**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 | Zr50Cu40Al10  Zr65Cu17Ni8Al10  Zr55Cu30Ni5Al10 | No difference observed vs. as-cast | [1, 2] |
| Elastostatic loading | Glass | Condition dependent rejuvenation or  relaxation | Nanoindentation | Homogenous | Cu57Zr43  Zr35Ti30Be27.5Cu7.5 | 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 | Zr50.7Cu28Ni9Al12.3  Zr50Cu40Al10 | 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 | Zr58.5Cu15.6Ni12.8Al10.3Nb2.8  Zr66.5Cu33.5  Pd77.5Cu6Si16.5 | .5 to 5 KJ/mol | [15] |
| Cyclic compression | Glass | Rejuvenation  elastic, plastic anisotropy | Compression testing  Vickers hardness | Inhomogeneous | Zr61Cu27Fe2Al10 | 0.25 KJ/mol | [16] |
| Laser shock peening. Shockwave imparted by a laser | Glass | Rejuvenation | Compression  testing | Inhomogeneous | Zr52.5Cu17.9Ni14.6Al10.0Ti5.0  Zr41.2Ti13.8Cu12.5Ni10Be22.5 | 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 | Cu46Zr46Al7Gd1  La55Ni20Al25 (ribbon)  La55Ni10Al35  Zr62Cu24Fe5Al9  ZrCuNiAl(Nb)  ZrTiCuNiBe  PdNiCuP  PtNiCuP | (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 ductility  Work-hardening  rejuvenation | Nanoindentation,  ultrasonic testing | Inhomogeneous | Zr55Cu30Ni5Al10  Cu47.5Zr47.5Al5  Zr46.5Cu45Al7Ti1.5 | .3-.5 KJ/mol | [28-30] |
| Ball milling | Glass | rejuvenation | None | Inhomogeneous | Pd40Cu30Ni10P20  Zr70Cu20Ni10 | <.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 hardening  Increased 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:

Where,

is the heat rate transfer out of the body

is the heat transfer coefficient

is the heat transfer surface area

is the temperature of the object’s surface

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 .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:

Differentiating U with respect to time:

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

Thus:

Where:

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 and the equation becomes:

Which solution by integration from the initial condition is:

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

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:

Where,

is the radius

is the length of the wire

Solving for the radius we get:

The curved surface area of the cylinder is given by:

and so:

So we can stablish:

Finally:

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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