**Supplementary table 1. Previous methods for ductility enhancement**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Method Description | Effect on glass or liquid | Effect | Mechanical tests | Homogeneous/Inhomogeneous | Alloys | Change in thermal signal | Reference |
| High temperature creep | Glass | Increased plasticity (in some samples) | Compression | Homogenous deformation, possible anisotropy | Zr50Cu40Al10Zr65Cu17Ni8Al10Zr55Cu30Ni5Al10 | No difference observed vs. as-cast  | [1, 2] |
| Elastostatic loading | Glass | Condition dependent rejuvenation orrelaxation | Nanoindentation | Homogenous | Cu57Zr43Zr35Ti30Be27.5Cu7.5 | 0.247-0.4 KJ/mol | [3-5] |
| Hot rolling | Liquid | Unstudied | N/A | Homogenous | Zr44Ti11Cu10Ni10Be25 | N/A | [6] |
| Twin roll casting | Liquid | Rejuvenation | Hardness | Homogenous | Zr41.2Ti13.8Cu12.5Ni10Be22.5 | 0.2 KJ/mol | [7] |
| Notched uniaxial compression (Triaxial) | Glass | Rejuvenation, decreased hardness, increased plasticity | Tensile and hardness | Inhomogeneous | Zr64.13Cu15.75Ni10.12Al10 | 0.59 KJ/mol | [8, 9] |
| High pressure annealing | Glass | Rejuvenation, increased density, shear and elastic modulus | N/A | N/A | La60Ni15Al25 | 0.1-0.9 KJ/mol | [10] |
| High pressure torsion | Glass | Rejuvenation | Nanoindentation | Inhomogeneous | Zr50.7Cu28Ni9Al12.3Zr50Cu40Al10 | 0.5-1.1 KJ/mol | [5, 11, 12] |
| Cyclic nanoindentation | Glass | Increased hardness | Nanoindentation | Inhomogeneous | Fe41Co7Cr15Mo14C15B6Y2 | N/A | [13] |
| Uniaxial compression | Glass | Increase in plastic strain | Uniaxial compression | Homogenous | Ni62Nb38 | .179 (from as cast) (.3 total) KJ/g | [14] |
| Dynamic excitation upon cooling | Glass | Rejuvenation | DMA | Homogenous | Zr58.5Cu15.6Ni12.8Al10.3Nb2.8Zr66.5Cu33.5Pd77.5Cu6Si16.5 | .5 to 5 KJ/mol | [15] |
| Cyclic compression | Glass | Rejuvenationelastic, plastic anisotropy | Compression testingVickers hardness | Inhomogeneous | Zr61Cu27Fe2Al10 | 0.25 KJ/mol | [16] |
| Laser shock peening. Shockwave imparted by a laser | Glass | Rejuvenation | Compressiontesting | Inhomogeneous | Zr52.5Cu17.9Ni14.6Al10.0Ti5.0Zr41.2Ti13.8Cu12.5Ni10Be22.5 | N/A | [17, 18] |

**Cont'd supplementary table 1. Previous methods for ductility enhancement**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Method Description | Effect on glass or liquid | Effect | Mechanical tests | Homogeneous/Inhomogeneous | Alloys | Magnitude of thermal signal | Reference |
| Shot peening | Glass | Increased plasticity (hardening by residual stress, softening by sheer bands) | Microhardness, compression | Inhomogeneous | Zr41.25Ti13.75Ni10Cu12.5Be22.5 | N/A | [19, 20] |
| Shock compression | Glass | Rejuvenation | N/A | Inhomogeneous | Zr55Cu30Ni5Al10 | .423 to 1.32KJ/mol | [5] |
| Thermal cycling | Glass | Rejuvenation, increased plasticity, decreased hardness | Uniaxial compression, hardness | Inhomogeneous  | Cu46Zr46Al7Gd1La55Ni20Al25 (ribbon) La55Ni10Al35Zr62Cu24Fe5Al9ZrCuNiAl(Nb)ZrTiCuNiBePdNiCuPPtNiCuP | (1.08-.74) = .34 KJ/mol | [21-23] [24-26] |
| Cold wire drawing | Glass | Decrease in yield stress, increase in fracture stress and plasticity | Tensile testing | Inhomogeneous | Pd77.5Cu6Si16.5 | N/A | [27] |
| Cold rolling | Glass | Increased ductilityWork-hardeningrejuvenation | Nanoindentation,ultrasonic testing | Inhomogeneous | Zr55Cu30Ni5Al10Cu47.5Zr47.5Al5Zr46.5Cu45Al7Ti1.5 | .3-.5 KJ/mol | [28-30] |
| Ball milling | Glass | rejuvenation | None | Inhomogeneous | Pd40Cu30Ni10P20Zr70Cu20Ni10 | <.1KJ/g | [31, 32] |
|  Neutron and high energy particles irradiation | Glass |  Rejuvenation or relaxation, increased ductility | Bending and Tension | Homogenous | many | N/A | [33-36] |
| Fatigue coaxing | Glass | Increase in fatigue limit | 3-point bending | Inhomogeneous | Zr41.8Ti12.9Ni9.5Cu12Be23.8 | N/A | [37] |
| Equal channel angular processing | Glass | Decreased yield strength, increased plasticity, likely due to shear banding not rejuvenation | Uniaxial compression | Inhomogeneous | Zr57Cu20Al10Ni8Ti5 | N/A | [38, 39] |
| Hot Wire Drawn | Liquid | Decreased modulus and hardness | Nanoindentation | Homogeneous | Pd40Cu30Ni10P20 | 28% increase from as cast | [34] |
| Static mechanical loading | glass | Strain hardeningIncreased plasticity | Tension, compression | Shear Transformation Zones | various | 40% | [40-42] |
| Cooling rate and annealing temperature | liquid | Density, Hardness, Modulus |  | Homogenous | Cu-based, ZrCuNiAl, MgCuY | yes | [43-45] |

**Supplementary model derivation 1. Cooling rate for pulled wires.**

Assuming that the temperature is uniform throughout the wire deforming region, varying with time (relative position) but not with absolute position, and a constant heat transfer coefficient; we can use the lumped capacitance model to obtain the change in temperature.

From newton’s law of cooling:

$$\dot{Q}=h\*A\* (T(t)-T\\_env )=h\*A\*∆T(t)$$

Where,

$\dot{Q}$ is the heat rate transfer out of the body

$h$ is the heat transfer coefficient

$A$ is the heat transfer surface area

$T\left(t\right)$ is the temperature of the object’s surface

$T\_{env}$ is the environment or room temperature

In the case of an incompressible material with a total internal energy U characterized by a single uniform temperature T(t), The heat capacity of the body C is $\frac{dU}{dT}$ .The internal energy may be written in terms of the temperature of the body, the heat capacitance and a reference temperature at which the internal energy is zero:

$$U=C(T-T\_{ref})$$

Differentiating U with respect to time:

$$\frac{dU}{dt}=C\frac{dT}{dt}$$

If no work is exerted, by the first law of thermodynamics:

$$\frac{dU}{dt}=-Q$$

Thus:

$$\frac{dT(t)}{dt}=-\frac{hA}{C}\left(T\left(t\right)-T\_{env}\right)=-\frac{1}{τ}∆T(t)$$

Where:

$$τ=\frac{C}{\left(hA\right)}= \frac{mc}{(hA)}$$

τ is the time constant of the system

C is the heat capacity

m is the mass of the material

c is the material specific heat capacity

When the environmental temperature is constant with time, we can define $∆T(t)=T(t)-T\_{env}$ and the equation becomes:

$$\frac{dT(t)}{dt}= \frac{d∆T(t)}{dt}=\frac{1}{τ}∆T(t)$$

Which solution by integration from the initial condition is:

$$∆T\left(t\right)= ∆T(0)e^{-t/τ}$$

Where ΔT(0) is the temperature difference at time 0, and to obtain the temperature at a given time t:

$$T\left(t\right)=T\_{env}+(T\_{0}-T\_{env})e^{^{-t}/\_{τ}}$$

Which becomes a function of the time and the heat transfer surface area.

If we assume that the region of interest from the wire it’s a cylinder-shaped region with constant volume, we can obtain the change in surface area with respect to the change in length.

The volume of a cylinder is given by:

$$V=πr^{2}L$$

Where,

$r$ is the radius

$L$ is the length of the wire

Solving for the radius we get:

$$r=\sqrt{\frac{V}{πL}}$$

The curved surface area of the cylinder is given by:

$$A=2πrL$$

and so:

$$r=\frac{A}{2πr}$$

So we can stablish:

$$\frac{A}{2πr}=\sqrt{\frac{V}{πL}}$$

Finally:

$$A=2\sqrt{πLV}$$

Where the volume (V) is constant and the length (L) varies with time.

**Supplementary Method 1.**



**Supplementary Figure 1. Temperature profile of wire annealing treatment.** Salt bath is preheated to 60 K above the calorimetric cooling glass transition temperature (683 K) for at least an hour. Sample wires are submerged in the salt bath for 180 s before being retrieved and allowed to air cool.

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