, DIN 1685 and DIN 1686.**

which fit in flasks of different sizes due to its dimensions of 810 x 810 x 140 mm.

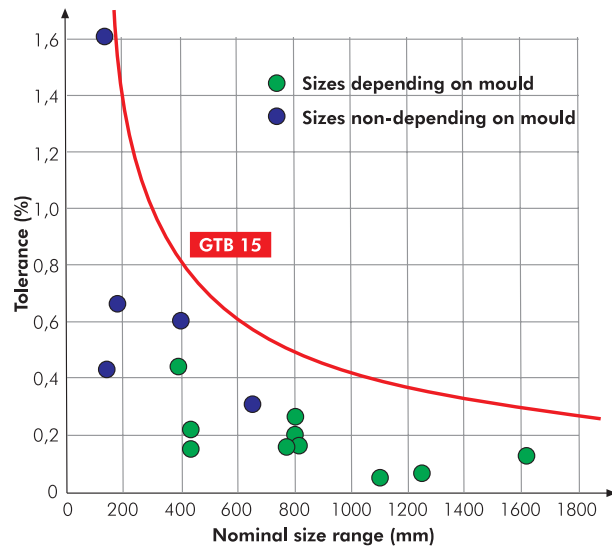
Table 5 shows the results of the co-operative test. The linear and latitudinal measure are with 1.5 mm (= 0.18 %) and/or 2 mm (= 0.25 %) resp. within small tolerance limits, with 0.6 mm – this corresponds to 0.43 % at a nominal size of 138 mm – the non-mould bonded measure of altitude has a range which is a bit higher. With a range of less than 1 % a high weight constancy has also been found out.

The measuring results of the co-operative test are also written down in picture 15. This shows that they are within the usual scope. Consequently, the dimensional accuracy of the vacuum moulding process is determined by the system, company specific influences are not relevant.

Special advantages will be reached with the vacuum moulding process if the spatial bent functional surfaces can be produced so exactly that a machining is no longer required due to dimensional accuracy and surface quality.



■ **Picture 16: Table of a machine-tool; material: GG-25, size: 810 x 810 x 138 mm, mass: 495 kg; dimensional evaluation see table 5**



The measuring points are mostly average values from 10 – 15 single measurements.

This applies, for example, to the blade of the ventilator (picture 18) at which differences in position, size and weight as well as a rough surface would have a negative effect on the resting, the conception and the efficiency of the plant.

At a production of 152 pieces the masses of the single pieces only differed by 150 g, that corresponds to a tolerance of 0.2 % at an average mass of 75 kg. The thickness measurements of all wing blades (wall thicknesses of 4.2 to 13.8 mm) are taken at 18 measuring points; a deviation from 0.1 to max. 0.4 mm has been measured.

Table 5: Dimensions of a vacuum moulded and poured workpiece according to picture 16 with the same pattern equipment at different manufacturers

Manufacturer	Length [mm]	Width [mm]	Height [mm]
1	811.0	809.0	138.5
2	809.5	807.0	138.4
3	810.5	808.5	138.9
4	811.0	809.0	138.4
5	810.5	807.5	138.3
maximum value x_{\max}	811.0	809.0	138.9
smallest value x_{\min}	809.5	807.0	138.3
average \bar{x}	810.5	808.2	138.5
standard deviation s	0.61	0.91	0.23
range R	1.5	2.0	0.6
	$\pm 0.18\%$	$\pm 0.25\%$	$\pm 0.43\%$
permissible tolerance range according to DIN 1686 GTB 15	4.0	4.0	2.6

POURING WITHOUT DRAFTS

In contrast to castings produced by conventional methods a draft, at least partial, is not necessary. Through reversing the sub pressure during the moulding process, that means at lifting the part off the mould from the pattern equipment, there is almost no friction between pattern and film, so that it is also easy to lift the pattern with a draft of 0°. To fully utilize this process-related benefit, an intensive dialogue between the foundry men and the design engineers is highly recommended.

Picture 11 has already shown such a solution. The walls of the rope drum, O.D. of 650 mm, had to be machined on the inside previously because of the existing draft, guaranteeing perfect entry of the rope. By using the vacuum process machining is no longer required and the finished product can be offered with less costs.

The height of the side walls of the case (picture 17) is 130 mm and they are poured without any draft. Aside of the major improvements, the number of cores can be reduced, e.g. the bore holes with small diameter are already pre-casted. As a result, machining expenditures are also less.

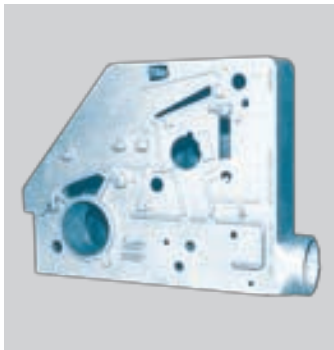
Another example can be given from the section of armatures. The case of the wedge gate valve shown in picture 9 is poured upright, top flange (picture 19) and both flow flanges are not conical, a facing of the sealing surface is sufficient. The used moulding material and the special production

cycle at vacuum moulding lead to an excellent surface quality of the workpieces. There are several reasons for this result. By using a dry, binder-free moulding sand a so called „bridging“ between single sand grains and a different compacting does not occur while compacting by vibration and the following application of the vacuum and therefore the casting surface is correspondingly smooth. In addition, very fine-grained sand is used, as it is not necessary to consider the usually indispensable permeability to gas off the mould. The direct contact between metal and moulding sand during the pouring can be avoided by applying a coating on the film and so the surface quality of the vacuum moulded casting is almost independent of the casting material. Compared to conventional technics it is astonishing that for example workpieces made of cast iron and cast steel have the same fine surface, even if the pouring temperature and aggressiveness of the melt are quite different.

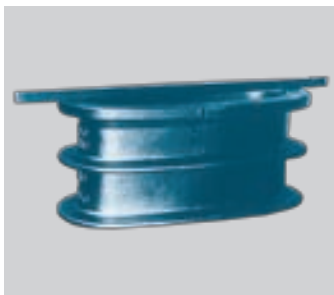
Picture 20 gives an impression of the high outline accuracy and the surface quality of vacuum moulded castings ; the picture shows a part of a machine piece made of grey cast iron with a mass of approximately 200 kg. Here, the pattern film cracked and had been repaired with a transparent scotch tape before coating. The „shape“ of the scotch tape fixed crosswise on the casting is clearly visible.

While in the past some authors only made verbal comparisons between the surface of vacuum casting and rolled steel, in the meantime objective measurements have been made and it is possible to quantify values. Picture 22 a shows that the depth of roughness R_{max} of vacuum casting is only 80 μm . Also shown is a profile screed of dry sand casting (furan resin bonded, picture 22 b) and green sand casting (bentonite bonded, picture 22 c).

The surface quality of vacuum casting is so high that, for example, the often used subsequent shot blasting may even have a negative effect on the surface roughness. The indications of table 6 which are compared to conventionally moulded casting show this clearly. Therefore, shot blasting may be considered as an „enemy“ of the vacuum pouring, especially when it is carried out improperly. – It should be pointed out that the information in line 1 of table 6 – cleaned with wire brush- is the evaluation of the profile screed in picture 22.



■ **Picture 17: Side flask; material: G-AlSi8Cu3, dimensions: 650 x 480 x 130 mm, mass: 11 kg**



■ **Picture 19: Top flange of the case of the wedge gate valve according to picture 9 (DIN 400) which is poured without conical form such as the two flow flanges**

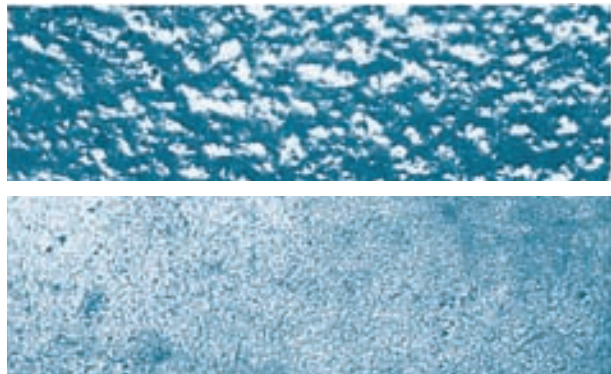


■ **Picture 18: Blade for wind tunnel blower; material GGG-40, length 750 mm, mass: 75 kg**

SURFACE QUALITY

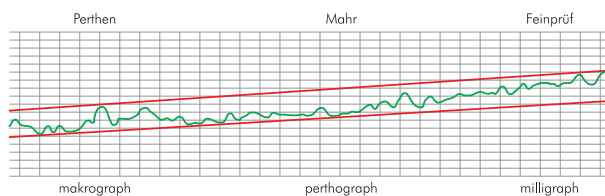


Picture 20: The crack of the pattern film was repaired with scotch tape – an accurate detail revealed by applying the vacuum process

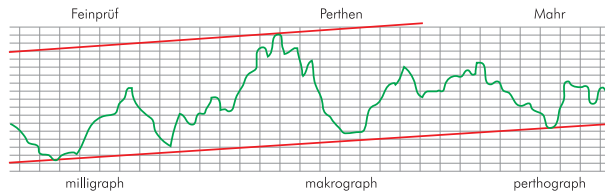


Picture 21: Surface quality of sandblasted aluminium-permanent mould casting (above) and vacuum casting (below), where sandblasting is not necessary; V = 5:1 (original: 6:1)

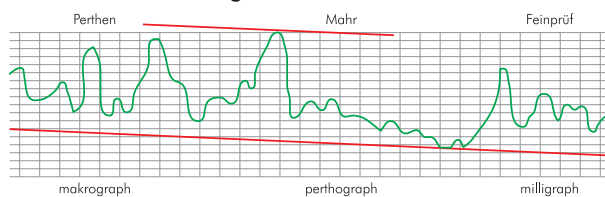
a = Vacuum casting



b = Dry and sand casting



c = Green sand casting



Picture 22

Table 6: Influence of shot blasting with steel shot on surface quality of differently produced grey cast iron parts

Condition of treatment	Moulding process		
	Vacuum pouring	Dry sand casting (Furan resin-bonded)	Green sand moulding (Bentonite-bonded)
	Depth of roughness R_{max} (mm)		
As-cast condition (unannealed), cleaned with wire brush ¹⁾	0.08	0.33	0.27
As-cast condition (unannealed), shot blasted with steel shot in shot-blasting wheel- or hose blasting cabin ²⁾	0.09 to 0.13	0.13 to 0.14	0.23 to 0.34
Annealed at 750 °C, shot blasted in shot-blasting wheel cabin ²⁾	0.13	0.15	0.16

¹⁾ Measurements of roughness depth see picture 22

²⁾ With different fines grades of steel shot

The roughening of the casting surface by shot blasting is also carried out at conventional aluminium-permanent mould casting. Usually, it has to be used to remove the oxide film but this does not apply for vacuum castings. In picture 21 both surfaces are compared and the differences are obvious.

Vacuum pouring has also remarkable characteristics below the surface – in the surface layer. There is no casting skin in the usual sense. On the one hand the complete coating of the mould prevents reactions between casting metal and moulding sand and on the other hand the quenching effect of the dry moulding material is considerably lower compared to green sand casting. The latter is also shown in table 6 when comparing the lines 2 and 3: Annealing at a temperature of 750 °C does not have an influence on the depth of roughness after shot blasting the vacuum casting. The higher skin hardness of green sand castings, can be reduced by two additional process steps (annealing and shot blasting).

The high quality surface of the vacuum casting enables painting without using a prime coating, thus reducing production cost (picture 23). A further advantage of the surface quality is that the burr which is created automatically at the mould joint normally is smooth and small, so that it is not necessary to fettle it.

However, if a burr still has to be grinded, an uneven pressing of the grinding wheel would be enough to get an unclear micrograph at the casting, as picture 25 shows schematically; due to high requirements to the surface quality it has to be chamfered.

MECHANICAL CHARACTERISTICS

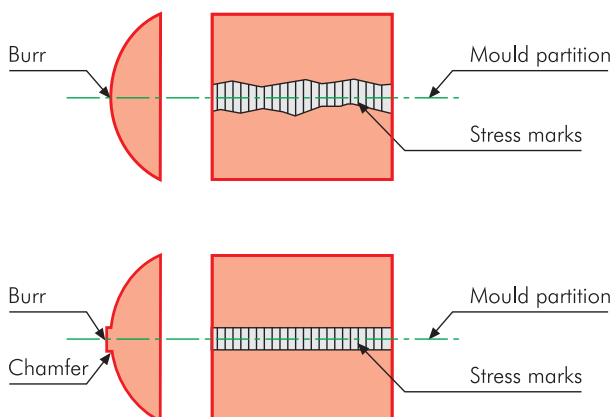


■ **Picture 23:** Side wall for a printing machine; material: GG-25, size: 80 x 1050 x 1280 mm, mass: 480 kg

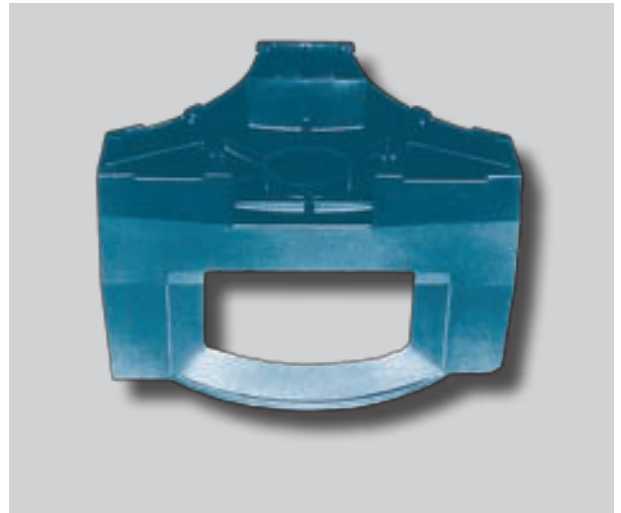
This can be avoided in case a chamfer is on the pattern on the level of the mould joint which is not grinded and can be clearly be seen as, for example, a circulating ring on the workpiece (see picture 25). The burr is integrated almost invisible into this chamfer. However, if there is a mould joint burr which has to be grinded, the chamfer is grinded in its complete height and/or its width resp., the micrograph is even and in a certain circumference an uneven grinding will not be noticed.

The good surface of vacuum casting has a decisive importance and/or is an important argument for a machine and plant builder in case, these high demands are reflected on the final product: i.e. „if it is bought with the eyes“. Functional advantages are achieved, too. Because of the clean surface filter clothes of vacuum moulded chamber filter plates have a longer life time than in the past.

Differing from other moulding- and/or casting methods resp. a special cooling behavior of the melt in the mould has been found out at vacuum moulding process. At the outset



■ **Picture 25:** Mould joint burr above: conventional burr, an uneven micrograph is often created when grinding below: an even micrograph is reached by means of a chamfer which takes up the burr



■ **Picture 24:** Machine case; material: GG-25, mass: 144 kg

the cooling velocity is heigher for a short time as there is no insulating gas pad: The melt is in direct contact with the mould wall. After that, the cooling velocity is much lower and this can be explained by the missing moisture of moulding material, the low thermal conductivity of the sand and the missing of convection in the moulding material.

Thereby the strength properties are not influenced much and the differences are even getting lower with the rising degree of saturation (shown in table 7). The lower hardness has a good influence on the machinability. The slow cooling has a good influence on the toughness properties, too. Workpieces made of GGG-40.3 for example – a type with a guaranteed notch impact energy according to DIN 1693 – can be produced without any problems in the as-cast condition by vacuum moulding process, if a minimum wall thickness of about 12 mm is given; then an additional heat treatment is not necessary.

Slow and constant cooling of the casting after pouring reduces the casting strains. In spite of high demands to the stress condition of a workpiece in general no stress relief by heat treatment is necessary.

The profitability of vacuum moulded casting already starts with the pattern. Because of the plastic film lying between the moulding sand and the pattern there is no direct contact with the pattern. The pattern does not wear and expensive metal- or plastic pattern are not required. „Simple“ wood pattern with a sufficient stability are enough. Even pattern for conventional machine moulding can be used, the necessary air suction bore holes can also be made later without any problems.

PROFITABILITY

High surface quality and low dimensional tolerances reduce the extent of machining and perhaps it is not necessary at all. The latter mainly applies to moulding without drafts.

The vacuum moulding process offers several possibilities to save material and to correspond to the requirements of the lightweight construction. The low dimensional tolerances enable a corresponding reduction of the wall thickness of weight-bearing cross sections. Furthermore, compared to other methods, the flowability of the casting metal between the coated films is better by 20 %, dependent among other things on the air in the mould and the mould emission which are sucked off by the vacuum during casting.

A remarkable convincing example for lightweight construction with vacuum casting is a tunnel ring consisting of 10 segments with an inside diameter of 5800 mm, picture 13 shows one of them. By reducing the wall thickness it was possible to approve the economic casting type and to replace the concrete construction used so far. In case of outer measurements of approximately 2200 x 1100 mm a back wall thickness of only 8 mm (!) is realized. The two-sided, arc-shaped connecting flanges are vacuum casted and ready for assembly, without the necessity of machining; with a latitudinal dimension of approx. 1100 mm the figures of picture 13 give an impression of the high manufacturing accuracy.

Reduction of mass has a special importance in the vehicle industry because low dead weight reduces the fuel consumption and increases the load capacity. Measures in this direction are mainly effective if the components in question are unsprung, as for example axle bridges, (picture 12). Compared with the past, the mass is reduced by 5 – 7 % with vacuum casting due to a higher dimensional accuracy.

However, there are also limits regarding the consistent usage of all possibilities offered by the vacuum moulding processes to reduce the wall thickness – dependent on the geometric shape of the workpiece. So the difficulty for the caster to produce the gear box for the drive of an electric locomotive (picture 26, the material is GGG-40; the wall thickness is only 8 mm) was not the filling of the mould during pouring but the seal feeding of many junctions; this was a consequence of the reduction of the wall thickness, through which the construction was dispersed in a multitude of feeding areas. The tightness of the highly stressed junctions had to be detected by x-ray testing.

The low quenching effect of the water-free moulding material and its good heat insulation cause a very slow solidification of the casting metal and cooling of the castings. That leads to constant mechanical characteristics, also at

considerable differences at the wall thickness. As also small wall thicknesses at casting metal have a grey solidification and there is no hard edge, a machining is unproblematic and can be executed economically.

The high stability of the vacuum moulds influences the profitability as well; because it is a prerequisite for the so-called riserless pouring of cast iron materials, with which the output – the relation between liquid insert and raw castings – is improved.

In many cases the good characteristics of vacuum casting lead to economically interesting results. Possible are:

- Saving of pattern costs,
- renunciation of permanent moulds by using light metal casting,
- less or no priming before painting,
- less scale of machining,
- better machinability,
- lightweight construction,
- stress-relieved castings.

A conversation between casting consumer and vacuum caster is always worthwhile, above all, if it concerns cast iron castings with a mass of approx. 100 kg – 1000 kg as well as aluminium castings with a mass of approx. 10 kg – 50 kg.

Table 7: Some mechanical characteristics of 5 types of grey cast iron, poured in vacuum- and in bentonite bonded green sand moulds

Trial number	Degree saturation S _c	Vacuum mould			Green sand mould		
		tensile strength (N/mm ²)	lateral power (kN)	deflection (mm)	tensile strength (N/mm ²)	lateral power (kN)	deflection (mm)
1	0.84	346	14.1	11.2	321	12.7	9.6
2	0.87	303	13.1	11.5	277	12.6	9.0
3	0.89	274	12.4	10.8	268	11.8	8.7
4	0.92	236	10.6	9.8	237	10.5	7.8
5	0.96	216	10.1	7.8	228	10.3	7.0



■ **Picture 26: Gear box for the drive of a electric locomotive; Material: GGG-40, Mass: 200 kg**

CONSTRUCTIONAL ADVICES

Fundamentally, the vacuum moulding process offers the designer the same possibilities of modelling like the conventional sand mould methods with mechanical or chemical bond of the moulding material.

The utilization of cores and inserts (composite casting), for example, should be mentioned; undercuts can be done at less cost without cores by using loose parts on the pattern or by means of pattern parts of foamed material remaining in the mould (partial full-mould casting). Therefore, in general the "typical casting" advices apply to construction of a vacuum casting.

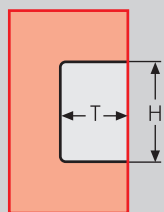
In addition, there are some specific features, whose observance has a positive influence on the profitability of the production of vacuum casting. The usage of dry, binder-free moulding sands with their excellent flowability makes the

fabrication of such workpiece contours possible, for which additional efforts would be necessary by using other methods. On the other hand it should be taken into consideration that the expansion of the covering film of the pattern is not unlimited. Concerning these two points the following examples are given:

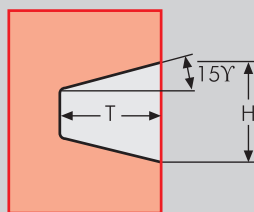
The horizontal surface of tension pockets and similar recesses can be executed horizontally up to a depth T of 50 % of the height H .

For bigger depths up to $T = H$, dependent on the ratio to each other, an inclination angle up to 15° should be intended on the surface which is lying above during the moulding.

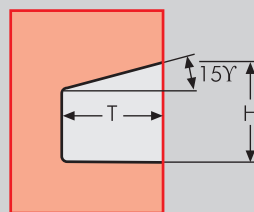
The undercut arising here is produced by means of a loose or a foamed part.



$$T \leq 0,5 H$$



$$0,5 H \leq T \leq H$$

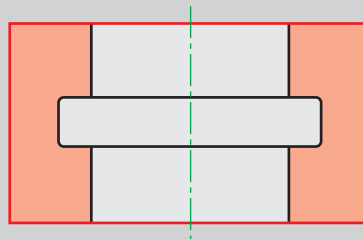


$$0,5 H \leq T \leq H$$

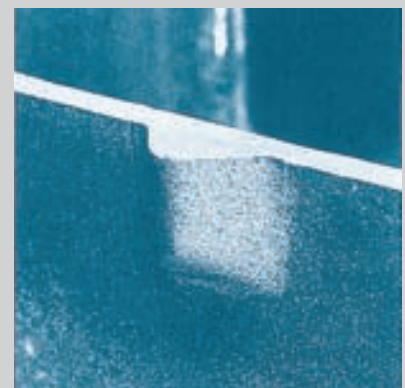
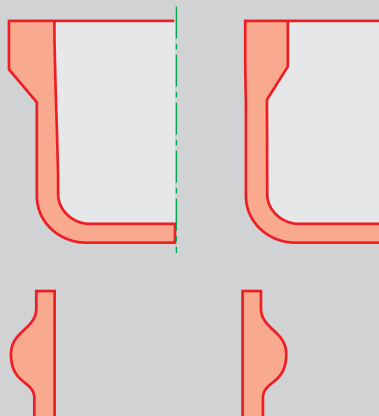


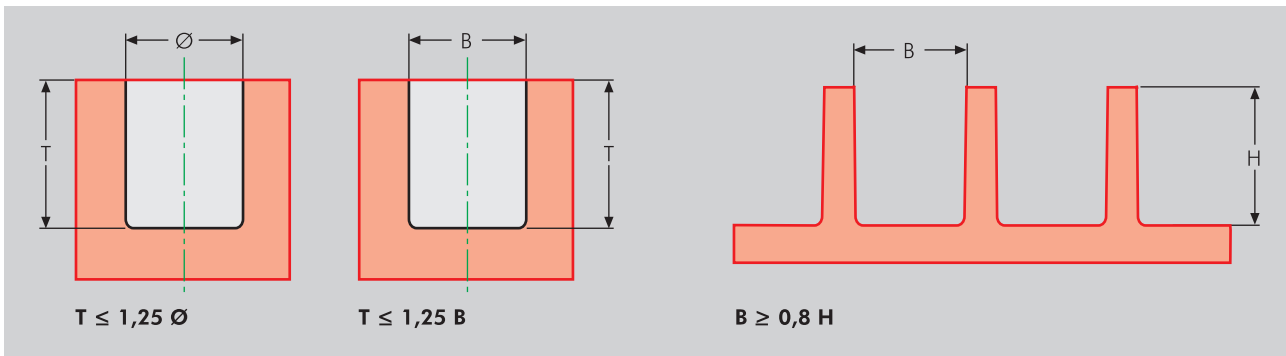
Oil grooves can be produced without core by means of loose parts or foamed parts.

Their dimensioning ratio (that height bears to depth) corresponds to those tension pockets which are described above.



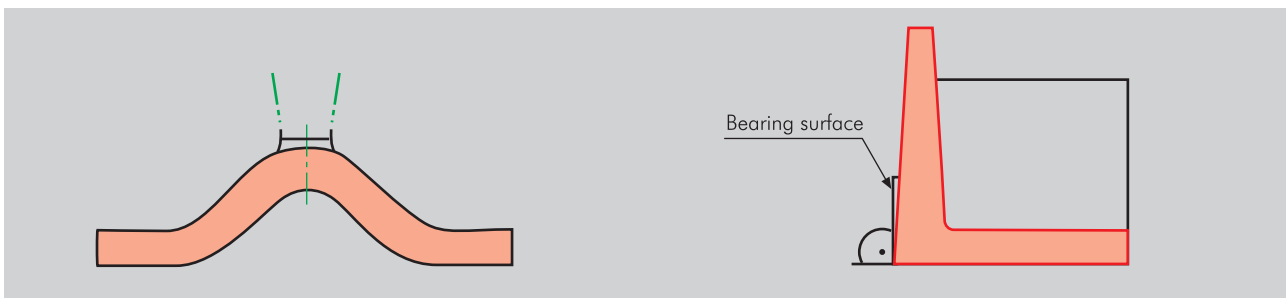
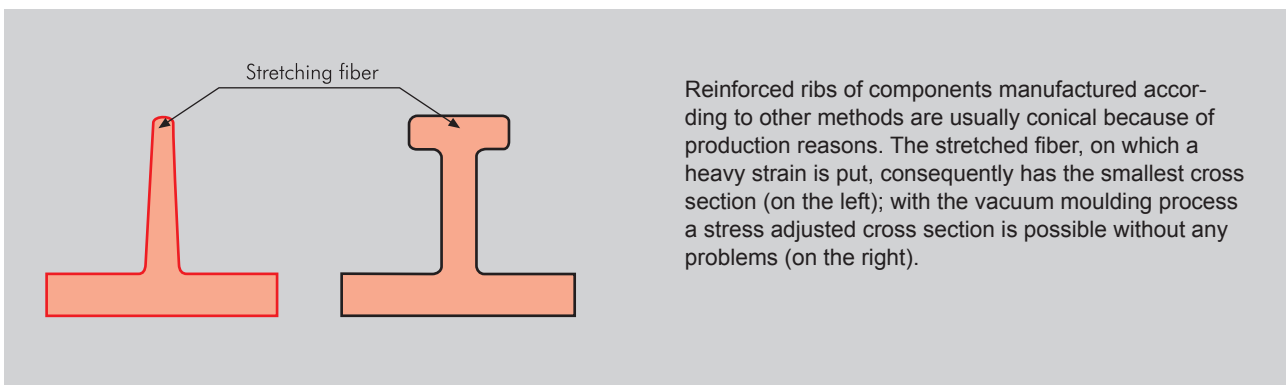
Fastening eyes can be fixed to the external shape as well as to the internal shape; arising undercuts are produced by means of loose parts and foamed parts.





The depth T of blind holes, pockets and slots is limited; the maximum depth is 125 % of the diameter and/or of the width B resp.; the length of open and closed slots can be chosen anyway.

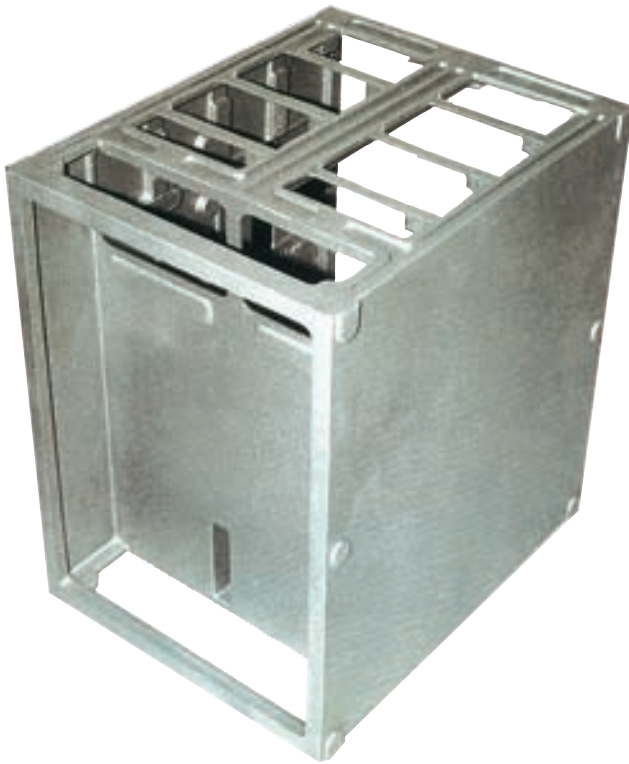
The distance B between two ribs has to be at least 80 % of the rib height. The rib length can also be chosen anyway.



If possible, a smooth surface which remains on the casting to place the venting or the feeder should be intended on the highest point of parts with round or nodular contours; so the fettling costs are reduced. Often a draft is not required.

However, if a draft is necessary, at least partially, vertical walls can be intended, for example for bearing surfaces in mechanical devices.

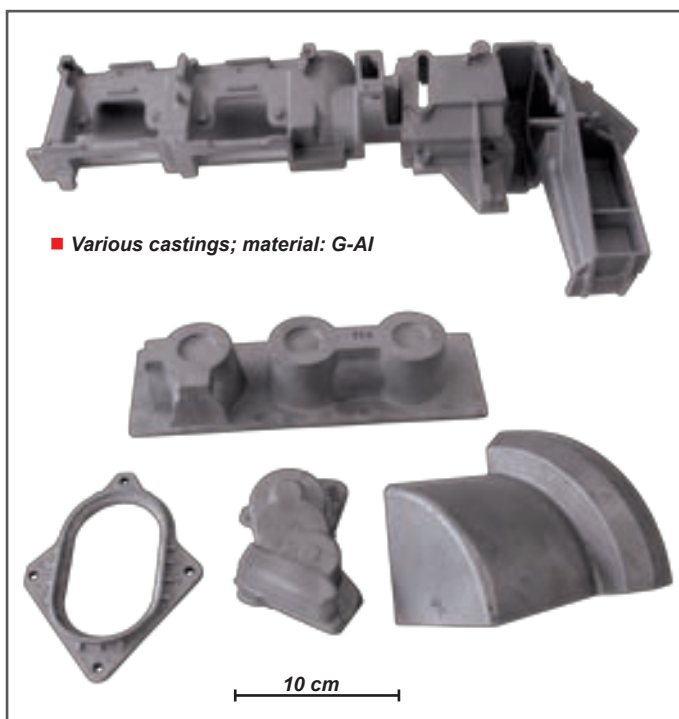
SAMPLES – ALUMINIUM



■ Case; material: G- AlSi12 , mass: 33 kg, dimensions: 650 x 610 x 470 mm



■ Cooler case with high demands to the gas tightness, material: G- AlSi10Mg wa, mass: 10 kg, dimensions: 710 x 300 x 120 mm



■ Various castings; material: G- Al

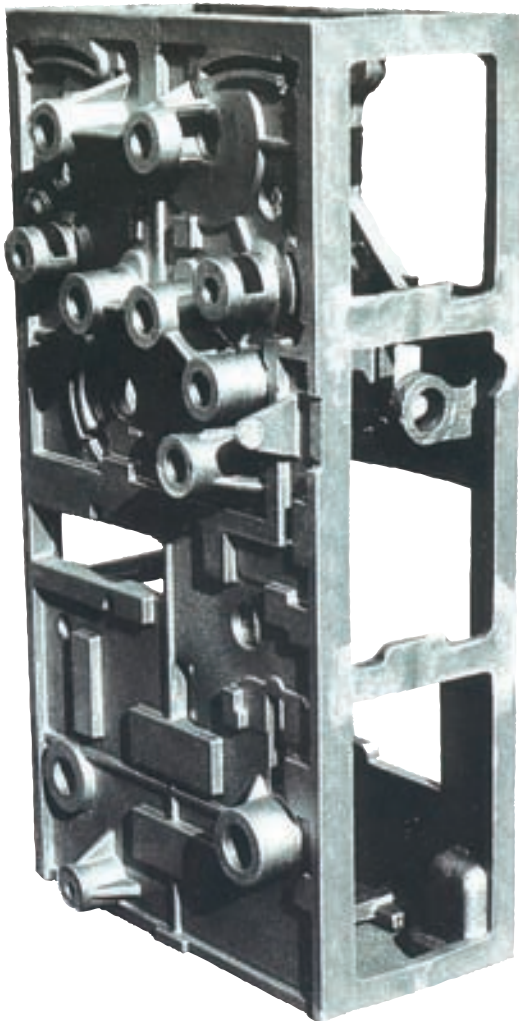
SAMPLES – GREY AND DUCTILE IRON



■ Filter case DN 200 for shipbuilding; material: GL-250, mass: 112 kg



■ Sewage casting; material: GJL-200, mass: approx. 80 kg, Ø 700 mm



■ Case of driving gear; material: GJL-250, mass: 495 kg



■ Case DN 400 for water meter; material: grey cast iron or nodular iron, mass: 250 kg

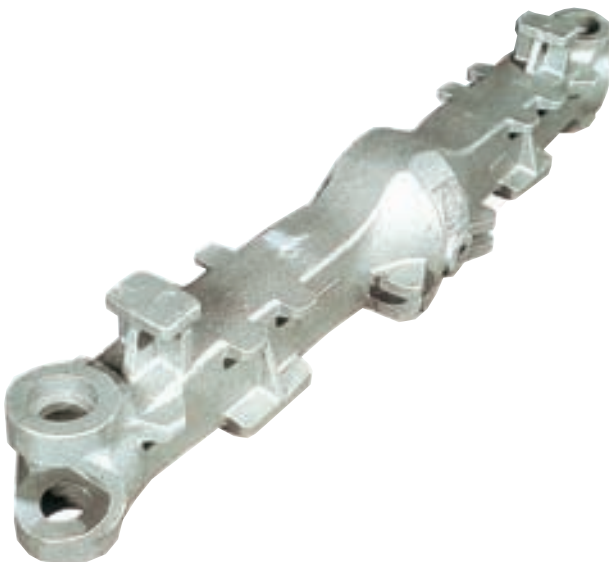


■ Side shield for sheet metal shears; material: grey cast iron or nodular iron, mass per piece: 52 kg

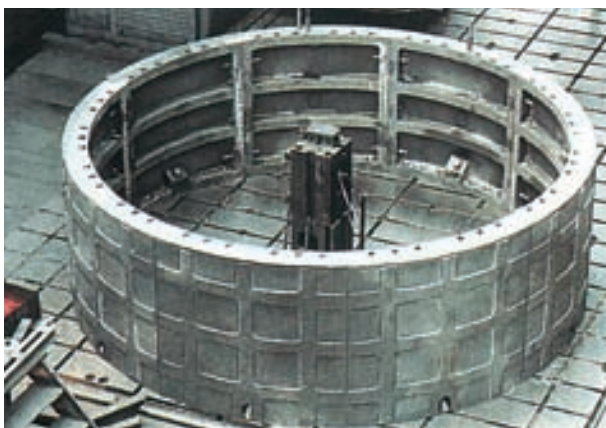
SAMPLES – DUCTILE IRON



■ Pallet bogie for moulding machine; material: GJS-500-7, mass: 1070 kg, dimensions: 1800 x 1200 x 160 mm



■ Axle bridge for utility vehicles; material: GJS-400, mass: 190 kg



■ Lining ring for a shaft of $\varnothing 4800$ mm in potassium mining, consisting of 9 segments with a wall thickness up to 120 mm; material GJS-500-7, segment mass: 3.3 t



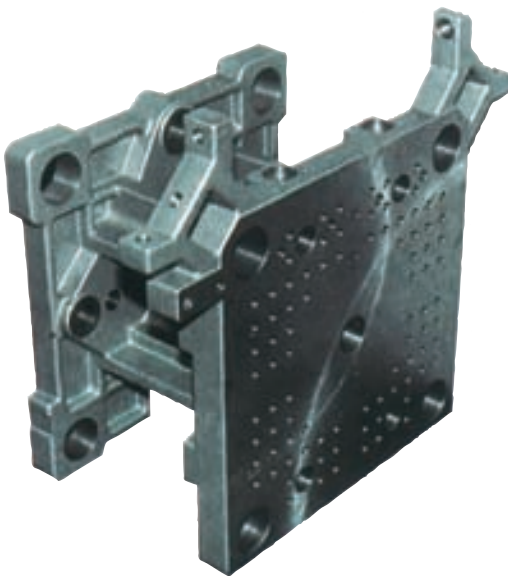
■ Half-axle for utility vehicle; material: GJS-400, mass: 79 kg



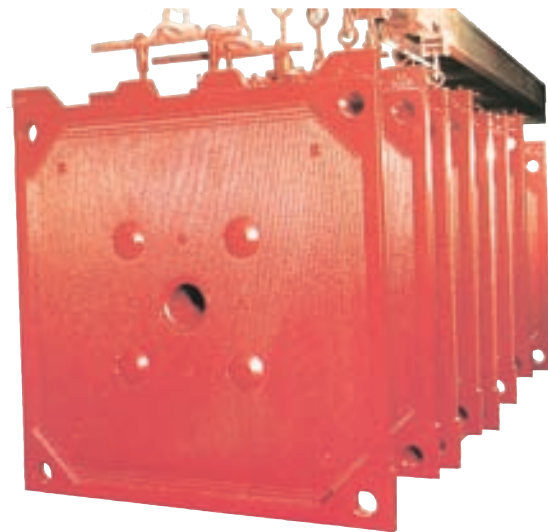
■ Case for roll stand; material: GJS-400-18LT, mass: 420 kg



■ Moulding box for a moulding machine; material: GJS-500-7, mass: 800 kg, dimensions: 1790 x 1400 x 350 mm



■ Tool holder for a injection moulding machine, without drafts, only poured with grinding allowance; material: GJS-500-7, mass: 270 kg, dimensions: 580 x 550 x 400 mm



■ Plates for filter presses with protection against corrosion, material: GJS-500-7, dimensions: 2000 x 2000 x 80 mm



■ Axle-case housing material: GJS, mass: 104 kg

SAMPLES – STEEL



■ **Stone breaker conus**
material: Manganese steel, mass: 1005 kg
Sweden



■ **Valve body for gas pipeline up to 500 mm nominal diameter (160 bar)** material: Cr-Ni-Steel, mass: 435 kg
Russia



■ **Casting for Space Shuttle transportation (NASA)** „Best Casting of Amerika in 2006“ Award by AFS
L = ca. 2.500 mm, material: Manganese steel
USA



■ **Devices of a railway chassis-bolster**
material: Carbon steel, mass: 560 kg
China



■ **Valve body**
material: high alloy steel
Japan

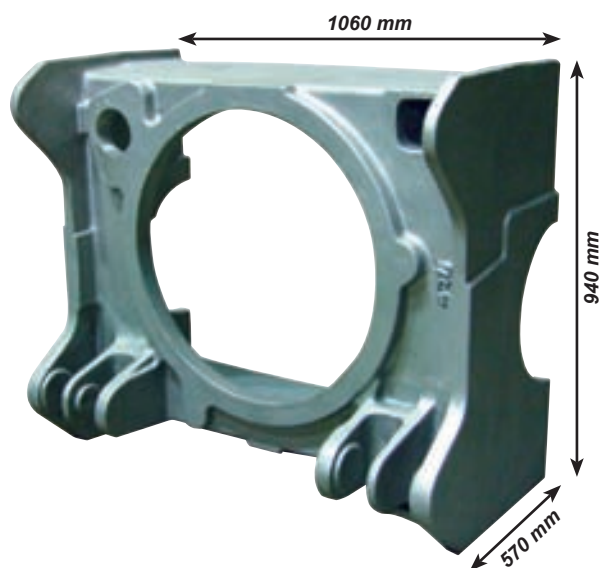


■ **Railway chassis-frame type 4**
material: Carbon steel
Russia

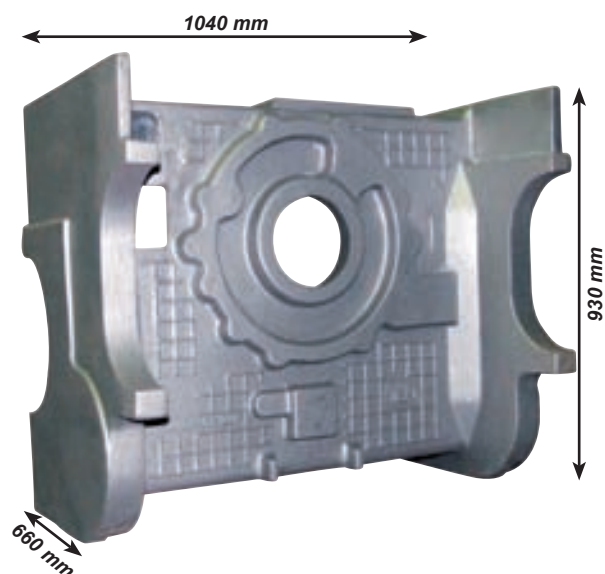


■ **Railway chassis-frame**
material: Carbon steel, mass: 430 kg
China

SAMPLES – STEEL



■ Axle-bearing for large industrial tractor
material: Carbon steel
mass: 725 kg
Russia



■ Axle-bearing for large industrial tractor
material: Carbon steel
mass: 743 kg
Russia



■ Charging car of blast furnace
Russia