Brazing properties and mechanical strength of new silver based brazing filler metals on the basis Ag-Cu-Zn-Mn with a 10-20 weight % reduced silver content

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Low melting brazing filler metals are used in a wide range of different industrial applications. Amongst others, heating, ventilation, air-conditioning and refrigeration industry (HVACR) and the tool manufacturing industry should be mentioned. Depending on the application, standard brazing filler metals with silver contents between 25 and 50 weight-% are widely used. Due to the high and volatile silver price, a decreased silver content in a brazing filler metal provides a direct cost saving potential.
With current standard brazing filler metals acc. to DIN EN ISO 17672, a reduced silver content goes in line with an increased brazing temperature, which leads to changed process parameters like increased process time, energy consumption and microstructural changes in the parent materials.
The main alloying elements for the developed brazing filler metal family - BrazeTec BlueBraze - are Ag-Cu-Zn-Mn with, depending on the application and brazing temperature, additions of tin, nickel, silicon or indium.
This paper will discuss the latest results on dynamic and static strengths of the described BrazeTec BlueBraze brazing filler metals in direct comparison to standard ones. Furthermore results and experiences out of the field will be discussed.

1 Introduction

Low melting silver brazing filler metals (below named BFM) are used in heating, ventilation, air-conditioning and refrigeration industry (HVACR) and tool manufacturing industry (e.g. manufacturing of saw blades). In these various application several different parent materials has to be joined, e.g. copper, brass, steel and stainless steel and in case of tool manufacturing industry also cemented carbides.

Due to the strong price increase and fluctuation of precious metals since 2009 silver content is an important factor in raw material perspective and price calculation for produced parts. So far, with reduction of silver content, the manufacturers had to face higher brazing temperatures leading to an increase of process times, energy costs and changes on the properties of the parent material [1], [2], [3]. Additionally the procedural brazeability is reduced with increasing temperatures for processes in air atmosphere [4].

Umicore developed a new cadmium free alloy system, which has a given liquidus temperature with a lower silver content, good deformability at ambient temperature and sufficient ductility in brazed joints. The basis of the product family are the alloy components Ag-Cu-Zn-Mn, with, depending on the application, the elements tin, silicon, nickel and indium are added. With this, BlueBraze named, innovating brazing filler metal system, working at same brazing temperatures as corresponding standard BFM, Umicore offers alternative filler metals with 10 weight-% for HVACR industry. For the tool manufacturing industry the new BFM contains 20 weight-% less silver.
Standard silver BFM and their corresponding BrazeTec BlueBraze BFM, which can be used as a substitution, are listed in **Table 1**.

Table 1: Standard silver BFM acc. to DIN EN ISO 17672 [6] and their corresponding BlueBraze products (grey lines).

	Code acc. ISO 17672/ BrazeTec product	Ag	Cu	Zn	Sn	Mn	Other	Melting range
HVACR	Ag 145	45	27	25,5	2,5			645-695
	BlueBraze 3510	35	32,6	20	2	10	Si 0,4	680-700
	Ag 140	40	30	28	2			660-720
	BlueBraze 3010	30	37,8	20	2	10	Si 0,2	690-730
	Ag 134	34	36	27,5	2,5			655-745
	BlueBraze 2410	24	43,7	20	2	10	Si 0,3	690-750
	Ag 130	30	36	32	2			670-755
	BlueBraze 2010	20	42,8	25	2	10	Si 0,2	710-765
Tool	Ag 450	50	20	28			Ni 2	670-730
	Ag 449	49	16	23		7,5	Ni 4,5	680-705
	BlueBraze 2810	28	39	20		10	In 2 Ni 1	680-760

The performance of these new BFM has been investigated in several tests, e.g. wetting behaviour, metallographic examinations, different joint strength tests, dynamic load tests and corrosion behaviour.

In this paper the results of shear strength tests, acc. to DIN EN 12797 [5] and high-cycle fatigue tests of BlueBraze alloys in comparison to standard Ag-Cu-Zn-Sn-BFM (HVACR) respectively Ag-Cu-Zn-Mn-Ni-BFM (Tooling) will be presented, as well as the results for the shear strength with principle specimen for tooling application.
Finally, some test results and experiences from industrial application at customers will be summarized.

2 Experimental Procedures

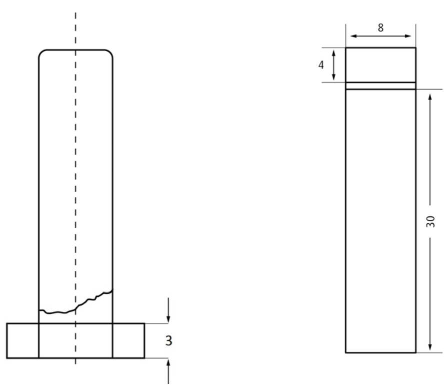
2.1 Shear Strength Test According DIN EN 12797

Shear strength was tested on carbon steel S235JR acc. to DIN EN 12797 specimen type II, **Figure 1**.
Therefore cylindrical bar with a diameter of 9.7 mm is brazed into a disc with an inner diameter of 9.9 mm. Due to screw fitting between both parts, cylinder is centred and a constant joint width is ensured.
The specimen was manually brazed with an acetylene-oxygen torch and FH10 flux acc. to DIN EN 1045 [9] (BrazeTec h Paste). Final overlap of 3.0 mm was created by a post machining process. A universal testing machine “Zwick 1474” with a speed of 1 mm/min. was used for testing the shear strength.

Additional trials with cemented carbides were conducted to approximate the test conditions in case of tool application as well. Based on setup of DIN EN 12797 a cemented carbide disc (WC-Co; 10% Co) with final shape was choosen, as post-machinig is impossible. The thicknes of the cemented carbide disc was 3.3 mm and with an inner of diameter 5.5 mm. It was brazed directly onto a cylindric bar of S235JR with a diameter of 5.3 mm.

2.2 Shear Strength with squared Specimen

For another comparison of the tool application, a rectangular test specimen was defined, **Figure 1**. A non-coated fine grain cemented carbide segment of the type K10 (94.4% WC; 5.6% Co) acc. to DIN ISO 513 [10] with the dimension 8 x 8 x 4 mm was brazed onto a 1.2210 (115CrV3) steel cuboid with the dimensions of 8 x 8 x 30 mm.



(a) (b)

Figure 1: Shear test specimen: **(a)** Specimen acc. DIN EN 12797; **(b)** Squared principle specimen for “tool” parent materials.

The brazing trials of the specimen were conducted in normal air atmosphere using flux FH12 flux paste acc. to DIN EN 1045 (BrazeTec spezial h Paste) and a BFM foil of 8 x 8 x 0.2 mm. Heating of the specimen was performed with an high frequency induction machine (3.5 kW) at a frequency of 1.2 MHz. The inductor coil was square shaped with an edge length of 13 mm. The holding time was set to 3 seconds at defined brazing temperature of 720 °C controlled by pyrometer and thermocouples.
Due to the hygroscopic and corrosive properties of flux residues, the brazed specimen were washed with water to avoid corrosion. Shear test was performed on manual testing machine with a maximum load of 40 kN. The steel body side of the specimen was placed in a tailor-made fixation.
The design of the punch correlated with the dimension of the cemented carbide (8 x 4 mm) for a planar and homogeneous pressure application.

2.3 High-Cycle Fatigue Tests

Specimen was produced of steel S235JR with a thickness of 3 mm, **Figure 2.** The overlap was calculated according the rules for lap joints with 12 mm (4T) [11], [12].

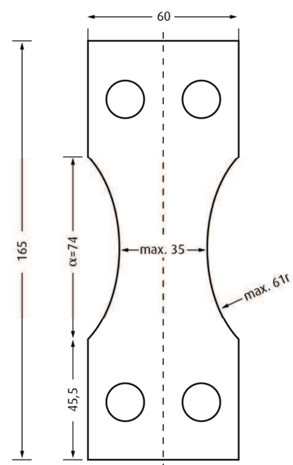


Figure 2: Specimen of high-cycle fatigue test.

To ensure a homogeneous brazing gap of 0.2 mm the specimen were spot welded. The joint was brazed by acetylene-oxygen torch using a FH10 flux acc. to DIN EN 1045 (BrazeTec h Paste). Afterwards the parts were machined to remove fillets and tested on a “Schenk PWY” bending device.
To ensure desired stress level on specimen, machine settings were evaluated in pre-tests on massive steel parts by strain gauges. The brazed overlapping steel plates were tested with the evaluated settings. Due to the geometric design local stresses might be elevated at the overlap area.
Brazed parts were tested with bending stress loads of 100 to 300 MPa until rupture or cycle numbers of minimum 1,000,000.

3 Results

3.1 Shear Strength According DIN EN 12797

Due to the design of the specimen and the machining of overlap a direct load transmission into the braze metal layer is ensured. The steel S235JR as parent material leads to cracking at braze metal layer. In contrast all cemented carbide/steel-specimen failed by rupture of the cemented carbide ring and therefore no reliable values of the joints shear strength were generated, **Figure 4**.

The standard Ag-Cu-Zn-Sn-alloys had a median shear strength of 179 – 190 MPa. The related new filler metal system showed similar average values of 172 – 185 MPa.
In direct comparison the standard alloy Ag 449 and newly developed alloy BrazeTec BlueBraze 2810 (below named 2810) for the tool manufacturing industry had average shear strengths of 220 MPa respectively 215 MPa.
This means, that the alloy composition of Ag 449 and 2810 ensures approx. 25 % higher shear strength values compared to the BFM for HVACR industry.
Generally the shear strength and therefore, also the standard deviation, is influenced by the BFM and the parent materials as other process parameters like heat distribution, flux inclusion and the skill of the brazers.
However, even though the number of samples was limited, the low differences in the average strength and the overlap of the standard deviation of standard BFM and corresponding new BFM validate that both filler metal systems show same shear strength in the performed trials.

The results of the shear strength tests acc. to DIN EN 12797 on steel S235JR are summarized in **Figure 3**. The values are based on minimum 5 specimen.

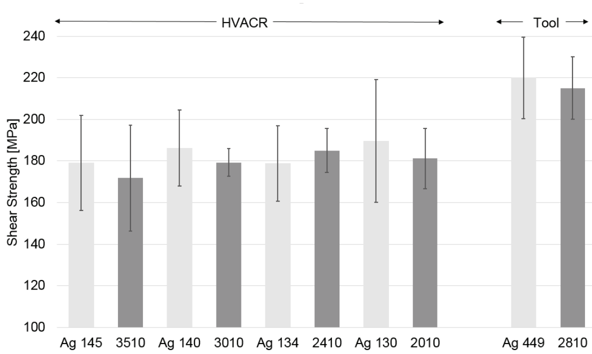
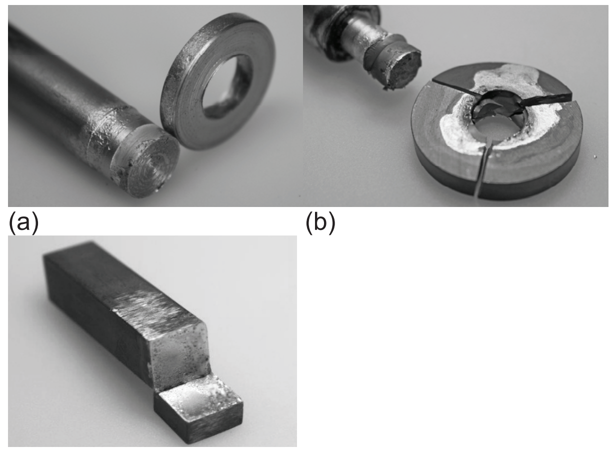


Figure 3: Average shear strength and standard deviation of tested BFM acc. to DIN EN 12797.

3.2 Shear Strength With Squared Specimen

In contrast to the DIN EN 12797 specimen, it was possible to measure reproducible values with cracking in the braze metal and without affecting the cemented carbide; **Figure 4**. The shear strength of 2810 had an average value of 280 MPa with a standard deviation of 17 MPa. In comparison Ag 449 showed a shear strength on the same level but the standard deviation was 30 % higher (24 MPa).



(a) (b)

(c)

Figure 4: Shear strength specimen after testing: **(a)** Acc. DIN EN 12797; **(b)** Based on DIN EN 12797 with cemented carbide ring; **(c)** Square shaped specimen

To get a direct relation to a standard BFM with a comparable silver content like 2810, Ag 427 (27 % silver) was brazed and tested under same conditions. The evaluated shear strength for Ag 427 was dramatically lower than the other two tested BFM at a brazing temperature of 720 °C. The average was 210 MPa with a minimum of 180 MPa, **Figure 5**.

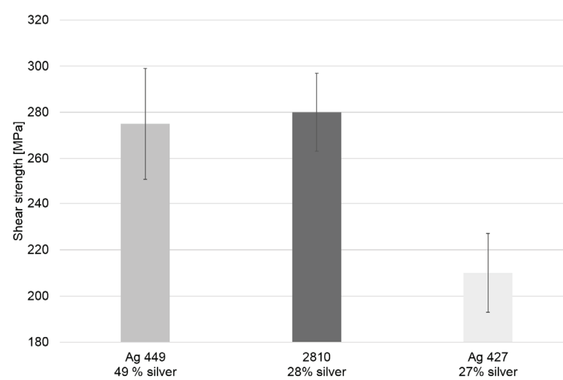


Figure 5: Average shear strength and standard deviation of standard BFM and BrazeTec BlueBraze 2810.

In addition the gap sizes of brazed specimen (Ag 449 and 2810) were evaluated by measuring cross sections. The thickness of 2810 braze metal layer was approx. 110 - 120 µm and for Ag 449 approx.

50 - 60 µm, probably caused by melting ranges and set brazing temperature.

3.3 High-Cycle Fatigue Tests

Based on the results of the high-cycle fatigue tests, Wöhler curves for Ag 134 and BlueBraze 2410 (below named 2410) were prepared, **Figure 6**. Both curves show similar characteristics to plain steel and therefore the concentration factor caused by brazing joint should be 1.

The load for the brazed specimen was set to 100 – 300 MPa.

With a load of 300 MPa the specimen failed between 9,200 - 63,000 cycles. Beside one specimen (brazed with Ag 134), all cracks occurred in the steel plates, starting at the heat effected zone or at the end of braze metal fillet on steel plate surface.

By decreasing the load to 250 MPa the tolerated cycle number increased to 70,000 - 190,000.

Only at a stress level of 200 MPa cracking of the steel plates occurred on a significant different cycle number. While specimen brazed with Ag 134 failed after 197,500 - 496,000 cycles, specimen brazed with 2410 withstand up to 506,000 - 932,000 cycles. Due to the numbers of specimen the statistic relevance is limited. Additionally an influence of manual flame brazing process onto the steel parent material can't be excluded. Further investigation of crack of parent material microstructure was not performed.

At a stress level of 100 MPa tests were stopped at cycle numbers between 1,000,000 and 1,350,000 cycles. To prove the assumption of endurance limit, specimen brazed with Ag 134 was tested up to 15,900,000 and brazed with 2410 up to 21,000,000 cycles without failure of brazing joint or parent material.

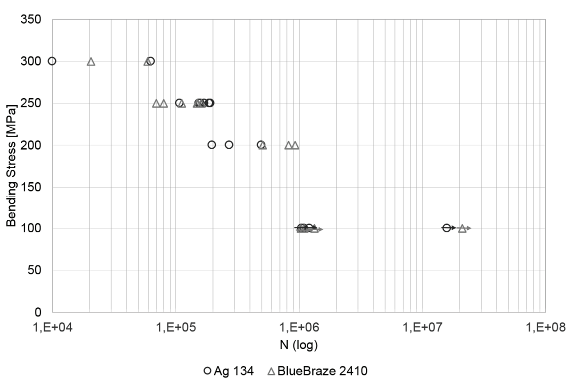


Figure 6: Wöhler curve of brazed steel specimen with Ag 134 and 2410.

3.4 Result in the Field

Experiences were gained in HVACR industry in various applications, like compressors and refrigerators.

In automated processes same liquidus respectively brazing temperature of BlueBraze filler metals were approved on several brazing machines worldwide. Substitution of standard BFM without changing of process parameters was possible, resulting in perfectly filled joints. All customer commented that this was never achieved before with BFM containing 5 – 10 weight-% less silver.

The smaller melting range causes a later initial melting of BrazeTec BlueBraze alloys which causes a different melting impression in manual processes when applying the rod onto the joint while heating.

After brazing, different colour occurs on the resolidified BlueBraze in comparison the standard alloys which is caused by the addition of manganese. The appearance is influenced by brazing temperature, maximum part temperature and part cooling speed, as reaction starts after removing reducing flame.

In refrigerators several pipe connections between compressor and heat exchangers are brazed manually with flame by silver brazing alloys for various steel and copper connections. After short adaption period of up to 3 weeks the workers achieved the same performance level with leakage rates like standard BFM. Additionally the results showed a common dependency of unexperienced and experienced brazers and also of the weekdays when brazed.

In tool manufacturing industry primarily the production of saw blades was tested.

Commonly 2810 was tested with same process parameters, especially considering brazing temperature, as the standard BFM.

The brazing temperature for the new product was the same as defined previously in the brazing process for Ag 449. Depending on geometric conditions, parent materials and visual appearance instructions, a slightly higher brazing temperature might be needed.

The average of shear strength of brazed saw blades is on a comparable level with Ag 449 and 2810 but, as indicated in some test runs, had parallely a lower standard deviation, **Figure 7**.

A reduced standard deviation, as seen with 2810, goes in line with a rising product quality because the quality limiting saw tips with lower shear strength are eliminated.

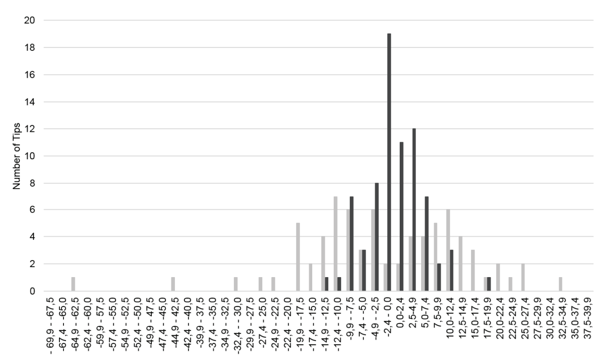


Figure 7: Distribution of single shear values related to the calculated average shear strength (based on 75 tips).

4 Conclusions

Shear strength tests acc. DIN EN 12797 were performed and show similar results for the standard and their corresponding BlueBraze alloys.
The measured average shear strengths were in range of 170 – 190 MPa for HVACR application. The tested BFM for tool application had a 25 % higher shear strengths with 215-220 MPa. This may be influenced due to different alloying elements like tin, indium and nickel.

High cycle fatigue test demonstrates the usability of the new filler metal system in HVACR application. The joints withstand increased stress levels and if, failed in steel plates. The specimen passed up to 21 Mio. Cycles without filing. As the toughest combination (steel to steel) was successfully tested, other combination could be used unconsidered.

Latest research by 3rd party investigated brazeability in silane doped atmospheres with induction or furnace heating. The authors concluded, that 3510 performs with a comparable shear strength on steel S235 in comparison to Ag 155 and Ag 244 and confirmed findings of this paper. In addition only 3510 was suitable for brazing 1.4301 under the defined atmospheric conditions due to its Mn-content [13].

Specimen for shear tests based on DIN EN 12797 with cemented carbides for the tool manufacturing industry approach failed, because all specimen cracked in the cemented carbide parent material due to high stresses.

The shear strength of brazed specimen (DIN EN 12797 and principle specimen) with 2810 and Ag 449, are on the same level. Especially on industrial brazed saw blades a lower standard deviation was observed with 2810. These findings lead to a more reliable quality of products brazed with BlueBraze 2810.
Scientific reports for the correlation of braze gap width and shear strength of joints, made out of cemented carbides and steel [14] concluded, that at a gap width of 100 µm represent a maximum for the shear strength. Cross sections of 2810 showed braze gap width of approx. 100 µm in contrast to approx. 50 µm of Ag 449. Therefore the possibility to ensure an optimized brazing gap width with BlueBraze 2810 is increased.

Standard brazing filler metal Ag 427, with a comparable silver content like 2810, performed on a significant lower shear strength level at the evaluated brazing temperature of 720 °C.

All performed tests in laboratories and the experience in the field on various customers' sites in production applications demonstrated same results and performance of the new silver brazing filler metals. These products enables the customer to ensure savings on silver costs with less impact of metal price fluctuations onto final products without changes of production processes.

5 Literature

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