ALTERING FRACTURE TOUGHNESS OF GLASS BY A SURFACE MODIFICATION

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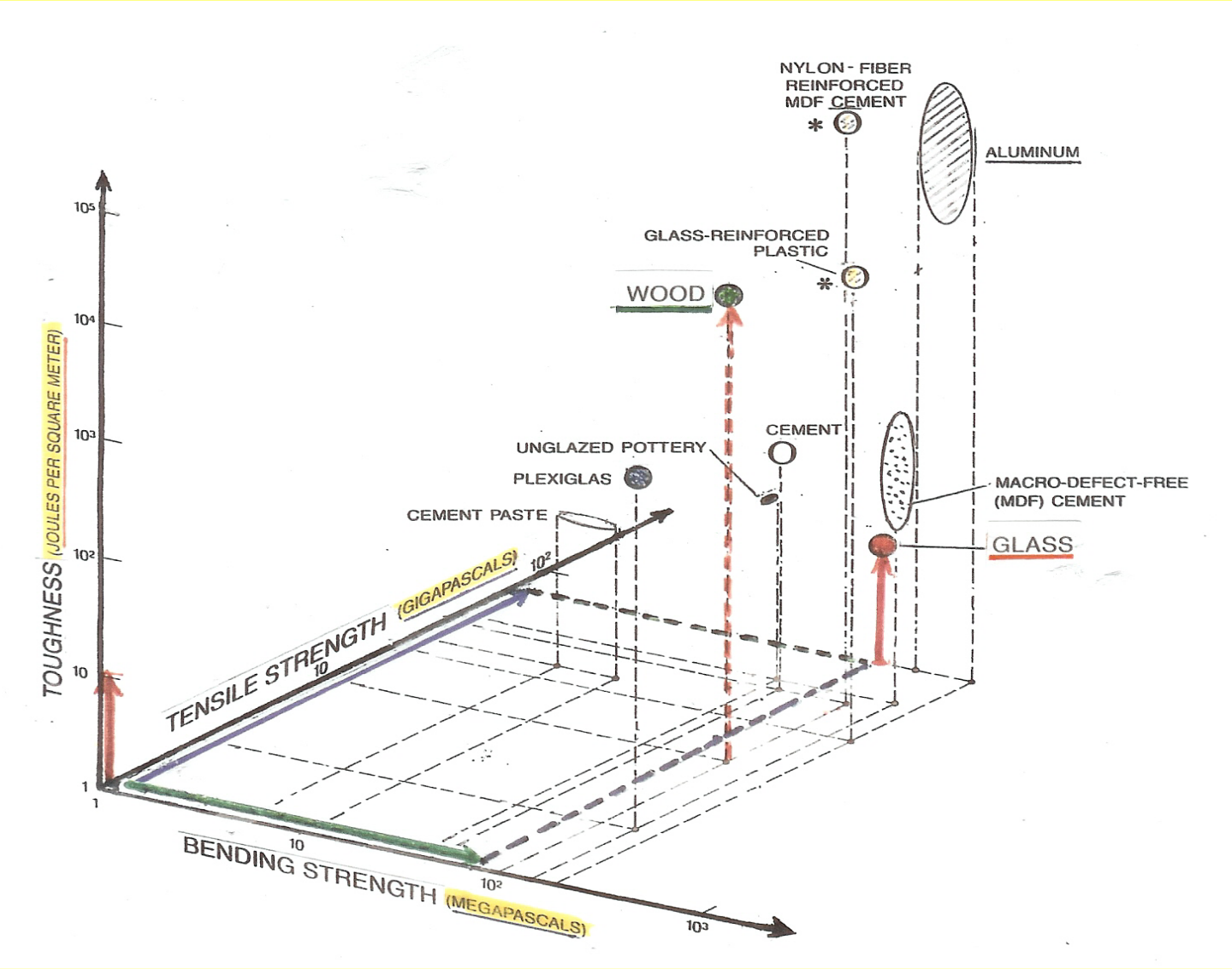
Colors of Strength

- **Stiffness** (resistance to bending).
- **Tensile strength** (resistance to pulling).
- **Fracture toughness** (resistance to impact).



Materials in the strength space

Fracture patterns of week and strong glass

A Problem and a Remedy

- Inorganic materials (excluding metals) **lack toughness.** Their toughness needs to be significantly improved in order to compete with metals and plastics.

- The **abalone shell**, (which is~99% $CaCO_3$) is **~3000 times tougher** than pure $CaCO_3$crystals. **This toughness is due to the inclusion of ~1% organics in the shell's microstructure**

  (embarrassingly, this structural remedy has been engineered by an invertebrate).

Main Difficulties for structural engineering of Glass

- **High temperature requirements** of the manufacturing (e.g. where organics burn).

- **Chemistry of the raw materials,** and the thermodynamics of the process, which do not allow micro-structural engineering (use of metal-organic compounds would).

Noteworthy Observations About Glass Fracture

- **Commercially produced glasses commonly fracture at stresses less than 1% of their theoretical strength.**

- **Fracture originates from the surface.**

- **These traits are the manifestations of :**

  *a) **brittle** nature of the structure, and thus*

  *b) **surface that is prone to micro-cracks**.*

A Fact and a Response

- Manifested strength of glass is statistically distributed **extrinsic property,** which is mainly determined by the **surface conditions** (i.e., **brittleness induced micro-cracks and defects**).

- **Shift the strength distribution to higher values by eliminating surface brittleness** (**without compromising the hardness & transparency**).

What is accomplished

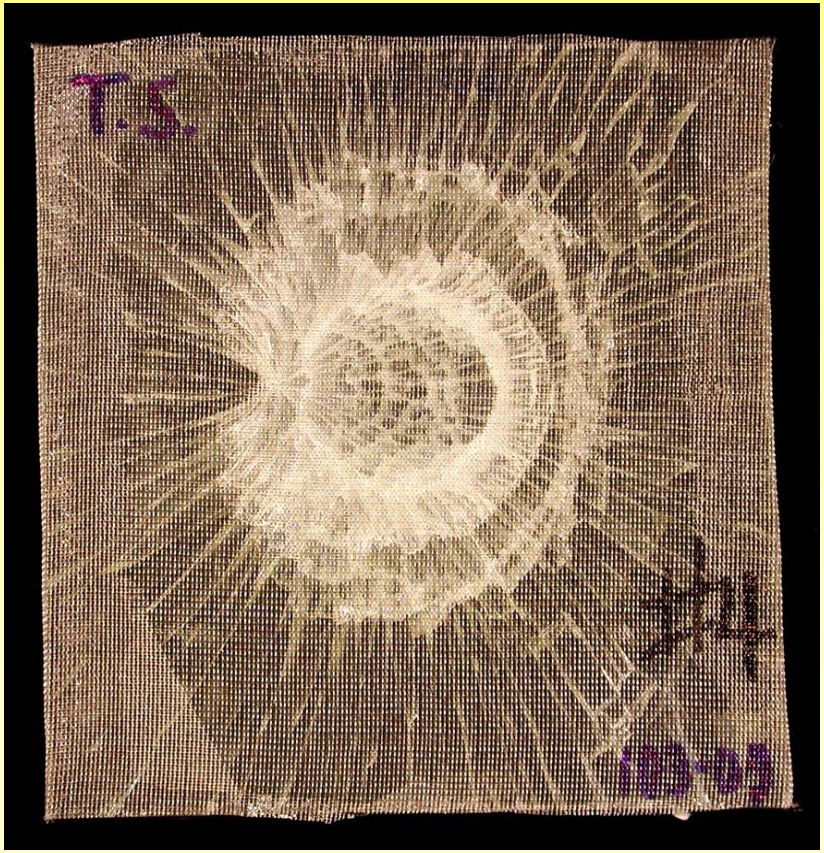
- A coating that increases the glass strength **2** to **5 fold** has been demonstrated on float glass.

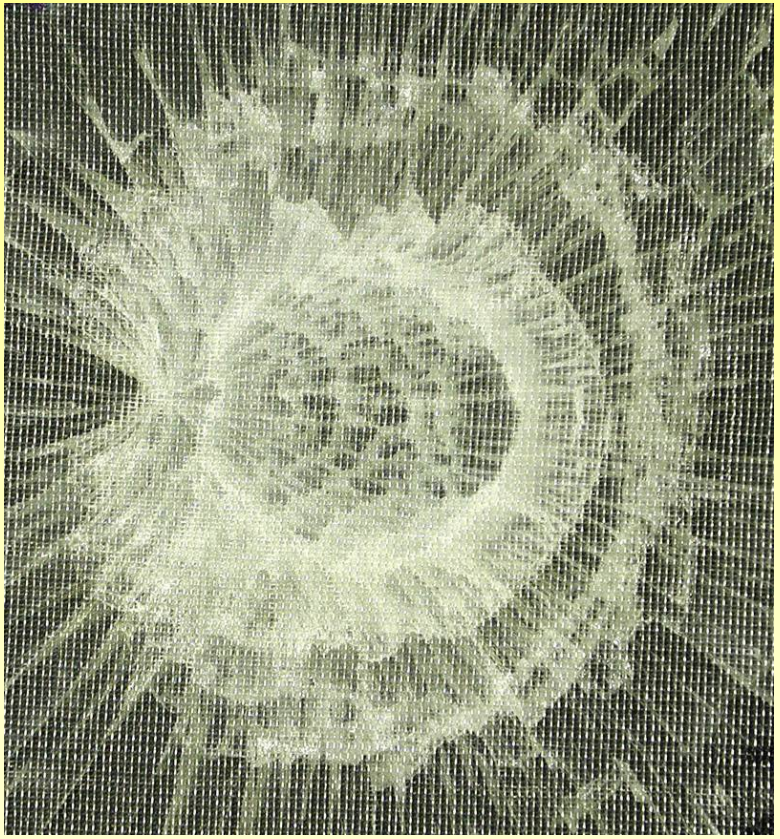
- The chemistry has been engineered to provide **transparency with matching optical index** , **non-brittleness with hardness**, and **strong bonding to glass** in the same coating.

Thoughts & Comments

- **Eliminating surface brittleness** of glass by a coating appears to increase its toughness by a factor of 3-5 (may be limited to this level).
- **Incorporating fibers into the coating matrix** should result even higher level of toughness (up to 7-9 factor ?).
- **Abating surface brittleness of traditionnaly strengthened glasses** should further increase their fracture toughness (e.g., coating chemically, or thermally tempered glass etc.,).
- **Grading the chemical composition of glass** (therefore, the thermal expansion coefficient) during its manufacturing should result in much stronger glass (this may or may not be possible in all cases) .

Fracture of Coated Glasses With Fabric





Strength improvements of 2&3 mm. float glass by this coating

2 mm. Glass (MPa)		3 mm. Glass (MPa)	
uncoated	coated	uncoated	coated
157	262	128	213
159	301	106	227
266	364	110	283
178	292	136	311
79	314	171	246
Av. 168	306	130	256

Fracture patterns of week and strong glass