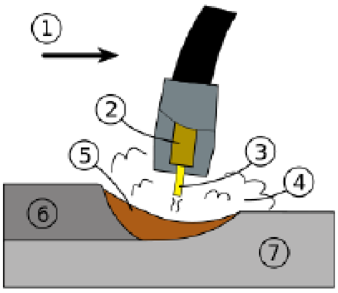
Selection of materials and welding processes:

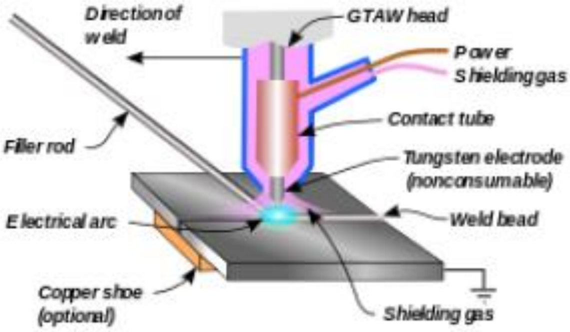
Welding is a common process for joining metals using a large variety of applications

- **Gas metal arc welding** (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt and join .

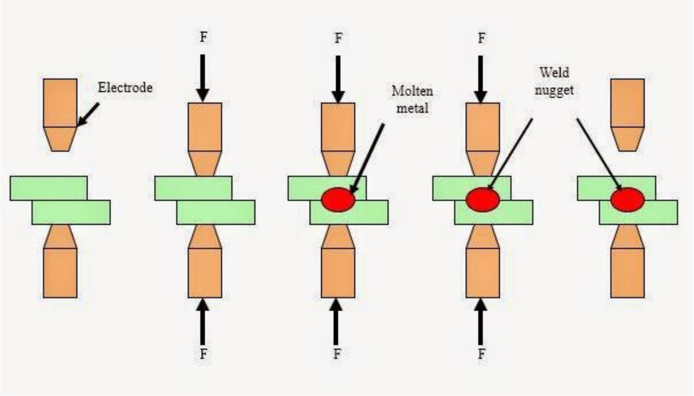


GMAW weld area. (1) Direction of travel, (2)Contact tube, (3) Electrode, (4) Shielding gas, (5)Molten weld metal, (6) Solidified weld metal, (7)Workpiece

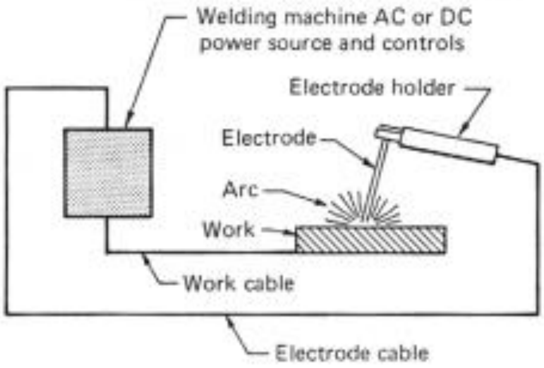
- **TIG** : Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area and electrode is protected from oxidation or other atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used



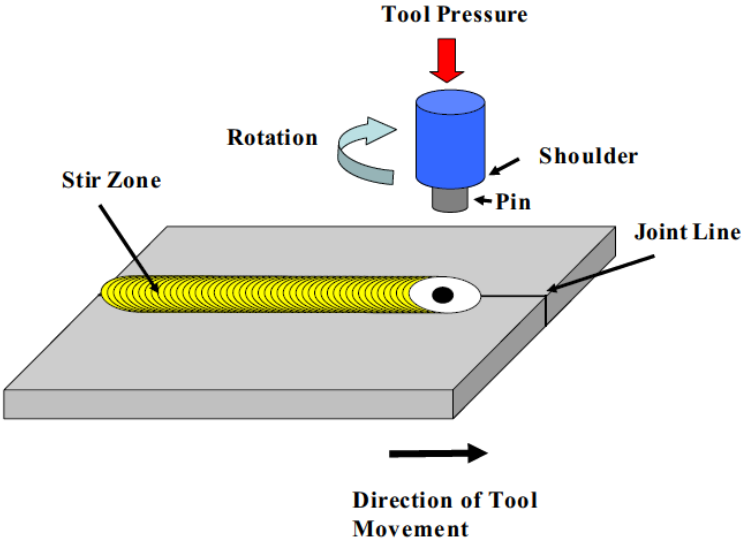
- **Spot welding :** Resistance **spot welding** (RSW) is a process in which contacting metal surface points are joined by the heat obtained from resistance to electric current. It is a subset of electric resistance welding. Spot welding can be performed on metals from 0.5 to 3 mm.



- Stick welding is technically defined as "Shielded Metal Arc Welding". The term "stick welding" is a common slang term that the welding industry has adopted becuse the electrode that welds the metal comes in the form of a "Stick". Stick welding is a form of welding that uses electricity to melt a metal filler rod/electrode/stick (electrode is the proper term) that melts both the metal joint and electrode all at once to fuse two pieces of metal together and fill the joint with filler metal at the same time. Stick and TIG welding use the same Constant Voltage power supply and a Stick welder can be adapted to TIG Weld just by adding a torch set-up.



- Friction Stir Welding (FSW), a solid state joining process. FSW, does not involve exceeding the melting temperature of the metal that is to be processed. Friction stir welding process involve joining the materials by plasticizing and then eventually consolidating the material around the joint line of the weld. First the base metal pieces which have to be joined are held suitable clamping force so that the work pieces do not fly away while welding. A rotating steel pin pierces a hole in the joint line between the workpieces to a predetermined depth and moves forward in the direction of the weld as shown in Figure



Friction stir welding process involve joining the materials by plasticizing and then eventually consolidating the material around the joint line of the weld. First the base metal pieces which have to be joined are held suitable clamping force so that the work pieces do not fly away while welding. A rotating steel pin pierces a hole in the joint line between the workpieces to a predetermined depth and moves forward in the direction of the weld as shown in Figure . FSW typically characterized as being comprised of three primary zones: the heat-affected zone (HAZ), the thermo mechanically affected zone (TMAZ), and the dynamically recrystallized zone (DXZ) or weld nugget as shown in Figure

Weldability of aluminum alloys

Weldability of some aluminum alloys is an issue with the fusion welding processes such as metal inert gas welding (MIG), tungsten inert gas welding (TIG) etc . The 2000 series, 5000 series, 6000 series and 7000 series of aluminum alloys have different weldabilities. The 2000 series of aluminum alloys have poor weldability generally because of the cooper content which causes hot cracking and poor solidification microstructure and porosity in the fusion zone so the fusion welding processes are not very suitable for these alloys. The 5000 series of aluminum alloys with more than 3% of Mg content is susceptible to cracking due to stress concentration in corrosive environments, so high Mg alloys of 5000 series of aluminum should not be exposed to corrosive environments at high temperatures to avoid stress corrosion cracking. All the 6000 series of aluminum are readily weldable but are some times susceptible to hot cracking under certain conditions. The 7000 series of aluminum are both weldable and non-weldable depending on the chemical composition of the alloy.

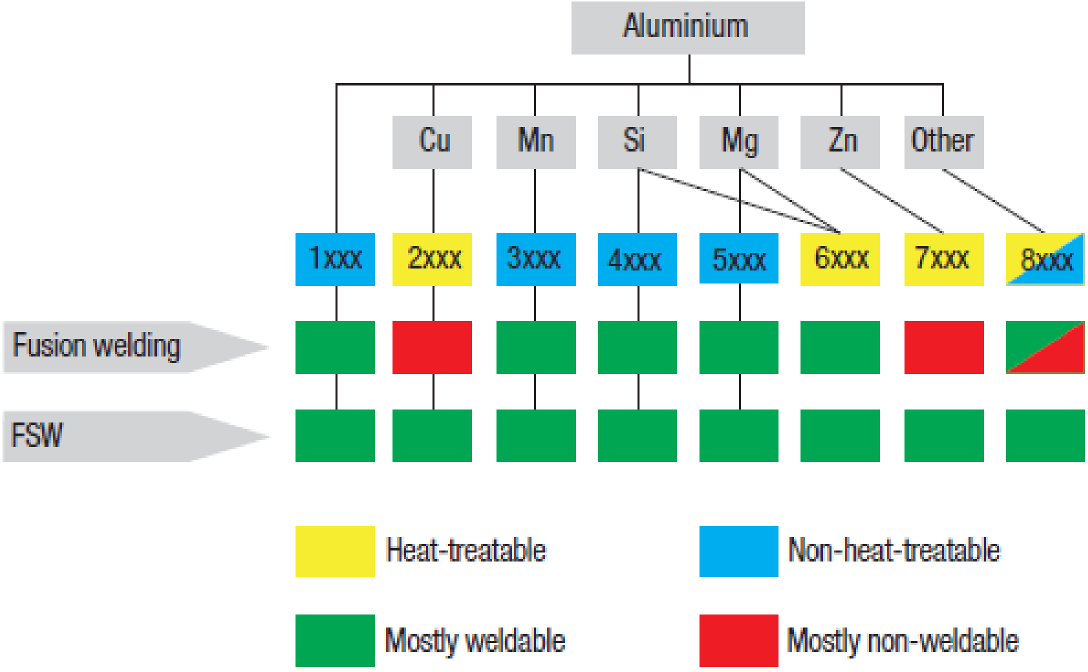
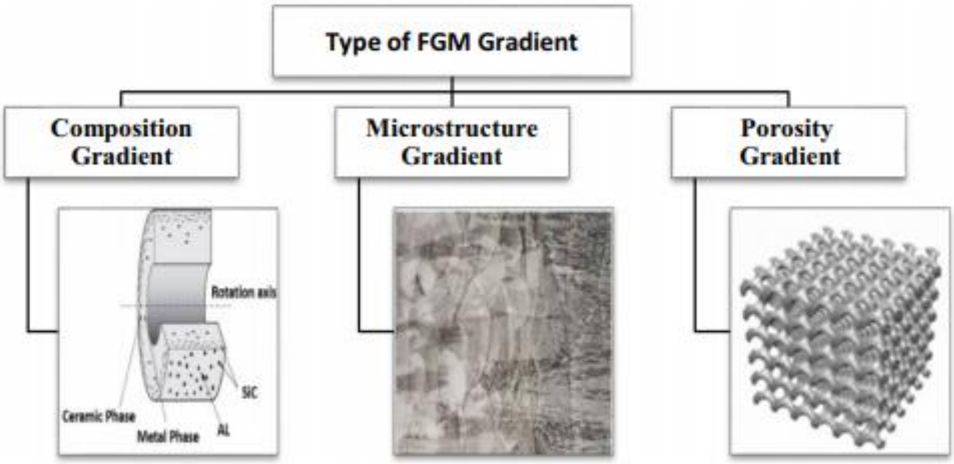


Fig Weldability of various aluminum alloys according to ASTM.

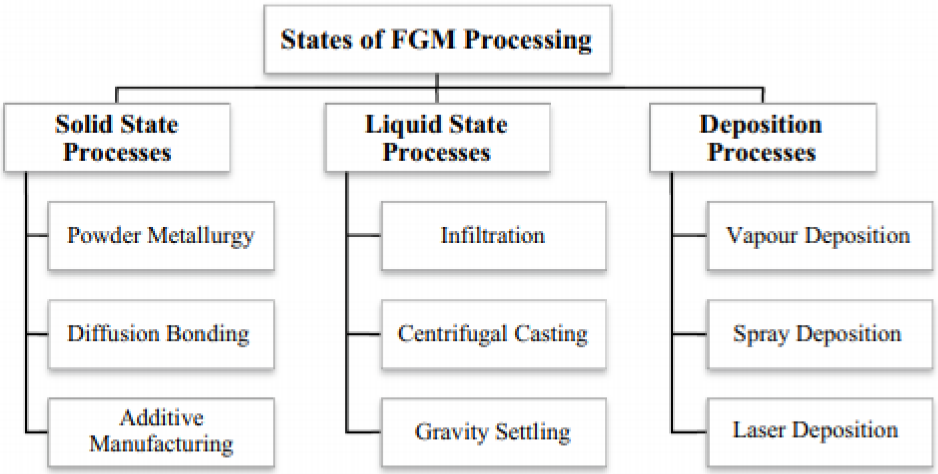
Functionally graded materials :

Functionally graded materials (FGMs) are novel materials whose properties change gradually with respect to their dimensions. It is the advanced development of formerly used composite materials and consists of two or more materials in order to achieve the desired properties according to the application where an Functionally graded materials is used. Functionally graded materials have obtained a great attention of researchers in the past decade due to their graded properties at every single point in various dimensions. The properties of an Functionally graded materialsare not identical to the materials that constitute it.

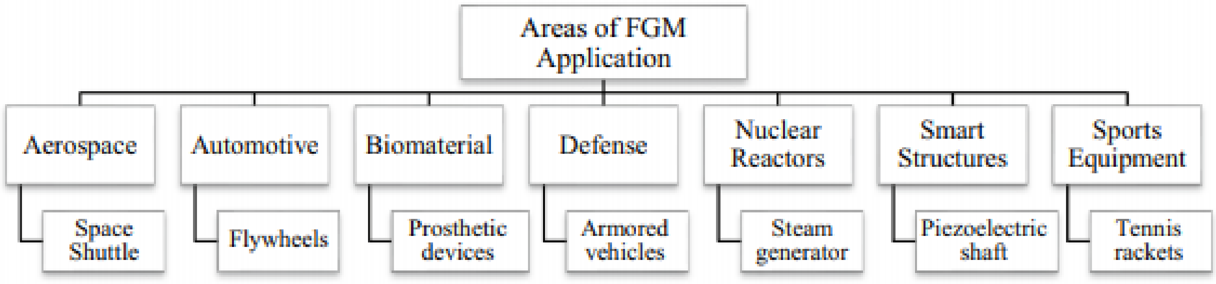
FGMs can be generally classified into three different groups of gradient: **composition, microstructure, and porosity** as shown in Fig. . The composition type of FGM gradient depends on the composition of the material, which varies from one substance to another, leading to different phases with different chemical structures. These different phases of production depend on the synthetic quantity and the conditions under which the reinforced materials are produced . During the solidification process, the microstructure type of the FGM gradient can be achieved so that the surface of the material is extinguished. In this type, the core of the same material can cool slowly, helping generate different microstructures from the surface to the inside of the material. With the changes in the spatial location in the bulk material, the porosity type of FGM gradient in the material changes . Powder particle sizes can be measured by varying the pore particle sizes used during gradation at different positions in the bulk material



Thin FGMs are manufactured by different methods like physical vapor deposition (PVD) , chemical vapor deposition (CVD) , thermal spray deposition and self-propagating high temperature synthesis (SHS) techniques like laser cladding , while “Bulk FGMs” are manufactured by powder metallurgy , centrifugal casting , solid freeform techniques , gravity settling.



Application of FGM : FGMs can be classified into biomaterial , aerospace , automotive , defense , cutting tools, nuclear reactor , smart structure , turbine blades and sports equipment . Figure below represent an overview of the classification according to the major fields of applications.



Material property charts (Ashby charts):

The charts in this booklet summarize material properties and process attributes. Each chart appears on a single page with a brief commentary about its use. They can be used in three ways:

(a) to retrieve approximate values for material properties
(b) to select materials which have prescribed property profiles
(c) to design hybrid materials.

The collection of process charts, similarly, can be used as a data source or as a selection tool.. Any other can be created easily using the CES software.

Material classes and class members The materials of mechanical and structural engineering fall into the broad classes listed in this Table. Within each class, the Materials Selection Charts show data for a representative set of materials, chosen both to span the full range of behaviour for that class, and to include the most widely used members of it. In this way the envelope for a class (heavy lines) encloses data not only for the materials listed here but virtually all other members of the class as well. These same materials appear on all the charts.

CES Selector for Materials Selection software:

Link :https://www.youtube.com/watch?v=E8ZuOAusTxg

Chart 1: Young's modulus, E and Density, ρ

This chart guides selection of materials for light, stiff, components. The moduli of engineering materials span a range of 10^7; the densities span a range of 3000. The contours show the longitudinal wave speed in m/s; natural vibration frequencies are proportional to this quantity. The guide lines show the loci of points for which

- $E/\rho = C$ (minimum weight design of stiff ties; minimum deflection in centrifugal loading, etc)
- $E^{1/2}/\rho = C$ (minimum weight design of stiff beams, shafts and columns)
- $E^{1/3}/\rho = C$ (minimum weight design of stiff plates)

The value of the constant C increases as the lines are displaced upwards and to the left; materials offering the greatest stiffness-to-weight ratio lie towards the upper left hand corner. Other moduli are obtained approximately from E using

- $\nu = 1/3$; $G = 3/8E$; $K \approx E$ (metals, ceramics, glasses and glassy polymers)
- or $\nu \approx 0.5$; $G \approx E/3$; $K \approx 10E$ (elastomers, rubbery polymers)

where ν is Poisson's ratio, G the shear modulus and K the bulk modulus.

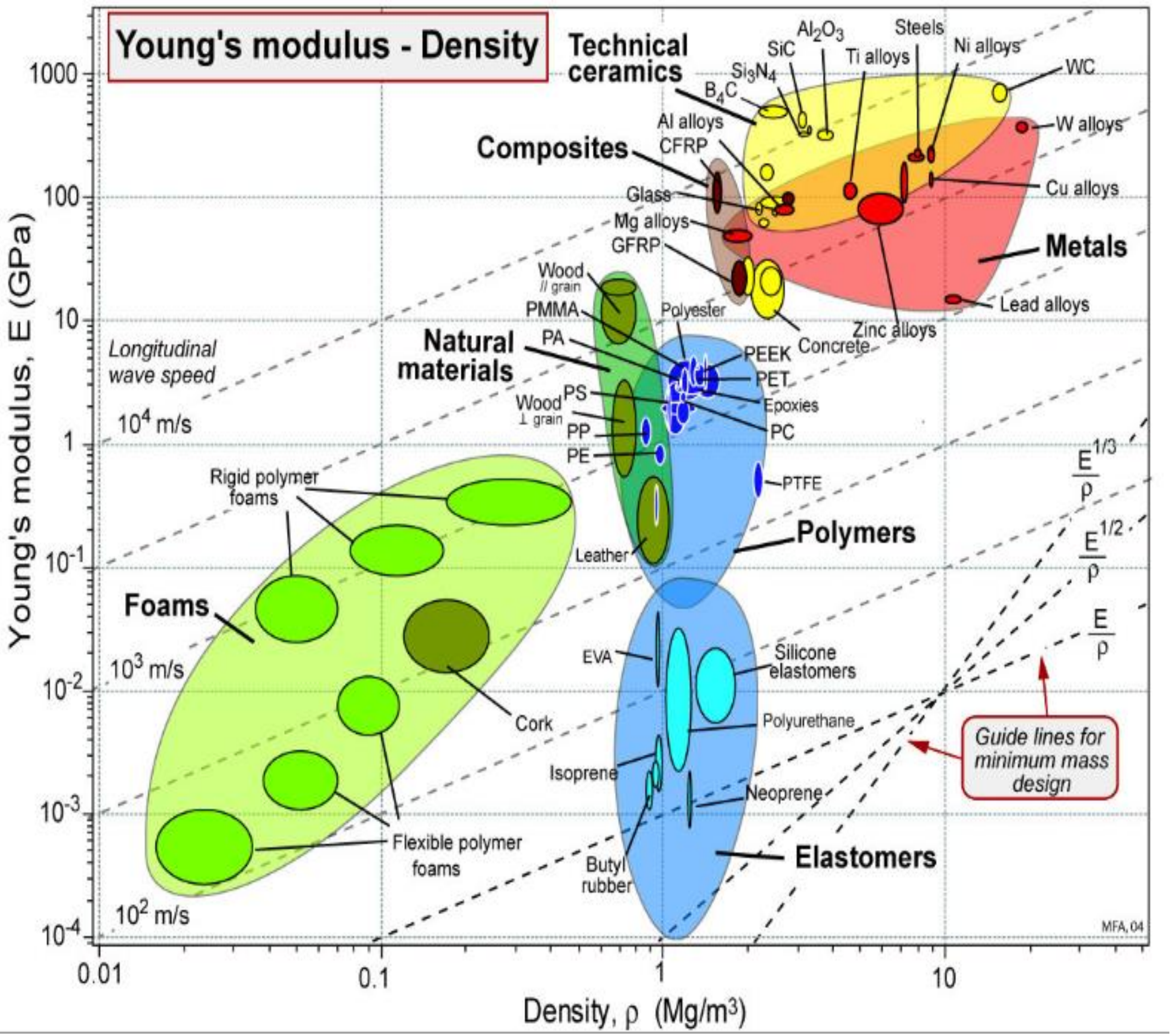


Chart 2: Strength, σ_f, against Density, ρ

This is the chart for designing light, strong structures. The "strength" for metals is the 0.2% offset yield strength. For polymers, it is the stress at which the stress-strain curve becomes markedly non-linear - typically, a strain of abut 1%. For ceramics and glasses, it is the compressive crushing strength; remember that this is roughly 15 times larger than the tensile (fracture) strength. For composites it is the tensile strength. For elastomers it is the tear-strength. The chart guides selection of materials for light, strong, components. The guide lines show the loci of points for which:

(a) $\sigma_f/\rho = C$ (minimum weight design of strong ties; maximum rotational velocity of disks)

(b) $\sigma_f^{2/3}/\rho = C$ (minimum weight design of strong beams and shafts)

(c) $\sigma_f^{1/2}/\rho = C$ (minimum weight design of strong plates)

The value of the constant C increases as the lines are displaced upwards and to the left. Materials offering the greatest strength-to-weight ratio lie towards the upper left corner.

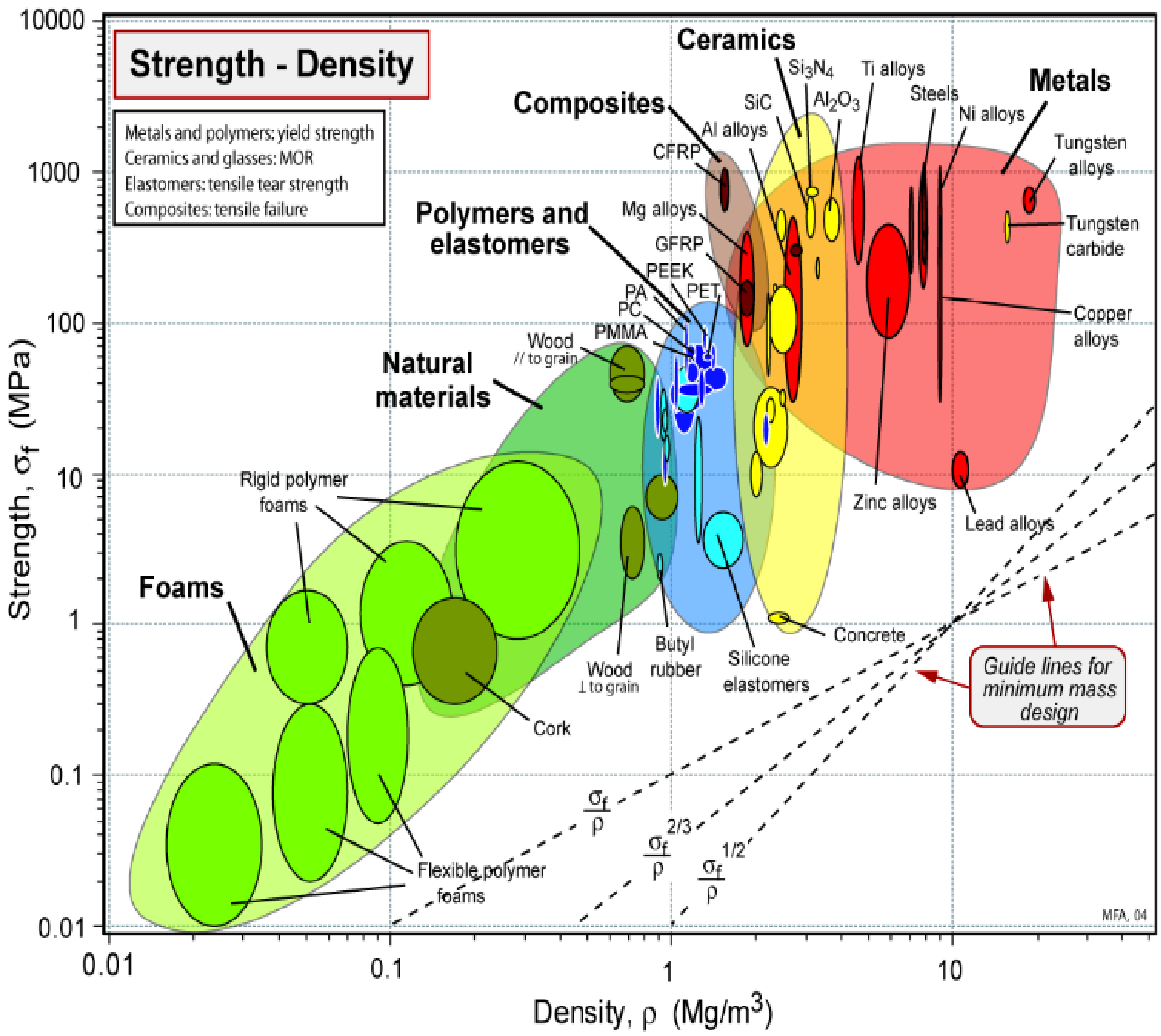


Chart 3: Young's modulus, E, against Strength, σ_f

The chart for elastic design. The "strength" for metals is the 0.2% offset yield strength. For polymers, it is the 1% yield strength. For ceramics and glasses, it is the compressive crushing strength; remember that this is roughly 15 times larger than the tensile (fracture) strength. For composites it is the tensile strength. For elastomers it is the tear-strength. The chart has numerous applications among them: the selection of materials for springs, elastic hinges, pivots and elastic bearings, and for yield-before-buckling design. The contours show the failure strain, σ_f / E. The guide lines show three of these; they are the loci of points for which:

(a) $\sigma_f /E = C$ (elastic hinges)

(b) $\sigma_f^2 /E = C$ (springs, elastic energy storage per unit volume)

(c) $\sigma_f^{3/2}/E = C$ (selection for elastic constants such as knife edges; elastic diaphragms, compression seals)

The value of the constant C increases as the lines are displaced downward and to the right.

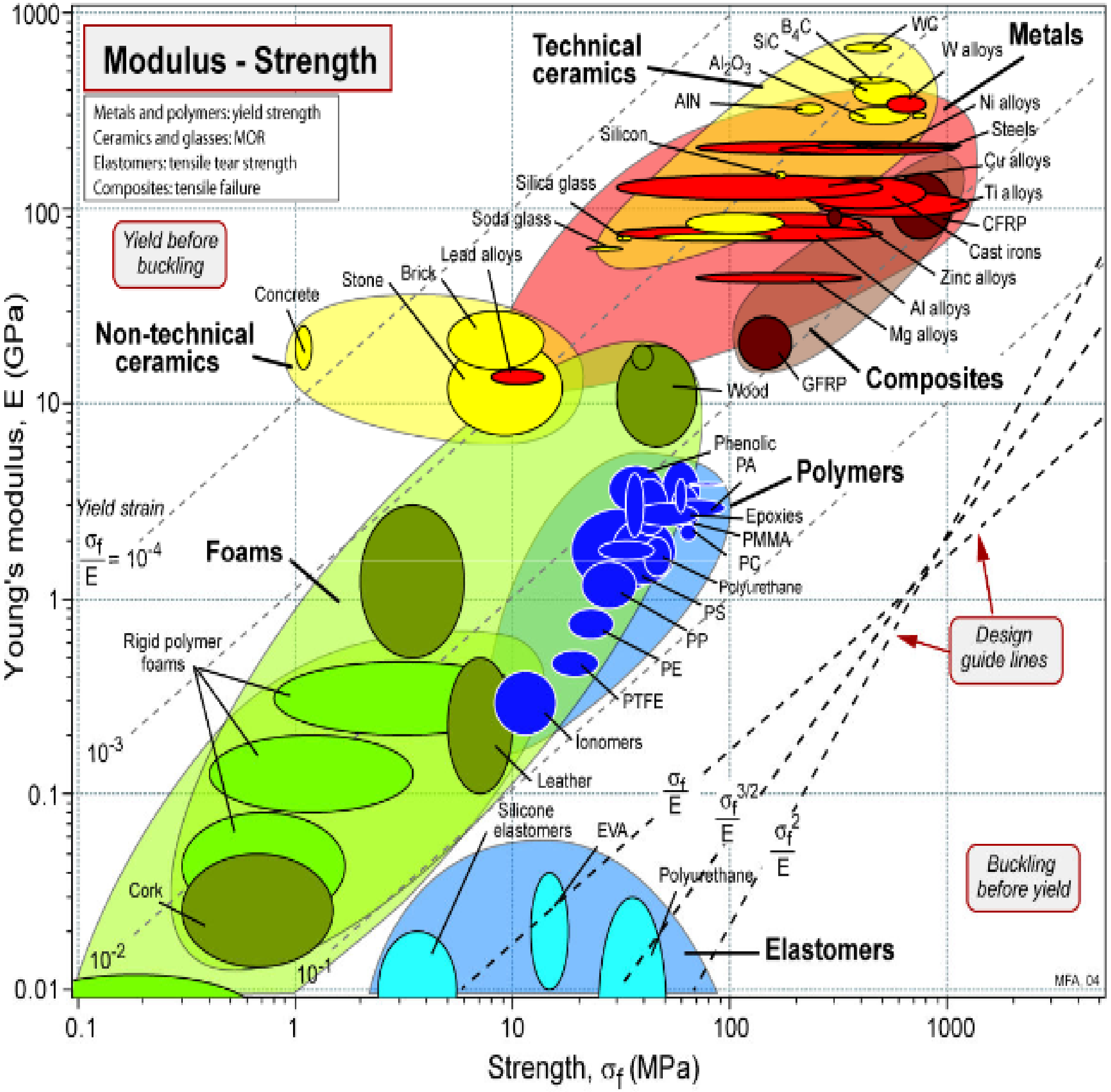


Chart 4: Specific modulus, E/ρ, against Specific strength, σ_f/ρ

The chart for specific stiffness and strength. The contours show the yield strain, σ_f/E. The qualifications on strength given for Charts 2 and 4 apply here also. The chart finds application in minimum weight design of ties and springs, and in the design of rotating components to maximize rotational speed or energy storage, etc. The guide lines show the loci of points for which

(a) $\sigma_f^2/E\rho = C$ (ties, springs of minimum weight; maximum rotational velocity of disks)

(b) $\sigma_f^{2/3}/E\rho^{1/2} = C$

(c) $\sigma_f/E = C$ (elastic hinge design)

The value of the constant C increases as the lines are displaced downwards and to the right.

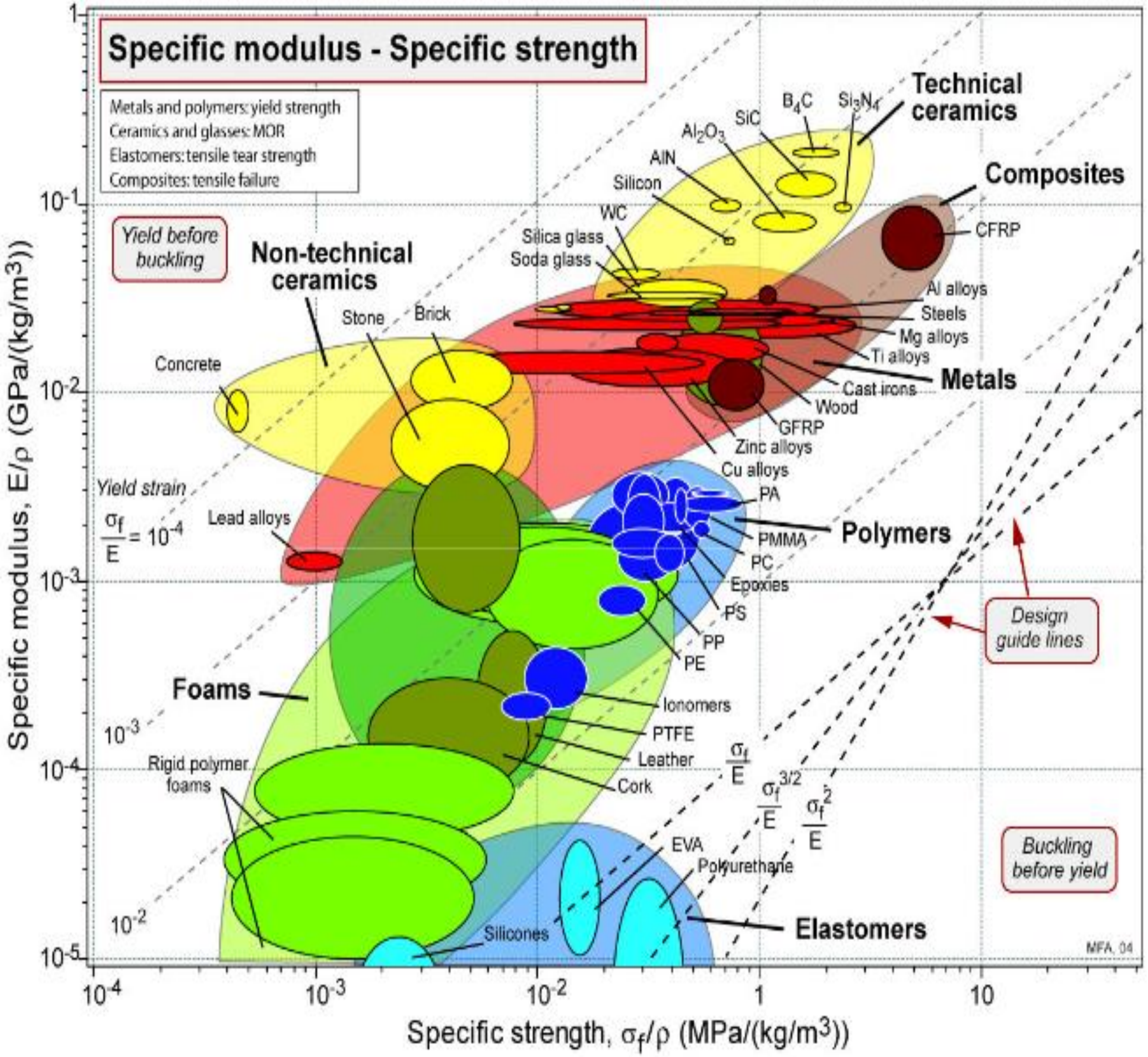


Chart 5: Fracture toughness, K_{Ic}, against Young's modulus, E

The chart displays both the fracture toughness, K_{1c}, and (as contours) the toughness, $G_{1c} \approx K_{1c}^2 / E$. It allows criteria for stress and displacement-limited failure criteria (K_{1c} and K_{1c} / E) to be compared. The guidelines show the loci of points for which

(a) $K_{Ic}^{\,2} / E = C$ (lines of constant toughness, G_c; energy-limited failure)

(b) $K_{Ic} / E = C$ (guideline for displacement-limited brittle failure)

The values of the constant C increases as the lines are displaced upwards and to the left. Tough materials lie towards the upper left corner, brittle materials towards the bottom right.