Laminating with Graphite

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Polymers

Monomers Chained Together

Millions of Molecules

Polymers

Thermoplastic (Reheatable) spaghetti like structure

Thermoset (Non-reheatable) three dimensional crosslinked network which is permanent

Polymers

Weak Compared to Metals

Less Stiff Than Metals

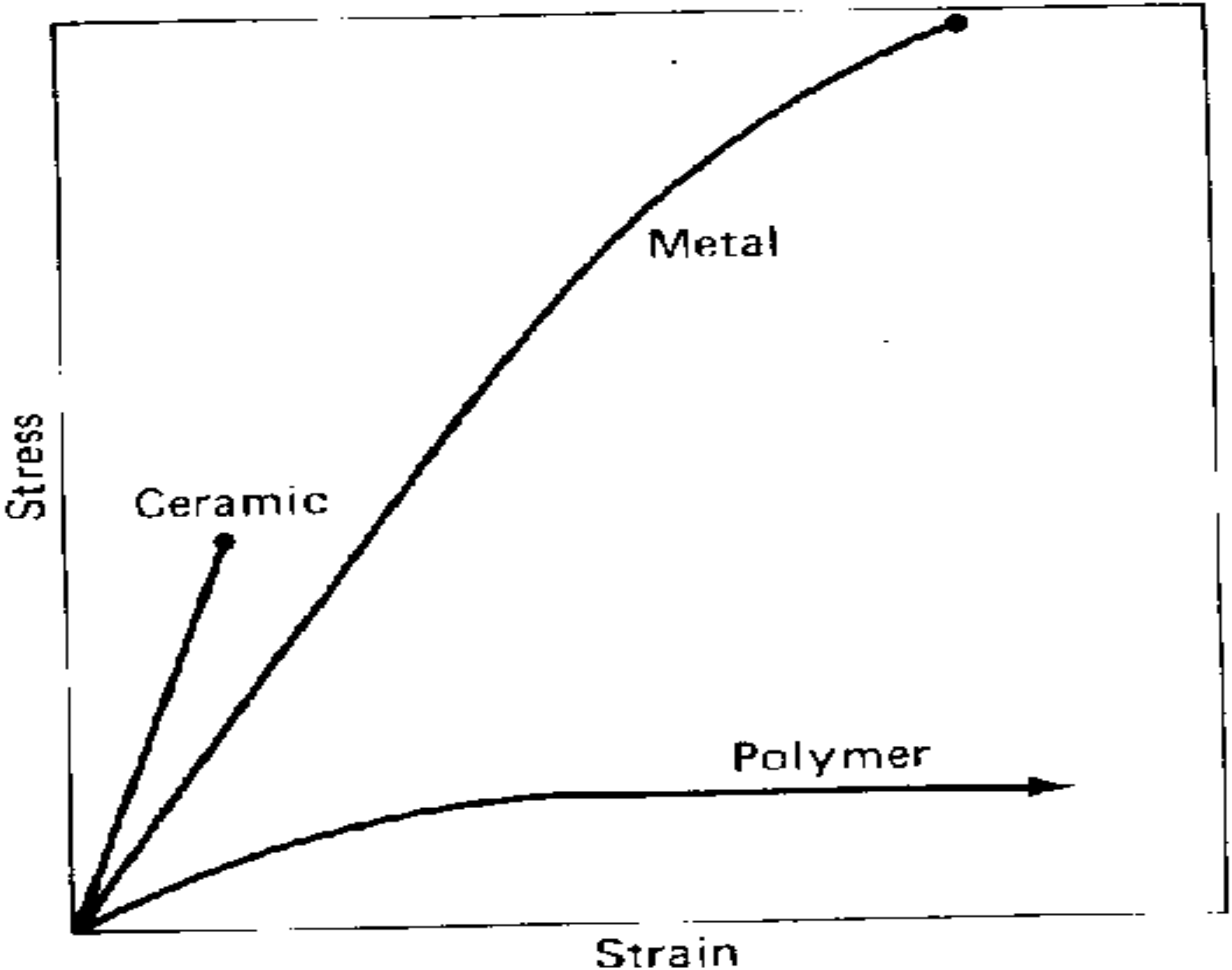
Metal
Ceramic
Polymer
Stress
Strain

Table 4. Properties of the Fibers, Matrix an
Interfacial Shear Strengths and Failure Modes

Material	Tensile Modulus (Gpa)	Tensile Strength (Gpa)	Intf.Shear Strength (Mpa)	Interfac Failur Mechani
AU4	234.4	3.58	37.2	Poor Interfac
AS4	234.4	3.58	68.3	Modera Interfac
AS4C	234.4	3.58	81.4	Strong Matrix
Epoxy	3.6	0.09	---	---

Composites (Laminants)

Reinforcement

Matrix

Interface (Adhesion of Primary Importance)

Materials Selection

Resin Type:

Acrylic

Epoxy

Vinyl Ester

Polyester

Materials Selection

Fiber Type:

Carbon

Nylon

Fiberglass

Aramid (Kevlar)

Polyethylene (Spectra)

Materials Form Selection

Fiber:

Unidirectional

Woven

Braided

Stockingette

Random

Fiber Materials

Principle load bearing component

High strength but brittle and notch-sensitive

Small diameter

Used in bundles called tows

Fiberglass

Ceramic fiber

Inexpensive raw materials: sand, coke, and coal

Fiberglass Types

E-glass (most common)
S-glass (stronger)
R-glass
D-glass
A-glass
M-glass

Fiberglass

Superior tensile strength

Strong but not stiff

Low cost

Tough

Perfectly elastic (Obeying Hooke' s Law)

Fiberglass

Very brittle

Highly notch-sensitive

Surface defects from dust, water, and touch greatly effect strength

Fiberglass

Very poor bond to polymer resins

Silane coupling agents used to improve adhesion but bond is still poor

Fiberglass Composites

Design flexibility

Low cost tooling

Lower cost materials

Heavier composites

Fiberglass Composites

Static fatigue loading will decrease ultimate strength

Fiber pull out, debond and delamination improves toughness by accumulating damage and dissipating fracture energy

Aramid Fiber

Trade Names:

Kevlar

Twaron

Technora

Aramid Fiber (Kevlar)

Aromatic polyamide thermoplastic polymer

Several grades

Aramid Fiber (Kevlar)

Low density

High specific strength

Good toughness

Damage tolerant

Aramid Fiber (Kevlar)

Low compressive strength

Absorbs moisture (up to 3%)

Poor adhesion to polymers

Spectra

Ultra high molecular weight polyethylene fiber (UHMPE)

Thermoplastic fiber

Spectra

Very high tensile strength

Low weight

Good abrasion resistance

Spectra

Very poor adhesion to polymers

Must be plasma treated to improve adhesion

Poor compressive strength

Carbon Fiber

Two dimensionally covalently bonded material

Carbon Fiber or Graphite

Precursor materials:

Polyacrylonitrile (PAN)

Rayon

Extruded pitch

Carbon Fiber or Graphite

Well oriented fiber

Stiff and strong in one plane

Higher modulus (stiffness)

Carbon Fiber or Graphite

Linear stress-strain behavior

Elastic to failure

Elongation to failure 2%

Carbon Fiber or Graphite

Creep resistant

Chemically inert

Negative coefficient of thermal expansion

Does not absorb moisture

Carbon Fiber or Graphite

Brittle

Expensive

Low impact strength

Carbon Fiber or Graphite

Surface treatments used to protect the fibers and to improve adhesion

Composite Properties Dependent On:

Fiber Type

Fiber Volume Fraction (V_f)

Fiber Orientation

Fiber Size

Fiber Adhesion to Resin

Resin Type

Process Variables

Reinforced Plastics (Low Strength)

Short Fibers

Low Fiber Volume Fraction

Poor Fiber Orientation

Weaker Fibers

Thermoset and Thermoplastic Resins

Composites (Medium Strength)

Longer Fibers

Moderate Fiber Volume Fraction

Good Fiber Orientation

Strong Fibers

Thermoset and Thermoplastic Resin

Advanced Composites (High Strength)

Long Fibers (7 cm minimum)

Maximized Fiber Volume (50-80%)

Superior Fiber Orientation (Fibers Aligned with the Axis of Stress

High Strength-High Stiffness Fibers (Carbon)

Thermoset and Thermoplastic Resins

High Performance Composites

Fiber orientation along the axis of stress

Fiber type strong and stiff

Fiber volume fraction 50-70%

Void content or air bubbles minimal

Resin type having good strength

Good compaction or consolidation of layers

High Performance Composites Design

Understanding laminate structural behavior vital

Adhesion of layers (plies) critical under multiple stress, strain, impact load conditions

Affected by fabrication method

Component Design

Surface finish

Fatigue life

Overall configuration

Scrap or rework potential

Overall Configuration Endoskeletal Sockets

Sockets with openings inherently weaker

Distal stresses are mostly out of the fiber plane

Ply Lay Up Design

Adhesion

Strength

Weight

Stiffness

Operating temperature

Toughness

Liquid Composite Molding Factors

Preform permeability

Preform volume fraction

Preform fiber orientation

Resin viscosity

Resin injection rate

Liquid Composite Molding Advantages

Excellent weight:performance ratios

Cheap tooling

Design flexibility

Noncorrosive parts

Parts consolidation

Vacuum Assisted Resin Transfer Molding (VARTM)

- Voids 0-2%
- Thick near net-shape
- Less post fabrication work (Peel ply removal and surface finishing)
- Good surface detail and accuracy
- Can mold in fittings, hardware and foam cores

Vacuum Assisted Resin Transfer Molding (VARTM)

Volume fractions to 68%

Less wasted material

Woven Fabric Composites

- More balanced properties in fabric plane
- Higher impact resistance than UD
- Higher out-of-plane strength
- Easier handling (reduction in labor)
- Reduced in-plane stiffness and strength

Matrix

"Weak link"- transfers load to fibers

Keeps fibers in orientation

Provides resistance to crack propagation and damage

Provides <u>ALL</u> interlaminar shear strength

Protects fibers from abrasion and chemical attack

Resin Flow Depends On

Resin viscosity

Preform permeability

Part thickness

Part shape

Resin Flow Depends On

Tow shape

Tow size

Fiber orientation

Stacking sequence

Fiber volume fraction

Resin Flow

Flatter is better

Changes in direction should be smooth and gentle

Minimum radii two or three times the thickness

Resin Flow

Dry fiber flow

Wet fiber flow

Racetracking

Open Weaves

Better wettability

Handling more difficult

Gap- space between yarns facilitates resin flow

Prosthetic Composites

Combinations of Unidirectional and Woven Carbon Fiber or Graphite Cloths or Braids

Prosthetic Composites

Recommendations:

Even and balanced reinforcement distribution

Small tow sizes (3K) and spaces between fiber tows to facilitate resin flow

Prosthetic Composites

Recommendations:

Maximum vacuum pressure

Low viscosity resin with 30 minute gel time

Prevent bag bridging by keeping it moist

Seal off resin reservoir

Prosthetic Composites

Recommendations:

Use a thin fiberglass inner layer to protect the patient from brittle failures (2 oz.)

Use layers of fiberglass to reduce compressive stress at fasteners

Use a layer of fiberglass to protect aluminum from contact with carbon

Prosthetic Composites

Recommendations:

Use an external layer of fiberglass to protect against expected impact damage

Use of hybrid cloths with fiberglass or Kevlar will reduce cost and increase impact resistance

Prosthetic Composites

Recommendations:

Sandwich unidirectional cloths between layers of plain weave cloths

Do not sandwich dissimilar materials because it will cause a delamination mode under fatigue loading

Prosthetic Composites

Recommendations:

Keep resin content as little as possible, the fiber should carry the load

Avoid resin-rich areas

Prosthetic Composites

Recommendations:

Use soft linings for protection from skin irritation and to facilitate reliefs

Use extra cloth over bony prominences and brims for extra relief areas

Prosthetic Composites

Recommendations:

Use large amounts of unitape for structures that are not cylindrical in nature such as syme prostheses and AFO's and orient some of them at $+45^0$ and -45^0 to reduce torsional deformation

Prosthetic Composites

Recommendations:

Grinding operations should be done with large amounts of air flow (dust collector)

Wet sand ground areas with 300 grit sand paper by hand

Clean interfaces with acetone to remove carbon residue

Prosthetic Composites

Recommendations:

Use large amounts of carbon fiber in off axis stress areas such as socket attachments and hip joint areas or anywhere high stress is expected

Prosthetic Composites

Recommendations:

Inspect structures regularly and modify layups accordingly

Spot repairs can be easily made

Prosthetic Composites

Recommendations:

Consider the main structure of the device first

Then deal with the cosmesis separately