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Heavy Copper Wire Bonding Ready for Industrial Mass Production

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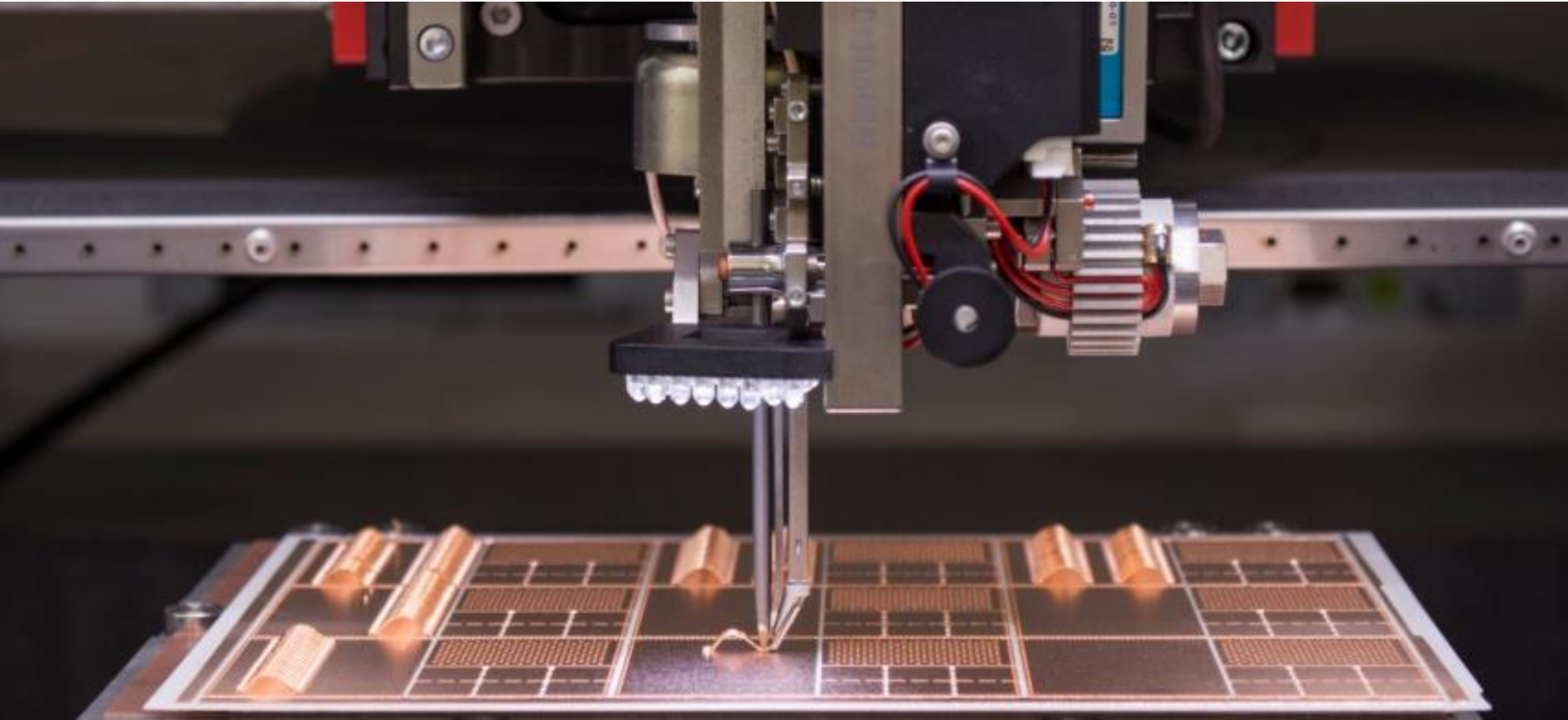
Heavy Copper Wire Bonding



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Agenda

- **Introduction**
- Copper Wire Bonding: Advantages and Challenges
- Tool Wear and Lifetime
  - Wear mechanisms
  - Parameters influencing tool wear and lifetime
  - Impact of bonding parameters on tool wear
  - Impact of tool wear on bond quality
- Monitoring Tool Wear via Machine Data
- Cutter and Wire Guide Lifetime
- Summary and Outlook

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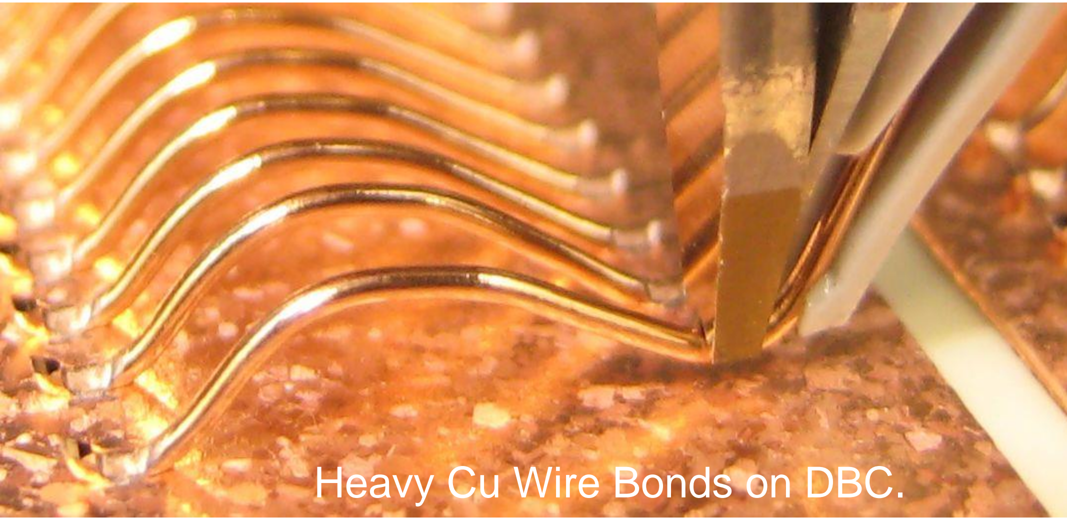
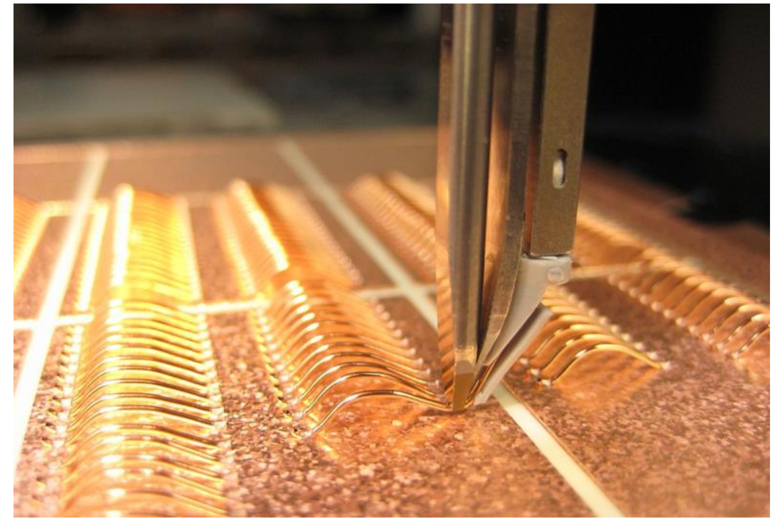
Introduction


Heavy Cu Wire Bonds on DBC.



- Industry needs a next generation interconnection system for a desired rise of junction temperature and to increase lifetime.
- Aluminum does not fulfill these new power requirements.
- Heavy Cu wire is one such system available today.

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Limits of Heavy Aluminum Wire Bonding

- Al heavy wire bonding is state-of-the-art in connecting power devices.
- Power cycling is limited by max. operation temperature of Al wire above $0.4*T_{melt}$ (100ºC) due to creep.

Cross section through Al wire bond failed after power cycling
Siepe et al., The Future of Wire Bonding is? Wire Bonding!, CIPS 2010

- Al wire is the weakest link - cracks run through the wire and not along the interface to the chips.
- Thermo-mechanical mismatch (Si: 2.6 ppm/K, Al: 23 ppm/K, Cu: 17 ppm/K)
- The wire material limits the lifetime. Alternative materials need to meet the requirements to increase junction temperature and lifetime.

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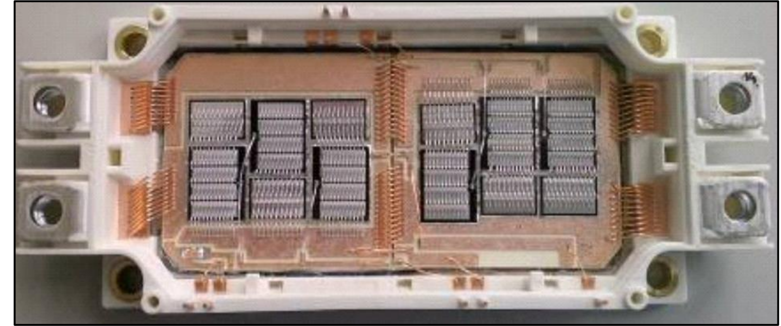
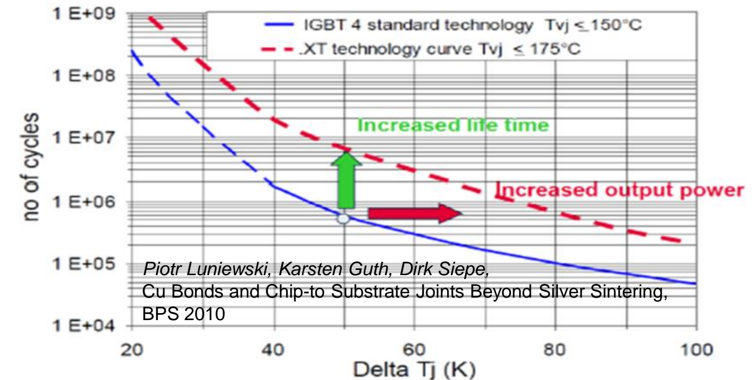
Advantages and Challenges

- Currently heavy aluminum wire is widely used with limited lifetime and adequate electrical conductivity.
- Elevated junction temperature and increased lifetime in system environment is desired.
- New die attach techniques and copper wire bonding enable approximately
  - 10x higher lifetime or
  - 10x increased output power



20 mil copper wire bonding in power modul, Infineon Technologies
Siepe et al., The Future of Wire Bonding is? Wire Bonding!, CIPS 2010



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Advantages and Challenges

- Technology migration to copper wire:
  - Better thermal and electrical conductivity
  - Higher homologous temperature
  - Larger current density
  - Smaller chips
  - Better long-term stability
  - Higher mechanical stability

	Aluminum	Copper
Specific Resistance	0,027 Ω mm^2	0,017 Ω mm^2
Thermal conductivity	220 W/m K	400 W/m K
Thermal Expansion Coef.	23 ppm	16,5 ppm
Yield strength	29 MPa	140 MPa
Tensile strength	40-50 MPa	210-230 MPa
Elastic modulus	70 GPa	110-140 GPa
Melting temperature	660 °C	1083 °C
Typical Bondforce	7 N	25 N
Ultrasonic Power	100 %	200-300 %

- 2-3 times higher bonding force and ultrasonic power necessary
- Cu plated dies necessary for heavy Cu wire bonding.
- Lower lifetime of consumables compared to aluminum bonding, increased change intervals and higher costs.

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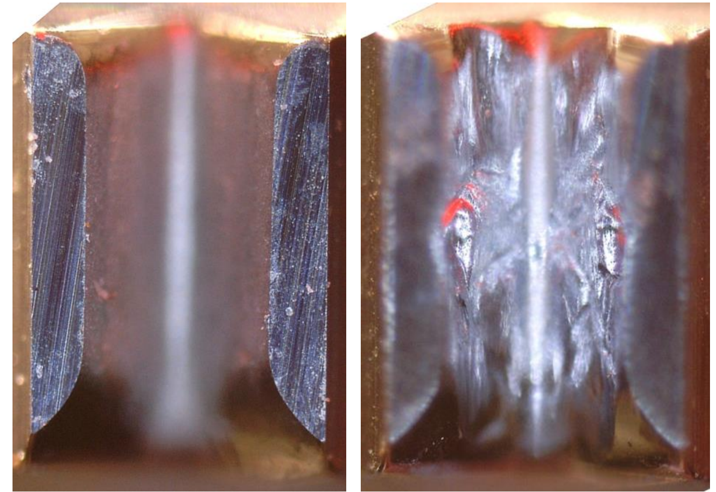
Wear Mechanisms

- With Al wire, material collects on the tool which then needs to be cleaned after about 100k bonds. Tool can be cleaned & reused up to 10 times.
- With heavy Cu wire bonding, strong wear is visible quite quickly.
- No build-up of Cu in the V-groove area. No cleaning possible.
- Tool can only be used once for Cu and is then discarded.

New wedge groove (bottom view) | Wedge groove after 25k bonds



Reference tungsten carbide tool, reference parameters, 500 micron Cu wire

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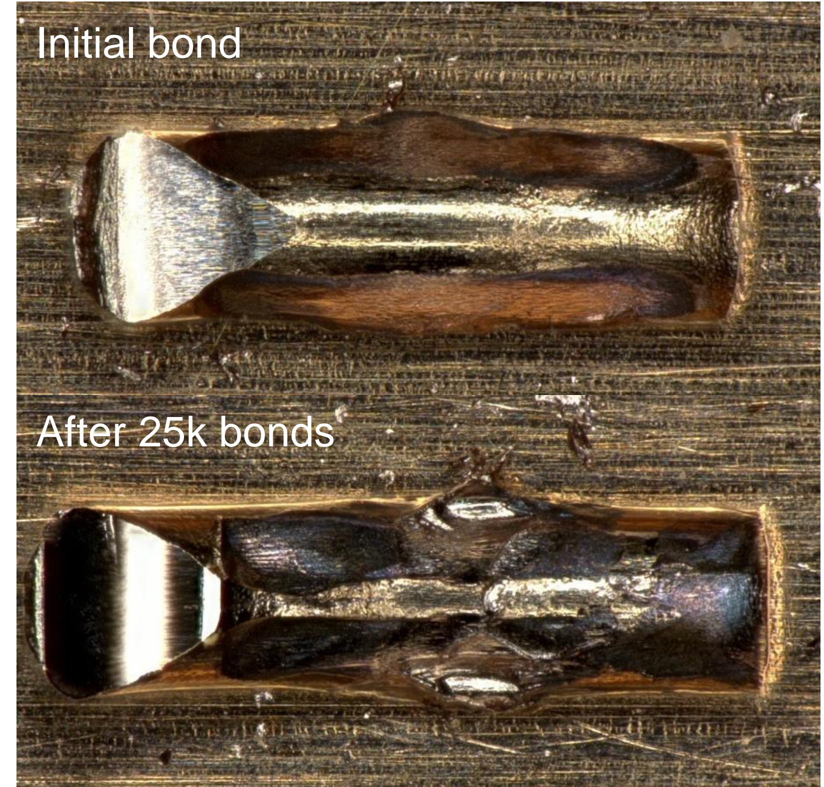
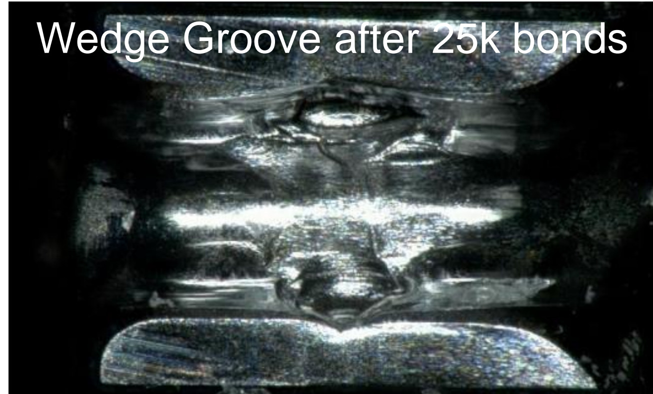
Wear Mechanisms – Visual appearance

- Noticeable degradation of the bond shape after just 25k bonds.
- Shiny surfaces indicate micro-slip.





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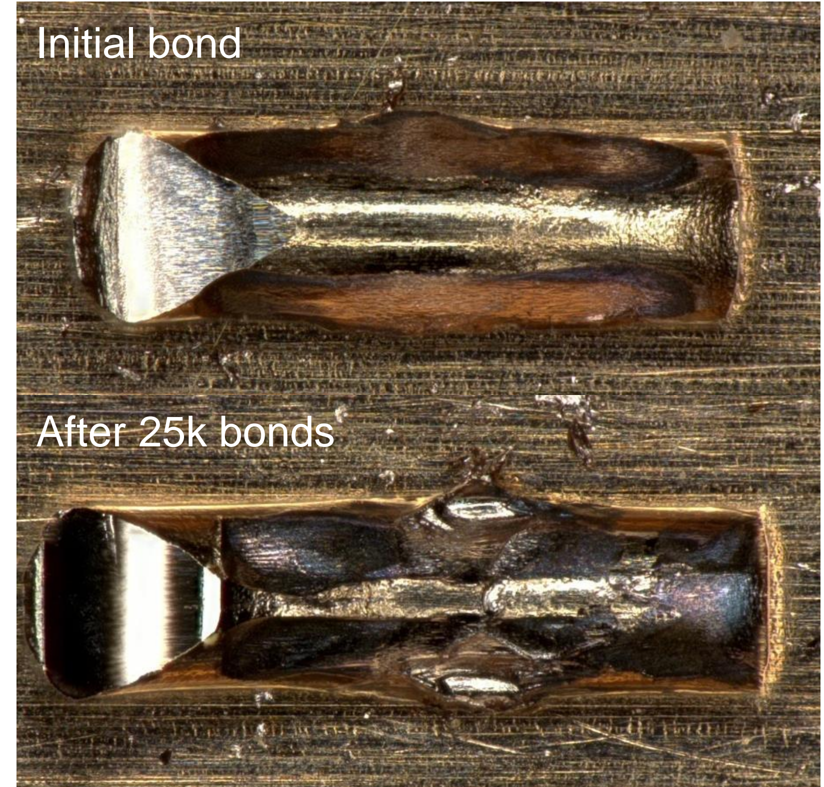
Wear Mechanisms – Causes

- Wear mechanisms:
  - Abrasion
  - Plastic deformation
  - Breaking of surface material
  - Recurrent deposition of small particles of copper oxide



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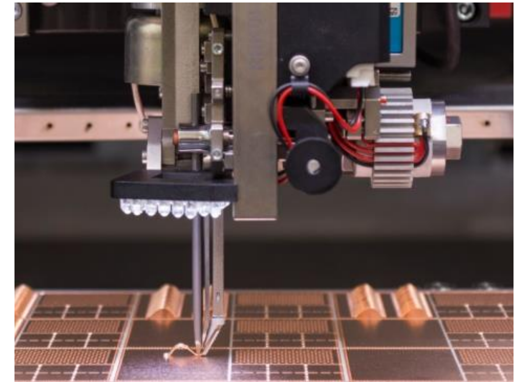
Tool Wear & Lifetime – Experimental Setup

- Heraeus *PowerCu* Copper Wire
  - 500 microns (20 mils)
  - Breaking load 3100 – 4800 gf
  - Elongation > 15%
  - 100 meters per spool (up to 500 m)
- BJ939 Hesse Heavy Wire Bonder
  - Copper/heavy ribbon bond head,
    back-cut, 60 kHz, bonding force up to 4200 gf,
    ultrasonic power up to 120 Watts
  - Note: typical bond head used for heavy Al wire
    is 60 kHz, 80 Watts up to 1500 gf

Source: http://heraeus-contactmaterials.com



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Tool Wear & Lifetime – Experimental Setup

- Pure Cu plates 0.8 mm thick, C194
- Only single bonds without loops
- Reference bond tool with reference bond parameters
- Made 100,000 bonds and monitored:
  - Bond shape by microscopy
  - Shear values
  - Machine process data
- DOE was done to obtain the wear-optimized parameters
- Tried alternative bond tool materials and bond tool tip designs

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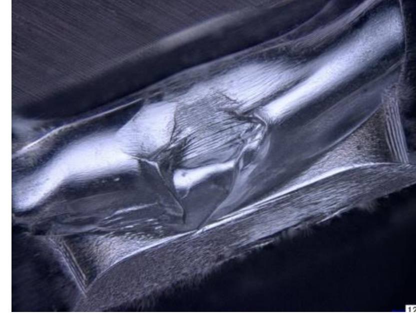
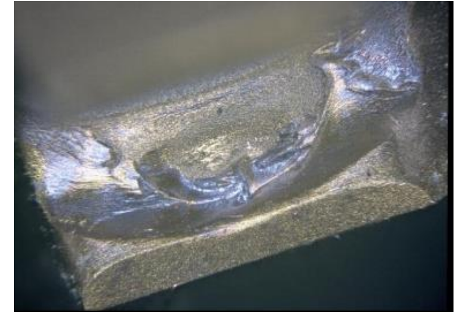
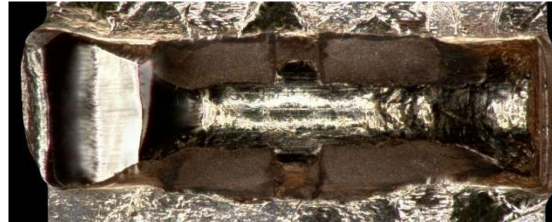
Parameters Influencing Tool Wear and Lifetime

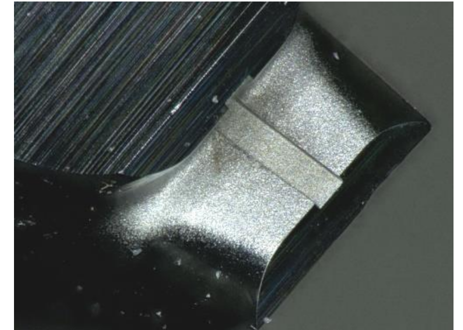
Different parameters influence tool wear and lifetime:

- Material
  - Tungsten carbide
  - Cermet (tip)
  - Other materials – no improvement
- Geometry
  - V-Groove
  - Cross groove
  - Other type to improve grip
- Bonding parameters
- Looping – not tested here









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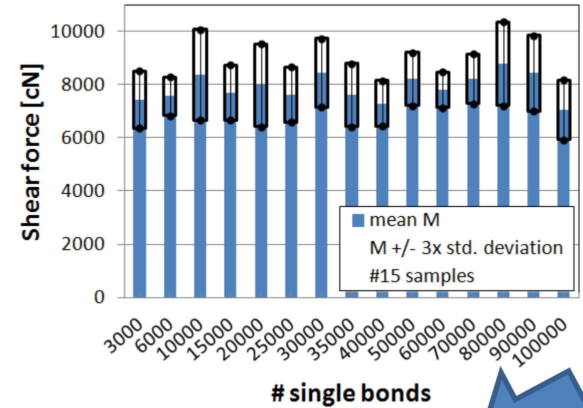
Definition of Bond Quality – 3 Criteria

- Bond strength
  - Measured via bond shear test
  - Shear values and shear code as a measure
- Visual criteria
  - Optical inspection of the top side of the bond foot
  - Topography of contact area, width and length, carving on the sides
  - Is the surface matte or shiny? (indication for micro-slip)
  - Does bond tool touchdown occur during bonding?
- Machine process data



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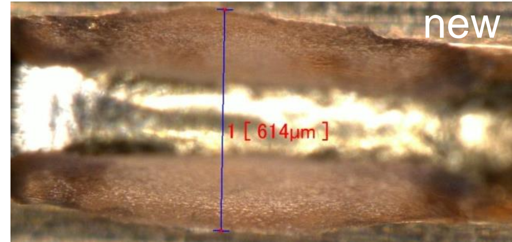
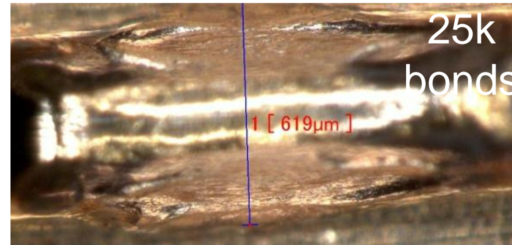
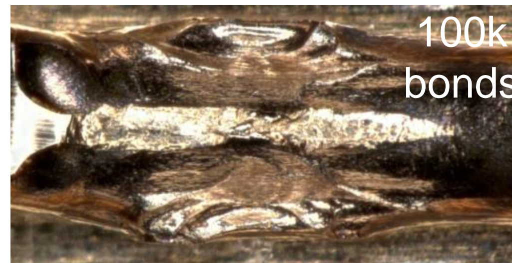
Impact of Bonding Parameters on Tool Wear

- Tool lifetime was increased by a factor of 4 by using wear-optimized parameters
- No decrease in bond strength between the two parameter sets.
- Look at 25k bonds photos between optimized and standard parameters.

Optimized parameters







Standard parameters

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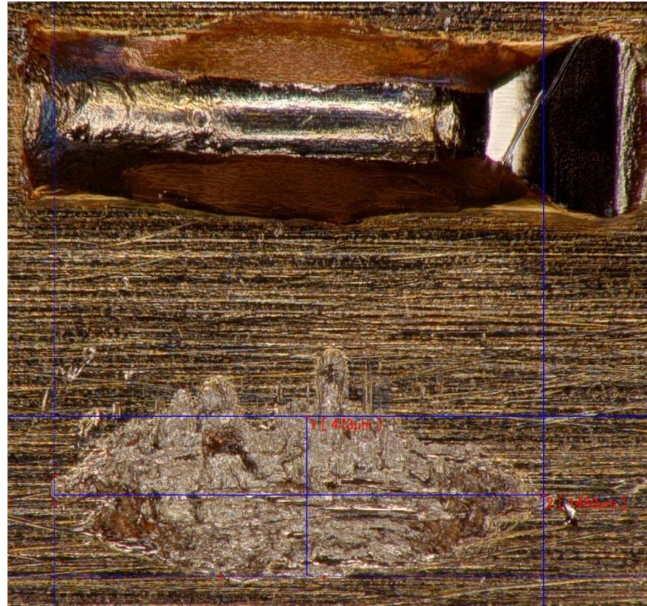
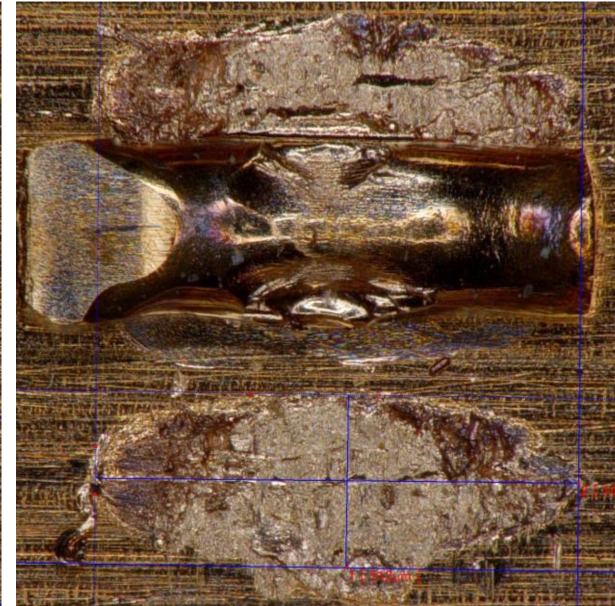
Impact of Tool Wear on Bond Quality

- Bond foot visual does not correlate with shear remnants with heavy Cu wire.

New tool



100k bonds



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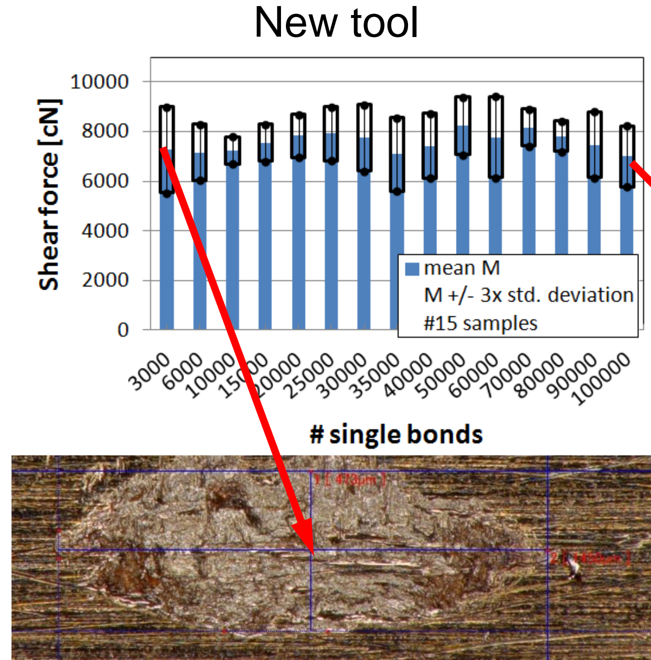
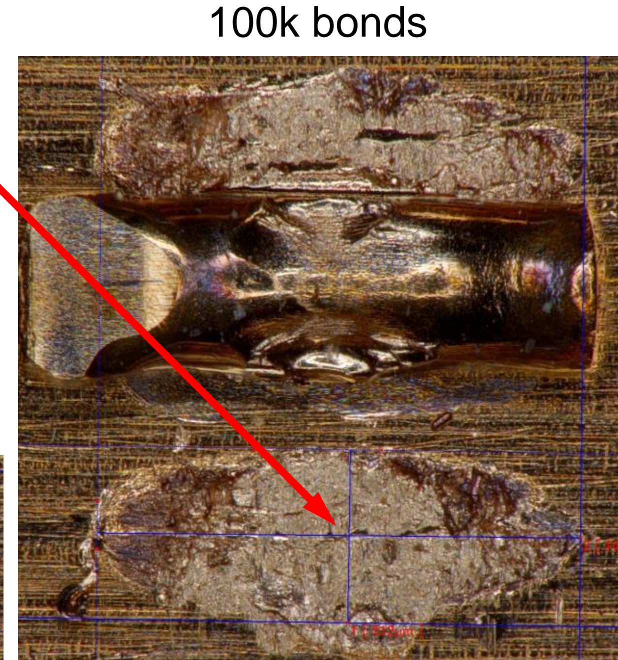
Impact of Tool Wear on Bond Quality

- Bond foot visual does not correlate with shear remnants
- Shear values correlate with shear remnants
- … and can stay at a high level despite massive tool wear

New tool



100k bonds



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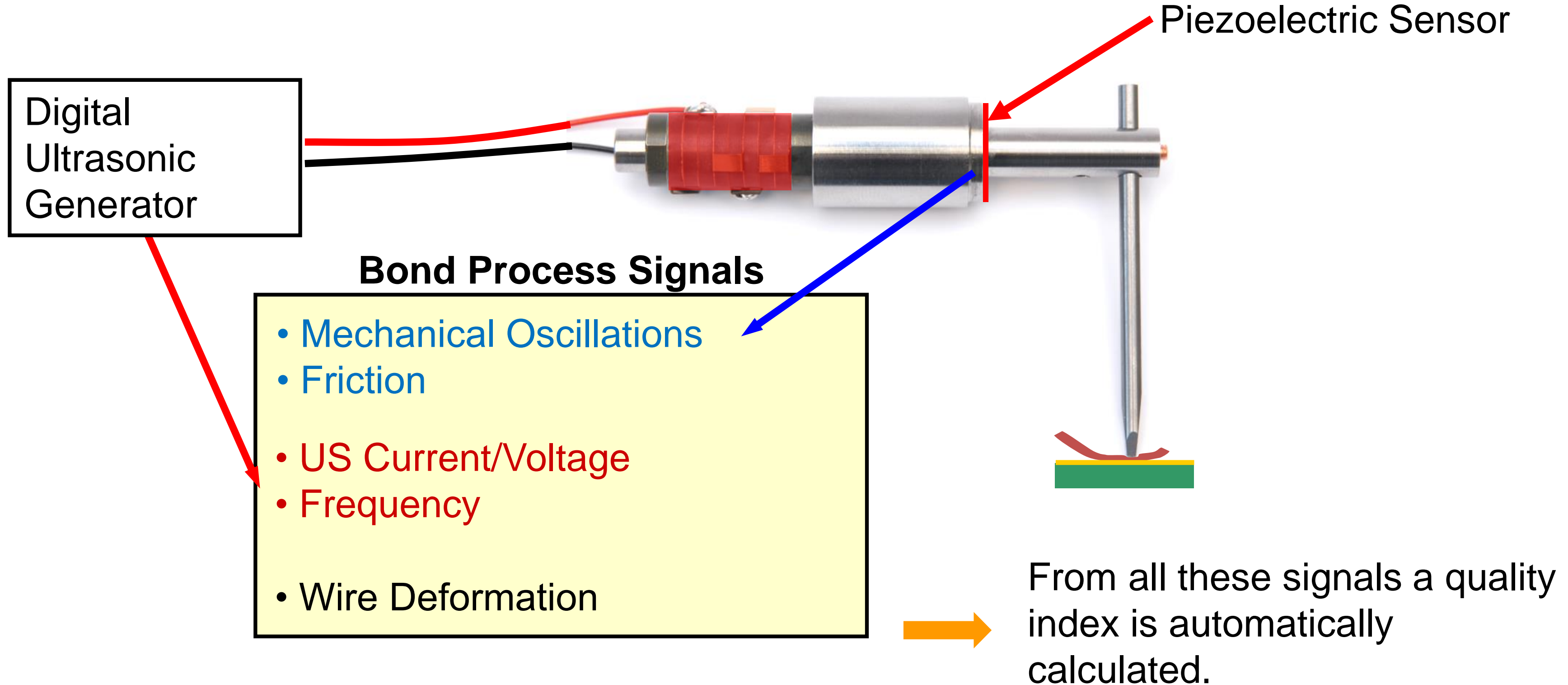
Monitoring Tool Wear via Machine Data



From all these signals a quality index is automatically calculated.

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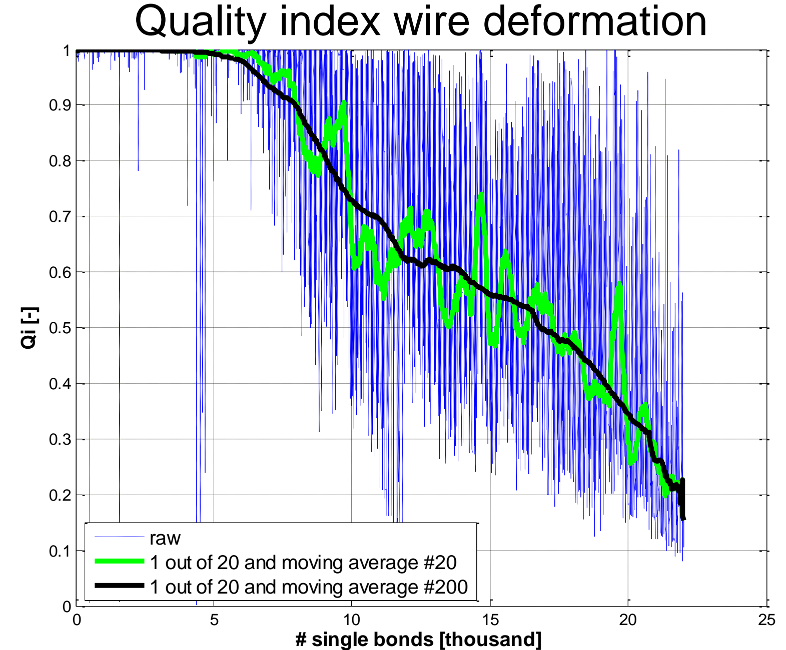
Monitoring Tool Wear via Machine Data

- Not looking at a single bond but overall trend.
- ‘Tool wear monitor’ derived by filtering (black curve).
- Quality index for wire deformation shows high sensitivity towards tool wear.
- Proper setup and alignment of wire guide and cutter blade is critical to ensure optimum wire flow beneath the bond tool.



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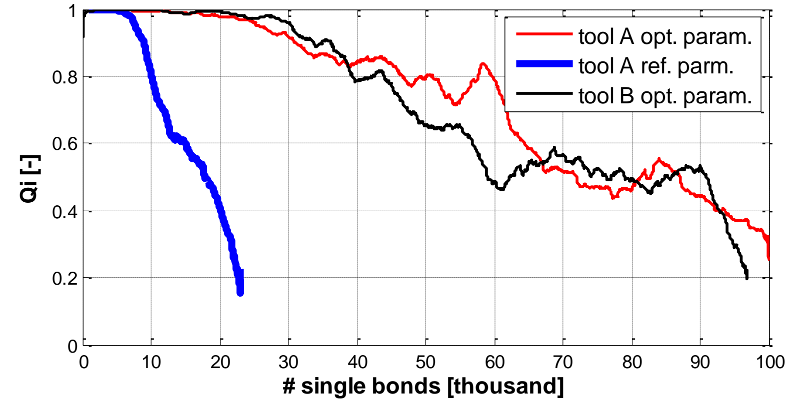
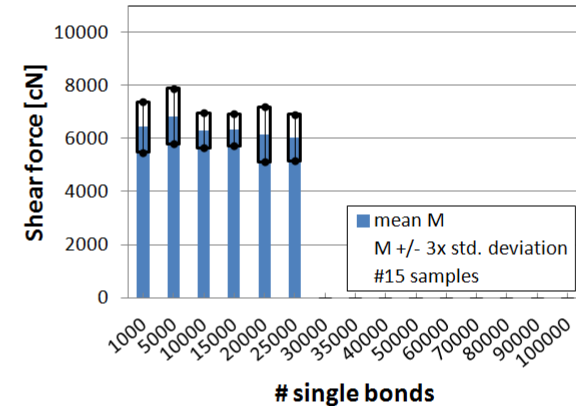
Monitoring Tool Wear via Machine Data

- Reference process:
  - Tungsten carbide tool as reference
  - Reference parameters, not optimized fo tool wear
  - Physical degradation of the bond at 25k bonds.
  - Bond tool is worn.





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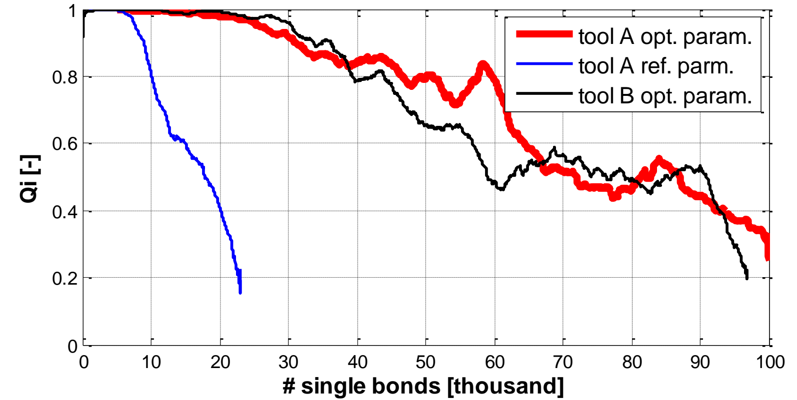
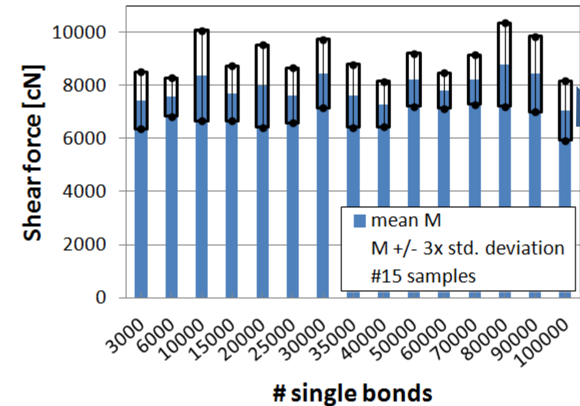
Monitoring Tool Wear via Machine Data

- Optimized parameters:
  - Tungsten carbide tool as reference
  - Wear-Optimized parameters
  - Show equivalent bond quality
  - 4 x the lifetime of the bond tool
  - Tool touchdowns during bonding since 95k bonds → decrease in shear values





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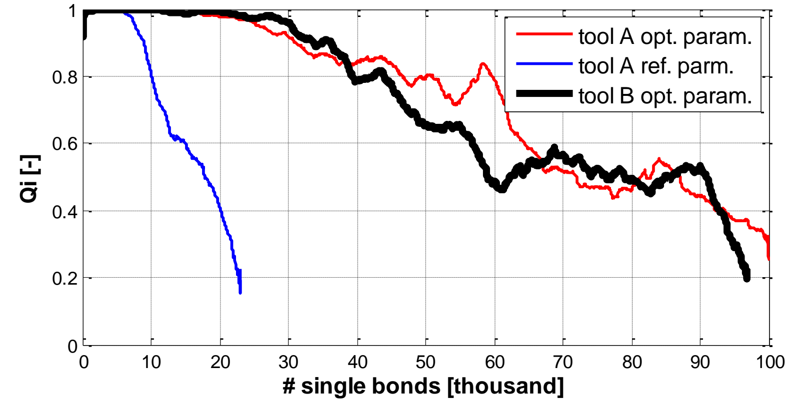
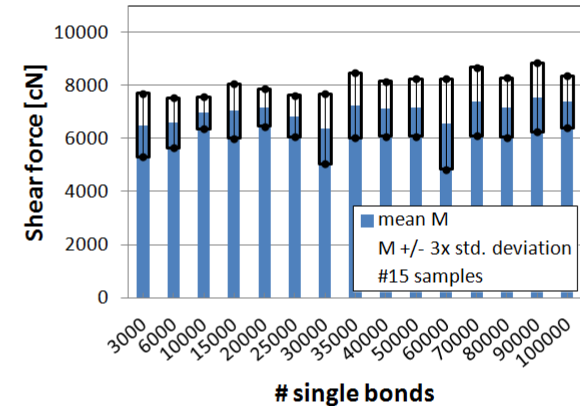
Monitoring Tool Wear via Machine Data

- Cermet-tipped tool:
  - Cermet-tipped tool, identical geometry
  - Wear optimized parameters
  - Shows slightly better lifetime than the tungsten carbide tool
  - Bond tool is not hitting surface at 100k bonds.
  - 2 of 3 quality requirements are not met - Bad quality monitor and bad visual.





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Cutter Lifetime

- Changed cutter material from hardened steel to cemented carbides for improved lifetime (initially only a few thousand).
- Alternative design avoids contact of cutter with edge of bond tool and that helps reduce wear.
- 1 million cuts is now achievable.

New

1.0 million cuts

1.2 million cuts

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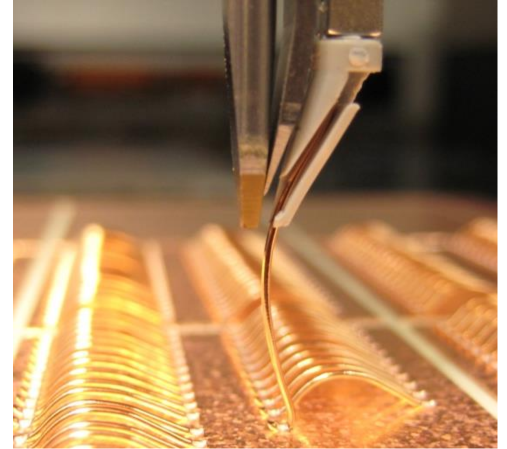
Wire Guide Lifetime

- The wire guide showed reasonable lifetime from the beginning.
- No changes were needed to the existing wire guide to reach up to 500,000 bonds (ideal conditions).
- Abrasive wear on the plastic material is typical, no material build up like in aluminum bonding.
- Frictional forces within the wire guide itself during wire feeding and looping have to be kept to a minimum.
- Vertical and lateral alignment as well as a proper distance to the bonding tool are important to reduce frictional wear.



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Summary

1. Reference bonding with tungsten carbide tool and reference parameters showed strong wear.
2. Tool wear and optical appearance of bond foot and tool tip do not correlate linearly with bond strength.
3. Increased micro-slip between tool and wire and tool touchdowns during bonding indicate tool's EOL. Therefore the shear values will decrease.
4. Cermet-tipped tool showed little improvement in bond tool lifetime over the tungsten carbide.
5. Optimizing bond parameters had a major impact and increased the bond tool lifetime by a factor of 4.

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Summary and Outlook

6. Changing cutter blade tip from hardened steel to cemented carbide improved cutting up to 1,000,000 cuts.
7. Wire guide showed reasonable lifetime of up to 500,000 bonds without optimization.
8. Machine data allowed online monitoring of bond tool wear to trigger optimal bond tool change.

Future Outlook

- Further lifetime improvements with new bond tool materials are being considered.
- Implementation of tool wear monitor onto the bonding machine.

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