HYDROGEN EMBRITTLEMENT
FROM
COATING & RELATED
OPERATIONS

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PLATING PROCESSES

- **TANK ELECTRODEPOSITION**
  - H₂ GENERATED AT WORKPIECE (CATHODE)
  - CAN CAUSE HYDROGEN EMBRITTLEMENT (H.E.) IN STEELS & OTHER METALS

- **SELECTIVE (LOCALIZED) ELECTRODEPOSITION**
  AKA STYLUS / BRUSH PLATING
  - H₂ GENERATED AT WORKPIECE (CATHODE)
  - CAN CAUSE H.E. IN STEELS & OTHER METALS
  - SOME VENDORS CLAIM NO HE CONCERNS IN USING THEIR PROCESSES / SOLUTIONS
    - QUALIFICATION TESTING REQUIRED
PLATING PROCESSES, CONTD.

- ELECTROLESS PLATING
  - H₂ GENERATED
  - NOT AS MUCH AS IN ELECTRODEPOSITION
  - STILL A PROBLEM
  - H.E. A CONCERN FOR STEELS & OTHER METALS

- MECHANICAL PLATING
  - SOME H₂ GENERATED BUT NOT TRAPPED
  - H.E. NOT A CONCERN
H.E. ALSO A CONCERN IN:

- PHOSPHATE CONVERSION COATINGS
  - PHOSPHORIC ACID INVOLVED

- NON-ELECTROLYTIC (CHEMICAL) OPERATIONS IN ACIDS
  - CLEANING, DESCALING, PICKLING, STRIPPING, ETCHING, CHEMICAL MILLING, ETC.

- ELECTROLYTIC SURFACE PREPARATION METHODS
  - ONLY IF WORKPIECE IS CATHODE OR IF AC IS USED
    - TYPICALLY, WORKPIECE IS ANODE
H.E. IN STEELS
H.E. RELIEF PROVISIONS

- SUSCEPTIBILITY TO H.E. INCREASES WITH
  - INCREASING HARDNESS / STRENGTH
  - INCREASING RESIDUAL TENSILE STRESS

- H.E. RELIEF PROVISIONS

  - STRESS RELIEVE BEFORE PLATING
    - TO REDUCE RESIDUAL STRESSES

  AND

  - BAKE AFTER PLATING
    - WITHIN A SPECIFIED TIME AFTER PLATING
      - TYPICALLY 4 HOURS
    - TO REDISTRIBUTE / DRIVE OUT HYDROGEN
STRESS RELIEF & BAKING STEELS

- STRESS RELIEF REQUIRED
  - ONLY FOR PARTS MACHINED, GROUND OR COLD FORMED / STRAIGHTENED AFTER TEMPERING

- STRESS RELIEF AND BAKING REQUIRED
  - ONLY WHEN HARDNESS / STRENGTH > SET MINIMUM VALUE OR
  - FOR ALL PARTS REGARDLESS OF HARDNESS / STRENGTH
  - DEPENDING ON SPECIFICATION (SEE APPENDIX)

- SET VALUE ALSO DEPENDS ON SPECIFICATION (SEE APPENDIX)
  - EVEN FOR SAME COATING (E.G., Cd)
    - GENERALLY IN THE HRC 31-40 (APPROX. $F_{tu}$ 145-180 KSI) RANGE

- SET VALUES FOR BAKING & STRESS RELIEF OFTEN DIFFERENT
  - EVEN IN DIFFERENT REVISIONS OF SAME SPECIFICATION (SEE APPENDIX)
STRESS RELIEF & BAKING TEMPERATURES & TIMES-STEELS

- STRESS RELIEF & BAKING TEMPERATURE: 375 F IN MOST SPECIFICATIONS
  - SOME SPECIFICATIONS ALLOW UP TO ABOUT 900 F
    - DEPENDING ON STRENGTH / HARDNESS LEVEL
  - OTHER SPECIFICATIONS ALLOW STRESS RELIEF AT ANY TEMPERATURE
    - UP TO 50 F BELOW TEMPERING / AGING TEMPERATURE

- TIME: 1-24 HRS (STRESS RELIEF); 1-23 HRS (BAKING)
  - DEPENDING ON:
    - COATING SPECIFICATION
      • EVEN FOR SAME STEEL AND SAME COATING (SEE APPENDIX)
    - REVISION OF PARTICULAR SPECIFICATION
      • E.G., AMS 2759/9, AMS 2419, AMS 2406 (SEE APPENDIX)

- BAKING REQUIRED WITHIN SET TIME
  - USUALLY 4 HRS, AFTER COATING
H.E. RELIEF PROVISIONS ARE SPECIFICATION-DEPENDENT. THEY DO NOT APPEAR TO BE BASED ON EXPERIMENTAL DATA OR FIELD EXPERIENCE. RECOMMENDATION: FOLLOW CONTROLLING SPECIFICATION TO THE LETTER.

- **STRESS RELIEF NOT PERFORMED BEFORE PLATING?**
  - IT IS OF NO USE TO PERFORM IT AFTER PLATING
  - THE HARDWARE IS SUSPECT

- **BAKING NOT PERFORMED WITHIN SET TIME AFTER PLATING?**
  - THE HARDWARE IS SUSPECT

- **BAKING NOT PERFORMED AT ALL?**
  - IT IS OF NO USE TO PERFORM IT AFTER DEPLOYMENT
  - THE HARDWARE IS SUSPECT

- **LOWER TEMPERATURES AND / OR SHORTER TIMES USED?**
  - THE HARDWARE IS SUSPECT
HEEDING THE WARNING

- VERBATIM COMPLIANCE WITH THE H.E. PROVISIONS OF THE CONTROLLING SPECIFICATION IS IMPERATIVE
  - OTHERWISE, HARDWARE IS SUSPECT

- WHEN THE HARDWARE IS SUSPECT
  - IT IS USUALLY DIFFICULT, OFTEN IMPOSSIBLE, TO FIND DATA TO:
    - JUSTIFY A USE-AS-IS DISPOSITION
    - CONFIRM THAT A RISK IS INVOLVED IN A USE-AS-IS DISPOSITION
    - DEMONSTRATE EFFECTIVENESS OF ANY PROPOSED CORRECTIVE ACTION IN ALLEVIATING H.E. RISK

- WHEN REQUIRED DATA CANNOT BE LOCATED, COGNIZANT ENGINEERING ACTIVITY HAS THREE OPTIONS:
  - REVERT TO GUESS WORK / RISK TAKING
  - HIRE A CONSULTANT FOR EDUCATED GUESS WORK / RISK TAKING
  - REJECT HARDWARE
NONCOMPLIANCE TRIGGERS

- **ASSIGNED BUYER NOT AWARE H.E. PROVISIONS EXIST**
  - PROVISIONS “BURIED” IN SPECIFICATION(S)
  - WHEN ALERTED TO PROVISIONS & COST THEREOF
    - MAY WAIVE THEM TO SAVE MONEY

- **HARDWARE PRODUCTION DELEGATED TO SUBCONTRACTOR**
  - MACHINE SHOP, WELD SHOP, ETC.
    - NOT FAMILIAR WITH H.E. PROVISIONS (STRESS RELIEF & BAKE)
  - HIRES SECOND-TIER SUBCONTRACTORS FOR HEAT TREAT & COATING
  - NEGOTIATES WITH HEAT TREAT & COATING SHOPS
    - INCLINED TO WAIVE PROVISIONS TO SAVE MONEY
  - FREQUENTLY FAILS TO INDICATE PRODUCTION SEQUENCE TO COATING SHOP
    - MAY NOT EVEN SEND DRAWINGS WITH HARDWARE
    - COATING SHOP MAY:
      - NOT BE AWARE THAT HE PROVISIONS APPLY
      - ASSUME STRESS RELIEF & BAKING ARE THE RESPONSIBILITY OF THE HEAT TREAT SHOP

- **OEM NOT ADEQUATELY MONITORING SUBCONTRACTORS**
IMPROVING THE ODDS

- TO IMPROVE THE ODDS FOR PROCURING COMPLIANT HARDWARE
  - ALERT BUYERS & SUBCONTRACTORS TO HE PROVISIONS

- MENTION H.E. PROVISIONS IN THE APPLICABLE DRAWING NOTE(S)
  - E.G., CADMIUM PLATE PER AMS-QQ-P-416, TYPE __, CLASS __
  - HYDROGEN EMBRITTLEMENT RELIEF PROVISIONS APPLY

- BETTER YET, SPELL OUT WHAT NEEDS TO BE DONE (AS APPLICABLE)
  - E.G., CADMIUM PLATE PER AMS-QQ-P-416, TYPE __, CLASS __
  - HYDROGEN EMBRITTLEMENT RELIEF PROVISIONS APPLY: STRESS
  - RELIEVE __ F / __ HRS BEFORE PLATING; BAKE __ F / __ HRS, WITHIN 4
  - HRS AFTER PLATING

- BEST IS TO REQUIRE MECHANICAL TEST
  - TO CHECK SUSCEPTIBILITY TO H.E.
  - ADDS TO COST
  - SERVER AS WAKEUP CALL-THE DESIGNER MEANS BUSINESS
MECHANICAL TESTING REQUIRED

- BY SOME SPECIFICATIONS
  - E.G., AMS-QQ-P-416
    - FOR STEEL PARTS WITH \( F_{\text{TU}} \geq 160 \text{ KSI} \)

AMS-QQ-P-416 REQUIRES (UNLESS OTHERWISE SPECIFIED)

- NOTCHED TENSILE SPECIMENS, PLATED WITH HARDWARE
- SPECIMENS SUBJECTED TO TENSILE LOAD
  - 75 % OF NOTCHED ULTIMATE TENSILE STRENGTH
- LOAD SUSTAINED FOR 200 HRS, WITHOUT CRACKING
- SPECIAL TEST CONDITIONS FOR FASTENERS & BEARING COMPONENTS

ULTIMATE DRAWING NOTE FOR AMS-QQ-P-416

- CADMIUM PLATE PER AMS-QQ-P-416, TYPE _, CLASS _
- HYDROGEN EMBRITTLEMENT RELIEF PROVISIONS APPLY:
  - STRESS RELIEVE \( _\text{F} / _\text{HRS} \) BEFORE PLATING; BAKE \( _\text{F} / _\text{HRS} \),
  - WITHIN 4 HRS AFTER PLATING. HYDROGEN EMBRITTLEMENT RELIEF TEST (PARA. 3.3.4) REQUIRED
NOTES OF CAUTION

1. PERFORM SEPARATE BAKE
   - AFTER EACH OPERATION INVOLVING HYDROGEN
     - E.G., ACID CLEANING (PICKLING) & PLATING
       - INCORRECT SEQUENCE: ACID CLEAN, PLATE, BAKE
       - CORRECT SEQUENCE: ACID CLEAN, BAKE, PLATE, BAKE

2. SPELL OUT DESIRED SEQUENCE IN A DRAWING NOTE
   - WITH THE DETAILS OF STRESS RELIEF AND BAKING
     - AND MECHANICAL TESTING, IF REQUIRED

3. BEST IF TRAVELERS ACCOMPANY PRODUCTION HARDWARE
   - TRAVELER: OPERATION SEQUENCE DOCUMENT (PRODUCTION FLOW CHART)
     - CONTAIN INSTRUCTIONS FOR EACH OPERATION
     - LIST FACILITIES PERFORMING THE VARIOUS OPERATIONS
     - CONTAIN OPERATION BUY-OFF BLOCKS TO INDICATE COMPLETION

4. ALL PRECAUTIONS MEANINGLESS
   - WITHOUT OVERVIEW OF “PAPER TRAIL”
     - SUPPLIER QUALITY- AT SUBCONTRACTORS
     - RECEIVING INSPECTION- AT THE DOCKS
HYDROGEN EMBRITTLEMENT & NONFERROUS ALLOYS

- H.E. ALSO OBSERVED IN NONFERROUS ALLOYS
  - Ti & Ni ALLOYS, OTHER METALLIC ALLOYS
    - H.E. RELIEF PROCEDURES NOT READILY AVAILABLE

- NO DATA AVAILABLE FOR Ni AND ITS ALLOYS

- FOR Ti & ITS ALLOYS:
  - STRESS RELIEF:
    - PER HEAT TREAT SPECIFICATION (ABOVE 1000 F)
    - 375 F NOT ADEQUATE
  - BAKING:
    - 1400 F / 4-6 HRS IN VACUUM (10^{-4} TORR OR BETTER)
    - 375 F NOT ADEQUATE
  - ELEVATED TEMPERATURES
    - CAN ADVERSELY AFFECT COATING AND/OR HARDWARE
  - PRESENCE OF COATING
    - CAN INTERFERE WITH HYDROGEN EGRESS IN BAKING
  - OTHER MEANS TO REDUCE RISK OF H.E. MAYBE REQUIRED
REDUCING RISK OF H.E.
Ti & ITS ALLOYS

- CONTROL PROCESSING CONDITIONS
  - CURRENT DENSITY, BATH COMPOSITION & TEMPERATURE, ETC.
    - TO MINIMIZE HYDROGEN (H) PICKUP
- REQUIRE CHEMICAL ANALYSIS AFTER PROCESSING
  - TO CHECK HYDROGEN PICKUP IN PROCESSING
    - PICKUP NOT TO EXCEED SET LIMIT
      - E.G., 10 % OF HYDROGEN ALLOWED IN MATERIAL SPECIFICATION
- REQUIRE MECHANICAL TESTING
  - OF PROCESSED SPECIMENS OR HARDWARE
- ELIMINATE HYDROGEN GENERATING PROCESSES
  - E.G., REPLACE PLATING WITH THERMALLY SPRAYED, ORGANIC OR VACUUM DEPOSITED COATINGS; REPLACE ACID CLEANING WITH ALKALINE CLEANING
- ABOVE CONTROLS EQUALLY APPLICABLE TO STEELS
APPENDIX
<table>
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<th>Specification</th>
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<th>Bake Within (Max. Delay)</th>
<th>Baking</th>
<th>Temperature &amp; Time</th>
<th>Mechanical Test</th>
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</thead>
<tbody>
<tr>
<td>Mil-C-26074 E (N-3)</td>
<td>E-Ni (3)</td>
<td>HRC ≥ 40</td>
<td>4 hr</td>
<td>HRC ≥ 40</td>
<td>375 F / 3 hr, min.</td>
<td>Required HRC ≥ 40</td>
</tr>
<tr>
<td>Mil-C-26074 C</td>
<td>E-Ni (3)</td>
<td>HRC &gt; 40</td>
<td>4 hr</td>
<td>Class 1</td>
<td>375 F / 3 hr, min.</td>
<td>Not Required</td>
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<tr>
<td>AMS 2404 D</td>
<td>E-Ni (3)</td>
<td>HRC ≥ 40</td>
<td>4 hr</td>
<td>HRC ≥ 33</td>
<td>375 F / 3 hr, min.</td>
<td>Required HRC ≥ 33</td>
</tr>
<tr>
<td>AMS 2404 F</td>
<td>E-Ni (3)</td>
<td>HRC ≥ 40</td>
<td>NS (8)</td>
<td>HRC ≥ 33</td>
<td>375 F / 3 hr, min.</td>
<td>Required All</td>
</tr>
<tr>
<td>AMS 2405 B</td>
<td>E-Ni (3)</td>
<td>HRC &gt; 40</td>
<td>NS (8)</td>
<td>HRC ≥ 33</td>
<td>375 F / 3 hr, min.</td>
<td>Not Required</td>
</tr>
<tr>
<td>ASTM B 733-90</td>
<td>E-Ni (3)</td>
<td>F_{tu} &gt; 1050 MPa (9) (152 Ksi; HRC 34)</td>
<td>4 hr</td>
<td>F_{tu} &gt; 1050 MPa (9) (152 Ksi; HRC 34)</td>
<td>375 F / 3-23 hr, min (10) or 266-302 F / 5 hr, min (carburized)</td>
<td>Not Required</td>
</tr>
<tr>
<td>QQ-N-290 A</td>
<td>Ni</td>
<td>All</td>
<td>4 hr</td>
<td>HRC ≥ 40</td>
<td>375 F / 3 hr, min.</td>
<td>Required F_{tu} ≥ 240 Ksi (12)</td>
</tr>
<tr>
<td>ASTM B 650-95</td>
<td>Cr</td>
<td>ASTM B 849</td>
<td>1.5 hr</td>
<td>ASTM B 850</td>
<td>375 F / 3 hr, min.</td>
<td>Required (13)</td>
</tr>
<tr>
<td>QQ-C-320 B</td>
<td>Cr</td>
<td>F_{tu} ≥ 150 Ksi (HRC 34)</td>
<td>4 hr</td>
<td>HRC ≥ 40</td>
<td>375 F / 3 hr, min.</td>
<td>Required (12) F_{tu} ≥ 240 Ksi</td>
</tr>
<tr>
<td>QQ-C-320 B (A-4)</td>
<td>Cr</td>
<td>F_{tu} ≥ 150 Ksi (HRC 34)</td>
<td>4 hr</td>
<td>F_{tu} ≥ 160 Ksi (HRC 36)</td>
<td>375 F / 3 hr-12 hr, min (10)</td>
<td>Required (12) F_{tu} ≥ 180 Ksi</td>
</tr>
<tr>
<td>AMS 2460 (14)</td>
<td>Cr</td>
<td>F_{tu} ≥ 152 Ksi (HRC 34)</td>
<td>NS (8)</td>
<td>AMS 2759/11</td>
<td>AMS 2759/9 (8a), (15)</td>
<td>Required HRC ≥ 40 (16)</td>
</tr>
<tr>
<td>Specification</td>
<td>Coating</td>
<td>Stress Relief</td>
<td>Bake Within (Max. Delay)</td>
<td>Baking</td>
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<tr>
<td>AMS 2406 G</td>
<td></td>
<td></td>
<td></td>
<td>NS (6)</td>
<td>Not Required</td>
<td></td>
</tr>
<tr>
<td>AMS 2406 H</td>
<td>Cr</td>
<td>HRC &gt; 40</td>
<td></td>
<td>4 hr</td>
<td>Required HRC ≥ 40</td>
<td></td>
</tr>
<tr>
<td>AMS 2406 J</td>
<td></td>
<td>275 F / 5 hr, min (HRC ≥ 55)</td>
<td>NS (8)</td>
<td>HRC &gt; 36</td>
<td>Required HRC ≥ 36</td>
<td></td>
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<tr>
<td>AMS 2406 L</td>
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<tr>
<td>QQ-P-416 C</td>
<td>Cd</td>
<td>Fₜ ≥ 150 ksi (HRC 34)</td>
<td>375 F / 3 hr, min</td>
<td>4 hr</td>
<td>HRC ≥ 40</td>
<td></td>
</tr>
<tr>
<td>QQ-P-416 F</td>
<td>Cd</td>
<td>HRC ≥ 55 (17)</td>
<td>275 F / 5 hr, min</td>
<td>4 hrs</td>
<td>HRC ≥ 55 (17)</td>
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<tr>
<td></td>
<td></td>
<td>Fₜ ≥ 220 ksi (HRC 46)</td>
<td>375 F / 4 hr, min</td>
<td></td>
<td>275 F / 23 hr, min</td>
<td>Required (18)</td>
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<tr>
<td></td>
<td></td>
<td>Fₜ ≥ 160 ksi (HRC 36)</td>
<td>375 F / 4 hr, min</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Fₜ &lt; 160 ksi (HRC 36)</td>
<td>375 F / 4 hr, min</td>
<td>NA (20)</td>
<td>Fₜ &lt; 160 ksi (HRC 36)</td>
<td>Not Required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fₜ &lt; 150 ksi (HRC 34)</td>
<td>Not Required</td>
<td></td>
<td>Fₜ &lt; 150 ksi (HRC 34)</td>
<td>Not Required</td>
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<tr>
<td>QQ-P-416 F (A-3) &amp; AMS-QQ-P-416 B, C (Parts Other Than Fastener &amp; Bearing Components)</td>
<td>Cd</td>
<td>HRC ≥ 55 (17)</td>
<td>275 F / 5 hr, min</td>
<td>4 hrs</td>
<td>HRC ≥ 55 (17)</td>
<td></td>
</tr>
<tr>
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<td>Fₜ ≥ 220 ksi (HRC 46)</td>
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<tr>
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<td></td>
<td>Fₜ &lt; 160 ksi (HRC 36)</td>
<td>375 F / 4 hr, min</td>
<td>NA (20)</td>
<td>Fₜ &lt; 160 ksi (HRC 36)</td>
<td>Not Required</td>
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<tr>
<td></td>
<td></td>
<td>Fₜ &lt; 150 ksi (HRC 34)</td>
<td>Not Required</td>
<td></td>
<td>Fₜ &lt; 150 ksi (HRC 34)</td>
<td>Not Required</td>
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<tr>
<td>Fastener &amp; Bearing Components</td>
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<td>HRC ≥ 55</td>
<td>275 F / 5 hr, min (22)</td>
<td>4 hr</td>
<td>HRC ≥ 55</td>
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<tr>
<td></td>
<td></td>
<td>Fₜ ≥ 150 ksi (HRC 34)</td>
<td>375 F / 4 hr, min (22)</td>
<td></td>
<td>375 F / 23 hr, min</td>
<td>Required (17)</td>
</tr>
</tbody>
</table>

**Stress Relief Requirements**:
- Fₜ: Tensile Strength
- HRC: Rockwell Hardness
- NS: Not Specified

**Bake Within (Max. Delay)**:
- 375 F / 3 hr, min
- 375 F / 23 hr, min
- 275 F / 5 hr, min

**Baking Requirements**:
- Fₜ ≥ 220 KSI
- Fₜ ≥ 160 KSI
- Fₜ < 160 KSI

**Mechanical Test**:
- Not Required
- Required

**Notes**:
- (1) 
- (2) 
- (4) 
- (6) 
- (8) 
- (8a) 
- (10) 
- (17) 
- (19) 
- (20) 
- (21) 
- (22)
<table>
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<tr>
<th>Specification</th>
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<th>Baking</th>
<th>Mechanical Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM B 766-86 (2003)</td>
<td>Cd</td>
<td>$F_{tu} \geq 1050 \text{ MPa (152 Ksi, HRC 35)}$</td>
<td>375 F / 5 hr, min</td>
<td>4 hr</td>
<td>$F_{tu} \geq 1200 \text{ MPa (174 Ksi, HRC 38)}$</td>
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<tr>
<td>AMS 2419 A</td>
<td>Cd-Ti</td>
<td>All Parts</td>
<td>Or</td>
<td>NS (8)</td>
<td>AMS 2759/9 (2a)</td>
</tr>
<tr>
<td>AMS 2419 C</td>
<td>Cd-Ti</td>
<td>HRC $\geq 55$ HRC $\geq 40$</td>
<td>275 F / 5 hr, min 375 F / 4 hr, min</td>
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<td></td>
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<tr>
<td>Mil-STD-1500 B</td>
<td>LE Cd (28)</td>
<td>All Parts</td>
<td>375 F / 4 hr, min</td>
<td>4 hr</td>
<td>$F_{tu} &gt; 180 \text{ Ksi}$</td>
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<tr>
<td>Mil-STD-870 B (30)</td>
<td>LE Cd</td>
<td>$F_{tu} &gt; 180 \text{ Ksi}$</td>
<td>375 F / 4 hrs, min</td>
<td>4 hr</td>
<td>$F_{tu} &gt; 180 \text{ Ksi}$</td>
</tr>
<tr>
<td>Mil-STD-870 C (30)</td>
<td>Cd</td>
<td>$F_{tu} \geq 180 \text{ ksi}$</td>
<td>275 F / 5 hr, min 375 F / 4 hr, min</td>
<td>4 hr</td>
<td>$F_{tu} \geq 180 \text{ ksi}$</td>
</tr>
<tr>
<td>ASTM B 633-07</td>
<td>Zn</td>
<td>$F_{tu} &gt; 1000 \text{ MPa (145 ksi, HRC 31)}$</td>
<td>ASTM B 849</td>
<td>4 hr</td>
<td>$F_{tu} &gt; 1000 \text{ MPa (145 ksi, HRC 31)}$</td>
</tr>
<tr>
<td>QQ-S-365 D</td>
<td>Ag</td>
<td>All Parts</td>
<td>375 F / 3 hr, min (4)</td>
<td>4 hr</td>
<td>HRC $\geq 40$</td>
</tr>
<tr>
<td>Mil-STD-865 D (Brush Plating)</td>
<td>Various</td>
<td>No Requirements</td>
<td>4 hr</td>
<td>$F_{tu} \geq 180 \text{ Ksi}$</td>
<td>375 F / 4 hr, min (31)</td>
</tr>
<tr>
<td>Mil-DTL-16232 G</td>
<td>Phosphate</td>
<td>HRC $\geq 39$</td>
<td>350-400 F / 1 hr, min</td>
<td>NS (8)</td>
<td>HRC $\geq 39$ (Incl. Carburized)</td>
</tr>
<tr>
<td>ASTM B 849-02 (Pretreatment)</td>
<td>Various</td>
<td>$F_{tu} &gt; 1000 \text{ MPa (145 Ksi, HRC 31)}$</td>
<td>375-445 F / 1-24 hr min (4)</td>
<td>NS (8)</td>
<td>Not Covered</td>
</tr>
<tr>
<td>ASTM B 850-98 (2003) (Post-treatment)</td>
<td>Various</td>
<td>Not Covered</td>
<td>3 hr</td>
<td>$F_{tu} \geq 1000 \text{ MPa (145 Ksi, HRC 31)}$</td>
<td>375-895 F / 1-22 hr, min (26)</td>
</tr>
<tr>
<td>AMS 2759/9 (33) (Baking)</td>
<td>N/C, Revs. A, B Revs. C, D (35)</td>
<td>Various</td>
<td>Not Covered</td>
<td>NS (8)</td>
<td>$F_{tu} \geq 180 \text{ ksi}$ (HRC 40)</td>
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<tr>
<td>Def Stan 03-4 (36)</td>
<td>Various</td>
<td>All Parts (37)</td>
<td>190 C (375 F) / 18 hr, min 250 C (482 F) / 6 hr, min 300 C (572 F) / 2 hr, min 400 C (752 F) / 1 hr, min</td>
<td>4 hr</td>
<td>$F_{tu} &gt; 1451 \text{ MPa (210 Ksi, HRC 44)}$</td>
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</table>
Footnotes:

(1) Converted values not listed in the specification are presented here in red font. It is noted that hardness-Strength conversions are approximate, and they vary according to source.

(2) Unless otherwise indicated here, stress relief is required only for steel parts that have been machined, ground and / or cold formed / straightened after tempering.

(3) E-Ni: Electroless Ni.

(4) Stress relief at a temperature that would produce maximum stress relief, without adversely affecting strength of the parts.

(5) Stress relief regardless of whether or not the parts have been machined, ground or cold formed / straightened after tempering.

(6) It may be that the specification considers that class 2 thermal treatment (to harden deposit) is an acceptable alternative to baking. See footnote 7.

(7) Class 2 thermal treatment (to harden deposit) that starts within 4 hr of plating is an acceptable alternative to baking.

(8) NS: Not specified.

(8a) Revisions C and D of AMS 2759/9 include a provision that requires baking within 4 hrs of plating. Earlier revisions did not include that provision.

(9) The specification indicates that the operation is to be performed if required. It is not clear as to who makes the decision that it is required.

(10) Depending on the strength level.

(11) In the notes section (non-mandatory), the specification states that it may be beneficial to extend the baking time to 23 hr.

(12) The specification further qualifies the requirement by indicating that it is applicable to parts subjected to sustained tensile stress in service. Since only the designer can make this determination, it seems that a drawing note would be required to specifically require mechanical testing.

(13) The specification does not indicate the strength / hardness levels where testing would be required. It must be that mechanical testing is required for all parts that require baking (according to ASTM B 850).

(14) AMS 2460 superseded AMS-Q-C-320 in July 2007. An updated notice of cancellation was issued in January 2008.

(15) AMS 2460 requires that baking be per AMS 2759/9, except that steels with Ftu \(\geq 160\) ksi shall be baked for 3-23 hr, depending on the strength level. See also footnote 8a.

(16) The wording of the specification in this regard is very confusing.

(17) For carburized and other parts which would be adversely affected by heating to 375 F.

(18) Some types of fastener and bearing components are excepted.

(19) 375 / 23 hr min for fastener and bearing components.

(20) NA: Not applicable, since baking is not required.

(21) Amendment 3 affects only the times, temperatures, hardness / strength ranges for all parts other than fastener and bearing components. For these components, the ranges presented in QQ-P-416 F still apply.

(22) Option to stress relief at a temperature not higher than 50 F below the tempering temperature.

(23) For steels having strength \(\geq 1300\) MPa (HRC 40, 189 ksi), the specification recommends extending the bake time to 23 hr.

(24) Also, the test details are to be specified.

(25) Temperature and time are to be such that maximum stress relief is obtained without reducing mechanical properties of parts below those specified on applicable drawing.

(26) Depending on strength level.

(27) Option to use electronic gage, when approved.

(28) LE Cd: Low Embrittlement Cd.

(29) Option to use electronic gage.

(30) Specification is for high strength steels, defined as those with Ftu \(> 180\) ksi (Rev. B) or Ftu \(\geq 180\) ksi (Rev. C).

(31) Certain Cd plated solutions are exempt from the baking requirement.

(32) 16 hr min, for items that are surface hardened and plated with Zn, Cd, Sn or their alloys.

(33) The specification covers various types of coatings, as well as etch inspection and other chemical processing.

(34) Depending on the type of steel, strength level, type of coating / processing and / or type of hardware (fastener / non-fastener).

(35) Rev. A adds a note to extend the bake time for dense Cr to 96 hr, and another note instructing that bake time requirements for Cd be used for other plating types not listed. Rev. B revised the note for dense Cr: bake for 96 hr at 275 F if the steel is tempered below 375 F, 23 hr at 375 F, if the steel is tempered above 375 F. Rev. C retains the same basic baking information of the previous revision, but displays that information in two tables, instead of one. Rev. D was issued to correct one publishing error, regarding baking after etch inspection.

(36) Def Stan: Defence Standard, a British specification system.

(37) For case hardened parts, stress relief at 130 C (266 F) / 6 hr.

(38) Depending strength level and type of coating / processing. Option for Cr plate: 440-480 C (824-896 F) / 1 hr min.