BrazeTec®

Brazing of Cemented Carbides

Brazing is BrazeTec

Brazing hard metals

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The quality and lifetime of brazed tools are influenced by the choice of hard metal and materials to be joined, the choice of brazing alloys and fluxes, the geometry of the materials to be joined, the brazing technique that is used and the management of the process and the testing procedures.

Figure 1: Saw blade brazed with BrazeTec 49/Cu. Photo BrazeTec Hanau

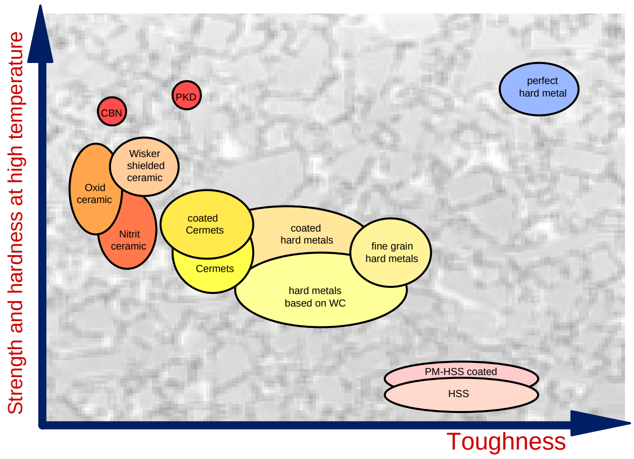
Hard metals

Hard metals are sintered materials comprising one or several hard materials that are embedded in a metallic binder-matrix. The different compositions, microstructures and manufacturing technologies mean that a wide range of hard metals with diverse properties are currently commercially available. Many hard metals, in particular those with the highest wear-resistance and toughness, are almost exclusively composed of tungsten carbide with cobalt as the metal binder. The property spectrum can be broadened using other carbides such as TiC /1/.

The parameters that determine the performance of the hard metals are essentially: hardness, high-temperature hardness, ultimate bending strength, diffusion and oxidation resistance and resistance to thermal shock /2/.

An ideal hard metal combines the opposing properties of high hardness and high ultimate bending strength. Developments in the area of hard metals and manufacturing technology have resulted in new fine-grained hard metals having high hardness without detriment to the toughness (Graph 1, Table 1).

Graph 1: Strength, hardness and toughness of hard metals /2/



Type	Grain size µm	WC %	Co %	TiC/Ta NbC %	Density g/cm^3	Vicker-shard-ness	Ultimate bending strength MPa
K05	1.5	95.0	4.0	1.0	15.0	1850	2200
K10	1.5	94.5	5.0	0.5	14.9	1800	2400
K20	2.0	93.0	7.0	-	14.7	1700	2500
K30	2.0	91.0	9.0	-	14.6	1630	2600
K40	2.0	89.0	11.0	-	14.4	1360	2700
K05F	0.8	94.0	6.0	-	14.9	1870	2600
K10F	0.8	91.5	8.5	-	14.7	1800	3100
K10FF	0.5	91.5	8.5	-	14.7	1800	3200
K20FF	0.8	90.5	9.5	-	14.6	1800	3200
K30F	0.8	90.0	10.0	-	14.5	1700	3800
K30FF	0.5	90.0	10.0	-	14.5	1700	3900
K40F	0.8	88.0	12.0	-	14.3	1630	4000
K40FF	0.4	88.0	12.0	-	14.3	1700	4400

Table 1: Types of hard metals for wood, plastic and paper processing /1/

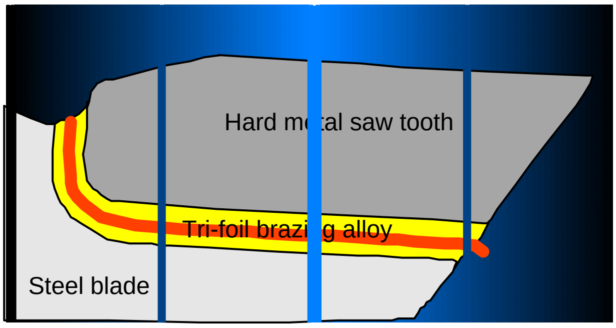
The materials to be joined

Tools are subjected to widely varying load conditions. At the contact point with the workpeice that is being processed the material is subjected to extremely high frictional forces. This means that the key requirement of any tool is that it has high wear-resistance, namely is of high hardness. For impact-like stresses, the material must possess adequate toughness. High-performance high-speed steels such as HSS 1.3343 and HSS-E 1.3243 are normally used.
Compared to the hard metal, the components being joined have higher toughness and lower strength and hardness. The coefficients of expansion are also different. High requirements are hence put on the joint design and on the selection of the brazing alloy.

Coefficients of heat expansion
- Steel: 11-14 x 10^{-6} K^{-1}
- Hard metal: 5-7 x 10^{-6} K^{-1}

Geometry

When using the tool, the brazed joint must withstand the forces that are acting and there must be no damage to the joint. The brazed joints must not introduce stress peaks into the hard metal so running the risk of fracture. This is achieved by using larger brazing gaps and tri-metal brazing alloys. The brazing gap should have a constant thickness across the whole area of the join. To this end, the hard metal and tool-support must have the same contour in the joint region. Depending on the components being joined, the brazing alloy that is used and the quality of the resultant brazed joint, the joint region can withstand shear forces of ca. 150-300 MPa.



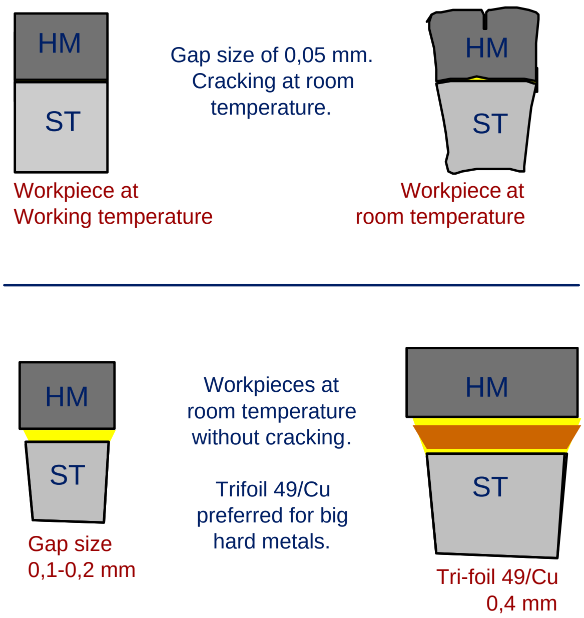
Graph 2: Hard metal joint on a saw blade

	Checklist: Geometry
!	Construction of the joint region for optimum introduction of pressure and shear loads.
!	Constant gap widths in the joint region
!	Identical contouring of the components being joined
!	Design gap width adequately wide for stress redistribution.

Brazing alloys

Influencing parameters

The hard metals are difficult to wet. For that reason, brazing alloys with wetting-promoting additives such as manganese and nickel are used.
Due to the widely different coefficients of heat expansion of hard metal and steel, stresses arise on cooling due to the hindered thermal contraction. This can lead to distortion of the component and cracks in the hard metal (Graph 3). At the brazing temperature, the composite is initially free of stress. During cooling the steel contracts twice as much as the hard metal, causing warping of the component. The consequence of this is tensile stress in the surface of the hard metal. In unfavourable situations this causes cracks to develop and diminishment of the lifetime of the tool /1/.



Graph 3: Schematic representation of the effect of the brazing alloy layer thickness on the susceptibility of hard metal sheets to crack development during brazing /3/.

***The amount of stress depends on**:*
- the difference in the coefficients of heat expansion;
- the solidus temperature of the brazing alloy;
- the plastic deformability of the brazing alloy;
- the thickness of the brazing alloy seam;
- the geometry of the components, specifically the size of the component;
- the mechanical properties of the support-steel.

Options for decreasing the stress:
- Use a brazing alloy with as low as possible solidus temperature;
- Ensure the thickness of the layer of brazing alloy is adequate;
- Use tri-metal brazing alloys, (Cu-layer, nickel mesh.).

Cu/Cu-based brazing alloys

Provided high brazing temperatures are permissible or desired, brazed joints can be made with copper and copper alloys. Mn, Ni, Co and Si are chiefly used in the copper alloys. Compared to pure copper, copper alloys have higher strength. Copper-containing brazing alloys can be used for brazing in a furnace under an inert gas atmosphere, for inductive brazing under an inert gas atmosphere or for brazing in combination with high temperature fluxes BrazeTec s and special s (Tables 2 and 3).

Photo 2: Mining chisel inductively brazed with brazing alloy BrazeTec 21/80 or 21/68, flux BrazeTec special h or h285. Brazing under an inert gas possible (N_2/H_2-mixture 95%/5%). Photo BrazeTec Hanau.

Ag brazing alloys
The use of cadmium-free silver brazing alloys allows significantly lower brazing temperatures to be employed than when Cu/Cu-based brazing alloys are used. The brazing is mostly carried out using fluxes, either inductively or with a flame in air (Tables 2 and 3). The low brazing temperature reduces the maximum stress that occurs in the hard metal. By increasing the brazing gap, part of the stress can be dissipated by plastic deformation of the brazing alloy.

If tools have to be coated after brazing with TiN in order to increase their lifetime, a suitable zinc-free silver brazing alloy must be used for brazing (BrazeTec 6488, BrazeTec 64/Cu, Table 2). Due to the lower vapour pressure of zinc and the surface temperature of up to 500°C for the PVD coating process, the zinc evaporates during the vacuum treatment. Besides loss of dimensional accuracy this causes a loss of strength of the brazed joint and contamination of the vacuum furnace with zinc.
The use of zinc-free brazing alloys is also recommended for furnace brazing. The comparatively long brazing times for furnace brazing cause evaporation of zinc.

Photo 3: TiN coated drill inductively brazed with brazing alloy BrazeTec 6488 and flux BrazeTec special h. Photo BrazeTec Hanau.

Tri-metal brazing alloys
Tri-metal brazing alloys are widely used for brazing tools. They combine the good plastic deformation properties of copper with the low working temperature of silver brazing alloys. An intermediate layer of copper is plated on both sides with silver brazing alloy (BrazeTec 49/Cu or 64/Cu, see Table 2). On cooling after brazing, the stress is reduced due to plastic deformation of the intermediate copper layer that is relatively soft compared to the brazing alloy and the components being joined. As a result the hard metal remains free of stress-free (see Graph 3). For brazing areas greater than ca. 100 mm^2, hard metals can only be brazed in a stress-free way using tri-metal brazing alloys. Depending on the geometry and application, tri-metal brazing alloys are also used for smaller brazing areas.
A special type is the nickel mesh tri-metal brazing alloys. During brazing, the brazing alloy that is incorporated into the mesh melts. The non-molten nickel mesh holds the components being joined at a

BrazeTec Brazing alloy	Composition in wt. % Ag	Cu	Zn	Mn	Ni	Other	Melting range in °C	Workingt tempera-ture in °C	Density in g/cm3	Comments
6488	64	26	-	2	2	6 In	730-780	770	9.6	Suitable for TiN coating
5662	56	19	17	-	-	5 Sn/3 Ga	608-630	630	9.1	
4900	49	16	23	7.5	4.5	-	680-705	690	8.9	DIN EN 1044, AG 502
4900A	49	27.5	20.5	2.5	0.5	-	670-690	690	8.9	
2700	27	38	20	9.5	5.5	-	680-850	840	8.7	DIN EN 1044, AG 503
21/80	-	86	-	12	2	-	970-990	990	8.8	
21/68	-	87	-	10	-	3 Co	980-1030	1020	8.8	Suitable for furnance brazing
Tri-metal brazing alloy										
64/Cu*	64	26	-	2	2	6 In	730-780	770	9.6	Suitable for TiN coating
49/Cu*	49	16	23	7.5	4.5	-	680-705	690	8.9	
49/NiN*	49	16	23	7.5	4.5	-	680-705	690	8.9	Nickel mesh tri-metal brazing alloy
Cu/NiN*	-	100	-	-	-	-	1083	1100	8.9	Nickel mesh tri-metal brazing alloy

*Table 2: BrazeTec brazing alloys for hard metals /4/5/ * Composition based on plated brazing alloy.*
BrazeTec recommends customers to always use cadmium-free silver brazing alloys.

constant gap width. On solidifying there is stress dissipation due to plastic deformation of the brazing alloy (Table 2).

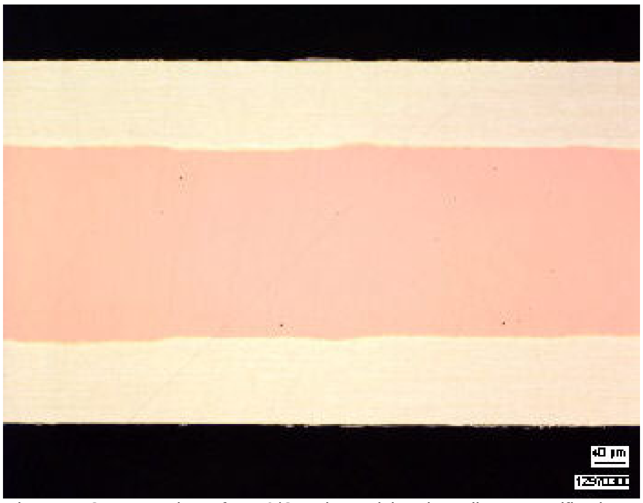


Photo 4: Cross-section of a 49/Cu tri-metal brazing alloy. Magnification: 250:1, Photo Brazing Centre Hanau.

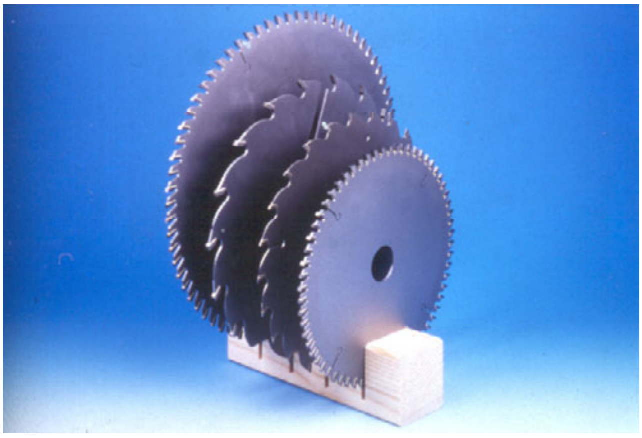


Photo 5: Circular saw blade inductively brazed. Brazing alloys BrazeTec 4900, 4900A, 49/Cu. Flux BrazeTec special h, h285. Photo BrazeTec Hanau.

	Checklist: Brazing alloys
!	Use low melting point brazing alloys suitable for hard metal joints.
!	Ensure the brazing alloy layer is sufficiently thick.
!	Use suitable tri-metal brazing alloys.
!	Apply tri-metal brazing alloy to the entire brazing gap.

Fluxes

For successful wetting of the components being joined by the brazing alloy it is necessary to have a surface that is free of oxide. The fluxes for different areas of application differ with regard to their working temperature, metal-specific solving capacity of the oxides and their consistency as a function of the way of addition. All fluxes in the BrazeTec product range conform to the DIN EN 1045 standard.

Photo 6: BrazeTec fluxes and brazing alloys for the tool-making industry. Photo BrazeTec.

BrazeTec Brazing flux	Working temperature in °C	DIN EN 1045	Suitability for base materials
special h	550-800	FH 12	Paste-like, for non-rusting and scale-resistant steels, hard metals and special metals
H 80	550-800	FH 10	Paste-like, for surface-brazing, also for brazing many hard metals
h 90	550-800	FH 12	Powder form, for special hard metals
h 285	550-800	FH 12	Can be dosed, for machine brazing, also for brazing hard metals
h 900	550-800	FH 12	Can be dosed, for machine brazing, for special hard metals
s	over 800	FH 21	Paste-like, also for high-alloy steels, Ni-alloys, hard metals
special s	over 800	FH 21	Paste-like, for non-rusting steels, super-alloys, hard metals, special metals

Table 3: BrazeTec fluxes for brazinghard metals /4/.

	Checklist: Fluxes
!	Use a flux recommended by the manufacturer for brazing hard metals.
!	Use a flux that can be added in doses for automatic brazing processes.
!	Use adequate amounts of flux.

Brazing methods

For the mass-production of tools, induction brazing has proven to be an efficient technique for automated processes and for most applications has proved to be a fast process with localised heating of the components. The heat is immediately generated in the workpiece and this allows considerably faster heating than other brazing methods (Table 4).

Means of heating	Possible energy transfer in W/cm^2
Convection heating	0.5
Radiant heat, muffle furnace	8
Heat conduction, heating table	20
Burner flame	1,000
Induction heating	30,000

Table 4: Energy transfer for different means of heating /7/

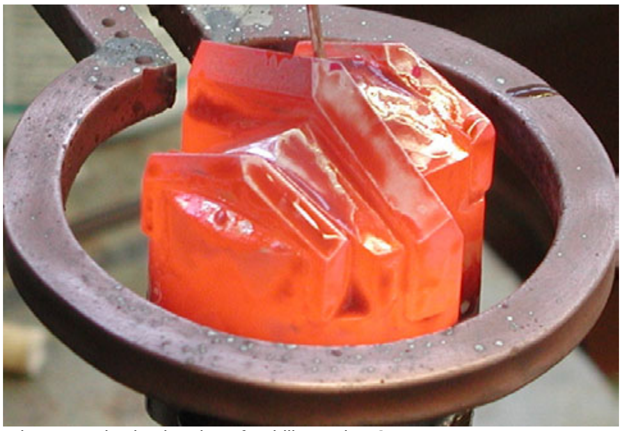
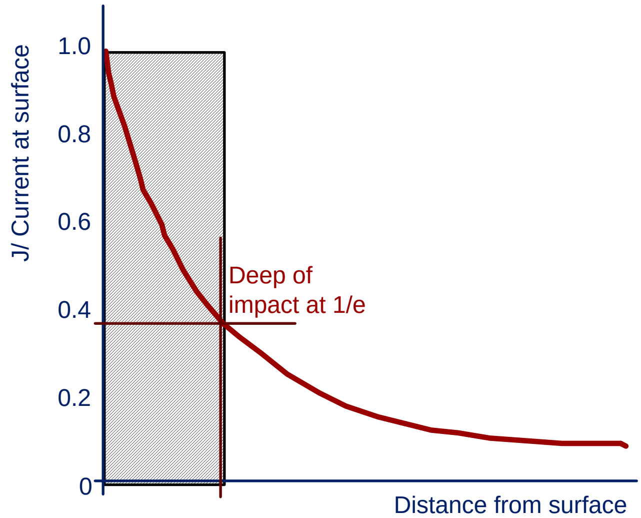


Photo 7: Induction brazing of a drill, Brazing Centre Hanau.

Principle of induction brazing

A single-coiled or multiple-coiled water-cooled induction coil (inductor) is placed around the area that is to be heated. The alternating current flowing in the inductor induces a current in electrically conducting workpieces. As a result of the electrical resistance of the workpiece heating occurs. As the currents largely flow at the surface, the heat energy is stored in the near-surface region and only flows to inner regions by heat conduction. In this context one talks about a “skin-effect“: Due to self-induction an eddy current is produced in the inner regions of the workpiece. This opposing eddy current causes greater electrical resistance in the overlapping zone of incoming and outgoing eddy currents and this results in concentration of the current at the surface. The layer thickness into which the current penetrates to the 1/e-point is called the penetration depth or effective depth. In this region about 85% of the induced energy is converted into heat. The skin-effect increases with increasing frequency. Simultaneously, the energy that can be induced due to increase of the effective electrical resistance decreases (Graph 4) /6/.

The practical ramifications of this are that small components being joined can be brazed using high-frequency induction equipment and large components with medium-frequency induction equipment.



Material	Temp. °C	Deep of impact at f= 50 Hz	500 Hz	10 kHz	1 MHz
Steel µ=1	900	70	23	5	0.5
Steel µ=10	620	14	5	1	0.1
Brass	600	26	8.5	1.8	0.18
Copper	600	17	5.5	1.2	0.12

Graph 4: Skin-effect as a function of frequency and material /6/

The shape and positioning of the inductor or inductors and the frequency, time profile and energy profile of the power supply must be adapted to the geometry and materials of the components being joined. Due to the very complex interdependencies, it is advised to have the design and construction of the inductors carried out by trained personnel or the manufacturer of the induction equipment. Some induction equipment manufacturers offer relevant training courses.

	Checklist: Brazing methods
!	Optimise the inductor for the brazing task in hand.
!	The frequency, quantity of energy, positioning of the inductor and heating time must be chosen such that there is uniform heating.
!	Lightly secure hard metals for the brazing process.
!	Use sufficient brazing alloy to completely fill the brazing gap and the fillets.
!	Flame brazing: Adapt the burner size to the component.

Process management

Induction brazing

The advantage of induction brazing is the precise reproducibility of the brazing process. For brazed joints that will be subjected to high loads, it is sensible to first of all determine the optimum process parameters in a pre-production run.

With inductive heating, the major part of the energy is transferred to the tool steel. The hard metal warms up after a delay and a considerable part of its energy is obtained via heat conduction. The same occurs in components have large cross-sections. The energy transfer occurs on the outside and the inside zones are heated after a delay and only via heat conduction from outside to inside.
This results in there being different local temperatures in the component. The energy, time and if necessary movement profiles that have to be set must ensure that there is no local overheating of the brazing alloy (outgassing, pore formation, flux lifetime) but must ensure that the working temperature is reached over the entire joint region (wetting of the brazing alloy).

As a result of the molten flux, small hard metal components can experience buoyancy and can move from their intended position. They must therefore be fixed in position using suitable ceramic holding devices, either with wire or by hand using a ceramic pin. If their own weight is inadequate, they must be lightly pressed down, without liquid brazing alloy being pressed out of the gap. During the brazing process the flux is driven out of the gap. As a result the hard metal moves down somewhat.

If hard metals are introduced into the gap, the volume of flux driven out must be compensated by adding brazing alloy otherwise this would result in defects.
As a source of brazing alloy, an over-sized area of brazing alloy foil or brazing alloy wire can be fed from the outside (Photo 7).

Flame brazing

The burner must be so designed that the joint region can be heated to working temperature within the 4 minute lifetime of the flux. The flame heating must not overheat the brazing alloy or burn the flux. It is often hence sensible to carry out the main energy input via the steel components being joined.
For good reproducibility of the brazing, the qualifications and experience of the brazing personnel play a key role.

	Checklist: Brazing process
!	Add an adequate amount of flux.
!	Lightly secure hard metals for the brazing process.
!	Avoid overheating of the brazing alloy and flux.
!	Ensure that the entire joint region has reached the working temperature of the brazing alloy.
!	Keep the brazing time short.

Testing/inspection

The methods that can be used for testing/inspecting brazed joints depend on the geometry, material combinations and size of the brazed components. A fundamental distinction is made between destructive and non-destructive testing/inspection methods. These are described in more detail in the European standards EN 12797 and EN 12799 (Table 5).

EN	Test/inspection method	Relating to the brazing of hard metals
12797	Tensile shear test	Absolute statement about the quality, direct function of the quality of the brazing.
12797	Tensile test	Absolute statement about the quality, direct function of the quality of the brazing.
12797	Metallographic inspection	Very meaningful results, many influences can be isolated.
12797	Hardness test	Depending on the material, conclusions about the temperature profile during the brazing process.
12797	Peeling test	
12797	Bending test	
12799	Visible inspection	Qualitative, limited meaningfulness depending on the way of adding the brazing alloy
12799	Ultra sound test	Quantification of the wetting area possible, can only be used to a limited extent.
12799	Radiographic test	High investment costs, conclusions about pores and defects
12799	Liquid penetration test	
12799	Tightness test	For pipes, containers, tanks
12799	Overpressure test	For pipes, containers, tanks
12799	Thermography	High investment costs, conclusions about the degree of wetting

Table 5: Testing/inspection methods for brazed joints in accordance with the EN 12797 and EN 12799 standards /8/

It is sometimes desirable to evaluate the fundamental quality of a brazing process. This is for example the case when there are quality problems, when a new plant is being started up and when it is desired to improve the quality of the process. Non-destructive tests on large numbers of samples can be employed for this purpose due to the very high meaningfulness of the results. If a high quality level has already been introduced, then the quality can be maintained using reduced tests by using statistical quality control.

The selection of testing/inspection methods, their applicability, suitable sample sizes and their number are highly dependent on the component, the brazing process, the requirements specified by the customers, the objective of the test and the economic viability. These must be laid down for each individual situation.

Visual inspection of brazed seams

That a fillet looks good does not necessarily mean that the brazed joint is of good quality. If however a high number of pores are visible then the reverse can be inferred, namely that the quality is poor. The cause of pores could be flux inclusions or overheating of the brazing alloy.

- Flux inclusions occur to a higher degree when the brazing region has not at least been heated to the working temperature of the brazing alloy. The flux residues can then no longer be so easily flushed to the surface in the resultant highly viscous brazing alloy.

- If the brazing alloy is overheated there is “boiling“. The alloying element zinc has a very low vapour pressure and is evaporated to a greater extent. The zinc vapour bubbles remain behind as pores in the solidified brazing alloy.

Destructive shearing tests

The maximum load of the brazed joint can be measured by shearing tests. The results represent the sum of all effects of the design of the components being joined and the brazing process and are hence suitable for quantitative determination of the quality of the brazed joint.

Metallographic tests

Metallographic preparation of a joint and its examination under a light microscope allow a large number of influences to be isolated. This testing method hence gives very meaningful results.

Photo 8: The brazing gap in a good brazed joint using tri-metal brazing alloy BrazeTec 49/Cu. Magnification 100:1. Photo Brazing Centre Hanau.

Photo 9: Porous brazed layer, too large a gap. Magnification 100:1. Photo Brazing Centre Hanau. The brazing alloy was overheated in the brazing process. The hard metal was inadequately secured.

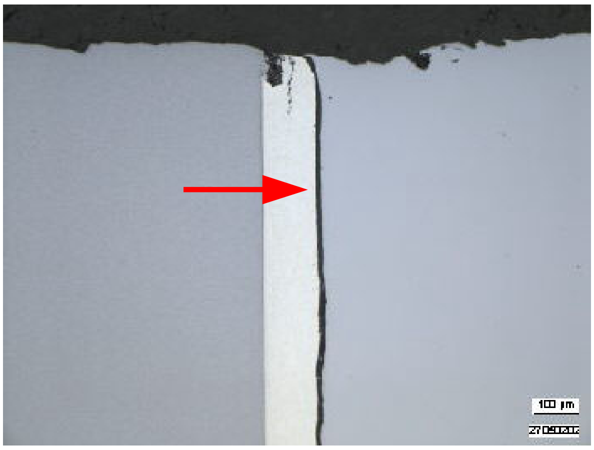


Photo 10: Saw tooth brazing with fracture line between the brazing alloy and saw-body. Magnification 100:1. Photo Brazing Centre Hanau. Saw-body was not up to an adequate working temperature for the brazing alloy.

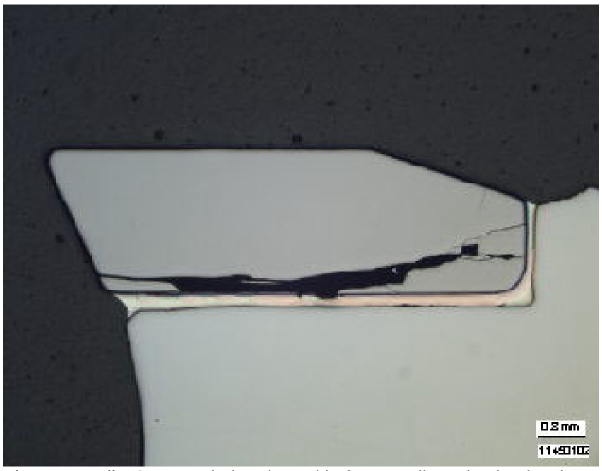


*Photo 11: alloy*Saw tooth brazing with fracture lines in the hard metal. Magnification 12,5:1. Photo Brazing Centre Hanau. Overloading of the hard metal as a result of unfavourable forces or quality problems with the hard metal. Contour in the corner between the saw-body and hard metal not identical.

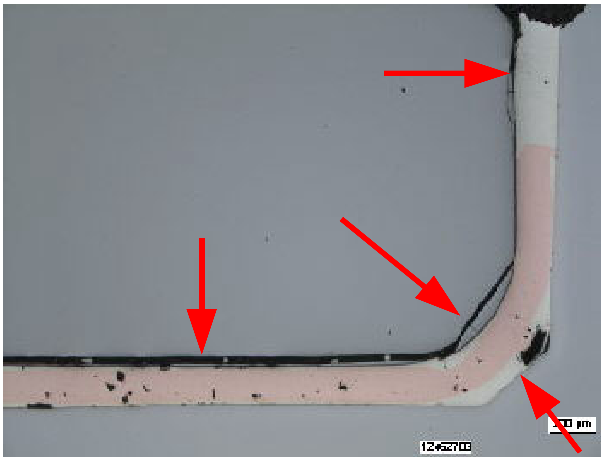


Photo 12: Saw tooth with fracture line between the brazing alloy and hard metal. Magnification 100:1. Photo Brazing Centre Hanau. The hard metal / saw-body geometry in the corner is not contour-accurate. The down pressure during brazing was too high, causing the liquid brazing alloy to be pressed out and the remaining brazing gap between the copper and hard metal tending to zero. Brazing alloy film was not fed in the back-region up to the fillet and the result was cracking.

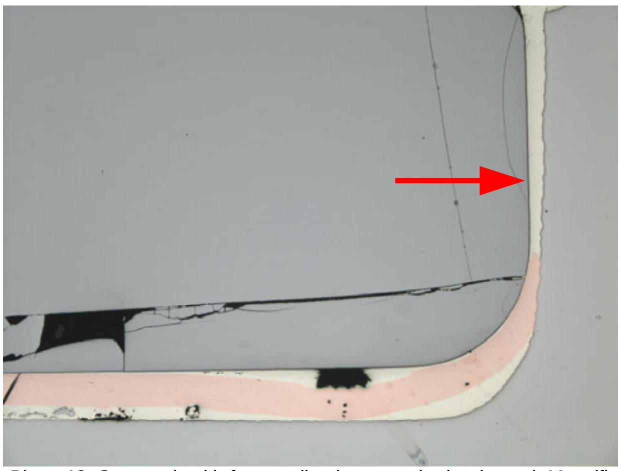


Photo 13: Saw tooth with fracture line between the hard metal. Magnification 100:1. Photo Brazing Centre Hanau. Lack of stress dissipation in the hard metal / overloading during use as a result of too small a brazing gap in the back-region and lack of an intermediate Cu layer there.

Visual inspection of returned defective tools

Wear and overloading of tools results in failure of individual saw teeth. Such tools are often given a general overhaul and new saw teeth are brazed to the saw-body. Analysis of the brazed regions of the broken teeth allows valuable information to be obtained about the brazing process.

The sum of all the described parameters that have effects – the materials used, the geometry, the brazing alloy, the flux, the joining process and the life history of use of the tool – determine the lifetime of the tool and the nature of the damage to it. Due to the complexity of the interrelationships, such an analysis must be carried out very diligently.

Fracture lines in the hard metal

Fracture lines in the hard metal are indicative of overloading of the hard metal (see Photo 13). Possible causes can be:

- The quality of the hard metals;
- Unfavourable forces due to the geometry of the joint and the components being joined;
- Too high internal stresses in the hard metal due to too small a brazing gap or lack of / incomplete intermediate Cu layer.

Break between brazing alloy and components being joined

A break between the hard metal and the brazing alloy or between the saw-body and brazing alloy indicates inadequate wetting of the brazing alloy (see Photo 11). Possible causes can be:

- The components being joined were not at the working temperature of the brazing alloy;
- Too little flux or incorrect flux used for brazing;
- Too long a brazing time.

Break in the intermediate copper layer

A break in the intermediate copper layer is the “theoretical fracture point“. Compared to the brazing alloy and the components being joined, the intermediate Cu layer has the lowest strength. This desired property foremost allows stress dissipation after the brazing process. For breaks that clearly occur before the average end of life of a tool, possible causes are:

- Overloading of the tools;
- Too small a brazing gap or wrong thickness of the intermediate Cu layer;
- Dissolved intermediate Cu layer due to overheating during the brazing process;
- Too low a wetting area achieved.

Porous break-surfaces in the brazing alloy
Porous break-surfaces in the brazing alloy mean reduced strength for the brazed joint (see Photo 9). Possible causes can be:

- Overheating of the brazing alloy during the brazing process;
- Overheating of the flux during the brazing process;
- Inclusions of flux residues in the brazing gap;
- Too little available brazing alloy in the brazing gap.

	Checklist: Tests
!	Use suitable testing methods for attaining and maintaining the reliability of a brazing process.
!	Carry out simple failure analysis on tools that are returned for repairs.
!	From failure analyses from all tests, derive process improvements.

Summary

The brazing alloys and fluxes offered by BrazeTec for brazing hard metals allow high quality tools to be efficiently brazed. The quality of a brazed joint is dependent on many parameters associated with the components being joined and the brazing process that is used. Successful fault-free brazing requires ...

... the design of the components being joined and selection of materials for the particular brazing process;
... selection of a suitable brazing alloy and flux;
... use of a suitable brazing method for the tool;
... good process management for the brazing process;
... process monitoring via sufficient process and component tests;
... continuous use of test results for laying down and implementing process improvements.

The basic principles, key parameters and tests/inspections described in this article are not claimed to be exhaustive. For more complex issues and solutions to problems contact the technical/application advisors at the Brazing Centre of BrazeTec.

Brazing is BrazeTec
Detailed information about the principles of brazing, applications, products and links to associations and companies can be found on our website at www.BrazeTec.de.

Literature

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