The material selection process

Introduction to material selection process

A problem of materials selection usually involves two problems:

1. The Selection of materials for a new design or new product
2. Reevaluation of an existing product or design to reduce cost, increase reliability, improves performance, etc.

The material selection Problem for the design of an engineering component involves three interrelated problems:

1. Selecting a material,
2. Specifying a shape, and
3. Choosing a manufacturing process.

Getting this selection right the first time by selecting the optimal combination your design has enormous benefits to any engineering-based business. It leads to lower product costs, faster time-to-market, a reduction in the number of in-service failures and, sometimes, significant advantages relative to your competition.

But to realize these benefits, engineers have to deal with an extremely complex problem. There are literally tens of thousands of materials and hundreds of manufacturing processes. No engineer can expect to know more than a small subset of this ever-growing body of information. Furthermore, there are demanding and shifting design requirements such as cost, performance, safety, risk and aesthetics, as well as environmental impact and recycle-ability. This document is meant to provide an introduction to the material selection process.

The basic question is how do we go about selecting a material for a given part? This may seem like a very complicated process until we realize that we are often restrained by choices we have already made. For example, if different parts have to interact then the material choice becomes limited.

INITIAL SCREENING OF MATERIALS

In the first stages of development of a new product, such questions as the following are posed: What is it? What does it do? How does it do it? After answering these questions it is possible to specify the performance requirements of the different parts involved in the design and to broadly outline the main materials performance and processing requirements. This is then followed by the initial screening of materials whereby certain classes of materials and manufacturing processes may be eliminated and others were chosen as likely candidates.

Analysis of Material Performance Requirements

The material performance requirements can be divided into five broad categories: functional requirements, processability requirements, cost, reliability, and resistance to service conditions.

Functional Requirements

Functional requirements are directly related to the required characteristics of the part or the product. For example, if the part carries a uniaxial tensile load, the yield strength of a candidate material can be directly related to the load-carrying capacity of the product. However, some characteristics of the part or product may not have simple correspondence with measurable material properties, as in the case of thermal shock resistance, wear resistance, reliability, etc. Under these conditions, the evaluation process can be quite complex and may depend upon predictions based on simulated service tests or upon the most closely related mechanical, physical, or chemical properties. For example, thermal shock resistance can be related to the thermal expansion coefficient, thermal conductivity, modulus of elasticity, ductility, and tensile strength. On the other hand, resistance to stress–corrosion cracking can be related to tensile strength and electrochemical potential.

Process ability Requirements

The process ability of a material is a measure of its ability to be worked and shaped into a finished part. With reference to a specific manufacturing method, processability can be defined as castability, weldability, machinability, etc. Ductility and hardenability can be relevant to processability if the material is to be deformed or hardened by heat treatment, respectively.

The closeness of the stock form to the required product form can be taken as a measure of processability in some cases. It is important to remember that processing operations will almost always affect the material properties so that processability considerations are closely related to functional requirements.

Cost

Cost is usually an important factor in evaluating materials because in many applications there is a cost limit for a given component. When the cost limit is exceeded, the design may have to be changed to allow for the use of a less expensive material or process. In some cases, a relatively more expensive material may eventually yield a less expensive component than a low-priced material that is more expensive to process.

Reliability Requirements

Reliability of a material can be defined as the probability that it will perform the intended function for the expected life without failure. Material reliability is difficult to measure because it is not only dependent upon the material's inherent properties, but it is also greatly affected by its production and processing history. Generally, new and nonstandard materials will tend to have lower reliability than established, standard materials. Despite difficulties of evaluating reliability, it is often an important selection factor that must be taken into account. Failure analysis techniques are usually used to predict the different ways in which a product can fail and can be considered as a systematic approach to reliability evaluation. The causes of failure of a part of service can usually be traced back to defects in materials and processing, faulty design, unexpected service conditions, or misuse of the product.

Resistance to Service Conditions

The environment in which the product or part will operate plays an important role in determining the material performance requirements. Corrosive environments, as well as high or low temperatures, can adversely affect the performance of most materials in service. Whenever more than one material is involved in an application, compatibility becomes a selection consideration. In a thermal environment, for example, the coefficients of thermal expansion of all the materials involved may have to be similar in order to avoid thermal stresses. In wet environments, materials that will be in electrical contact should be chosen carefully to avoid galvanic corrosion. In applications where relative movement exists between different parts, wear resistance of the materials involved should be considered. The design should provide access for lubrication; otherwise, self- lubricating materials have to be used.

Quantitative Methods for Initial Screening:

Having specified the performance requirements of the different parts, the required material properties can be established for each of them. These properties may be quantitative or qualitative, essential or desirable. For example, the function of a connecting rod in an internal combustion engine is to connect the piston to the crankshaft. The performance requirements are that it should transmit the power efficiently without failing during the expected life of the engine. The essential material properties are tensile and fatigue strengths, while the desirable properties that should be maximized are processability, weight, reliability, and resistance to service conditions. All these properties should be achieved at a reasonable cost. The selection process involves the search for the material or materials that would best meet those requirements. In some cases, none of the available materials can meet the requirements or the possible materials are too expensive or environmentally unsafe. In such cases, alternatives must be made possible through a redesign, compromise of requirements, or development of new materials. Generally, the starting point for materials selection is the entire range of engineering materials. At this stage, creativity is essential in order to open up channels in different directions, not let traditional thinking interfere with the exploration of ideas, and ensure that potential materials are not overlooked. Steel may be the best material for one design concept while a plastic is best for a different concept, even though the two designs provide the same function.

After all the alternatives have been suggested, the ideas that are obviously unsuitable are eliminated and attention is concentrated on those that look practical. Quantitative methods can be used for initial screening in order to narrow down the choices to a manageable number for subsequent detailed evaluation. Following are some of the quantitative methods for initial screening of materials.

Limits on Material Properties:

Initial screening of materials can be achieved by first classifying their performance requirements into two main categories

- Rigid, or go–no go, requirements
- Soft, or relative, requirements

Rigid requirements are those which must be met by the material if it is to be considered at all. Such requirements can be used for the initial screening of materials to eliminate the unsuitable groups.

For example, metallic materials are eliminated when selecting materials for an electrical insulator. If the insulator is to be flexible, the field is narrowed further as all ceramic materials are eliminated. Other examples of material rigid requirements include behaviour under operating temperature, resistance to a corrosive environment, ductility, electrical and thermal conductivity or insulation, and transparency to light or other waves. Examples of process rigid requirements include batch size, production rate, product size and shape, tolerances, and surface finish. Whether or not the equipment or experience for a given manufacturing process exists in a plant can also be considered as a hard requirement in many cases. Compatibility between the manufacturing process and the material is also an important screening parameter. For example, cast irons are not compatible with sheet-metal-forming processes and steels are not easy to process by die casting. In some cases, eliminating a group of materials results in the automatic elimination of some manufacturing processes. For example, if plastics are eliminated because service temperature is too high, injection and transfer moulding should be eliminated as they are unsuitable for other materials. Soft, or relative, requirements are those which are subject to compromise and trade-offs.

Examples of soft requirements include mechanical properties, specific gravity, and cost. Soft requirements can be compared in terms of their relative importance, which depends on the application under study.

The steps in Materials selection process

Materials selection like any other aspect of engineering design is a problem-solving process. The steps in Materials selection process can be defined as follows:

1. Analysis of the material requirements. Determine the conditions of service and environment that the product must withstand. Translate them into critical material properties. See the table (4-2).
2. Screening of candidate materials. Compare the needed properties (responses) with a large materials property database to select a few materials that look promising for the application.(absolute lower or upper limit for the materials properties). A“go-no-go” screening method must use to eliminates the discriminating parameters such as availability, weldability, corrosion, and to rate unmeasured properties as S- satisfactory, or the US- unsatisfactory, A- availability, and UA- unavailability before proceeding to next step.
3. Selecting of candidate materials. Analyze candidate materials in terms of trade-offs product performance, cost, fabricability, and availability to select the best material for the application.
4. Development of design data. Determine experimentally the key material properties for the selected material to obtain statistically reliable measures of the material performance under the specific conditions expected to be encountered in service.

Methods used in material selections:

Some of the more common and analytical methods used in materials selection (and also used for project selection) are:

1. Cost versus Performance / or property
2. Weighted Property Indices
3. Value Analysis
4. Failure Analysis
5. Benefit-Cost Analysis

Cost vs. Performance / or property the method

The cost-per-unit-property method is suitable for initial screening in applications where one property stands out as the most critical service requirement. As an example, consider the case of a bar of a given length L to support a tensile force F.

The cross-sectional area A of the bar is given by:

$$A = \frac{F}{S}$$

where S is the working stress of the material, which is related to its yield strength divided by an appropriate factor of safety.

$$C' = C\rho AL = \frac{C\rho FL}{S}$$

The cost of the bar (C') is given by
where C = cost of material per unit mass

ρ = density of material

Since F and L are constant for all materials, comparison can be based on the cost of unit strength, which is the quantity

$$\frac{C\rho}{S}$$

Materials with a lower cost per unit strength are preferable. If an upper limit is set for The quantity $C\rho/S$, then materials satisfying this condition can be identified and used as possible candidates for more detailed analysis in the next stage of selection.

The working stress of the material in Eqs. Related to the static yield strength of the material since the applied load is static. If the applied load is alternating, it is more appropriate to use the fatigue strength of the material. Similarly, the creep strength should be used under loading conditions that cause creep. Equations similar to can be used to compare materials on the basis of cost per unit stiffness when the important design criterion is a deflection in the bar. In such cases, S is replaced by the elastic modulus of the material. The above equations can also be modified to allow comparison of different materials under loading systems other than uniaxial tension. Table 1 gives some formulas for the cost per unit property under different loading conditions based on either yield strength or stiffness.

The consideration of cost:

- Because cost is so important in selecting materials, it is logical to consider cost at the start of the material selection process
- Usually, a target cost is set to eliminate the materials that are very expensive
- The final choice is a trade-off between cost and performance.
- Overall, cost is the most important criterion in selecting a material
- Cost is a most useful parameter when it can be related to a critical material property that controls the performance of the design
- Such a cost vs. performance index can be used for optimalings the selection of a material
- However, the cost of a material expressed in $ / kg may not always be the most valid criterion
- It depends on the material function: whether it is used as a load bearing or just as space filling
- It is also very important to emphasise that there are many ways to compute costs_ Total life-cycle cost is the most appropriate cost to consider. This cost consists of The initial material costs + manufacturing costs + operation costs + maintenance costs.

Consideration of factors beyond just the initial materials cost leads to relations such as shown in Figure (6-1).

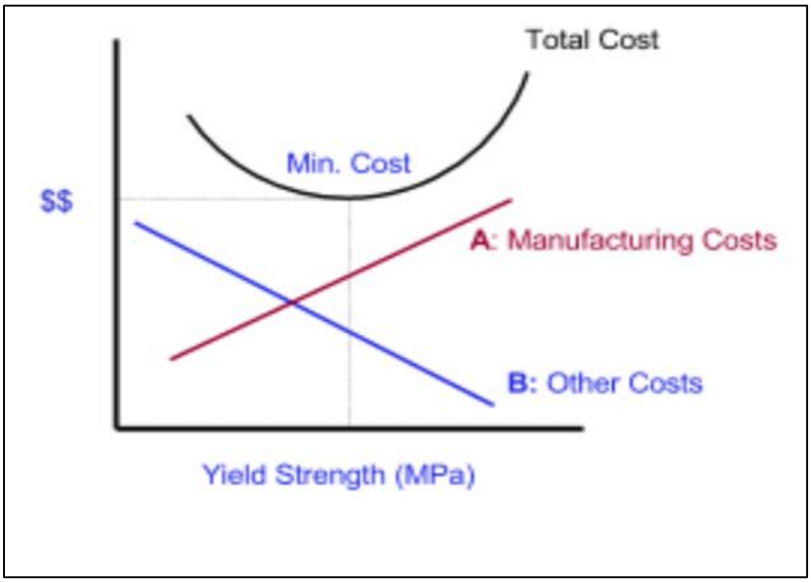


Fig.(6-1)

Ashby's Method

Ashby's material selection charts[4,5,8,10] are also useful for initial screening of materials. Figure 2 plots the strength versus density for a variety of materials. Depending upon the geometry and type of loading, different S–ρ relationships apply, as shown in Table 1. For simple axial loading, the relationship is S/ρ. For a solid rectangle under bending, $S^{1/2}/\rho$ applies, and for a solid cylinder under bending or torsion the relationship $S^{2/3}/\rho$ applies. Lines with these slopes are shown in Fig. 2. Thus, if a line is drawn parallel to the line $S/\rho = C$, all the materials which lie on the line will perform equally well under simple axial loading conditions. Materials above the line are better and those below it are worse. A similar diagram can be drawn for elastic modulus versus density and formulas similar to those in Table 1 can be used to screen materials under conditions where stiffness is a major requirement

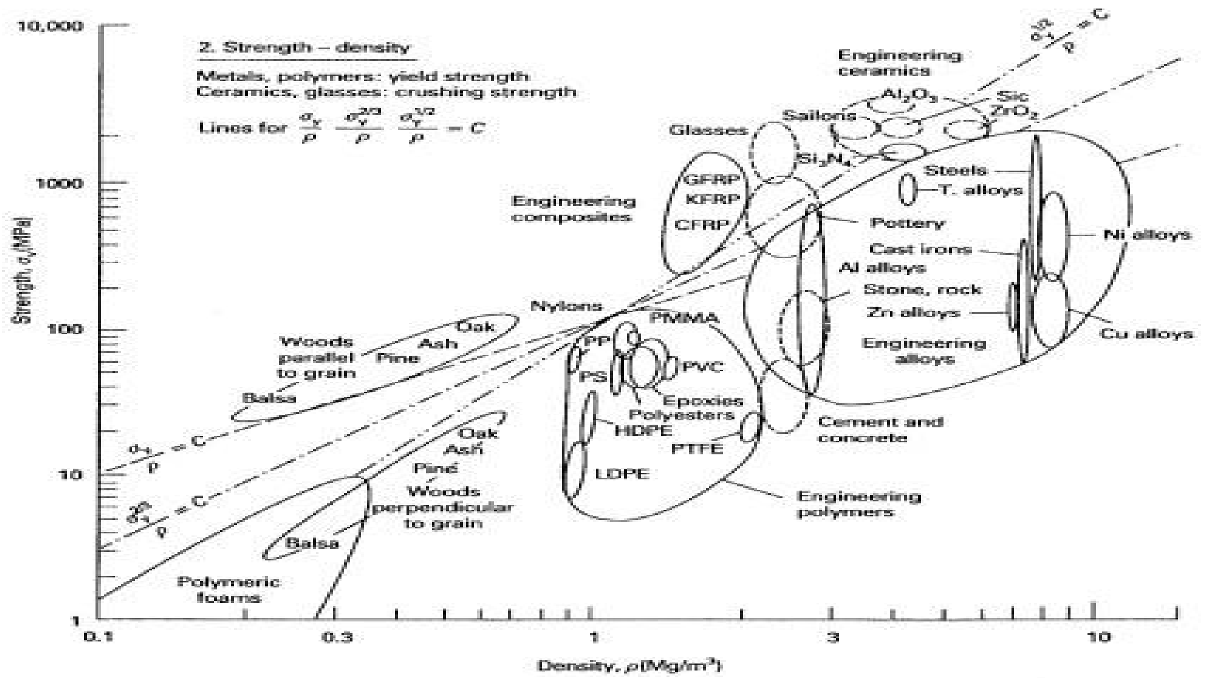


Table 1 Formulas for Estimating Cost per Unit Property

Cross Section and Loading Condition	Cost per Unit Strength	Cost per Unit Stiffness
Solid cylinder in tension or compression	$C\rho/S$	$C\rho/E$
Solid cylinder in bending	$C\rho/S^{2/3}$	$C\rho/E^{1/2}$
Solid cylinder in torsion	$C\rho/S^{2/3}$	$C\rho/G^{1/2}$
Solid cylindrical bar as slender column	—	$C\rho/E^{1/2}$
Solid rectangle in bending	$C\rho/S^{1/2}$	$C\rho/E^{1/3}$
Thin-walled cylindrical pressure vessel	$C\rho/S$	—

Fig.(6-2) The strength – density char

Weighted-Properties Method

In the weighted-properties method each material requirement, or property, is assigned a certain weight, depending on its Importance to the performance of part In service.

A weighted-property value is obtained by multiplying the numerical value of the property by the weighting factor (α) the individual weighted-property values of each material are then summed to give a comparative materials performance index (γ). Materials with the higher performance index (γ) are considered more suitable for the application.

Digital Logic Method

In the cases where numerous material properties are specified and the relative importance of each property is not clear, determinations of the weighting factor - can be largely Iuntil thetime, which reduces the reliability of selection. The digital logic approach can be used as a systematic tool to determine

In this procedure, evaluations are arranged such that only two properties are considered at a time. Every possible combination of properties or goals is compared and no shades of choice are required, only a yes or no decision for each evaluation.

To determine the relative Importance of each property or goal, a table is constructed, the properties or goals are listed on the left-hand column and comparisons are made in the columns to the right, as shown In Table 2.

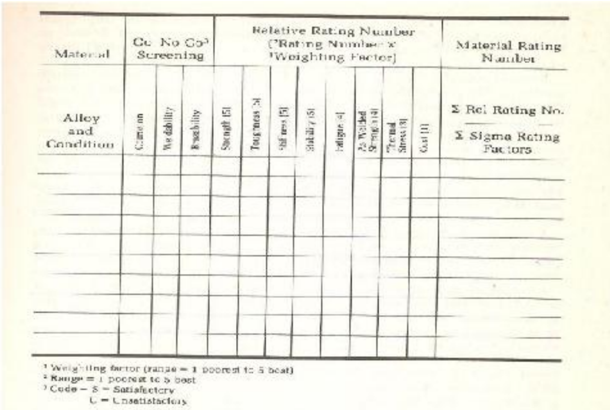
In comparing two properties or goals, the more important goal is given the Number 1 and the less important is given as 0. The total number of possible decisions is N = n (n - 1) / 2, where n is the number of properties or goals under consideration. A relative-emphasis coefficient or weighting factor - for each goal is obtained by dividing the number of positive decisions for each goal (m) into the total number of possible decisions (N). In this case

$$\Sigma \alpha = 1.$$

To increase the accuracy of decisions based on the digital logic approach, the yes-no evaluations can be modified by allocating gradation marks ranging from 0 (no difference in importance) to 3 (large difference in importance). In this case, the total gradation marks for each selection criterion are reached by adding up the individual gradation marks. The weighting factors are then found by dividing these total gradation marks by their grand total. A simple interactive computer program can be written to help in determining the weighting factors. A computer program will also make it easier to perform several runs of the process in order to test the sensitivity of the final ranking to changes in some of the decisions - sensitivity analysis.

Table 2 Determination of Relative Importance of Goals Using Digital Logic Method

Goals	Number of Positive Decisions $N = n(n-1)/2$										Positive Decisions	Relative Emphasis Coefficient α
	1	2	3	4	5	6	7	8	9	10		
1	1	1	0	1							3	0.3
2	0				1	0	1				2	0.2
3		0			0			1	0		1	0.1
4			1			1		0		0	2	0.2
5				0			0		1	1	2	0.2
Total positive decisions											10	$\Sigma\alpha = 1.0$



Material	Go No Go[3] Screening			Relative Rating Number ([2]Rating Number x [1]Weighting Factor)								Material Rating Number
Alloy and Condition	Corrosion	Weldability	Brazability	Strength (5)	Toughness (3)	Stiffness (5)	Stability (5)	Fatigue (4)	As Welded Strength (4)	Thermal Stress (3)	Cost (1)	Σ Rel Rating No. / Σ Sigma Rating Factors

[1] Weighting factor (range = 1 poorest to 5 best)
[2] Range = 1 poorest to 5 best
[3] Code — S = Satisfactory
U = Unsatisfactory

Fig. 2.8 Example of weighted index rating chart

Performance Index

In its simple form, the weighted-properties method has the drawback of having to combine unlike units, which could yield irrational results. This is particularly true when different mechanical, physical, and chemical properties with widely different numerical values are combined. The property with higher numerical value will have more influence than is warranted by its weighting factor. This drawback is overcome by introducing scaling factors.

Each property is so scaled that its highest numerical value does not exceed 100. When evaluating a list of candidate materials, one property is considered at a time. The best value in the list is rated as 100 and the others are scaled proportionally. Introducing a scaling factor facilitates the conversion of normal material property values to scaled dimensionless values. For a given property, the scaled value B for a given candidate material is equal to

$$B = \text{scaled property} = \frac{\text{numerical value of property} \times 100}{\text{maximum value in list}}$$

For properties like cost, corrosion or wear loss, and weight gain in oxidation, a lower value is more desirable. In such cases, the lowest value is rated as

$$B = \text{scaled property} = \frac{\text{minimum value in list} \times 100}{\text{numerical value of property}}$$

For material properties that can be represented by numerical values, application of the above procedure is simple. However, with properties like corrosion, wear resistance, machinability, and weldability, numerical values are rarely given and materials are usually rated as very good, good, fair, poor, etc. In such cases, the rating can be converted to numerical values using an arbitrary scale. For example, corrosion resistance ratings excellent, very good, good, fair, and poor can be given numerical values of 5, 4, 3, 2, and 1, respectively. After scaling the different properties, the material performance index γ can be calculated as

$$\text{Material performance index} = \gamma = \sum_{i=1}^{n} B_i \, \alpha_i$$

Where I am summed overall the n relevant properties. Cost (stock material, processing, finishing, etc.) can be considered as one of the properties and given the appropriate weighting factor. However, if there are a large number of properties to consider, the importance of cost may be emphasized by considering it separately as a modifier to the material performance index. In the cases where the material is used for space filling, the cost can be introduced on a per-unit-volume basis. A figure of merit M for the material can then be defined as

$$M = \frac{\gamma}{C\rho}$$

where C = total cost of material per unit weight (stock, processing, finishing, etc.) ρ = density of the material

When an important function of the material is to bear stresses, it may be more appropriate to use the cost of unit strength instead of the cost per unit volume. This is because higher strength will allow less material to be used to bear the load and the cost of unit strength may be a better indicator of the amount of material actually used in making the part. In this case, Eq. (7) is rewritten as

$$M = \frac{\gamma}{C'}$$

Where C` is determined from Table 1 depending on the type of loading.

This argument may also hold in other cases where the material performs an important function like electrical conductivity or thermal insulation. In these cases, the amount of the material and consequently the cost is directly affected by the value of the property.

When a large number of materials with a large number of specified properties are being evaluated for selection, the weighted properties method can involve a large number of tedious and time-consuming calculations. In such cases, the use of a computer would facilitate the selection process. The steps involved in the weighted-properties method can be written in the form of a simple computer program to select materials from a data bank. The type of material information needed for computer-assisted ranking of an alternative solution is normally structured in the form of databases of properties such as those published by ASM.

SELECTING THE OPTIMUM SOLUTION

Candidates that have the most promising performance indices can each now be used to develop a detailed design. Each detailed design will exploit the points of strength of the material, avoid the weak points, and reflect the requirements of the manufacturing processes needed for the material. The type of material information needed for detail design is different from that needed for initial screening and ranking. What is needed at this stage is detailed high-quality information about the highest ranking candidates. Such information is usually unstructured and can be obtained from handbooks, publications of trade organizations, and technical reports in the form of text, pdf files, tables, graphs, photographs, etc. There are instances where some of the desired data may not be available or may be for slightly different test conditions. In such cases, educated judgment is required.

After completing the different designs, solutions are then compared, taking the cost elements into consideration in order to arrive at the optimum design– material–process combination, as will be illustrated in the following case study.

Case study:

Select the proper material to use for wing among the listed materials.

Material	**±y(Mpa)**	**Kc(Mpa/m^2)**	**°(ton/m^3)**	**E (Gpa)**	**Cost ($/ ton)**
M1	350	45	2.7	70	590
M2	550	25	2.7	70	700
M3	880	60	4.5	110	5500
M4	900	100	7.8	200	500

Solution:

For the first column, consider relative stress to density: σy/ρ, for forth column apply B for min. value:

Material	**±y/° (Mpa) / (ton/m^3)**	**(Kc/±y)^2 (Mpa/m^2)**	**(E)$^{1/3}$ / (Gpa) / (ton/m^3)**	**Cost ($/ ton)**
M1	= 129.6	(45/350)= 1.64	70	590
M2	= 203.7	25	70	700
M3	880 / 4.5= 195.6	60	110	5500
M4	900 / 7.8= 115.4	100	200	500

Then:

Material	**±y/°**	**(Kc/±y)^2**	**(E)$^{1/3}$/°**	**Cost**
M1	0.64	1	1	0.11
M2	1	0.13	1	0.13
M3	0.96	0.27	0.17	1
M4	0.56	0.27	0.5	0.09

Cost can be considered as one of the properties and given a weighting factor or considered separately as a modifier to the material performance index (γ).

In the cases where the material is used for space filling, the cost can be introduced on per unit volume basis. A figure of merit (M) for the material can then be defined as:

$M = \gamma/(C\ \rho)$

C = total cost of the material per unit weight (stock, processing, finishing, ...etc)

ρ = density of the material.

Value engineering (VE) / Value Analysis

Value Analysis (VA) and Value Engineering (VE) is a function-oriented, structured, multi-disciplinary team approach to solving problems or identifying improvements. The goal of any VA Study is to:

Improve value by sustaining or improving performance attributes (of the project, product, and/or service being studied) while at the same time reducing overall cost (Including lifecycle operations and maintenance expenses).

D.1- VE/ VA

can be defined as a process of systematic review that is applied to existing and newproduct designs in order to compare the function of the product required by a customer to meet their requirements at the lowest cost consistent with the specified performance and reliability needed. This is a rather complicated definition and it is worth reducing the definition to key points and elements:

1. Value Analysis (and Value Engineering) is a systematic, formal and organized process of analysis and evaluation. It is not haphazard or informal and it is a management activity that requires planning, control and coordination.
2. The analysis concerns the function of a product to meet the demands or application needed by a customer. To meet this functional requirement the review process must include an understanding of the purpose to which the product is used.
3. Understanding the use of a product implies that specifications can be established to assess the level of fit between the product and the value derived by the customer or consumer.
4. To succeed, the formal management process must meet these functional specification and performance criteria consistently in order to give value to the customer.
5. In order to yield a benefit to the company, the formal review process must result in a process of design improvements that serve to lower the production costs of that product whilst maintaining this level of value through function.

D2- VA

Is a systematic method to improve the "value" of goods or products and services by using an examination of function. Value, as defined, is the ratio of function to cost. Value can, therefore, be increased by either improving the function or reducing the cost. It is a primary tenet of value engineering that basic functions be preserved and not be reduced as a consequence of pursuing value improvements

In value engineering "functions" are always described in a two-word abridgement consisting of an active verb and measurable noun (what is being done - the verb - and what it is being done to - the noun) and to do so in the most non-prescriptive way possible. In the screwdriver and can of paint example, the most basic function would be "blend liquid" which is less prescriptive than "stir paint" which can be seen to limit the action (by stirring) and to limit the application (only considers paint.) This is the basis of what value engineering refers to as "function analysis". Basic steps/stages in the job plan:

Value engineering is often done by systematically following a multi-stage job plan, see fig. (6-3):

1- Information gathering - This asks what the requirements are for the object. Function analysis, an important technique in value engineering is usually done in this initial stage. It tries to determine what functions or performance characteristics are important. It asks questions like.

- ❖ What does the object do?
- ❖ What must it do?
- ❖ What must it not do?

- ❖ What should it do?
- ❖ What could it do?
- ❖ What is being done now?
- ❖ Who is doing it?
- ❖ What must it not do?

In this stage, every part must be examined due its function or performance and function classify to primary or secondary.

Alternative generation (creation)

- In this stage value engineers ask;
- What are the various alternative ways of meeting requirements?
- What else will perform the desired function?

Evaluation

In this stage, all the alternatives are assessed by evaluating how well they meet the required functions and how great will the cost savings be.

- ❖ Which Ideas are the best?
- ❖ What are the impacts?
- ❖ What is the cost?
- ❖ What is the performance?

Presentation/implementation

In the final stage, the best alternative will be chosen and presented to the client for a final decision.

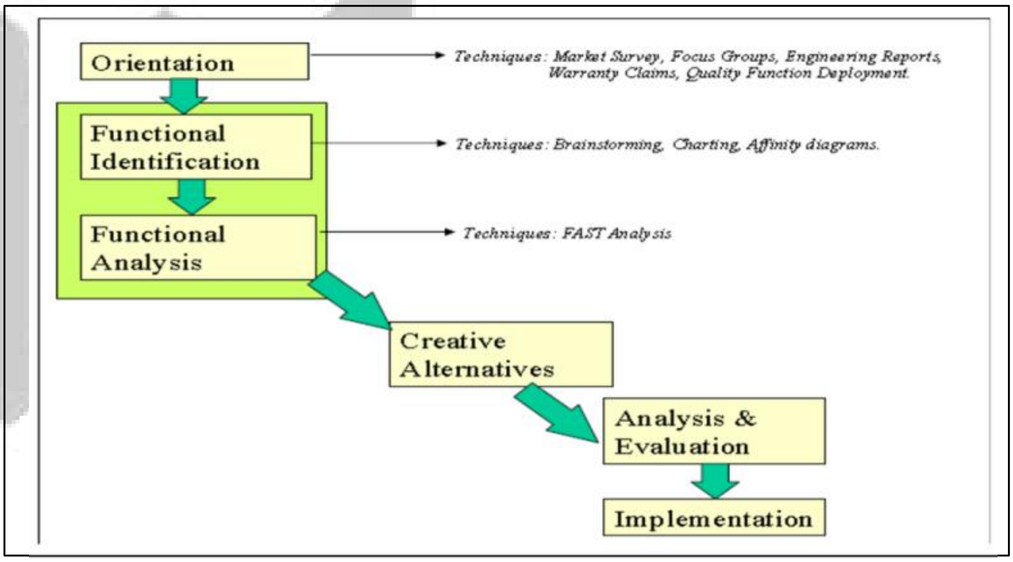


fig. (6-3) VA stapes.

Defining Cost and Value

Any attempt to improve the value of a product must consider two elements, the first concerns the use of the product (known as Use value) and the second source of value come from ownership (Esteem value). This can be shown as the difference between a luxury car and a basic small car that each has the same engine. From a use point of view, both cars conduct the same function – they both offer safe economical travel (Use value) – but the luxury car has a greater esteem value. The difference between a gold-plated ball pen and a disposable pen is another example. However, use value and the price paid for a product are rarely the same; the difference is actually the esteem value, so even though the disposable pen is priced at X the use value may be far less.

$$V_{alue} = \frac{P_{erformance}}{C_{ost}}$$

Value index:

The index of value is calculated as:

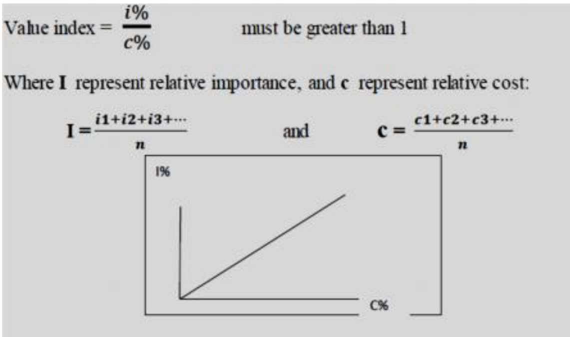


fig. (6-4) value index scheme

Example

A product manager at a company that produced nails had received several requests from customers for a nail that could not work loose. Identifying this 'improved nail' as a possible new product line, he decided to do a Value Analysis to help identify costs and values.

Working with a major customer in the building industry, he first identified the basic function and measure of an ideal nail as holding two 1cm battens together, such that when the battens were twisted, the wood would break before the nails moved. With an engineering team, this was broken down into secondary functions, which were evaluated and related to components and costs as in Fig. 6-. During this process, the concept of how the nail gripped the wood was discussed. They brainstormed alternative ways of gripping wood, and an engineer, who was also an amateur fisherman, came up with the idea of putting barbs on the nails.

The initial prototype was partially successful but did become a little loose after a period. Spiral barbs helped, and straight barbs on the top of the nail resulted in the nail being locked in place by the final hammer blow.

The solution was produced as a specialist nail and sold well at twice the price of a normal nail, more than covering the increased production costs.

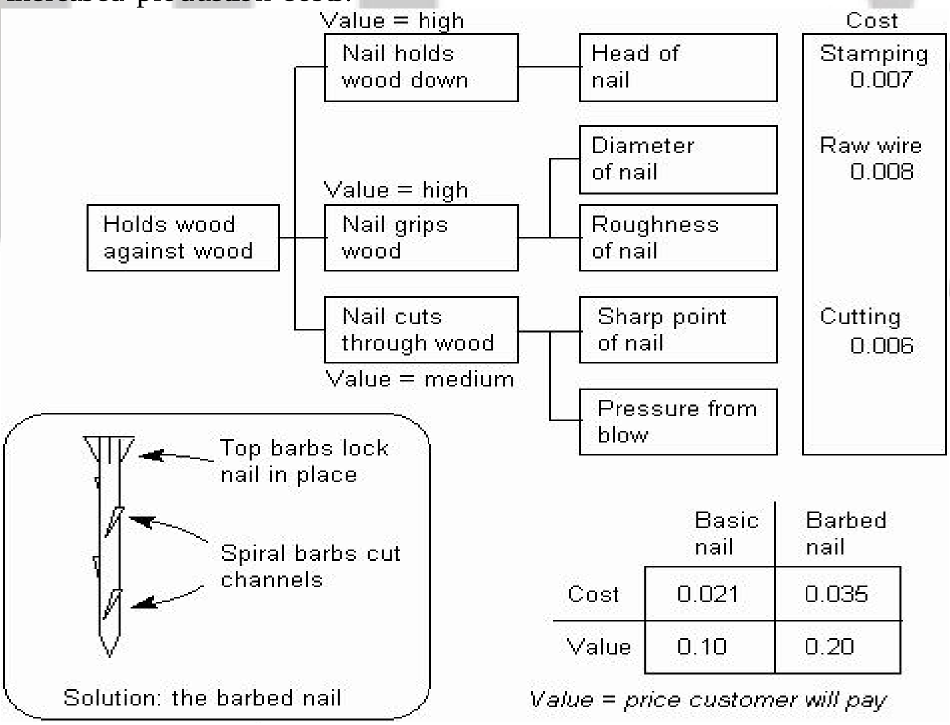


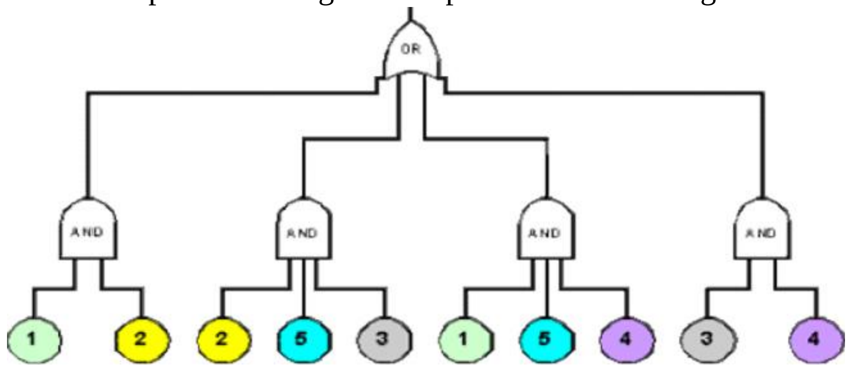
Fig. 6-5. Example Value Analysis

Failure Analysis

Fault analysis, also known asfault tree analysis, is a method used to determine the various chains of effects that would cause a system to fail, compromising safety or stability. Engineers often use fault analysis for safety or hazard evaluations.

In fault analysis, complex relationships between hardware, software, and humans are analyzed with methods derived from Boolean algebra, probability theory, and reliability theory. The final product of fault analysis is a logical, visual diagram representing any potential failure that a system may suffer, or existing failures that already have happened and why they've happened.

The top of a fault tree diagram displays the final failed state of the system, while the events that branch off below show the states of all the separate components of the system that could allow the final state to happen. The lines and shapes connecting the components show the logical relationship.



Consideration must be given to the spectrum of loading that a structure will be called upon to withstand in relation to the scatter in the ability of materials to sustain these loads. As indicated in Fig. 1-1, the danger of failure is present when these two distributions overlap.

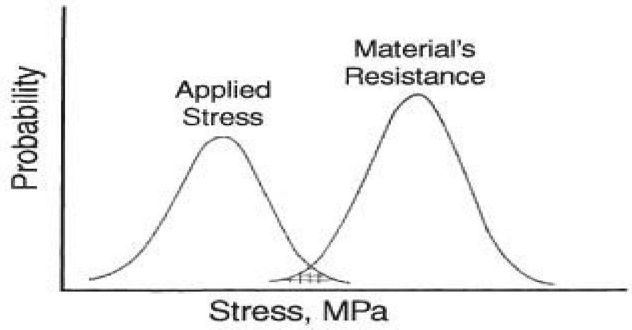


Fig. 1-1. Schematic frequency distributions showing the applied stresses and the resistance of the material.

In addition, new fields such as fracture mechanics, fatigue research, corrosion science, and nondestructive testing have emerged. Important advances have also been made in improving the resistance of materials to fracture. In the metallurgical field, these advances have been brought about through improvements in alloy design, better control of alloy chemistry, and improvements in metal processing and heat treatment.

The failure analyst often has to determine the nature of a failure; for example, was it due to fatigue or to an overload? In many cases, a simple visual examination may suffice to provide the answer. In other cases, however, the examination of a fracture surface (fractography) may be more involved and may require the use of laboratory instruments such as the light microscope, the transmission electron microscope, and the scanning electron microscope.

steps of systematic failure analysis:

- Collect background information about the function, source, fabrication, materials used, service history of the component and environmental condition.
- Visual examination and select the parts to be used for further laboratory investigation.
- Macroscopic, microscopic, chemical analysis, nondestructive, and destructive tests to locate possible material and manufacturing defects.
- Identify the origin of failure, the direction of crack propagation, and sequence of failure.
- Write a report to document the findings.

Causes of failures

Common causes of failure are usually one or more of these four:

1. Material failure
2. Human mistake by the operation staff
3. Human mistake by maintenance staff
4. Abnormal external conditions

Benefit /Cost Analysis

Both cost - benefit analysis (CBA) and cost- effectiveness analysis (CEA) is Useful tools for program evaluation. Cost- effectiveness analysis is a technique that relates the costs of a program to its key outcomes or benefits. Cost - benefit analysis taken that process one step further, attempting to compare costs with the dollar value of all (or most) of a program’s many benefits. When the new material is technically better but more expensive, the economic gain as a result of improved performance $\Delta\gamma_e$ should be more than the additional cost (ΔC_t): $\Delta\gamma_e - \Delta C_t > 1$

The economic gain as a result of improved performance $\Delta\gamma_e$ can be related to the difference in performance index of the new and currently used materials, γ_n and γ_o.

$$\Delta\gamma_e = A\ (\gamma_n - \gamma_o)$$

A is the benefit of improved performance of the component expressed in $ per unit increase in material performance index γ.