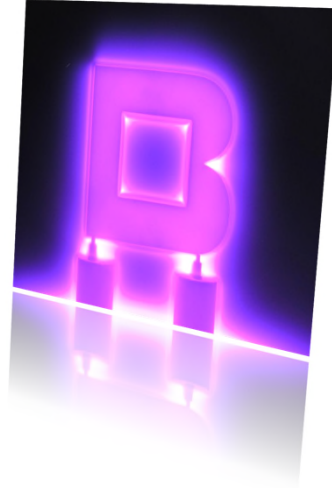


Varmebehandling af Aluminium



Historien bag Duraluminium®

- Fænomenet blev opdaget første gang i 1906
- Alfred Wilms's forsøg hos Dürener Metallwerken
- Første anvendelse i luftfartøj i 1919
- Anvendes i dag som elementer til strukturdele



1

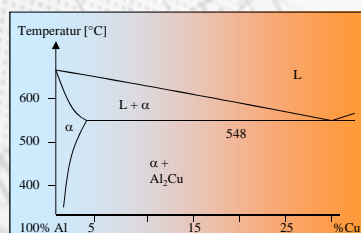
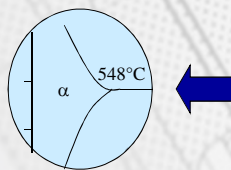


Forudsætninger for modningshærdning

- Der skal foreligge et to- eller flerkomponent legeringssystem
- Legeringssystemet skal indeholde mulighed for dannelse af intermetalliske faser
- Med faldende temperatur skal opløseligheden af mindst et legeringselement aftage

Modningshærdning af aluminium

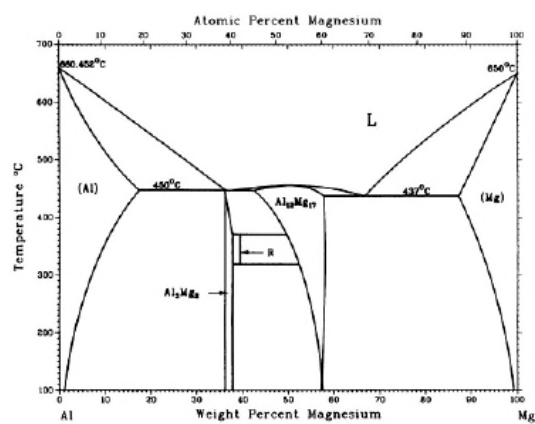
- Legeringselementets opløselighed stiger med stigende temperatur – eks. Al-Cu-systemet
- Styrkeforøgelsen fremkommer ved udskillelse af stabile intermetalliske faser




AL-Mg


Al-Mg (Aluminum - Magnesium)

J.L. Murray, 1988



Al-Mg phase diagram

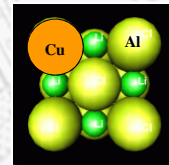
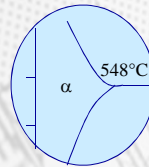
| Wrought alloys | |  |
|---|------|---|
| Aluminum, $\geq 99.00\%$ | 1xxx | |
| Aluminum alloys grouped by major alloying element(s): Copper | 2xxx | |
| Manganese | 3xxx | |
| Silicon | 4xxx | |
| Magnesium | 5xxx | |
| Magnesium and silicon | 6xxx | |
| Zinc | 7xxx | |
| Other elements | 8xxx | |
| Unused series | 9xxx | |

| Castings | |  |
|---|-------|---|
| Aluminum, $\geq 99.00\%$ | 1xx.x | |
| Aluminum alloys grouped by major alloying element(s): Copper | 2xx.x | |
| Silicon, with added copper and/or magnesium | 3xx.x | |
| Silicon | 4xx.x | |
| Magnesium | 5xx.x | |
| Zinc | 7xx.x | |
| Tin | 8xx.x | |
| Other elements | 9xx.x | |
| Unused series | 6xx.x | |

Opløsningsglødning

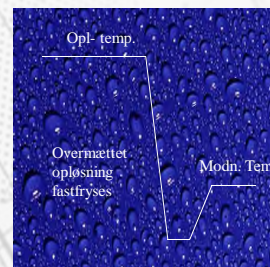
- ▶ Hvis opløsligheden stiger med stigende temperatur, kan legeringselementer som f.eks. Cu bringes i fast opløsning
- ▶ Eksempler på glødetemperaturer [°C]


| | |
|------|-----------|
| 2014 | 496 - 507 |
| 2024 | 488 - 499 |
| 6061 | 521 - 538 |
| 7075 | 460 - 471 |
| 7079 | 438 - 449 |




Bratkøling


- ▶ For at undgå uønsket udfældning efter opløsningsglødning skal bratkøling ske så hurtigt som muligt.
- ▶ Afkølingshastigheden skal være høj. Helst i størrelsesordenen 300 °C/sek.
- ▶ I praksis anvendes oftest vandkøling.
- ▶ Resultatet bliver en overmættet opløsning af Cu i Al-matrix.




 **STRUCTURAL REPAIR MANUAL**



| STATUS | MATERIAL CONDITION | REMARKS |
|--------|---|--|
| 0 | It is annealed (a soft temper). The 0 may be followed by a digit other than 0. | It is applied to wrought products which are annealed to obtain the lowest strength temper and to cast products which are annealed to improve ductility and dimensional stability. |
| R 01 | It is a special thermal process at approximately same time and temperature required for solution heat treatment and air cooled to room temperature to optimize ultrasonic inspection or to lower residual stress of forgings. | It is applied to products which are to be machined prior to solution heat treatment to the required temper. This is neither a final heat treatment nor an intermediate heat treatment leading to a final heat treatment. |
| F | It is as fabricated. Not subsequently heat treated, annealed or strain hardened after manufacture. | It is applied to the products of shaping processes in which no special control or thermal conditions or strain hardening is employed. |
| H | It is strain hardener for wrought products only. The H is always followed by two and sometimes three digits. The first digit indicates basic operation or combination of operations. The second digit indicates the final degree of strain hardening. | It is applied to products whose strength is increased by strain hardening such as 1XXX, 3XXX and 5XXX series alloys. |
| H1 | It is strain hardened only. | It is applied to products that are strain hardened only with no supplemental thermal treatment. |
| H11 | It is strain hardened less than the amount required for a controlled H1 temper. | Strain hardening occurs during flattening and material is slightly harder than -0 temper. |
| H2 | It is strain hardened and partially annealed. | It is applied to products that are strain-hardened more than the desired amount and then reduced in strength to the desired level by partial annealing. |

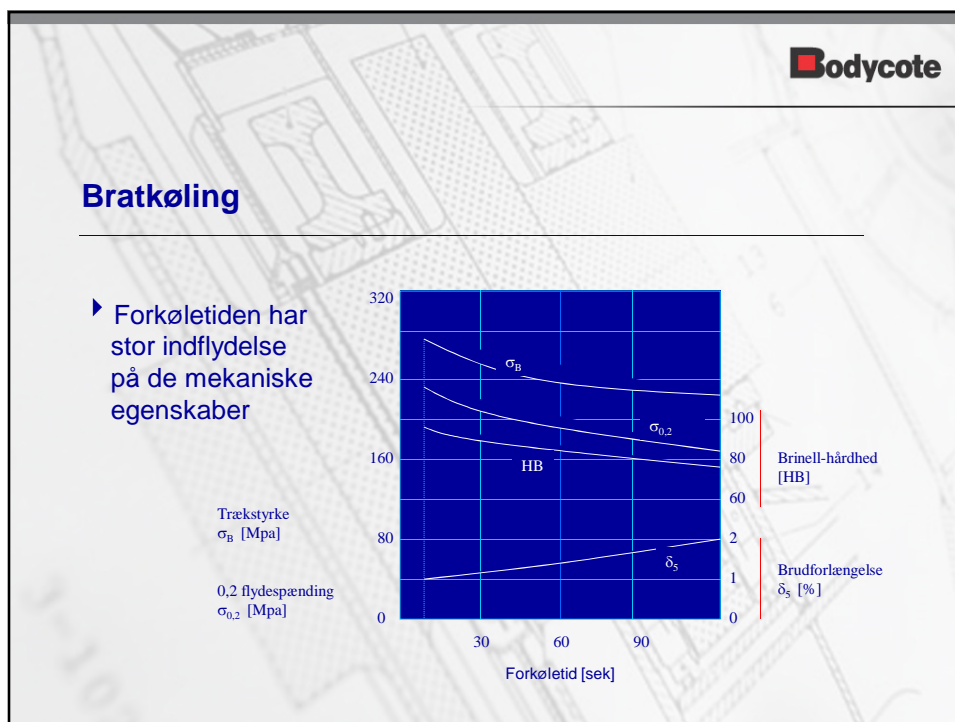
 **STRUCTURAL REPAIR MANUAL**



| STATUS | MATERIAL CONDITION | REMARKS |
|--------|---|--|
| T3511 | It is solution heat treated, stress relieved by stretching and naturally aged. Minor straightening is allowed. | It is similar to T4 temper. It is applied to 2024, 2219 and 2224 extrusion. |
| T361 | It is solution heat treated and cold worked by a reduction of 6 % and naturally aged. | It is applied to 2024 sheet and plate. |
| T37 | It is solution heat treated and cold worked by a reduction of 8 % and naturally aged. | It is applied to 2219 sheet and plate. |
| T39 | It is solution heat treated, pre-aged at room temperature, cold rolled 11 ± 2 % stress relieved by stretching and naturally aged. | It is applied to 2324 plate. |
| T4 | It is solution heat treated and naturally aged to a substantially stable condition. After solution heat treatment, it is not cold worked or the effect of cold work in flattening or straightening may not be recognized in mechanical property limits. | It is applied to mill solution heat treated materials 2024 and 2061, which acquire superior yield strength property through the mill heat treatment only. |
| T42 | It is solution heat treated and naturally aged to substantially stable condition. | It is applied to 2024-0 and 6061-0 sheet, bar, plate and extrusions which are heat treated by user from annealed condition. It is also applied to 2024 and 6061 heat treated forms that have been re-heat treated properties are lower than for T-4 temper material. |
| T451 | It is solution heat treated, stress relieved by stretching, and naturally aged. This is similar to T4 temper. | It is applied to plate and rolled bars stock of 6061. |
| T4511 | It is solution heat treated, stress relieved by stretching and naturally aged. Minor straightening is allowed. It is similar to T4 temper. | It is applied to 6061 extrusions. |

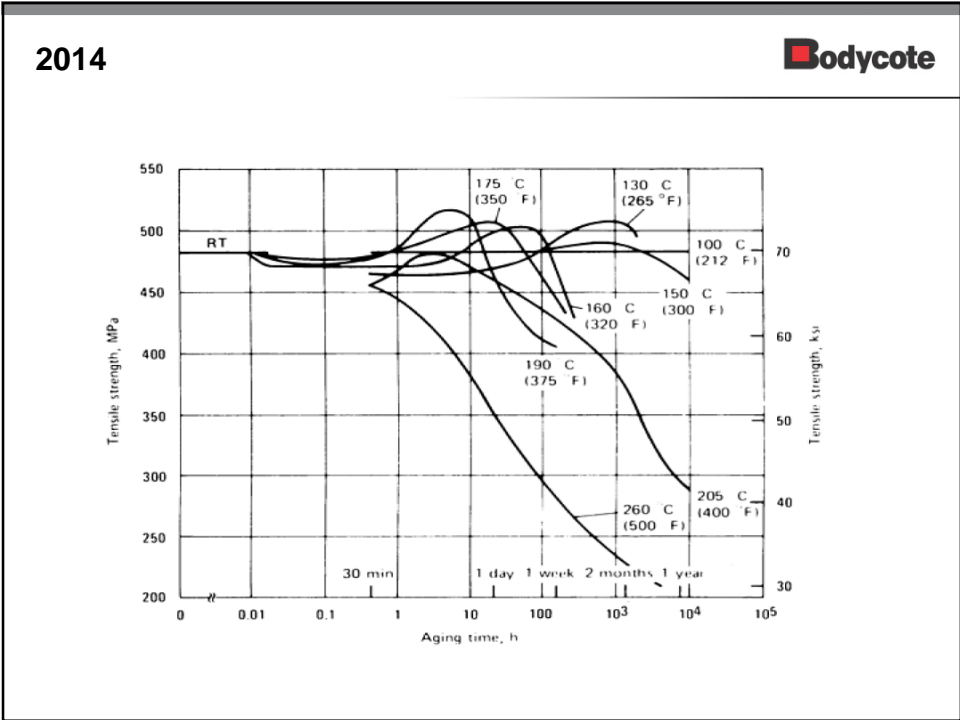
STRUCTURAL REPAIR MANUAL

| STATUS | MATERIAL CONDITION | REMARKS |
|--------|---|--|
| T761 | It is solution heat treated and overaged. | It is applied to 7475 bare and clad sheet only. |
| T7651 | It is solution heat treated, stress relieved by stretching and overaged to improve exfoliation and stress corrosion resistance. | It is applied to 7075 and 7050 plate. This temper is similar to T76. |
| T76511 | It is solution heat treated, stress relieved by stretching by minor straightening, and overaged to improve exfoliation and stress corrosion resistance. | It is applied to 7075 and 7050 extrusions. This temper is similar to T76. |
| T77511 | It is solution heat treated, stress relieved by stretching by minor straightening and overaged. | It is applied only to 7150 extrusions. It is used where minor strength loss is acceptable in obtaining better exfoliation and stress corrosion resistance than the 7150 T6511 and T6511F. |
| T8 | It is solution heat treated, cold worked and artificially aged. | It is applied to products that are cold-worked to improve strength and to products for which the effect of cold working in flattening or straightening is recognized in applicable specifications. |
| T81 | It is solution heat treated, cold worked and artificially aged. | It is applied to 2024 T3 to convert it to 2024 T81 by artificial aging. |
| T83 | It is solution heat treated, stretched and artificially aged. | It is applied to 2090 sheet. |
| T851 | It is solution heat treated, stress relieved by stretching and artificially aged. | It is applied to plate, rolled bar and rod. 2024 T351 is artificially aged to 2024 T8511. |
| T8511 | It is solution heat treated, stress relieved by stretching, by minor straightening and artificially aged. | It is applied to 2024 and 2219 extrusions. 2024 T3511 is artificially aged to 2024 T8511. |

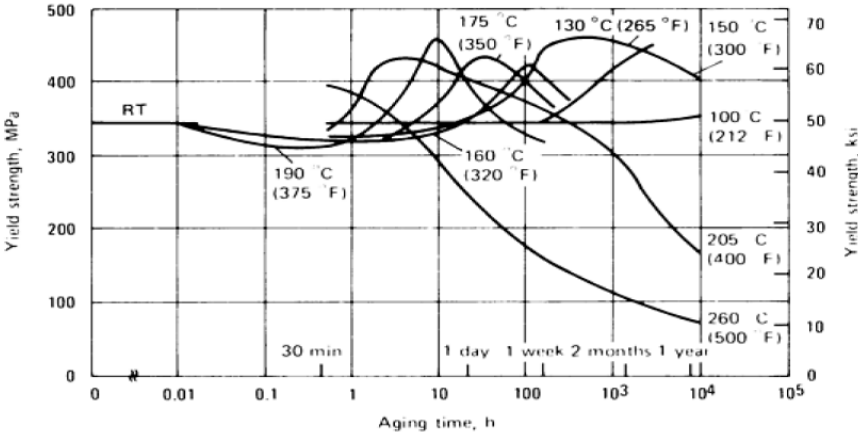


Bodycote

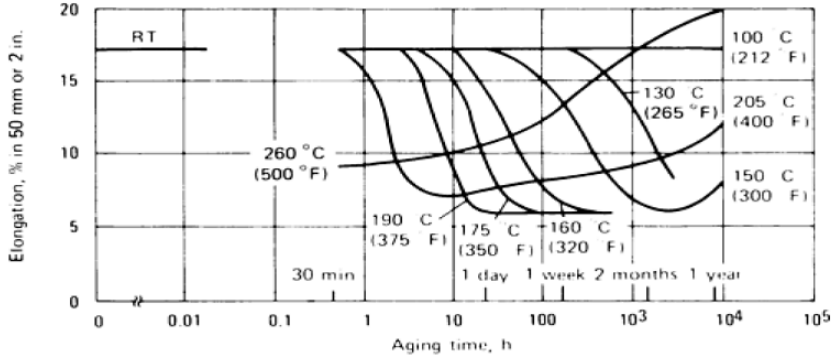
| | | | | | | | | |
|--|---------------------------|---|-----------------|-----|----|-----|------|-----|
| Al-2.58Li-1.36Cu-0.89Mg-0.13Zr-0.17Fe-0.04Si | Air cool (~0.25 °C/s) | 2 | 190 °C for 16 h | 417 | 60 | 485 | 70.3 | 6.5 |
| | | 4 | 170 °C for 24 h | 442 | 64 | 503 | 73 | 4.5 |
| | Polymer quench (~18 °C/s) | 2 | 190 °C for 16 h | 448 | 65 | 524 | 76 | 6.8 |
| | | 4 | 170 °C for 24 h | 448 | 65 | 519 | 75 | 5.0 |
| | Water quench (~120 °C/s) | 2 | 190 °C for 16 h | 464 | 67 | 535 | 77.5 | 8.2 |
| | | 4 | 170 °C for 24 h | 448 | 65 | 517 | 75 | 6.3 |



2014



2014





7075 (A-25GU)
clad 7075 (A-25GU/AZ1)
7175

| INITIAL CONDITION | FINAL CONDITION | TREATMENT TO BE PERFORMED |
|-------------------|-----------------|---------------------------|
| F | T42 | Quenching + ageing |
| F | T62 | Quenching + tempering |
| T4 | T6 | Tempering |
| T451 | T651 | Tempering |

Solution heat treatment temperature: 465°C ± 5°C (869°F ± 9°F)

| THICKNESS OF MATERIAL (Th.) mm (in.) | SOAK TIME (min.) | | MAXIMUM TRANSFER TIME(S) | COOLING |
|---|-------------------------|-----------------------------|--------------------------|---------------------------|
| | MINIMUM PLATED PRODUCTS | MINIMUM NON-PLATED PRODUCTS | | |
| Th. ≤ 0.6 (0.0236) | 20 | 15 | ≤ 5 | Water ≤ 30°C (86°F) |
| 0.6 < Th. ≤ 0.8 (0.0236) (0.031) | 25 | 20 | ≤ 7 | |
| 0.8 < Th. ≤ 1.6 (0.031) (0.063) | 30 | 25 | ≤ 10 | |
| 1.6 < Th. ≤ 2.5 (0.063) (0.098) | 35 | 30 | ≤ 10 | |
| 2.5 < Th. ≤ 6 (0.098) (0.236) | 50 | 40 | ≤ 10 | |
| 6 < Th. ≤ 10 (0.236) (0.394) | 60 | 50 | ≤ 10 | |



| ALLOYS | TEMPER CODE (SEE TABLE 1) |
|------------------|---|
| 2024 (A-U4G1) | T3 T351 T3510 T3511 T4 T42 |
| 2017 (A-U4G) | T3 T42 |
| 2014 (A-U4SG) | T6 T651 |
| 6061 (A-6S) | T4 T6 T42 T62 |
| 6082 (A-SGM) | T6 |
| 7020 (A-25G) | T6 |
| 7075 (A-25GU) | T73 T7351 T73511 T6 T651 T6510 T6511 T76 |
| 7175 | T73 T7351 T7352 |
| 5086 (A-64MC) | H1111 F |
| A-S7G08 | F |



- **Så i praksis er der mange hensyn at tage:**

Ovnen skal være meget præcis

Det kan ikke accepteres at der er Overshoot

Ovnen skal være lynhurtig

Fixturering er vigtig

Dokumentation er vigtig

Kølemiddel

Kølemiddel temperatur



<https://www.youtube.com/watch?v=roFF9H5Qlxc>

