Designing with silicon tombac

Casting alloy with stainless steel properties

Maximum corrosion resistance

High strength and elongation at break

Cost-efficient production

Sitomb®

Preamble

> Quality is no coincidence, it is always the result of hard thinking.
>
> John Ruskin (1819 – 1900)

The aim of this manual is to support the designer in his work with silicon tombac, to give him helpful hints for a safe and economical design of components and to convey some background knowledge.

The topics range from material properties and application areas to relevant drawing notes, design recommendations and important post-processing instructions.

Sitomb® castings form the basis for resilient component designs due to their outstanding mechanical properties. In order to exploit the full potential of this alloy, we recommend that you read this documentation and observe the guidelines and notes described. It is also recommended to contact Breuckmann GmbH & Co. KG at an early stage of the development of new component designs or assemblies. Management, sales, design, production and quality assurance work hand in hand and will be pleased to support you from development through prototype production to the series order with a view to component and process reliability as well as cost-effectiveness.

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1 Metallurgy of the CuZnSi system

Alloys of copper (Cu) and zinc (Zn) are referred to as brass (CuZn). From a copper mass percentage of 80 wt. %, the term "tombac" is also used.

Copper and zinc mix optimally in the melt and remain evenly mixed even after solidification. Theoretically, an infinite number of alloys between copper and zinc can be produced, but in practice the number of brass types is limited to around 60[1]. The technical usability of the copper-zinc alloys is possible up to approx. 45 wt. % zinc, since with the occurrence of the brittle γ-portion the technical application possibility is strongly reduced[2].

The increase in strength of copper-zinc alloys compared to copper is due to the formation of substitution solid solution. Strength and hardness increase with the zinc concentration. As soon as the composition of the brass exceeds 37 wt. % zinc, (α+β)-brass is formed. The β-phase causes a rapid drop in the toughness of the alloys with a simultaneous further increase in hardness.

If a third element is added to this binary CuZn system, new properties are created. Lead, for example, improves machinability, aluminium increases strength and corrosion resistance. Nickel improves the strength properties and the ability to change shape. Silicon exerts the strongest influence of all alloying elements on brass. The sensitivity to stress corrosion cracking and corrosion in general is reduced even by alloying 1 wt. % silicon. Silicon also improves the mechanical values as well as the flow properties and castability of the CuZn alloy.

The CuZnSi alloy group also includes the **CuZn16Si4-C silicon tombac** alloy. Silicon fundamentally changes the CuZn alloy by limiting the solubility of zinc in copper in the α-area. In α-brass, up to 4 wt. % of silicon can be dissolved interstitially in the solid solution (Figure 1). As the zinc content increases, the solubility of the silicon in the α-solid solution decreases. In the CuZn16Si4 alloy, the maximum amount of silicon is alloyed with the highest possible zinc content. Since the silicon atoms are small compared to the copper and zinc atoms, they can move freely through the metal lattice at high temperatures. During rapid solidification/cooling, the metal lattice shrinks and the silicon atoms are firmly enclosed in the intermediate lattice. The resulting lattice distortion leads to tension in the metal lattice and thus to increased hardness and strength of the material (A similar behaviour can be observed with the addition of carbon to steel). The fast solidification further leads to a fine grain structure having good mechanical characteristics. Additionally, using silicon for alloys results in an unusual behaviour during the local extension when cooling down (Avoidance/reduction of casting porosities).

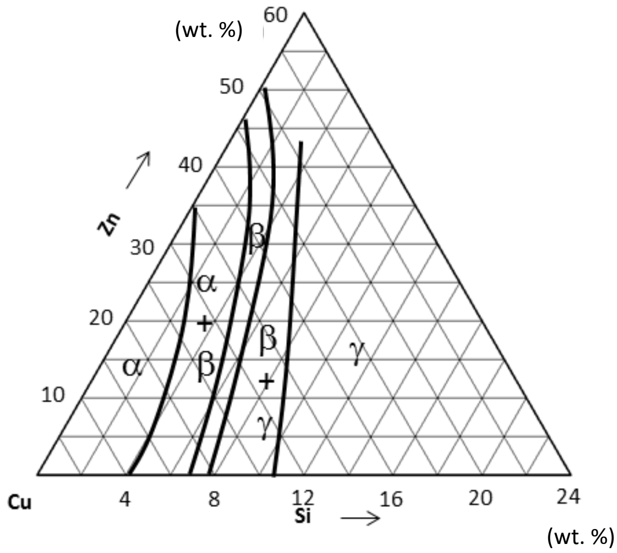


Figure 1: CuZnSi three-component system

With the aim of further improving the mechanical properties, the company-standard of Breuckmann GmbH & Co. KG severely limits the permissible tolerance ranges of the alloying elements of silicon tombac according to DIN EN ISO 1982. This material achieves optimum metallurgical properties and is known as **Sitomb®**.

[1] German Copper Institute, http://www.kupferinstitut.de
[2] Kurt Dies, Kupfer und Kupferlegierungen in der Technik, Springer-Verlag, Berlin 1967, p. 254-404

2 Differentiation between silicon tombac and Sitomb ®

As described in Chapter 1, silicon tombac consists of about 80 wt. % copper, 16 wt. % zinc and 4 wt. % silicon. For the realization of technologically sophisticated components, however, this rough consideration is not enough and must therefore be further specified. A first look at the standard (DIN EN ISO 1982) shows that the alloying elements mentioned may vary (Table 1Table 3). In addition, there are further alloying and trace elements in the material. A qualitative overview of the influences of alloying elements and some trace elements can be found in To produce Sitomb®, brass is mixed with silicon before being cooled down very rapidly. For this to function reliably in the die-casting process, the tolerance ranges of the individual alloying elements of silicon tombac must be strictly limited in accordance with DIN EN ISO 1982 (Table 1). The result of this tolerance optimization is based on more than 50 years of alloy and process development and is expressed in the form of the Breuckmann factory standard (Sitomb®).

Table 2.

Table 1: Comparison of silicon tombac and Sitomb®

Source	Property	Cu	Si	Zn	Pb
DIN EN ISO 1982	Alloy content / wt. %	78 – 83	3 – 5	Other	≤ 0,8
	Tolerance range / wt. %	5	2	Other	0,8
Breuckmann factory standard Sitomb®	Tolerance range / wt. %	0,5	0,1	0,6	0,02[3]
	Increased accuracy	x 10	x 20	-	x 40

To produce Sitomb®, brass is mixed with silicon before being cooled down very rapidly. For this to function reliably in the die-casting process, the tolerance ranges of the individual alloying elements of silicon tombac must be strictly limited in accordance with DIN EN ISO 1982 (Table 1). The result of this tolerance optimization is based on more than 50 years of alloy and process development and is expressed in the form of the Breuckmann factory standard (Sitomb®).

Table 2: Influence of alloying elements on silicon tombac

Alloying element/s	**Influence**
Copper (Cu)	If there is too much copper, the material becomes too soft. If there is too little copper, the corrosion resistance is reduced.
Zinc (Zn)	The zinc content lowers the melting temperature and forms substitutional solid solution in conjunction with the copper. Due to its larger atomic diameter, it distorts and strains the elementary cell of the copper, which increases its hardness.
Silicon (Si)	If the silicon content is too low, the strength and hardness of the material becomes insufficient. If the silicon content is too high, the material becomes too brittle and sensitive to hot tears in the production process.
Lead[3] (Pb)	Lead is present as a segregation in the structure and thus weakens the fatigue strength. From a technical, ecological and occupational health point of view, the less lead, the better.
Trace elements Al, Fe, Mn, Ni, etc.	These trace elements also influence strength, ductility, corrosion resistance, hardness, elongation at break, etc. and must therefore be controlled.

In addition to the production and correct handling of the silicon tombac melt, it is important to maintain it during the production process. Furthermore, technically correct processing (mould material, mould

[3] The actual lead content in Sitomb® is typically well below 0.01 wt.%. From a technical perspective, Sitomb® is therefore considered lead-free.

temperature control, permissible heat transfer of the mould coating, shortening of the flow paths, casting run and gate technology, special die-casting machine technology for high temperatures etc.) is decisive for ideal technical material properties. The control of all these factors is firmly embedded in the quality management system of Breuckmann GmbH & Co. KG's quality management system.

3 Material properties

The mechanical properties are largely retained even at temperatures of up to 200 °C. Compared to many cast iron materials, the almost constant toughness with a slightly increasing strength at low temperatures down to -200 °C proves to be advantageous.

Tensile strength	R_m	min. 500[4]	MPa
Yield strength	$R_{p0.2}$	min. 300	MPa
Elongation at break	A	8 bis 15[5]	%
Brinell Hardness	HB10	180	1
Modulus of elasticity	E	122	GPa
Poisson's ratio	ν	0.34	1
Sliding module	G	46	GPa
Shear strength	τ_{aB}	290	MPa
Flexural fatigue strength at 10^8 load cycles	σ_{bWN}	± 150	MPa
Electrical conductivity	σ	3	MS/m
Thermal conductivity	λ	34	W/(m · K)
Permeability at $H = 80\ A/cm$	μ	1.01	1
Coefficient of thermal expansion at $25\ to\ 300\ °C$	α	$18 \cdot 10^{-6}$	K
Density at $20\ °C$	ρ	8.3	kg/dm³
Melting range	θ	850 bis 1000	°C

Corrosion resistance	Very good corrosion and seawater resistance. Resistance to water, seawater, acids and alkalis is better than that of copper. Salt spray test according to DIN 50021: 1064 hours, discoloration, but no corrosion, not resistant to ammonia.
Bearing properties	Good sliding and bearing/emergency running properties under moderate load.
Heat resistance	Constant up to 200 °C.
Cold strength	Up to -200 °C slightly increasing strength.
Weldability	Weldable using the TIG process. Arc, resistance press and resistance spot welding conditionally applicable.
Solderability	Good soft and hard solderability. The casting surface must be prepared by mechanical machining or chemical treatment.
Surface treatment	Suitable for mechanical polishing. Very good electroplating properties.
Machinability	Good machinability.

[4] With Sitomb®, tensile strengths of up to 700 MPa are demonstrably achieved in some applications. The strength values are dependent on geometry and component.

[5] Compared to the silicon tombac (CuZn16Si4) standardized according to DIN EN ISO 1982, Sitomb® achieves a breaking elongation limit of 15 to 25 % and is therefore significantly more plastically deformable before the material cracks.

4 Drawing guidelines

The material designation CuZn16Si4-GP (for die casting) or CuZn16Si4-GM (for gravity die casting) should be entered in the **material designation field**.

The **general tolerances** should be selected according to DCTG 4 according to DIN EN ISO 8062-3 or coarser.

The typical **surface roughness** for die casting with silicon tombac is Rz 16 to 25 (Ra 1.6 to 3.2). The surface roughness can change as a result of subsequent sandblasting or vibratory grinding when removing burrs and sharp edges. The permanent steel mould for casting also wears over the course of its service life, resulting in higher roughness and thermal cracks in the mould and thus on the casting. The thermal cracks often occur on sharp component edges, which expand with each casting cycle. In order to be able to produce on a mould for as long as possible, constructive countermeasures must be initiated here on the component (e.g. good edge rounding or cut-outs). Attention! Thermal cracks do not mean that the casting has cracks. These are cracks in the casting mould which are also cast and thus mapped from the casting.

A **general demoulding slope** of at least 1° (better 2°) is required. In the case of critical and/or deep contours, individual demoulding chamfers of 3° to 15° may also be necessary.

General edge conditions for outer and inner edges should be at least R=0.5. Edge states greater than R=1 are considerably better. In exceptional cases, edge states of R=0.3 are possible. If the fillets are too small, there is always the danger of premature thermal cracks in the mould, which then form a raised image on the component. Too small inner radius and corresponding stress can also result in notch effects, which can lead to undesired failure of the component.

It is also possible to note areas on the component where **material savings** are desired. The usual formulation is: "Material savings according to the manufacturer's choice".

As a rule, **engravings** are raised by 0.2 mm in a 0.3 mm deep marking field. A marking of the desired labelling area is sufficient here. If a date labeling is required, this will be carried out as **date stamping** during subsequent punch deburring. Due to the high casting temperatures (> 1000 °C) it is not possible to insert a casting clock.

A marking for **safety relevance** (SR part) must be clearly shown on the drawing.

Drawings should be kept simple. Marking or describing functional surfaces & elements improves technical communication. Minor dimensions can remain undimensioned. Here, the 3D model is used for taking the measurements.

5 Typical casting volumes and component dimensions

Common casting volumes for Sitomb® die cast parts range from 0.1 to 24 cm³ (more possible). Optimum casting volumes are between 1 and 5 cm³. In the gravity die casting process, volumes of up to 100 cm³ are also possible.

Typical component dimensions in the die casting process range from (width x length x height) 5 x 5 x 2 mm to 250 x 250 x 80 mm.

Deviating volumes, weights and dimensions can be individually checked for their feasibility.

6 Tolerances

In the case of **dimensions that are not bound to a specific mould** (dimensions that result from the two mould halves), tolerance fields of at least T=0.2 (T=0.15 possible in exceptional cases) are required.

Tolerance fields of at least T=0.05 are required for **shape-related dimensions** (dimensions that are created in a mold half).

Smaller tolerance ranges than those specified in the general tolerances should only be selected if necessary and after consultation, as economic production is endangered here. In some cases, tolerance zones up to T=0.1 are possible.

Tolerance zones up to T=0.05 are economically possible for **drilling** operations. Fit dimensions according to the fit system unit bore / unit shaft are possible by the additional operation of **reaming**.

7 Blowholes and pores

Blowholes and pores are not always completely avoidable with cast components. A distinction is made here between **shrinkage blowholes** and **gas porosities**. Blowholes and pores often occur in interaction.

Even if the component and mold design interact well, **macro blowholes** (greater than or equal to 0.5 mm) can occur.

Typical are evenly distributed **micro blowholes** (smaller than 0.5 mm) up to micro pores visible to the eyes (larger than 50 nm).

7.1 Shrinkage blowholes

Shrinkage blowholes occur during solidification and cooling of the cast part. During this process, the density of the casting increases and its volume decreases. During this decrease in volume, material is pushed into the die casting by high pressures (hence the term die casting), so that this decrease is somewhat compensated by an active feeding of material. Since the cast part first solidifies at the surface layer due to contact with the permanent steel mould (it forms a casting skin) and solidifies more slowly inside (the heat has to travel a greater distance and takes more time to do so), these shrinkage blowholes tend to occur in areas of larger volume accumulations. You can recognize them by their rough inner surface. This effect can be reduced by an even wall thickness distribution of the casting. The component solidifies and shrinks evenly from the surface to the inside through clever part construction, leaving only small micro blowholes or micro pores behind.

7.2 Gas porosities

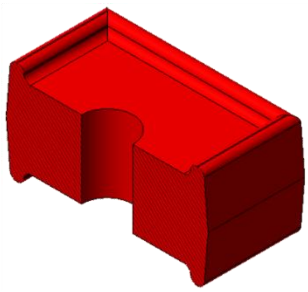
With gas porosity, casting gases and air are trapped in the casting during the mould filling phase. These can be reduced, but not completely excluded, by optimizing the casting technology of the component and by skilfully designing the mould (consisting of mould separation, gate, overflow, venting, temperature control, etc.). Gas porosity can be recognized by the smoothed and sponge-like inner surface.

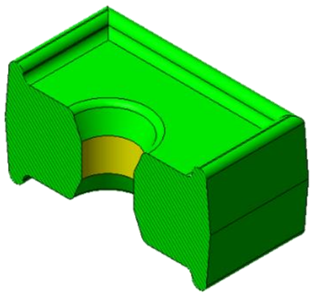
8 Wall thicknesses

The optimum wall thickness of Sitomb® is 2.5 mm. Wall thicknesses of less than 1 mm are possible, but should be avoided for reasons of process reliability. For wall thicknesses over 4 mm, the probability of macro blowholes (≥ 0.5 mm) is greater.

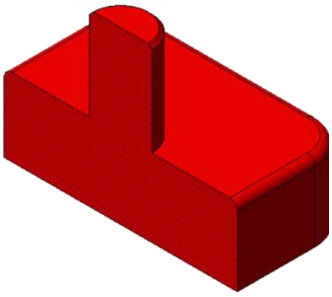
9 Production-oriented design

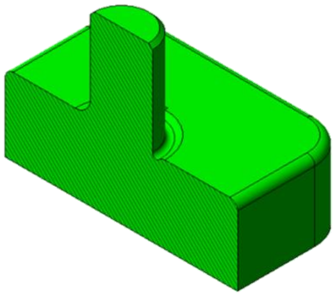
Bad | Good | Comment



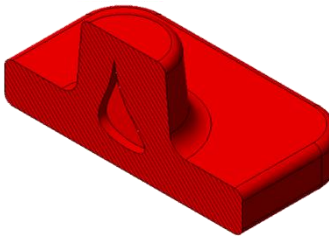


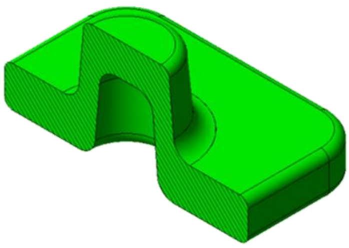
In many cases, holes can also be punched in the subsequent punch deburring process. In order to minimize material chipping during punching, the height of the effective shear area should be reduced. A diameter to shear height ratio of D/S=1 as well as a maximum shear height of 4 mm have proven their reliability here. Chamfers of 5° to 15° should be applied on both sides for the entry and exit of the punch.



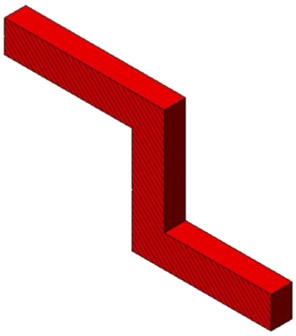


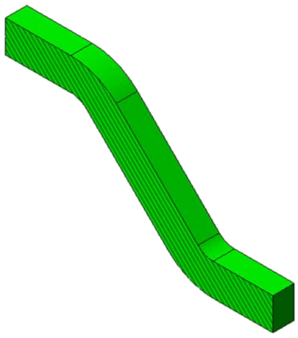
Sharp-edged transitions should always be avoided on pins. There is a risk of notch breakage here. Thermal cracks also appear early in the casting mould in the edges. Transitions should always be provided with the largest possible radii or coves or undercuts. A torus with a radius of 0.5 mm, which ends with a 30° bevel, is suitable as a chamfer.



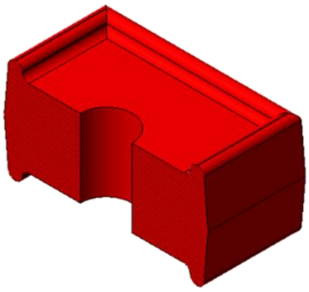


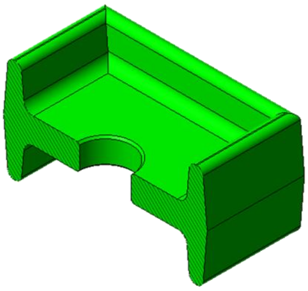
In order to reduce the risk of blowholes in cones, material savings should be made on the reverse side of these cones. The notch should be made above the load-bearing cross-section. In this way, the blowhole is moved further into the pin and no longer endangers the load-bearing cross-section. A diameter of 3 mm and a ratio between length and diameter of the recess of L/D=1.5 should not be undershot.



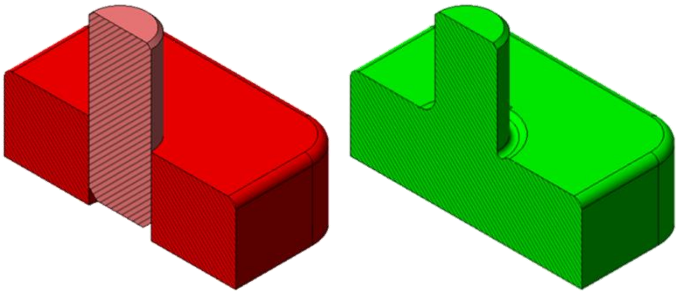


In order to promote good filling and reduce shrinkage forces, 90° angles should not be used. Try to achieve the bluntest possible angles with large transition radii.

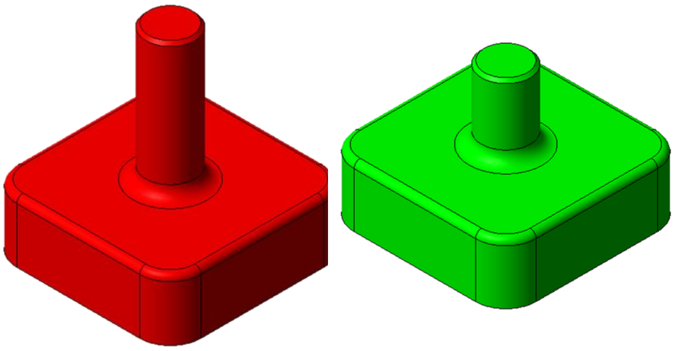




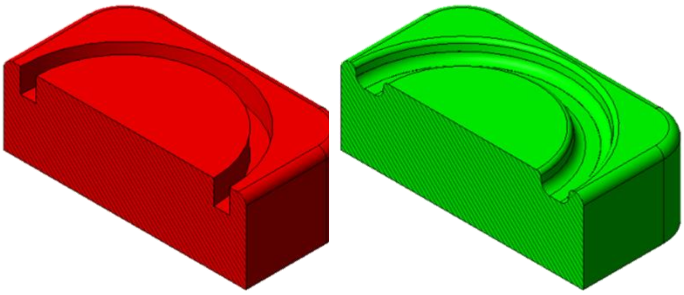
If possible, thick-walled areas should always be avoided, as these promote shrinkage, increase unit costs (more material costs) and burden the heat balance of the permanent steel mould (process costs). Optimum wall thicknesses for Sitomb® are 2.5 mm.



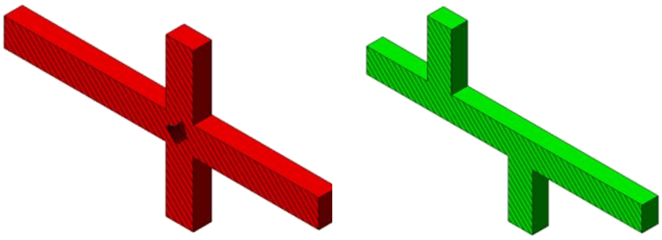
If possible, pins should be located directly on the casting. In this way, the costs of subsequent work steps (e.g. due to missing pinning) can be reduced.



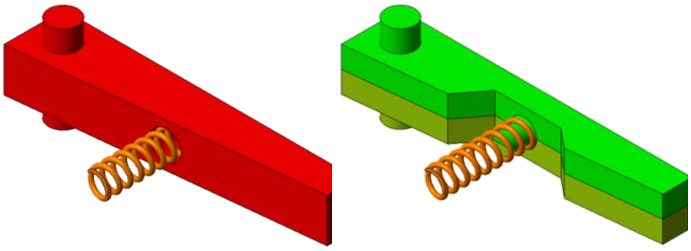
Too long taps are difficult or almost impossible to achieve in a die casting mould. The mould filling is difficult due to the longer flow paths of the liquid metal. Air can hardly escape in these deep cavities and air cushions could form at the end of the cones. The increased demoulding forces damage or destroy the pins (drawing marks). A good length to diameter ratio is L/D=1.5. The pin diameter should not be smaller than 3 mm and the demoulding angle should be greater than 1°. For better technical communication, the functional area of the pin should be indicated and dimensioned on the drawing.



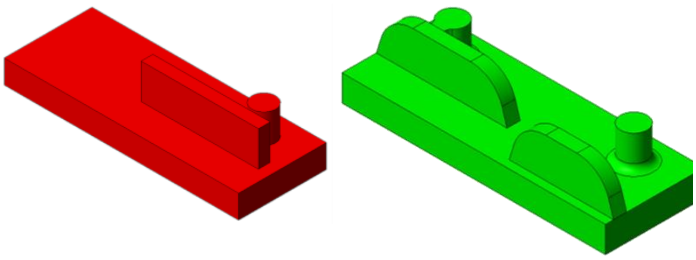
Too deep and narrow grooves should be avoided. These would require thin wall thicknesses in the mold, which could easily overheat at the required casting temperatures of over 1000 °C. A ratio of depth to width of T/B=1 should be targeted. A groove width of 2.5 mm should not be undershot.



When crossing walls or attaching stiffening ribs, these should be offset in order to avoid volume accumulations and thus larger shrinkage cavities.



In order to prevent undercuts or subsequent drilling, spring guides can also be machined and cast as pins.



If component elements are too close together, they must either be further apart or joined to avoid thin wall thicknesses in the mold. The aim should be to achieve distances greater than 4.5 mm.

10 Ejector positions

Ejectors are required to eject the casted part from the mould, in which it remains after opening the two mould halves on the so-called ejector side. The diameters of these ejector pins for Sitomb® castings are typically Ø 3 to 4 mm. These are located about 0.1 mm in the casting. Suitable positions for ejectors should be determined in consultation with our designers.

11 Punch deburring

After casting, punch deburring tools are required. These tools separate the castings from the casting grapes, on which several castings are usually attached, and also remove burrs (Figure 2). Since the positioning accuracy of the castings in the punching deburring tool in series production is approx. 0.1 mm, a sufficiently large shear area is required for a clean punching pattern.

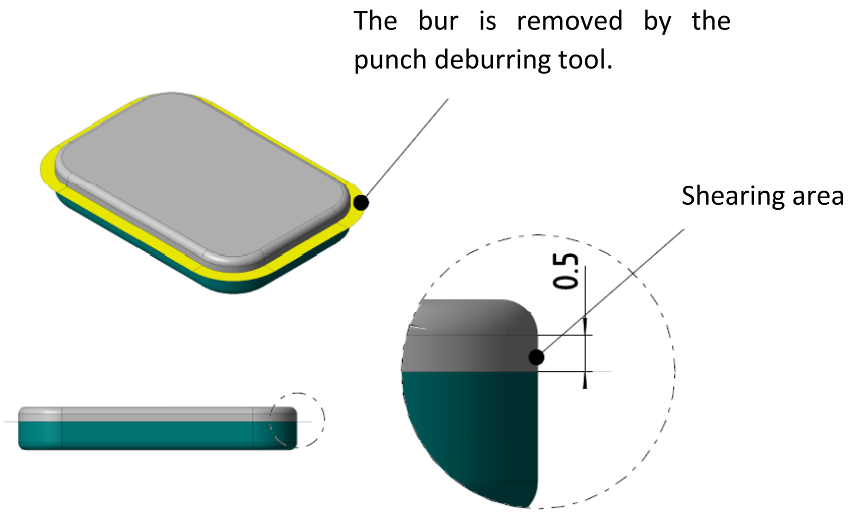


Figure 2: Shearing area

12 Nut square

The cutting surface must be kept as small as possible so that the component is not damaged by excessive cutting forces (component breakage or break-outs on the shearing surfaces) during punching deburring of higher inner square geometries. This is achieved by reducing the effective height of the square to the required functional height. Below (Figure 3 and Table 3) a recommendation of our factory standard, which we have developed for this application. A tolerance field of T=0.1 is required here.

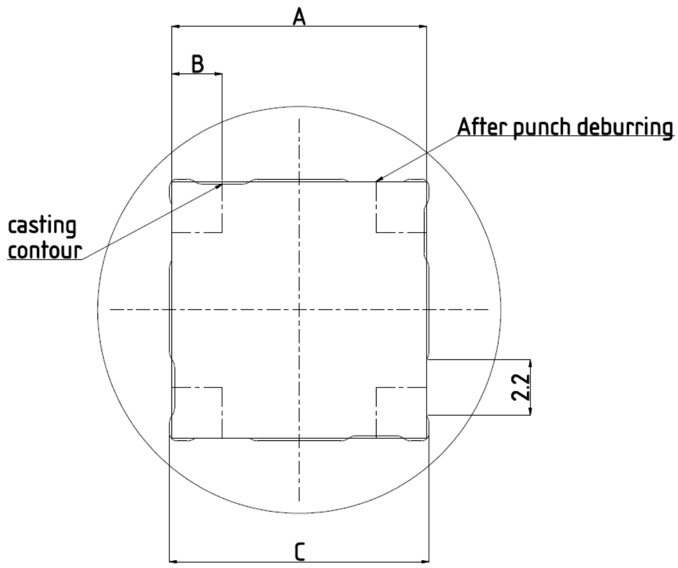


Figure 3: Inside square

Table 3: Extract from the Breuckmann nut square standard

Nut square / mm	$A + 0{,}07$ / mm	B / mm	C_{slot} / mm
7	7,03	1.6	7.3
8	8,03	1.8	8.3
8,5	8.53	1.8	8.8
9	9.03	2.0	9.3
10	10.03	2.0	10.3

13 Rivet spigots

Forming processes are also possible with Sitomb®. The process parameters (product-specific) must be determined and selected so that the forming process can be mastered in series production. Crack formation, material spalling or even material fractures must be prevented.

The forming speed of Sitomb® must be slow. A too high degree of deformation, which takes place in one step or in a too short time, causes the material to crack. In this case "forming in several steps with sufficient time" applies.

The most common application for components made of silicon tombac for such forming processes is riveting. The recommendations for the design of the rivet spigot and the performance of the riveting process (tumbling process) are given hereafter.

13.1 The rivet pin before the tumbling process

The size of the rivet drop must be larger in relation to the volume of the stud. Avoid squeezing formed material beyond the edge of the countersink. Cracks can appear from the edges to the centre of the rivet spigot. Then segments of the riveting spigot break out (Figure 5). In order to further reduce the risk of material throw-up, a stepped material additive must be placed on the rivet spigot (Figure 4). This is about 0.5 mm high for a Ø 4 mm rivet spigot.

Throat and edge radii must be as large as possible in the areas to be formed. Sharp edges should always be avoided. The risk of notch cracks and fractures during forming would be too high.

A radius as large as possible should be attached to the base of the rivet pin in order to promote the flow of force and counteract the notch inclination. Alternatively, undercuts are recommended here. The joined sheet must not be sharp-edged in this area. A chamfer creates free space here so that the sheet does not work into the material of the stud and causes a crack.

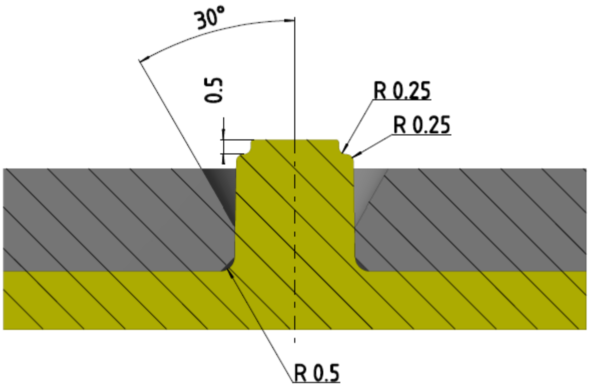


Figure 4: Rivet spigot before the tumbling process

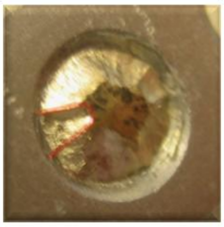


Figure 5: Outburst

13.2 The rivet pin in the tumbling process
A tumbling process should be used when riveting silicon tombac. The requirement for forming in several steps at controllable and low flow rates is met.

The shape of the wobble mandrel should be convex so that the force is applied via the centre of the rivet pin and the pin edge is not stressed. In addition, the wobble mandrel should perform a circular movement around the axis of symmetry of the stud during the wobble process (Figure 6). At the base of the riveted joint, a small and cylindrical area should centre the pin in the sheet metal. This reduces the transverse force effect at the base of the stud.

A hydraulic tumbling press is recommended for the tumbling process as the force setting of pneumatic presses is too inaccurate. The material needs time to flow (low forming speeds). Brittle cracks can thus be avoided.

The aim is to form the material as gently as possible.

13.3 The rivet pin after the wobbling process
The head of the riveted joint must have a remaining radius at the end of the wobbling process (Figure 7). Tips or sharp-edged geometries lead to partial breakage of the rivet head.

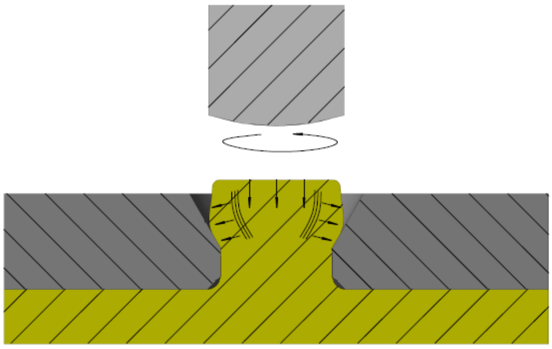


Figure 6: Rivet spigot in the tumbling process

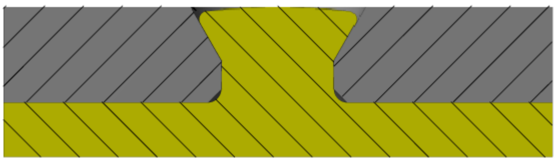


Figure 7: Rivet spigot after the tumbling process