Aerospace Metal Composites Limited
tel: 44 1252 375001 fax: 44 1252 375002
www.amc-mmc.co.uk

AMC

Technical Data

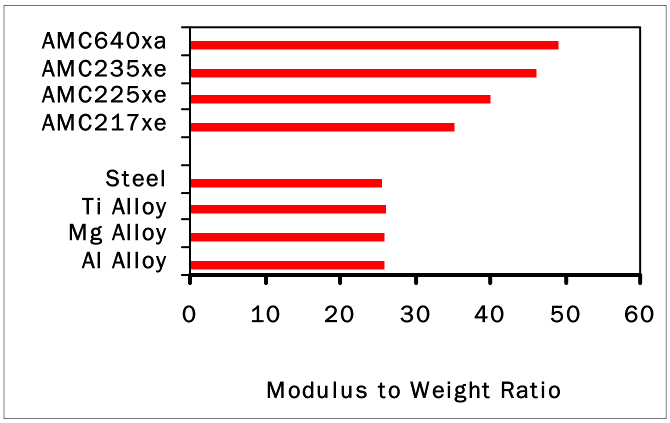
# AMC225xe

## PARTICLE REINFORCED ALUMINIUM ALLOY

AMC225xe is a high quality aerospace grade aluminium alloy (AA2124) reinforced with 25% by volume of ultrafine particles of silicon carbide. It is manufactured by a special powder metallurgy route using a proprietary high-energy mixing process which ensures excellent particle distribution and enhances mechanical properties.

The key benefits of AMC225xe for structural applications include:

- Weight saving
- Increased component stiffness
- High fatigue resistance.



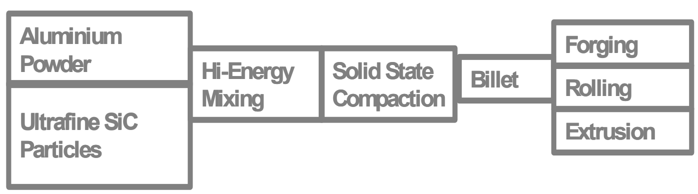

AMC225xe Typical Properties T4 (QOP041)

| | |
|---|---|
| Elastic Modulus | 115 *GPa* |
| Ultimate Tensile Strength | 650 *MPa* |
| 0.2% Yield Strength | 480 *MPa* |
| Strain to Fail | 5% |
| Poisson's Ratio | 0.3 |
| Vickers Hardness | 210 |
| Thermal Conductivity | 150 *W/m/ºC* |
| Thermal Expansion Coefficient | 15.5 *ppm/ºC* |
| Heat Capacity | 0.836 *J/g/ºC* |
| Solidus | 548ºC |
| Electrical Conductivity | 21 *% IACS* |
| Density | 2.88 *g/cm³* |

Information is provided for guidance purposes only and does not constitute a guarantee.

AMC powder metallurgy and mechanical alloying techniques are used to combine the aluminium alloy (AA2124) matrix with fine (2-3 micron) Silicon Carbide (SiC) particles. Process conditions are controlled to produce an even distribution of these particles, whilst maintaining the purity of the matrix alloy. Powders are compacted to fully dense billet by hot isostatic compaction. Billets are available for direct manufacture to component or for fabrication by forging, extrusion or rolling techniques. Selection of the process route depends on property requirements, component shape and the resulting process cost.

A wide range of machining methods may be applied. High speed machining with diamond tools achieves excellent surface finish and tolerances. Where appropriate a range of coating technologies may be applied for additional tribological performance.




The combination of properties achieved with AMC225xe provides the potential for outstanding structural performance in a wide range of markets and applications including:

**Motorsport**

- Performance valve train
- Cylinder liners
- Pistons
- Connecting rods
- Brake callipers
- Disk Bells
- Suspension parts

**Aerospace & Defence**

- Aero engine vanes
- Aircraft structure
- Brakes and Wheels
- Control Systems
- Valve Blocks

# THERMAL STABILITY

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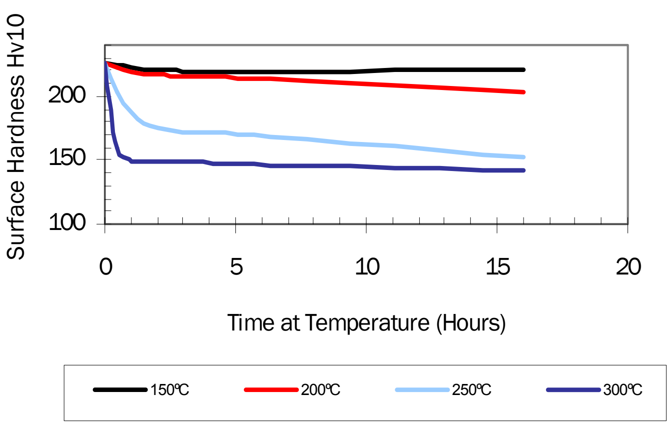
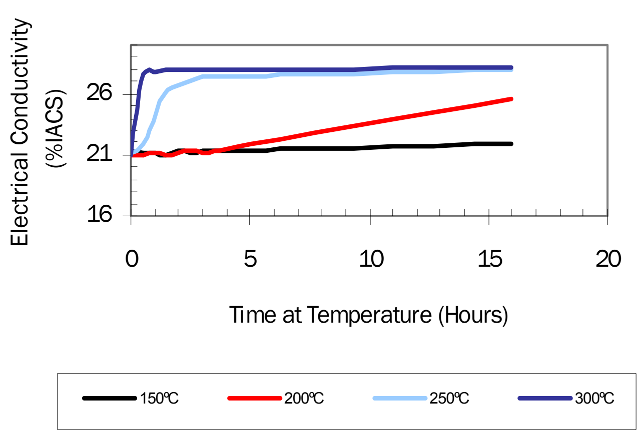
Addition of fine ceramic reinforcement accelerates ageing reactions in the AMC225xe. Peak strength is achieved by room temperature ageing (a T4 temper) without the need for artificial ageing. Natural ageing is complete after 100 hours, but significant proportion of peak strength is attained within a few hours of quenching.

AMC225xe CWQ Natural Ageing

| Room Temperature Age Time (Hours) | % of Maximum Hardness |
|---|---|
| 0.5 | 85 % |
| 2 | 93 % |
| 22 | 97% |
| 100 | 100% |

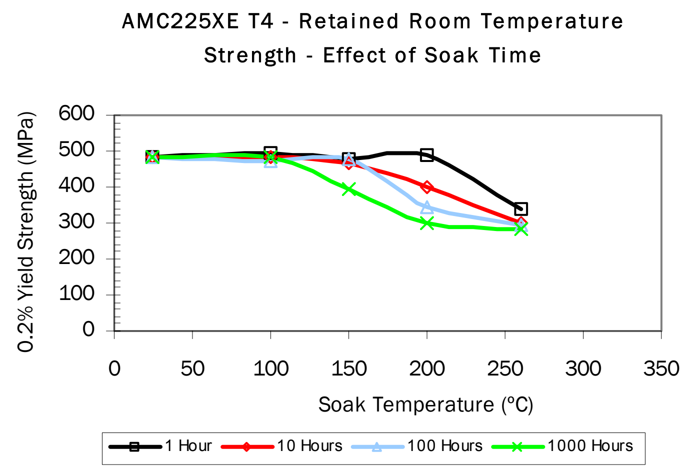
Hardness and electrical conductivity provide simple measurements to confirm heat treatment status and an inspection tool for heat treatment processes. In addition, for applications where thermal history is difficult to measure, these properties can help to map a component's thermal history.



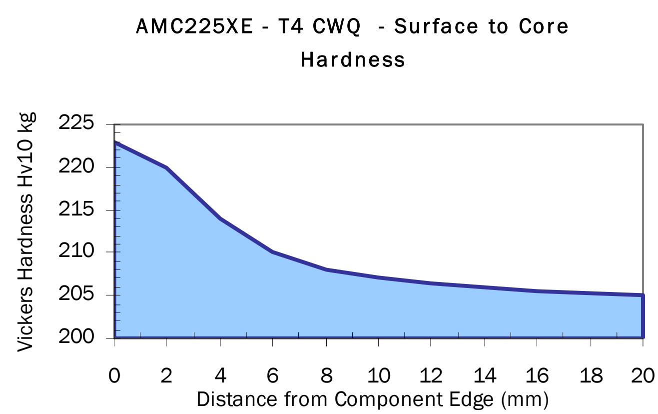




AMC225xe is insensitive to over ageing at temperatures below 150°C. However, ageing at more than 200°C, precipitate coarsening results in lower retained strength. At temperatures of more than 300°C, the retained room temperature strength is reduced to a base "T1" temper with 0.2% yield strength of 280 to 300 MPa.

(Data courtesy: Dr J Lord & Dr B Roebuck, National Physical Laboratory)




Small changes are noted between surface and core hardness as a result of heat flow during quench treatments. Care must be taken when comparing hardness to establish whether surface regions or cut surfaces are measured. Data is compared for extruded bar with a surface Vickers Hardness of 223 and a core hardness of 205 Hv10kg.



# Thermal Properties (1)

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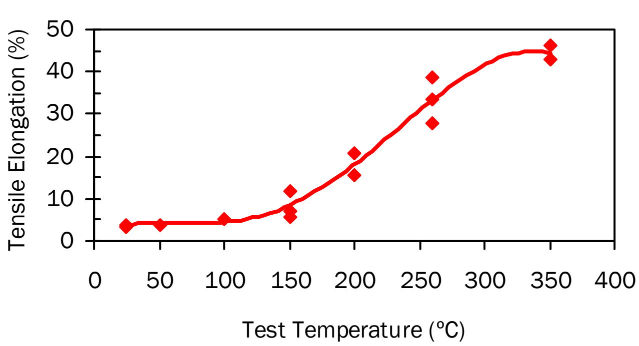
AMC225xe shows significant strength, fatigue and hardness benefits at elevated temperatures. This enables successful application for engine components including; valve train, pistons, cylinder liners and connecting rods. Strength and modulus at temperature follow similar trends to other precipitation hardened aluminium alloys, but from a higher room temperature base point. Strength and modulus benefits feed through to enhanced elevated temperature fatigue performance.

*AMC225XE — Plate*
*Tensile Strength at Temperature.*

| | *As Heat Treated T4 (QOP042)* | | *T4 + Thermal Cycled 200 cycles 50-200°C* | | *T4 + Thermal Exposure 150°C for 1000 hours* | |
|---|---|---|---|---|---|---|
| Test Temp °C | 0.2% Yield Strength (MPa) | Ultimate Strength (MPa) | 0.2% Yield Strength (MPa) | Ultimate Strength (MPa) | 0.2% Yield Strength (MPa) | Ultimate Strength (MPa) |
| 150 | 474 | 616 | 369 | 442 | 343 | 424 |
| 200 | 448 | 530 | 265 | 343 | 259 | 331 |
| 260 | 128 | 194 | 125 | 193 | 127 | 198 |
| 350 | 48 | 65 | 45 | 59 | 49 | 67 |

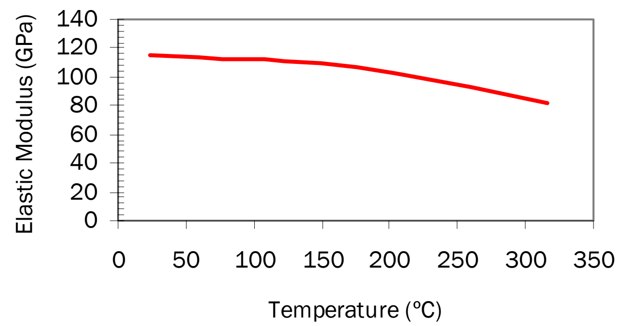
| | *As Fabricated T1 (QOP041)* | | *T1 + Thermal Cycled 200 cycles 50-200°C* | | *T1 + Thermal Exposure 150°C for 1000 hours* | |
|---|---|---|---|---|---|---|
| Test Temp °C | 0.2% Yield Strength (MPa) | Ultimate Strength (MPa) | 0.2% Yield Strength (MPa) | Ultimate Strength (MPa) | 0.2% Yield Strength (MPa) | Ultimate Strength (MPa) |
| 150 | 321 | 428 | 269 | 348 | 261 | 336 |
| 200 | 276 | 358 | 187 | 265 | 175 | 253 |
| 260 | 102 | 200 | 92 | 150 | 99 | 154 |
| 350 | 48 | 65 | 46 | 56 | 45 | 60 |

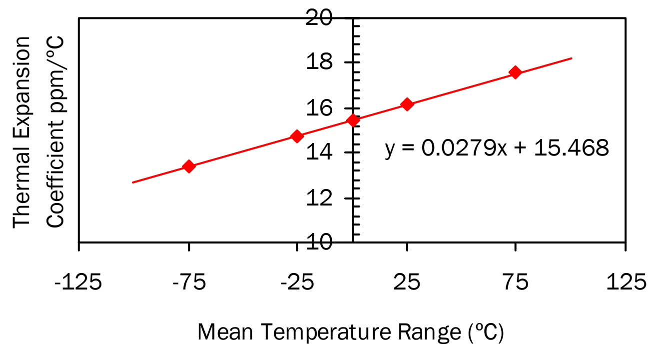
Data Courtesy: Dr P.Pitcher & Dr A.Shakesheff, DERA Farnborough.

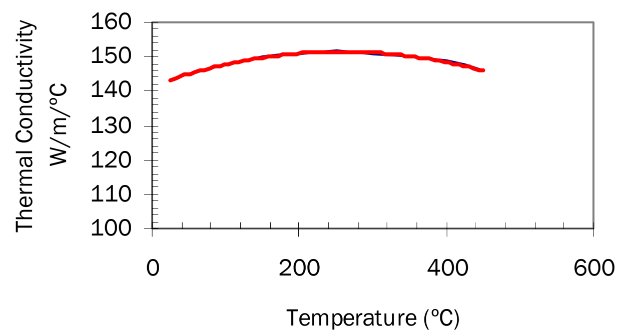



*Physical Properties*

Elastic modulus is reduced with temperature following a similar trend to aluminium alloys, but from a higher room temperature base point of 115 GPa. Thermal expansion coefficient over a temperature range of –100 to +100°C is approximately 15.5 ppm / °C. A temperature sensitivity of 0.0279 per °C (mean temperature from range) is calculated from experimental data. Thermal conductivity shows a small temperature sensitivity related to the state of alloy elements i.e. whether they are present in solid solution and the size of precipitates.



# THERMAL PROPERTIES (2)

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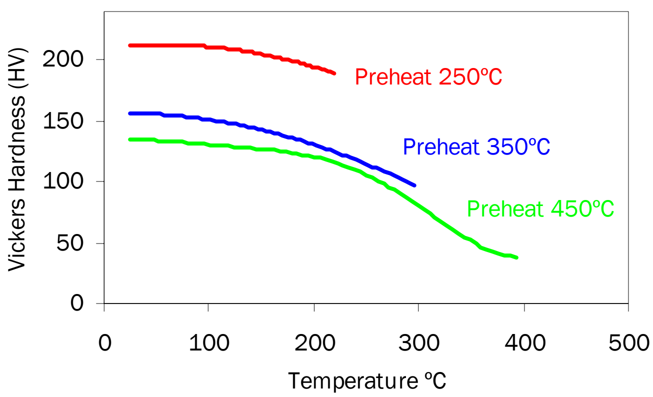
*Hardness at Temperature*

Figures below provide Vickers Hardness measurements for

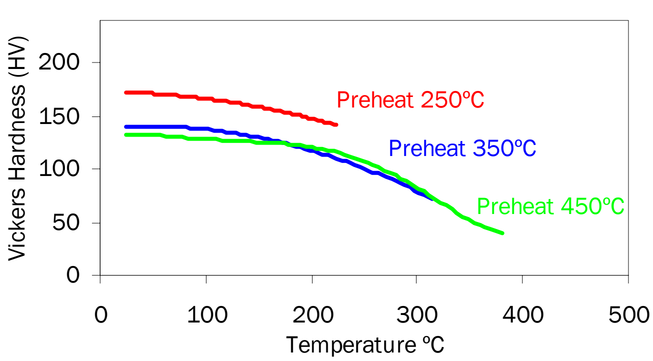
AMC225xe T4 at elevated temperature. Samples are preheated for 10 or 60 minutes and hardness is measured during controlled sample cooling. Transfer from the furnace means that it is impossible to measure hardness at the soak temperature. Measurements are typically started at 30 to 60°C below the soak temperature.

The data combines softening due to precipitate coarsening with elevated temperature hardness characteristics. The curve for preheat at 450°C for 60 minutes effectively provides lower bound hardness at temperature. Preheat at 250°C for 10 minutes will be close to an upper bound.

AMC225xe T4 - Preheat 10 minutes



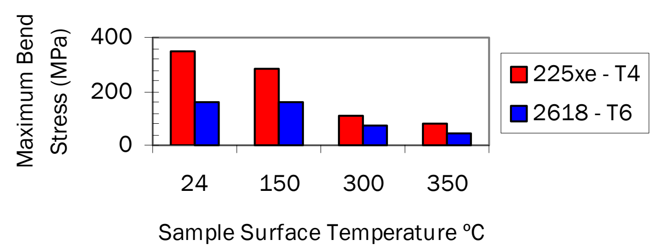

AMC225xe T4 - Preheat 60 minutes



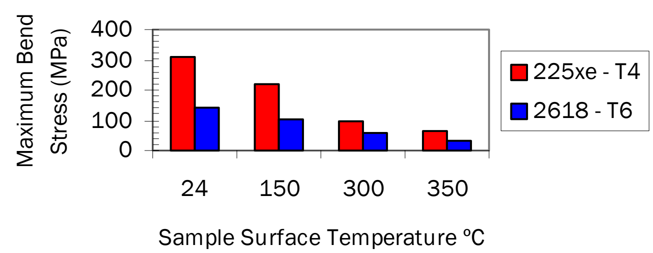

*Fatigue at Temperature*

Rotating bend fatigue tests (Kt=1, R=-1) have been used to compare fatigue strength at elevated temperature between 225xe and 2618 alloys. The test is completed at 2800 rpm, leading to a 5.95 hour test for 1 million fatigue cycles. Heat flow is calibrated for the fatigue test to provide a sample surface temperature as detailed below.

Rotating Bend Fatigue Limit at 1 Million Cycles.




Rotating Bend Fatigue Limit at 10 Million Cycles.

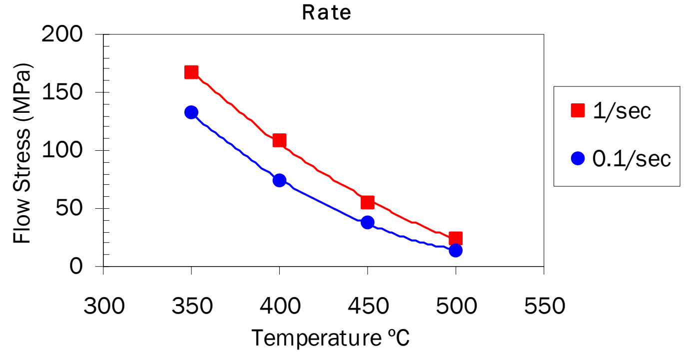



*Compressive Flow at Temperature*

Cylindrical samples are compressed at elevated temperature to provide flow stress data at varied strain rates. This information is particularly useful for modelling of extrusion or forging processes.

(Data courtesy: Dr R Dashwood & R Thackray, Imperial College of Science, Technology & Medicine)

Compressive Flow Stress - Effect of Strain Rate



# Fatigue Properties

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**AMC225XE** offers significant fatigue advantages for structural applications at ambient and elevated temperature conditions.

Fatigue properties for AMC225xe are controlled by similar factors to other aluminium alloys:

- Heat Treatment Condition.
- Product Form & Degree of Fabrication Work.
- Fatigue Conditions.
- Component Design, Shape & Finish.

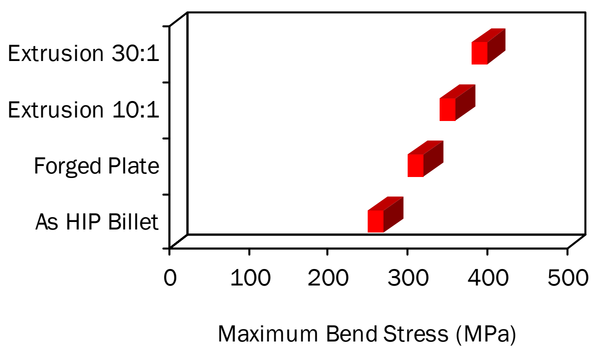
For general guidance, maximum fatigue performance will be achieved with peak strength heat treatments, with highly worked product and avoidance of notch factors in design.

### *Heat Treatment*

Heat treatment to a T4 temper (QOP042) is recommended to maximise fatigue strength. See heat treatment guidelines for full details of process conditions and their effect on fatigue characteristics.

### *Product Form*

A greater degree of fabrication work generally enhances fatigue performance. A comparison of as HIP billet, forged plate and extruded product is given below for a T4 (QOP042) condition. This data is for a rotating bend test (kt=1, R=-1) and shows the fatigue limit stress at 10 million cycles.

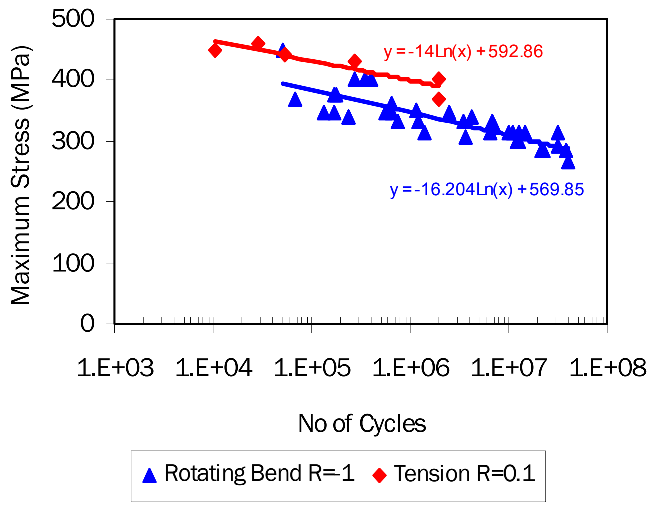



### *Component Design, Shape & Finish.*

Design guidelines follow the same outline as for other conventional metallic alloys. Sharp notches should be avoided where possible, especially in high stress regions. Good surface finish will help to enhance fatigue characteristics for finished components.

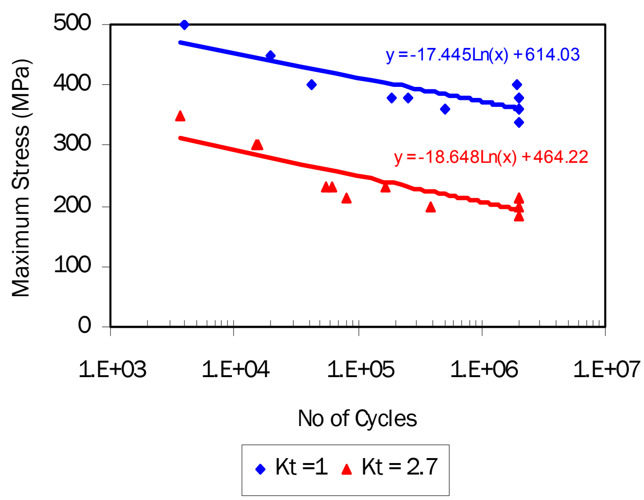
### *Fatigue Conditions*

A comparison of rotating bend and tension - tension fatigue curves for forged plate in a T4 (QOP042) heat treatment is given below:




### *Notched Fatigue*

The chart below provides a comparison of notched (Kt=2.7) and un-notched (Kt=1) tension—tension (R=0.1) fatigue curves for extruded bar in a T4 polymer glycol quench (QOP044) heat treatment.



# Heat Treatment

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AMC225xe is based on a 2124 precipitate hardened aluminium alloy, reinforced with 25 volume % of 2-3 micron Silicon Carbide particles. The alloy responds to conventional solution treatment, quench and age treatments to achieve high strength and fatigue performance. However, certain heat treatment conditions are modified as a result of the powder metallurgy manufacturing route and the presence of the fine reinforcement.

*Solution Heat Treatment*

- *505°C for a time dependent on section thickness.*

Use a minimum time of *1 hour at temperature for up to 25mm thick section.* Increase this solution treatment time pro-rata for thicker sections

*Preferred tolerance for furnace control is +/- 5°C.* To avoid formation of intermetallic phases, the solidus at 548°C should not be exceed during heat treatment or fabrication processes. Significant reduction in solution heat treat temperature and time will result in incomplete solid solution of alloy elements and the presence of intermetallic phases in the final microstructure. Such phases will reduce strength because a lower fraction of strengthening precipitate will be formed; they can also reduce fatigue performance in the composite.

*Quench Processes*

The quench medium and conditions may be selected to balance strength and residual stress.

Maximum quench rate will result in:

Maximum strength and fatigue performance.
Residual stress that may cause distortion for complex parts and / or for close tolerance machining processes.

For general guidance; to maximise quench rate, transfer time from furnace to quench medium should be minimised, especially for thin section parts.

*Heat Treatment Designation*

QOP041 - Designation: T1 Air cooled from elevated temperature forming process. *Suitable for low stress parts or those subject to high temperature soak in operation. Suitable as a supply condition for material that will be further processed (forged, rolled or extruded) and heat treated.*

QOP042 - Designation: T4 (CWQ) Solution Heat Treated. Quenched in Cold water. Aged at Room Temperature. Ageing Time: stable condition is achieved after 100 hours. *Suitable for thin section and / or symmetrical parts. Maximum properties, but some risk of distortion during quench or during subsequent machining.*

QOP043 - Designation: T6 (CWQ) Solution Heat Treated. Quenched in Cold water. Ageing / Stabilisation Temperature: 150°C. Ageing / Stabilisation Time: 1 hour. *Reduces distortion risk. No effect on properties.*

QOP044 - Designation: T4 (PGQ) Solution Heat Treated. Quenched in 25% Polymer Glycol Solution. Ageing Temperature: Room Temperature. Ageing Time: stable condition is achieved after 100 hours. *Softer quench reduces risk of distortion on complex or thick section components. Lower quench rate causes some reduction in fatigue properties, depending on section.*

QOP045 - Designation: T6 (PGQ) Solution Heat Treated. Quenched in 25% Polymer Glycol Solution. Ageing / Stabilisation Temperature: 150°C. Ageing / Stabilisation Time: 1 hour. *Potentially provides greater reduction in distortion risk.*

Effect of Heat Treatment - AMC225xe – Measured Values on Forged Plate 15mm thick.

| 505°C Solution Treated<br>Quench Treatment | Ultimate Strength (MPa) | 0.2% Yield Strength (MPa) | Strain to Fail (%) | Core Vickers Hardness (Hv5kg) | Electrical Conductivity (%IACS) | Surface Residual Stress * (MPa) | Fatigue Limit $1x10^6$ Cycles R=0.1, Kt=1. * (MPa) |
|---|---|---|---|---|---|---|---|
| Air Cool | 446 | 283 | 5.2 | 142 | 26.4 | 0 | 281 |
| Polymer Glycol Quench | 616 | 410 | 5.1 | 188 | 23.3 | -36 | 350 |
| Hot Water Quench | 649 | 469 | 3.3 | 205 | 21.8 | -116 | 387 |
| Cold Water Quench | 670 | 468 | 4.3 | 211 | 21.2 | -120 | 399 |

** Data courtesy: Dr M.Fitzpatrick, Open University.*