Pb-free Solder Applications and Requirements in Automotive Industry

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What Bill Gates said about the automotive industry

Bill Gates (at a previous computer expo COMDEX):

"If automotive technology had kept pace with computer technology over the past few decades, you would now be driving a V-32 instead of a V-8, and it would have a top speed of 10,000 miles per hour. Or you could have an economy car that weighs 30 pounds and gets a thousand miles to a gallon of gas. In either case the sticker price of a new car would be less than $50."

Top 10 Things That Would Be Different If Microsoft Started Building Cars!

10. A particular model year of car wouldn't be available until after that year.
9. Every time they repainted the lines on the road you would have to buy a new car.
8. Occasionally, executing a maneuver such as a left turn, would cause your car to shut down and refuse to restart, in which case you would have to reinstall the engine.
7. Only one person at a time could use the car, unless you bought "CarME" or "CarNT." But then you would have to buy more seats.
6. "Macintosh Motorsystems" would make a car that was powered by the sun, reliable, five times as fast, and twice as easy to drive, but would only run on five percent of the roads.

Top 10 Things That Would Be Different If Microsoft Started Building Cars!

5. New seats would force everyone to have the same size butt.
4. The airbag system would say "Are you sure?" before going off.
3. Occasionally for no reason whatsoever, your car would lock you out and refuse to let you in until you simultaneously lifted the door handle, turned the key, and grab hold of the radio antenna.
2. You'd press the "start" button to shut off the engine.

#1 Thing That Would Be Different If Microsoft Started Building Cars!

1. For no reason whatsoever your car would crash twice a day.

Major differences between automotive electronics and the rest of the electronic industry

- Harsh environment
  - High temperature
  - Low temperature
  - Temperature cycle
  - Vibration
  - Corrosive/dust
- No redundancy
- **Cost**

Operation Temperature Ranges

Electronic/control modules

Ford Worldwide Design Standard (WDS)

- Interior Components -40°C to +75/85/95/105/120°C
  (function & location dependent)
- Exterior Components -40°C to +85/120/125/150°C
  (function & location dependent)
- Underhood Components -40°C to +95/115/150°C
  (function & location dependent)

Design Verification Test Sequence

Electronic/control modules

Ford Worldwide Design Standard (WDS)

- Low temperature exposure
- Low temperature operation
- High temperature exposure
- High temperature operation
- Powered thermal cycle
- Thermal shock resistance
- Thermal shock endurance
- Humidity-Temperature
- Water/fluid ingress
- Dust
- Powered vibration
- Audible noise
- Mechanical shock/drop
- Connector & leak/lock strength
- Salt mist atmosphere
- Chemical resistance
- High temperature endurance
- Controls durability
- Mechanical wearout
- 85/85 high temp/humidity endurance
- Performance/functional evaluations
- Inspections

Selected Operation Test Conditions

Electronic/control modules

Ford Worldwide Design Standard (WDS)

- -40°C, 9-10V operation after 72 hr soak.
- -40°C, 9-10V operation for 72 hr.
- +85 to 150°C, 13 to 16V operation after 72 hr soak.
- +85 to 150°C, 13 to 16V operation for 72 hr.
- Overvoltage, +23°C, 19V operation for 1hr.
- Jump Start, +23°C, 24V operation for 1 min.
- Reverse Battery, +23°C, -14V Connection for 1 min.

Mechanical Tests

Electronic/control modules

Ford Worldwide Design Standard (WDS)

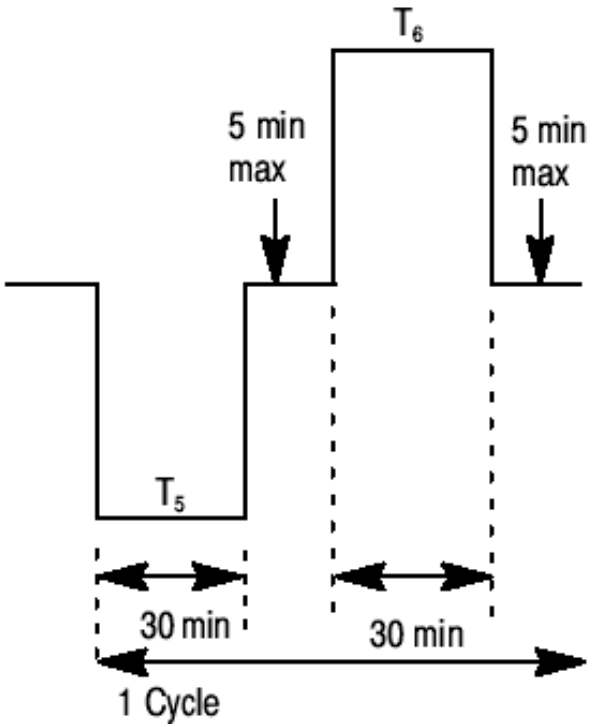
Package Drop	With the component in its protective shipping package drop the package a distance of 100 cm onto a concrete or steel surface. Repeat once for each package surface and corner. Note: If the package is of open design (e.g., top is not covered), appropriate dropping axis and number of drops shall be agreed upon by the supplier and user.
Handling Drop	Drop the component a distance of 76 cm onto a concrete or steel surface. Repeat once for each component surface and corner.

Thermal Cycling Test

Electronic/control modules

Ford Worldwide Design Standard (WDS)

Subject the component printed wiring board assembly, without the case, (non-operating) to 1000 thermal shock cycles between minimum and maximum storage temperatures T_5 and T_6 as shown below. Perform solder joint inspections at 250, 500, 750 and 1000 cycles as specified. Testing for PWB solder integrity may be terminated at 500 cycles if there is no cracking, no holes or voids in solder or conformed coat and no loss or decrease of electrical continuity.



Key Life Test
Electronic/control modules
Ford Corporate Engineering Test

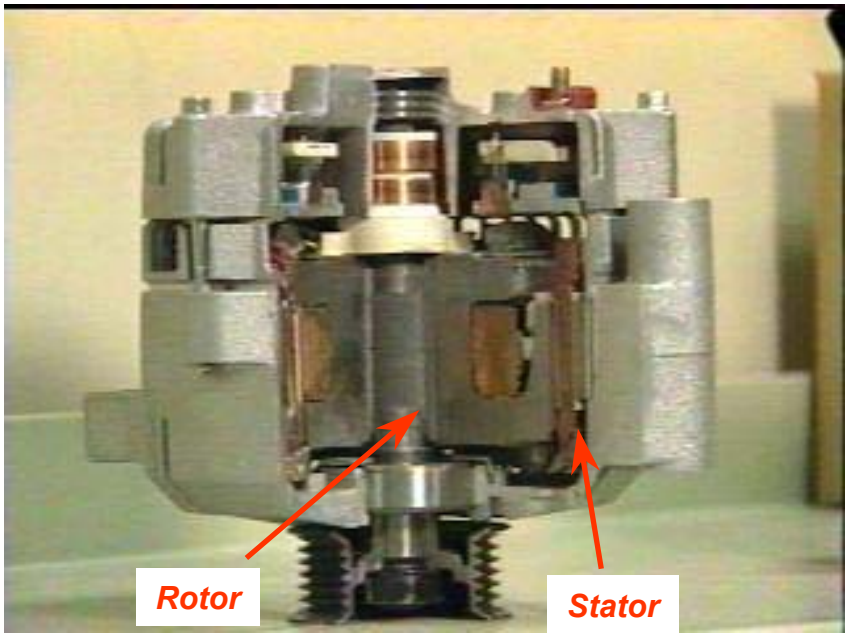
Key Life Test

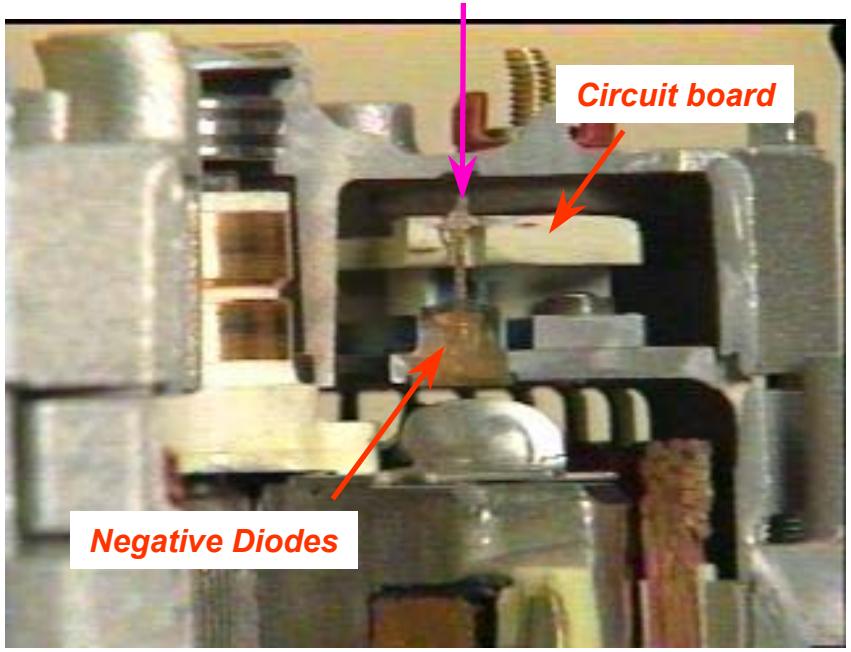
- An accelerated life test to evaluate a product's robustness to one of more "key" wearout modes or mechanisms.
- Acceleration factors: correlated to actual vehicle environmental conditions and duty cycles for 90th and/or 95th percentile customer usage for 10 years/150,000 miles useful life.

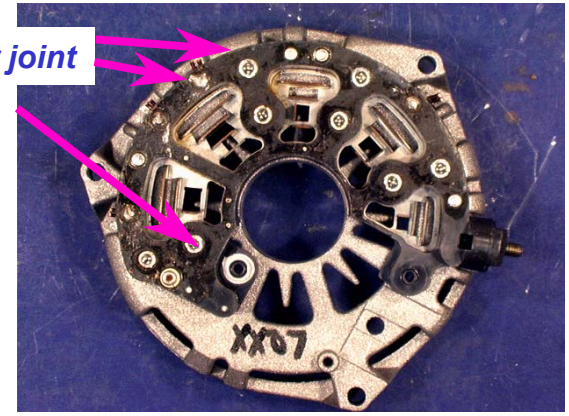
Ford's Pb-free Solder Experience

- Alternators

Typical Alternator Cut-Away







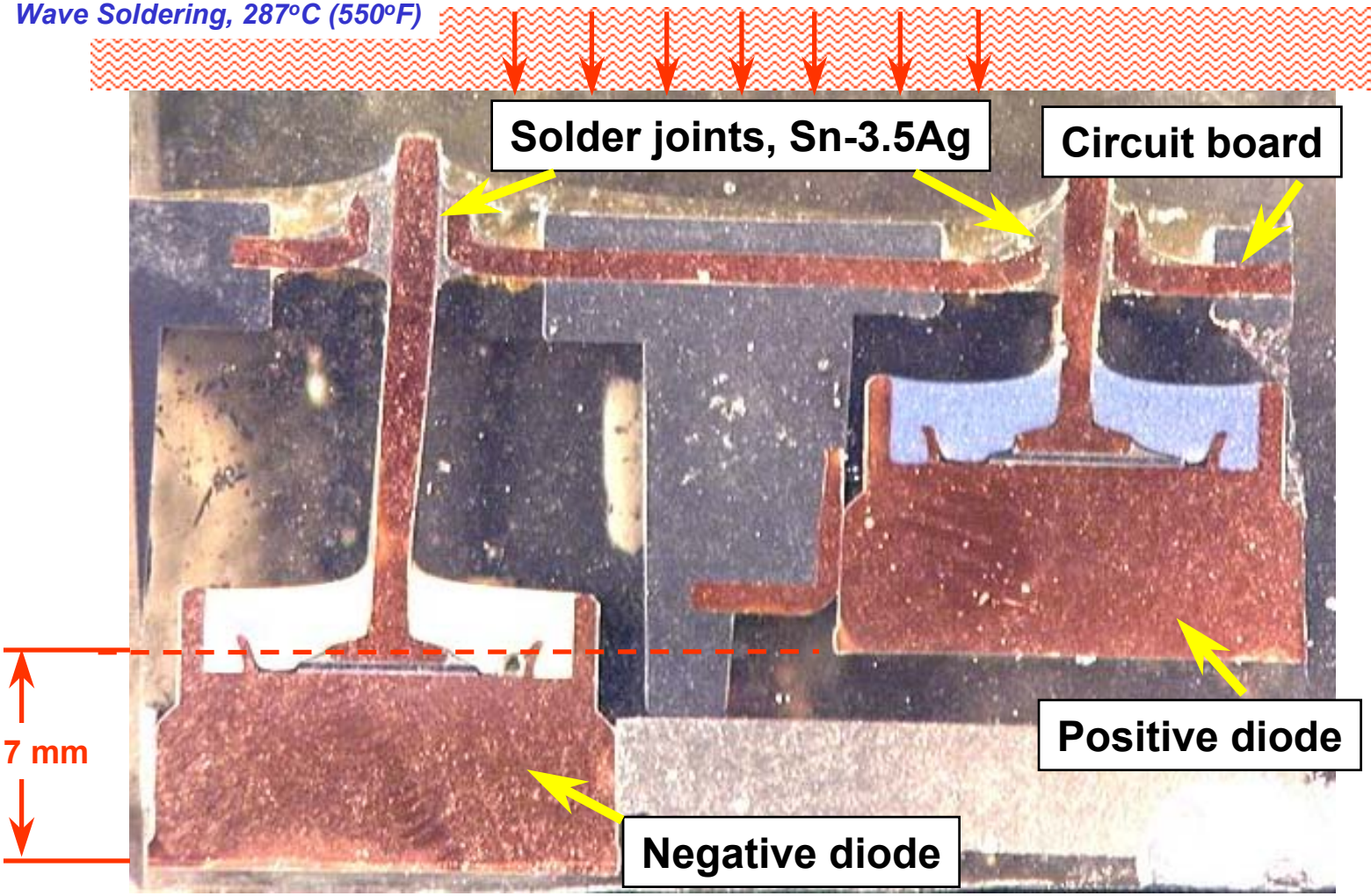
Solder joints on rectifier:

- Alternator Rectifier Diodes:
  3 positive, 3 negative, 2 neutral.
- 6 pairs of stator copper wires

Alternator Rectifier Cross Section

Positive and Negative Diodes, by wave soldering

Sn-3.5Ag Solder (T_m = 221°C)
Wave Soldering, 287°C (550°F)

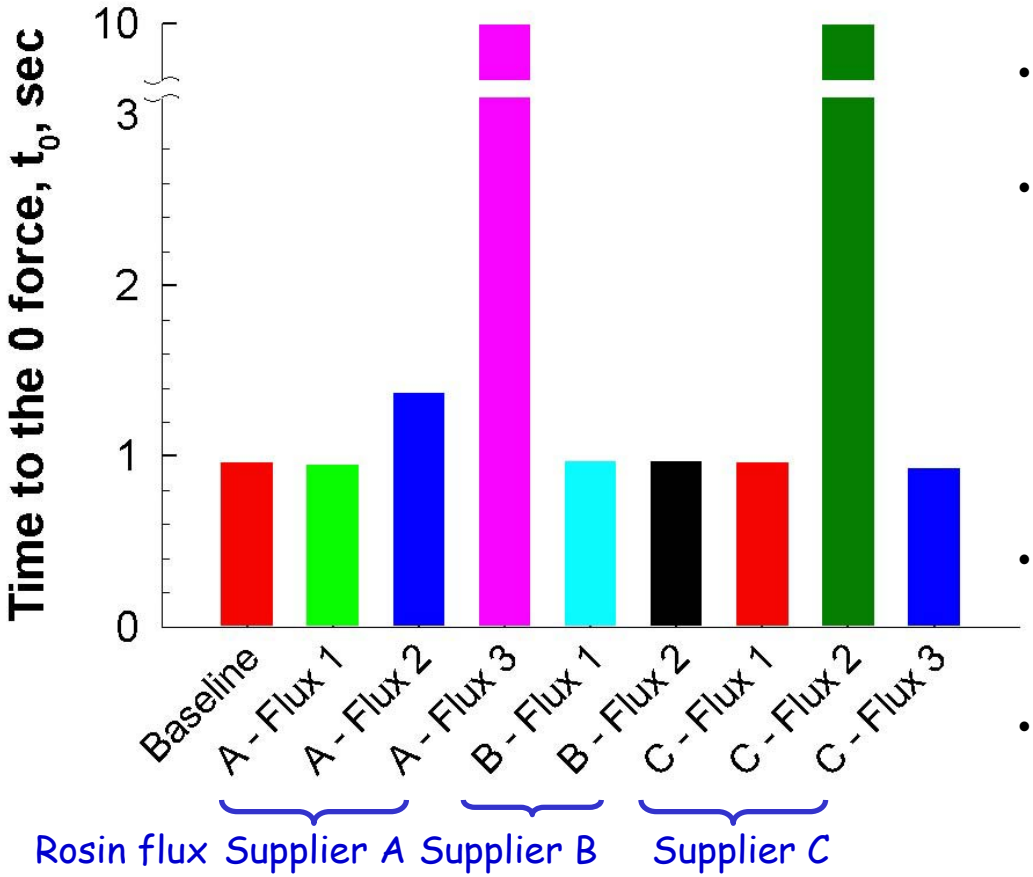


Reliability of Alternators with Sn-Ag solder

- Over 5 million alternators per year are manufactured in NA since 1988 using Sn-3.5Ag solder for diode and stator lead connections.
- Passed 6,000 power thermal cycles:
  - External convective-heated temperature cycles from +43°C to +176°C.
  - 8.5 min/cycle
  - 120 amp total rectifier current.
- Passed 100,000 miles performance in a fleet evaluation under actual desert conditions.

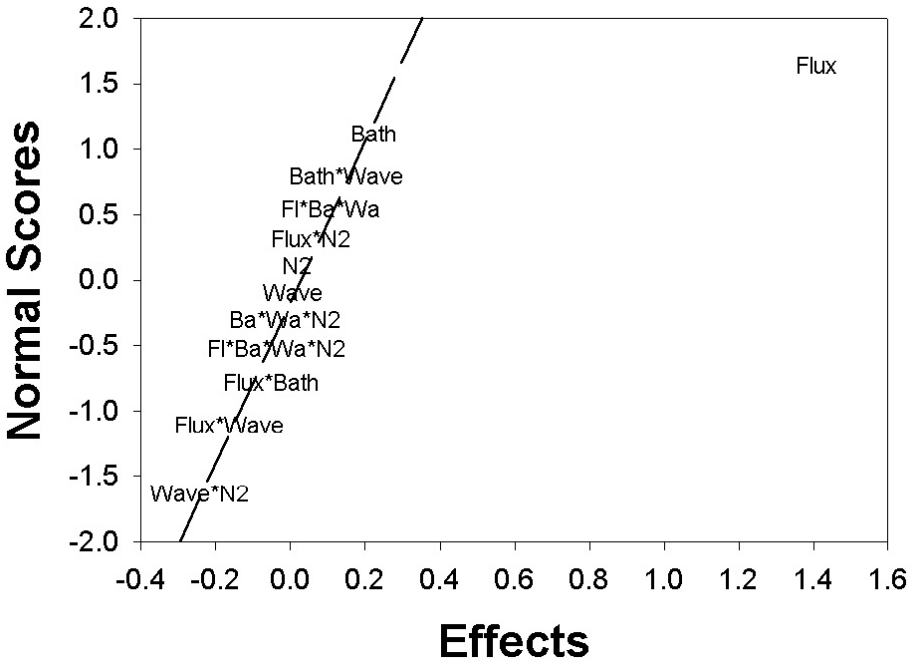
Alternators

No-clean, VOC-free flux for Sn-Ag solder



- A rosin, alcohol-based flux was used historically.
- A no-clean, VOC-free, water-based flux was implemented.
  - Compatible with Sn-Ag, bare copper, Sn-coated diode leads.
  - Can be foamed or sprayed.
  - Existed equipments.
  - Solder joint quality.
- Wetting balance test
  - 280 and 300°C
  - t_o, $t_{2/3}$, F_{max}
- Selected flux was chosen based on a combined score.

Alternator
Wave Soldering Process Optimization



- Design of Experiment (DOE) analysis was performed.
- Parameters:
  - flux flow rate
  - solder bath temperature
  - wave height
  - nitrogen flow
- Solder joint quality was inspected visually.
- 2^4 factorial analysis.
- Only flux flow rate had a significant effect in solder joint quality.
- This is a very robust manufacturing process.

Ford's Involvements in the Pb-free Solder Research

National Center for Manufacturing Sciences (NCMS)

- **Pb-free Solder Project**
  - From 1994 to 1997.
  - 11 companies/institutions/laboratories
  - Evaluations:
    - Toxicology
    - Economics/Availability
    - Properties
    - Manufacturability
    - Reliability
- **High Temperature Fatigue Resistant Solder Project**
  - From 1996 to 2000.
  - 10 companies/institutes.
  - To determine whether high reliability, nontoxic, cost-effective substitutes could be found for high lead and Sn-Ag eutectic solders in harsh environments up to 160?C.

National Center for Manufacturing Sciences (NCMS)
Future Activities Required for Alloy Implementation

- All the Pb-free alloys performed well, but the Bi-containing alloys showed especially outstanding performance.
- Ternary and higher alloys performed as well or better than the standard Sn-Ag eutectic.
- Continued study for thorough understanding and the reliability of fillet lifting for through-hole joints.
- Consistency among world markets.
- Flux evaluation/development for Pb-free alloys.
- Continued work on Pb-free solderable surface materials.
- Qualification of components for 260°C processing.
- Development of cost competitive 180°C T_g PWB laminates.
- Development of world wide infrastructure to support Pb-free alloys.

Future of the Automotive Electronics with Pb-free Solders

- More electronics for fuel cells and hybrid vehicles.
- Governed by the legislations, mainly in Europe, Japan, and US.
- Relied on contract manufacturers/suppliers to lead development.
- Have had some experiences in Sn-Ag solder.
- Very interested in Sn-Ag-Cu solders, as rest of the industries.