

Stressors: What they are, where they come from, and how to stop them from hurting products

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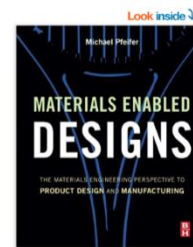
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- ~ Product design, manufacturing, quality improvement, failure analysis, root cause analysis
- ~ Metallurgy training: On-demand courses, webinars, on-site

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Topics covered

- " Products, components, joints, and reliability
- " Stressors that act on components and joints
- " Material degradation mechanisms
- " Sources of stressors
- " Evaluating effects of stressors

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Product is an assembly of components and joints



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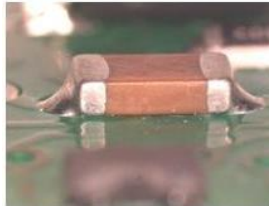
Joints

Non-mechanical joints between components

Weld



Solder joint



Adhesive



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Reliability

Materials in components/joints can degrade due to exposure to use conditions

- " Steel screws corrode when exposed to water
- " Some plastics become brittle when exposed to sunlight
- " Coatings on surfaces wear away

Too much degradation

- Component/joint stops functioning as required
- One or more product functions no longer meet specifications

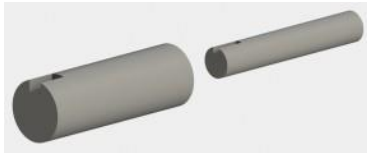
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Component performance, reliability, and cost

Engineer form and materials to meet performance and reliability requirements at low cost

Make materials and form trade-offs to optimize design

Component form
Shape, dimensions, features



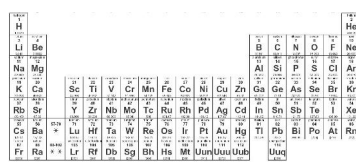
Component metals (materials)
Alloy, fabrication method, heat treatment, coating



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Materials engineering

Apply materials science (e.g. metallurgy) to engineering decisions and problems



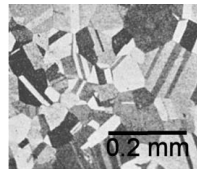
Composition

Properties

Mechanical, electrical, reliability,
fabrication, joining, physical, cost

Microstructure

Manufacturing
Processes



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Stressors

Conditions to which a component is exposed during handling, shipping, and product use

Stressors

- " Mechanical: static, dynamic, or cyclic loads; impact; rubbing
- " Thermal: Elevated temperature; Low temperature
- " Chemical: Gas, solvent, acid, or base
- " Electrochemical: corrosive environment
- " Radiation: UV lighting, sunlight, radiation for nuclear power plants
- " Electrical: voltage, current

Combination: hot gas

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Degradation mechanisms

Corrosion

Fatigue

Wear

Creep

Property change: embrittlement, loss of strength, color change, δ

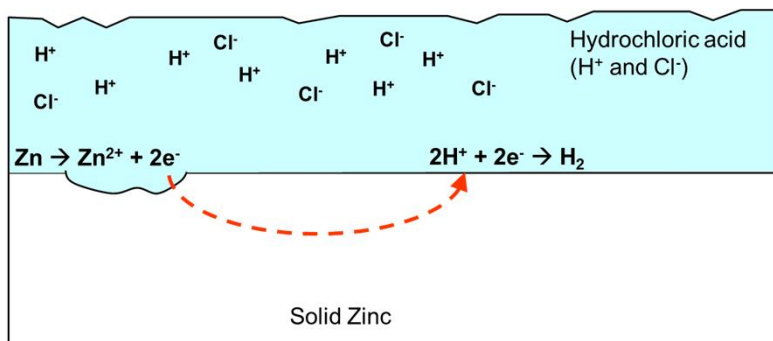
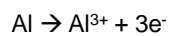
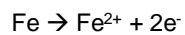
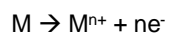
Electromigration

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Corrosion

Electrochemical reaction with oxygen, fluorine, chlorine, acids, bases, water, δ

- " Chemical changes of metal and environment
- " Electrical charges flow from metal to environment

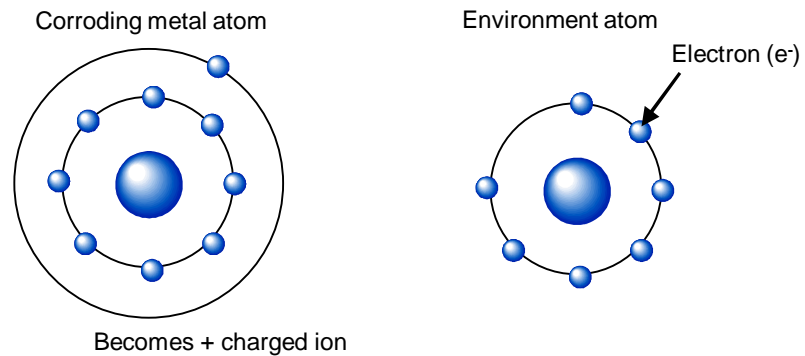


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Electrochemical reaction

Loss of electrons: oxidation

Gaining electrons: reduction



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Types of corrosion

1. Uniform corrosion
2. Galvanic corrosion
3. Intergranular corrosion
4. Dealloying
5. Pitting corrosion
6. Stress corrosion cracking
7. Crevice corrosion

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Fatigue

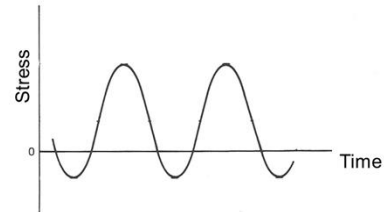
Progressive, localized, and permanent damage arising from repeated stress or strain

Results in crack formation and growth

“ Occurs even though average (nominal) stress < yield strength

Three requirements for fatigue to occur

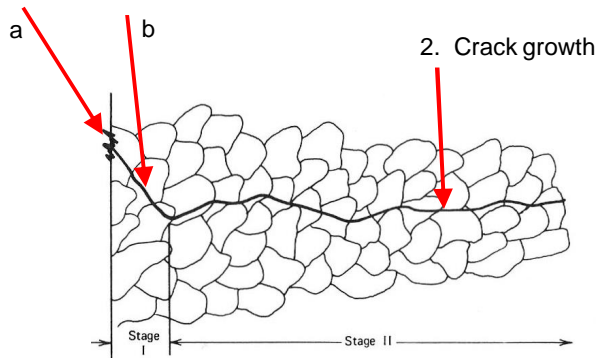
- “ Cyclic stress or strain
- “ Tensile in nature
- “ Localized stress exceeds metal's yield strength



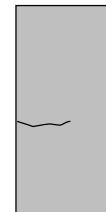
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Three stages of fatigue failure

1. Crack initiation
 - a. Microcracks form
 - b. Microcracks grow and coalesce to form larger cracks

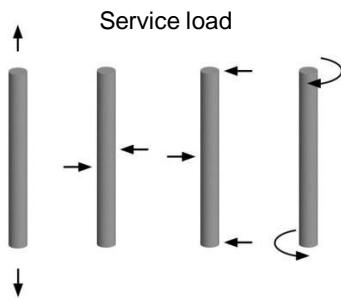


3. Fracture: Cross-section of intact material too small to support applied load

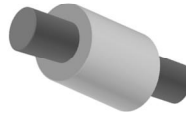


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Sources of stress



Differential thermal expansion



Vibration

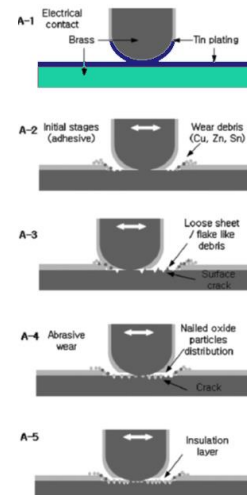
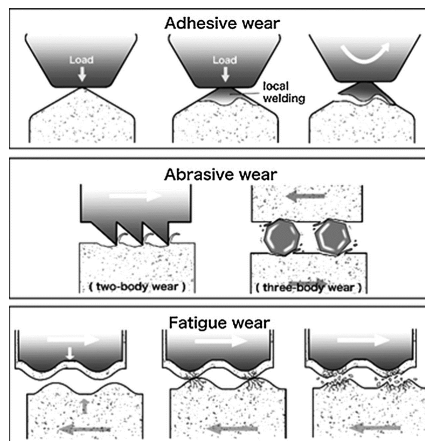


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Wear

Friction that results in material removal

- “ Rolling, sliding, and impact
- “ Particles and fluids

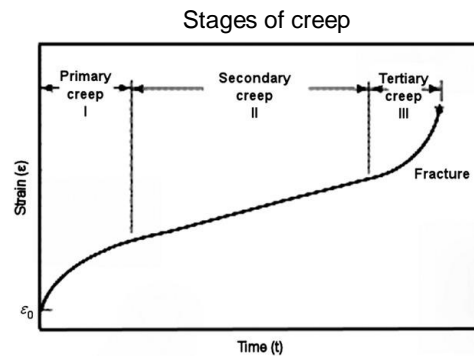


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Creep - Metals

Time dependent deformation at elevated temperatures

~ $0.3 - 0.5 T_m$, in K



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Creep - Polymers

Time dependent deformation

Can occur at room temperature for some polymers

Environmental degradation can hasten creep

~ UV, solvents, water, δ

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Property changes due to environment exposure

Microstructure changes that result in property changes

Metals

- " Elevated temperatures can lead to formation or growth of embrittling phase
- " Loss of ductility, cracking and fracture at stresses less than a material's yield strength

Polymers

- " Ultraviolet radiation from the sun, acids, and organic solvents can break up molecules or alter molecules
- " Loss of ductility, cracking and fracture at stresses less than a material's yield strength
- " Reduce strength
- " Appearance change

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Sources of stressors

Component/joint functionality
 Use environment
 Interactions with other components/joints
 Minor abuse
 Misuse

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Sources of stressors - Component/joint functionality

Stressors related to the purpose of the component/joint

Mechanical loads



Heat



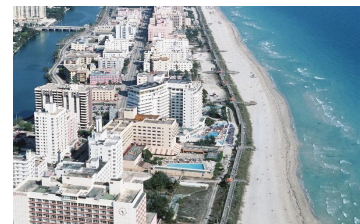
Current and voltage



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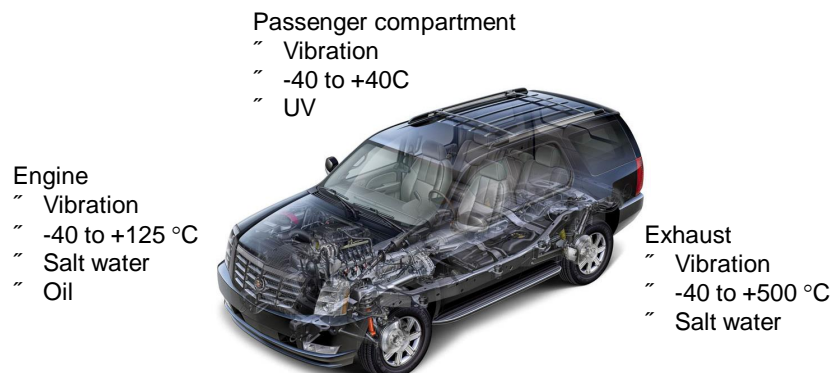
Sources of stressors – Use environment

Temperature
Chemicals
Gases
Radiation
Body fluids



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Use environment stressors may depend on location within product



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Sources of stressors - Interactions with other components/joints

Components in contact: wear, fatigue, corrosion

Components not in contact: outgassing, radiation

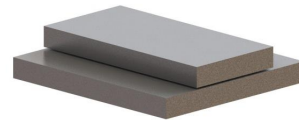
Wear



Thermal expansion



Crevice corrosion
Galvanic corrosion



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Sources of stressors - Minor abuse

Normal, reasonable mishandling

Drop phone



Potholes



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Misuse

Stressors far exceed typical use conditions

Not included in design requirements considerations

“ There is a reasonable outer limit



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Identifying stressors

First three steps critical

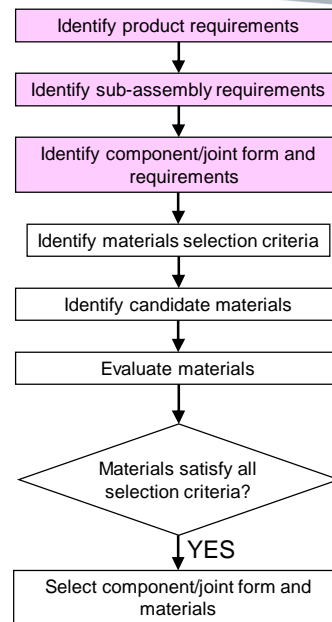
“ Need thorough and accurate information, as soon as possible

Tier1 or government project

“ Depend on design requirements document
 “ Industry standards (SAE, IPC, UL, NEMA, etc.)
 “ govt. regulations
 “ Internal reviews . FMEA

OEM

“ Industry standards, govt. regulations
 “ Internal reviews . FMEA



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Example: Missing design requirements

Electronic module immersed in transmission fluid

Missing requirements about chemistry of fluid in contact with module

- " Plastic? Compatibility with fluid
- " Lead sealant material? Compatibility with fluid



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Evaluating effects of stressors – reliability testing

Expose materials to stressors and evaluate the response

- “ Type and amount of degradation: composition, microstructure, mass, $\bar{\sigma}$
- “ Effects on properties and performance: strength, adhesion, appearance, $\bar{\sigma}$



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Product testing and materials testing

Product testing

- “ Test sample: product
- “ Evaluate product performance vs. exposure to use conditions

Materials testing

- “ Test sample: simulated component/joint
- “ Evaluate properties, performance, and signs of materials degradation

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Product testing vs. materials testing

	Pros	Cons
Product testing	<ul style="list-style-type: none"> " Closer to application " Uncover unanticipated interactions and responses " Less expensive 	<ul style="list-style-type: none"> " Need complete assembly " Risk of delays if failures occur
Materials testing	<ul style="list-style-type: none"> " Generate data early → faster design decisions " Test multiple designs (materials and form) " Generate design data library 	<ul style="list-style-type: none"> " Extra cost

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Materials test specimens

Fabricate from stock or components

Should be same materials as intended

Stock materials, e.g.
sheet, bar, and tube



Component



Coating



Joining material
and joint



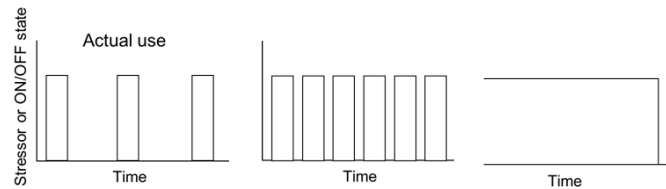
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Accelerated stress testing

Can take a long time to generate data using actual use conditions and usage rate

Increase use rate

- " Constant exposure
- " Faster on/off cycling



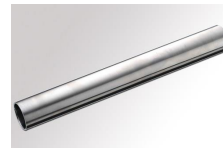
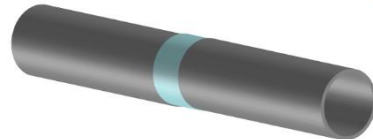
Overstress: Increase stressor severity

- " Examples: Increase temperature, oxidant concentration, or electrical current
- " Must understand effects of accelerated conditions on materials. Don't cause degradation or failure modes that do not correspond to normal use

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Example: Tube weld joint

- " Test sample: Welded samples of different steel alloys
- " Stressors: Fatigue
- " Attributes to measure: Cycles to failure, weld strength
- " Measurement technique: microscope, NDT, tensile testing



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Example: non-stick coating for cooking pan

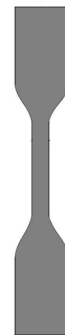
- " Test sample: Apply coating over pan material
- " Stressors: Wear, scratching, heat, 25 to 200 °C cycle
- " Attributes to measure: Adhesion, amount of wear, scratch depth, non-stick behavior
- " Measurement technique: microscope, ASTM D4541 Pull-Off Strength of Coatings, coating surface energy



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Example: Plastic component exposed to solvent

- " Test sample: tensile test specimen made of plastics being considered
- " Stressors: soak in solvent
- " Attributes to measure: strength and ductility
- " Measurement technique: tensile test



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Example: Tanker coating

Permeation of coating by liquid food chemical

Immerse coated steel plaques in chemical

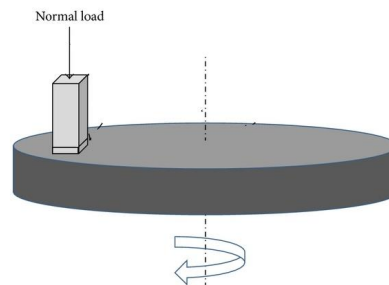
- " Different coatings and thicknesses
- " 75 °F, 90 °F, 110 °F



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Example: Scrapping/cutting component

- " Test sample: Different alloys, heat treatments, and coatings
- " Test conditions: Repeated scraping over materials seen during use
- " Attributes to measure: Amount of wear (mass, thickness) vs. number of cycles or test time
- " Measurement technique: scale, micrometer, microscope



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Q & A