MATERIAL SELECTION

Bibliography:

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Metals Handbook, Volume 20, *Material Selection and Design,* ASM International, 10th ed., 1990.

Ashby, M. F., *Materials Selection in Mechanical Design*, Pergamon Press, 1992.

Ashby, M. F., *Materials Selection in Mechanical Design – Materials and Process Selection Charts*, Pergamon Press, 1992.

Note, a few of the Ashby charts are found in various machine design textbooks, including Juvinall.

Poli, C., *Design for Manufacturing, a Structured Approach,* Butterworth Heinemann, 2001.

Material Selection

With over 100,000 engineering materials, material selection is a very complex process that requires concurrent iterations with the design process itself. Not only must the material be able to handle the chemical, mechanical and thermal loads, but parts must be economically produced from the material. As such, not only is a thorough understanding of the required properties necessary, but so is a good knowledge of various manufacturing processes. And ultimately, availability of the material may be the deciding factor in the decision.

Machine design is an iterative process involving an ever improving level of definition to geometry and material. At the early stages of design, only conceptual ideas are developed. For example, the conceptual design may require identifying viable methods of transmitting mechanical power. Various concepts should be considered such as gears, pulleys, chains, hydraulics, etc. At this stage, a very general understanding of thermal and mechanical limitations of materials is all that is required.

The next stage of design is “Configuration Design”. At this stage, the basic layout of the design is determined. The basic elements should be defined and their respective location known. For example, if the down select for a method of transmitting power transmission was to use gears, then the key components should be identified (gears, shafts, bearings, etc.). At this stage, the general type of material should be chosen. Using charts such as those developed by Ashby can help identify the general type of material best suited to specific design criteria. The general category can be *aluminum alloys*, or *steel*, or *thermoplastic*, etc. This level of detail is usually sufficient for the Configuration Design stage. By knowing the general material category, material properties of stiffness, thermal stability, approximate strength, etc., should be sufficiently well known.
During the Configuration Design stage, the engineer should make a comprehensive list of the material requirements:

Define the Criteria

As with the design process itself, it is important to define what the material must do (criteria). You must understand the load and environment and their potential effects. The designer must define the chemical, thermal and mechanical requirements, and any other requirements that affect product success:

Keep in mind the effects of:

Low Temperature

Ductile-to-Brittle Transition – most metals (except FCC structures) become brittle at "low" temperature. Depending upon the material, "low" may be very cold, or it may actually be above room temperature.

Thermal Stress – Thermal cycling between higher and lower temperatures can induce stress in the part if there are:

- Thermal gradients
- Inclusions or precipitates that have different coefficient of thermal expansion than the bulk metal (CTE mismatch).
- External physical constraint.

Elevated Temperature

- increases the rate of chemical reactions (such as corrosion)
- makes metals more reactive
- increases diffusion rates
- decreases elastic stiffness and strength
- may allow creep
- may cause recrystallization and grain growth in cold worked parts
- may cause phase changes including dissolving strengthening precipitates

Mechanical Loading

- Fatigue – high cycle or low cycle
- Impact loads
- Static overloads
- The existence of cracks or similar defects

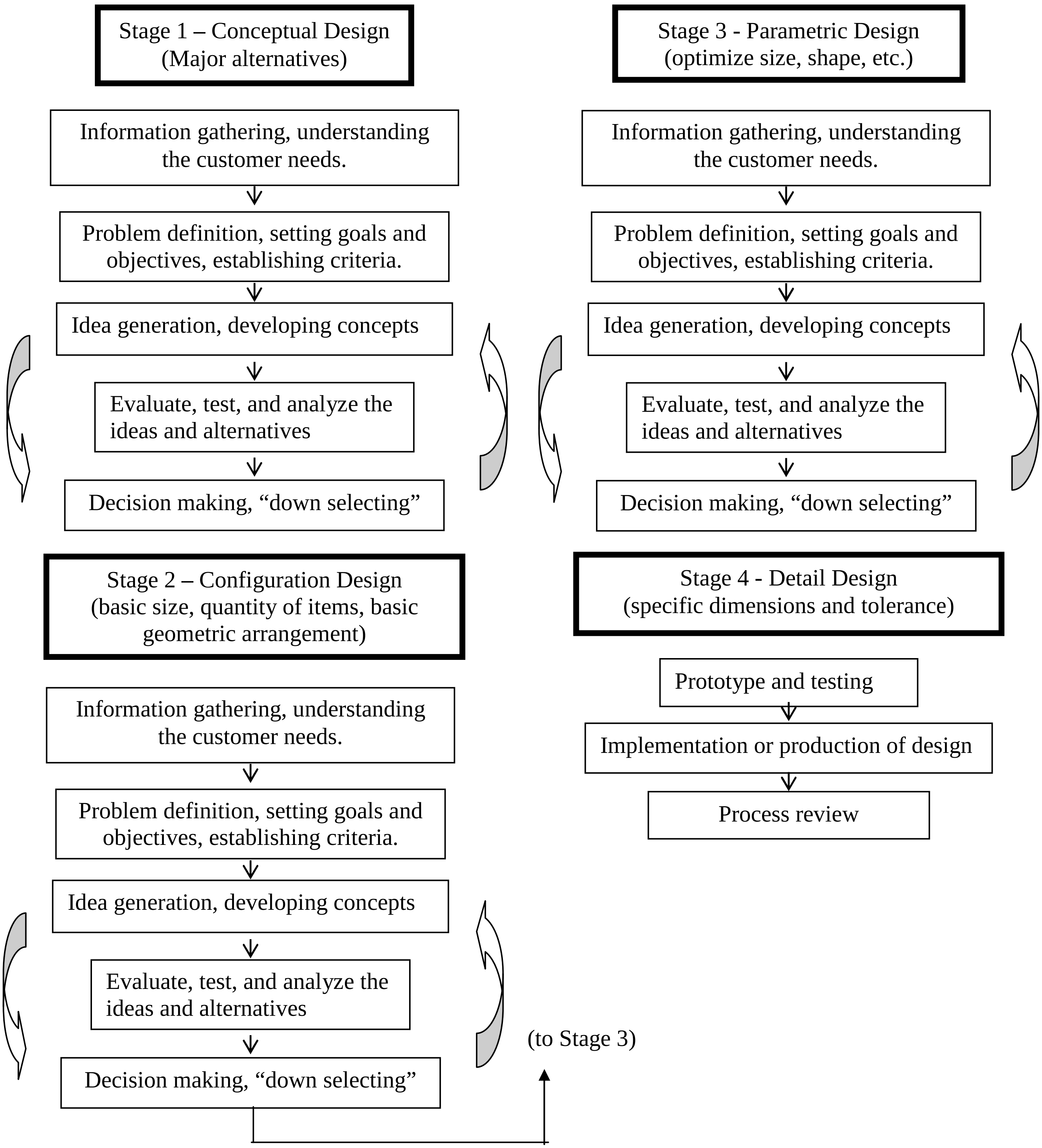
Chemical Environment

- Corrosion - pitting, crevice, galvanic corrosion, exfoliation, uniform, stress corrosion cracking, hydrogen embrittlement, etc.
- Sunlight and UV – will UV light be present (it can degrade many polymers)?
- Moisture – water, salt water, etc. can be particularly damaging to polymers and alloys

The above list is meant to help you be aware of the numerous conditions that a single part may experience.

After the material requirements have been fully defined, Parametric Design may begin. The objective is to develop details with respect to geometry and material. Select a specific material including heat treat and cold/hot worked. Selection of specific material should be done concurrently with defining specific geometry to optimize the design.

The final design stage is the detailed design. This is where specific dimensions and tolerances are determined. From a design stand point, analysis should be performed to assure the product will function properly given the dimensional and material tolerances.


Stage 1 – Conceptual Design
(Major alternatives)
Information gathering, understanding the customer needs.
Problem definition, setting goals and objectives, establishing criteria.
Idea generation, developing concepts
Evaluate, test, and analyze the ideas and alternatives
Decision making, "down selecting"
Stage 2 – Configuration Design
(basic size, quantity of items, basic geometric arrangement)
Information gathering, understanding the customer needs.
Problem definition, setting goals and objectives, establishing criteria.
Idea generation, developing concepts
Evaluate, test, and analyze the ideas and alternatives
Decision making, "down selecting"
(to Stage 3)
Stage 3 - Parametric Design
(optimize size, shape, etc.)
Information gathering, understanding the customer needs.
Problem definition, setting goals and objectives, establishing criteria.
Idea generation, developing concepts
Evaluate, test, and analyze the ideas and alternatives
Decision making, "down selecting"
Stage 4 - Detail Design
(specific dimensions and tolerance)
Prototype and testing
Implementation or production of design
Process review