

Systematical pull and shear test investigations on very small bond loops (wire $\leq 25\ \mu\text{m}$) and innovative alloys

M. Schneider-Ramelow, J.-M. Göhre

Fraunhofer Institute for Reliability and Microintegration (IZM)

Gustav-Meyer-Allee 25, 13355 Berlin, Germany

Phone: 49 30 46403-172, Fax: -271, Email: martin.schneider-ramelow@izm.fraunhofer.de

Abstract

Due to the rapid development of the semiconductor industry and future product generations the packaging of electronic components and systems faces demanding challenges in terms of miniaturization, reliability and production costs. Beside the need to develop adapted technologies and materials this also calls for completely new packaging and testing concepts.

For wire bonding - still the dominating interconnection technology for semiconductors – this means the application of bond wires as thin as $15\ \mu\text{m}$ or ribbons as low as $12.5\ \mu\text{m}$, often of specially doped or alloyed materials. These material versions with higher mechanical stability partially compensate for the decreased tensile strength of ever thinner wires and therefore also allow extreme loop geometries (very low, short, long loops). This leads to the question, whether the guidelines for assessing the quality in terms of visual evaluations and mechanical tests that were developed in the middle of the 1970s (in the US: MIL-STD-883) and concretized in Germany in the 1990s (DVS Guideline 2811) for wires with diameter $\geq 25\ \mu\text{m}$ are still appropriate today. For instance, with the new high strength Au wires the mixed shear code “partially crack in chip metallization, in the ball and at the interface”, which is not even mentioned in old guidelines, may be a sign of good quality in the case of high enough shear forces.

The presented results contain systematic pull and shear test analyses on thin wire bond connections and give recommendations for a revision of the DVS Guidelines 2811 (from 1996).

Key words: wire bonding, ribbon bonding, pull test, shear test

Introduction

The destructive pull test is still the most commonly used mechanical test to measure bond strength, evaluate bond strength distribution, or determine compliance with specified bond strength requirements of the applicable acquisition document. It was developed in the middle of the 1970s [1] and concretized and expanded to ball shear test in Germany in the 1990s (DVS Guidelines 2811) for wires with diameters $\geq 25\ \mu\text{m}$ [2].

Nowadays, advanced ball/wedge bonding takes place with pitches smaller than $50\ \mu\text{m}$ and advanced gold ball auto bonders can bond to test pads with a pitch of $25\ \mu\text{m}$ (wire $12 - 15\ \mu\text{m}$). Advanced wedge/wedge auto bonders can also bond $15\ \mu\text{m}$ wires with these small pitches. Furthermore, high strength Au wires, which are highly doped or

alloyed, with nearly $20\ \text{nm}$ Al coated Au wires as well as Cu wires have been developed and have been in application for years [3]. Today Au ribbon bonding for RF applications is one more bonding technology in modern electronic packaging [4, 5]. So the question now is: Do these new wires with smaller and/or special geometries and higher strength fulfill the quality criteria for wire bond interconnections from the “old” guidelines? Or do these guidelines have to be adapted (and if yes, in what ways)?

For instance, in the majority of cases the first bonding contact is the mashed ball on a chip pad with Al metallization. The interconnection quality of this ball is commonly analyzed by means of shear testing. In this context, it has been common knowledge for years that shear codes exist, which

are not described in guidelines. A mixed break as shear code can be taken as an example, where the crack takes course fractional through the ball, fractional through the metallization and particular alongside the interface of the ball and the metallization.

The paper describes the results of systematic pull and shear test analyses on thin wire bond connections and loops with high strength material. Main findings concern pull test results if bottle neck capillaries are used as well as Au ball shear codes and attainable shear strengths. Another important result is the recommendation to use the DVS guideline 2811 concerning the pull test for all kinds of wedge/wedge bonds (smaller dimensions, higher strengths, ribbons and so on) [6].

Pull test results

Typical quality criteria for pull test results of quality-like bond interconnections (over ≥ 30 loops) are (notice correction factor) [2]:

- Average pull force value $\geq 50\%$ of the breaking load of the non-deformed wire
- Standard deviation (based on average value) $\leq 25\%$ (Fab.) or $\leq 15\%$ (Lab.), respectively.
- No pull value below a standard minimum pull value based on wire diameter and strength
- No pull lift offs (Lab.) or $< 10\%$ (Fab.), respectively.

Table 1 and Table 2 show wire bond materials (wire and ribbon) investigated by means of pull testing.

Table 1: Materials for wedge/wedge bonding

Wire (W/W)	$\emptyset$ resp. L x W	Company
AlSi1	15 – 25 μm	Swissbit
Au	12,5 – 17,5 μm	EADS
Au	20 – 25 μm	Cis
Au	50 μm x 12,5 μm	EADS
Au + Al layer	25 μm + 20 and 40 nm Al	TUD
Cu + Al layer	25 μm + 20 nm Al	TUD

Table 2: Materials for ball/wedge bonding

Wire (B/W)	$\emptyset$	Company
Au, GID Tanaka	25 μm	Infineon
Au HA6	25 μm	TUD
Au HD2	30 μm	TUD
Au HA7	32 μm	TUD
Cu, Tanaka	20 μm	Qimonda

The results of pull test investigations are summarized in Table 3. Apparently no pull lift offs or minimum pull values occur. Also the criteria for mean pull values and standard deviation are fulfilled in all cases (see last two columns in Table 3).

In the course of shear test investigations on ball bonds discussed later the ball/wedge bonding with standard and fine pitch capillaries proceeded including pull testing (s. Figure 1). These tests were done on loops bonded with a 25 μm Au wire (HA 10; 10.5 cN breaking load) onto a relatively rough PCB with Ni/Pd/Flash-Au finish as well as on smoother Al chip metallization. As a result quality-like bonding results which fulfilled the guideline criteria were achieved with the standard capillary on both metallizations, but not with the bottle neck capillary. Using such a fine pitch capillary led to mean pull force values below 4 cN (thus less than 50% of this wire's breaking load but without lift offs) and this despite comprehensive variation of the bonding parameters. The reason therefore must be the relatively small wedge geometry and sharp pinch-off at bonding with the fine pitch capillary (Figure 2). Hence the type of capillary has an influence on the wedge geometry and therefore on the pull test result (wedge appearance, pull force). Consequently, this should be considered in future guidelines.

Table 3: Results of pull test investigations

wedge/wedge bonds				
	ϕ	BL	MV	S
Wire	[μm]	[cN]	[cN]	[cN]
AlSi1	15	4 – 6	4.1	0.3
AlSi1	17.5	6.5 – 7.5	4.6	0.3
AlSi1	20	8 – 10	5.5	0.3
AlSi1	22	10 – 12	7.9	0.4
AlSi1	25	13 – 15	11.6	0.7
Au (HA3)	20	17	11.5	0.6
Au	12.5	1.5 – 2.5	1.4	0.2
Au	17.5	3 – 5	3.8	0.2
Au	12.5x50	10 – 14	8.9	0.7
Au+40 nm Al	25	> 9	9.6	0.7
Au+20 nm Al	25	> 8	9.6	0.6
Cu+20 nm Al	25	> 8	10.2	1.1
ball/wedge bonds				
	ϕ	BL	MV	S
Wire	[μm]	[cN]	[cN]	[cN]
Cu Tanaka	20	> 4	5.9	0.8
Au (HA6)	25	> 10	12.2	0.4
Au Tanaka	25	10 - 14	10.0	0.8

Remarks:

ϕ = Cross sectional area of bond wire resp. ribbon;

BL = Breaking Load of wire;

MV and S = Pull force mean value and standard deviation

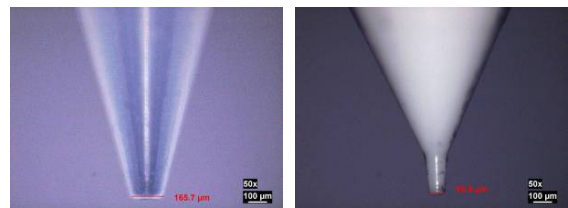


Figure 1: Different capillary types

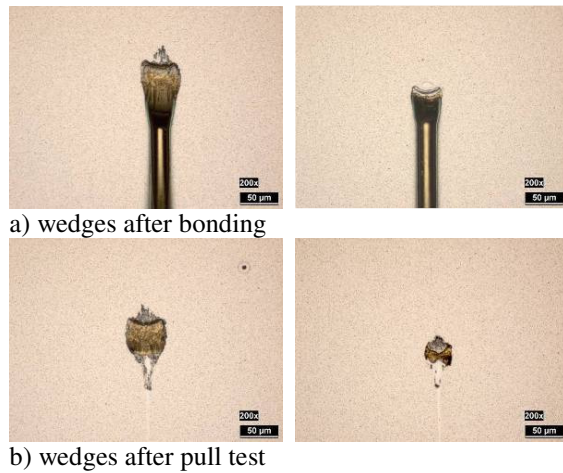


Figure 2: Wedge geometries by comparison (left standard and right fine pitch capillary)

In summary the guideline 2811 is applicable to fine bonding wires (15 μm) and ribbons (12.5 μm) as well as new wire qualities (highly doped, alloyed or coated with Al). Hence one might consider updating the minimum pull force values in guidelines to wire diameters below 25 μm as to be seen in Table 4.

Table 4: Minimum pull values for fine wires

Wire diameter in μm	12.5	15	17.5	20	22.5	25
Minimum pull force value in cN	0.8	2.0	2.3	3.3	3.6	4.0

Shear test results

Shear testing typically serves to qualify ball bond interconnection (welding) and its strength. The shear tool height is well defined (e.g. 1/3 of the bonding wire diameter) and the shear level has to be within the ball for the most part (remaining Au must be visible on the pad). Guidelines [2] distinguish between the following characteristic shear codes (failure codes):

- (1) Cratering: break out of chip material
- (2) Metallization lift off: bond lifted with pad metallization from basic material
- (3) Shear lift off: shear break at the interface of ball bond and pad metallization
- (4) Shear break within the ball bond (> 50% ball bond material on pad after test)

The shear codes (1) – (3) indicate poor bonding and should not occur. The shear test results of 25 μm Au wire on a test chip with Al metallization are summarized in Figure 3. The mashed ball diameter was in the range of 70 μm with the US current from 80 to 125 mA used for these investigations (slowly increasing diameters

and decreasing height with increasing US current as expected, bottom diagram in Figure 3). All shear codes were mixed breaks with fractional shearing through the ball, fractional through the metallization and particular alongside the interface of ball and metallization (Figure 4).

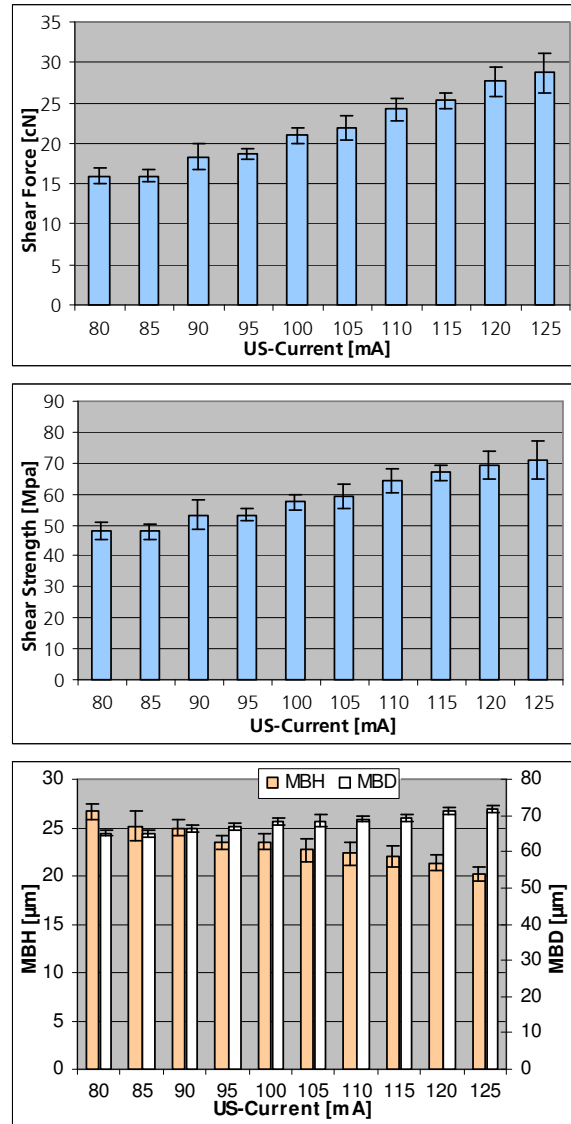


Figure 3: Shear test results with 25 μm Au wire (HA10: 10.5 cN breaking load) and ball geometries (MBD and MBH: Mashed Ball Diameter or Height, respectively); variation of US current

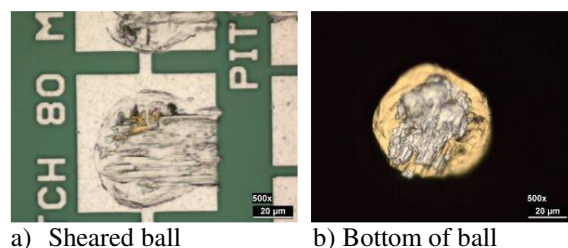


Figure 4: Typical shear code with 25 μm Au wire

This mixed failure code was without much doubt responsible for not reaching the required shear force values from the DVS-guideline 2811 (here mean shear force of 40 cN e.g. 84 MPa mean shear strength for ball width of 70 μm). Further increase of US current was not allowed according to DVS-guideline 2811, because at the maximum used power of 125 mA of US current (s. Figure 3) the minimum ball height was reached (declared with 0.8 wire diameter, so here 20 μm). A systematical variation of bonding force at a constant US current of 110 mA confirmed the results and the technical expertise. The mean shear force and strength values were too low (s. Figure 5) and the shear code was again a mixed break as to be seen in Figure 4.

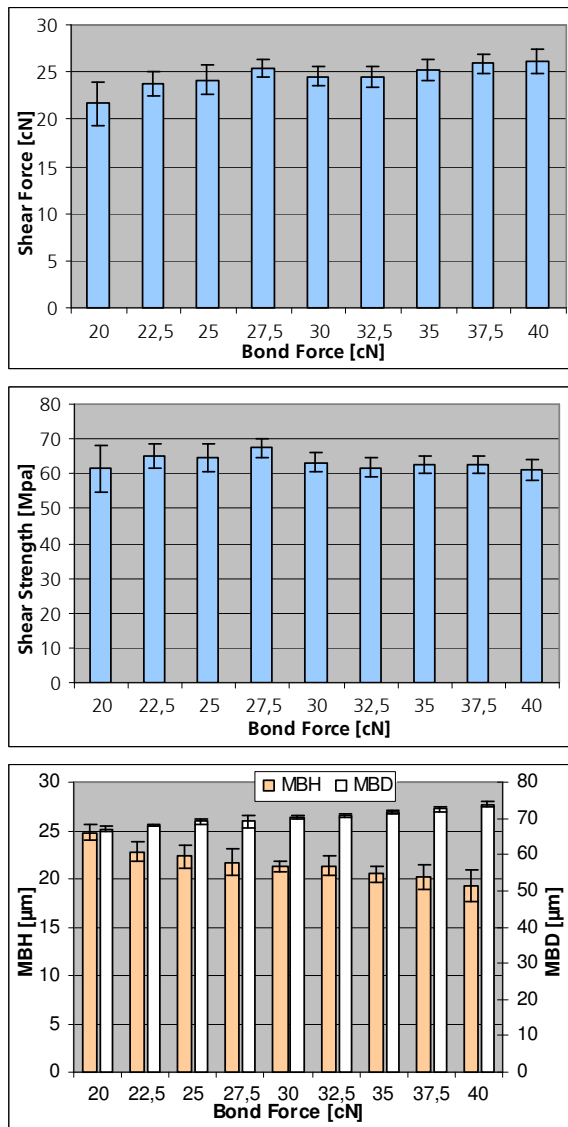


Figure 5: Shear test results with 25 μm Au wire (HA10: 10.5 cN breaking load) and ball geometries (MBD and MBH: Mashed Ball Diameter or Height, respectively); variation of bond force

To finish the shear test investigation 17.5 μm Au wire (HD2; > 2 cN breaking load) was bonded on pads with Al chip metallization and a pitch of 40 μm (with fine pitch capillary, s. Figure 6). Shear height was fixed at 4 μm . A maximum mashed ball height of 7 μm was tolerated in these experiments for this fine Au wire, because a minimum mashed ball height value of 0.4 x wire diameter should be allowed for future guidelines (as a recommendation instead of 0.8 x wire diameter).

Shear test results of 17.5 Au wire bonding depending on bonding parameters are summarized in Table 5. Again only mixed shear codes occur and mean shear force and strength values were too low (< 84 MPa). This was true for the most deformed ball (6 μm) bonded with the highest bonding force of 11 cN, too (s. last row in Table 5).

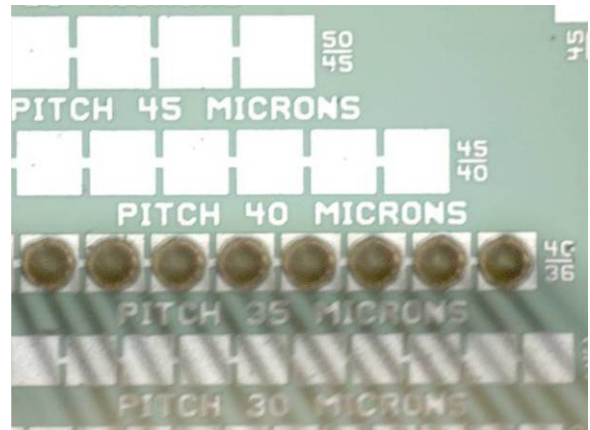


Figure 6: 40 μm bond pad pitch with 17.5 μm Au

Table 5: Shear test results of 17.5 μm Au wire

Variation of US current at 8 ms time and 7 cN force						
	shear force		shear strength		ball geometry	
US	MV	S	MV	S	MBD	MBH
[mA]	[cN]	[cN]	[MPa]	[MPa]	[μm]	[μm]
40	5.0	0.3	55.9	3.1	33.7	11.1
45	5.7	0.2	62.4	2.3	34.0	--
50	6.2	0.2	68.7	2.6	33.8	--
55	6.3	0.2	67.5	2.5	34.5	10.5
60	7.4	0.2	78.0	2.0	34.8	--
65	7.3	0.2	74.6	1.9	35.2	9.4
70	7.3	0.3	70.5	3.0	36.3	--
75	7.1	0.2	68.8	2.1	36.3	8.2
Variation of bond force (BF) at 8 ms and 60 mA						
	shear force		shear strength		ball geometry	
BF	MV	S	MV	S	MBD	MBH
[cN]	[cN]	[cN]	[MPa]	[MPa]	[μm]	[μm]
7	7.4	0.2	78.0	2.0	34.8	--
8	7.1	0.2	71.7	2.2	35.5	9.6
9	7.3	0.2	69.1	2.1	36.7	--
10	7.2	0.3	64.2	2.6	37.9	--
11	7.4	0.3	60.9	2.4	39.4	6.0

Remarks:

MV and S = Shear force mean value and standard deviation;

MBD and MBH = mashed ball diameter and height

Cross section investigations at these fine pitch ball bonds ($17.5\text{ }\mu\text{m}$ HD2) on chip pads with Al metallization confirmed that quality-like bonding took place with very good interfacial welding between the Au ball and the chip metallization (s. Figure 7 and Figure 8). Thereby a nearly $1\text{ }\mu\text{m}$ thick and continuously developed layer of intermetallic phases could be detected directly after the bonding process (initial state in Figure 7). This intermetallic layer thickness of the initial state increased to more than $3\text{ }\mu\text{m}$ after 48 h temperature storage at 150°C (Figure 8).

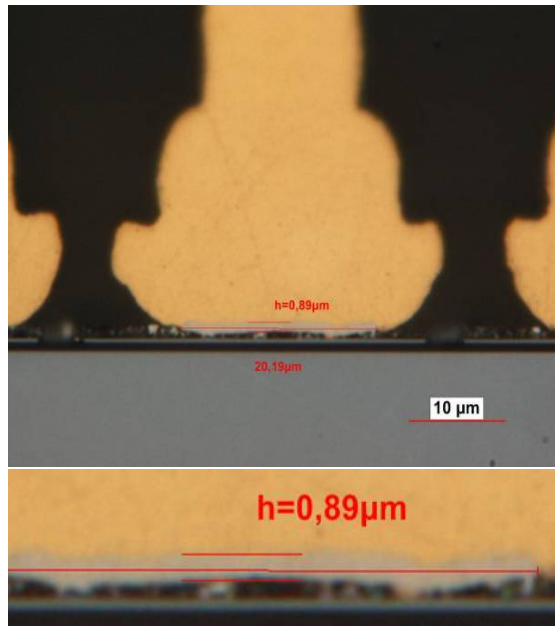


Figure 7: Cross section of a mashed ball ($17.5\text{ }\mu\text{m}$ HD2-Au wire) after bonding

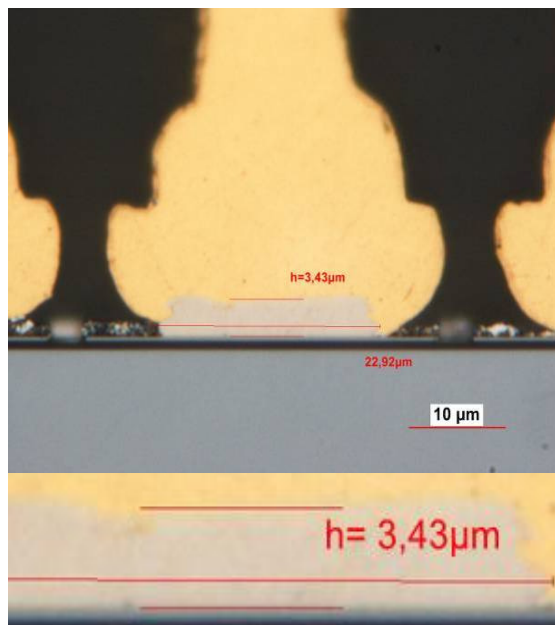


Figure 8: Cross section of a mashed ball ($17.5\text{ }\mu\text{m}$ HD2-Au wire) after 48 h at 150°C

Conclusions

The investigations described in this paper were aimed at the interpretation of pull and shear test results of wire bonding interconnects with wires of very small geometries ($< 25\text{ }\mu\text{m}$) and/or with higher mechanical stability (alloyed or highly doped Au, Cu). One target was to validate existing guidelines for mechanical testing of bonded wires. The experimental results allow the following conclusions:

Pull test criteria of guidelines (e.g. DVS guideline 2811) for bonding interconnects with smaller wires, high strength or with Al coated wires as well as small ribbons can be adopted the new guidelines. However, some restrictive conditions have to be included in new guidelines if fine pitch capillaries are used and pull test results are being interpreted. Furthermore, heel cracks with rather less Au remaining on bond pads are acceptable as one more available characteristic pull code for quality-like ball/wedge bonding or pull testing of these loops, respectively.

On the other hand it is not so easy to transfer shear test criteria for ball bonds to smallest dimensions and alternative wire materials. Innovative bond tools and extremely fine wires bring about changed ball bond geometries with smaller dimensions than the minimum dimensions referred to in the “old” guidelines (especially mashed ball bond height). This aspect needs to be considered and taken into account. A variety of other shear codes apart from the ones described in the guidelines is possible and has to be defined and interpreted. Another challenge is to enable the operators in production lines to identify the shear codes. Shear force and shear strength values have to be redefined, too. Further fundamental discussions among experts and more intensive systematical investigations are required at this point to develop a new international guideline “test method for wire bond interconnections”.

References

- [1] MIL-STD-883 Test Method Standard, Microcircuits, Revision: G, Dated: 28 February 2006.
- [2] Guideline DVS 2811: Test method for wire bond interconnections, Deutscher Verband für Schweißtechnik e.V. (German Association for Welding), 1996.
- [3] Lang, K.-D., Harman, G. G.; Schneider-Ramelow, M.: Modern wire bond technologies – ready for the challenges of future microelectronic packaging. in: The World of Electronic Packaging and System Integration. B. Michel, R. Aschenbrenner (Eds.), Anniversary Edition, 60th Birthday of Herbert Reichl, ddp goldenbogen 2004, S.332-339.

- [4] US Patent 5894983: High frequency, low temperature thermosonic ribbon bonding process for system-level applications. Issued on April 20, 1999.
- [5] Seufert, K.: Ribon wedge bonding. Advanced Packaging July, 2003.
- [6] Schneider-Ramelow, M.; Rudolf, F.; et al: Mechanische Prüfverfahren für Mikroverbindungen elektronischer Schaltungen mit extrem verkleinerten Geometrien. BMWA/AiF-Abschlussbericht AiF 14.428 B, Sept. 2007. (only in german).

Acknowledgements

Research for this article was funded by the „Bundesministerium für Wirtschaft über die Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e.V. (AiF-Nr. 14.428 B) and supported by the „Forschungsvereinigung Schweißen und verwandte Verfahren e.V. des DVS“. Authors are deeply grateful for this support.