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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of: Thorne et al.

Serial No.: 09/686,312	Group Art Unit: 1775
Filed: October 11, 2000	Examiner: John J. Zimmerman
For: TOOL HAVING AN ATTACHED WORKING PORTION AND METHOD OF MANUFACTURE	Attorney Docket No.: 3696-346-999

DECLARATION OF DR. FRANCIS H. FROES UNDER 37 C.F.R. § 1.132

Commissioner for Patents
Washington, D.C. 20231

Sir:

I, Francis H. Froes, Ph.D., do declare and state as follows:

1. I am the head of the Department of Materials, Metallurgical, Mining, and Geological Engineering at the University of Idaho in Moscow, Idaho. I am also director of the Institute for Materials and Advanced Processes at the University.

2. I received a Ph.D. in Physical Metallurgy from the University of Sheffield, England in 1967.

3. After graduating from the University of Sheffield, I spent eleven years working for Crucible Steel Company in Pittsburgh, Pennsylvania where I was manager of the titanium group. Subsequently, I spent eleven years at the U.S. Air Force Materials Laboratory, serving in various managerial roles including: leader of the in-house program, Branch Chief of the Structural Metals Branch, and Special Assistant to the Director, Metals and

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Ceramics Division. In sum, I have worked in the area of synthesis, characterization, and testing of advanced materials for more than thirty years. I also have almost 750 scientific and technical publications, 60 patents, and have edited 27 books and have contributed 7 encyclopedia articles on advanced materials.

[redacted]

5. It is my understanding that most steel hammer heads are made of high carbon steel and the material of choice for titanium hammer heads is the Ti-6Al-4V alloy.

6. After reviewing available technical information and publications, it is my opinion that the damping behavior of the Ti-6Al-4V alloy should exceed that of high carbon steels normally used in hammer heads.

7. Attachment 1, and specifically section 3.7 and Figure 11, is a true and accurate copy of a map of damping behavior of a variety of materials compiled by Professor Mike Ashby of Cambridge University, UK. (M. F. Ashby, Materials Selection in Mechanical Design in Materials Engineering and Design, Proc. Conf. "Materials '88", Inst. of Metals, London (1988)). This map shows the range of damping values (η) of titanium from 10^{-4} (low end) to 10^{-3} (high end). The high carbon steels range from 10^{-5} (low end) up to about 10^{-4}, i.e. the low end of the titanium levels. On average, therefore, titanium provides approximately 10 times greater damping than high carbon steels. In this context, damping is a measure of the ability of "a material to quell vibrations," the higher the value, the greater the ability to quell such vibrations (definition from American Society of Materials (ASM) International Handbook, Materials Park, Ohio, vol. 1, p. 31).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so

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made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: 01 Aug '02

Francis H. Froes

ATTACHMENT 1

requires that the structure will *yield before it breaks*. If the minimum detectable crack size is $2a_c$, then this condition can be expressed as

$$\frac{K_{Ic}}{\sigma_y} \geq \sqrt{\pi a_c}. \qquad (12)$$

The safest material is the one with the greatest value of K_{Ic}/σ_y: it will tolerate the longest crack. But, though safe, it may not be efficient. The section required to carry the load decreases as σ_y increases. We want high K_{Ic}/σ_y *and* high σ_y. The reader may wish to plot two lines onto the figure, isolating the material which best satisfies both criteria at once: it is steel. It is this which gives steel its pre-eminence as the material for highly stressed structures when weight is not important.

One such structure is the pressure vessel. Here safe design requires that the vessel *leaks before it breaks*: leakage is not catastrophic, fast fracture is. To ensure this, the vessel must tolerate a crack of length, $2a_c$, equal to the wall thickness t, and this leads to a different criterion for materials selection. From the last equation, the leak-before-break criterion is

$$\frac{K_{Ic}^2}{\sigma_y^2} \geq \pi t.$$

But the pressure, p, that the vessel can support is limited by yield, so that, for a thin walled cylindrical vessel of radius R,

$$\frac{pR}{t} \leq \sigma_y.$$

Substituting for t gives

$$p \leq \frac{1}{\pi R}\left[\frac{K_{Ic}^2}{\sigma_y}\right]$$

The greatest pressure is carried by the vessel with the largest value of K_{Ic}^2/σ_y. A guide line of K_{Ic}^2/σ_y is shown on the chart. It, and the yield-before-break line, are used in the way described in Section 1. Again, steel and copper are optimal.

3.7. The loss coefficient—modulus chart (Chart 7, Fig. 11)

Bells, traditionally, are made of bronze. They can be (and sometimes are) made of glass; and they could (if you could afford it) be made of silicon carbide. Metals, glasses and ceramics all, under the right circumstances, have low intrinsic damping, or "internal friction", an important material property when structures vibrate. We measure intrinsic damping by the *loss coefficient*, η, which is plotted in Fig. 11. Other measures include the *specific damping capacity* D/U (the energy D dissipated per cycle of vibrational energy U), the *log decrement*, Δ (the log of the ratio of successive amplitudes), the *phase lag*, δ, between stress and strain and the *resonance factor*, Q. When the damping is small ($\eta < 0.01$) these measures are related by

$$\eta = \frac{D}{2\pi U} = \frac{\Delta}{\pi} = \tan\delta = \frac{1}{Q} \qquad (13)$$

but when the damping is large, the definitions are no longer equivalent. Large η's are best measured by recording a symmetric load cycle and dividing the area of the stress-strain loop by 2π times the peak energy stored.

There are many mechanisms of intrinsic damping and hysteresis. Some (the "damping" mechanisms) are associated with a process that has a specific time constant; then the energy loss is centred about a characteristic frequency. Others (the "hysteresis" mechanisms) are associated with time-independent mechanisms, and absorb energy at all frequencies.

One damping mechanism, common to all materials, is a thermoelastic effect. A suddenly-applied tensile stress causes a true solid to cool slightly as it expands (elastomers are not true solids, and show the opposite effect). As it warms back to its initial temperature it expands further, giving additional strain that lags behind the stress. The anisotropy of moduli means that a polycrystal, even when uniformly loaded, shows a thermoelastic damping because neighbouring grains distort—and thus cool—by differing amounts. The damping is proportional to the difference between the adiabatic modulus, E_A and that measured at constant temperature, E_T. A thermodynamic analysis (e.g. [24]) shows that

$$\eta = C\frac{E_A - E_T}{E_T} = \frac{CT\alpha^2 E_T}{\rho C_v} \qquad (14)$$

where α is the coefficient of linear thermal expansion, C_v the specific heat, T the temperature and C a constant. This leads to the shaded line on the Chart marked "thermal damping". Single crystals and glasses lie below the line, because, when loaded uniformly, no temperature gradients exist.

The loss coefficient of most materials is far higher than this. In metals a large part of the loss is hysteretic, caused by dislocation movement: it is high in soft metals like lead and aluminium, but heavily alloyed metals like bronze, and high-carbon steels have low loss because the solute pins the dislocations. Exceptionally high loss is found in the Mn–Cu alloys, because of a strain-induced martensitic transformation, and in magnesium, perhaps because of reversible twinning. The elongated balloons for metals span the large range accessible by alloying and working. Engineering ceramics have low damping because the enormous lattice resistance (Section 3.2) pins dislocations in place at room temperature. Porous ceramics, on the other hand, are filled with cracks, the surfaces of which rub, dissipating energy, when the material is loaded; the high damping of some cast irons has a similar origin. In polymers, chain segments slide against each other when loaded; the relative motion lowers the compliance and dissipates energy. The ease with which they slide depends on the ratio of the temperature (in this case, room

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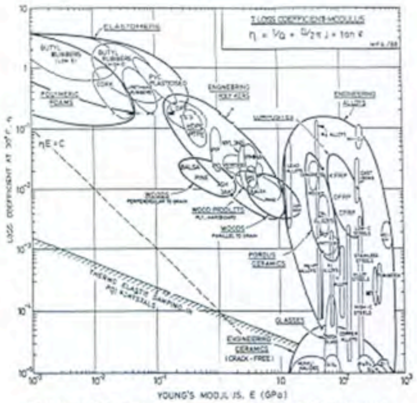

Fig. 11. Chart 7: The loss coefficient, η, plotted against Youngs modulus, E. the guide-line corresponds to the condition $\eta = C/E$.

temperature) to the glass temperature, T_g, of the polymer. When $T/T_g < 1$, the secondary bonds are "frozen", the modulus is high and the damping is relatively low. When $T/T_g > 1$, the **secondary bonds** have melted, allowing easy chain slippage: the modulus is low and the damping is high. This accounts for the obvious inverse dependence of η on E for polymers in Fig. 11; indeed, to a first approximation

$$\eta = \frac{4 \times 10^{-2}}{E} \qquad (15)$$

with E in *GPa*.

3.8. The thermal conductivity–thermal diffusivity chart (Chart 8, Fig. 12)

The material property governing the flow of heat through a material at steady state is the *thermal conductivity*, λ (units: J/mK); that governing transient heat flow is the *thermal diffusivity*, a (units: m^2/s). They are related by

$$a = \frac{\lambda}{\rho C_p} \qquad (16)$$

where ρ is the density and C_p the specific heat, measured in J/kg·K; the quantity ρC_p is the *volumetric specific heat*. Figure 12 relates conductivity, diffusivity and volumetric specific heat, at room temperature.

The data span almost 5 decades in λ and a. Solid materials are strung out along the line

$$\rho C_p \approx 3 \times 10^6 \ J/m^3K \qquad (17)$$

This can be understood by noting that a solid containing N atoms has $3N$ vibrational modes. Each (in the classical approximation) absorbs thermal energy kT at the absolute temperature T, and the vibrational specific heat is $C_p \approx C_v = 3Nk$ (J/K) where k is Bolzmann's constant. The volume per atom, Ω, for almost all solids lies within a factor of two of $1 \times 10^{-29} m^3$, so the volume of N atoms is